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This comprehensive research report has been developed as a fundamental resource for providing WSDOT managers with a better understanding of the current wireless environment that can guide future decisions on mobile communications. The background histories and conclusions developed as a result of this research should prove valuable in helping the WSDOT to make wise choices when investing in wireless technologies.

This research project has consisted primarily of a comprehensive literature review of wireless communications technologies to establish an historical backdrop outlining the growth of today's mobile communications systems, while also describing the current state of the art. This extensive literature review has been supplemented by personal interviews with industry representatives and WSDOT officials.

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Final Technical Report
Research Project T9903, Task 11
IVHS Data and Information Structure

IVHS DATA AND INFORMATION STRUCTURE

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DISCLAIMER

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LIST OF ABBREVIATIONS

ACTS	NASA's Advanced Communications Technology Satellite
ADPCM	Adaptive differential pulse code modulation
AM	Amplitude modulation
AMBCS	Alaska Meteor Burst Communications System
AMPS	Advanced mobile phone service
ARDIS	Advanced radio data information service
ARQ	Automatic retransmission request
ATIS	Advanced traveler information system
AVL	Automatic vehicle location
BER	Bit error rate
BLOS	Beyond line of sight
BLOSSOM	Beyond Line of Sight Signaling Over Meteors
BPSK	Binary phase shift keying
BS	Base station
BTA	Basic trading area
CAI	Common air interface
CDI	Cellular Data, Inc.
CDMA	Code-division multiple-access
CDPD	Cellular digital packet data
CECOM	U.S. Army Communications-Electronics Command
CELP	Code excited linear prediction
CEPT	European Conference of Postal and Telecommunications Administrations
CFR	Code of Federal Regulations
COMSAT	U.S. Communications Satellite Corporation
CT	Cordless telecommunications
CT-2	Second-generation cordless telecommunications
CT-2 Plus	Revised version of CT-2 adding capabilities
CTIA	Cellular Telecommunications Industry Association
D-AMPS	Digital AMPS (formerly IS-54)
DBS	Direct broadcast satellite
DCA	Dynamic channel allocation
DECT	Digital European cordless telecommunications
DOT	Department of Transportation
DQPSK	Differential quadrature phase shift keying

DSI	Digital speech interpolation
DTI	British Department of Trade and Industry
EHF	Extremely high frequency
EMBARC	Electronic Mail Broadcast to A Roaming Computer
ESMR	Enhanced specialized mobile radio
E-TDMA	Enhanced time-division multiple-access
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDD	Frequency division duplex
FDMA	Frequency-division multiple-access
FEC	Forward error correction coding
FM	Frequency modulation
FR	Federal Register
GDP	Gross domestic product
GFSK	Gaussian frequency shift keying
GHz	Gigahertz
GMSK	Gaussian minimum shift keying
GPS	Global positioning system
GSM	Global system of mobile communications
HDTV	High-definition television
HF	High frequency
IMDN	Intelligent mobile data network
IMO	International Maritime Organization
IMS	Egyptian irrigation management system
INTELSAT	International Satellite Consortium
ISDN	Integrated services digital network
ISM	Industrial, scientific, and medical frequencies
ITT	International Telephone and Telegraph
ITU	International Telecommunications Union
IVHS	Intelligent Vehicle-Highway System
kbps	Kilobits-per-second
kHz	Kilohertz
LAN	Local area network
LEO	Low-earth-orbit satellite
LF	Low frequency
log-PCM	Logarithmic pulse code modulation

LORAN	Long-range navigation
LOS	Line of sight
MA	Multiple-access
MAN	Metropolitan area network
MB	Meteor burst
MCC	Meteor Communications Corporation
MF	Medium frequency
MFJ	Modified final judgment
MHz	Megahertz
MIRS	Motorola integrated radio system
MPT	Japanese Ministry of Posts and Telecommunications
MPWWR	Egyptian Ministry of Public Works and Water Resources
MS	Mobile station
MSA	Metropolitan service area
MTA	Metropolitan trading area
MTEL	Mobile Telecommunication Technologies Corporation
MTSO	Mobile telephone switching office
mW	Milliwatts
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NBS	National Bureau of Standards
NOI	Notice of Inquiry
NRTS	Near-real-time-speech
NTIA	National Telecommunications and Information Administration
NWN	Nationwide Wireless Network
PBX	Private branch exchange
PC	Personal computer
PCMCIA	Personal Computer Memory Card Industry Association
PCN	Personal communications network
PCP	Private Carrier Paging
PCS	Personal communications services
PDA	Personal digital assistant
PHS	Personal handy phone system
POCSAG	Post Office Code Standardization Advisory Group
Pocsat	Pocket satellite phone
PPO	Private Paging Operator

PRMA	Packet-reservation multiple-access
PSTN	Public switched telephone network
PTT	Post, telephone, and telegraph authorities
PUC	Public Utilities Commission
QAM	Quadrature amplitude modulation
RBOC	Regional Bell operating company
RCC	Radio Common Carrier
RDN	Radio data network
RDSS	Radio determination satellite system
RF	Radio frequency
RPC1	CCIR radio paging code number 1
RSA	Rural service area
SBC	Subband coding
SDI	Space Defense Initiative
SHF	Super high frequency
SIR	Signal-to-interference ratio
SMR	Specialized mobile radio
SNOTEL	Snowpack telemetry
SNR	Signal-to-noise ratio
SRI	Stanford Research Institute
SSMA	Spread-spectrum multiple-access
TACAN	Tactical air navigation
TCP/IP	Transmission control protocol/Internet protocol
TDD	Time division duplex
TDMA	Time-division multiple-access
TSS	Transportation support system
UHF	Ultra-high frequency
UK	United Kingdom
UPS	United Parcel Service
USAT	Ultra-small satellite terminal
VHF	Very high frequency
VLF	Very low frequency
VSELP	Vector sum excited linear predication
WAN	Wide area network
WARC	World Administrative Radio Conference
WLAN	Wireless local area network

Preface

The research effort that has produced this report is only the first stage of a larger project intended to aid the establishment of a regional Intelligent Vehicle-Highway System (IVHS) across Washington State. Most IVHS applications have some component involving the flow of data and voice messaging between vehicles, remote sites, and coordinated control centers. Such two-way communications must provide low-cost and reliable service among participants. Until now, wireless communications alternatives have not been studied in detail relative to Washington State's regional IVHS needs. A number of wireless technologies are currently available, and others are predicted to come on the market before the turn of the century. The ultimate selection of particular mobile communications systems will, in turn, affect the viability of any IVHS network, so this decision must be based upon a clear understanding of the costs and other performance parameters of the various technologies available.

With this in mind, this comprehensive research report has been developed as a fundamental resource for providing DOT managers with a better understanding of the current wireless environment that can guide future decisions on mobile communications. The background histories and conclusions developed as the result of this research should prove valuable in helping the DOT to make wise choices when investing in wireless technologies.

This initial research project has consisted primarily of a comprehensive literature review of wireless communications technologies to establish an historical backdrop outlining the growth of today's mobile communications systems, while also describing the current state of the art. This extensive literature review has been supplemented by personal interviews with industry representatives and DOT officials. As the research progressed, the leading wireless technologies identified for serious evaluation included: cellular telephony, personal communications services, cordless telephony, radiopaging, private land mobile radio, radio data networks, satellites, and meteor burst. Each of these technologies is reviewed at length in separate chapters that make up the body of the research report that follows.

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Chapter I

Needs and Analysis

Introduction

Public and private sector managers who are considering the pros and cons of today's wireless communications options are faced with a wide variety of choices. Some of these corporate and government decisionmakers have been able to sort through the competing mobile communications services and identify the perfect technology to fit their own special needs. But just as many others are confused and frustrated—and understandably so.

Ever since the late 1960's and early 1970's, the Federal Communications Commission has relied increasingly on the commercial marketplace to guide the future direction of broadcast services. In the past, the FCC was inclined to structure radio networks according to the technology employed or primary function undertaken (i.e. to provide microwave relays for broadcasters or satellite links for marine vessels). Now a laissez faire approach holds sway, with the marketplace determining which technology is most efficient at providing which radio service. Lower regulatory barriers are also encouraging the trial of innovative applications for wireless technologies, like two-way paging and radio data networks. Many of these new mobile communications services will ultimately fail. But until the marketplace passes through the current "shake-down" period, industry analysts expect the technological choices available for wireless communications to proliferate.

Regulatory policy is not the only stimulant causing vast changes to our nation's airwaves. Technological improvements seem to be appearing at an ever faster rate. One prominent example is the advent of digital transmission techniques, which have overturned past analog approaches and are revamping the broadcast environment. As a result, the insides of most modern television sets resemble computers more than traditional TV receivers. Digital advances also make possible the compression of wide bandwidth signals into narrow bandwidth radio channels; plus reception quality has been dramatically improved. Beyond digital transmission improvements, advances in image display systems, rechargeable batteries, software functionality, and computer chip design have converged in unforeseen ways, sparking new communications potential—as in the case of low-earth-orbit satellites and meteor burst systems. Prompted by these technological developments, old mobile communications systems have been reshaped and new wireless networks have bolted onto the scene.

This research report has been developed for the Washington State Department of Transportation as a first step in creating some coherence for the wireless communications choices that confront the DOT. Mobile communications technology has such powerful potential for improving departmental efficiency, informing the public of transit options, and supporting traffic management tasks that it simply cannot be ignored. Yet the pitfalls involved in selecting the best technologies for different communications tasks are daunting. This report will provide DOT managers with a better understanding of the current wireless environment, and that can then serve as one reference to guide future decisions about system designs and service providers. Considering that a recent workshop on Intelligent Vehicle-Highway Systems (IVHS) concluded that many IVHS functions could be addressed using existing commercial wireless networks,[1] this report will begin the process of identifying the leading mobile communications systems that should be taken into account.

The section that follows will outline some of the key requirements that should be used to judge the effectiveness of different mobile communications technologies; special attention will also be given to the specific responsibilities of the DOT for statewide transportation management. A later section will summarize some of the primary conclusions reached regarding the efficacy of competing wireless systems, especially in relation to their potential application by the DOT. Although the discussions of each technology will be brief, they will highlight key points derived from later chapters that investigate a variety of mobile technologies in more depth. Those expanded chapters can then be reviewed for more detailed overviews of the prominent mobile communications services. Subsequent chapters will spotlight: cellular telephony, personal communications services, cordless telephony, radiopaging, private land mobile radio, radio data networks, satellites, and meteor burst, in that order.

Wireless Communications Needs

Steven Bell, a head librarian with the University of Pennsylvania, has written an article on the usefulness of wireless technologies for researchers wanting to access remote databases while away from the office.[2] While Bell's topic may, at first, seem to be of limited relevance regarding the wireless communications needs of the State's DOT, he offers some useful advice on the more general traits necessary for the successful implementation of a mobile communications technology. Bell's listing of critical characteristics for evaluating wireless systems provides a helpful starting point for identifying those features that distinguish different mobile services.

Reliability

Any wireless system is severely handicapped unless customers can be reasonably sure that their messages will be reliably conveyed. The broadcast environment often presents harsh

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[1]Transportation Research Board, National Research Council, Spectrum Needs for Intelligent Vehicle-Highway System Application, Transportation Research Circular No. 428 (Washington, DC: Transportation Research Board, National Research Council, June 1994).

[2]Steven J. Bell, "What Online Searchers Should Know About Wireless Data Communications," ONLINE, January 1994, pp. 45-52.

challenges: interference from natural and man-made sources scuttle transmissions, propagation vagaries like signal fading and multipath occurrences complicate broadcasts, and shadowing from tall buildings and undulations in terrain block some messages from getting through. Packetizing data into smaller chunks, instead of a continuous stream (i.e. circuit-switched), makes it easier for equipment to check for transmission errors and prompt retransmissions when initial packets are somehow scrambled. Any system that requires multiple broadcasts to deliver a single "clean" dispatch, no matter how fast the transmission speed, will prove to be an inefficient carrier of over-the-air messages. For any wireless technology to be worthy of sincere consideration, it must have a proven track record for providing a robust radio channel that can swiftly and surely carry mobile communications.

Coverage

Many of the newer mobile technologies serve only metropolitan areas; cities and suburbs offer system operators the best opportunity for recouping their investment in constructing wireless infrastructures. Yet, in discussions with representatives of the DOT, the opinion was expressed that rural communications are at least as vital to the workings of the department as are urban and suburban messaging ties.[3] Snow plows moving through the Cascades or Olympics are frequently beyond the range of many commercial mobile services. Also, remote sensing devices along less frequently traveled stretches of highway often have no available wireless link for connecting with DOT headquarters. Certainly, the established mobile networks available to urban workers are not ignored in this report, since they have a potential role to play as messaging channels for DOT road crews or as data relays for triggering reader boards and traffic lights. But the requirement of statewide coverage is important, and those technologies that offer seamless reception throughout the state will be noted. Coverage maps for a variety of mobile communication services are included in Appendix E.

Transmission Speeds

Figures cited by wireless providers regarding the transmission speeds supported by their networks can be misleading. Because all wireless systems must incorporate some method of error correction, which limits the full data capacity available on radio channels, the information given on transmission speeds is often less important than reliable figures on a network's "throughput": the amount of message-specific data that reaches recipients in a given period of time. Of course, service providers boasting of fast transmission speeds will generally provide fast throughput, as well. But customers should not base their evaluations on

[3]Meeting with Alan C. Hull and Bob St. Andre, Washington State Department of Transportation, Headquarters Radio Operations, 6431 Corson Avenue South, Seattle, WA 98108, April 1994.

transmission speeds alone, since they may be disappointed when they actually begin to use the service and are faced with longer communications delays.

Transmission speed and throughput information are critical because they will affect the efficiency of employees using mobile communications systems. Equipment that is frustrating because of its slow performance will be discouraging to workers and may ultimately be scrapped altogether. A network's data transfer characteristics are also important because they will bear heavily on the associated airtime costs. Since some systems, like cellular networks, bill customers according to the <u>length of each call</u>, high transmission speeds and throughput can bring financial savings through reduced airtime charges. Other systems that use packet data technology generally charge according to the <u>amount of data transmitted</u> and are not time sensitive. Even so, fast transfer times will bolster employee acceptance of mobile communications and improve its usefulness to clients on-the-go.

Quite a few mobile technologies employ store-and-forward network designs. With such systems, messages are not passed immediately between the interacting parties but are held in a queue until their turn arrives for transmission. Such systems commonly do not have enough radio bandwidth and service capacity to instantaneously meet all messaging demands. As a result, such store-and-forward networks can delay communications for seconds, minutes, and sometimes even hours. As a trade-off, such services usually offer much cheaper subscriber fees and airtime costs.

Of course, some systems do not ably support data transmission and are better equipped for the relay of voice communications; cellular telephony comes to mind as just one example. Meanwhile, other mobile systems—like radio data networks and meteor burst—ignore voice service altogether. Options for either voice or data messaging are pertinent to decisionmakers since some applications demand the convenience and personal interaction allowed through voice communications; other times, the speed and versatility of data transmission are preferred—not to mention their cheaper cost. Distinctions will be made between systems offering one, or both, of these capabilities.

<u>**Equipment and Airtime Costs**</u>

The critical value of equipment and airtime charges is obvious. There are few situations in which wireless technologies are cheaper to employ than traditional wired networks; one exception would be the value of satellites or meteor burst systems to reach isolated regions that cannot be served by copper or fiber optic cables because of the cost or the rugged terrain involved. But generally speaking, wireless communications will always carry a premium cost. Heightened competition in the marketplace is giving customers increasing service options and acting to drive down the cost of transceivers (transmitters/receivers) and wireless airtime. As a result, mobile communications is becoming a viable option for many managers who appreciate the mobility and convenience that only wireless technologies can permit.

Security

Some situations demand that personal or interdepartmental communications are kept private, while at other times efforts to thwart eavesdroppers are totally unnecessary. For years, radio buffs have been able to purchase scanners that can intercept cellular phone conversations, and only recently has the FCC banned the manufacture of such scanners. The highway maintenance frequencies allocated to the DOT are still regularly included in the bands available through these scanners tuned to public service channels. The transition to digital transmission techniques from past analog standards makes it harder for the public to casually listen in on communications carried by these newer wireless technologies; it also makes it simpler for manufacturers to design equipment that can encrypt broadcast signals and keep them secure.

The tasks to be accomplished through wireless communications must be evaluated to determine the need for secure mobile messaging. In some cases, the DOT might want the public to have ready access to its communications so as to easily keep travelers informed about highway conditions. It would be foolish to pay a premium price for encrypted radio transmissions when such a feature is either unnecessary or undesirable. At other times, such as severe emergency situations, the department might desire private radio channels so as not to arouse public panic or attract "sightseers" to hazardous locations.

Simplex or Duplex

Simplex radio services are those that only support one-way transmissions. Paging, for example, has traditionally been a simplex service. Duplex equipment, such as today's cellular phones, are able to carry full, two-way conversations. Not all mobile systems are duplex because two-way transmissions demand greater bandwidth than one-way messaging services, and spectrum bandwidth is always in short supply. Also, not every situation demands two-way communications. In the case of remote sensing, for instance, managers may only by interested in collecting environmental readings from distant, hard-to-reach locations. The selection of a duplex service to handle such a task would be wasteful and, since duplex services are more expensive, it would be costly as well.

DOT Specific Wireless Communications Needs

An understanding of the DOT's demands for wireless communications has been developed through meetings with departmental representatives and through an investigation of other state and federal transportation agencies regarding their application of mobile communications equipment. As a result, five general classes of service have been identified. First, and perhaps most obvious, is the DOT's need for wireless links to handle internal communications between managers at centralized offices and mobile road crews and professional staff in the field. Second, there is a growing demand for methods by which the DOT can directly reach drivers in their cars and influence the driving patterns of people before and during their trips on state highways. So, communications between the DOT and the traveling public represents another niche that might best be served by wireless networks.

Third is the need for some sort of flexible and inexpensive relay system for passing data measurements from remote sensors to city offices from which DOT can monitor changing traffic and meteorological conditions. Fourth is the department's related requirement for some way to continuously and unobtrusively track DOT vehicles and, thereby, make the most efficient use of finite state resources for the effective management of Washington's highways. Fifth, and finally, the DOT could benefit from remote triggering equipment that could be used to instantaneously react to emergency situations that are inaccessible or which demand prompt and decisive action. Distant control of highway reader boards or traffic signals are obvious examples of how such wireless relays might be applied.

Analysis

The analysis that follows will be succinct but will cover the most pertinent features of the wireless technologies evaluated as part of this report. Table 1.1 provides a broad overview of some of the most prominent mobile communications services now available or expected within the next decade. Of course, any matrix like the one in Table 1.1 takes some liberties by making generalizations in order to simplify the comparisons between different technologies. This matrix is intended as a quick reference to the leading wireless technologies that should be considered by the DOT. While a substantial effort has been made to ensure accuracy in the comparisons drawn between competing systems, some simplifications were unavoidable if the matrix was to remain manageable. Readers interested in more elaborate evaluations of certain technologies—or those wanting to know more about the service variations available within each broad technological classification (i.e. paging or meteor burst)—should refer to later chapters which discuss the different systems in much greater detail.

Analog Cellular Telephony

The growing popularity of analog cellular service reflects the success of the technology in providing good-quality voice service and acceptable data transfer capabilities. Additionally, United Postal Service (UPS) has been using cellular networks nationwide for package tracking and delivery confirmation functions, and the company seems well satisfied with the performance of analog cellular technology. Nevertheless, until just a few years ago, there were limited wireless communications options available to consumers. If UPS were making its choice today, it seems unlikely it would stick with analog cellular for handling its mobile links.

	reliability	coverage	avg. data transfer speed	equipment & airtime costs	security	simplex, or duplex	circuit-switched or packet data	support for voice or data	real-time or store-and-forward	availability
analog cellular	**F**	urban	9.6 kbps	**F**	**P**	duplex	circuit-switched	both	real-time	1983
digital cellular	**E**	urban	9.6 kbps	**F-VG**	**E**	duplex	packet data	both	real-time	1994
CDPD	**E**	urban	19.2 kbps	**E**	**E**	duplex	packet data	data	real-time	1994
PCS	**E**	urban	at least 8 kbps	**E**	**E**	duplex	packet data	both	real-time	2000
DECT (telepoint)	**E**	none in USA	at least 32 kbps	**VG**	**E**	duplex	packet data	both	real-time	must be State-built
radiopaging	**E**	urban, some rural	2.4 kbps	**E**	**E**	simplex	shifting to packet data	both	store-and-forward	early 1960's
N.W.N.	**E**	urban	faster than 2.4 kbps	**E**	**E**	duplex	packet data	data	real-time	1995
analog private land mobile radio	**VG**	urban, some rural	4.8 kbps	**E**	**P**	duplex	circuit-switched	both	real-time	1950's
ESMR	**E**	urban, some rural	19.2 kbps	**F-VG**	**E**	duplex	packet data	both	real-time	1995-1996
ARDIS & RAM	**E**	urban	4.8 kbps-A 8 kbps-R	**F-VG**	**E**	duplex	packet data	data	real-time	1990-A 1989-R
Ricochet	**VG-E**	urban	77 kbps	**E**	**E**	duplex	packet data	data	real-time	1994
geostationary satellite	**E**	statewide	21.33 kbps	**P-F**	**E**	duplex	both	both	real-time	1965
big LEO	**E**	statewide	2.4 kbps	**F-VG**	**E**	duplex	packet data	both	real-time	1997
little LEO	**E**	statewide	2.4 kbps to 4.8 kbps	**E**	**E**	duplex	packet data	data	both	1995-96
meteor burst	**E**	statewide	2 kbps to 32 kbps	**E**	**E**	duplex	packet data	data	acts like store-and-forward	1953

P = poor	**F** = fair	**VG** = very good	**E** = excellent

Table 1.1: Wireless Technology Comparison Matrix

There are a number of newer technologies that not only perform better but do so at less expense.

Analog cellular equipment has come down greatly in cost, but airtime can still add up quickly to produce hefty monthly service charges. Also, analog cellular networks never were intended to be used for data transfers, so they perform poorly in comparison to modern packet data systems. Their coverage area is primarily urban, and this limits their usefulness, especially in most areas of eastern Washington. Finally, conversations over present cellular systems can be listened to by anyone with a modified scanner. In times of emergency, this lack of security may be a severe disadvantage.

Digital Cellular Telephony

Cellular operators are just now beginning to implement digital standards that will greatly improve the reliability of cellular service and make cellular networks much more hospitable for data transmissions. Like analog cellular, digital systems will support data transfer speeds of at least 9.6 kilobits-per-second, but cellular hand-offs will no longer cause disastrous breaks midstream in a data file traveling over cellular radio channels. Packet data capabilities will vastly improve the flow of data from mobile units to cellular transmitter towers and back. For the near future, hybrid analog-digital phones will be necessary to ease the transition to full digital service, and these phones will be somewhat larger and considerably more expensive. As a trade-off, digital airtime rates are advertised as being 40 percent cheaper than analog charges.

A problem may develop with the installation of different digital standards by the duopoly service providers in each metropolitan service area. For example, as Appendix A illustrates, Cellular One in Seattle is opting for a time-division multiple-access (TDMA) standard, while U.S. West has yet to decide on a true digital specification; the N-AMPS standard chosen in the interim is an advanced analog standard. Different digital standards in each market could make it confusing for customers to understand their options, thereby slowing the adoption of digital equipment and keeping cellular costs high. Even with digital standards, cellular networks rarely reach beyond the suburbs and will be of limited use on the less-frequently traveled state highways that crisscross the Olympic Peninsula and the Inland Empire.

Cellular Digital Packet Data

Much has been written in the press about the promise of cellular digital packet data (CDPD) technology to bring low-cost and reliable data service to regions served by cellular operators. CDPD uses the short pauses in between cellular calls to transmit bursts of data along radio channels that would otherwise be idle. Promoters claim that CDPD will support data transfer rates as high as 19.2 kilobits-per-second—a reasonably good speed for a wireless connection. It remains to be seen, however, how much of this early publicity will prove true and how much will remain as just hype. Delays in the implementation of CDPD already have some industry analysts speculating that there are technical problems with the service and that cellular operators are not unified in their support. CDPD did recently receive a shot in the arm when Federal Express announced that it would be an early customer.

Like digital cellular, CDPD should offer a reliable over-the-air service by employing packet data transmission techniques and error checking protocols. CDPD will also provide two-way data messaging, not one-way service like most paging systems. Even so, CDPD will be handicapped by the same coverage limitations that hamper the usefulness of both analog and digital cellular service. Since CDPD uses vacant space on cellular radio channels, it can only travel as far as the cellular network will allow. Cellular operators are unlikely to extend their cellular nets far beyond most cities, since the cost of developing the cellular infrastructure demands high population densities to ensure a broad customer base.

Personal Communications Services

Like CDPD, Personal Communications Services (PCS) have been given extensive play in both the popular press and in industry journals. PCS can be thought of as a cellular system that uses equipment operating on greatly reduced transmitter power. In fact, instead of using large transmitter towers, PCS is envisioned as employing transmitter/receivers small enough to be mounted inconspicuously on the sides of buildings and atop light standards. Since PCS devices will use lower power, the phones should be smaller, lighter and able to run longer on a single charge—even for weeks at a time. Although no PCS systems have yet been built in the U.S., promoters boast that they will be able to accommodate many more callers than cellular networks and, as a result, will offer much cheaper airtime rates.

Auctions selling the first licenses for PCS began in August of 1994, but the main body of licenses will not be sold until December. These spectrum auctions are the first ever in the U.S. and have already earned the government an extra $617 million in revenue. Once the licenses have been awarded to the highest bidders, it may take anywhere from three to five years for PCS providers to construct the first systems and work out the bugs. The DOT should keep an eye on further developments with PCS, since it could become an inexpensive resource for mobile voice and data communications—costing considerably less than either analog or digital cellular. But PCS service is still too far in the future to predict with much accuracy how well the technology will perform.

Digital European Cordless Telecommunications

Much more experimentation in cordless telephony has been conducted in Europe than in the United States, to date. As a result, the Europeans have devised a cordless phone system that allows people to take their cordless receivers out of the home, use them at designated public gathering places, and then make business calls on the same devices at the office, as well. An early version of the technology was known as CT-2 (for the second generation cordless telephone standard). But a more recent technology, called the Digital European Cordless Telecommunications standard (DECT), offers improvements over CT-2 while still permitting less expensive service than is associated with cellular phones. DECT has the additional advantage of having broader political support across Europe than did CT-2, which was primarily a British innovation.

When DECT phones are used on the street they can only interface with the public switched telephone network (PSTN) when they are within range of a clearly marked telepoint. These telepoints can be thought of as cordless phone base units that work with all cordless receivers in operation. Some telepoints register the presence of a customer when the person comes within range—say at a train station. Calls can then be forwarded to that customer, as long as the person stays within range. Many telepoints, however, do not allow incoming calls and only facilitate calls from the customer to someone on the PSTN.

There are no telepoint networks in the U.S., although some Canadian and American firms have shown interest in importing the technology. The value of DECT for the DOT is that the department could establish its own private system of telepoints strategically located along highways so that mobile road crews could use them to call dispatchers. Such a system would be isolated from public use, so it would not get crowded during times of emergency or disaster, as would cellular channels. Telepoints located throughout the Cascade mountain passes would allow snow plow drivers to check in regularly with headquarters without having to leave their trucks. In addition to voice communications, the DECT system supports data transmission of 32 kilobits-per-second. If telepoints were only established in those regions not served by more common commercial mobile systems, they could ably supplement those metropolitan-based wireless networks.

Radiopaging

Radiopaging has so many attractive features that it is understandable why public interest in the technology has grown by leaps and bounds over the last decade. It is not uncommon now for businesses to have employees on-call through the use of pagers, or for parents to use pagers to stay in touch with busy teens while still allowing them their freedom. Paging channels are fairly robust and most can reach deep into buildings to reach customers inside. The technology is simple, and pagers are becoming even more versatile and portable as they integrate digital signaling techniques. Competition among service providers is also creating a host of options for consumers ranging from basic tone-only models that beep when someone is needed to alphanumeric devices that can display shorts messages about 80 characters long. The most expensive pagers are the "tone-and-voice" models that notify the user of a call and then relay 20 seconds of a voice message at the customer's convenience.

Paging is hamstrung by two main shortcomings. First, it, too, is primarily an urban service, although most paging networks reach further into the suburbs than do cellular systems. Second—and most critical—is the fact that paging is traditionally just a one-way service. Users can receive brief messages, but they cannot acknowledge them unless they have a cellular phone or are near a wired telephone. Despite these setbacks, paging cannot be ignored because it is such an affordable means of communications. The DOT could establish its own paging network in outlying areas by using FM subcarrier signals to transmit short messages along with the programming broadcast by FM radio stations. FM radio listeners would never hear these pages. Using such an approach, the DOT could establish a rural network without having to construct its own costly radio transmitters. Such a paging system could serve as an adjunct to other commercial services and would come into use whenever mobile workers traveled beyond the range of the privately-run networks.

Nationwide Wireless Network

Whenever a technology has a prominent weakness, it's a sure bet that someone will come along with a "new and improved" version that they hope will gain a substantial following. Such is the case with the Nationwide Wireless Network (NWN) being promoted by Mobile Telecommunication Technologies Corporation, better known as MTEL. Recognizing that one of the major drawbacks of conventional paging is that callers wanting to reach someone are never sure if their page was received, MTEL has come up with a state-of-the-art paging system that supports two-way messaging. In the hopes of encouraging similar innovations, the FCC has devised a "pioneer's preference" licensing status whereby companies pushing new ideas are rewarded with an early grant of spectrum to permit the implementation of the new service. MTEL was given just such an award in September of 1993 when it was given the license to 50 kHz in the 940 MHz band.

As is the case with CDPD and PCS, it is impossible to tell how effective this new technology will be until MTEL has the technology up and running. The company expects to have the NWN operating in the top 300 markets across the U.S. by mid-1995. Not only will the NWN allow two-way paging, but is should also support faster data transfer speeds than are common with today's paging systems. Despite its advantages, the NWN will still share one of paging's remaining flaws: that is, the lack of network coverage outside urban and suburban neighborhoods.

Conventional Private Land Mobile Radio

One of the oldest mobile communications technologies is private land mobile radio. With private land mobile radio, the FCC set aside frequencies so that industries, trucking firms, and public safety groups could take advantage of radio service to improve their productivity and safeguard the public's welfare. Included within the category of public service radio allocations are the frequencies established by the FCC to be used for highway maintenance. The DOT currently uses those radio channels for voice communications with workers within range of the department's transmitter towers.

Although private land mobile radio is admittedly less "high-tech" than other wireless services appearing on the scene, part of the attraction of this technology is its simplicity and reliability. Having been in existence for some forty years, the equipment has been refined to the point where it is dependable and rugged. The fact that spectrum is freely available for DOT use is a tremendous advantage when one considers the annual service costs associated with other commercial systems. The money saved on airtime alone could permit the DOT to expand its network of private land mobile radio transmitters across the state.

Frustrations with the limited number of highway maintenance channels available could possibly be solved by adopting some of the newer mobile radio technologies that use more narrow frequency channels and, thereby, boost capacity. Switching from the current configuration that supports voice communications to one allowing data messaging could very dramatically increase the channel capacity of the highway frequency bands. Although road crews might grumble over the loss of voice communications, such a change would help the DOT make the most of its small radio allocation. Even a hybrid system, permitting both voice and data, would bring substantial capacity gains. Additionally, conversations on private land mobile radio channels are not private. Only by switching to a digital data transmission scheme could the DOT thwart radio hobbyists listening in on scanners, which can pick up voice communications.

Enhanced Specialized Mobile Radio

Some of those same private land mobile radio frequencies that are used by taxi fleets and the DOT will soon be changed in a way to make the service they support comparable to that of cellular telephony, only more versatile. Enhanced Specialized Mobile Radio (ESMR) technology can be thought of as private land mobile radio gone digital and cellular; instead of using widely spaced transmitter towers to beam radio signals, ESMR providers will employ smaller cells that enable them to reuse their limited number of frequencies. The handsets used by customers will also serve multiple functions, including voice, paging and data messaging all in one transceiver. The ESMR standard was devised by Motorola and is being heralded by operators like NEXTEL, Dial Page, and American Digital Communications, Inc. A company called OneComm previously held the specialized mobile radio licenses covering Washington State, but OneComm announced a merger with NEXTEL in the summer of 1994.

The only ESMR network up and running is in Los Angeles, but OneComm has recently announced that it will start service in Washington State during the fall of 1994; some industry observers question whether OneComm can meet this ambitious time schedule. The early literature on the technology suggests that ESMR airtime could be 10 to 15 percent cheaper than cellular; ESMR transceivers, on the other hand, will be somewhat expensive—estimated to cost between $500 and $700. The handsets will be powerful communications devices, since they will carry voice, paging and data messages. But these hybrid radios—called "Unicators"—will be too expensive for the average consumer, and may be too expensive for the DOT, too. Also, like the cellular networks that ESMR will emulate, the service will be spotty and operators will concentrate on reaching highly populated urban areas, at least initially. The main benefit attached to ESMR service may be the competition it provides to other established wireless systems, which then drives down wireless prices across the board.

ARDIS and RAM

As the field of wireless communications matures, the market is diversifying and service providers are specializing by targeting distinctive mobile communications needs. One example is the arrival of radio data networks (RDN), which are able to flourish even though they cannot carry voice conversations. Their niche is the market segment demanding mobile data communications: long-haul truckers, field service workers, white collar workers desiring continuous access to e-mail accounts, and others. The two main players in this area are the Advanced Radio Data Information Service (ARDIS) and RAM Mobile Data. Both services have been in existence since the early 1990's and use their nationwide radio licenses to provide data networking to a broad range of clients. Wilson Sporting Goods, for example, uses ARDIS so that its salespeople can check warehouse inventories when making deals with the owners of athletic supply stores. Conrail uses RAM to track the location of train shipments and to continuously update the work orders followed by locomotive engineers.

Both systems have fairly slow data transmission speeds. However, the radio channels created by ARDIS and RAM are quite robust and, so, offer reliable messaging service, even to workers stationed deep inside downtown skyscrapers. Unfortunately, if those same workers make a service call into the country, both systems have very limited reach into those areas. The modems used with both networks are still priced close to $1,000, and the pricing schedules for estimating airtime charges are so elaborate that reliable cost estimates are difficult to calculate. Industry analysts insist that, for short messaging, the per-packet charges of these RDN's should be less expensive than transferring data over circuit-switched analog cellular telephones. ARDIS and RAM both have a surprisingly small number of subscribers (50,000 and 15,000, respectively, as of most recent estimates). Perhaps as the number of subscribers grows they will be able to offer cheaper transceivers and lower airtime rates.

<u>Ricochet Micro Cellular Data Network</u>

Another radio data network that is just getting started in California is the Ricochet Micro Cellular Data Network. Designed by a company called Metricom, Ricochet was conceived with the intent of providing low-cost, high-speed data communications for operations like public utilities—a goal it seems poised to achieve. Unlike ARDIS and RAM, Ricochet uses a frequency-hopping spread spectrum transmission standard which allows very efficient use of radio spectrum and inherent security against unwanted message interception. Calls from various customers share the same broad range of frequencies, but individual calls are moved along with their radio carriers, whose frequencies are continuously varied. This approach has been used for years to carry military communiqués because of the difficulties of message interception. Ricochet also employs a "mesh network" in which system intelligence is spread throughout the net instead of concentrating it in centralized hubs. This lets data connections occur faster without crowding radio channels to and from an operations center. The data speed advertised for Ricochet is a relatively fast 77 kilobits-per-second.

Ricochet sports another key difference from ARDIS and RAM. Both those data networks use licensed radio frequencies in the 800 and 900 MHz bands. Ricochet, on the other hand, takes advantage of unlicensed frequencies that fall between 902 and 928 MHz. This means that Metricom does not have to gain FCC approval before it can build out its network in any city; it also could lead to interference problems since Metricom must share those same frequencies with other industrial, scientific and medical users. Given its emphasis on urban wireless communications, the chances for interference in the Ricochet network may grow as those unlicensed frequencies get heavier use in the years ahead.

At least one source cites plans to establish a Ricochet network in Seattle before the end of 1994. That date may be overly optimistic. However, since Ricochet uses small transmitters the size of a cereal box, which are easily attached to light stands and telephone poles, the system can be put in service quite quickly and at comparatively low cost. Ricochet will not support voice connections. But its low prices for both equipment and airtime deserve serious consideration. If Ricochet does, indeed, come to the Seattle area, it should stand head-and-shoulders above any of its mobile data competitors.

<u>Geostationary Satellites</u>

Futurist Arthur Clark conjectured in 1945 that man-made satellites placed 22,300 miles above the equator and moving at the proper velocity would demonstrate an unusual characteristic: to observers on the ground, the satellites would appear to be holding still. As a result, such satellites came to be known as "geostationary," "geosynchronous," or "fixed." The prospect of geosynchronous satellites was attractive to operators and their customers because they would simplify the construction of satellite dishes on the ground (earth stations) that could remained pointed at one spot in the sky. Initially, the long distance to geosynchronous satellites was worrisome because of the signal delays that were anticipated. But once the first fixed satellites demonstrated that those signal delays were minuscule, enthusiasm grew at a fast pace.

Geostationary satellites are the only technology available right now that can provide high-quality voice communications to all four corners of Washington State. These satellites also support data transmission speeds around 21.33 kilobits-per-second. But the costs associated with fixed satellites limit the technology's market reach. It is not uncommon for phone calls over geostationary "birds" to cost at least $10 per minute. Since the orbital plane around the equator can only hold 180 satellites, which serve countries all around the world, geostationary satellite operators have had only limited competition. As a result, their prices have remained high. Nevertheless, that premium price may sometimes be justified by the ability of geosynchronous satellites to allow voice communications to people who would otherwise remain isolated. These satellites also claim an outstanding history of service reliability.

"Big" and "Little" Low-Earth-Orbit Satellites

After years of being the dominant satellite communications technology, geostationary satellites may finally be getting some serious competition. Low-earth-orbit (LEO) satellites travel much closer to the surface of the planet, some 500 miles above the ground. As a result, their signals suffer less interference and distortion. Also, less power is needed for handsets to communicate with the LEO's above. This helps to keep transceivers small and makes it possible to employ short whip antennas instead of clumsy earth dishes. But LEO's do not hold a fixed position in the sky. So, if operators want to provide continuous coverage to customers on the ground, they must deploy 10, 20, or more LEO's into orbits designed to blanket the earth.

Two broad classes of LEO's are emerging. "Little" LEO's are those that can only carry data transmissions; they use VHF transmission frequencies around 140 MHz. The "big" LEO's use frequencies above 1 GHz and can support both voice and data services. It is these big LEO's that may finally provide a more cost effective alternative to earlier geosynchronous satellites. No big or little LEO's have yet made it off the drawing board and into the sky. But some little LEO projects, such as ORBCOMM and Starsys, should begin operations in the next two years, and big LEO systems are not far behind.

The progress of the little LEO programs should be keenly watched. They will permit data communications throughout our state at very reasonable rates: ORBCOMM estimates that a 250 character message will cost customers about 19¢ to send, and their handsets will cost

$400, at most. The digital transmissions will be secure, and two-way data communications will be possible. For relaying remote sensing data from Omak or Pullman—or for sending brief messages to DOT dump trucks traveling near Port Angeles, for instance—these little LEO satellite networks could be strong performers.

It is the big LEO efforts, however, which have gotten the most publicity. The Iridium project, spearheaded by Motorola, was first, followed by Teledesic (supported financially by Craig McCaw and Bill Gates). At least five other ambitious big LEO projects are in the works. Teledesic, which is one of the most recently announced big LEO programs, projects an operational network size and complexity unmatched by its competitors: it will involved the launch of an amazing 840 refrigerator-sized satellites into circular orbits.

The big LEO's will never be able to beat terrestrial-based mobile communications networks on price, their investors admit. But at $2-to-$3-per-minute, they are much cheaper than their fixed satellite cousins. Just a few years ago, observers scoffed when Motorola said the Iridium project would require the launch of 77 satellites (now reduced to 66); today, Iridium is much further along and stands a reasonable chance of implementation. Whether or not these big LEO's will attract customers once they are operational is yet another question. Nevertheless, big LEO's show promise, and the DOT should consider them as an option for providing remote voice communications links.

Meteor Burst

Meteor burst seems to be the one wireless technology in this group that gets the least public attention. Perhaps this is because it is perceived to be too fanciful to really work. Meteor burst equipment "watches" for meteor trails to streak across the sky and then uses the ionized meteor particles to bounce bursts of data between distant locations. Using just one or two meteor burst base stations (constructed at a cost of $510,000), the DOT could gain unhindered statewide data communications. Most importantly, <u>there would never be any airtime costs</u>, since the meteors flashing above act like free natural satellite relays. Meteor burst technology is one of those deals that just sounds too good to be true. Yet years of experience by the U.S. Department of Agriculture in using meteor burst to relay meteorological readings from the locations scattered across the West Coast prove that it does work. Meteor burst transmitters are also at work inside Mount St. Helens, sending snow pack data to distant scientists.

Meteor burst technology has compiled an impressive track record over the past 40 years. Yet this technology is not without its drawbacks. For instance, usable meteor trails are not always present, so there can be some delays in sending data messages. Base stations use more power, so their longest delays usually last just a few minutes. But mobile units are more hard pressed to detect coherent meteor showers; they may take between 10 and 20 minutes (as a worst case scenario) to send a full message. In essence, meteor burst behaves like store-and-forward paging systems, since communications are not instantaneous. (The worst time of the year to send meteor burst messages is in winter, because that is when meteor activity is at its lowest.) Customers need to realize, too, that meteor burst is best at sending short messages, since meteor trails don't last long enough to bounce long messages back to earth.

Despite its shortcomings, meteor burst has many good traits. For short data messaging to remote locations not requiring real-time communications, it is hard to beat. It may sound like Buck Rogers technology, but it has proven itself in a variety of real-world situations and could be an inexpensive option for DOT mobile data communications. Joined with radiolocation equipment, meteor burst technology could help DOT dispatchers track and direct highway work crews across the state.

Chapter II

Cellular Telephony

Introduction

Within the last five years, cellular telephony has outgrown its image as a yuppie status symbol to become ever more a mass consumer item. No longer seen as a luxury, many small business owners regard cellular phones as a necessity to stay in touch with employees and clients, and increasing numbers of families are investing in portable cell phones to guard their safety while on the road. When cellular telephony celebrated its tenth anniversary in October of 1993, it could boast of service to a record number 13 million subscribers across the United States with increased growth expected in the years just ahead.[1] Analysis by Northern Business Information (NBI), a unit of McGraw-Hill Inc.,[2] suggests that cellular revenues will grow yet another 17 percent this year to $12.4 billion.[3]

This rapid growth in the cellular sector brings marked advantages and disadvantages for potential users. As the cellular industry matures it is broadening its technological base in an effort to reach beyond traditional voice customers and increase service to new, untapped markets. This should bring about new capabilities and falling prices for data transmission services. On the other hand, the hotly contested wireless marketplace is fast becoming a quagmire of choices for the uninitiated user. Options are rapidly increasing, and with those options come new possibilities for accomplishing old tasks, as well as potential pitfalls for the creation of ill-fitting or rapidly outdated data communication networks.

Background

Today's cellular radio systems trace their history back to the first commercial mobile telephone services established in 1946. Those early pre-cellular systems used what is known as a wide-area architecture; in other words, they operated much like a radio station, using a single transmitter to cover an area of 40 to 50 miles around a metropolitan area. However, such a design limited the system's customer capacity, since the few radio frequency channels available to each operator were quickly saturated by just a small number of calls in progress. In describing the system's limitations, Michael Paetsch notes: "In 1976, for example, Bell Mobile

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[1]Ellen Messmer, "U.S. Cellular Telephone Service Celebrates 10th Anniversary," Network World, 4 October 1983, p. 32.

[2]Bart Ziegler, "Clash of the Telecom Titans," Business Week, 10 January 1994, p. 84.

[3]Although cellular service has shown marked growth over the past decade, attracting interest outside an upper class clientele to appeal to middle class consumers, it must be noted that today's cellular subscriber base still represents only five percent of the total U.S. population—clearly a small percentage of total potential customers. This percentage is calculated from population statistics given in The World Almanac and Book of Facts, 1994, edited by Robert Famighetti. Mahwah, NJ: Funk & Wagnalls, 1993, pp. 358-361.

provided 12 channels for the entire metropolitan area of New York (more than 20 million people) to serve 543 customers, with an additional 3,700 on a waiting list."[4] (Emphasis mine.) This problem of spectrum scarcity is one that is a recurrent theme in the history of cellular telephony to date.

Although efforts had been made since the 1930's to improve the performance of mobile telephony, the breakthrough idea of "cellular" radio was initially devised by engineers at Bell Labs in 1947. It occurred to the Bell Labs staff that if they greatly reduced the power of the transmitter so that its signal covered a much smaller area (which came to be known as a cell), they might be able to reuse the allotted frequencies in a way that could support more customers through a network of strategically-located, low-power cell sites. Although the radio frequencies used could not be reused in immediately adjacent cells because of problems with interference (known as co-channel interference), the engineers were able to devise reuse patterns that permitted the same radio frequencies to be efficiently reapplied throughout the system in scattered cells. (See Figure 2.1.)[5]

Another advantage of the cellular design was its ability to adapt to changing customer demands. Engineers came to realize that as the customer base of a cellular system approached full capacity, key cells could be divided into a number of smaller cells—each time reducing the transmitter power to the new cells and redistributing the allotted frequencies so as to make a gain in the volume of customers allowed. This characteristic of cellular telephony would allow system operators to begin with a small number of large cells and then add more cells by sub-division as demand required and revenue permitted. (See Figure 2.2.)

Despite theoretical projections that cell sizes could be reduced almost indefinitely, real-world technical and economic considerations soon made it clear that such was not the case. Practical experience revealed that the development of small cells caused increased engineering headaches with heightened co-channel interference and shadow losses (whereby buildings or tall foliage block signal propagation). Cell division also proved costly, since each new cell required its own transmitter and the accompanying real estate on which to locate it. This proved to be an expensive proposition in those same metropolitan areas where cell-splitting was most urgently needed. Now that the limitations of cell-splitting are more clearly understood, emphasis is being placed, instead, on new transmission standards that will squeeze more calls onto the finite number of radio channels allotted to cellular operators.

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[4]Michael Paetsch, Mobile Communications in the U.S. and Europe: Regulation, Technology, and Markets (Boston, MA: Artech House, 1993), p. 23.

[5]The cells in this diagram are shown as regular geometric shapes. In the real world, cells have irregular outlines owing to topographical changes, urban architecture, and other factors that cause propagation irregularities. It is common for ease of display in basic diagrams of cellular systems to show cells as following regular geometric patterns, ignoring the propagation distortions that make cellular deployment so challenging.

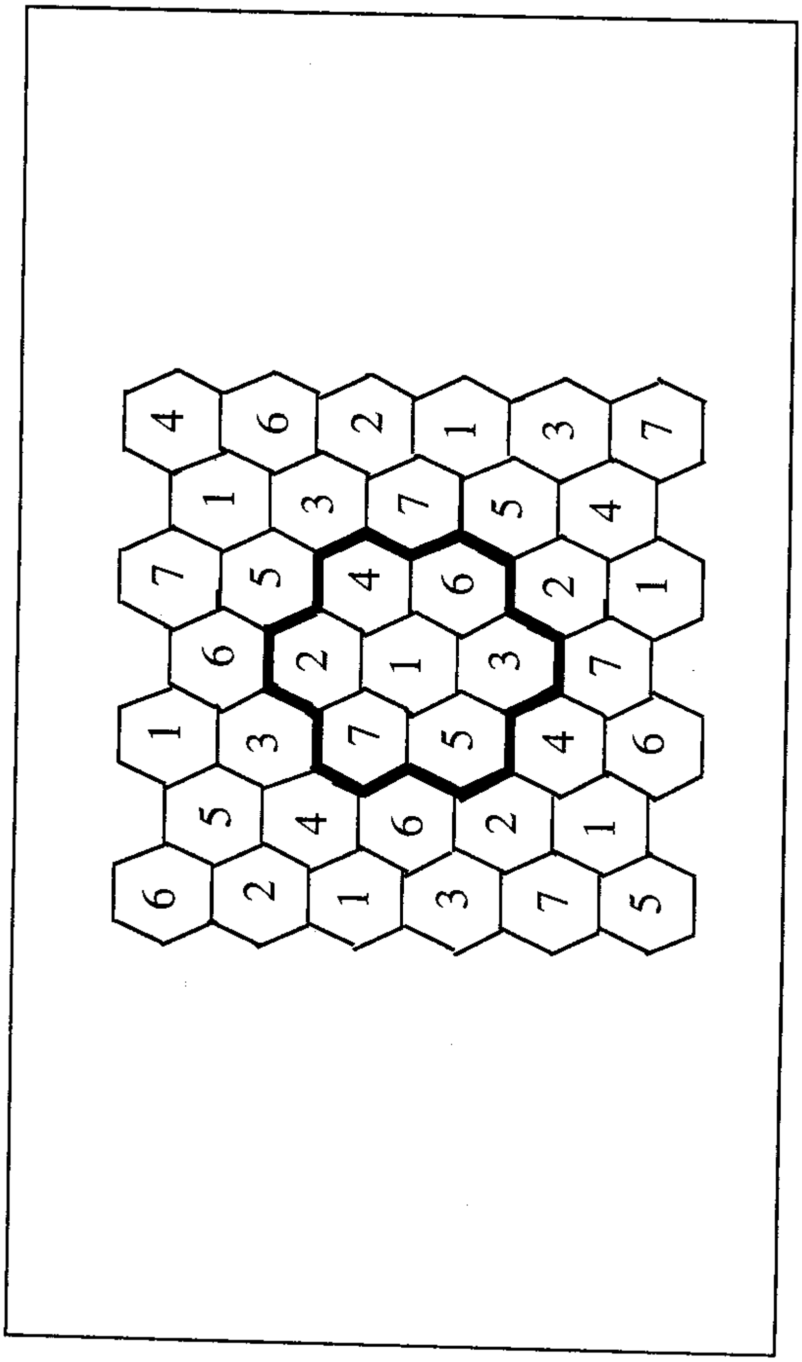

Figure 2.1: Common Cellular Frequency Reuse Pattern Employing 7 Frequency Sets*

(Adapted from: Michael Paetsch, Mobile Communications in the U.S. and Europe. Boston, MA: Artech House, 1993, p. 24.)

* Cells containing the same number use the same set of frequencies

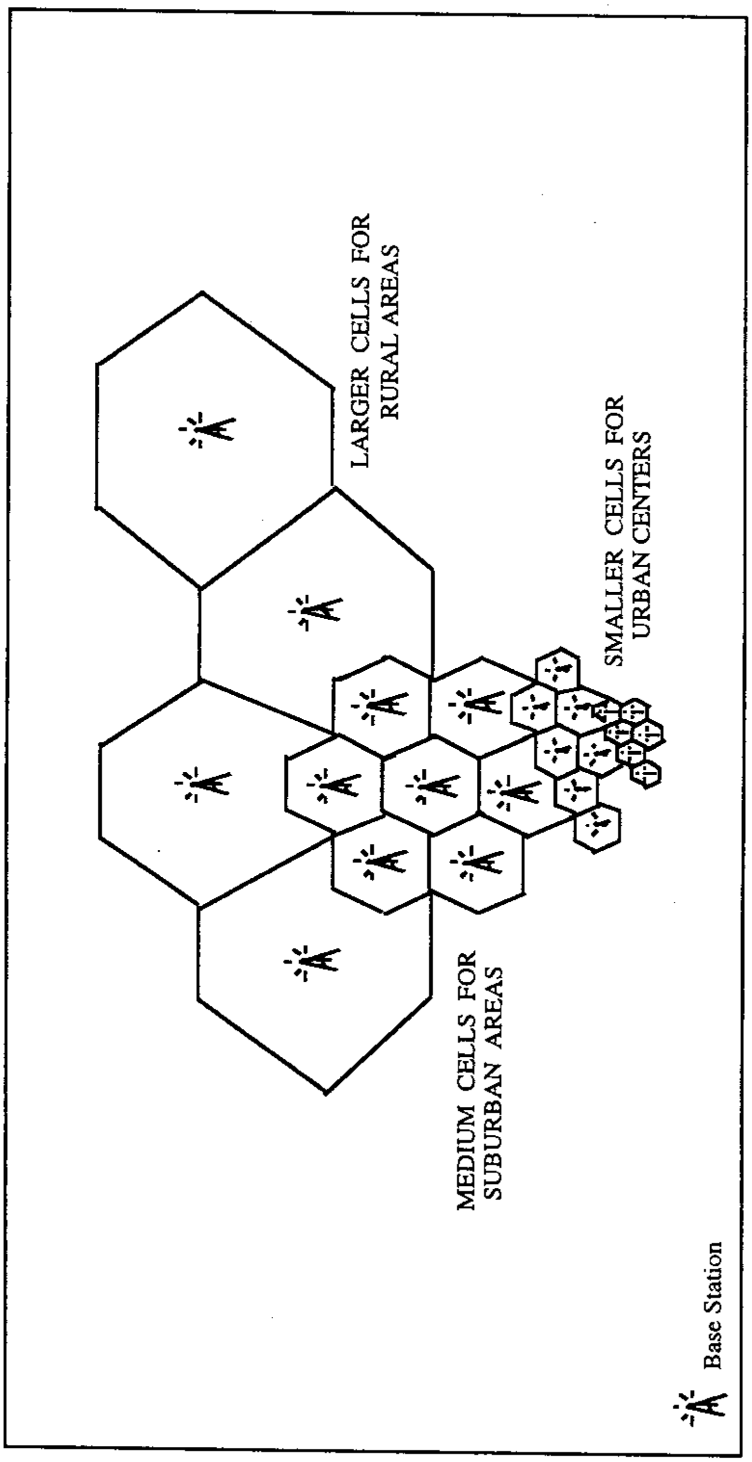

Figure 2.2: Cell Splitting to Achieve System Capacity Gains

(Adapted from: George Calhoun, Digital Cellular Radio. Boston, MA: Artech House, 1988, p. 43.)

Of course, with the advent of cell sites, some technique had to be created to allow drivers involved in telephone conversations to move from one cell to another, thereby changing to a different frequency, without interrupting the call. The answer has come to be known as a cellular "hand-off." In a sophisticated process, the mobile telephone switching office, or MTSO—which can be thought of as the intelligence of the cellular system—detects when a caller's signal is getting weak. The MTSO then queries other cell sites to determine which is the next best cell to pick up the call. When another cell demonstrates that it is receiving a suitably strong signal from the mobile unit, the MTSO transfer the call from the first cell to the new host cell. This transfer, or "hand-off," takes a microsecond to complete and, while a brief segment of the conversation in progress might be lost during the switch, the changeover is so quick that it usually goes undetected by the human ear.

This hand-off creates more of a problem for data transfers over current cellular systems, however, because even a brief loss within a continuous stream of data can inject serious errors into the information transfer. As a result, customers are often advised to remain stationary when transmitting data over existing cellular networks. Advances in cellular technology are underway which are intended to remedy these shortcomings.

The First-Generation Cellular System

Interestingly, even though the cellular concept was first conceived in 1947, it was not until 1983 that cellular technology was finally put into operation in the United States. Again, the problem of spectrum scarcity was a leading reason for this delay, along with the FCC's emphasis throughout the 1950's and much of the '60's on establishing a competitive, nationwide television service through the implementation of UHF broadcasting. In spite of growing public demand for mobile telephone service, the FCC was swayed by the arguments of the broadcasting industry and by its belief that television would be of greater use to a larger proportion of the population. As a result, the Commission allocated spectrum for the infant UHF service instead of cellular telephony and repeatedly denied requests for spectrum space from the mobile radio community and AT&T.

Finally, in 1970, the FCC voted 3-2 in favor of allocating more radio frequencies for mobile radio—frequencies garnered from the largely unused upper regions of the UHF-TV band. There subsequently began another decade of delay while the Commission debated the manner in which the new cellular frequencies would be made available. This debate reflected an ever larger discussion in Washington, DC over the value of a monopoly-based telephone service versus a competitive approach, which ultimately resulted in the divestiture of the Regional Bell Operating Companies (RBOC's) from AT&T. In the matter of cellular telephony, the FCC struggled over a policy position: should the cellular frequencies be granted entirely to a single operator, like AT&T who could guarantee standardized, universal service—or should the frequencies be divided among two or more competing operators who might drive down service prices and introduce innovative technologies?

Ultimately, the pro-competitive forces won out. As a result, the United States was broken down into 306 metropolitan service areas (MSA's) and 522 rural service areas (RSA's), and provisions were made to split the cellular frequencies between two operators in each area. The frequency assignments were divided into two blocks of 416 frequency pairs employing 30 kHz channel spacing. Under this duopoly plan, one half of the cellular channels were to be granted to a wireline operator (an established telephone interest), while the other half were to be issued to a non-wireline operator (one of the many small Radio Common Carriers (RCC's) in existence). This explains why Seattle, for instance, has two cellular operators: U.S. West (the traditional wireline interest) and McCaw Cellular. Although the FCC admitted that by creating a duopoly it was reducing the overall system capacity, it was felt that the competition that would be introduced by having two operators would brings substantial customer benefits in exchange.

Cellular System	Mobile Frequencies	Base Frequencies
Non-wireline	824-835 MHz, 845-846.5 MHz	869-880 MHz, 890-891.5 MHz
Wireline	835-845 MHz, 846.5-849 MHz	880-890 MHz, 891.5-894 MHz

Table 2.1: Frequency Assignments for U.S. Cellular Systems[6]

The technical standard that was established by the FCC for cellular operation was the Advanced Mobile Phone Service (AMPS) air interface, which was based on the foundational efforts of Bell Labs mentioned earlier. As might be expected considering the early developmental work behind AMPS, it is an analog system based on FM radio modulation techniques. Much as had occurred with the requests for spectrum space by mobile interests, the technological underpinnings of AMPS were weakened as the result of unfortunate timing. Developed during the late 1940's and ultimately approved in the early 1970's, AMPS froze the cellular standard at a time when digital transmission techniques were just beginning to open opportunities for better signal transmission quality and system capacity. As a result, within five years of the first cellular system going on line in 1983, serious debate was underway within the Cellular Telecommunications Industry Association (CTIA), an industry forum, to come to a common agreement on a digital replacement system for AMPS. A tenuous transition to such a second-generation system is presently underway. Dual-mode analog/digital transceivers are

[6]Adapted from Paetsch, Mobile Computing, p. 150. In Seattle, McCaw Cellular (associated with the Cellular One network) is the non-wireline cellular service provider and U.S. West (associated with the MobiLink network) is the wireline cellular service provider.

U.S. WEST CELLULAR	McCAW CELLULAR
The "Maximizer Plan":	**The "Premier Plan":**
320 min./month max. @ $129.95	360 min./month max. @ $139.99
The "Budget Plan":	**The "Standard Plan":**
150 min./month max. @ $74.95	180 min./month max. @ $86.99
The "Intro Plan":	**No comparable plan**
60 min./month max. @ $49.95	————————
The "Optimum Plan":	**The "Occasional Plan":**
$29.95/month, plus airtime charges:	30 min./month max. @ $29.99
0-100 min.—58¢ peak, 25¢ off-peak	
101-200 min.:—56¢ peak, 25¢ off-peak	

Table 2.2: Cost Comparisons Between Seattle Duopoly Cellular Service Providers[7]

being promoted in an effort to segue from the AMPS first-generation standard to a second-generation, digital cellular standard.

Even as some cellular systems begin switching from analog to digital technologies, there is as yet no common agreement on the part of the FCC or cellular operators as to what the next technical standard should be for cellular service. In fact, in 1988 the FCC decided to leave the choice of the next generation cellular standard open to the marketplace. Through its ruling entitled Liberalization of Technology and Auxiliary Service Offerings in the Cellular Radio Service, the agency gave its permission for cellular carriers to use "alternative cellular technologies and auxiliary common carrier services in the frequency bands 824-849 MHz and 869-894 MHz, except on cellular control channels"[8] on a secondary basis. The intent of this ruling is to encourage innovation in both the services offered and the technologies employed by licensed cellular carriers. One effect of this ruling, however, may be that the cellular marketplace will become fragmented by the installation of incompatible technologies, lessening the chances for a nationwide, digital, cellular network to develop.

Applications

Since the current AMPS standard was designed with voice telephony in mind, it should not be too surprising that its ability to handle data has severe limitations. However, as cellular

[7]Prices quoted from the following promotional materials: "Cellular Q & A," in One To One, (quarterly newsletter), edited by Lisa Wiseman, Winter 1994, pp. 2-3; and US West Cellular, Services and Price Plans, Greater Puget Sound, (informational brochure), prices effective 22 July 1993, dated July 1993.

[8]47 C.F.R. @ 22.930.

system designers have prepared for the switch to digital (and as cellular operators have looked for new revenue streams to fund system expansion), they have better anticipated the broader needs of customers that extend beyond voice communications. So, while AMPS has shown somewhat limited abilities to carry data, one can expect second generation systems to make great steps forward in this regard. Nevertheless, difficulties may arise in the future, not from restraints on the ability to transmit data over cellular channels but from a confusing array of options, many of which will be incompatible.

One of the main problems with data transmission over AMPS channels, which was noted earlier, is the break that can occur in the middle of a data stream as the MTSO hands the mobile off from one cell to another. This can be especially troublesome if the mobile is skirting the boundary between two cells, since the mobile will be continuously "hopping" between the frequencies of the two adjacent cells. While a hand-off of 0.05 to 0.2 seconds may be negligible to the human ear, it is often disastrous for data communications equipment using cellular channels. In situations involving telemetry from stationary equipment, this is not a problem, providing the location of the equipment is clearly within the boundaries of one host cell.

Cellular equipment manufacturers like Microcom (Norwood, MA) and Zyxel USA (Anaheim, CA) have done their best to remedy some of the problems of transmitting data over analog cellular channels by producing special cellular modems. These modems employ protocols like MNP 10, which is designed with features that enable it to better handle the rigorous demands of the wireless environment. For example, these modems perform error correction and data compression, they increase or decrease transmission speed depending on the strength of the cellular channel, and they bundle data in various size packets. Also, these modems simulate central phone company switching functions that regular modems need to operate, providing the dial tone, for instance, that isn't available on a cellular phone.

Because these modems perform special functions like robust error checking, and since they are not in wide demand, they tend to be expensive, costing as much as $1,500. One must remember, too, that cellular airtime has premium prices compared to standard wireline prices. A major advantage, however, is that cellular connections allow for temporary, remote telemetry installations to be connected with central computer equipment quickly and easily—and to be repositioned with little effort.

Two other data transmission methods have been designed to work with AMPS. The first has been created by Cellular Data, Inc. (CDI) of Palo Alto, CA. In between each 30 kHz voice channel in an AMPS system is a 3 kHz "guardband" intended to lessen interference between frequencies by slightly separating adjacent channels. It is within these 3 kHz guardbands that the CDI system broadcasts its data using a low-power transmitter of less than

200 mW. The power employed varies continuously in relation to the adjacent voice channels to avoid interference.

The size of these guardbands does limit somewhat the capacity of the CDI system. CDI provides 2,400 bits/sec data transmission. But it also offers some advantages. The system is more than adequate for short data transmissions, such as brief messages for highway reader boards. CDI receivers also require less battery power, allowing them to be smaller and more portable. Bell Atlantic, for example, is promoting CDI for such tasks as point-of-sale verification, store-and-forward telemetry, vending machine management, and alarm systems. Part of its appeal to alarm services is the fact that there are no wires that can be cut; so, unlike wired systems, it is more secure. It is also less prone to weather disturbances.

A second data transmission method compatible with AMPS is known as cellular digital packet data, or CDPD. This technology is designed to take advantage of the idle time after one cellular call ends and before another is connected. The delay which results can often take as long as 20 seconds—perhaps not much time for a voice conversation, but a wide open window for data transmission. The CDPD approach, which is based on IBM's CellPlan II technology, is to "look" for open voice channels and then skip data transmissions from one free frequency to the next. In fact, as David Miller of Cellular One admitted, there are often entire voice channels that are vacant, so little channel hopping currently takes place using CDPD.[9]

Unlike CDI, CDPD takes advantage of 30 kHz cellular voice channels to offer data transfer rates of 19.2 kilobits/sec using compression. This allows CDPD to go beyond simple messaging to provide remote computer communications and continuous connections to networks like the IBM data network. While some analog cellular customers claim that their present equipment provides nearly an identical data transfer rate, CDPD should still have a cost advantage over AMPS for data communications. It is expected that CDPD will be priced according to the number of packets transmitted or on a flat monthly rate; that contrasts with cellular voice service which is priced according to connect time.[10] CDPD is also expected to deliver a cleaner signal transmission, thereby reducing error rates.

McCaw Cellular of Seattle expects CDPD service to be available across Washington State by the end of 1994.[11] The company plans to market the technology in its coverage areas under the service name "Air Data."[12] It is anticipated that basic monthly CDPD service will cost

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[9]Personal Interview with David Miller of Cellular One following a presentation on Mobile Computing delivered at the Apple Market Center, Kirkland, WA, on Wednesday, 19 January 1994.

[10]Joanie Wexler, "Analog Cellular Nets Suit Users in Pre-CDPD Era," Network World, 4 April 1994, pp. 27, 30.

[11]Ibid.

[12]Dana Blankenhorn, "CDPD Interoperability Tests Completed," Newsbytes News Network, 7 June 1994.

$50 or less.[13] Additionally, the cost for a mobile phone-modem duo that can be connected to a laptop is expected to be between $200 and $400. While McCaw is presently installing CDPD functionality, it is important to remember that different cellular operators are taking different technological approaches as permitted by the FCC's 1988 liberalization ruling—meaning that nationwide, and even statewide, systems may vary significantly.

In a recent development, Federal Express has announced that it will use CDPD to supplement its present specialized mobile radio (SMR) package tracking system.[14] (The technology of SMR will be discussed in a later chapter.) Providing a tremendous lift for the fortunes of CDPD—which some industry analysts have come to criticize[15]—Federal Express has said that it will use CDPD technology in Las Vegas and in another city yet to be announced. The company will become the first major "Air Data" customer when it initiates the service sometime during the fall of 1994. Federal Express spokespeople have said they became interested in CDPD because the cellular networks on which it will operate have a broader national reach than the delivery firm's own SMR system; plus CDPD should provide additional messaging capacity and flexibility.

Second-Generation Cellular Systems

As was mentioned earlier, the first American commercial cellular system was activated in Chicago by AT&T in 1983. Less than a year later, the Chicago system was already saturated in some of its cells.[16] It has been this failure of AMPS to provide the necessary customer capacity for rapidly growing metropolitan systems that has stimulated experimentation into alternative cellular designs. The promise of digital techniques to improve wireless telephony has led to a variety of proposed second-generation cellular systems.

Between 1985 and 1988, cellular interests began discussing the possibility of implementing a new cellular standard offering greater user capacity and additional features, like improved data handling. Coordinated through the offices of the CTIA, the industry decided that the next generation standard would be a digital system, based on time-division multiple-access (TDMA). More formally, this TDMA-based standard was first known as IS-54 and then D-AMPS, but it is more commonly referred to as simply TDMA in most of the research literature. Initially the TDMA standard will increase channel capacity three times by interleaving three

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[13]"CDPD provider McCaw Cellular Communications, Inc. says users will likely pay an average of $35 a month for its service." Joanie Wexler, "Speedy Wireless Net to Go Live in Silicon Valley," Network World, 20 June 1994, p. 38.

[14]Dana Blankenhorn, "FedEx to Supplement Existing Data Network," Newsbytes News Network, 7 July 1994.

[15]See: Andrew Seybold, "CDPD Watch, January 1994," Andrew Seybold's Outlook on Mobile Computing 2 (January 1994): 2.

[16]George Calhoun, Digital Cellular Radio (Boston, MA: Artech House, 1988), p. 13.

calls on a single 30 kHz channel. It is anticipated that capacity will later be increased eight to ten times over the original AMPS channelization through the use of a more efficient speech coder and through the lower carrier-to-interference ratio (C/I)[17] afforded by digital techniques. The TDMA system is intended to provide data transmission speeds of no less than 9.6 kilobits/sec.

The transition scenario to second-generation cellular that has been sketched out by the CTIA takes a different approach from that being employed in Europe. A number of different first-generation cellular systems had taken hold there, and the move to a second-generation system was seen as a way to bolster cross-national unity and economic opportunity through the creation of a common market. Hence the second generation standard, known as the Global System for Mobile Communications (GSM), is incompatible with earlier analog cellular systems both in terms of the frequency location for the new service and the technology employed. In the U.S., on the other hand, a conscious decision was made that the second-generation standard would work in the same frequency band as the initial cellular systems and would employ convertible technologies. The upshot of this decision is that analog and digital systems are intended to coexist in the American plan—at least until the full conversion to digital is complete.

This is important to note, at least for the immediate future, since any transceivers intended for this joint market must permit dual-mode operation; they will allow digital capabilities where the infrastructure is in place, but will switch to analog operation in those areas that have yet to be updated to TDMA specifications. Initial expectations were that these new dual-mode phones would be heavier and more bulky, but at least one model shown by Nokia during the 1994 Consumer Electronics Show was surprisingly compact.[18] Prices for the equipment are, however, somewhat higher than for analog-only gear.

David Miller of Cellular One says that his firm is in the process of installing TDMA-based equipment in Washington State.[19] One can expect that metropolitan areas will be converted to TDMA first, with rural areas to follow, since the high-volume calling regions are most in need of added capacity, and income from those areas can help to fund expansion into other parts of the state. Meanwhile, another leading cellular operator in Washington State, U.S. West, is endorsing a rival digital technology produced by Qualcomm and based on Code-

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[17]"Co-channel interference occurs when two transmitters using the same radio channel have overlapping coverage areas. Thus, a mobile unit within this overlapping area receives energy from both transmitters. The degree of co-channel interference is measured by the so-called carrier-to-interference ratio (C/I), which equals the ratio of the carrier to the interference of both sources." Paetsch, Mobile Communications, p. 63.

[18]Dana Blankenhorn, "Consumer Electronics Show—Analog-Digital Cellular Phones," Newsbytes News Network, 7 January 1994.

[19]Miller, 19 January 1994.

Division Multiple-Access techniques, or CDMA. To be more specific, CDMA is actually direct sequence spread spectrum multiple-access (SSMA), but it is more casually known as CDMA.[20] (Qualcomm CDMA is also sometimes referred to as IS-95.) Although TDMA was first selected by the CTIA membership to provide the second-generation cellular standard, technologies like CDMA have since come forward to challenge that decision and, thereby, fragment the industry.

Whereas TDMA is a narrowband approach (dividing the allotted frequency band into individual radio channels, each with its own specific carrier frequency), CDMA is a wideband system. With CDMA, the entire frequency band is used as a channel for all the users at the same time. CDMA takes advantage of spread spectrum technology in which individual radio signals are broadcast using bandwidth much in excess of what is needed and are coded using pseudo-random code sequences. A technique first employed by the military to hinder signal jamming, the spread spectrum technique offers a high level of security—since intercepted calls are coded—and does not exhibit call blocking as occurs with other approaches when full capacity is reached. Instead, it is purported that CDMA system quality slowly degrades as large numbers of calls are placed, leading customers to either shorten or postpone their conversations. It is the coding of the individual calls which allows them to be separated at the receiving end.

While Qualcomm has won some CDMA endorsements and signed manufacturing licenses for the production of dual-standard AMPS/CDMA phones, it must be stressed that many of the claims for CDMA have yet to be proven in real-world applications. Most notably, CDMA proponents predict that this technology will offer a ten-fold capacity increase over present-day AMPS service. On top of the technical questions that remain, Qualcomm is also facing a legal challenge to its CDMA patents. Nevertheless, most observers point to TDMA and CDMA as the leading candidates to provide the foundation for the next generation of cellular service.

Two other potential cellular standards intended to increase system capacity are receiving some consideration. One known as N-AMPS is not a digital approach but still relies on analog transmission methods. N-AMPS works by dividing the standard 30 kHz AMPS channel into three, 10 kHz channels, thereby offering a three-fold increase in capacity. Dual-mode phones manufactured to this specifications are said to be simpler to produce than analog-digital phones. But the N-AMPS standard, while offering overall capacity improvement, does not address the problems of more efficient data transmission or message security.

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[20] A second version of spread spectrum multiple-access is frequency hopping SSMA.

Finally, there is another digital standard known as Enhanced-TDMA, or simply E-TDMA, which has been put forward by General Motor's Hughes Division. E-TDMA boasts even greater capacity increases than CDMA, claiming to offer 15-times the calling capacity of AMPS. As one might expect, E-TDMA is broadly compatible with TDMA, so it may prove useful as the "next step" following TDMA implementation. E-TDMA uses a more efficient voice coder to provide six carriers per traditional AMPS channel. This approach also employs digital speech interpolation (DSI), which is expected to yield additional capacity gains. DSI makes it possible for E-TDMA to take advantage of the pauses in everyday conversation to intersperse portions of other simultaneous conversations. In effect, it increases the efficiency of the channel by putting to work short periods of "dead time" that had previously just been wasted transmission space. Whether or not E-TDMA will be able to make good on all of its efficiency claims has yet to be clearly demonstrated.[21]

Transportation-Specific Applications

There are two broad applications of cellular communications to transportation needs: first, to support information transfer between Washington DOT regional headquarters and mobile crews; second, to share highway status information between DOT highway monitors and the traveling public.

Regarding internal deployment, the most obvious approach for DOT to employ cellular technology would be for the department to simply buy equipment and airtime from a commercial vendor. Clearly cellular phones handle voice communications well and are adequate for many instances requiring data transmission. Such a proposal would save the state the heavy burden of developing its own network of base stations to offer blanket cellular coverage. But it does force the DOT to be dependent on a commercial service which can charge extremely high airtime rates. Plus, with cellular technology evolving rapidly, the cost of upgrading equipment for all mobile fleets each time a commercial vendor pushes a change could become expensive. For example, should the DOT invest in AMPS-based phones or the newer TDMA models—or should it wait to consider CDMA-type transceivers? If the Department of Transportation would build its own statewide cellular network, emphasizing major thoroughfares, it would retain control of its own technology and could depreciate those costs over a much longer time frame. Plus in-house operational costs could be substituted for commercial airtime costs, which should yield substantial savings over the life of the system.

Of course, another problem with relying on a commercial cellular provider is that the general public relies on that same provider to make calls. So, in a time of emergency, such as a

[21]Informational charts listing some of the engineering specifics of the AMPS, CDMA-based, and TDMA-based standards have been provided at the end of the chapter. Specifications for N-AMPS and E-TDMA are not given due to the limited amount of detailed data available at this time in the research literature.

severe local weather disturbance that has roadways snarled, the DOT will have to compete with a glut of other callers to try to gain access to the cellular network. Clearly, total control over the cellular network would ease these problems. Complete control brings with it a heavy financial burden, however, with much of the construction costs for a state-owned cellular network coming at the start of the project. On a positive note, however, one of the largest monetary challenges that face commercial cellular operators would be less of a problem for the DOT: that is, the real estate for the siting of base stations. Given the state's existing right-of-ways along highways, as well as other strategic property holdings, one of the biggest financial drains on commercial cellular builders would be less of a problem for the state. Since much of the DOT's interests lie outside congested metropolitan areas—and since internal communications would probably not be too numerous—most cells could probably be as large as 60 miles in diameter, further reducing the amount of money needed for construction. Additionally, any network built could be shared among those state agencies that have substantial numbers of workers in the field, spreading out the costs of developing a state-run network. If nothing else, a DOT-run cellular network in key locations, like the mountain passes, could supplement commercial service and insure adequate internal communications ties in those areas that present continuous transportation challenges.

Should the state seriously consider construction of its own cellular network, major regulatory and technical problem could still hamper development. Since all of the frequency channels allocated to cellular service have already been designated to duopoly service providers, any state-run cellular system would have to be custom designed to work on other available frequencies approved by the FCC and favorable to cellular signal propagation. The tremendous burden of having vendors retool for specialized cellular applications—on top of the scarcity of spectrum available for such a proposal—would seem to doom the possibility of ever seeing such a proposal become reality.

Despite the obvious advantages of developing a state-owned cellular service for internal agency communications, the current political climate, too, remains a major barrier to such a proposal. With voters complaining about rising tax burdens and a perception of inefficient government operations, it seems unlikely that such a cellular network could gain approval in the state legislature. As a result, it is most likely that the DOT will have to rely on commercial providers for cellular service. Perhaps the answer, then, is for the department to purchase just enough portable cellular transceivers to equip those vehicles that must maintain constant contact with a centralized base. The DOT should look seriously into data communications specifically, since the brevity of such transmissions can lead to big savings over voice communications when airtime charges are considered. According to at least one source, CDPD will be most economical for messages of less than two thousand characters, such as two-way messaging, file transfer, and database inquiries.[22] Local establishment of a CDPD service by McCaw Cellular—or any other system designed entirely with data transfer in mind—could have real advantages for DOT operations.

Regarding communications between the DOT and the driving public, commercial cellular services could provide a key link with daily commuters or with travelers driving into heavy construction areas. Using DOT monitoring stations, average highway speeds could be relayed back to DOT central computers; this information could then be accessed by commuters on their cellular phones as they begin their rides home. This information could encourage drivers to change their travel plans so as to bypass trouble spots on the freeway. If severe highway problems develop, short messages advising drivers to avoid certain routes could be included. Such highway data might best be delivered graphically, and that may be in the works for the future. But within current cellular limitations, informational reports will have to be verbal, or, perhaps, short typed messages on data screens. Of course, only five percent of the nation's population currently own cellular phones. Even so, one might expect that this five percent is the group most commonly on the go; whether or not they would be willing to alter their driving plans based on cellular advisories is another question entirely.

Conclusion

A central determining factor in the development of the current cellular environment has been the FCC's 1988 liberalization ruling. With that administrative decision, the Commission opened up the cellular marketplace to greater competition in the hopes of encouraging technological innovation and a higher quality of customer service. So far, the ruling appears to have had a beneficial impact. Cellular operators are looking to make technological changes to improve both their system capacity and capabilities—most notably the improvement of data handling. Equipment costs have been driven lower through heated competition. Service costs remain high, however, in comparison to that of traditional wireline providers. Even so, these higher prices may prove to be a good value when one considers the ease of mobility that cellular equipment has to offer.

There is, of course, a flip side to the FCC's liberalization ruling. Along with the increased competition among service providers and equipment manufacturers comes the potential for marketplace confusion. Innovation opens freedom of choice, but it is possible to be faced with too many choices, or with choices that are changing too rapidly. Although the FCC used to provide a drag on innovation through its deliberate and comprehensive rulings, it also used to provide a measure of stability to the marketplace. What remains to be seen, then, is whether the increased choices being made to the consumer will spur on the useful application

[22]Wexler, "Analog Cellular Nets Suit Users," p. 30.

of cellular technology or whether market forces will self-destruct in a cacophony of competing claims.

The current situation presents an increasing array of attractive data transmission options for state agencies and departments, but it also raises the specter that any firm decisions on technological choices will fast be made obsolete. In a sense, one must approach the cellular environment in much the same way that one evaluates a computer purchase today. It must be understood that any purchase will lock one into the capabilities of the technology at that specific point in time. However, a commitment to any one system or standard also allows the powerful potential for networking and interoperability. These pros and cons must be weighed when making any future commitment to a nascent cellular system.

Regarding specific data transmission systems, CDI and CDPD appear to offer different advantages depending on the needs of the buyer. CDI permits flexible and highly portable short message exchange. CDPD, on the other hand, is a broadband service that will make possible remote computer operation. Additionally, the move by part of the industry to a TDMA standard will also make available another digital data transmission option. More so than any of the other second-generation cellular standards addressed in this chapter, the advent of TDMA is assured and should be accomplished relatively soon. It is unclear, however, whether TDMA will ultimately be implemented nationwide or even statewide because of the choices left open to cellular carriers. Standards like CDMA and E-TDMA promise the potential of greater system capacity and, therefore, lower costs for airtime. But their technical viability is still very much in question.

Key Sources:

Raymond Steele, "Speech Codecs for..."
Balston & Macario, Cellular Radio Systems
Michael Paetsch, Mobile Communications in...
Ron Schneiderman, "In Search of a New Mkt."

CELLULAR TELEPHONY

	AMPS (EIA-TIA-553)
Band (MHz)	824-849 (reverse band) 869-894 (forward band)
Bandwidth	50 MHz
Channelization	FDMA
Channel Spacing	30 kHz
Number of Frequency Channels	832
Voice Channels/Frequency Channel	1
Total Duplex Channels	832
Duplex Method	FDD
Equivalent Bandwidth/Duplex Channel	60 kHz
Channel Bit Rate	
Data Service	9.6 kbps
Speech Coder	
Bit Rate	
Frame Time	
Transmission Pattern	isochronous
Modulation	analog FM
Voice/Data/Imaging	voice and data
Average Transmit Power (W)	0.6, 1.2, 3.0
Peak Transmit Power (W)	0.6, 1.2, 3.0
Hand-off?	yes
Cell Radius	30 miles
Availability	1983
Industry/Government Support	AT&T, NYNEX Mobile, Delco, Motorola, Fujitsu, OKI, Ericsson, PacTel Cellular, Toshiba, Uniden, Sony, Panasonic, NEC, Mitsubishi, Nokia, Ameritech Mobile, Pioneer, Antel, Blaupunkt, DiamondTel, GE, Tandy, Shintom, GTE Mobilenet, Bell Atlantic
Typical Applications	mobile voice and data communications
Geographical Deployment	USA, Argentina, Bermuda, Brunei, Chile, El Salvador, Indonesia, New Zealand, Peru, Philippines, Taiwan, Venezuela, Australia, Bolivia, Canada, costa Rica, Guatemala, Israel, Pakistan, Samoa, Thailand, Zaire, Bahamas, Brazil, Cayman Islands, Dominican Republic, Hong Kong, Mexico, Singapore.
Perceived Utility	communications mobility, status symbol, continuous access to clients and family.
Cost	Equipment: $200-$1,000 Airtime: 38¢ to 99¢ per minute

Notes: AMPS (Advanced Mobile Phone Service)

Key Sources:

Raymond Steele, "Speech Codecs for..."
Balston & Macario, <u>Cellular Radio Systems</u>
Michael Paetsch, <u>Mobile Communications in...</u>
Ron Schneiderman, "In Search of a New Mkt."

CELLULAR TELEPHONY

	TDMA (IS-54, D-AMPS)
Band (MHz)	824-849 (reverse band) 869-894 (forward band)
Bandwidth	50 MHz
Channelization	TDMA
Channel Spacing	30 kHz
Number of Frequency Channels	832
Voice Channels/Frequency Channel	3 (eventually 6)
Total Duplex Channels	2,496
Duplex Method	FDD
Equivalent Bandwidth/Duplex Channel	10 kHz
Channel Bit Rate	48.6 kbps
Data Service	9.6 kbps
Speech Coder	VSELP
Bit Rate	13.2 kbps
Frame Time	40 ms
Transmission Pattern	packet
Modulation	π/4-DQPSK
Voice/Data/Imaging	voice, data
Average Transmit Power (W)	0.6, 1.2, 3
Peak Transmit Power (W)	0.6, 1.2, 3
Hand-off?	yes
Cell Radius	30 miles
Availability	1994
Industry/Government Support	McCaw Cellular, Motorola, CTIA, Pacific Communication Sciences, Inc. (PCSI), AT&T, Northern Telecomm, Ericsson, Hughes, Rogers Cantel.
Typical Applications	mobile voice and data communications
Geographical Deployment	USA
Perceived Utility	communications mobility, status symbol, continuous access to clients and family, secure communications and billing fraud is deterred.
Cost	Dual mode analog/digital phones may cost twice as much as current AMPS equipment. Airtime: cheaper than AMPS

Notes: TDMA (Time-Division Multiple-Access channelization method)

Key Sources:

Raymond Steele, "Speech Codecs for..."
Balston & Macario, Cellular Radio Systems
Michael Paetsch, Mobile Communications in...
Ron Schneiderman, "In Search of a New Mkt."

CELLULAR TELEPHONY

	CDMA (IS-95, direct sequence SSMA)
Band (MHz)	824-849 (reverse band) 869-894 (forward band)
Bandwidth	50 MHz
Channelization	CDMA
Channel Spacing	1250 kHz
Number of Frequency Channels	
Voice Channels/Frequency Channel	
Total Duplex Channels	8,320 (estimated)
Duplex Method	FDD
Equivalent Bandwidth/Duplex Channel	20 kHz
Channel Bit Rate	1,228 kbps
Data Service	
Speech Coder	CELP
Bit Rate	19.2/28.8 kbps
Frame Time	
Transmission Pattern	packet
Modulation	QPSK
Voice/Data/Imaging	voice, data
Average Transmit Power (W)	0.6, 1.2, 3
Peak Transmit Power (W)	0.6, 1.2, 3
Hand-off?	yes
Cell Radius	30 miles
Availability	1995?
Industry/Government Support	Qualcomm, AT&T, Motorola, Northern Telecom, Tatung, OKI Telecom, RBOC's: U.S. West, NYNEX, PacTel, Ameritech.
Typical Applications	mobile voice and data communications
Geographical Deployment	anticipated in USA
Perceived Utility	communications mobility, status symbol, continuous access to clients and family, secure communications, billing fraud is deterred.
Cost	not yet available

Notes: CDMA (Code-Division Multiple-Access channelization method)

Chapter III

Personal Communications Services

Introduction

Part of the challenge in investigating the potential of Personal Communications Services, or PCS, is that no commercial systems as yet exist. Experimental systems have been developed to test PCS fundamentals, and the FCC has assigned specific frequency bands and is issuing operator licenses, but this promising technology remains, at present, more a vision than a concrete reality. More accurately, the label PCS is used to describe many different visions for what this service may eventually become. As such, the outline provided in this chapter will be broad in scope, providing few specifics. Nevertheless, there are some common elements that bind these different visions for PCS, and these will be emphasized.

In formulating the regulatory framework for this nascent technology, the FCC has defined PCS as "a broad range of radio communications services that free individuals from the constraints of the wireline public switched-telephone network and enable them to communicated when they are away from their home or office telephone."[1] While this may sound similar to the capabilities of the cellular telephone network, PCS is different in that it is expected to deliver unprecedented mobility to many more people than cellular can accommodate. Whereas today's cellular technology is used primarily as a way for people to communicate while they're on the road—an adjunct to the home and office phone—tomorrow's PCS phone could be the only phone a person needs. Similar in some key respects to the Dick Tracy wristwatch phone of comic strip fame, this personal communicator should be small, will need infrequent recharging, and, most importantly, will be able to accommodate a greater number of subscribers than current cellular networks. The hope is that a larger fold of customers will help PCS providers drive down service costs to a level close to that of the established wireline network.

It must be remembered that early cellular providers made equally promising pronouncements in the 1970's before establishing their mobile service. Yet current cellular service remains out of the financial reach of most consumers;[2] and even if it was more affordable, many urban cellular networks are already congested. The potential of cellular telephony looked boundless on paper, but in practice there were complications and limitations.

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[1]Federal Communications Commission, Notice of Inquiry, General Docket 90-314, 5 FCC Record 3995 (1990), p. 1.

[2]As was noted in the first chapter, cellular service has grown in usage by middle class Americans. Nevertheless, only some five percent of the nation's population are cellular subscribers.

The same can be expected for PCS. We are still at a stage when it is hard to separate PCS fact from fiction, and it is wise for the curious to be skeptical as well.

While this new technology is commonly referred to as "Personal Communications Services" in the U.S., it is not unusual to hear it also referred to as "Personal Communications Networks" or PCN, especially in literature from Europe. The term PCN was first coined in an early British white paper titled Phones on the Move, and the labels "PCN" and "PCS" are regularly interchanged to refer to the same budding communications technology. For the purposes of this report, the term PCS will be used exclusively.[3]

Background

The concept for PCS grew out of the recognition that cellular telephony has severe limitations—as does cordless telephony (which has come to be used in many U.S. homes). But it was also reasoned that if the best traits of both could be combined, the communications technology that would result could have strong public appeal.

Cellular service has provided a small segment of the population with the ability to stay in touch while on the move, but its Achilles heel has proven to be its inadequate capacity to handle broad public demand. Cordless phones, on the other hand, have been refined to the point where they have gained mass appeal, but they are severely limited as to the range of mobility they offer. Like cellular telephones, cordless phones use a base station to create a sort of "cell" within which the customer can move around while conducting a conversation. But since the transmitter power is greatly reduced, the size of the cordless "cell" is minuscule in comparison to that employed in a true cellular system; also, cordless "cells" are not designed to allow a "hand-off" to another base station as the user moves out of transmission range—further restricting mobility. The answer to the shortcomings of cellular and cordless telephone technology was to strike some sort of a compromise, and the idea of PCS was born.

The development of PCS has been made possible through technological advances that have allowed engineers to design systems employing much smaller transmission cells. These tiny cells are often referred to as "microcells," "nanocells," or "picocells," hinting at their reduced coverage area. The impetus behind this move to smaller cells has been the recognition that more subscribers must somehow be supported if a third-generation mobile system is to move beyond the limitations of the second-generation mobile network. Engineers began with the premise that PCS could not expect generous spectrum allocations to solve their problem of expanding system capacity. At the same time, it was assumed that consumers would only be

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[3]The label "Personal Communications Services" was reportedly initiated by FCC Chairman Alfred Sikes in 1990 and has been a mainstay of FCC documents since.

satisfied if the voice quality and blocking probability[4] of a third-generation mobile system was on par with that of the traditional wireline network. With these constraints in mind, cell size seemed to be the primary variable left for engineers to manipulate in order to provide PCS with enhanced subscriber capacity.[5]

The cell size for PCS is expected to range anywhere from 1,000 feet to a 2.5 miles. That contrasts with cellular telephone cells that are commonly a mile or two in diameter in the most congested portions of an urban area, where cell sites are by necessity at their smallest. It follows that another key difference between cellular and PCS will be the design of the transmission antennas deployed. Whereas cellular uses fairly substantial antenna platforms based on strategically located property throughout a coverage area, it is envisioned that PCS will be implemented through the use of much smaller broadcast devices—antennas so small that they can easily be mounted on light poles, for example.

On the one hand, this should substantially reduce the costs for PCS deployment, since the required real estate costs will be greatly reduced. Also, the close spacing of PCS transmitters should lessen the signal propagation vagaries that hamper cellular service, since there will be much less distance between the mobile user and the base station. This change should provide PCS with a cleaner transmitted signal, which will enhance both voice and data transmissions.

One must remember, however, that complete PCS coverage will require many more base station antennas than are needed for cellular service, and that will add to the system's expense.[6] The popular vision for PCS has base stations located along city streets and surrounding busy public terminals (i.e. airports and bus stations), but also includes the installation of transmitters inside office buildings and homes. These interior base stations will be necessary for PCS to identify phone numbers with subscribers and not with separate home and business locations.

This proliferation of PCS base stations will also markedly increase the frequency of "hand-offs" between base stations as mobile users move from microcell to microcell, complicating the network architecture with the addition of many more switching circuits. This

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[4]Blocking probability refers to the likelihood that a caller will not be able to get a free circuit when he picks up the telephone receiver to make a call. The traditional wireline network was designed to achieve a very low blocking probability, so that customers would only on rare occasions be "blocked" from using the telephone system because full capacity had been reached. PCS is striving for comparable performance.

[5]Michael Paetsch, Mobile Communications in the U.S. and Europe: Regulation, Technology, and Markets (Boston, MA: Artech House, 1993), page 234.

[6]Despite the incremental cost of many additional base stations and enhanced circuit-switching capabilities, at lease one author still predicts that PCS will be less expensive to implement than other wireless and wireline options: "The initial cost of a PCN is expected to be about $300 per subscriber, compared with $800 for cellular and $1,600 for wireline networks." Roger P. Newell, "Personal Communication Networks," Radio-Electronics, May 1991, p. 62.

will add to the expense of building out PCS infrastructures. Network intelligence will have to be upgraded, too, in order to track the location of PCS users throughout the service area and insure that calls are routed properly.

It should be clear that the PCS design that has been described will demand that transmitters operate on much less power than conventional cellular systems since they will be required to service dramatically smaller areas. The use of this low transmitter power helps to explain how PCS base stations will be able to be reduced in size. As an added plus, this reduction in transmission power will make it possible for consumers to use portable phones with smaller, lighter batteries—perhaps leading to the first mobile phone that is truly comfortable to carry in a pocket. Since mobile users will be much closer to the base stations of the PCS network, PCS phones will need less power to make a stable broadcast connection.

According to one source, a PCS phone will draw only 10 milliwatts of power; by comparison, a portable cell phone typically uses 600 milliwatts and an installed cellular car phone commonly uses 3 watts of power. Considering the concern that has been raised over the health risks associated with portable cellular units, this dramatic reduction in transmitted power should be a welcome advantage for consumers.[7] This diminished power drain on PCS portables will bring the added advantage of extended call and stand-by time between recharging. Some engineers contend that PCS phones will run for weeks at a time on a single charge. If true, this will be a vast improvement over cellular phones that must be recharged daily.

There are still more features that will make PCS distinctive from other early mobile services. Chief among these is the location of PCS in the microwave band, between 1.850 and 2.20 GHz.[8] (See Table 3.1.) Researcher Michael Paetsch explains: "At frequencies above 1 GHz, radio waves increasingly start to behave like light and cannot pass around obstructions such as mountains or buildings."[9] Considered in conjunction with the fact that PCS will be employing low-powered base stations, these two factors demand the deployment of multiple strategically-positioned PCS transmitters inside and outside buildings if PCS is to provide complete mobile communications coverage. In some respects, this will simplify the design and linkage of PCS cells, since the limited reach of PCS signals should reduce interference between cell sites. It will, however, multiply the number of base stations required for blanket PCS coverage.

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[7]See: Mark Fischetti, "The Cellular Phone Scare," IEEE Spectrum, June 1993, pp. 43-47.

[8]Dana Blankenhorn, "FCC Adopts Final PCS Auction Rules," Newsbytes News Network, 30 June 1994.

[9]Paetsch, Mobile Communications, p. 55.

PCS will also boast the advantage of being a digital service from the start. Not only will this spare PCS from having to make the transition from analog to digital that is complicating cellular operations, but this digital advantage will make possible transmission schemes promoting the most effective use of spectrum and utmost subscriber capacity. A variety of design specifications are being considered by rival PCS firms, including different voice coding techniques and signal compression approaches (like TDMA and CDMA). But regardless of which standards gain prominence, PCS should have the technological potential to support a broader base of users than earlier mobile networks, thanks to state-of-the-art engineering advances.

<table>
<tr><th>Band</th><th>Frequency Subdivision</th><th>Frequency Range</th><th>Propagation Characteristic</th></tr>
<tr><td>4</td><td>VLF (very low frequency)</td><td>Below 30 kHz</td><td rowspan="3">Groundwaves that travel far along the curvature of the earth.</td></tr>
<tr><td>5</td><td>LF (low frequency)</td><td>30 to 300 kHz</td></tr>
<tr><td>6</td><td>MF (medium frequency)</td><td>300 to 3,000 kHz</td></tr>
<tr><td>7</td><td>HF (high frequency)</td><td>3 to 30 MHz</td><td>Groundwaves and Skywaves (that are reflected off the ionosphere)</td></tr>
<tr><td>8</td><td>VHF (very high frequency)</td><td>30 to 300 MHz</td><td rowspan="5">Line-of-sight transmissions follow a straight line. Above 1,000 MHz, waves increasingly behave like light. Above 10 GHz, radio waves are more easily disturbed by bad weather.</td></tr>
<tr><td>9</td><td>UHF (ultra high frequency)</td><td>300 to 3,000 MHz</td></tr>
<tr><td>10</td><td>SHF (super high frequency)</td><td>3 to 30 GHz</td></tr>
<tr><td>11</td><td>EHF (extremely high frequency)</td><td>30 to 300 GHz</td></tr>
<tr><td>12</td><td>(unnamed)</td><td>300 to 3,000 GHz</td></tr>
</table>

Table 3.1: Nomenclature of Frequencies[10]

The possibility that PCS will be able to serve a larger percentage of the population than cellular telephony has managed is a key advantage. As several authors have noted, the technical constraints that have limited cellular's customer capacity have kept it from achieving efficiencies that could drive down operating costs.[11] In other words, high prices for airtime discourage the bulk of consumers from subscribing to a cellular service. But even if these prices were somehow subsidized to lower cellular airtime costs, most urban cellular networks

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[10]Source: Code of Federal Regulations, p. 290.

[11]See, for example: George Calhoun, Digital Cellular Radio (Boston, MA: Artech House, 1988).

could not handle many more callers than are presently on board. Cellular systems are hamstrung by their own technological inefficiencies, and only sweeping engineering innovations (like TDMA, CDMA and E-TDMA) can alter this situation. The move to digital compression schemes by cellular operators is intended to bring substantial subscriber gains. PCS, on the other hand, has had the benefit of learning from cellular's shortcomings.

The primary impetus behind PCS, as has been mentioned, was the desire to develop a mobile architecture able to satisfy increased customer demand. Cutting edge engineering advances have been incorporated into PCS designs in order to accomplish that goal, but none is more important than the advent of microcellular transmission techniques. Like their cellular counterparts, PCS microcells will reuse their assigned broadcast frequencies. But because PCS microcells are a fraction the size of traditional cellular cell sites, they will allow the limited number of assigned frequencies to be reused more often. That, in turn, will allow the same number of frequencies to support a greater number of subscribers. With the addition of more subscribers, the PCS network will be able to spread developmental costs over a broader client base, gaining operational efficiencies. As a result, it is anticipated that PCS will be able to beat cellular airtime prices and even further stimulate public interest in the service. (See Table 3.2.) Whereas cellular providers will only be able to meet the mobile communications needs of ten percent of the population at full capacity, it is predicted that PCS will be able to accommodate at least 35 percent.[12] What cellular service had hoped to become—a mass market, mobile communications service—PCS may finally achieve.

Conceived from the start to serve a larger number of users, and intended to move beyond mere voice transmission to include a host of data-based tasks, the promise of PCS

	Consumer Equipment Costs	Airtime Prices
Cellular Phone	\$200-\$1,000 (In reality, many phones are given away for free—or nearly free—to encourage subscribers)	38¢ to 99¢ per minute
PCS Pocket Phone	\$100-\$200 (estimate)	13¢/minute (estimate)

Table 3.2: Cellular and PCS Cost Comparisons[13]

[12]J. Shelby Bryan, "PCN: Prospects in the United States," Telecommunications, January 1991, p. 54.

[13]The sources of these cost comparisons are the PCS industry association, Telocator, as quoted in an article by Christy Fisher, "What's Next After Cellular Telephones," Advertising Age, 26 October 1992, p. 12, as well as some informational materials from McCaw Cellular and U.S. West Cellular citing 1993 and 1994 prices.

shines brightly. Earle Mauldin, group president for mobile systems at BellSouth Corporation in Atlanta, Georgia, is enthusiastic about the potential of PCS—as one might well imagine:

> "Envision the possibilities. Instantaneous connections. Anyone, anyplace, anytime. Continuous interaction with personal resources, such as bank accounts and home management systems. Voice mail. Data capabilities. All from a pocket-size 'communicator.'"[14]

PCS Regulatory History

As one might expect, the regulatory history of PCS is quite short and has yet to bear fruit in a working, commercial mobile network. Even so, the same regulatory forces that have strongly influenced the character of cellular service since the late 1980's—specifically a growing reliance on marketplace forces—have, likewise, channeled the direction of early PCS development.

Most commentators acknowledge that Europe has taken the lead in PCS design and development. That fact is a sore point for U.S. mobile equipment manufacturers who once held a commanding competitive position in mobile communications, evidenced by the American introduction of cellular technology. Since that time, however, the divestiture proceedings against AT&T have destabilized the American market and given foreign manufacturers a chance to gain advantage. While the resulting increase in competition among domestic telecommunications businesses may pay dividends in the long run, the more immediate impact of the court's Modified Final Judgment (MFJ) regarding AT&T was that it set American firms scrambling to take advantage of changes in the regulatory landscape. During the uncertainty that followed, the Europeans gained a technological advantage. Whether or not the FCC's reliance on laissez faire policies will stimulate homegrown product innovations is a matter that is still being determined through the interplay of market forces.

Under the Communications Act of 1934 that created the Federal Communications Commission, the agency is statutorily directed to "Study new uses for radio, provide for experimental uses of frequencies, and generally encourage the larger and more effective use of radio in the public interest."[15] Following this mandate, the Commission began to issue experimental PCS licenses in September 1989. The next year, the FCC began formal regulatory proceedings by issuing a Notice of Inquiry (NOI) on PCS. An NOI is basically a request from the FCC to industry and other concerned parties for comments on how it should address a new regulatory matter. As the result of the public input the Commission received,

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[14]As quoted by Ron Schneiderman in the article: "Making Connections in a Wireless World," Microwaves & RF, April 1991, p. 35.

[15]Title III, Part I, Section 303 (g) of the Communications Act of 1934 as cited by Frank J. Kahn, ed., in Documents of American Broadcasting, 2nd ed., (Englewood Cliffs, NJ: Prentice-Hall, Inc., 1973), p. 65.

and still strongly influenced by a continued emphasis on deregulation, the FCC began to lay out its vision for PCS development in late 1993 and early 1994.

Some 120 MHz of microwave frequencies have been divided up by the FCC for auction to companies interested in building licensed PCS systems. (See Table 3.3.) As a report on the Newsbytes News Network explains:

> Two blocks of 30 MHz each will be given out on a wide geographic basis. Another five spectrum blocks, one at 20 MHz and the others at 10 MHz each, will be given out on a smaller geographic basis. And there are two unlicensed frequency bands of 20 MHz each, similar to those now used by cordless phones but including a data-only block. Licenses would be for 10 years, and renewal would be like that for existing cellular licenses. Existing cellular licensees, including the regional Bell companies, can compete for the new licenses outside their existing cellular service areas. Two of the blocks to be given out on narrow geographic bounds will feature favorable terms for small and minority businesses.[16]

In delivering its ruling, the FCC followed a plan similar to that which it had used for the initiation of cellular service: rather than establish nationwide networks for PCS, the Commission divided the country into 51 Metropolitan Trading Areas (MTA) and 492 Basic Trading Areas (BTA), or rural regions, as defined by Rand McNally. Interested companies will be able to bid on a maximum of 40 MHz of frequency space per service area. Anywhere from three to five competing companies will be licensed to operate within each service area.

This approach by the FCC reflects the Commission's continued reliance on commercial competition to guarantee a high quality of service and low prices for customers. In the days before deregulation at the FCC (pre-1976), the Commission relied on communications monopolies to insure interoperability within the telecommunications network; costs were regulated through agreements between the FCC and a small number of service providers in a manner that would guarantee profits while protecting against price gouging. It remains to be seen whether the agency's "experiment" in laissez faire regulation will encourage the desired product innovations and lower service costs without sacrificing network interconnections through a balkanization of the telecommunications marketplace.

It has also been suggested that the Commission's promotion of multiple service areas in place of national networks was stimulated by the realization that additional revenue could be generated for the government through the auction of smaller spectrum parcels.[17] Different

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[16]Dana Blankenhorn, "More on FCC's PCN Pocket Phone Decision," Newsbytes News Network, 24 September 1993.

[17]MCI, for example, had worked hard to develop a union of various companies that were willing to join together in developing a nationwide PCS network, and it had lobbied before the FCC to win support for a licensing plan that would accommodate several national service providers. Network World reports, however, that "...the FCC's decision, which chops the country into hundreds of service areas, means it will be difficult to build nationwide networks because network providers will have to aggregate spectrum in about 50 areas." Messmer, "FCC Divides U.S.," Network World, p. 1.

sources place the estimated auction value for the PCS frequency bands at between $7 and $10.2 billion.[18] Under the past trustee model of regulation, broadcast frequencies were licensed at no charge to operators with the understanding that the airwaves would be developed in the "public interest." Under the current laissez faire regulatory model, however, no public obligation is mandated as the FCC is relying on the profit motive of free enterprise to promote the most beneficial use of spectrum for public and private enrichment.

	Frequency Allotment	Frequency Band	Trading Area Type
LICENSED PCS	30 MHz	1850-1865 MHz 1930-1945 MHz	MTA
	30 MHz	1865-1880 MHz 1945-1960 MHz	MTA
	20 MHz	1880-1890 MHz 1960-1970 MHz	BTA
	10 MHz	2130-2135 MHz 2180-2185 MHz	BTA
	10 MHz	2135-2140 MHz 2185-2190 MHz	BTA
	10 MHz	2140-2145 MHz 2190-2195 MHz	BTA
	10 MHz	2145-2150 MHz 2195-2200 MHz	BTA
UNLICENSED PCS	20 MHz	1890-1910 MHz	n/a
	20 MHz	1910-1930 MHz	n/a
NARROWBAND PCS	1 MHz	901-902 MHz	n/a
	1 MHz	930-931 MHz	n/a
	1 MHz	940-941 MHz	n/a

Table 3.3: PCS Frequency Allocations[19]

[18]See: Dana Blankenhorn, "FCC Split on Personal Communication Networks," Newsbytes News Network, 23 September 1993; Dana Blankenhorn, "More on FCC's PCN Pocket Phone Decision," Newsbytes News Network, 24 September 1993; and Robert Kyle, "The Airwaves, Up for Grab," The New York Times, 10 July 1993, p. 19.

[19]Compiled from various sources, including: Ellen Messmer, "FCC Divides U.S. for New Wireless Providers," Network World, 27 September 1993, p. 1; and Federal Communications Commission, Final Rule, Narrowband Personal Communications Services, GEN Docket 90-314, ET Docket No. 92-100, FCC 93-329, 47 CFR Parts 2 and 99, (1993).

The Commission has allocated some additional spectrum to PCS for specialized applications. A total of 3 MHz has been set aside for narrowband PCS, including such uses as advanced voice paging, two-way acknowledgment paging, data messaging, electronic mail and facsimile transmissions. (See Table 3.3.) During a simultaneous multiple-round auction conducted in early August of 1994, the federal government sold 10 narrowband PCS licenses and raised $617 million—more than double the revenue experts had anticipated.[20] Out of the 29 companies that participated in our nation's first spectrum auction, those winning licenses included: McCaw Cellular (2 licenses); Paging Network, Inc. (PageNet) (3 licenses); Destineer, controlled by Mobile Telecommunication Technologies Corporation (MTEL) (2 licenses); BellSouth Wireless (1 license); Airtouch Paging (1 license); and Pagemart II Inc. (1 license).[21] An auction of the 2,000 general PCS licenses remaining is scheduled for December and is expected to bring another $10 billion into government coffers.

One example of a narrowband PCS application is the wireless paging and messaging service that MTEL is developing. As part of a special "pioneer's preference" designation, MTEL has been granted a nationwide license for a 50 kHz PCS channel.[22] Separate from the spectrum auction mentioned above, the "pioneer's preference" is a new licensing category designed by the FCC to reward those companies that have done developmental work on innovative technologies, like PCS. The awarding of a "pioneer's preference" is another mechanism by which the FCC hopes to stimulate broadcasting service innovations.

MTEL reportedly plans to use its pioneers preference to introduce a wireless messaging service operating at data speeds of 24 kbits/sec. (CDPD, by comparison, has a current maximum data transfer rate of 19.2 kbits/sec.) MTEL will also introduce an alphanumeric service that will notify the sender when a message has been received, as well as a 2-way messaging service that will be integrated with public and private e-mail systems.

Another 40 MHz between 1890 MHz and 1930 MHz have been allocated by the FCC for unlicensed PCS. (See Table 3.3.) This allocation will make it possible for companies like Boeing, for example, to set up their own wireless private branch exchanges (PBX's) to provide in-house voice and data connections without requiring licenses from the FCC. Since these PCS systems will operate in the microwave band at low transmission powers, the FCC expects little interference between distinct unlicensed PCS networks that might be developed.

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[20] Dean Foust and Mark Lewyn, "These Airwaves are Hotter Than Anyone Thought," Business Week, 15 August 1994, p. 34. Also see: Dan Morrison, "Going Once: Auction of Airwaves to Commence," The Seattle Times, 23 July 1994, p. D3; and Heather Bruce, (Knight-Ridder/Tribune Business News), "Auction Bids Total $150 Million," OverNET Daily Wireless Update, 27 July 1994.

[21] Claudia Cummins and Jacob Marvel, "Vigorous Bidding for Airwaves Highlights Potential of Business," The Seattle Times, 30 July 1994, p. D3.

[22] FCC, Final Rule, Narrowband Personal Communications Services.

In total, the FCC has allocated more than 160 MHz to PCS, compared with only 50 MHz that has been allocated to cellular telephony. Such a generous frequency allocation reflects the high hopes the Commission has for PCS, as well as, perhaps, a recognition that the agency previously underestimated the enthusiastic public demand for mobile communications.

Applications

In considering PCS applications, one need only point to the sorts of service options cellular telephony is straining to provide to understand why PCS is considered a third-generation wireless system. PCS owes much of its promise to the lessons learned from cellular's shortcoming and through the experience gained through cellular deployment. In PCS, the FCC is trying to establish a wireless technology that is customer-driven rather than regulatory-driven, is stressing the need for service flexibility over rigid technical standards, and is using incentives like the "pioneer's preference" to reward technological innovation.

If PCS follows the most optimistic of predictions, it will make available better quality voice transmissions than today's cellular networks have achieved and will have an enhanced capacity to meet pent-up consumer demand. As a benefit of this greater customer capacity, PCS systems should be able to take advantage of operational efficiencies currently unavailable to cellular-based services. This should make it possible for PCS to offer mobile communications at a reduced airtime rate which will, of course, stimulate even more public interest. Also, the relative simplicity of tomorrow's low-power PCS phones may make it possible for consumer equipment to be offered at prices closer to that of today's cordless models and far below prices for cellular telephones.

In addition to the benefits of higher capacity and lower service and equipment costs, PCS is expected to provide customers with options beyond mere voice communications. Of special interest to business users, the shorter transmission paths employed and the digital character of the PCS signal will make it better suited for data transfer. In fact, unlike the case of cellular telephony, PCS is being created from the start with the idea that data communications will be a essential feature.

As a result of the FCC's decision not to set a technical standard for PCS, one can expect a variety of user-specific, PCS-based solutions to battle for dominance in the business and home wireless communications environment. Whereas in the past, the telecommunications marketplace was horizontally integrated—with just a few companies providing limited service options for customers—the budding PCS market points to the availability of vertically-integrated telecom solutions, with multiple suppliers offering wireless systems specially designed to meet the unique needs of each client.[23] Hence, the FCC's emphasis on technological innovation and flexible technical standards may bring clear benefits for wireless users with dissimilar communications goals, including, for example, the Washington State Department of Transportation. But it will also introduce new hazards.

In the past, the limited number of telecommunications providers and the emphasis on rigid technical standards provided some insurance that different user groups would be able to easily link their separate communications systems into broader networks for sharing information. It also implied a level of marketplace stability protecting substantial equipment purchases against overnight obsolescence. Today's economic and regulatory environment portends a vastly different experience with PCS.

The new emphasis on customer-driven technical solutions may drastically complicate attempts at data networking between different private companies or between different governmental agencies. Also, as anyone making a computer purchase can verify, it will be impossible for customers to keep up with rapidly-changing, state-of-the-art equipment upgrades. Hardware investments will be dated within months of their installation. The new challenges for customers, then, will be maintaining system interoperability and managing shortened equipment life cycles.

Transportation-Specific Applications

The most important application of PCS to transportation-specific demands will be the convenient and inexpensive transmission of data in those situations demanding immediate user access or mobility within the environment. PCS should make possible the transmission of longer data messages (as are available through CDPD) at more reasonable equipment and service prices (more comparable to costs available on paging networks). For example, field engineers using palmtop computers or personal digital assistants (PDA's) will be able to instantly transfer collected data back to a central computer using a PCS network solution. Likewise, as long as mobile crews are in the range of a pole-top PCS base station, they will be able to interact with personnel at the central office. Highway telemetry operations will have the same flexibility of movement that they had using cellular transmission equipment, but at reduced airtime prices. Solar-powered, PCS emergency call boxes will be feasible in areas not covered previously because of the expense, thereby heightening travel safety for motorists. At first warning of a traffic problem, road patrols will be able to instantly relay messages to highway reader boards, suggesting alternative routes to on-coming traffic. The potential even exists for commuters to register their PCS phone numbers so as to receive recorded traffic advisories—either voice or short message read-outs—as they start their daily trips home. In

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[23]Peter Rysavy, Wireless Data Networks Seminar, sponsored by IEEE, Miller Science Learning Center, Seattle Pacific University, 8 February 1994.

sum, to the extent that spectrum capacity can accommodate it, data PCS will permit a heightened quantity and quality of mobile messaging that is impossible within the limits of today's cellular and paging technologies. Economic and regulatory constraints will become more important barriers to the potential of PCS than its technical capabilities as the new networks are built and strive to carve out a niche within the established telecommunications environment.

Conclusion

There can be no doubt that PCS has the potential to improve on the technical and economic performance of mobile communication technologies already in place. Nevertheless, it is useful to remember that much of the early literature on PCS has been written by engineers with vested interests who are more concerned about technical possibilities than economic practicalities. Even those few PCS articles written by economists are based on economic models that may or may not prove to be reliable. In other words, no one has a crystal ball to predict how well PCS applications will match the hype they have been given in press releases, and much of PCS's success will hinge on its ability to capture the interest and pocket books of mainstream consumers.

With the licensing on PCS complicated by the inauguration of auction proceedings never tried before at the FCC,[24] the build-out on PCS networks will not be complete for at least another three-to-five years, and only then in the most highly populated areas. PCS will have no immediate impact on the communication needs of the state's DOT. But the strong possibility that PCS operators will be major mobile service providers in the early twenty-first century must be considered if DOT planners hope to transition smoothly from present communication systems to the next generation of wireless technology.

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[24] Dana Blankenhorn, "FCC Adopts Final PCS Auction Rules," Newsbytes News Network, 30 June 1994.

Key Sources:

Schneiderman, "In Search of a New Mkt."
Blankenhorn, "PCS Equipment Already..."
IEEE Seminar, 8 February 1994
White, Communication Technology Update

PCS

	Anticipated Specifications
Band (MHz)	1850-1970, 2130-2150, 2180-2200, 901-902, 930-931, 940-941
Bandwidth	160 MHz
Channelization	TDMA, CDMA, E-TDMA
Channel Spacing	highly variable (left to marketplace)
Number of Frequency Channels	highly variable (left to marketplace)
Voice Channels/Frequency Channel	highly variable (left to marketplace)
Total Duplex Channels	highly variable (left to marketplace)
Duplex Method	highly variable (left to marketplace)
Equivalent Bandwidth/Duplex Channel	highly variable (left to marketplace)
Channel Bit Rate	highly variable (left to marketplace)
Data Service	highly variable (left to marketplace)
Speech Coder	highly variable (left to marketplace)
Bit Rate	highly variable (left to marketplace)
Frame Time	highly variable (left to marketplace)
Transmission Pattern	packet
Modulation	GMSK
Voice/Data/Imaging	voice/data/video
Average Transmit Power (W)	unavailable
Peak Transmit Power (W)	unavailable
Hand-off?	yes, below 65 mph
Cell Radius	1,000 feet to 2.5 miles
Availability	Licensing in 1994, operational by 1997/98
Industry/Government Support	AT&T, BellSouth, MTEL, GTE Mobile Communications, McCaw, Motorola, MCI, Time Warner Cable, American Personal Communications, Cox Enterprises, Omnipoint, US West, Northern Telecom, Rockwell, Nokia, Cablevision Systems, Pacific Telesis, Viacom, TCI, etc.
Typical Applications	Mobile telephony, mobile data transfer
Geographical Deployment	Build-out imminent in US, Europe, and Asia; PCS already operational in England
Perceived Utility	Continuous accessibility; user mobility
Cost	Telephone: $100-$200 Airtime: 13¢/minute

Notes: PCS (Personal Communications Services)

Chapter IV

Cordless Telephony

Introduction

The cordless telephone has proven to be an extremely popular consumer item in the United States. Following its introduction during the late 1970's, the sale of cordless phones for personal use increased from 2 million units per year in 1982 to 17 million a decade later.[1] At least one report indicates that cordless phones now outnumber traditional wired telephones in homes across America.[2] Clearly, consumers enjoy the mobility and convenience that cordless telephony provides; additionally, technical improvements and additional frequency allocations have bolstered cordless phone performance. But in the United States, at least, cordless telephones are confined to service within the home and do not accompany consumers on the road or in the office.

The situation in Europe is markedly different. Led by pioneering work done in the United Kingdom, Europe has seen the growth of two competing, second-generation cordless telephone standards intended to provide untethered service as people there move between home, work and other destinations. These standards—known as CT-2 and DECT—are considered second-generation largely on the basis of their digital signal transmission techniques and on the siting of numerous base stations outside the home that can work with people's individual handsets. (First-generation cordless, such as is common in the U.S., employs analog signal transmissions and is intended to work only between unique receiver-base station pairs within one's residence.) Another second-generation cordless standard has just recently been announced by Japan, and it is associated with a product called the Personal Handy Phone System (PHS).[3] Like CT-2 and DECT, PHS is a digital cordless standard.

European and Asian cordless systems, then, can be distinguished as providing a level and quality of service above American analog cordless systems, while remaining on a performance tier below that of cellular networks. These second-generation cordless systems have been purposely designed so as to provide less expensive mobile service by eliminating some of the features common to cellular customers. As a result, some of these cordless standards do not permit callers freedom of movement during a call because they do not support

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[1]Michael Paetsch, Mobile Communications in the U.S. and Europe: Regulation, Technology, and Markets (Boston, MA: Artech House, 1993), pp. 202-203.

[2]Bob Johnstone, "Personal Connections," Far Eastern Economic Review, 2 August 1990, p. 38.

[3]The Personal Handy Phone System, or PHS, was previously known as just the Personal Handy Phone, with the acronym PHP. The name was changed, however, to avoid confusion with the PHP General Institute of Konosuke Matsushita, a founder of Matsushita Electric. See: Masayuki Miyazawa, "Japan—Personal Handy Phone Name Changed to PHS," Newsbytes News Network, 27 April 1994.

hand-offs like cellular phones do. Also, some cordless service providers do not guarantee blanket mobile coverage but only manage islands of coverage using strategically-located base stations. While the trend is for cordless networks to provide a level of service approaching that of their cellular rivals, this directive is balanced by the competing goal that cordless equipment and airtime remain available and affordable to larger masses of consumers than cellular can promise. With that in mind, cordless technology is evolving so as to support greater customer capacity with the expectation that a broader client base will help service providers keep costs low while improvements continue on network capabilities.

The development of second-generation cordless systems abroad has relevance for this report. First, advances in cordless technology have helped to spur the technological vision of a "cordless approach to PCS" that is challenging a rival "cellular approach to PCS" in discussions over third-generation wireless systems. The "cordless approach" would expand the cordless model of wireless communications beyond the home by promoting the deployment of many small PCS cells, the development of a simplified, smaller handset, and the use of greatly reduce transmission power. This contrasts with a competing cellular model of PCS development, which would not require the extensive infrastructure needed to establish "cordless PCS"; instead, "cellular-style PCS" would used higher transmission power to enable bulkier handsets to transmit across much broader cell sites. It is presently unclear whether the PCS networks of tomorrow will more closely resemble the second-generation cordless systems now being deployed overseas, established cellular systems operating worldwide, or some type of hybrid approach.[4]

Of even more practical significance for transportation planners in Washington State, there exists the possibility that cordless technologies promoted in foreign markets might be adapted so as to provide vital communication links well suited to local applications. The main problems in importing such technology would be its conversion to usable frequencies in this country and approval from the FCC for its deployment.

Background

The operation of cordless phones in the United States is regulated under Part 15 of the Code of Federal Regulations, Title 47 on Telecommunications. According to Part 15, special frequencies have been set aside for low-power devices that radiate electromagnetic energy but which are inappropriate for licensing by the FCC. For example, there is a wide variety of medical, industrial and scientific equipment that transmit low levels of electromagnetic energy, and the spectrum space reserved for such transmissions is specified through Part 15. Cordless phones are included within this special class of low-power radiators.

[4] See: Paetsch, Mobile Communications, pp. 225-253, 325-342.

As one might imagine, the frequencies set aside by Part 15 for low-power equipment have become popular with manufacturers and their customers since such devices can be operated without the burden of first obtaining a government license. There is a serious trade-off, however, for the freedom that comes with the use of this unlicensed equipment: it is not protected from any interference—intentional or unintentional—that might be created by other high- and low-power radiators. With manufacturers flocking to take advantage of the open frequencies delineated through Part 15, such interference is a growing problem for end users of Part 15 devices.

Recognizing the popularity of cordless telephony, the FCC responded in 1987 by amending its Part 15 rules to permanently allocate segments of the 46 and 49 MHz bands for cordless phones. (See Table 4.1.) As Michael Paetsch explains, the FCC took an additional step in amending cordless standards in order to promote spectrum efficiency:

> ...the Commission revised its standards so as to allow cordless phones to center their channels at frequencies others than those listed in 47 C.F.R...., as long as the emission is confined within the 20 kHz bandwidth. The provision, commonly known as [the] offset channel rule, makes it possible to design equipment that splits the current 20 kHz channel, for example, into two 10 kHz channels, thus increasing the number of available channels.[5]

Frequency Band	FCC Limitations
46.60-46.98 MHz	Restricted to cordless telephones
49.66-50.00 MHz	
902-928 MHz	Intentional radiators using frequency-hopping or direct-sequence spread-spectrum technology
2400-2483.5 MHz	
5725-5850 MHz	

Table 4.1: Possible Cordless Telephony Applications Within Part 15 Frequency Bands[6]

This ruling by the FCC makes it possible for cordless equipment designers to further subdivide the ten duplex channels that had previously been established for cordless telephony in the 46 and 49 MHz bands as technological advances present opportunities. Individual cordless phone manufacturers in the U.S. are free to decide upon with their own transmission standards since there is no formal, domestic common air interface (CAI).[7]

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[5]Ibid., p. 202.

[6]Adapted from Paetsch, Mobile Communications, p. 201.

[7]A common air interface refers to an agreed-upon set of standards for wireless signal transmission which allow the equipment built by different suppliers to operate reliably with a joint network architecture. For example, the European cordless standards CT-2-CAI and DECT have established CAI's which allow all manufacturers mobile stations to work together with all manner of public and private base stations.

There are three other frequency bands where U.S. cordless systems might operate: between 902 and 928 MHz, and, to a lesser degree, between 2400 to 2483.5 and 5725 and 5850 MHz. All three of these bands are unlicensed (See Table 4.1), but they are restricted to the application of spread-spectrum technology, such as frequency-hopping or direct-sequence transmission schemes. The Commission's hope is that by leaving specific transmission standards to the marketplace for these three, unlicensed frequency bands, innovative applications will follow, including wireless LAN's (WLAN's), remote meter reading by utilities, and personal communication networks.

Some of the newer cordless phones do, indeed, operate in the 900 MHz band, and they are advertised as offering wireless connections between the mobile and base stations over a distance of 875 yards—a vast improvement on earlier 46/49 MHz systems. They are, however, four-times more expensive.[8] And, unlike the second-generation cordless technology created in Europe or Japan, they do not allow wireless telecommunications outside one's residence.

CT-2 Technology

CT-2, or second-generation cordless technology, was invented in Great Britain. At least one author claims the development of CT-2 was spurred on by the shortage of public phone booths in that country.[9] But whatever the impetus, CT-2 was clearly intended to fill the gap that existed between traditional cordless phones, which couldn't leave the home, and cellular service, which was becoming congested and was prohibitively expensive. Like its predecessor, the CT-2 handset would work with a base station in the home. But its added capability was that it could also be used to make calls whenever one was in sight of public base stations—called telepoints—which were strategically located in places like train and bus stations and shopping areas. These public telepoints interconnect the cordless caller with the public switched telephone network (PSTN). Then, too, it was envisioned that the CT-2 handset could be taken to the office where it could be used with the company's wireless PBX. In sum, CT-2 was seen as the common person's mobile phone, offering many of the advantages anticipated for PCS phones, especially much cheaper equipment and service costs.

Since its commercial introduction about mid-1989, CT-2 services have had trouble proving their viability in the United Kingdom and across Europe. To start off, the British Department of Trade and Industry (DTI) did not immediately establish a common air interface for CT-2, which led to some marketplace confusion since different proprietary standards were being promoted. Consumer were unsure which telepoints would work with their own handsets. There was also some dissatisfaction with the service, since public telepoints were not

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[8]See: Otis Port, "A Cordless Phone that Can Thwart Eavesdroppers," Business Week, 3 August 1992, p. 67; and "$129.90 900 MHz Cordless Crusher," DAK Early Summer Catalog, DAK Industries Inc., 8200 Remmet Avenue, Canoga Park, CA 91304, Summer 1994, p. 7.

[9]Johnstone, "Personal Connections," p. 38.

as numerous as some customers would have liked, and these telepoints did not allow users to receive calls—only to place calls. A lack of residential and office base stations also limited the usefulness of the CT-2 service. Of the four CT-2 operations licenses in Great Britain, none was able to survive. The only CT-2 systems still running in Europe are located in France and the Netherlands, but opinion seems to be turning against the establishment of sister systems in other European countries.

CT-2 has found a home in many Asian countries, and in some instances is proving tremendously successful. CT-2 systems have been established and are growing in Singapore, the People's Republic of China, Hong Kong, Thailand and Malaysia. In some instances, CT-2 service is seen as a less expensive alternative to fully expanding the existing wired network into previously unserved areas. The acceptance of CT-2 in Asia may be based partly on clever marketing maneuvers, but it seems also to have benefited from cultural and environmental factors. Newsbytes observes:

> Hong Kong was uniquely well placed to develop a CT-2 service. It already had an exceptionally high penetration of both fixed and mobile services, a large volume of traffic, a strong street culture, and a high existing pager customer base. It also consists of a large number of small businesses, a history of sustained GDP growth and an inherent willingness to embrace new technology. The territory has the additional benefit of its small densely populated urban areas which means that operators can establish rapid coverage in key business and residential districts with minimum infrastructure investment.[10]

Some of the handicaps of CT-2 are already being addressed in an attempt to make it more attractive to customers in Asia and Europe. Since CT-2 users can't receive in-coming calls from telepoints, pagers are being incorporated into the handset so that their owners can still be contacted while on the move. A variation on CT-2, called CT-2 Plus, will also allow its equipment to hand-off calls to adjacent base stations while they are in progress; conventional CT-2 can not accommodate hand-offs. CT-2 Plus, which was developed for the Canadian market, has also been adapted to better enable its equipment to perform wireless data transfers.[11] While these changes make CT-2 more versatile, they also increase its costs to a level approaching that of its closest cordless competitor, DECT.

DECT Technology

CT-2 is not alone in its quest to become established as the cordless telephone standard across Europe and worldwide. It is facing growing competition from another standard called DECT. Work on DECT was begun in 1988 in formal European standards organizations with

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[10]Keith Cameron, "Hong Kong—Chevalier CT-2 Succeeding," Newsbytes News Network, 8 October 1993.

[11]Robert Koven, "Public Cordless Telephone Service," In "Telecom 2000," (special advertising supplement), Maclean's, 13 September 1993, pp. 4-5.

the intention that it would become the agreed-upon pan-European cordless standard. This is a key difference between DECT and CT-2, which was conceived as a strictly British initiative with later attempts made to gain full European backing. As such, DECT has at least that political advantage over CT-2. However, DECT has been running about a year behind CT-2 in developmental progress, and, at least until recently, was more expensive to implement. New DECT chip sets will reportedly cut the cost of associated handsets and base stations and price DECT more closely with CT-2 gear.[12]

DECT phones and service have been more expensive than CT-2 offerings because the technology has more capabilities. Similar to CT-2, DECT was envisioned as the standard to support handsets that could move between home and the office and allow virtually continuous telephone service along the way. But DECT was designed to offer three-times the full-duplex channels of CT-2 (120 versus 40), and provides a total channel bit rate of 1,152 kbps compared with 72 kbps for CT-2. Like CT-2, DECT is compatible with the PSTN, but it will also interface with ISDN (voice and data), X25, and IEEE 802 networks. DECT has even been demonstrated as having the capability to support full-motion color video transmissions.[13] Additionally, DECT will support hand-off between cells since its equipment employs dynamic channel selection; this enables DECT gear to choose from among available frequency channels for the one offering the strongest signal and the least interference. Unlike CT-2 phones, DECT mobile phones include security measures to thwart eavesdropping and reduce telephone fraud.

In Europe, at least, DECT seems poised to overtake the struggling CT-2 networks. However, some observers have questioned whether DECT, too, will have time to become sufficiently established before PCS becomes a reality and pushes DECT aside as an outmoded technology.[14]

The Personal Handy Phone System

Participating in this fray over international cordless standards is Japan's recent entrant known as the Personal Handy Phone System, or PHS. PHS equipment faces an uphill battle since it lags behind both CT-2 and DECT in development. It is gaining ground quickly, however. In mid-April, U.S. West and Bell Atlantic announced their intention to immediately test PHS systems in the United States.[15]

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[12] "DECT Kills CT2," Electronics, 8 March 1993, p. 7.

[13] Peter Fletcher, "DECT-Standard Demo Puts Full-Motion Video Over Cordless-Telephone Link," Electronic Design, 17 September 1992, p. 34.

[14] Peter Fletcher, "Will PCN Conflict Derail DECT?" Electronics, 13 July 1992, p. 40.

[15] Masayuki Miyazawa, "US West, Bell Atlantic to Test Handy Phones," Newsbytes News Network, 22 April 1994.

Perhaps because it is so new, little detailed information is available in industry journals regarding technical specifications for PHS products.[16] But it is clear that it shares many similarities with CT-2 and DECT. It is a true second-generation cordless standard, using digital signal transmission techniques. Like DECT, it allows the user to both make and receive telephone calls while on the go. It employs a handset that is less complex in design than a cellular handset, and therefore lighter, less costly, and requiring less power. (See cost comparisons in Table 4.2.) An agreement has also been reached between U.S. West, Bell Atlantic, and the Japanese firm Daini Denden to produce a PHS adaptor enabling the new cordless phones to be ISDN compatible.[17] There seems to be some concern, however, by Japan's Ministry of Posts and Telecommunications (MPT) as to when it should begin licensing PHS services. There is a fear, apparently, that PHS networks, because of their cheaper cost, could seriously delay public acceptance of digital cellular service in that country.[18]

	Consumer Equipment Costs	Airtime Prices
Cellular Phone	$200-$1,000 (In reality, many phones are given away for free—or nearly free—to encourage subscribers)	38¢ to 99¢ per minute
CT-2	$100-$300	8¢ to 12¢/minute
DECT	higher than CT-2, lower than cellular	higher than CT-2, lower than cellular
Personal Handy Phone System	cheaper than cellular	15¢ to 20¢/minute

Table 4.2: Cellular and Cordless Cost Comparisons[19]

Applications

According to many industry accounts, the optimum wireless solution of the future will be a PCS-type network in which personal telephone numbers associated with PCS handsets allow a person to be reached at any time—avoiding today's inconvenience of multiple phone

[16] As a result, no technical description is provided for PHS equipment at the end of this chapter, while data is provided for CT-2 and DECT.

[17] Miyazawa, "US West, Bell Atlantic to Test Handy Phones."

[18] See: Bob Johnstone, "Japan: Cordless Explosion," Far Eastern Economic Review, 8 April 1993, p. 56.

[19] The following cost figures have been compiled from a variety of sources, including: Johnstone, "Japan: Cordless Explosion;" Miyazawa, "US West, Bell Atlantic to Test Handy Phones;" Koven, "Public Cordless Telephone Service;" Richard Lambley, "A Cordless Future," Electronics & Wireless World, December 1988, pp. 1198-1199; and "Ringing in a Revolution," The Engineer, 6 July 1989, p. 24.

numbers tied to various locations. However, the Europeans and Asians seem to be taking a very different path from the Americans to reaching that ultimate goal. They are following what might be labeled a more evolutionary path, establishing cordless standards as a stepping stone to lead from today's cellular service to tomorrow's PCS network. The U.S. approach, on the other hand, might be described as being "revolutionary" in the sense that it sidesteps the intermediate cordless stage to bound straight from cellular to PCS communications—a more abrupt transition. As a result, while the cordless technologies described in this chapter might elicit visions of applications to domestic communications needs, regulatory decision guiding the move to PCS have left little opportunity for second-generation cordless products to gain a foothold in the U.S.

For organizations hoping to import advanced cordless equipment from abroad, the lack of spectrum allocations for such devices means that they cannot be licensed for use in the United States. Even so, the opportunity created by the Part 15 ruling means that foreign cordless equipment than can be adapted to operate within the delineated frequency bands could be allowed to operate without a license. One must remember, however, that Part 15 equipment is not protected from intentional or unintentional interference, which is a severe limitation. Also, any proprietary adaptations of advanced cordless equipment to meet Part 15 guidelines would be more expensive to procure and would not work with devices offered by other vendors. Even so, such proprietary solutions may prove more cost effective and secure, over the long term, than options available with public cellular or other wireless networks.

Transportation-Specific Applications

The most obvious application of cordless technology to the needs of the Washington State DOT would be to establish a network of telepoints from which mobile crews could receive and transmit information with a central office. The telepoints could be linked in groups by twisted copper pairs or fiber optics, with each group's messages relayed by microwave link to headquarters. Such a cordless network would have several advantages. Since it would be owned and operated by the department, there would be no service fees to a private contractor. Also, in times of emergency, the DOT would not have to compete with the citizenry for access to a public network, such as a cellular or paging network, for example. While a telepoint network would not allow continuous wireless coverage, a network of telepoints without hand-off capabilities would be comparatively simple to construct and, therefore, present financial savings over other options, like analog or digital cellular systems. Key factors determining the attractiveness of a cordless DOT network hinge on the pros and cons of a state-owned system versus access to a public service.

Of course, a network of telepoints along highways could also be of considerable value to motorists. Any driver experiencing car trouble and within range of a DOT telepoint could stay inside his or her car and still be able to summon highway assistance, assuming handsets were made available to the public. These telepoints could also be used to transmit messages to daily commuters, alerting drivers to problem conditions and suggesting alternate routes. It is likely that these telepoint information systems would be primarily of use to in-state drivers, since they would use equipment based on proprietary standards that would probably not be available to out-of-state visitors. Even so, their usefulness to Washington drivers could be substantial.

It has already been noted that any state effort to deploy a cordless network, either for exclusive DOT use or for service to the broader public, would require considerable effort and state resources. Since there are no FCC allocations for telepoint applications, no domestic manufacturers have off-the-shelf systems for purchase. Design and implementation of such a cordless network would demand much staff time and public expense. Nevertheless, the advantages of such a system for DOT efficiency and public safety could be considerable. The decision on whether or not to move ahead on such an endeavor could only be made after considerable cost-benefit analysis and public debate. Also, decisionmakers must remember that PCS service may be a decade away from implementation, and PCS may address many of these same needs at lower cost and with greater capabilities.

Conclusion

Second-generation cordless technology has a great many features which make it attractive. As some of the foreign applications demonstrate, cordless telephony can offer many of the advantages of cellular communications at a fraction of the cost to implement and operate. In many ways, cordless technology comes closer to fulfilling the dream of PCS visionaries than does cellular in offering a single telephone address for each user and in making that technology available to the masses. But on our own shores the potential of cordless technology has been abbreviated by regulatory directives that focus instead on third-generation wireless solutions. As a result, any attempts to apply CT-2, DECT, or PHS to meet statewide transportation/communications problems would only be successful after a great expense of time and fiscal resources. Therefore, despite their attractiveness, second-generation cordless equipment will most likely be of little usefulness within our borders unless private companies make a serious effort to make their products conform to the limitations of Part 15 rules established by the FCC.

Key Sources:

McLeod, "Qualcomm Combines Three..."
Paetsch, Mobile Communications...
Fox, "Confused Over Personal ..."
Vincent, "Personal Communications"

CORDLESS TELEPHONY

	CT-2 (UK Specifications)
Band (MHz)	864.1-868.1
Bandwidth	4 MHz
Channelization	FDMA
Channel Spacing	100 kHz
Number of Frequency Channels	40
Voice Channels/Frequency Channel	1
Total Duplex Channels	40
Duplex Method	TDD
Equivalent Bandwidth/Duplex Channel	100 kHz
Channel Bit Rate	72 kbps
Data Service	32 kbps
Speech Coder	ADPCM (G721)
Bit Rate	32 kbps
Frame Time	2 ms
Transmission Pattern	packet
Modulation	GMSK
Voice/Data/Imaging	voice
Average Transmit Power	5 mW
Peak Transmit Power	10 mW
Hand-off?	no
Cell Radius	45-220 yards
Availability	1992
Industry/Government Support	British Telecom, Ferranti, Mercury, Shell, Barclays, Philips, STC, French Telecom, Nynex, Motorola, Shaye, Orbitel, GPT, Bell Atlantic Mobile, Chevalier Telepoint, Telezone Corp., Canada Popfone Corp., Rogers Cantel Mobile Inc.
Typical Applications	Mobile telephony
Geographical Deployment	Conceived in England, but commercially unsuccessful. Some success in Paris, France. Greatest commercial success in Asia: Hong Kong, Singapore, Thailand, Malaysia, etc. Service starts in Canada in 1994.
Perceived Utility	User mobility; inexpensive equipment and service costs
Cost	Handset & home base station: $100-$300 Airtime: one-quarter cellular prices

Notes: CT-2 (Second-generation cordless telephony)

Key Sources:

"DECT Kills CT2," Electronics
Paetsch, Mobile Communications...
"Ringing in a Revolution," The Engineer
Lambley, "A Cordless Future"

CORDLESS TELEPHONY

	DECT
Band (GHz)	1.88-1.90
Bandwidth	20 MHz
Channelization	TDMA/FDMA
Channel Spacing	1.728 MHz
Number of Frequency Channels	10
Voice Channels/Frequency Channel	12
Total Duplex Channels	120
Duplex Method	TDD
Equivalent Bandwidth/Duplex Channel	166.66 kHz
Channel Bit Rate	1152 kbps
Data Service	
Speech Coder	ADPCM (G721)
Bit Rate	32 kbps
Frame Time	10 ms
Transmission Pattern	packet
Modulation	GMSK
Voice/Data/Imaging	voice/data/imaging
Average Transmit Power	10 mW
Peak Transmit Power	250 mW
Hand-off?	yes
Cell Radius	45-220 yards
Availability	1993
Industry/Government Support	Standard initially developed by the European Conference of Postal and Telecommunications Administrations (CEPT), then completed by the European Telecommunications Standards Institute (ETSI)
Typical Applications	Mobile telephony; mobile data transfer
Geographical Deployment	Pan-European standard
Perceived Utility	User mobility; enhanced service features in comparison with CT-2; less expensive than cellular
Cost	Expected to fall between costs for CT-2 and cellular equipment and service.

Notes: DECT (Digital European Cordless Telephone)

Chapter V

Radiopaging

Introduction

Many parts of the world are struggling to move into the Information Age but don't have the financial resources to invest in extensive wireline telecommunications infrastructures. In India, for example, satellites have proven their worth by providing communications service to rural areas that, otherwise, could not be reached. Some other countries are installing cellular networks in their urban areas because cellular systems can be constructed quickly and gradually adapted with smaller cells as telephone traffic grows. But most developing countries, it seems, have seized on the potential of radiopaging to inexpensively and effectively link together people who are separated by distance and a lack of other communications channels.[1]

The popularity of paging is well founded considering the expanding capabilities of the technology and the cost effectiveness of paging service. This chapter will highlight the possibilities that paging brings to mobile communications within Washington State while noting, too, the very real limitations that set paging apart from other wireless technologies.

Background

Some of the first radiopaging systems began to appear in the early 1950's and were generally private on-site systems.[2] They were found to be especially useful at locations like hospitals, where they could be used to notify key personnel of emergency situations that demanded their attention. After some initial interference between pagers and other medical equipment, they were adapted to use a 35 kHz carrier signal modulated by audio tones.

Initially two of 30 possible audio tones were used to supply each pager with a unique address, or code, by which that pager could be identified. Whenever a pager would "hear" its two identifying tones being broadcast, it would be activated and signal its wearer by a beep to phone the dispatch center and receive a message. By combining the 30 available audio tones into distinct pairs, system operators were able to achieve 870 total pager addresses and, thereby, service that same number of clients. Clearly, these early pagers were very simple in design, yet they marked a first step toward the advanced pager services available today.

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[1]See, for example: C. T. Mahabharat, "India—Motorola Offers Assistance to Paging Operators," Newsbytes News Network, 18 April 1994; C. T. Mahabharat, "BE & All India Radio Plan Radio Paging Service," Newsbytes News Network, 1 December 1993; and Steve Gold, "Nokia Scores Chinese Radiopaging Contract," Newsbytes News Network, 20 August 1993.

[2]Much of this history is gleaned from two texts: John Walker, ed., Mobile Information Systems (Boston, MA: Artech House, 1990); and Michael Paetsch, Mobile Communications in the U.S. and Europe: Regulation, Technology, and Markets (Boston, MA: Artech House, 1993).

As paging coverage expanded, enabling it to be employed in operations like construction sites and oil refineries, equipment designers gradually recognized that the best paging frequencies would be in the region between 80 MHz and 1,000 MHz. Pagers engineered to work within this range were able to use integral antennas in place of external antennas, plus it became evident that these frequencies were the most effective at penetrating inside large buildings. As paging gradually increased in convenience and usefulness, it became evident that the service would be attractive to the general public as well. So, public wide-area systems were conceived as commercial counterparts to the initial private on-site systems.

The earliest public wide-area paging systems were developed in the U.S. and Canada in the early 1960's. At first, pages were initiated when callers would phone operators who, in turn, would manually input the desired address to activate a page. But the inefficiency of this process quickly became apparent. Soon systems were adapted so that callers could directly dial a number that represented a pager address, and the page would subsequently be completed. The limitations of tone coding, too, doomed that technology to obsolescence.

Two-tone coding had been improved, first, by increasing the total reserve of available tones to 70, which boosted the capacity of pager addresses to nearly 5,000. The maximum number of pager addresses subsequently jumped to 100,000 when the switch was made to five-tone coding, thereby allowing more unique tone combinations. Despite these gains in capacity, tone coding had inherent faults, like its tendency to trigger false paging alerts due to misread tones, and its more costly and complex receiver design. Even more limiting was the fact that tone coding is not well suited to delivering alphanumeric text. So, by the late 1960's, paging systems were converted to binary digital signaling.

The change from an analog to a digital-based paging scheme has greatly improved the spectrum efficiency of today's paging systems and, thereby, expanded paging capacity. For example, analog tone-and-voice pagers, which signal with a tone and then deliver a short voice message, commonly need about 7 seconds of airtime for the page itself, and then another 10 to 20 seconds for the voice message. In comparison, early digital pagers could broadcast up to five alphanumeric messages each second. Newer digital compression algorithms have further boosted the capacity of today's paging systems.

Since this switch to binary digital signaling, a variety of paging standards have come into wide-spread application. The appearance of such multiple standards has even been encouraged by the shift in FCC regulatory policy away from monopolistic delivery of telecommunications services to an emphasis on industrywide competition. One of the most influential paging standards came about in the late 1970's when the British Post Office invited industry leaders to reach agreement on a single paging code. The resulting standard was named after the Post Office Code Standardization Advisory Group (POCSAG) that created it, and it included the potential for full numeric and alphanumeric message capabilities. Its popularity later resulted in recognition before the International Radio Consultative Committee (CCIR) as a true world standard identified as CCIR Radio Paging Code Number 1 (RPC1).[3] By 1983, pagers using the RPC1 standard were coming out on the market. Nevertheless, it is not alone, and other prominent paging codes used worldwide include: the Motorola Golay Sequential Code, Eurosignal, Ortsruf A, Autoruf, RDS, 2-tone, 5-tone, and 6-tone systems.

About 1978, another approach to radiopaging was being developed in Sweden. This paging system takes advantage of the radio towers that are already in place to broadcast FM programming and multiplexes (or inserts) a 57 kHz data subcarrier along with the FM signal. (See Figure 5.1.) The paging data is not decoded by FM receivers, so it doesn't impair regular FM broadcasts. Yet pagers designed to scan the FM frequencies for data services can filter out the FM programming to reproduce only the paging information. A clear advantage of this system is that the amount of infrastructure needed to implement FM-based paging is greatly reduced; a disadvantage results from FM's inability to penetrate as deeply into buildings as traditional paging signals.

Today, paging signals can be superimposed on FM and AM radio signals, and on TV signals, as well. The Seiko Receptor paging watches which have gained some popularity in the Pacific Northwest during the past few years use an FM-based paging technique to broadcast paging notes and short data messages to people wearing the special watch decoders.[4]

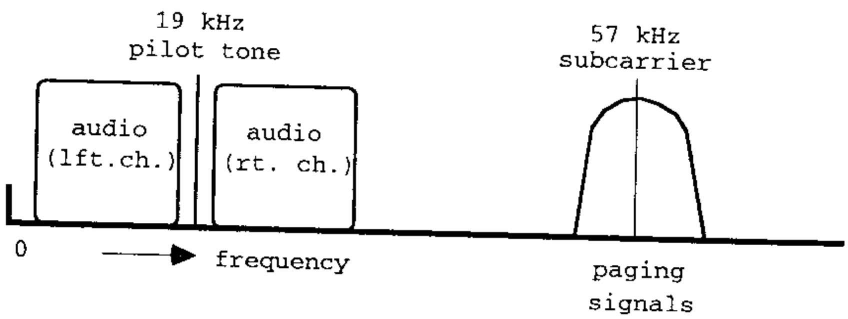

Figure 5.1: Multiplexed Paging and FM Stereo Broadcast Baseband Signals

The U.S. Paging Environment

Since its earliest days in the United States, paging has been a competitive enterprise and has not come under the domination of monopolistic control. In looking ahead to the

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[3]The CCIR is an international standard-setting body that manages worldwide sharing of the radio frequency spectrum. The CCIR is a committee of the International Telecommunications Union (ITU), which is, in turn, a specialized agency of the United Nations.

[4]Directions on operation of the Seiko Receptor watch, and a mention of the FM subcarrier technology, are provided in the "User Guide" that comes with each watch-pager, 1990.

introduction of paging, the FCC set aside two radio channels in 1949 to be assigned to nonwireline common carriers. In the years that followed, paging services have been operated by rival private businesses, independent telephone companies, and the Regional Bell Operating Companies (RBOC's); this has fulfilled the FCC's intent that marketplace competition be used to promote the provision of innovative services to paging customers.

The FCC has established two different classifications for paging operators which indicate what services they can offer and how they will be regulated. **Radio Common Carriers**, or RCC's, are regulated by the Common Carrier Bureau of the FCC as outlined under Part 22 of the Code of Federal Regulations, Title 47, pertaining to Telecommunications. RCC's are also regulated by Public Utility Commissions (PUC's) in some states. As with any other entity regulated by state and federal authorities, these RCC's are licensed to operate on exclusive frequencies in certain geographic areas. RCC's have traditionally made their services available to private citizens, and also to fire stations, police units, and local government bodies.

Another class of paging service providers is known as **Private Paging Operators**, or PPO's. Title 47 of the Code of Federal Regulations, Part 90, has set aside paging frequencies to meet specialized needs, like those of the medical community, and it is within these provisions that PPO's are designed to operate. Unlike RCC's, the PPO's don't have to follow FCC technical standards for things like transmitter siting and operation, but they do have to share their radio frequencies with other users approved through Part 90.

Within the past decade, these two designations have blurred somewhat as the FCC has gradually approved more direct competition between RCC's and PPO's. In 1985, the FCC made additional frequencies available for Private-Carrier-Paging (PCP) licensees, as well as other Part 90 services. This served to dramatically increase the number of private paging operators. Then, in 1991, the Commission gave its approval for PPO's to vie with RCC's in offering paging service to local governments and fire and police departments. This convergence in the service characteristics of RCC's and PPO's is consistent with the trend described in earlier chapters of heightened competition encouraged by the FCC in an effort to further technological innovations and more responsive public service.

As paging technology has matured and public demand for paging services has grown, the FCC has authorized additional bands of frequencies for paging transmissions. This progression in paging authorizations has also followed scientific advances that have made available the higher broadcast frequencies that once were deemed unusable. As a result, paging services have been in established in the 30 MHz, 150 MHz, 450 MHz, and 900 MHz bands of the radio frequency spectrum. Plus, as part of its allocation of forty 25 kHz channels for public paging in the 900 MHz band, the FCC designated three channels specifically for the provision of nationwide paging service: 931.8875 MHz, 931.9125 MHz, and 931.9375 MHz. These three national paging channels are now used by Motorola for its EMBARC[5] subsidiary, by Bell South's MobileComm network, and by Mobile Telecommunications, Inc.'s (MTEL's) Skytel system.

The Rising Popularity of Paging

Pagers have gained in popularity in the U.S. (and abroad) as they have shrunk in size and become much more affordable. Whereas early pagers weighed in at between one-to-two pounds, the modern pager weighs between two-to-six ounces—and that's with a two-month battery. As was mentioned earlier, Seiko even markets a "Receptor" watch that doubles as a pager.

Paging costs have been slashed, too. That bulky, black receiver that used to cost up to $500 can now be purchased for one-tenth the cost. (See Table 5.1.) They also come in a

	Consumer Equipment	Airtime Prices
Cellular Phone	$200-$1,000 (In reality, many phones are practically given away for free to encourage business)	$30-$140/month (service plans)
Conventional Pager (WA State coverage)	$50-$225	$6-$21/month (service plans)
SkyPage through Telepage Northwest (numeric messages) SkyTalk Voice Mail (30 sec voice messages)	$50-$225	Regional One of 6 US regions $49/month National Includes 2 or more regions $60/month ....Additional $15/month
EMBARC e-mail (offers information services and longer messages)	$480-$543 plus cost of desktop, notebook, laptop, or palmtop computer	Sender costs — Single area code / national; Receiver Costs $18/month standby:* 7¢ 28¢ express:* 15¢ 60¢ priority:* 50¢ $2 *cost per 100 characters to an unlimited number of addresses (maximum 30,000 characters)

Table 5.1: Cellular and Pager Cost Comparisons[6]

[5]EMBARC is an acronym for "Electronic Mail Broadcast to A Roaming Computer."

[6]The following cost figures have been compiled from a variety of promotional sources, as well as interviews with paging retailers.

variety of fashion colors intended to appeal to younger consumers. In response to these changes, today about 17 million people own pagers in the U.S., or nearly seven percent of the population; that's slightly higher than the five percent of the population that uses cellular phones. It is estimated that 75 percent of pagers are purchased strictly for business use, but the remaining 25 percent of customers who want pagers to stay in touch with family and friends make up the fastest growing segment of the pager market today.

As paging has evolved from its earliest forms, four distinct types of paging receivers have come on the market, each with its own special capabilities. The simplest and least expensive devices are the "tone-only" pagers; these beep when the user is being paged, or they vibrate silently so as not to disturb others in the surrounding area. The wearer knows by the beep pattern of the pager who she should phone. These are the pagers that can commonly be found at the discounted price of around $50.

The next level of service is delivered through a "numeric" pager, which has a tiny screen that can display about 20 numbers at a time. The numbers are most commonly phone numbers of people who want to be called. But the numbers can also be agreed-upon codes that represent pre-determined messages: like "01" instructing a worker to call the office, or "04" advising a child to come home immediately. Many of these pagers can also store messages for viewing at a more convenient time.

The next most advanced pager is what is called an "alphanumeric" unit. It has a bigger screen, usually able to display about 4 lines of text, and can receive messages about 80 characters in length. These alphanumeric pagers can store messages, too.

Finally, the most expensive pagers are the "tone-and-voice" units, which can sell for as little as $225. These pagers beep or vibrate to signal an incoming message; when the wearer wants to know the message, she can actually play back a 10-to-20 second analog voice recording made by the caller. Naturally, a drawback of these voice pagers is that they are much less spectrum efficient than the others, so they tend to reduce the capacity of a paging system much faster. R. H. Tridgell makes that point vividly with a practical illustration:

> Apart from analog voice paging systems, paging is a highly efficient method of utilizing the radio spectrum. In view of the rapidly growing demands for radio spectrum for mobile services of all types, this aspect of paging is particularly important. For example, simulations...indicate that a single 1200 [bits/second] radio channel could carry (without frequency reuse) the entire paging needs of a population of about 16 million persons, assuming a 2% use within the covered population and employing

normal paging traffic figures...A beep plus analog voice paging system would cover a population of only about 120,000 people.[7]

A key advantage to voice pagers, however, is that the wearer often does not have to make a callback, since she will already have all the information she may need.

One of the most recent developments in paging is the adaptation of desktop, laptop, palmtop, and notebook computers to both send and receive pages.[8] For example, some paging services, like EMBARC, have established gateways that allow users to send alphanumeric messages over paging systems directly from their own desktop computers connected to corporate and commercial e-mail networks; this makes wireless communications more convenient for message senders and renders the paging service more transparent.

Those same e-mail notes, or any other paging messages, can now be received on mobile computers equipped with a $250 PCMCIA (Personal Computer Memory Card Industry Association) card and appropriate software. The PCMCIA card plugs into the portable computer and acts as the paging receiver. The software interface for these portables makes it possible for the home office to update an employee's electronic schedule or other data files simply by paging the changes to the mobile worker's computer. Portable computers can even be reconfigured "on the fly," for example, to change paging addresses and, thereby, shift employees among different mobile work groups as needs change. When the worker next reviews her files, she is notified of the changes that have been made to her revised database. This adaptation of mobile computers to receive pages is indicative of a trend within the paging field to enable the transmission of ever-longer message files.

Data Broadcasting Over High-Definition Television Channels

Since the late 1980's, the FCC has been working with various industry advisory groups to establish a standard for the next generation of TV service, known as high-definition television (HDTV). This new TV technology will provide the public with much sharper broadcast images (especially noticeable on big-screen TV's), compact-disc-quality sound, and a wider screen shape—closer to that of the movies—which should make the viewing experience more realistic and captivating. After about seven years of debate and evaluation, a final standard for HDTV is expected to be field tested early in 1995.[9]

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[7]R. H. Tridgell, "Radiopaging and Messaging," in Mobile Information Systems, ed. John Walker (Boston, MA: Artech House, 1990), p. 18.

[8]Some palmtop computers are also referred to as PDA's, or personal digital assistants. Prominent PDA models include the Apple Messagepad (commonly called the Newton), the Casio Z-7000, the Tandy Z-550 Zoomer, the Motorola Envoy, and the GRiD 2390. PDA's are priced between $450 and $1,500. Nelson King, "Put a PDA in Your Pocket," Puget Sound Computer User, June 1994, pp. 1, 20, 22-23.

[9]Peter Coy, "Airplay: Do Broadcasters Want Their HDTV," Business Week, 23 May 1994, p. 4; and "Green Light to Testing of HDTV Prototype," Broadcasting & Cable, 28 February 1994, p. 14.

Implementation of HDTV service should be approved later in 1995, and the FCC has proposed a transition scenario whereby each TV station will be given an additional 6 MHz of spectrum so that it can simulcast TV shows in today's NTSC standard on its current channel and HDTV on its new channel assignment. A transition period of about twenty years has been suggested so that home viewers can purchase high-definition sets as their old NTSC receivers wear out; that way consumers will not lose the value of their present TV's. After twenty year, or so, NTSC broadcasting will cease and HDTV programming will gain full prominence.

Many stations, however, are concerned about the high cost of up-dating their TV studios with the expensive HDTV cameras and transmitting equipment. Small market stations, especially, may take years to convert their studios for HDTV program production. In the meantime, broadcasters argue, they should be allowed "flexible use" to determine how best to apply the additional 6 MHz granted to them by the FCC—and many are indicating they'll use their surplus frequency allocation to begin data broadcasting. Such an approach could help many hard-pressed stations raise the money to buy HDTV gear. A report on the Newsbytes News Network explains further:

> TV stations are getting six megahertz (MHz) of new spectrum per channel for HDTV, but broadcasters do not expect to go to 24-hour HDTV for many years. For news shows, old re-runs and soap operas, they say, HDTV may in fact be a distraction compared to the NTSC they now broadcast. Some NAB [National Association of Broadcasters] officials think that the extra 6 MHz could allow each station to broadcast as much as 24 million bits-per-second of data over the air. While this would be a one-way signal, it could be very useful for remote learning and some commercial applications.[10]

Given that data broadcasting over vacant HDTV channels would provide a simplex service, paging seems a likely commercial application for these supplemental frequencies—at least for the ten years or more that it takes stations to make the switch to high-definition broadcasting. Of course, the inception of a paging service that would use traditional broadcasting channels is still very much uncertain. Congress must pass a bill that would permit flexible use of the 6 MHz supplemental grants and a final HDTV standard must win FCC approval;[11] it also remains to be seen whether TV stations would move into paging or would use the additional 6 MHz to broadcast more television programming. Nevertheless, if TV station owners initiate paging operations, they could offer inexpensive airtime rates since it would represent a secondary revenue stream in comparison to their established television

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[10]Dana Blankenhorn, "NAB Keeps Pressing for Access to Info Highway," Newsbytes News Network, 2 March 1994.

[11]Dana Blankenhorn, "Broadcasters Seek to Replace Shows With Data," Newsbytes News Network, 4 February 1994; and Dana Blankenhorn, "NAB—Broadcasting's Place on Information Highway," Newsbytes News Network, 22 March 1994.

outlets. Managers at the DOT should be aware of the possibility of paging and other one-way data services being offered by broadcasters and keep such an option in mind as they formulate a mobile communications strategy.

Applications

For a variety of reasons—including a regulatory posture that relies heavily on marketplace forces to mold technological advance—the paging environment has become a hodgepodge of proprietary messaging solutions, each seeking to fill some competitive market niche. There are, in fact, so many exclusive paging options available to consumers that they are too numerous to mention them all here. As a result, this section will focus on the dominant patterns expected to mold paging for the next decade and on the technological solutions that seem most pertinent to the needs of the Washington State Department of Transportation.

Two main industry trends seem to dominate the future development of radiopaging: first, a tendency to distill paging to its core service strengths and to simplify the paging process; second, an evolution beyond traditional short message capabilities to expand paging into a mobile information service. In short, a clear divergence is evident among industry leaders that are reshaping paging according to two different visions: one embracing paging's basic messaging roots, the other grafting a new service onto the old by emphasizing demands for mobile data over status quo paging features.

Building on the foundation of basic paging is Paging Network, Inc. (PageNET), the largest paging company in the U.S. with three million subscribers. PageNet is betting that the core quality of paging—its ability to deliver succinct mobile messages inexpensively—will continue to sustain the business well into the twenty-first century. Unlike other national paging firms that have moved to satellite distribution of electronic messages, PageNet still uses leased phone lines as its backbone delivery system servicing a network of regional community antenna sites. As a result, the company has been able to undercut the prices of many of its competitors.[12]

A corporate belief in paging's basic strengths is influencing PageNet's investment in future technology: the company is working with Motorola to perfect a pager that will work like a tiny, wireless voice recorder.[13] Unlike conventional analog voice pagers, however, these new pagers will support <u>digital</u> voice messaging. An early forerunner of the technology has been on trial since March of 1993 and is marketed under the service name "VoiceNow." Using digital transmissions, the pager will store voice messages the way today's pagers store alphanumeric data; in essence, the pager will perform like a simple answering machine.

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[12]Dana Blankenhorn, "PageNet, Motorola Work on Advanced Pager," Newsbytes News Network, 11 April 1994.

[13]Ibid.

Problems with the spectrum inefficiency of voice transmissions will be solved, Motorola says, by employing digital compression and frequency re-use.

Two special features anticipated for the VoiceNow service that will further distinguish it from today's one-way paging systems will be its ability to track the location of pagers within the nationwide network and to acknowledge the reception of voice messages.[14] The development of this technology for the VoiceNow service is not yet complete. When fully developed, the technology will not be proprietary to PageNet but will be available to other Motorola customers.

Wireless Information Services

At the other end of the spectrum of paging capabilities, led by the example of Motorola's EMBARC service, are those firms reshaping the technology into a more intensive data communications service. Companies like Bell South's MobileComm and MTEL's SkyTel are emulating EMBARC's advance by transforming their paging networks into information delivery services.[15] These state-of-the-art systems are pushing the envelop on message length by allowing file transfers up to 30,000 characters; traditional pager messages were limited to abbreviated notes of about 80 characters each. They are also making paging more convenient by adding gateways compatible with X.400 protocols from many corporate e-mail networks directly onto paging channels.

Even more distinguishing, however, is the ability of these services to keep users current with changing world events by linking customers to a growing variety of information providers. EMBARC, for example, can offer customers subscriptions to news, weather, and feature stories supplied by USA Today; breaking financial reports from Reuters; and specialty industry briefs researched by INDIVIDUAL, Inc.[16] In fact, the expansion of paging into an information service is blurring the defining characteristics that made paging unique from data communications, for example.

Hand-in-hand with developments supporting longer text messages over paging networks are advances promoting faster data transmission speeds over narrow 25 kHz paging channels. The common POCSAG standard, for instance, has supported transmission speeds of between 1,200 and 2,400 bits per second. But a new standard called FLEX being developed

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[14] Telephone interview with Sandra Humphrey, Motorola, 7 June 1994.

[15] See: Dana Blankenhorn, "Franklin Digital Book to Support SkyTel," Newsbytes News Network, 4 January 1994; Dana Blankenhorn, "Paging Networks Become Messaging Networks," Newsbytes News Network, 4 October 1993; Dana Blankenhorn, "SkyTel Launches Quote Service," Newsbytes News Network, 28 October 1993; and Steve Gold, "Comdex—Motorola's EMBARC System Examined," Newsbytes News Network, 17 November 1993.

[16] Described in a letter and promotional materials mailed by Edward A. Popovich, Customer Satisfaction Manager, EMBARC, Salt Lake City, UT, 8 March 1994.

by Motorola will allow data transmissions up to 6,400 bits per second.[17] Plus FLEX is compatible with older POCSAG pagers, meaning that customers will not have to trade in their current paging receivers. The value of FLEX to paging operators is clear when one considers that PageNet estimates the new Motorola system would allow it to triple its channel capacity.[18]

Two-Way Paging

Paging has been defined by the FCC as:

> A *one-way communications service* from a base station to mobile or fixed receivers that provide signaling or information transfer by such means as tone, tone-voice, tactile, optical readout, etc.[19] (Italics mine.)

This definition is being challenged now as technological changes introduce two-way capabilities to paging. Since paging began some forty years ago, technical limitations, costs, and design constraints kept paging limited to one-way transmissions. As these different challenges have been addressed, however, paging has strived to move beyond simplex operation to become a duplex, or two-way, service.

R. H. Tridgell explains why paging acknowledgment does not require the power or spectrum bandwidth necessary for transmission of the original paging message:

> The volume of information in an acknowledgment is small, perhaps as little as one bit. Therefore, the bit transmission rate of the acknowledgment direction could be much lower than in the message paging direction. In theory, a few bits require less energy and, at low rate, less radio spectrum than do many bits. As little as 1[watt] for 1/16th [sec] has been calculated to be sufficient transmitted power for acknowledgment in a wide-area system with acknowledgment receivers co-sited with the paging transmitters. Of course, if the acknowledgment receivers could be spaced much closer, even such a modest transmitting requirement could be greatly reduced.[20]

One of the first attempts at two-way paging was introduced by Japan City Media in Tokyo last April.[21] Despite its duplex operation and large screen for displaying long messages, the pocket pager is reportedly no bigger than conventional paging units. Users can not only acknowledge receipt of a message, but they can transmit replies, as well. The pager comes with a stylus that can be used to jot messages or drawings directly on the display screen, which then becomes a writing surface. The device is called the Message TC301 and is expected to sell for ¥128,000 ($1,160).

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[17] Dana Blankenhorn, "Motorola FLEX on Schedule," Newsbytes News Network, 7 March 1994.
[18] Ibid.
[19] Code of Federal Regulations, Title 47, Part 80 to End, Telecommunication, p. 246
[20] Tridgell, "Radiopaging and Messaging," in Mobile Information Systems, pp. 42-43.
[21] Masayuki Miyazawa, "Advanced Pocket Pagers to Debut in Japan," Newsbytes News Network, 9 February 1994.

In the U.S., MTEL is leading the way in two-way paging with its Nationwide Wireless Network, or NWN.[22] In September of 1993, the FCC granted MTEL a "pioneer's preference" as a reward, of sorts, for the developmental work the company had done in two-way paging.[23] In recognition of MTEL's innovative proposal for introducing duplex capabilities to paging, the FCC responded with an early licensing grant of 50 kHz in the 940 MHz band for the firm to begin commercial operation. As a result, MTEL can begin developing this innovative service immediately without having to wait for the PCS spectrum auction expected later this year. Not only will the NWN be a two-way paging network, but it will also reportedly offer faster data transmission speeds than today's standard paging service. MTEL predicts that it will be delivering two-way paging service to the top 300 markets in the U.S. by mid-1995.

The fact that MTEL's pioneer's preference was announced in an FCC ruling on PCS hints at how the lines of distinction are blurring between what were once distinct technologies. In fact, through its regulatory rulings, the FCC is no longer trying to pigeon hole each new technology into a particular service function but is encouraging competition between different technological options. The goal, clearly, is to let the marketplace decide which technology performs best at delivering a certain communications service instead of relying on agency planning, as was done in the past.

So, it is not unusual that McCaw Cellular and Lotus are also moving into the paging field by employing Cellular Digital Packet Data (CDPD) as a foundational technology.[24] As was noted in the earlier chapter on cellular telephony, CDPD is a recent innovation that converts unused time on cellular channels into packet networks transmitting data at 19.2 kilobits per sec. The McCaw/Lotus proposal is to use those same empty cellular time slots to develop a CDPD-based, two-way paging system. Other challenges to what were traditionally "paging services" are coming from the data communications field, as well.

Transportation-Specific Applications

Of all the technologies reviewed so far in this report, paging has the most advantages to recommend it for application by the Washington State DOT. It is a proven technology which, with recent enhancements, has gained in its capabilities. The receivers are lightweight and small, making them unobtrusive, and their simple operation makes them extremely user friendly. The technology is elegant in its simplicity, which would ease installation by the DOT whether it decides on using a commercial wide-area paging network or considers constructing a

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[22]Microsoft has invested $30 million in the NWN project, Bill Gates has invested $10 million of his own money, and Paul Allen has invested another $10 million. Jim Mallory, "Microsoft, MTEL to Build Nationwide Wireless Net," Newsbytes News Network, 29 March 1994.

[23]U.S. Federal Communications Commission, Final Rule: Narrowband Personal Communications Services, Gen. Docket No. 90-314, FCC 93-329. In Federal Register, Vol. 58, p. 42681.

[24]Jacqueline Emigh, "Lotus and SkyTel Release Notes Gateway for Paging," Newsbytes News Network, 9 February 1994.

private wide-area network under its own control. Finally, for all the communications potential its provides, a paging system is relatively inexpensive to construct and operate—a big plus considering taxpayer concerns with state fiscal responsibility. Evidence of the cost effectiveness of paging can be found in the readiness of developing countries to invest in the technology as a backbone for their telecommunications infrastructure . In sum, paging has the most to offer for each dollar invested in the service.

In an article on the future of mobile information systems, John Walker provides several examples of how paging is already being used in support of transportation management goals.[25] For example, in 1989 one test site in London connected the output of several display pagers to some highway reader boards in order to provide up-to-the-minute traffic advisories along key sections of roadway exiting the city. The electronic display was fed information that was broadcast over paging channels from the Automobile Association's "Roadwatch" headquarters. More recently, EMBARC has been testing the potential of its network for wireless display of messages on electronic signs, which clearly may have applications along state highways.[26]

Walker also points to experiments with large paging displays installed on automobile dashboards.[27] By developing group addresses for study participants that leave work at the same time, and from the same regional locations, multiple drivers can be alerted with a single paging message and advised how best to travel home.

Looking ahead, Walker suggests the useful combination of paging with cordless technology:[28] for example, a DOT employee who receives a page could drive near the closest DOT telepoint and, from inside his vehicle, phone for additional information. Such a union of paging with telepoint service could be especially useful for snowplow drivers, for example, who could maintain convenient contact with headquarters, answering only those calls that demanded additional information—and answering at a time convenient for the driver.

Finally, the ability to dynamically readdress pagers without having to manually change chips inside the receivers would also allow a central dispatcher to regroup road crews with new instructions in order to meet changing work priorities.

Private or State-Owned Network Operations

The decision as to whether the State should contract with a private commercial firm for paging service demands a detailed cost/benefit analysis that is outside the scope of this report.

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[25]John Walker, "Mobile Information Systems—the Future," in Mobile Information Systems, ed. John Walker (Boston, MA: Artech House, 1990), pp. 349-368.

[26]Described in a letter and promotional materials mailed by Edward A. Popovich, Customer Satisfaction Manager, EMBARC, Salt Lake City, UT, 8 March 1994.

[27]Walker, "Mobile Information Systems—the Future," in Mobile Information Systems, p. 358.

[28]Ibid.

Such a decision must also take into account the fact that any commercial service will become most busy during times of emergency—just the instance when the DOT most needs uninterrupted service to insure smooth transportation management. However, contracting with a private service provider would also relieve the State of the annual maintenance costs that go along with operation of any communications network. Even so, the possibility of developing a State-owned paging system should be seriously considered because of the tremendous communications advantages that could be gained for a comparatively reasonable expense.

A key advantage to paging that has been noted is the ability to piggyback paging messages onto FM radio signals. Taking advantage of this potential, the DOT could build a paging network relatively inexpensively by contracting with FM stations across the State.[29] Certainly the most populous regions could be covered quite easily, and the DOT would only have to build a limited number of transmitters in "dead zones," such as in the mountain passes, to achieve blanket coverage. Paging signals could be distributed from control centers to FM transmitters either by leased phone lines or microwave links. Operation of such a State-owned network could begin with a POCSAG-based system offering lower data rates of 2,400 bits per second and gradually be upgraded to FLEX standards, for instance, offering nearly triple the data capacity. Control centers could dispatch paging messages as short e-mail notes using ordinary desktop computers. Paging messages could be transmitted to field employees equipped with pagers or PDA's, which would store them until the user had an opportunity to view them.

Paging messages could also be used to control a number of other transportation-related functions, like altering traffic signals or activating highway reader boards—each of which could be given a unique paging address. Since paging receivers attached to reader boards would be stationary objects, operators could be reasonably sure of a completed transmission if paging signal strengths had been tested when the system was initiated; a higher probability of message reception could be achieved by staggering redundant messages.

To insure message reception by mobile users, special receiving towers could be sited alongside the FM broadcast transmitters to detect paging acknowledgments, if that was deemed necessary. Obviously, implementation of a reverse communications channel, no matter how limited, would raise developmental costs substantially; even so, a paging system with

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[29]By using an FM subcarrier approach to paging, the DOT could establish its own paging network at relatively low expense. Although the cost of building a paging transmitter tower is highly variable, Fred Radovich, an account manager with Motorola, indicated that a ballpark figure for such construction would run between $50,000 and $100,000, with the higher figure the more reasonable of the two. This is based on an assumption that the tower would be about 100 feet tall and includes the cost of the necessary antenna. Considering that an FM subcarrier paging network would take advantage of FM radio station towers already in use, it is obvious that this approach could save a substantial amount of money over a traditional paging system for which dedicated transmitter towers must be built. Phone interview with Fred Radovich, Motorola, 220 120th Avenue N.E., Suite 102, Bellevue, WA 98005, 5 July 1994. Phone: 646-0302.

acknowledgment capabilities would still be considerably cheaper to build than a cellular, PCS, or cordless network—yet would offer comparable service. Even eight-bit binary files could be transmitted over a paging system if the right paging standard was employed. Longer data files could be transmitted in segments and then reconstituted by software in the receiving mobile computer.

Of course, paging does have its limitations. While it is increasingly being used as an information service, its strengths lie more in the transmission of short data messages. Also, despite advances, paging is primarily a one-way communications medium. These limitations may doom paging as a significant contributing technology for mobile communications by the State's DOT. Additionally, because paging lacks the high-tech image associated with PCS or cellular telephony, for example, it may be hard to garner political support for a State-operated paging network. Nevertheless, paging has proven itself to be a reliable communications tool for many public and private applications and should not be overlooked due to its simplicity. In fact, it is this simplicity that truly makes paging so attractive a communications option.

Conclusion

Paging stands out as a prime example of how the FCC's marketplace philosophy can work to increase technological options and drive down consumer prices. Today's paging clients can choose from a variety of service options, ranging from basic tone-only units to receivers that keep mobile users in touch with worldwide events. Plus the equipment keeps adapting to make placing and receiving pages more convenient. Many callers can now send out paging messages on their office e-mail systems, and message recipients can have their laptop computers store in-coming messages on PCMCIA cards even when the computer is powered down. Paging customers can also choose from local, regional and national paging services, depending on the extent of their travels.

Despite paging's new capabilities, it still remains remarkably affordable. So much so, in fact, that many teens are now buying pagers to stay in touch with family and friends. Customers have many different service providers to choose from, and the competition between providers has helped to drive down paging prices.

The rivalry among paging operators has also spawned different paging standards, each attuned to best meet the needs of niche markets. This variety of standards has actually helped operators to specialize their services, and since paging networks are not interconnected these differences in standards have not hindered communications.

Broadcasters, too, might soon jump into the paging field and increase the competition in what is already a crowded service. Using supplemental spectrum earmarked for HDTV, some station owners might offer low-cost paging for a number of years until the start of high-definition broadcasting proves profitable. Even so, paging by traditional broadcasters will not go on indefinitely, since the FCC will eventually demand they start HDTV programming and evacuate their prior NTSC channel assignment. As a result, broadcaster-run paging—if it ever arrives—will provide only a short-term option and should not figure prominently in DOT mobile communications planning.

Paging is currently the most popular mobile communications technology with the general public, and its popularity can be expected to grow as data compression techniques bolster paging capacity and hold down paging costs. In conclusion, paging is popular because it is an effective communications tools for a mobile population that wants to stay in touch without sacrificing freedom of movement.

Chapter VI

Private Land Mobile Radio

Introduction

The first few chapters of this report have covered the more "high profile" mobile communications systems; those mobile technologies that get the most coverage in the popular press and with which the general public is most familiar. The topic of this chapter—private land mobile radio—is much less well-known, even though it provides a wireless communications link for a wide variety of public services and private enterprises. It is the radio technique commonly used to direct ambulances to accident scenes, to keep long-haul truckers on schedule, to coordinate police patrols, and to tie mobile service crews to their home base, among many other uses. The Washington State DOT, too, regularly employs private mobile radio to maintain communications with highway maintenance crews. Private mobile radio truly is, as one author has noted, the "work-horse" of the mobile technologies.[1]

During the last decade, especially, private mobile radio has been quietly undergoing a "face-lift" that promises increased functionality for private industries and public agencies that need responsive wireless communications service. So, the radio technology which has long served faithfully in the background has suddenly stepped forward to receive increased recognition from regulators and radio equipment manufacturers. An emphasis on the potential of Specialized Mobile Radio (SMR), a newer class of mobile radio service, has been especially prevalent in the business and general press. This chapter will explore the evolution of private land mobile radio and investigate its usefulness to the future communications needs of the State's Department of Transportation.

Background

Reports on land mobile radio are often confusing because of their frequent reference to the different classes of public and private mobile radio which are, nevertheless, not clearly defined. Keeping this in mind, a typology of land mobile radio should provide a useful foundation for later discussions.

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[1] Jeremiah Courtney and Arthur Blooston, "Development of Mobile Radio Communications—the 'Work-horse' Radio Services," Law and Contemporary Problems 22 (Autumn 1957): 626-643.

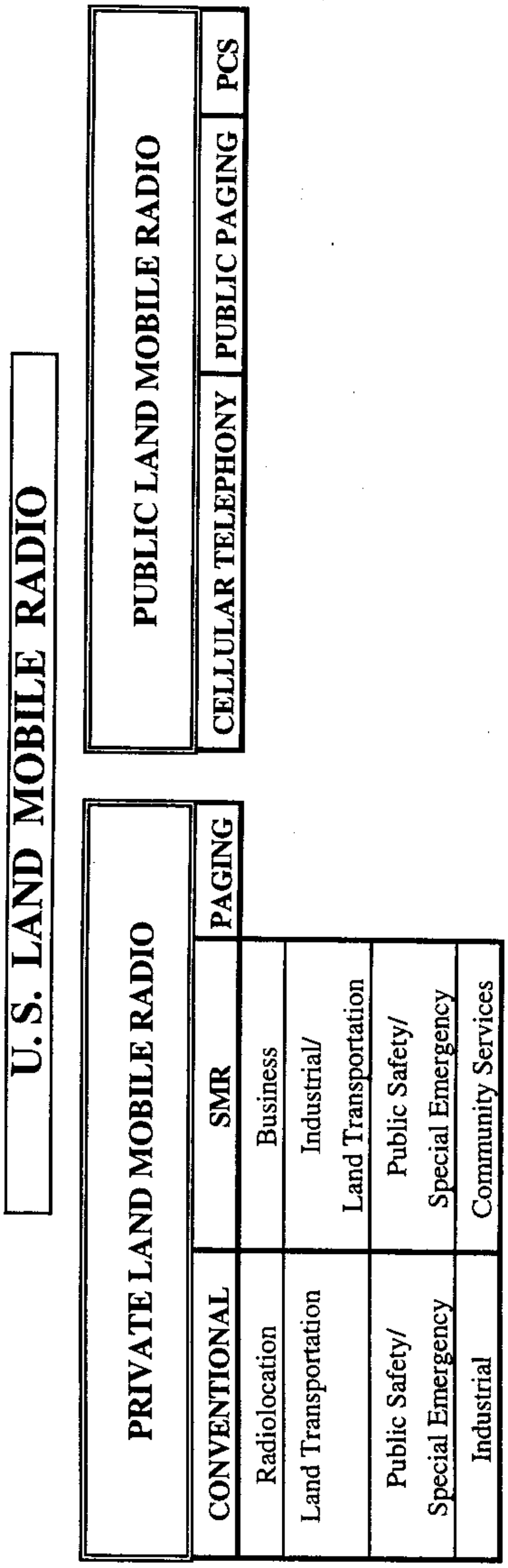

Figure 6.1: Land Mobile Radio Service Categories

Land mobile radio can be broadly divided into two separate classes of service: private and public.[2] (See Figure 6.1.) Three of the technologies already reviewed in this report—cellular telephony, paging, and PCS—fall under the classification of public land mobile radio; these services are available to the public at large, or, in the case of PCS, will be available in the near future.[3]

In contrast, private land mobile radio services provide "regularly interacting" users of "base, mobile, portable, and associated control and relay stations (whether licensed on an individual, cooperative, or multiple basis) with radio communications."[4] In other words, private land mobile radio refers to those frequencies that were set aside for the special wireless needs of industry, transportation, and public service providers. Traditionally, the bulk of private land mobile radio activity has been in the area known as "conventional" services, and the development of today's varied land mobile radio environment can be traced back to the early success of these conventional services. The four subcategories of conventional land mobile radio—radiolocation, land transportation, public safety/special emergency, and industrial—are broken down into their individual service classes in Figure 6.2.

When one considers the multiple applications of these conventional mobile radio services across the public and private sectors, their productive value to industry and to the general public welfare becomes obvious. As a result, it is easy to understand why conventional land mobile radio frequencies have been in great demand and why the FCC has made increasing efforts to free up more spectrum for these conventional services. Table 6.1 illustrates the growth that has occurred in the conventional land mobile services over the past decade. (Note that conventional private land mobile radio includes frequencies established by the FCC for highway maintenance communications; these frequencies are part of the public safety category of service. A table listing the current FCC VHF channel allocations established for use by highway maintenance crews is included in the appendices to this report.)

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[2]In developing the following typology, the author is building on the delineations suggested by Alfred Lee, an NTIA researcher, in his article "Land Mobile Radio Services," in NTIA Telecom 2000: Charting the Course for a New Century, NTIA Special Publication 88-21 (Washington, DC: U.S. Department of Commerce, October 1988), pp. 283-304.

[3]Lee's article was written in 1988, several years before discussions on PCS intensified. As a result, Lee does not refer to PCS in his typology. Based on the leading features of PCS—the characteristics of the message carried, the number of radio channels allocated, and the nature and purpose of the mobile radio user—it seems appropriate to identify PCS as a public land mobile radio system.

[4]47 USC Sec. 153 (gg) (Supp. II 1984).

CONVENTIONAL PRIVATE LAND MOBILE RADIO				
Radiolocation	**Land Transportation**	**Public Safety / Special Emergency**		**Industrial**
	auto emergency	fire	medical services	business
	railroad	police	rescue services	forest products
	taxicab	state guard	veterinarians	manufacturers
	motor carrier	local government	handicapped	motion picture
		forestry conservation	establishments in isolated places	special industrial
		highway maintenance	communications standby facilities	telephone maintenance
			disaster relief	petroleum
			school buses	power
			beach patrols	relay press
			emergency repair of public communications facilities	

Figure 6.2: Conventional Private Land Mobile Radio Service Categories

Services	1983	1986	1989
RADIOLOCATION			
Total	**4,337**	**6,809**	**n/a**
LAND TRANSPORTATION			
Auto Emergency	7,379	8,189	7,616
Railroad	12,036	15,016	15,966
Taxicab	6,274	6,053	5,883
Motor Carrier	10,179	10,575	10,913
Total	**35,868**	**39,833**	**40,378**
PUBLIC SAFETY			
Fire	27,242	39,101	42,799
Police	47,802	45,429	49,136
State Guard	5	0	0
Local Government	44,463	61,313	69,958
Forestry Conservation	8,749	10,187	11,106
Highway Maintenance	11,556	13,541	14,587
Total	**139,817**	**169,571**	**187,586**
SPECIAL EMERGENCY			
Total	**32,339**	**39,433**	**n/a**
INDUSTRIAL			
Business	510,813	637,138	637,977
Forest Products	6,550	10,649	11,591
Manufacturers	11,770	19,906	22,673
Motion Picture	358	391	392
Special Industrial	94,728	118,650	115,418
Telephone Maintenance	3,599	6,464	8,490
Petroleum	22,323	26,662	26,976
Power	28,288	38,397	44,256
Relay Press	734	1,179	1,221
Total	**679,163**	**859,446**	**868,994**

n/a = not available

TABLE 6.1: Growth of Conventional Private Land Mobile Radio

In 1974, the FCC created the Specialized Mobile Radio (SMR) classification under the umbrella of private land mobile radio.[5] The SMR services were established to provide private land mobile services on a commercial basis; in contrast, the conventional services represent frequencies set aside for direct use by specific groups who can transmit over their radio channels without incurring airtime charges. While conventional mobile radio frequencies are commonly allocated as single radio channels for simplex service or as a single channel pair for duplex service, SMR frequencies are usually assigned in no fewer than five channel pairs. This makes it possible for many SMR operators to employ a newer approach to mobile communications known as multichannel trunking, which is much more spectrum efficient.

It is important to understand how multichannel trunking works since it offers significant service advantages and many mobile systems are evolving into trunked operations. When conventional mobile radio services use their single radio channels, there are many instances when dispatchers have to wait to transmit messages because the channel is being used by another dispatcher that shares the same frequency assignment. Even though there are times when adjacent conventional radio channels are free, they cannot be used by dispatchers on the congested channel because they have not been authorized access. Multichannel trunked services have the benefit of access to multiple radio channels; so, even when several assigned channels are busy, a system computer is often able to locate a free radio channel and automatically switch the dispatcher to that unoccupied frequency. As a result, dispatchers have to wait less often to transmit their messages, and the blocking probability—the likelihood that a free channel will be unavailable—is reduced. Author Michael Paetsch provides a real-life illustration that demonstrates the spectrum efficiency of multichannel trunking:

> In essence, trunking refers to the fact that all users of a radio system can access all available channels. If, for example, a single channel can support only two or three mobile-telephone users (10% chance of blocking and an average call duration of 150 sec.), then a 20-channel non-trunked system could support only about 50 customers, whereas a 20-channel trunked system could support 420 users. This gain is commonly referred to as trunking efficiency, and comes about because, statistically, it is unlikely that all users want to make a telephone call at the same time.[6]

Certainly, there are some SMR operators that still operate as conventional services on single radio channels, but the majority are multichannel trunked systems.

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[5]See: Lee, "Land Mobile Radio Services," pp. 288-291, 293, 298-299; Michael Paetsch, Mobile Telecommunications in the U.S. and Europe: Regulation, Technology, and Markets (Boston, MA: Artech House, 1993), pp. 29, 185-191; "NEXTEL Keeps Making the Right Connections," Business Week, 14 March 1994, pp. 31-32; Gary Slutsker, "The Company that Likes to Obsolete Itself," Forbes, 13 September 1993, pp. 139-144; Norm Alster, "A Third-generation Galvin Moves Up," Forbes, 30 April 1990, pp. 57, 60, 62; and Kevin Maney, "MCI-Nextel Deal Could Spark Wireless Free-for-all," The Seattle Times, 1 March 1994, pp. D1, D6.

[6]Paetsch, Mobile Telecommunications in the U.S. and Europe, p. 80.

Like conventional land mobile services, SMR frequencies have been set aside for specific applications: business, industrial/land transportation, public safety/special emergency, and community services. (See Figure 6.1.) It is this class of frequencies, for example, that were acquired nationwide by Federal Express and which were molded into a data network for tracking package deliveries.

SMR has experienced explosive growth since its inception; even more so than the conventional mobile radio services. (See Table 6.2.) In fact, SMR is forecast by most analysts to become a viable public option for mobile telephony in the next few years.[7] If this prediction is fulfilled, most U.S. markets will gain a third mobile telephone provider to challenge the present duopoly that exists with cellular service. The ensuing competition is expected to further drive down prices for cellular equipment and airtime. In this somewhat recent development, one can also see that some of the differences that formerly distinguished private and public land mobile radio are disappearing and distinctions between the two categories are becoming blurred.[8]

There is a third category of private land mobile radio service, which is private paging. The operators of private paging systems employ a special set of frequencies set aside just for

Services	1984	1986	1988
CONVENTIONAL			
Business	18,351	20,293	21,646
Industrial/Land Transportation	2,726	3,742	4,122
Public Safety/Special Emergency	1,529	2,093	2,340
Community Services	498	660	671
TRUNKED			
Business	60,229	127,036	165,890
Industrial/Land Transportation	284	665	782
Public Safety/Special Emergency	388	1,013	1,436
Community Services	2,309	2,941	3,499
TOTAL SMR LICENSES	86,314	158,443	200,386

Table 6.2: Growth of Specialized Mobile Radio Licenses

[7]See: Mark Lewyn, "Welcome to the Wireless War," Business Week, Special Edition on "The Information Revolution," 1994, p. 178; Pam Black, "Dialing Into the Telecoms of Tomorrow," Business Week, 2 May 1994, p. 132; Thomas McCarroll, "Betting on the Sky," Time, 22 November 1993, p. 57; and Maney, "MCI-Nextel Deal Could Spark Wireless Free-for-all;" among others.

[8]Lee, "Land Mobile Radio Services," pp. 298-299.

that purpose. In 1984, the FCC doubled the amount of channels allocated to private paging when it allocated 40 additional radio channels to the existing private paging service. A year later those 40 channels were split so that half of the channels were earmarked for commercial service and the other half were reserved for non-commercial service. Like conventional land mobile radio and SMR, private paging has experienced strong demand and a steady growth in the number of licensees approved for operation.[9]

Regulatory History

Land mobile radio was first put into service during the late 1920's; the first mobile radio system was introduced by the Detroit Police in 1928.[10] Early experiments were conducted mostly by police departments during mobile radio's early years, but gradually the technology began to be applied by other emergency services, as well. The first systems were simple, one-way transmitters, but they were soon replaced with half-duplex, and then duplex, mobile radio services. Unlike today's cellular telephone systems, these initial mobile radio links were not interconnected with the public switched telephone network (PSTN)—a distinction which, until recently, was one of the characteristics that differentiated mobile radio from cellular service. As mobile radio became more established, interest began to grow among businesses that foresaw the fruitful application of this technology to the control of an expanding mobile workforce.

Following the Second World War, the FCC began to take its first steps in organizing the nascent mobile radio service. Some of the first conventional mobile radio classes were established for use by railroads, truckers and taxis, among others. The public land mobile radio classification was also developed, and mobile telephone services were introduced to the public on an experimental basis. (Early mobile telephone operations were not cellular but used large transmitters to provide blanket coverage of metropolitan areas on limited frequencies.) By the late 1940's, public paging services were also gaining a foothold. During the 1950's, the FCC added to its list of conventional mobile radio categories until they came to look much as they do today.

In the fifty years since World War II ended, the maturation of private land mobile radio has been strongly influenced by the constant shortage of spectrum space in relation to overwhelming demand from prospective operators. Through a series of technological advances, regulatory rulings, and frequency shuffling between broadcast and mobile radio services, the FCC has tried to responsively manage land mobile radio in a way to extended its application among various user groups. Nevertheless, as evidenced by the countless license

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[9]In 1983, the number of private paging licenses stood at 508. By 1985, that figure had jumped to 802, and in 1987 there were 980 assigned private paging licenses. Lee, "Land Mobile Radio Services," p. 290.

[10]For some of the early history on land mobile radio, see: Courtney and Blooston, "Development of Mobile Radio Communications—the 'Work-horse' Radio Services."

applications that inundate the agency whenever frequency space becomes available, land mobile radio has been persistently handicapped by the demands imposed as the result of its own broad popularity.

Technical Advances

One of the first major steps forward for the infant service came from the application of frequency modulation.[11] Unlike amplitude modulation, FM offered much cleaner transmissions, free of the troublesome static that plagued AM. FM also displayed a characteristic known as the "capture effect," which meant that FM receivers were able to block out weaker transmissions to lock on to the strongest FM signal available—an important trait considering the growth of mobile services. AM transmissions, lacking this "capture effect," had been hampered by the tendency of multiple AM signals to compete with each other for reception, which would subsequently garble many AM-based broadcasts. The FCC approved FM for use in land mobile equipment starting in 1941.

A second technological jump forward came during the 1970's when the FCC began encouraging the operation of trunked systems over non-trunked. The advantage of trunking, which was mentioned earlier, is not that it improved the sound quality of land mobile radio but that it dramatically boosted its spectrum efficiency. Considering the constant demand for more mobile radio channels, the fact that trunking makes it possible for systems to handle greater transmission loads explains the popularity this technology has gained among system operators. By designating that some land mobile licenses would only be granted to applicants who agreed to use computerized trunking technology, the FCC has been able to promote this technical advance and help it gain a stronger foothold in the marketplace.

A third technological advance is coming with the introduction of digital SMR services, expected in Washington State by the end of 1994. Of course, digital transmissions will offer better audio quality over current analog land mobile signals; but it will also boost channel capacity at least six times beyond present capabilities.[12] In 1989, the FCC approved a plan presented by Fleet Call (now NEXTEL) to establish nationwide, digital SMR service. NEXTEL has since proceeded to acquire blocks of SMR licenses across the country in its effort to lay the groundwork for its national network. The company has already gone on-line with the first of its digital SMR systems in Los Angeles and optimistically forecasts a completed U.S. network by the end of 1995. Other companies like American Digital

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[11]Frequency modulation was invented by Edwin Howard Armstrong during the late 1920's and early 1930's and was approved by the FCC for radio broadcast service in 1941.

[12]Dana Blankenhorn, "MCI Buys Into Nextel," Newsbytes News Network, 1 March 1994; Gary Slutsker, "Look Out for the Taxi Dispatchers," Forbes, 20 August 1990, p. 87; and Prudential Securities Telecommunications Research, a report on the SMR industry, no date given. A photocopy of portions of this report were supplied by Dave Parker, Senior Account Executive, OneComm, Kirkland, WA.

Communications, Inc., Dial Page, and OneComm are also buying clusters of SMR licenses with the intent of forming regional, if not national, networks. OneComm owns licenses in the Pacific Northwest, including Washington State.[13] In a recent development, NEXTEL and OneComm announced in July of 1994 that they intend to merge their two companies.[14] While OneComm/NEXTEL have announced their intent to begin digital SMR service in Washington State before the end of 1994, some industry representatives doubt the merged firms can meet that timetable.[15]

Unlike the situation with digital cellular telephony in which multiple standards are still vying for dominance, these advanced SMR operators have all agreed to use a digital technology invented by Motorola and known as the Motorola Integrated Radio System (or MIRS).[16] By converting their traditional single-transmitter systems into cellular-type systems—employing multiple, low-power antennae to reuse frequencies over smaller cell sites—these so-called Enhanced SMR (ESMR) operators are expected to become a competitive force to challenge the cellular duopoly status quo. By joining together to agree on a single, digital standard, ESMR service companies will have a distinct advantage over cellular in their ability to provide hassle-free roaming across the entire country.[17] Additionally, SMR handsets are expected to provide integrated services, meaning they will offer voice, paging and data functions using a single, mobile transceiver.[18] For customers who currently have to carry three different devices to perform these communications functions, the integrated services promised by ESMR providers should prove attractive—even if the ESMR handset will be bulkier than a cellular telephone, and more expensive. It is anticipated that dispatch companies and large fleet operators form the largest market for this advanced ESMR service.

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[13]OneComm also has SMR frequencies in Colorado and the central U.S. Jim Mallory, "Phone, Pager, 2-way Radio in One Handset," Newsbytes News Network, 6 May 1994.

[14]According to a report by the Business Wire news service, NEXTEL and OneComm will execute a tax-free merger involving an exchange of stock shares by NEXTEL. The transaction is valued at over $650 million. "NEXTEL, OneComm to Merge," Business Wire, OverNET Daily Wireless Update, 14 July 1994; and "NEXTEL Swaps $650 M in Stock for OneComm," Knight-Ridder, OverNET Daily Wireless Update, 14 July 1994.

[15]O. Casey Corr, "Cellular Competition to Heat Up," The Seattle Times, 19 August 1994, pp. F1, F4.

[16]MIRS is reportedly technically similar to the European Global System of Mobile communications (GSM) standard for digital cellular telephony. Peter Coy, "NEXTEL Keeps Making the Right Connections," Business Week, 14 March 1994, p. 31.

[17]MIRS is reportedly a time-division multiple-access (TDMA) digital technology. "Fleet Call to Build New Cellular Network," Microwaves & RF, March 1992, p. 40; and Prudential Securities Telecommunications Research.

[18]"For example, brief text messages—up to 140 characters—can be sent even to someone who is already on the phone." Ibid.

Despite its advantages, ESMR technology is not a sure bet in the marketplace because of some of the peculiarities of SMR frequencies and their licensing patterns. An article on the Newsbytes News Network cautions:

> An SMR license is not like a cellular license...The frequencies are lower, so that while antennae can be further apart, it takes more power to generate a signal, so phones must be larger and require more power than conventional cellular units. Also, separate SMR licenses are offered for each calling channel, so merely having a license in a market doesn't guarantee that a license holder has the spectrum necessary to provide real competition to cellular operators. Each cellular operator has dozens of calling channels available, at the same frequencies, in each market. SMR license holders must acquire their licenses channel-by-channel, and may not have the same frequencies in adjacent markets.[19]

Since many of these ESMR operators are still in the process of purchasing available SMR licenses, it remains to be seen whether digital SMR services will prove to be a robust market challenger, or merely a bust.

Regulatory Rulings

The continuing development of land mobile radio has also been strongly influenced by the tenor of regulatory rulings issued by the FCC. Over the history of land mobile radio, three approaches to regulatory policy can be discerned. Up until the 1970's, the FCC allocated spectrum for private land mobile radio according to the perceived needs and value of various user groups. As a result, at different times varying amounts of spectrum were released for radiolocation, land transportation, public safety, and industrial services as was seen fit. That changed in the 1970's, however, as the FCC took a new tack by tying some land mobile radio frequencies to the use of trunking technology. The FCC's intent, clearly, was to encourage the introduction of the newer spectrum-efficient innovation. So, for example, when the FCC allocated 300 new channels for private land mobile radio in 1974, two-thirds of those channels were reserved for trunked systems and only a third were left for single channel, conventional operations.[20] When SMR licenses were later awarded in the 900 MHz band, operators were required, again, to employ trunking technology.

At the same time the FCC began experimenting with technology-based allocations, the Commission also began shifting from its universal service position that had molded early telecommunications systems to more of a pro-competitive stance. Instead of rigidly categorizing certain new land mobile frequencies for specific user classes—a process that relied heavily on administrative judgments as to how the land mobile service should develop—the FCC took on a more flexible stance and began encouraging market-based applications. For

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[19]Dana Blankenhorn, "Motorola-NEXTEL Create Largest Wireless Network," Newsbytes News Network, 9 November 1993.

[20]Lee, "Land Mobile Radio Services," p. 293.

instance, in the mid-70's the Commission took the controversial step of introducing the new license classification of SMR. As an SMR licensee, operators would be able to offer mobile communications on a commercial basis to users eligible for private mobile radio service. This signaled a move away from the FCC as the controlling interest in shaping mobile radio growth to a newfound confidence in the wisdom of the marketplace.

This same sort of marketplace philosophy can be seen in another FCC decision in the mid-1980's to set aside frequencies for a proposed General Purpose Mobile Service. This new service would be able to offer its facilities for use by all mobile customers, including land mobile interests. Again, the Commission's intent was to create a category of service that could be flexible to respond to market demand for mobile communications. As NTIA researcher Alfred Lee explains: "Among the important, and perhaps controversial, ideas mentioned in the context of this new service are that: (1) individual licensees should decide details of service use and system design; and (2) licenses may be assigned by auction."[21] Consistent with its market-based philosophy, the FCC was moving away from time-consuming comparative hearings for license allocations to embrace license lotteries and spectrum auctions.[22]

This agency mandate to support service flexibility can also be seen in the Commission's willingness to allow, and even encourage, the sharing of frequencies among what had formerly been distinct user groups. Lee notes this changed attitude at the FCC:

> In 1984, for example, the FCC permitted the Business and Industrial/Land Transportation services operating in the 800 MHz band to share the use of those allocated frequencies, under certain conditions. SMR services, also at 800 MHz were allowed to join this sharing arrangement in 1987. Users, lacking designated channels for a particular service area, may apply for licenses in other user categories—allowing supply of channels to be adapted to market demand.[23]

In summary, the early pattern of FCC land mobile frequency allocations being defined strictly according to user groups is being superseded by experimental emphases on technology-based licensing and, even more dominant, market-based regulatory decisionmaking. The ramifications of this policy shift should include the promulgation of more spectrum-efficient technologies and the allocation of frequency supply in a manner to better match industry and community demands.

Additional Frequency Allocations

Another approach the FCC has used to help relieve congestion within the private land mobile radio service has been to identify additional spectrum resources that can be reallocated

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[21] Ibid., p. 294.

[22] Paetsch, Mobile Telecommunications in the U.S. and Europe, pp. 130, 186; and Lee, "Land Mobile Radio Services," pp. 293-294, 298.

[23] Lee, "Land Mobile Radio Services," p. 295.

from other services or developed in previously unused sectors of the ether. In fact, land mobile radio interests have had a long-running feud with TV and radio broadcasters, who they felt had been allocated a disproportionate amount of spectrum "real estate."[24] In early battles between broadcasters and land mobile groups, the television and radio leadership was able to convince the Commission to protect their spectrum holdings. However, by the late 1960's, with a majority of UHF-TV allocations lying fallow, and demand for land mobile radio channels still as fierce as ever, FCC commissioners warmed to the idea of reallocating vacant UHF frequencies. First, TV channels 14 through 20 in metropolitan markets were made available to land mobile radio interests. Soon thereafter the FCC reallocated the spectrum between 806 MHz and 947 MHz, deposing TV channels 70 through 83, broadcast auxiliary, and government services. In this one ruling alone, the FCC nearly quadrupled the amount of spectrum previously available to land mobile radio. The vanquishing of UHF-TV operators might have proceeded further had not broadcasters raised the objection that unused higher frequency television channels could be of value for introducing high-definition television in the years ahead.

In related FCC actions, the Commission sought to gain more spectrum space for mobile radio operators by encouraging innovative techniques for reducing channel spacing. At the same time that the FCC opened up frequencies for land mobile radio in the 900 MHz band, the commissioners also ruled that private mobile services included in this allocation be designed to operated on channels only 12.5 kHz wide; since the traditional channel width was 25 kHz, this effectively doubled the number of private mobile radio channels that would be created.[25] (Public safety services were excluded from this decision.) This same approach would be taken again in 1986 when the FCC allocated more spectrum space for private land mobile radio services in the 900 MHz band.[26] Just one year earlier, the FCC had given its okay for the introduction of groundbreaking private land mobile radio technologies operating on only 5 kHz channels in the 150 to 170 MHz band.

Clearly, as improvements in technology over the years have made available higher bands of previously unusable spectrum, the FCC has included private land mobile radio in its allocations of those radio frequencies. Presently, private land mobile radio services are assigned in the following frequency bands: 30-50 MHz, 150-170 MHz, 450-470 MHz, 470-512 MHz, 806-821 MHz, 851-866 MHz, 896-901 MHz, and 935-940 MHz. Yet, as this review of FCC rulings has shown, not only was the Commission looking to the higher

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[24]Courtney and Blooston, "Development of Mobile Radio Communications," pp. 626-643.

[25]Lee, "Land Mobile Radio Services," p. 294. The 25 kHz figure is cited by Paetsch, Mobile Telecommunications in the U.S. and Europe, p. 186.

[26]Ibid., p. 295.

frequency bands to secure additional channels for land mobile radio, but it was actively trying to stimulate more efficient use of that limited resource. While these regulatory changes should help to relieve some of the pressure for additional private land mobile radio frequencies, the vast popularity of these services virtually assures that spectrum congestion will continue to be an on-going problem.

Applications

The applications for private land mobile radio are virtually identical to those of its sister services—cellular telephony and paging—in the public land mobile radio class. Conventional land mobile radio can provide 2-way voice links and data communications, as well as paging service; in fact, the DOT has years of experience with this technology through its management of highway maintenance frequencies as allocated by the FCC. Additionally, parcels of spectrum have been set aside specifically for private paging alone. The newest development in private land mobile radio involves the flurry of activity among SMR operators to establish regional and national digital networks that will compete more directly with established cellular service providers by virtue of their enhanced technical capabilities and their ties into the PSTN. So, in analyzing the strengths and shortcomings of private land mobile radio, one needs to differentiate between the conventional, or more traditional, systems and the forthcoming enhanced SMR services.

Conventional Private Land Mobile Radio

Conventional private land mobile radio has been with us in its current configuration for at least 40 years. As a result, this technology has been tested and refined for decades in real-world situations. It is also a mature analog technology that has little room left for technical improvement; some would say it is antiquated in comparison to today's digital offerings. Even so, the conventional services do have some advantages over their ESMR counterparts.

Conventional land mobile radio systems do not employ cellular configurations but use powerful, single transmitters to blanket large coverage areas. Of course, this makes conventional systems less expensive to build out, but it also offers service advantages—especially for the transmission of wireless data. Unlike cellular telephony, conventional land mobile radio does not require hand-offs between cells; as a result, these is no chance that data transmissions will be scuttled by the transmission breaks that occur during cellular hand-offs. In some cases, the stronger signal employed also makes for more robust radio channels that deliver cleaner signals and better reception. (At other times, the stronger radio signals only worsen multipath interference.)

The fact that the DOT has privileges to use conventional highway maintenance frequencies is also no small convenience. If the DOT were to convert these spectrum allocations to data-only radio service, it could free up airtime that would greatly boost the signal-handling capacity of these channels. Paetsch explains that the efficiency gains resulting from a shift away from voice to strictly data transmissions makes such a change an enticing option for many operators:

> Private mobile radio systems and SMRs are fully capable of supporting low-data-rate transmissions. Many mobile radio systems are currently used to send instructions from the dispatch center (base station) to the mobile unit, followed by a short acknowledgment from the mobile unit to the base station. Indeed, it appears that for such transactions the exchange of data is more secure and spectrum-efficient, and thus less expensive than voice communications. The Yellow Cab taxi company in San Francisco, for example, shifted from voice to data mobile-radio for its dispatch service. Due to the increased spectrum efficiency of trunked mobile-data-networks, the company needs fewer radio channels, which makes the service cheaper. Furthermore, the address of a customer is printed on the screen, which greatly reduces the probability of misreading.[27]

Paetsch later goes on to point out that the data rate for analog trunked mobile radio systems, as well as conventional mobile radio channels, is 4,800 kilobits-per-second. (Digital land mobile systems will be able to support data rates up to 19,200 kilobits-per-second.)[28] Although analog land mobile channels lack the privacy and security of their digital counterparts when they are used for voice transmissions, they are not shared directly with the general public and, so, will not become inaccessible during times of emergency. Admittedly, mobile work crews may not like giving up the convenience of voice communications. However, the more these frequencies can be used for short-message paging and data communications, the greater the capacity of these radio channels will become.

Enhanced Specialized Mobile Radio

Evaluating the true capabilities of ESMR is difficult because there is little more than promotional announcements available on which to base a judgment; the only ESMR system currently in operation is owned by NEXTEL and began service in Los Angeles in January 1994. Nevertheless, some features can be reasonably assured on the basis of ESMR's cellular deployment and digital transmission standard.

If a nationwide ESMR network is in place by 1995 or 1996, it will succeed in providing what cellar operators have been unable to achieve: a digital network offering full voice, paging and data communications features along with hassle-free roaming across the country.[29] The cellular design should allow ESMR operators to reuse their limited frequencies

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[27]Paetsch, Mobile Telecommunications in the U.S. and Europe, p. 29.

[28]Ibid., p. 192.

[29]NEXTEL claims that the three largest ESMR networks will cooperatively reach 95 percent of the nation's population with mobile phone service by 1997. Coy, "NEXTEL Keeps Making the Right Connections," p. 32.

so as to provide adequate system capacity; in fact, all analysts anticipate that ESMR airtime will be cheaper than cellular. (See Table 6.3.) ESMR receivers are expected, however, to be somewhat more expensive because of their multifunctional voice and data features; they will also be bulkier and more power-hungry.

The digital nature of ESMR is central to its much-heralded capabilities. Of course, digital ESMR transmissions will be more secure from eavesdroppers. But their greater benefit is the system capacity gains they will create and the data transmission reliability they will promote. Since the ESMR signal will be packetized, cellular hand-offs will not present the challenge presented in analog cellular systems. During hand-off, the transmission of packets is simply suspended until a sure connection is made, and then message delivery continues; the shortcomings of linear isochronous transmission are side-stepped. The fact that ESMR will require the extensive construction of a cellular network, however, means that deployment of this service will come in stages as broader regions of cells are brought on-line. One can expect that only metropolitan areas and highly traveled freeway corridors will offer ESMR service, at least until the turn of the century.

Transportation-Specific Applications

In regards to the specific needs of the Washington State DOT, both conventional land mobile radio and ESMR services offer the potential to provide wireless voice, paging, and other general data-related services. The DOT already has access to some channels set aside for highway maintenance needs, but those radio channels are limited and may not be able to adequately meet all of the department's mobile communications needs. A shift to data-only transmission on those channels would boost their overall capacity, but, realistically, there may be some situations in which voice communications are both more convenient and acceptable. Also, while those highway maintenance frequencies may be able to handle many of the DOT's internal communications needs, the public currently has little awareness of their existence. Scanners costing $100 or more do allow private citizens to listen in on voice communications on those radio channels,[30] but they do not accept data transmissions. Since such scanners are only owned by a relatively small number of radio enthusiasts, the highway maintenance frequencies do not presently offer a convenient link between the DOT and the traveling public.

If OneComm does proceed to establish an ESMR system in the Seattle area and beyond, it could provide data, paging, and voice communications at airtime rates lower than those of analog cellular telephone providers. However, any cost savings could be offset by the higher cost of outfitting mobile crews with multipurpose ESMR transceivers. Also, one can

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[30]For example, the DAK Early Summer '94 catalog offers a 200-channel scanner that can pick up the highway maintenance frequencies for a cost of $249. Radio Shack's 1994 catalog lists scanners priced between $99 and $399.

	Consumer Equipment	Airtime Prices
Cellular Phone	$200-$1,000 (In reality, many phones are given away for free—or nearly free—to encourage subscribers)	$30-$140/month (service plans)
Conventional Low-band Land Mobile Radio Gear[31] (47 MHz band)	One mobile, 60 watt: (2 channel).......$525 ea. (6 channel).......$560 ea. (16 channel)......$640 ea. One base station, 60 watt: (2 channel).......$525 ea. (6 channel).......$560 ea. (16 channel)......$640 ea. Required base station conversion package: (power supply, antenna & mic)................ .$390 ea.	Not applicable since organizations are allocated these frequencies for their own internal use.
Trunked, 900 MHz, Motorola Commercial Voice Service[32]	One mobile, 30 watt: (2 channel).......$700 ea. (10 channel).......$790 ea. One base station, 30 watt: (2 channel).......$700 ea. (10 channel).......$790 ea. Required base station conversion package: (power supply, antenna & mic)................ .$390 ea.	For a single repeater:[33] $16/radio/month All five repeaters:* $18/radio/month *Only available with the 10-channel mobile radios
ESMR Phone	One estimate predicts phones costing as little as $200; another source prices ESMR phones between $500 and $700.[34] **All agree that ESMR phones will be more expensive than cellular.**	$25-$120/month **10-15% less than cellular**[35] (Some estimates predict even greater cost savings)

Table 6.3: Cellular, Conventional Land Mobile Radio, and ESMR Cost Comparisons[36]

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[31]Price estimates provided by Randy Schwardt, account representative, Ratelco Communication Services, Inc., 430 Dexter Avenue N., Seattle, WA 98109, 22 June 1994. Phone: 624-6332.

[32]Ibid.

[33]A coverage map showing repeater locations in Western Washington is included in the appendices.

[34]Kevin Maney (USA Today reporter), "MCI-Nextel Deal Could Spark Wireless Free-for-all," The Seattle Times, 1 March 1994, pp. D1-D6; and Mallory, "Phone, Pager, 2-way Radio in One Handset." The price estimate of ESMR phones costing between $500 and $700 is confirmed by Corr, "Cellular Competition to Heat Up," p. F1.

[35]McCarroll, "Betting on the Sky," p. 57; and Catherine Arnst, "Dial 'R' for Revolution," Business Week, 30 May 1994, p. 142 E4.

[36]SMR cost estimates are also gathered from: Catherine Arnst, "Anytime, Anywhere—But When?" Business Week, 4 April 1994, p. 99; Slutsker, "Look Out for the Taxi Dispatchers," pp. 86-87; Mark Lewyn,

expect that the OneComm service area will be limited to the more profitable highly-populated regions and heavily-traveled thoroughfares. Also, while any ESMR system could provide communications ties between the DOT and the driving public, it could prove frustrating if access to the ESMR network becomes limited due to heavy public usage.

Danny Briere, president of Telechoice—a consulting firm, predicts that these digital phones will have many everyday applications, including some that seem quite futuristic today:

> One possibility, from Briere: Hook the digital phone in your car to a device programmed with a map of the city and the location of parking garages. Tell the device where you're going. It would tell you which nearby garage has spaces available. Choose a garage and the device reserves a space. Drive past electronic sensors at the garage entrance and they charge the parking fee to your credit card. You never see an attendant.[37]

While technically possible, it remains to be seen whether such a scenario will prove economically feasible.

In sum, the primary advantage of any new ESMR operation in Washington State is that it will heighten competition within the mobile cellular duopoly that currently exists. That could trigger a host of innovative wireless service options and lower airtime charges. Catherine Arnst, a reporter with Business Week, has produced a simplified outline of the benefits of ESMR as it compares with cellular telephony, and cellular digital packet data (CDPD) specifically.[38] Her summary is reproduced with some slight alterations in Table 6.4.

Conclusion

With private land mobile radio, the Washington State Department of Transportation already has a technology that, with some alterations, could be all it needs to satisfy its wireless voice and data communications needs. The DOT has previously been allocated some private land mobile frequencies under the public safety provisions established by the FCC, and the Department could capitalize on those radio channels by converting their use entirely to data transfer as a way to make the most of this limited resource. The data transmitted on these frequencies could be used for most any purpose: to guide mobile highway repair crews, to display warning messages on electronic reader boards, to trigger traffic signal changes, to track shipments of hazardous waste, or to collect readings on changing freeway conditions. These

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"Welcome to the Wireless War," Business Week, Special Issue: The Information Revolution, 1994, p. 178; Pam Black, "Dialing into the Telecoms of Tomorrow," Business Week, 2 May 1994, p. 132; and Paetsch, Mobile Communications in the U.S. and Europe, p. 191.

[37]Maney, "MCI-Nextel Deal Could Spark Wireless Free-for-all," p. D6.

[38]Catherine Arnst, "Anytime, Anywhere—But When?" Business Week, 4 April 1994, p. 99.

radio frequencies have traditionally employed analog transmission technology, which is not the most spectrum efficient and is more subject to static and interference problems. But perhaps the

THE WIRELESS VOICE AND DATA RACE: TWO APPROACHES (IN SEATTLE)

McCAW CELLULAR	ONECOMM
TECHNOLOGY	
• Cellular digital packet data (CDPD): places data in electronic envelopes that are sent at high speed during pauses in cellular phone conversations.	• Specialized Mobile Radio (SMR): two-way radio dispatching service now used by taxis and trucks that OneComm is converting to digital by deploying Motorola equipment.
ADVANTAGES	
• Can be laid over existing analog cellular voice networks but is eight times faster at transmitting data. Makes possible delivery of voice and data on a single device: a cellular phone modified to receive CDPD data.	• Like CDPD, can deliver voice and data to a single device. OneComm has agreements with other providers like NEXTEL and Dial Page to build a seamless, digital national network using a single technical standard.
LIMITATIONS	
• Deployment delayed twice, with trial service in only one city (Las Vegas) so far.[39] Standards battles over CDPD service provider equipment must still be settled.	• National network does not yet exist and is expected to cost $2.5 billion to build. Conventional land mobile radios and pagers won't work with SMR.

Table 6.4: CDPD and ESMR Service Comparisons for the Seattle Metropolitan Region

greatest handicap of the highway maintenance allocation is the limited number of channels available to the DOT.

In order to squeeze the most out of its conventional land mobile radio allocations, the DOT should investigate some innovative options that perhaps have not been tried by other conventional mobile radio users. Motorola should be consulted to evaluate whether its digital ESMR equipment could be adapted to work on conventional mobile radio channels. The multifunctionality of the MIRS-based handsets associated with ESMR could help the DOT make the most of its radio channels without having to totally sacrifice voice communications.

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[39]Scott Goldman, "Seybold Offers Wireless Choices," Business Wire, 1 February 1994. Business Week reports that CDPD is presently available in three cities: Las Vegas, Dallas, and Seattle. Arnst, "Dial 'R' for Revolution," p. 142 E4.

Additionally, the application of technologies that work on bandwidths as narrow as 5 kHz—such as the FCC approved for operation in the 150-170 MHz band—should be reviewed. By dividing the DOT's present channel assignments into trunked systems employing more narrow bandwidths, even greater system capacities could be captured. Of course, each of these novel approaches will require FCC approval before they can be fully pursued. However, given the Commission's recent openness towards spectrum efficient technologies and flexible use options, these novel alternatives may not be as farfetched as they once might have been.

Increasingly, over the past decade, the FCC has taken steps to try to alleviate the shortage of spectrum available to private land mobile radio interests. As a result, the DOT should also investigate the possibility of sharing mobile frequencies with other groups that may have some excess capacity available. While such sharing arrangements might have been considered improper by the FCC in the past, they have now been identified as an innovative way to make the most of any idle radio frequencies. Additionally, considering the efficiency gains that could be made by trunking related public safety channels, the DOT should approach other public service agencies to see if a pooling of local frequencies could be profitably enhanced through the use of channel trunking technologies. Of course, any regional arrangements would have to be approved by the FCC, but the system-wide land mobile capacity gains could be of benefit to all agencies involved. Perhaps the biggest challenge to such a proposal will be the parochial interests that might prevent any cooperative agreement. If some sort of frequency sharing arrangement proves unachievable, other alternative service providers, like the General Purpose Mobile Service or traditional SMR operators, should be investigated.

Because private land mobile radio is founded on technologies that have been in service over seventy years, some critics will denigrate them as being inadequate for the future needs of the State. However, while land mobile radio technology may be "low-tech," its maturity and simplicity also makes it relatively low cost. Conventional land mobile radio may not be as "glamorous" as PCS or digital cellular, for example, but it is time-tested and readily available, and should not be casually discounted. With State-spending habits under constant public review, the availability of conventional land mobile radio frequencies that will free the DOT from having to pay additional airtime charges makes this technological option too promising to hurriedly overlook. Likewise, Motorola's 900 MHz land mobile service available commercially across much of Western Washington should be seriously considered as a much cheaper mobile communications alternative than is currently offered by cellular telephony, for instance. (See Table 6.3.)

Enhanced specialized mobile radio should come to Washington State within the next year and is advertised as offering mobile voice, data and paging options. But ESMR will be of only limited use to the DOT. First, ESMR systems will only be available in urbanized areas; rural areas will not be profitable enough to attract the interest of service providers. So, ESMR coverage will be spotty. Plus, ESMR transceivers will initially be quite expensive. Assuming that ESMR systems are built on schedule, the cost of using ESMR equipment may make it too expensive to provide wireless ties with all DOT mobile workers. Nevertheless, the arrival of ESMR to Washington State could be valuable for the competition it will promote with cellular telephone providers and other wireless operators, thereby driving down airtime prices. If OneComm follows through on its plans, multipurpose ESMR phones could prove useful, even if they are only purchased for the most critical members of the DOT staff. Additionally, given the potential of ESMR to provide paging and data communications in a single handset, the DOT could broadcast traffic advisories to the general public if interest was generated in subscribing to such a service.

Chapter VII

Radio Data Networks

Introduction

Our national wired telephone system, which was once used exclusively for voice communications, has evolved over the later half of the century to increasingly support data services that were unforeseen when the network was first built. What was once a channel to provide simple, oral messages has become a carrier of high-speed computer files and video images, as well as other "information" rendered in digital form. As a result, suggestions have been made to better adapt the wireline network to take on these new tasks: ideas like conversion to an Integrated Services Digital Network (ISDN) that can better manage these modern communications tasks, or the installation of fiber optic cable able to support data-intensive, wide-bandwidth applications. Similarly, the wireless communications environment has been increasingly shaped by demands for data communications services.

Clearly, much of the interest in mobile data communications has arisen from customers who want to stay linked with centralized computer mainframes while away from the office on business. Salesmen on the road want easy access to company data files showing the availability of equipment parts or offering customer profiles. Policemen and other public service workers in the field want to bypass time-consuming dispatch operators to directly tap into informational databases. But the demand for wireless data transmissions goes beyond these operational needs.

The constant shortage of radio frequencies makes it imperative that available channels are used as efficiently as possible, and digitized data consumes much less airtime to transmit than a comparable analog verbal message. For commercial firms and public agencies with privileges to use private radio channels, the channel capacity recovered by making a switch to all-data broadcasts can eliminate the need to supplement existing radio services. Likewise, for organizations that pay for commercial mobile service on public radio channels, a decision to replace voice with data communications can save considerable amounts of money.[1] In sum, wireless data services have become much more attractive to users on the basis of their spectrum efficiency and their resulting price advantages. Although data transmissions are not appropriate for every communications needs, their advantages in certain situations have prompted the development of networks designed exclusively for data relay. This chapter will investigate the

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[1] As was mentioned in the previous chapter, many taxicab operators are switching from voice to data dispatch in order to achieve spectrum capacity gains and cost efficiencies. Michael Paetsch, Mobile Telecommunications in the U.S. and Europe: Regulation, Technology, and Markets (Boston, MA: Artech House, 1993), p. 29.

growth and potential of radio data networks (RDN's) and their application to the needs of the Washington State DOT.

Background

The scarcity of previously unassigned radio spectrum in the United States has, so far, limited the establishment of domestic radio data networks. Two such networks—known as ARDIS and RAM Mobile Data—have been allocated frequencies in the 800 MHz and 900 MHz bands and have managed to gain a tenuous foothold in the wireless marketplace.[2] Other data networks have been planned for deployment in the unlicensed frequencies set aside for spread spectrum technologies, especially between 902 and 928 MHz.[3] But these proposed RDN's are at an even earlier stage of development than either the ARDIS or RAM systems.

As the wireless marketplace continues to mature, the current promotional hype over wireless data technologies will give way to factual evidence of real-world performance and recognition of customer preferences. As a result, some of the mobile communications "wonders" that look so promising today will certainly fall by the wayside to be overtaken by those technologies that are best able to gain advantage with consumers. But, regardless of how these upstart data networks fare, they all illustrate an increased willingness on the part of the FCC to accommodate innovative mobile communications technologies—despite cramped space in the ether.

Repeating a regulatory pattern mentioned in other chapters, the Commission's present encouragement of varied technological offerings demonstrates its own reluctance to supersede marketplace decisions with governmental decrees. It also indicates a more flexible regulatory posture in that traditional barriers between established service categories are being relaxed and competition among providers in previously distinct service classes is now actively promoted.[4] The FCC's ultimate goal, as evidenced through its efforts to introduce radio data networks into the wireless environment, is to increase customer options and decrease customer costs—all the while lessening governmental influence in the selection of marketplace "winners" and "losers."

ARDIS

The first RDN to be established in the U.S. was the Advanced Radio Data Information Service, commonly known as ARDIS (Lincolnshire, IL). The ARDIS system grew out of a wireless data network that Motorola started building specifically for IBM around 1983. IBM wanted such a network to permit internal data communications with its nationwide staff of field

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[2]The ARDIS and RAM systems employ specialized mobile radio (SMR) frequencies in the 800 MHz and 900 MHz bands as the radio carriers for mobile data transmissions. Dana Blankenhorn, "Motorola Buys-out IBM ARDIS Stake," Newsbytes News Network, 7 July 1994.

[3]These frequencies were first discussed in the earlier chapter on cordless telephony because of their potential usefulness for short-range cordless phone equipment. See Table 3.1.

[4]Paetsch, <u>Mobile Telecommunications in the U.S. and Europe</u>, p. 194.

technicians. In 1990, however, Motorola and IBM decided to expand the private network and makes its services available to other business firms with similar needs to stay in touch with mobile workers. A beneficiary of nearly seven years of "in-house" development, ARDIS began service with radio sites already constructed in over 400 cities and with 20,000 IBM and Rolm field employees already on-board. Today the ARDIS network estimates subscribers numbering between 33,000 and 50,000.[5] Most recently, in July of 1994, Motorola bought out IBM's half-stake in the ARDIS enterprise.[6]

Regarding its technical make-up, the ARDIS system employs between one and three duplex channel pairs in each of its service areas; these duplex channels are located in the 800 MHz band. The duplex channels consist of two 25 kHz channels spaced 45 MHz apart.[7] When the system was designed, a very deliberate decision was made to insure that ARDIS signals would be able to penetrate deep inside high-rise buildings. Since this RDN was expected to link IBM's regional headquarters with field employees fixing customers' office equipment, it seemed obvious that allowances would have to be made for "shading"—or the blocking of radio signals by exterior and interior building panels. Motorola engineers met this requirement by structuring the ARDIS network according to a cellular transmission scheme, but they deliberately overlapped the cells in a way to guarantee coverage in challenging urban environments.[8] (See Figure 7.1.) The resulting pattern of redundant transmitter/receivers virtually insures that the network will be able to detect in-coming messages from subscribers. One drawback, however, is that some of those same duplicate transmitters must be switched off at times when out-bound messages are broadcast to mobile units in order to prevent signal interference. This factor reduces the system's spectrum efficiency somewhat, but this was a sacrifice deemed necessary to improve reception by mobile users in metropolitan areas.

Initially ARDIS supported data transmissions of 4.8 kilobits-per-second, but it is upgrading its equipment in 30 of its largest metropolitan service areas to allow data rates up to 19.2 kilobits-per-second;[9] with allowances made for error correction, that results in an actual throughput of roughly 8 kilobits-per-second. This imminent upgrade of the ARDIS network has not been well explained in the popular press. As Senior Vice President Thomas Berger detailed during a telephone interview, ARDIS will not be replacing its earlier 4.8 kbps radio

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[5]ARDIS history gleaned from information supplied by: Ira Brodsky, "Wireless Data Networks and the Mobile Workforce," <u>Telecommunications</u>, December 1990, p. 31; and Peter Rysavy, "Separating the Reality from the Hype," IEEE Wireless Data Networks Seminar, Seattle Pacific University, Miller Science Learning Center, 8 February 1994.

[6]Blankenhorn, "Motorola Buys-out IBM ARDIS Stake."

[7]Brodsky, "Wireless Data Networks and the Mobile Workforce," p. 31; and Paetsch, <u>Mobile Telecommunications in the U.S. and Europe</u>, p. 194.

[8]Brodsky, "Wireless Data Networks and the Mobile Workforce," p. 31.

[9]The ARDIS technology used to support 19.2 kilobit-per-second data rates is reportedly called "RDLAP." It is unclear whether that is an acronym. Blankenhorn, "Motorola Buys-out IBM ARDIS Stake."

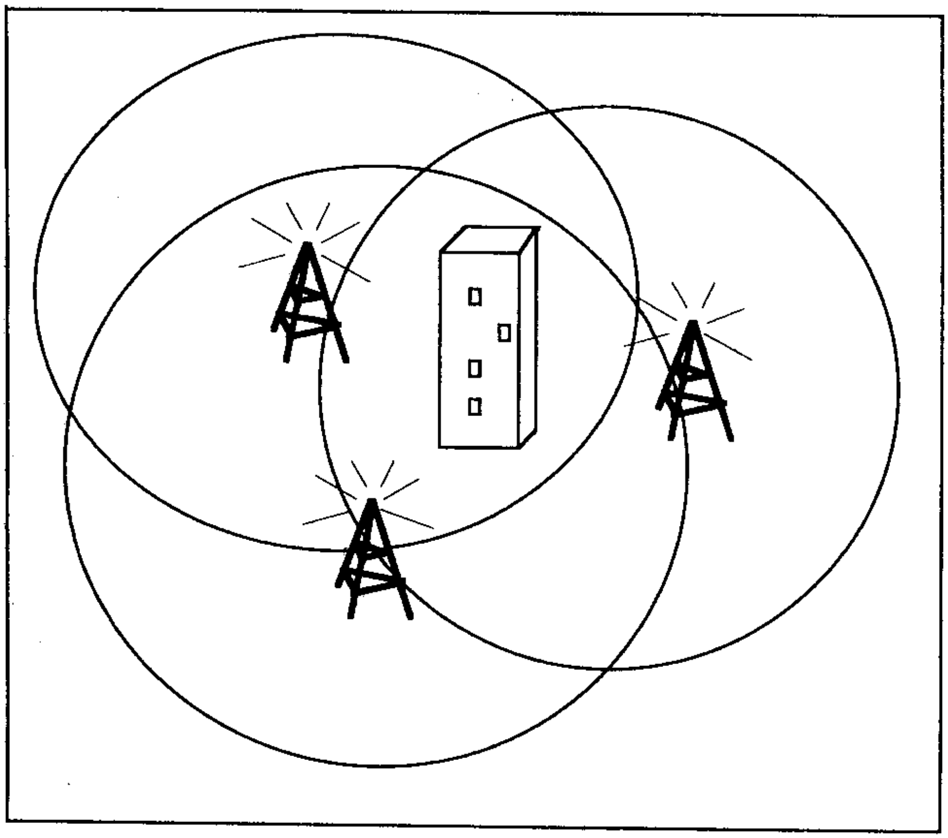

Figure 7.1: The ARDIS Network's Overlapping Cellular Design[10]

channels but will be supplementing them with additional channels able to support the higher data rate.[11] Thus, when a customer calls, the system controller will determine which radio channel is assigned to handle the transmission. Since charges for the use of ARDIS are based on the amount of data sent and not on the length of time of the transmission, assignment of a call to either faster or slower radio channels will not alter customer costs. The network will initially be upgraded in New York City, San Francisco, Washington, DC, Los Angeles, Atlanta, Detroit, and Las Vegas. Berger further explained that if Seattle shows significant population growth, the ARDIS system there might be upgraded sometime in 1996.

The common air interface (CAI) used by ARDIS to connect base stations with mobile units is proprietary. Nevertheless, it is possible for subscribing companies to use dedicated phone lines to interconnect ARDIS with their own internal computer networks that run on a

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[10]Figure adapted from Brodsky, "Wireless Data Networks and the Mobile Workforce," p. 31.

[11]Telephone interview with Thomas Berger, senior vice president, ARDIS, on July 12, 1994. Phone: (708)913-1215.

variety of other popular communications protocols, including: X.25 Asynch, SNA 3270, Bi-Synch 3270, and SNA LU 6.2.[12]

RAM Mobile Data

The only other RDN that is currently a serious contender with ARDIS is the RAM Mobile Data network (Woodbridge, NJ), sometimes also referred to as Mobitex. The RAM network is based on the Mobitex system design conceived by Ericsson and established in radio data networks across Scandinavia and in the U.K. The U.S. network, however, is being built by RAM Broadcasting and BellSouth Mobile Systems. This ARDIS rival appeared on the scene in 1989 (with BellSouth joining RAM in 1992) and has reportedly attracted between 5,000 and 15,000 subscribers so far;[13] obviously both ARDIS and RAM are not as well established as are cellular telephone providers. Nevertheless, RAM now claims to have base stations available in more than 210 metropolitan areas scattered across the country, and along major transportation corridors, too.[14]

One advantage claimed by RAM is that it has significantly more channel capacity than ARDIS. The RAM network employs between 10-to-30 radio channels having a bandwidth of 12.5 kHz in each metropolitan service area (MSA); that compares favorably against ARDIS' one-to-three channels per MSA.[15] The mobile channels are located between 896 and 902 MHz while the base station channels fall between 935 and 941 MHz.[16] Even with this greater potential capacity over ARDIS, the RAM network could presently only support a customer base of 1 million users[17]—considerably less than the 13 million callers using cellular phones today.

There are other factors, however, which further differentiate RAM from ARDIS. First, while RAM also uses a cellular network design, its coverage inside buildings is reported to be inferior to that of ARDIS;[18] this may be because RAM has geared its data system to the needs

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[12]Paetsch, Mobile Telecommunications in the U.S. and Europe, p. 194.

[13]Background information on RAM Mobile Data can be found in: Andrew Seybold, "CDPD Watch, January 1994," Andrew Seybold's Outlook on Mobile Computing 2 (January 1994): 2; Paetsch, Mobile Telecommunications in the U.S. and Europe, pp. 194-195; and Rysavy, "Separating the Reality from the Hype."

[14]Janet Boudris, "Corporate Backgrounder," Informational Handout (Woodbridge, NJ: RAM Mobile Data, April 1994), p. 4.

[15]ARDIS is reported to be making efforts to acquire additional radio channels to boost its system capacity. See: Greg Garry, "RAM Plans U.S. Wireless Network," Digital News & Review, 23 November 1992, p. 7; and "Network Update," On the Air, (Corporate Newsletter) (Lincolnshire, IL: ARDIS, Fall 1993), p. 5.

[16]David A. Harvey and Richard Santalesa, "Wireless Gets Real," BYTE, May 1994, p. 92. Paetsch reports slightly different frequencies for RAM operation, stating that the network: "...uses 10 to 30 channels in the 935-940 MHz band (base station), and 896-901 MHz frequency band (terminal equipment), respectively." Paetsch, Mobile Telecommunications in the U.S. and Europe, p. 195.

[17]Garry, "RAM Plans U.S. Wireless Network," p. 8.

[18]Charles Bruno, "Mobile Nets: Strings Attached," Network World, 5 July 1993, p. 24; Table 1 in the article by Brodsky," Wireless Data Networks and the Mobile Workforce," p. 34; and Catherine Arnst, "Dial 'R'

of mobile professionals working away from the office rather than the communications demands of service technicians, who regularly work deep inside buildings. In fact, several analysts report that ARDIS has historically been interested in attracting the business of only large service and fleet accounts and, so, ignored small companies and individual customers.[19] That company-wide predisposition may be changing, however, due to competition from RAM.[20]

A second key difference is that RAM transmissions support a data rate of 8 kilobits-per-second; faster than ARDIS in most locales, but slower in many of the largest cities. (A data rate of 8 kilobits-per-second translates into an effective throughput of about 4.8 kilobits-per-second.) Some of the more significant similarities and differences between these two RDNs are summed up in Table 7.1.

Packet versus Circuit-Switched Networks

For all their differences, ARDIS and RAM share one very important feature—a characteristic they also have in common with Cellular Digital Packet Data (CDPD): they are all packet data networks. In this way they are different from traditional communications networks—like wired and cellular phone systems—which have long been "circuit-switched" services. With circuit-switched systems, the electrical signal is provided a dedicated channel (or "circuit") in the airwaves or along telephone wires; the transmission, which has commonly been analog-based, occurs in a continuous, linear stream.[21] This is not the most efficient method of signal relay since the dedicated channel remains allocated to one pair of users even though there may be countless pauses in the conversation during which the channel's full bandwidth goes unused. Packet data systems have supplied a means to take advantage of such transmission lulls.

In explaining the operation of packet data systems, an analogy is often made with the delivery of mail.[22] Aural or visual information is first digitized and then broken into groups of bytes called packets. These packets can be compared to envelopes that contain information and

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for Revolution," Business Week, 30 May 1994, p. 142 E4. It should be noted that Andrew Seybold makes no differentiation regarding in-building performance in his practical testing of both systems: Seybold, "CDPD Watch, January 1994," pp. 6-7.

[19]Seybold, "CDPD Watch, January 1994," p. 3; James Daly, "Move Over, Dick Tracy," Forbes ASAP, 13 September 1993, p. S49.

[20]The recent buy-out of IBM's 50 percent share in ARDIS will probably speed along this transition. As one reporter has noted: "...IBM [had] favored a more vertical market approach, Motorola a more aggressive horizontal market approach. The new transaction will probably end the tension." Blankenhorn, "Motorola Buys-out IBM ARDIS Stake."

[21]See: Paetsch, Mobile Telecommunications in the U.S. and Europe, pp. 67-69; Steven J. Bell, "How Much Longer Before It All Works: What Online Searchers Should Know About Wireless Data Communications," ONLINE, January 1994, pp. 47-48; and Eric Jensen, "Wireless Data Networking: A Few Strings Attached," Network World, 18 October 1993, p. 41.

[22]See, for instance: Bell, "How Much Longer Before It All Works," p. 47; and Arnst, "Dial 'R' for Revolution," p. 142 E4.

	ARDIS	RAM Mobile Data
Operators	Motorola	RAM Broadcasting & BellSouth Mobile Systems
Year Initiated	Private network, 1983 Commercial network, 1990	1991
Frequency Allocation	800 MHz band	800 & 900 MHz bands
Channel Width	25 kHz	12.5 kHz
System Capacity	1-3 radio channels/MSA	10-30 radio channels/MSA (est. 19 times greater capacity)
Coverage	400 major metropolitan areas	100 major metropolitan areas
Base Stations	1,300	890
Subscribers	Between 33,000-50,000	Between 5,000-15,000
Data Transmission Rates	4.8 kbps generally; 19.2 kbps in 30 largest MSA's	8 kbps
Data Security	Digital packet data & dynamic channel selection hinders unauthorized reception	
Building Penetration	Excellent	Good; much better than cellular[23]
Rural Coverage	Virtually non-existent	
Nationwide Roaming	Yes, both systems	
Common Air Interface	Proprietary standard	Open standard
Marketing	Vertical market of field service workers & delivery fleets	Horizontal market of white-collar workers and professionals
Customer Equipment	Motorola InfoTac Modem, $1,000	Ericsson Mobidem, $795[24]

MSA = Metropolitan Service Area

Table 7.1: ARDIS and RAM Mobile Data Service Comparisons

(continued on the next page)

[23]For a comparison of the performance of ARDIS, RAM and analog cellular systems inside buildings, see: Seybold, "CDPD Watch, January 1994," pp. 6-7.

[24]A special limited-time offer by Wireless Telecom, Inc. includes the Ericsson Mobidem and 12 months of RadioMail e-mail service for $399. Dana Blankenhorn, "WTI Signs Master Agreement With RAM," Newsbytes News Network, 21 June 1994; Dana Blankenhorn, "WTI Announces Lower-cost Two-way Wireless Bundle," Newsbytes News Network, 1 June 1994, and Dana Blankenhorn, "Correction—WTI RadioMail Bundle Includes Mobidem," Newsbytes News Network, 2 June 1994.

	ARDIS	RAM Mobile Data
Airtime Costs	Registration Fee: one-time $50 charge/terminal Packet Message Charge:[25] ea. 240 character block @ 8¢ (peak hours, 7 am - 6 pm) ea. 240 character block @ 4¢ (off-peak hours, 6 pm - 7 am) PLUS, a character charge: $0.0004/ea. character or 4¢/100 characters Unlimited Messaging: $80/month/terminal Host Connection Charge: $1,395/month	Registration Fee: one-time $50 charge/terminal Subscription Fee: monthly $25 charge/terminal Packet Message Charge:[26] 218-271 characters @ 8¢[27] (peak hours, 6 am - 8 pm) 218-271 characters @ 4¢ (off-peak hours, 8 pm - 6 am, plus all day Sat. & Sun.) Unlimited Messaging: $135/month/terminal Host Connection Charge: $100/month (X.25 @ 9600 bps)
E-mail Connectivity	Yes, through RadioMail gateway[28]	
Clients	Wilson Sporting Goods; Otis Elevator; Avis; AT&T Global Info. Systems; Sheriff's Office, NYC; Pitney Bowes	Master Card; Conrail; Boston Edison; GE Consumer Service; Chicago Parking Authority; Physicians Sales & Service

Table 7.1 (cont.): ARDIS and RAM Mobile Data Service Comparisons

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[25]Data is sent over the ARDIS network in 240-character blocks. Each block is called a message unit.

[26]McCaw Cellular reportedly claims that CDPD users will pay an average of $35 per month for service. However, until CDPD is tested in real-world operations, that price figure should be considered as a low-end estimate, at best. Joanie Wexler, "Speedy Wireless Net to Go Live in Silicon Valley," Network World, 20 June 1994, p. 38

[27]Higher and lower charges are possible depending on the number of characters transmitted; these figures were chosen for their ease of comparison with ARDIS prices.

[28]"RadioMail, based in San Mateo, Calif., is a wireless E-mail service bureau that links users on the ARDIS and RAM Mobile Data networks to all major E-mail services in the wired world, including MCI Mail, CompuServe and Internet. Its advantage? 'RadioMail shields E-mail systems from the wireless network mess,' says [founder and chairman, Geoff] Goodfellow." In essence, RadioMail is a gateway between RDN's and countless e-mail systems. See: Robert X. Cringely, "A Goodfellow to Bet On," Forbes ASAP, 13 September 1993, p. S88.

are identified with special addresses for the sender and the receiver. The addresses associated with each packet identify the information inside and make it possible for the receiving device to reconstruct all of the small "envelopes" of data into the coherent, complete message that was originally sent. Thanks to this architecture, if the chain of data packets uses different radio channels to arrive at the same ultimate destination, a packet receiver is able to reconstruct the message as it was intended. Packet data networks can even permit the joint transmission of unrelated packets from different senders along a common channel because the unique packet identifiers will make sure that they are routed correctly and reassembled in the proper order. Hence, any gaps in message transmissions are simply "filled" with packets from other simultaneous "conversations."

As an article in BYTE explains when describing the RAM packet network, various types of system data are included with each packet of "pure" information to guard against errors in the process. These address and error correction codes are to blame for lowering the effective data transmission rate. So, when sending a data message on the RAM system, for instance:

> [Your] modem establishes a link with your computer [or PDA, or terminal], and as the message text arrives from your system, the modem breaks it into packets with a maximum size of 512 bytes. Each packet is preceded by a header that can be up to 33 bytes long. The header contains a 3-byte sender code, a 3-byte addressee code, a 1-byte flag, a 1-byte packet-type marker, a 22-byte space for other addresses, and finally, a 3-byte network time stamp...
>
> As it assembles the packet, the modem checks signal strength, verifies the connection to the base station, and transmits at 8 Kbps. At the base station, the received packet is verified, and a receipt verification is transmitted back to the Mobidem. From the base station, the header information is analyzed, and the data is relayed to a local switch—usually over a wired network or system. From there, it passes to a long-distance carrier switch that confers with a national control center. Here, RadioMail's system tallies billing charges and routes the complete final message through its Internet gateway to CompuServe's Internet gateway for delivery.[29]

(Incidentally, the 512 bytes of a single RAM Mobile packet can deliver the equivalent of three-quarters of a page of text.)[30]

The newer wireless communications systems all employ packet transmission designs—and many older systems are being converted to packet standards—because this new approach, aided by advances in digital encoding, has key service advantages over past circuit-switched models. Packet networks have been found to be more robust; data tend to maintain their integrity better during transmissions and are automatically re-transmitted if there is interference to the signal.

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[29]Harvey and Santalesa, "Wireless Gets Real," p. 92.
[30]Boudris, "Corporate Backgrounder," p. 3.

Strictly speaking, packet networks do not support hand-offs between cells—at least not in the manner employed by analog cellular systems.[31] Since each packet en route is treated as a "discrete event," system intelligence simply sends the packets on whichever channel presents the strongest transmission link at the time the message is relayed, and the packets may be split up among several radio channels as is seen fit. The end result bares resemblance to a cellular hand-off in that different cells might be called into action, but the chances of a "dropped call" are dramatically reduced.[32] Header information included with each data packet insures that the string of packets are reassembled in the proper sequence upon arrival.

These newer networks are also, by their nature, more secure because the packets require more sophisticated equipment to intercept and reproduce the message-carrying signal than did the older analog, circuit-switched systems.[33] As Ira Brodsky, a wireless consultant, has explained:

> This is because with circuit-switching, users establish a constant connection for the entire period of time during which a transmission traverses the channel. This gives an intruder time to pick up on a sequential, cohesive conversation.
>
> With wired and wireless packet-switching schemes, on the other hand—including X.25, frame relay, **Cellular Digital Packet Data (CDPD), the ARDIS protocol, and RAM Mobile Data's Mobitex protocol**—transmissions are chopped into snippets of data or packets, for transmission in the most efficient manner. They are then reassembled at the receiving end.
>
> This process makes it difficult for hackers to grab orderly, meaningful packets...[34] (Emphasis mine.)

With scanners on the market to receive many private land mobile radio channels—and even old television sets able to tune in cellular phone calls broadcast over what were previously UHF channels—many analog-based wireless channels provide listening entertainment for radio buffs. However, many of the newly-implemented packet networks assign broadcast channels dynamically, which means that the packets are shuttled through whatever radio channel is most available at the time. Plus frequency-hopping systems are constantly moving the packets between several different channels. This makes it hard for eavesdroppers to pinpoint specific conversations. When the digital signal is encrypted, as well, network security is further enhanced. (See Table 7.2.)

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[31] Telephone interview with Thomas Berger.

[32] As least one source claims that the RAM network performs "hand-offs" between cells, but this may be simply a loose interpretation of the term as it is used in the case of cellular telephony. See: John P. Mello, Jr. and Peter Wayner, "Wireless Mobile Communications," BYTE, February 1993, p. 148.

[33] "The least secure transmissions today are those running on analog circuit-switched cellular nets—as exemplified last year when members of the British royalty were overheard in the now infamous lovelorn cellular voice conversations that were splashed across the tabloids." Joanie Wexler, "Wireless Security Worries Wane," Network World, 30 May 1994, p. 30.

[34] Ibid.

WIRELESS SECURITY

NETWORK TYPE	INHERENT SECURITY
Analog, circuit-switched cellular (voice & data)	• No security.
Digital, circuit-switched cellular (voice & data)	• Requires sophisticated hacker able to modify scanner for different digital standards. • Encryption built into some digital cellular phones.
CDPD (voice & data)	• Requires sophisticated hacker and modified scanner. • RSA encryption built in. • Transmissions are broken into small packets that hop channels, making it nearly impossible to follow all packets of a given communication.
ARDIS RAM Mobile Data (data only)	• Requires sophisticated hacker and modified scanner. • Like CDPD, transmissions are broken into small, hard-to-follow packets.

Table 7.2: Security Features of Current and Future Wireless Communication Systems[35]

Pricing Per Packet

In addition to the features of improved transmission quality and enhanced message security, packet data networks offer the potential advantage of airtime billing per packet instead of charges based on the length of the call. For example, it can take between 15-to-20 seconds for a cellular network to establish connections as you prepare to transfer data files—time for which the caller is billed; there is also time taken up by cellular modems as they synchronize.[36] These expensive seconds are eliminated with billing based on the actual number of data packets transmitted. If most data files are short—such as with e-mail messages—communicating over packet data networks can prove to be more cost effective. In fact, for any message under 2,000 bytes, it is much less expensive to use a packet-switched data network than a circuit-switched system.[37]

Experience indicates that the cost of sending one kilobyte of data over the ARDIS or RAM networks is between 25¢ and 50¢. As the length of the data files to be broadcast expands, however, the advantage swings back to circuit-switched cellular and its per-minute billing approach. With some cellular modems able to transmit at 50 kilobytes-per-minute, each

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[35] Adapted from: Wexler, "Wireless Security Worries Wane," p. 30.

[36] Eric Jensen, "The Price of Wireless Freedom," Network World, 18 October 1993, p. 42.

[37] "Spectrum-efficient Mobile Data," Mobile and Cellular 4 (February 1993): no page number given, promotional reprint from Pinpoint Communications, Inc., Richardson, TX.

kilobyte of a lengthy data transfer can cost only a few cents to relay.[38] RDN's are using special promotions, like attractive rates for unlimited messaging, to try and counter the advantage analog cellular has for the transmission of longer data files.

One disadvantage of digital packet networks remains the steep "fade margins" that scuttle transmissions in outlying areas. A characteristic of analog signals is that they tend to decay more slowly as they reach the furthermost bounds of their broadcast range. This make it possible for rural TV viewers, for instance, to still watch programming from urban areas, even though their picture may be a little "snowy." When high-definition television (HDTV) arrives, however, viewers in the hinterlands will find that they can no longer receive the same range of channels that they once could; that is because the high-tech digital TV signal will decay much more rapidly as it attenuates. The same is true for packet data systems like ARDIS and RAM: the margin of error for acceptable service becomes a more finely defined boundary. Since these packet networks are emphasizing metropolitan areas for their early expansion, it may be years before these services extend their reach beyond the suburbs.

The Ricochet Network

In addition to ARDIS and RAM, there are at least two other technologies that have the potential to support wireless data services: one is called Ricochet[39] and the other ARRAY. Both of these systems take advantage of the unlicensed frequencies between 902 MHz and 928 MHz set aside by the FCC for spread-spectrum applications.[40] On the one hand, the use of these unlicensed frequencies gives the systems tremendous flexibility, since no FCC approval is required prior to their deployment. Bob Dilworth, the chief executive officer of Metricom—which is developing the Ricochet network—has said of the unlicensed frequencies: "We've found the band to be quite empty and discovered that spread-spectrum really works..."[41] It remains to be seen how much of a handicap these shared frequencies might become, however, as a variety of industrial, medical and scientific manufacturers take advantage of these open radio channels to produce a host of wireless products.

The Ricochet technology was first developed for utilities like Southern California Edison and waste water treatment plants that demanded low-cost but high-capacity data communications. Metricom decided to base Ricochet on a spread-spectrum scheme.[42] With a

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[38]Jensen, "The Price of Wireless Freedom," p. 42.

[39]Ricochet is known formally as the Ricochet Micro Cellular Data Network.

[40]The establishment of this unlicensed band was previously mentioned in Chapter 3 covering cordless telephony and was highlighted in Table 3.1 covering Part 15 Frequency Bands.

[41]Dana Blankenhorn, "More on Metricom's Frequency-Hopping Network," Newsbytes News Network, 16 June 1994.

[42]The idea for spread-spectrum technology reportedly was conceived by an Italian signal corpsman during the 1920's; it was patented in 1940 by movie actress Hedy LaMarr, whose interest in the technology allegedly stemmed from discussions with her husband, a soldier, about its military usefulness. Her patent has

spread-spectrum system, the allocated frequencies are not broken into individual, smaller channels, but all users simultaneous share what is essentially one broad channel. An advantage of this approach is that callers are never entirely blocked from access to the network. However, as the number of customers calling at one time gets too great, the general quality of the connections is degraded correspondingly; this leads customers to shorten their calls or cues them to wait for a different time to use the network.[43]

Unlike the code-division multiple-access (CDMA) standard being developed by Qualcomm for digital cellular telephony, which uses a direct sequence spread-spectrum implementation, Ricochet employs a frequency-hopping spread spectrum design.[44] As researcher Michael Paetsch explains: "In a frequency-hopping system, the position of the carrier frequency is shifted pseudo-randomly by the frequency synthesizer over the spread [wideband] bandwidth."[45] Again, this approach allows all customer calls to be "spread" over the entire frequency range allocated for the service. Frequency hopping also improves the security of the transmission, since it would be virtually impossible for outsiders to follow the random pattern of frequencies used over the course of a conversation.

Another innovation incorporated into the Ricochet technology is the implementation of something called a "mesh" network.[46] Unlike some communications networks which are hierarchical—with most of the system intelligence centered at one, or a few, strategic control points—this newer mesh network distributes intelligence equally throughout the system.[47] As a result of this configuration, Ricochet message transmissions can run faster without tying up the rest of the network, since all messages do not have to travel back and forth to the central routing hub.[48] As an added plus, Ricochet subscribers within range of each other can send messages directly to each other's modem without need for the network's scattered base stations; when this occurs, the customers do not incur any network charges. If Metricom's service has a weakness, it appears to be that <u>transmissions cannot be made from moving vehicles, since Ricochet cell sites cannot hand-off calls to each other</u>.

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since expired. Paetsch, <u>Mobile Telecommunications in the U.S. and Europe</u>, p. 77; and Blankenhorn, "More on Metricom's Frequency-hopping Network."

[43]Paetsch, <u>Mobile Telecommunications in the U.S. and Europe</u>, pp. 77-78.

[44]Blankenhorn, "More on Metricom's Frequency-hopping Network."

[45]Paetsch, <u>Mobile Telecommunications in the U.S. and Europe</u>, p. 78.

[46]Wexler, "Speedy Wireless Net to Go Live in Silicon Valley," p. 38; and Blankenhorn, "More on Metricom's Frequency-hopping Network."

[47]ARDIS is an example of an hierarchical network in which all transmitted messages have to be relayed through one of three central switching centers located in either Los Angeles, CA, Chicago, IL, or Lexington, KY. Garry, "RAM Plans U.S. Wireless Network," p. 8.

[48]There are two other types of networks: "One is a bus network, like Ethernet—everyone is on a shared line. Another is a star network, like [that used with] wireless telephones. In a star you have a master-slave [relationship] where everyone goes through the master." Blankenhorn, "More on Metricom's Frequency-hopping Network."

The Ricochet base stations are small and do not require the transmitter towers used in cellular telephone systems; in fact, the base stations appear to be predecessors of the sort of equipment anticipated for PCS. They are roughly the size of a cereal box and can easily be affixed to lamp standards, building exteriors, or existing telephone poles. Their configuration can also be changed with relative ease; something not possible with cellular transmitter towers. Plus additional access points can be quickly installed as demand increases. The base stations have access to 163 radio channels, which are reportedly able to accommodate at least 200 simultaneous callers.[49] Perhaps the most dramatic feature of the Ricochet network is the data transmission speed it allows: 77 kilobits-per-second—more than four times faster than the 19.2 kilobits-per-second available on the fastest ARDIS regional systems.

Just as Ricochet beats ARDIS, RAM, and CDPD on data transmission speed, it also offers lower prices. Charges are based on the transmission speed required by the client: 4.8 kilobit-per-second service will cost only $3 a month; 38.4 kilobit-per-second service will cost $30 per month.[50] For companies or agencies wanting wireless fleet communications, Metricom plans to offer bundled prices for modems and service contracts, as well as flat-rate Internet access. Firm figures on pricing plans for large accounts are not yet available.

Customers can access the network using their PC and a wireless Ricochet modem, costing $495. Ricochet will also make possible direct access to Internet or to any Local Area Network (LAN) based on the Transmission Control Protocol/Internet Protocol (TCP/IP). Dilworth explains how the system operates:

> ...We hang a radio every square mile. When we hang it we give each radio a geographic address, longitude and latitude. When that radio turns on it looks for neighbors, and exchanges geographic data. Now it knows where all the nearby radios are. When you're sending a message across the city, since we can only use one watt of power [on the unlicensed frequencies], that has to hop several times to get where it wants to go. The first [base station that] gets it sees it's for a distant address, and sends it in that direction. It moves across the city, hopping radios—we have a patent on that concept.
>
> ...We'd expect you to go on a wireless network and hop 3-4 times, then drop to a wired access point. We'd interface those wired access points at the frame relay level.[51]

Ricochet systems went on-line at corporate and academic campuses across the Silicon Valley in early July. Clients include: Apple Computer, Compaq Computer, Microsoft, Lotus, Hewlett-Packard, Stanford University, the City of Cupertino, and the company headquarters

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[49] Wexler, "Speedy Wireless Net to Go Live in Silicon Valley," p. 38.

[50] Ibid.; and Dana Blankenhorn, "Metricom Announces Low-cost Wireless Network," Newsbytes News Network, 14 June 1994.

[51] Blankenhorn, "More on Metricom's Frequency-hopping Network."

for Visa. Visa is using the Ricochet network for 4.8 kbps data transmissions in order to speed up point-of-sale credit verification.

Since most mobile workers never travel far beyond their immediate communities, Metricom expects that the local mobility it can provide will be popular with employees on the go.[52] Plans are set for similar Ricochet networks to be established in Seattle, Houston, and Boston before the end of 1994. The company optimistically hopes to have other Ricochet networks running in as many as 30 major cities before 1997.[53] Although Metricom has far to go in order to catch up with ARDIS and RAM, its technology has many advantages that could help it gain swift customer acceptance and nationwide expansion.

The ARRAY Network

Little information is available in the industry and research literature on a second spread-spectrum system, the ARRAY network, which claims equally impressive transmission speeds and cost savings as the Metricom service. ARRAY is being promoted by its designers at Pinpoint Communications (Richardson, TX).

ARRAY operates in the 902-928 MHz service class, like Ricochet. The system is also known as the Intelligent Mobile Data Network (IMDN) because it not only supports 38.4 kilobit-per-second data transfer rates but also incorporates Automatic Vehicle Location (AVL) technology that can determine a mobile's position with a margin of error of only 50 feet.[54] This AVL system triangulates any vehicle's position on the basis of calculations taken during packet data transmissions. If the claims made by Pinpoint Communications are true, ARRAY's AVL performance would be superior to that of Loran-C equipment, the Global Positioning System (GPS), or traditional radio techniques. Such a feature could be of real service to the Washington State DOT with its need to track road repair and snow plow crews, for example.

Promotional material from Pinpoint Communications also asserts that the ARRAY system can support over 1 million customers in each metropolitan area with inexpensive data service; charges are estimated at less than one cent for a 22-character data byte packet.[55] Regarding equipment costs, the IMDN wireless modem is said to cost "about $300."[56] The

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[52] "According to BIS CAP International, a Norwood, Mass.-based research firm, only 13% of the 27 million U.S. mobile workers today leave the metropolitan area." Wexler, "Speedy Wireless Net to Go Live in Silicon Valley," p. 38.

[53] Dana Blankenhorn, "Metricom Announces Low-cost Wireless Network," Newsbytes News Network, 14 June 1994.

[54] Charles L. Taylor, "Public Safety Intelligent Mobile Data Communications," APCO Bulletin 58 (May 1992), promotional reprint.

[55] Pinpoint Communications, Inc., "IMDN: What It Is; IMDN: What It Isn't," (Promotional Materials) (Richardson, TX: Pinpoint Communications, Inc., no date given); "Intelligent Mobile Data Networks: A Revolutionary Way to Locate Vehicles and Communicate Mobile Information to Drivers," Promotional Report (Richardson, TX: Pinpoint Communications, Inc., no date given).

[56] Charles Taylor, "Traffic Congestion and Navigation Challenges," The Urban Transportation Monitor, 24 December 1992, Promotional Reprint.

company explains that "Mobile data communications market research has demonstrated a greater need for inexpensive short messages (i.e. 'send tow truck,' or 'delivery complete, next location?') rather than long messages in combination with radio location in a mobile environment."[57] Hence, Pinpoint Communications developed its technology with an intent to provide emergency highway services, traffic information reporting, routing information, vehicle security, fleet management, and improve public service response times. These are all features that could be great value to the Washington State DOT.

Pinpoint Communications' stated goal, expressed during the early 1990's, was to provide immediate IMDN service in 50 of the largest U.S. metropolitan areas. The fact that its technology is not receiving the coverage in the popular press that is being given to Ricochet suggests that the company is having trouble finding investors or is experiencing technical hang-ups. Requests from the authors for more information has yielded little response. Nevertheless, even if the ARRAY Network is not as technically competent as was claimed, the potential combination of two-way data communications and AVL would be of value to the State's DOT and merits further investigation. If the technology proves worthwhile—and cost effective—the State might consider developing its own ARRAY Network; on the other hand, the claims made by Pinpoint Communications might prove to be vastly exaggerated.

Applications

So, what is the usefulness of radio data networks? It is important to emphasize, at this point, that RDN's have specialized their service by dropping voice capabilities in order to emphasize their data transmission features—all so that they can better manage tasks that are poorly handled by traditional wireless media geared to aural communications. RDN's are more spectrum efficient than previous cellular and land mobile radio technologies, and that, in turn, promises financial savings to customers. However, these networks have only been available for general use for five years, so they still don't offer the same geographic coverage as analog cellular systems, for example. The transceivers for the Ricochet system can't be used in moving vehicles either, since they don't support hand-offs. But that was a sacrifice made in order to boost data transmission throughput. Understanding the niche markets that these RDN's were introduced to serve (as explained in earlier sections of this report), will help to reveal the strengths and weaknesses they have in meeting specific customer needs.

One way to identify those services most effectively provided by RDN's would be to ask which communications transactions demand voice exchange and which lend themselves to data transfer. This might best be illustrated by some practical examples taken from the early

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[57] "To the Point," Promotional Data Sheet (Richardson, TX: Pinpoint Communications, Inc., no date given).

experiences of ARDIS and RAM. Since ARDIS was established as a communications network for IBM's field technicians, it's obvious the technology can be of use to workers who need to access corporate databases; it can also be used by managers to direct mobile service employees in those instances when short, non-verbal messages will clearly suffice. In addition to IBM, ARDIS technology is also used for similar tasks by field workers with AT&T Global Information Solutions, Memorex Telex (PC-based products), and Otis Elevator.[58] Pitney Bowes uses ARDIS so that its customers can reach its technical staff wherever they might be working in a metropolitan region; the firm reports improved service response times and heightened customer satisfaction.[59] Liebert Shields, a provider of uninterruptible power sources, agrees that mobile data systems have improved their own service response times.[60] Additionally, technicians with Liebert Shields now file all reports in wireless form, eliminating much of the paper shuffle that went on before.

Another example illustrates that RDN's can prove useful in relaying up-to-the-minute marketplace conditions. Sales representatives for the Wilson Sporting Goods Company used to call corporate headquarters at the end of each day to check product inventories. But demands to implement "just-in-time" manufacturing schedules made it imperative that remote salespeople have instant access to product data.[61] Wilson's reps can now guarantee item delivery on-the-spot with clients and, reportedly, have been able to boost their sales productivity. Wilson uses ARDIS for its mobile data communications.

A company called Physicians Sales and Service uses the RAM network in much the same way. Salespeople check inventory supplies and product prices using RAM transceivers while in the field at doctor's offices and hospital sites. An automated process makes it possible for sales representative to easily place remote orders for medical supplies while maintaining face-to-face contact with medical customers.[62]

Conrail, the railroad freight operation, uses the RAM system, too, and claims to have eliminated delays of at least several hours for the submission of completed work orders. Pickup and delivery information can now be simply transmitted to personnel on the trains—even while they are in transit—to confirm changes in customer shipping orders. Prior to the

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[58]"The True Pioneers," One the Air (Corporate Newsletter) (Lincolnshire, IL: ARDIS, Spring 1994), pp. 1-2.

[59]Ibid., p. 3.

[60]"Customer Profile: Liebert Shields," On the Air (Corporate Newsletter) (Lincolnshire, IL: ARDIS, Fall 1993), p. 3.

[61]"Why Wilson Went Wireless," On the Air (Corporate Newsletter) (Lincolnshire, IL: ARDIS, Winter 1994), p. 1.

[62]Boudris, "Corporate Backgrounder," p. 2.

introduction of wireless data messaging, all locomotives could only receive updated work orders when they were on-site in the freight yard.[63]

Both ARDIS and RAM have had some success in aiding law enforcement agencies, with ARDIS used by the Sheriff's Office of New York City and RAM used by police departments surrounding Cleveland, Ohio and in Des Moines, Iowa. In NYC, over 100 deputies use ARDIS terminals while on the beat to identify cars whose owners have not paid prior traffic tickets.[64] The system lets the officers query the department's database directly, saving time and improving accuracy. The Sheriff's Office claims that millions of dollars from deadbeats have since been added to the city's treasury. (The Chicago Parking Authority has had similar success using RAM wireless data terminals, making it possible for its officers to run license checks much faster.)[65]

Around Cleveland, 84 criminal justice departments have cooperatively deployed RAM terminals to their officers, who can now access data files without having to work through a dispatcher.[66] This new systems has reportedly allowed police to respond faster to crimes in progress, improving their chances of catching troublemakers in the act. Police communications are also more secure. By a strange coincidence, police in Cleveland, England are using RAM Mobile Data with much the same results.[67] Officials there plan to add an AVL feature so that police vehicles can be tracked, as well.

Another RDN application could have obvious implications related to the DOT's need to monitor remote traffic conditions. IBM has created a product called the SystemView SiteManager that works over the ARDIS network.[68] This automated service continually tests environmental conditions (air conditioning, water leaks, etc.) at the corporate data centers where it is installed and relays findings to the IBM monitoring center. When problems are detected, a data message is relayed via ARDIS to on-call service technicians, who respond immediately. Clearly, such technology could be adapted to monitor changing highway conditions and to forward status alerts to DOT response centers.

As all these examples illustrate, RAM and ARDIS have come to be used by a wide variety of customers applying the technology in novel ways. For instance, Master Card and TransNet have approved use of the RAM network for approval of credit card sales in locations

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[63]Ibid.

[64]"The True Pioneers," One the Air (Spring 1994), p. 3.

[65]Boudris, "Corporate Backgrounder," p. 2.

[66]Joanie Wexler, "Wireless Database Access Takes a Bite Out of Crime," Network World, 7 February 1994, p. 25.

[67]Steve Gold, "UK-Cleveland Police Use RAM Mobile Data," Newsbytes News Network, 4 November 1993.

[68]"Customer Profile: On-Site Surveillance from IBM's SiteManager," On the Air (Corporate Newsletter) (Lincolnshire, IL: ARDIS, Fall 1993), p. 6.

previously lacking easy access to hard-wired telephone connections: outdoor athletic stadiums, marinas, city sidewalks and public parking lots. The recent development of a wireless modem with an independent power supply, called the Ericsson GE M6000 Mobidem, also frees vendors from the need to have a standard power outlet nearby.[69] Wireless access to credit card records gives customers new flexibility in making purchases and helps outdoor businesses protect themselves from credit fraud.

One final example will illustrate a current weakness of all RDN's: their limited geographic coverage. When United Parcel Service (UPS) was evaluating which technology to use as the backbone for its "TotalTrack" package tracking system, it was swayed by the broader reach of national analog cellular systems.[70] Cost comparisons revealed no significant difference between analog cellular and RDN service either. With voice service providing a steady revenue stream to cellular operators, they were able to offer wireless data transfer at costs competitive with RDN's that have yet to build out their infrastructures. As a result, UPS spurned both ARDIS and RAM. Today, all 50,000 UPS trucks are outfitted with cellular modems. Network World reports:

> Everyday, the UPS fleet completes more than 525,000 cellular telephone calls, each lasting about 12 seconds, sending the latest delivery information back to a data processing center in Mahwah, N.J. With [analog cellular] wireless data technology, UPS keeps constant track of the 1.3 million packages it handles daily. [Doug] Fields [UPS vice president of telecommunications] says the network is "working very, very well."[71]

Obviously, RDN's continue to have some weaknesses that keep them from being the total technological solution for wireless data service. This should change, however, if ARDIS, RAM, and other providers continue to expand their service reach and develop a broader customer base.

Transportation-Specific Applications

The many applications of RDN technology to the wireless communications needs of the Washington State DOT can be extrapolated from the more general service illustrations noted above. Radio data networks could provide the State with reliable and secure data transmissions for a variety of jobs: transmitting messages to highway reader boards; carrying highway status reports from strategically-located sensors; coordinating mass transit schedules and updating bus and train arrival times on station displays; updating crew assignments on vehicle-mounted

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[69] Dana Blankenhorn, "Ericsson GE Mobidem for Credit Card Authorization," Newsbytes News Network, 7 July 1994.

[70] Joanie Wexler, "Wireless Users Move Beyond Messaging," Network World, 21 March 1994, pp. 29-30.

[71] Jensen, "Wireless Data Networking," p. 41.

PDA's for freeway repair teams; linking remote workers with key agency databases; and the list goes on.

Certainly not every job is suitable for data-only messages; some simply demand the personalization that voice communications provides. But many tasks can be accomplished more simply and cheaply using two-way data transmissions, and this service should be seriously considered as a way to free up capacity on the Department's crowded land mobile radio channels. The Department should also keep in mind that the same limitations that motivated UPS to use cellular telephone service may hinder the usefulness of RDN's for internal DOT data traffic. But as RDN's reach beyond the suburbs into outlying regions, they will become an even more attractive service option.

Andrew Seybold, a respected analyst on wireless communications, has recently emphasized the value of radio data networks as a technology that is in place and presently available to handle many data transmission needs. In the January 1994 issue of Seybold's Outlook on Mobile Computing newsletter, he questions the viability of CDPD and warns his readers not to be mislead by McCaw Cellular's strong claims for this untested technology:

> All during 1993, the CDPD players trouped out over and over again to meet with computer vendors, to keep industry analysts on the hook, and to keep the world from looking at the other options. They did their job well, and have probably been rewarded with raises and promotions. Meanwhile, the companies that have made huge investments in their own infrastructures [i.e. ARDIS & RAM] did not do nearly as good a job of marketing their products and services. Thus, the combination of outstanding marketing efforts by the CDPD folks, and poor marketing by companies with operational wireless data communications networks kept computer companies and the end-user community "on hold," waiting for CDPD to become a reality.[72]

Only time will tell if Seybold is justified for his critical evaluation of CDPD's present performance potential, but the DOT would be wise to follow his advice and not wait on CDPD exclusively for providing wireless communications service.[73] As Seybold warns: "Where is the data in 1994? The smart money is using ARDIS and RAM to send and receive data. Those inclined to follow McCaw Cellular to market are still waiting to be able to send their first packet."[74] If CDPD were available now, it would be an obvious choice on the basis of its dominant coverage across many areas of the state. But by the time CDPD hits the scene,

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[72]Andrew Seybold, "CDPD Watch, January 1994," Andrew Seybold's Outlook on Mobile Computing 2 (January 1994): 2.

[73]In July of 1994, Federal Express announced that it would be the first customer to use CDPD technology. Federal Express is expected to begin using CDPD in two cities (Las Vegas and another undetermined location) sometime in the fall in order to track package deliveries. CDPD service, called AirData, will be supplied by McCaw Cellular and will be used as a supplement to the SMR network Federal Express already uses across much of the country. Dana Blankenhorn, "FedEx to Supplement Existing Data Network," Newsbytes News Network, 7 July 1994.

[74]Seybold, "CDPD Watch, January 1994," p. 8.

RDN's may have comparable service reach with a more tested technology. As the State considers its mobile communications needs, Seybold's praise for ARDIS and RAM should help guide DOT decisionmaking.

Conclusion

One British market research company has issued a report predicting that the number of wireless data customers in Europe and North America will increase 25 times before the end of the decade.[75] This research group, called Ovum, anticipates that the base of mobile data subscribers on both continents will exceed 18 million by the year 2000. Whether or not this forecast proves true, there certainly is pent up demand for mobile data transmission operations, and the technology will prove its usefulness before the close of the century. That RDN's could be a useful adjunct to the State DOT's communications network is without question.

RDN's offer slow-to-moderate data transmission speeds (at least in Washington State), but they do provide duplex communications, and they seem reasonably priced for the current marketplace. The fee calculation tables for RDN's can be confusing to follow and reflect a complex pricing scheme. But, at least for moderate- or shorter-length data files, radio data networks have been cited by experts as levying the lowest charges per message. Full interactive communications are supported or, to save money, message reception can be rapidly confirmed with simple acknowledgments. The equipment for these networks—while often expensive—is coming down in price, and convenient customer access to the system is improving. The infant technology boosts transmission reliability to a new level of quality not previously available with data transmission over analog cellular channels. Also, privacy for internal communications is dramatically improved.

Yet, despite these advantages, radio data networks are still limited in their coverage, and service can only be expected in the most highly populated areas. Coverage maps included in the appendices to this report reveal that the current reach of ARDIS and RAM is only a small fraction of the State's total area. Each of these networks is trying to expand nationwide, so the emphasis they can give to any one state is diminished accordingly. RDN coverage will continue to handicap the usefulness of these services. Nevertheless, for those metropolitan regions that do have service, wireless data transfer can fulfill many functions supporting improved transportation management, and it should not be overlooked. RDN's can play an important role in taking pressure off the DOT's existing mobile communications networks and in expanding the application of wireless technology to many transportation flow problems. Finally, the even greater potential of Metricom's Ricochet service (and even the ARRAY network) should be watched as these nascent technologies establish a foothold in Seattle and beyond.

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[75] Steve Gold, "Mobile Data Users to Skyrocket," Newsbytes News Network, 6 June 1994.

This chapter will conclude with a table adapted from Business Week intended to provide a brief review of the primary technologies covered so far in this report. (See Table 7.3.)

WIRELESS DATA SERVICES: NICHE MARKETS OFFER CHOICES AND CONFUSION		
type	possible uses	availability
RADIO DATA NETWORKS Nationwide system of scattered radio towers that send and receive data messages only.	Customer data for field employees; e-mail for mobile professionals; police communications.	Now available from ARDIS & RAM; service soon from Metricom; other RDN technologies expected.
CDPD Data service currently being tested for overlay on the existing cellular telephone system.	Instant credit card verifications; remote database access; mobile messaging.	Roll out expected soon, with McCaw Cellular as the primary promoter of the technology.
SMR Two-way radio voice-dispatch service that is being digitally upgraded to offer voice & data.	Voice communications; data transmissions; paging; all in a single transceiver.	Nationwide network being established; leaders include: NEXTEL, Dial Page, and OneComm (Pacific NW).
DIGITAL CELLULAR Conversion of the existing analog cellular network to high capacity, digital service.	Voice communications; data transmissions, including faxes & e-mail messaging.	Slowly being introduced now by cellular operators; different digital standards may hamper nationwide roaming.
PCS Low-power cellular-type phones intended to create a mass market for wireless by lowering airtime costs.	Voice communications; data transfer, including headline news service, stock quotes, etc.	FCC to auction licenses late in 1994; service is realistically at least two-to-three years away.
CORDLESS TELEPHONY Inexpensive, low-power phones intended for travel between home and the office.	Voice communications; message transmission when in range of special "telepoint" sites.	No telepoint systems yet in U.S., but a WA State system could supplement existing DOT mobile communications.

Table 7.3: Prominent Wireless Data Communications Service Options[76]

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[76]Adapted from Arnst, "Dial 'R' for Revolution," p. 142 E4.

Chapter VIII

Satellites

Introduction

It wasn't that long ago that the thought of man-made satellites spinning around the earth had most folks watching in awe. It seemed incredible that we could lay a string of pulsing electronic globes around the planet to carry telephone conversations and even live pictures from the surface of the moon. Today, the vastly expanded power of advanced satellites is more commonly taken for granted. No one questions how it is possible that baseball games played in New York City can be watched in Seattle inning by inning. Live news reports from Bosnia on rapidly changing events are viewed in the States without a second thought. Companies have manufacturing divisions scattered across the globe, yet operate as a single entity thanks in large part to data transmissions and video conferences beamed routinely over satellite channels. In sum, satellite communications have become a very ordinary part of our lives—they have become "transparent" to most of us because they work so well.

Changes are now taking place in the satellite realm that may bring the technology to our conscious awareness once more. Multiple projects are underway to loft a net of satellites into the heavens able to make seamless mobile telephone coverage available to the most remote corners of our world. One's distance from urban areas, or travel through Third World nations, will no longer imply severed communications from loved ones or co-workers. While not as cheap as cellular phones, their higher cost will seem to many a small price to pay for complete untethered mobility. Once again, people will be reminded of the power of satellite communications. But if this new generation of high-tech phones equals the performance of the satellite vanguard, it may not be long before the technological details are forgotten and satellite phones, too, are taken for granted—at least until the phone bill arrives.

This chapter will review some of the pertinent history of satellite development leading up to current advances in the technology, with keen attention paid to the application of space-based communications services to the needs of the Washington State Department of Transportation.

Background

Today's satellite technology can most simply be divided into two broad classes based on the dominant orbital patterns employed: one is geosynchronous—also known as geostationary or fixed— and the other is low-earth-orbit (LEO). Geosynchronous satellites are easily identified by their specific location 22,300 miles above the equator. In 1945, futurist Arthur C. Clarke postulated that satellites boosted into just such an orbit, while maintaining the proper velocity, would appear from the ground to be holding a stationary position, or to be in sync with the earth's own rotation[1]—hence, the descriptive labels "geosynchronous," "geostationary," or "fixed." Using such satellites, it would be simple to construct stationary satellite dishes on the ground ("earth stations") that would only have to aim at one point in the sky to relay radio messages.

When the first geosynchronous satellite, known as Early Bird, was launched in April of 1965, its performance proved the validity of Clarke's earlier idea.[2] In further developing his vision, Clarke suggested that only three geosynchronous satellites would be needed to complete a communications link around the world. While only three satellites might have been necessary, they certainly have not proven sufficient; some 300 satellites (not all geosynchronous) are now in working orbits.[3] In fact, a serious problem has resulted from a lack of orbital slots for all interests demanding "parking spots" overhead, since only 180 satellites can be accommodated in geosynchronous orbit before interference problems result.[4]

For many years, geosynchronous satellites have dominated the field as the technology of choice. More recently, however, low-earth-orbit satellites are attracting new attention. As the name suggests, these satellites "fly" much lower in the sky—typically around 500 miles above the ground. Unlike geosynchronous satellites, LEO's, as they are commonly known, are not restricted to an equatorial orbit but can pass over most any place on the globe; LEO's can even serve polar regions with wireless communications—something that geosynchronous satellites are not able to do. Some LEO's have circular orbits—maintaining a fairly consistent altitude above the earth—while others have elliptical orbits that bring them near the ground for a time and then loft them higher in the sky. Geosynchronous and LEO satellites have their own advantages and disadvantages, which will be noted later in the chapter.

Despite their important differences, there are certain features to all satellites, and to satellite operation in general, that remain consistent.[5] All communications satellites have built-in electronic elements known as transponders. When pointed towards earth, these transponders are used to receive transmissions from signal-sending earth stations—called "uplinks"—and then relay those signals to distant receiving stations on the ground—called "downlinks." Some

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[1]Clarke's proposal for establishing geosynchronous satellites appeared in a 1945 edition of the journal Wireless World. See: R. L. Douglas, Satellite Communications Technology (Englewood Cliffs, NJ: Prentice-Hall, 1988), as cited by Michael G. Albrecht, "Satellites," in Communication Technology Update: 1993-1994, eds. August E. Grant and Kenton T. Wilkinson (Austin, TX: Technology Futures, Inc., 1993), p. 219.

[2]Lynne Schafer Gross, The New Television Technologies (Dubuque, IA: Wm. C. Brown Company, 1983), p. 20.

[3]Albrecht, "Satellites," p. 219.

[4]Ibid., p. 223, footnote 13.

[5]For a clear and concise description of satellite components and operational characteristics, see: Gross, The New Television Technologies, Chapter 2, pp. 17-26.

of the first satellites had only one transponder on board, but it is not unusual for modern satellites to have somewhere around 46 transponders.

When satellites receive radio signals from "dishes" on the ground, they don't merely spit those same signals out of a transponder pointing in a different direction. If they did, this would lead to interference between the uplink and the downlink since they would be using the same carrier frequency. Instead, when the satellite picks up a transmission, it translates it to a different frequency and then boosts the signals power, since it has been weakened as the result of its long distance travel. This requirement of different uplink and downlink frequencies reduces interference, but it also creates a need for increased satellite frequency allocations.

Satellite operation is complicated by the way such broadcasts reach the earth. When a satellite relays a signal back to an earth station it "illuminates" a certain region with a signal strong enough to allow reception; that area of reception is known as a "footprint." As one might expect, satellite downlinks often have very expansive footprints, and that can prove offensive to countries that want to shield their populations from foreign broadcasts that they find offensive. The "spillover" of satellite footprints into regions that want to remain isolated from such signals has caused political tension in the past. The end of the Cold War has eased this problem somewhat, but improvements have also been made in satellite technology so that "spot beams" provide a more controlled, condensed footprint. Enhancements like spot beams have also opened the door to cellular-type networks in which satellites are able to reuse their limited frequencies to boost their transmission capacity.

Early Satellite History

The first satellite to come into service as a relay station for distant radio signals was a natural one: the moon.[6] As early as the 1950's, the moon was being used as a passive reflector to bounce signals between Washington, DC and Hawaii.[7] Later a large metallic balloon some 100 feet across, known as Echo I, was launched into the sky to serve as the first artificial satellite; it, too, worked as a passive reflector.[8] With the Russian deployment of Sputnik, followed closely by the success of American space satellites like Score and Explorer, the technology took on more of the character it retains to this day as an active relay station for wireless signals and, more recently, as a signal processor, as well.

The demands of the space race led the U.S. to establish an organization known as COMSAT (the U.S. Communications Satellite Corporation), which was to coordinate the establishment of a domestically-controlled satellite network that could be used to link NASA

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[6]Historical accounts of early satellite development can be found in: Gross, The New Television Technologies, Chapter 2, pp. 17-26; Albrecht, "Satellites," pp. 219-232; and "After 10 Years of Satellites, The Sky's No Limit," (Special Report), Broadcasting, 9 April 1984, pp. 43-44, 48, 50, 52, 56-58, 60, 68.

[7]Albrecht, "Satellites," p. 220.

[8]"After 10 Years of Satellites, The Sky's No Limit," Broadcasting, p. 43.

spacecraft with ground stations. COMSAT was set up in 1963 as a private corporation backed by public and private investment. When the International Satellite Consortium (INTELSAT) was formed the following year as an international body to oversee global satellite expansion,[9] COMSAT served as the U.S. representative. While INTELSAT was started to encourage the productive worldwide application of satellite technology, the International Telecommunications Union (ITU) remains as the treaty organization recognized as arbiter of satellite spectrum and orbital placements.[10] The ITU is a regulatory arm of the United Nations.

During the first 35 years of satellite deployment, man-made satellites have grown in size and signal capacity, and their service life has also been extended. Researcher Michael Albrecht spotlights the tremendous improvement in satellite technology by comparing early capabilities with that of more recent "birds"[11]:

> The first INTELSAT-series satellite launched in 1965, Early Bird, could relay 240 telephone calls at a time, was two feet long, and had a life expectancy of about 1.5 years. In comparison, by 1985, INTELSAT V-A could carry 15,000 telephone signals simultaneously, was 21 feet long, and had a life expectancy of about seven years.[12]

As satellites have enhanced their productive capabilities, they have taken on ever more challenging communications tasks. While they started by relaying telephone conversations, which are low-bandwidth and low-power signals, they have assumed greater importance as they have expanded to carry television signals and high-volume data transmissions. In taking on these critical functions, satellites have grown in commercial value, national importance, and military usefulness. Hence, struggles have ensued over geosynchronous orbital slots, with developing countries straining to reserve space for their own satellites before all the open spots are snatched up by more developed nations, like the U.S.

Satellite slots have been established every two degrees along the equatorial orbital plane; current technology prevents them from being any closer lest they cause mutual interference. As a result, there are only 180 "addresses" available in geosynchronous orbit, and few remain unoccupied. As Table 8.1 illustrates, there were 120 civilian communications satellites in geostationary service as of February 1993. Given the vast popularity of these prime locations above the equator, it is understandable why this particular chunk of outer space real estate is in increasingly short supply.

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[9]INTELSAT was begun with eleven member nations on August 20, 1964. International agreements establishing INTELSAT were finalized in 1973. See: "After 10 Years of Satellites, The Sky's No Limit," Broadcasting, p. 58; and Peter Wood, "Mobile Satellite Services for Travellers," IEEE Communications Magazine, November 1991, p. 32.

[10]Albrecht, "Satellites," p. 222.

[11]Satellites are frequently referred to as "birds" by members of the industry.

[12]Albrecht, "Satellites," p. 220.

	ITU Region 1: Europe, Middle East, and Africa	ITU Region 2: North and South America	ITU Region 3: India, Asia, and Australia	TOTAL SATELLITE-TYPES DEPLOYED
	5 C-band	18 C-band	19 C-band	42 C-band
	15 C/Ku-band	13 C/Ku-band	8 C/Ku-band	36 C/Ku-band
	21 Ku-band	12 Ku-band	9 Ku-band	42 Ku-band
TOTALS FOR EACH REGION	41 satellites	43 satellites	36 satellites	**120 TOTAL SATELLITES**

Table 8.1: Civilian Communications Satellites in Geosynchronous Service[13]

As the number of satellites in orbit has grown—and the array of transponders aboard those satellites has been enlarged—more frequency bands have been needed to support the popular usage of this space-based technology. Regulators have had to look increasing to the higher frequencies to make room for new satellite applications. The most common bands used for satellite transmissions are the L-band, the C-band, and the Ku-band. (See Table 8.2.) Because of their location higher in the frequency spectrum, Ku-band satellites require more power to transmit usable radio signals.

Both the C-band and the Ku-band are nearing full capacity. With this in mind, an even higher frequency band—the K-band—has been set aside for Direct Broadcast Satellites (DBS) that may be used to relay television and radio programming over wide geographic regions in the U.S.[14] Other satellite bands include: the S-band, established for space exploration by NASA; the X-band, set aside for military operations; and the Ka-band—a broad swath of frequencies reserved for experimental satellite applications.

Real-Time Mobile Satellite Communications

As satellites have matured, they have taken on ever new communications tasks. As an example, in 1976 the opportunity was first made available for mobile personal communications over a satellite that eventually became known as INMARSAT-A. (All of the INMARSAT satellites are operated by the International Maritime Organization [IMO], hence the label

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[13]Source: M. Long, World Transponder Loading Report (Fort Lauderdale, FL: Long Enterprises, 1993), as cited by: Albrecht, "Satellites," p. 224.

[14]DBS service is already available in Europe. Japan is also using DBS for delivery of high-definition television (HDTV) programming. See: Seunghye Sohn, "Direct Broadcast Satellites," in Communication Technology Update: 1993-1994, eds. August E. Grant and Kenton T. Wilkinson (Austin, TX: Technology Futures, Inc., 1993), pp. 55-56.

Satellite	Frequency
L-band[15]	1530 to 1559 MHz—downlink 1631.5 to 1660.5 MHz—uplink
S-band (NASA)	2.0 GHz
C-band	3.7 to 4.2 GHz—downlink 5.925 to 6.425 GHz—uplink
X-band (military)	7.0 to 9.0 GHz
Ku-band	11.7 to 12.2 GHz—downlink 14.0 to 14.5 GHz—uplink
K-band (DBS)	12.2 to 17.8 GHz
Ka-band (experimental)	20.0 to 30.0 GHz

Table 8.2: Satellite Band Classifications[16]

INMARSAT.[17] INMARSAT is reported as operating nine satellites, all of which are in fixed orbit.[18]) For many years, INMARSAT-A was the only system to offer commercial mobile telephony by satellite. As one might expect—given INMARSAT's prime directive to serve ocean vessels—the interactive voice and high-speed data service made available through INMARSAT-A was first put to the test by commercial maritime groups. Obviously, such a service was of great value to the crews of ocean-going vessels, but it has also proven to be of great interest to passengers on board, as well. By using INMARSAT-A transceivers, customers are able to connect with the public switched telephone network (PSTN) through "gateway" stations. Also, in the case of large corporate or government clients, direct satellite connections have been made possible between remote callers and their centralized headquarter operations. Although initially entrusted with the oversight of maritime satellite communications, INMARSAT has gradually expanded its scope to provide mobile satellite transmissions for planes and land travelers, as well.

The system uses equipment that is quite bulky and expensive, especially when compared with today's cellular phones. Considering that airtime charges for phone service

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[15]L-band frequencies were allocated to mobile satellite communications during the 1987 World Administrative Radio Conference (WARC).

[16]Sources: Albrecht, "Satellites," p. 223; and John H. Lodge, "Mobile Satellite Communications Systems: Toward Global Personal Communications," IEEE Communications Magazine, November 1991, p. 25.

[17]Wood notes that INMARSAT "officially" began operations on February 1, 1982. Wood, "Mobile Satellite Services for Travellers," p. 32.

[18]Ibid., p. 34.

using these mobile terminals runs about $10 per minute, it is not surprising that the INMARSAT-A system has not caught the interest of a broad clientele. The portable telephones associated with INMARSAT-A are briefcase-size devices which use parabolic antennas about a yard in diameter.[19] Understandably, their size and cost have limited their application to commercial operations like cruise ships, and professional users like network TV reporters. It was INMARSAT-A equipment, for instance, which was used by CNN and competing networks to transmit field reports during the Gulf War and the military operation in Panama.[20] An INMARSAT-A portable earth station was also reportedly used in the base camp of a British mountain climbing expedition that scaled Mount Everest in 1988.[21] Sources estimate that between 10,000 to 14,000 INMARSAT-A transceivers are currently in operation.[22] Despite its proven utility, the shortcomings of the INMARSAT-A system—including its reliance on older technological standards like analog frequency modulation—have proven to be its undoing, and it is now being replaced with newer technologies.

INMARSAT is in the process of replacing its INMARSAT-A system with three different systems that take advantage of recent advances in digital technology. (See Tables 8.3 and 8.4.) One is the INMARSAT aeronautical system, which is intended to provide vital communications services to planes in flight. The technical standards for this system have been developed by the International Civil Aviation Organization and the Airline Electronic Engineering Committee.[23] Given its specialized application to flight communications, the INMARSAT aeronautical system will not be discussed further in this report.

The two other state-of-the-art INMARSAT mobile satellite systems use an identical signaling protocol but are aimed at servicing two different market groups. John H. Lodge, an expert on mobile satellite communications, and INMARSAT in particular, explains:

> The [INMARSAT] M system will offer low-cost, lightweight terminals which provide communications-quality voice, low-speed data, and facsimile services. In addition to marine and land mobile terminals, portable terminals the size of a small briefcase (including the antenna) supporting voice and facsimile are expected to be popular. Inmarsat-B is designed as the successor to Inmarsat-A, for providing high-quality professional communications services. The mobile antenna requirements for the A and B systems are identical...Inmarsat-M terminals will have smaller antennas...[24]

The performance differences between the INMARSAT-B and M systems are clearly evident in the specifications shown in Table 8.4. INMARSAT-M employs a more narrow

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[19] Lodge, "Mobile Satellite Communications Systems," p. 28.
[20] Ibid.

[21] Wood, "Mobile Satellite Services for Travellers," p. 33.

[22] Lodge, "Mobile Satellite Communications Systems," p. 24; and Wood, "Mobile Satellite Services for Travellers," p. 33.

[23] Lodge, "Mobile Satellite Communications Systems," p. 28.
[24] Ibid., p. 28.

	Organization	Service Categories	Coverage Region	Terminal Types	Operational
INMARSAT-A	INMARSAT	mobile telephone, circuit-switched data, store-and-forward data.	Global, excluding polar regions	marine vessels, large portables	1976
INMARSAT Aeronautical	INMARSAT	mobile telephone, circuit-switched data, interactive packet data, store-and-forward data.	Global, excluding polar regions	aircraft	1990
INMARSAT-M	INMARSAT	mobile telephone, circuit-switched data.	Global, excluding polar regions	marine vessels, land mobile	1993
INMARSAT-B	INMARSAT	mobile telephone, circuit-switched data, store-and-forward data.	Global, excluding polar regions	marine vessels, large portables	1993
MSAT	American Mobile Satellite Corporation (USA), Telesat Mobile Inc. (Canada)	mobile radio, mobile telephone, circuit-switched data, interactive packet data, store-and-forward data.	North America	all mobiles	1994

Table 8.3: Current Geosynchronous Mobile Satellite Systems Offering Voice and Data Services

(Source: John H. Lodge, "Mobile Satellite Communications Systems: Toward Global Personal Communications," IEEE Communications Magazine, November 1991, p. 27.)

	Voice Coding Rate	Data Rate (with error correction)	Modulation Scheme	Voice RF Channel Bandwidth
INMARSAT-A	not applicable	not applicable	FM	50 kHz
INMARSAT Aeronautical	9.6 kbps	19.2 kbps	Offset QPSK	17.5 kHz
INMARSAT-M	4.2 kbps	6.4 kbps	Offset QPSK	10 kHz
INMARSAT-B	16 kbps	21.33 kbps	Offset QPSK	20 kHz
MSAT[25]	4.2 kbps	6.4 kbps	π/4 QPSK Offset QPSK	7.5 kHz

Table 8.4: Transmission Characteristics of Leading Geostationary Mobile Satellite Systems Offering Voice and Data Services[26]

transmission bandwidth and slower voice coding and data transfer rates as dictated by its reduced radio channel capacity. All of the INMARSAT satellites that have been noted use the L-band frequencies set aside for mobile satellite communications to carry their transmissions.[27]

While INMARSAT has been the dominant supplier of voice and data satellite communications services in the past, its leadership position is being challenged by several new challengers.[28] One such competitor is the MSAT system, which is a joint venture of Telesat Mobile, Incorporated of Canada and the American Mobile Satellite Corporation based in the United States. The MSAT system has been planned to provide interactive voice and data communications to locations throughout North America, including Mexico and some Caribbean islands. (See Tables 8.3 and 8.4.) The system will employ two satellites to be launched in 1994 and 1995; one is intended to service Canada and the other to meet demand in the United States, but either can act as a back-up should one of the two birds become disabled. Rather than employing broadly-transmitting global antenna beams to cover far-flung regions, as INMARSAT has traditionally done, MSAT will have antennae on board that can produce overlapping spot beams able to emphasize areas of heavy communications traffic. Its data transmission rates will be on par with those of INMARSAT-M. (See Table 8.4.)

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[25]Table entries for MSAT are anticipated specifications.

[26]Source: Lodge, "Mobile Satellite Communications Systems," p. 27.

[27]Ibid., pp. 25, 27.

[28]INMARSAT boasts that its space satellites are tremendously dependable communications carriers. The organization claims to have a "99.99 percent" reliability record over its entire service history. John McCormick, "INTELSAT Maintains Satellite Reliability in Storm Wake," Newsbytes News Network, 27 January 1994.

Store-and-Forward Packet Data Satellite Services

The mobile satellite systems discussed so far are those that provide real-time voice and data communications. But there are other satellites which, while they do not provide instantaneous communications, do offer less expensive long distance transmission from space-based platforms. Because this class of service frequently employs slower transmission rates—and since strings of separate messages are often queued for their subsequent transmission—the delay in relaying a signal makes it inappropriate for carrying live conversations. Nevertheless, short data files, like e-mail messages, can be forwarded along the transponders of these satellites and will be delivered to their ultimate destinations as the systems' capacity allows. Some of the leading store-and-forward systems will be discussed to provide a sense of the range of services available, just as representative interactive voice and data systems were reviewed in the previous section.

Again, we find INMARSAT represented with its INMARSAT-C system.[29] INMARSAT-C came on the scene in 1990 and is able to provide telex, electronic mail, messaging, and position location services. The system employs a channel bandwidth of only 5 kHz; the associated data transfer rate is 600 bits-per-second—slow indeed when compared with many of the other ground-based mobile networks covered previously in this report. On the other hand, INMARSAT-C (and the other satellite systems discussed in this chapter) do offer communications service to outlying rural areas in First and Third World nations that are ignored by cellular, paging, SMR, and other networks;[30] those other technologies have to stress urban coverage in order to take advantage of the higher population densities that can support their related infrastructure development.

The INMARSAT-C's ground transceiver uses a relatively small antenna, but the antenna is still able to produce a broad enough beam to eliminate the need for an antenna steering mechanism. Comparable mobile services are available over the StarDrive system of the American Mobile Satellite Corporation and the Mobile Data Service of Telesat Mobile Incorporated; both employ technologies patterned on the model of INMARSAT-C. All of these services use frequency channels set aside in the L-band for mobile satellite communications.

Two other service providers stand out for their innovative utilization of satellite frequencies outside the L-band: Qualcomm and Geostar.[31] Both firms are reportedly interested

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[29] Ibid., p. 28.

[30] The value of this service to rural areas cannot be overstated. Many rural residents cannot use the existing wired telephone network to receive faxes or data files over their computer; many are tied to the phone network by party lines. Satellite communications may offer the best opportunity for customers in remote communities to receive modern telecommunications service for the first time. Jim Mallory, "US West Tests Satellite Service for Rural Customers," Newsbytes News Network, 24 January 1994.

[31] See: Ira Brodsky, "Wireless Data Networks and the Mobile Workforce," Telecommunications, December 1990, p. 34; and Lodge, "Mobile Satellite Communications Systems," p. 29.

in providing two-way data messaging and AVL capabilities to the long-haul trucking industry. The Qualcomm system, known in the U.S. as OmniTRACS, began operation in 1990. OmniTRACS uses frequencies in the Ku-band, but it is only licensed to operate in that band on a secondary basis. This means that Qualcomm has had to take special precautions to insure that its transmissions will not interfere with the communications of parties designated as primary operators in the Ku-band. One of the techniques used in the OmniTRACS system to reduce any chance of interference is the application of dynamic data transfer rates. As a result, the associated satellite downlink may employ a data transmission rate between 5 and 15 kilobits-per-second. The uplink, which uses a less powerful signal from the mobile terminal (under 1 watt), has a data transmission rate that varies between 55 and 165 bits-per-second. Spread spectrum approaches are also used as part of the uplink to disperse the signal power over a total signal bandwidth of 54 MHz; the downlink is TDMA-based.

Geostar began to offer two-way data messaging and AVL service in 1989. Geostar uses CDMA modulation for both its uplink and downlink. Operating in the C-band for transmissions from the satellite, the Geostar system has a data rate of 1.2 kilobits-per-second for the downlink portion of the transmission path. The uplink uses frequencies between 1610 MHz and 1626.5 MHz (the radio determination satellite system [RDSS] band) to transmit data at a rate of 15.625 kilobits-per-second.

Other advanced satellites are in the works. Many of these newest satellites are much larger, use higher-powered signals, and operate in upper portions of the frequency spectrum. Engineers are able to take advantage of advances in technological capabilities to make such changes a practical reality. Part of the reason for these changes is to make possible the use of a smaller transceiver—called a Pocsat, or pocket satellite phone—that approaches the convenience of today's cellular phones.[32] Additionally, engineers are striving to create future satellite designs that will support less unwieldy portable dishes. The newer satellites are also moving toward spot beam transmissions that will allow the reuse of downlink frequencies. That, in turn, will bring system capacity gains that should help to lower customer prices. By moving up to the experimental Ka-band, operators are finding more "free" spectrum available for supporting their expanding services. During the summer of 1993, NASA launched its Advanced Communications Technology Satellite (ACTS) which incorporates much of this forward-looking technology into its configuration.[33]

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[32]Wood, "Mobile Satellite Services for Travellers," p. 35.

[33]NASA's ACTS will make possible the use of an innovative antenna called the Ultra-Small Satellite Terminal (USAT) that measures just 1.2 meters in diameter. The spot beams generated by this satellite can be less than 200 miles wide. See: Ellen Messmer, "Shuttle to Launch Satellite That Will Usher in New Era," <u>Network World</u>, 26 July 1993, pp. 1, 109; John McCormick, "Shuttle Launch Failure Delays New Data Comm Services," Newsbytes News Network, 13 August 1993.

Renewed Interest in Low-Earth-Orbit Satellites

Very early in the history of satellite communications, interest had been expressed in the potential of both geosynchronous and low-earth-orbit satellites. Nevertheless, geosynchronous satellites grew in favor as it became evident that few of them would be needed to provide continuous worldwide coverage (excluding the polar regions). Much as Arthur Clarke has predicted, only three satellites parked above at 22,300 miles (a location now identified as the "Clarke Belt") were necessary to provide blanket wireless coverage of nearly the entire planet.

Even so, few observers could have anticipated the explosive growth of satellite traffic that would follow in the wake of the first satellite successes in the late 1950's and early 1960's. By some accounts, engineers were initially concerned about the long distances that fixed satellite signals would have to travel and the delays that might be caused during two-way phone conversations.[34] But once those fears were squelched by demonstrations of geostationary satellite performance, support for the service blossomed and LEO's were left behind in the dust of successive satellite launches.

Certainly, LEO's were not neglected altogether, and as time wore on changes in technological capabilities and regulatory attitudes worked together to stimulate a renewed interest in their potential. One theme repeated throughout this report has been the dramatic impact of the FCC's increasing reliance on marketplace competition to shape the evolving communications environment. That theme is no less valid in the case of satellite technology. In 1984, President Reagan signed a deregulation order which had the effect of loosening COMSAT's grip on domestic satellite operations and opening the field to broader commercial influence.[35] As a result, new companies began exploring the potential of satellite communications and fresh ideas were suggested for introducing alternative space-based services.[36]

In conjunction with the change in regulatory attitudes, technological advances hinted at innovative uses for satellite frequencies. The development of higher-powered birds using portions of the uppermost radio spectrum limits gave impetus to the application of spot beam techniques that could allow operators to gain more system capacity by reusing scant radio frequencies. Spin-offs from military projects—like the "smart pebbles" program associated with the Space Defense Initiative (SDI)—were able to stimulate private industry to apply new

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[34]Wood, "Mobile Satellite Services for Travellers," p. 32.

[35]Presidential Decree #85-2 released on November 28, 1984. See: Albrecht, "Satellites," p. 226, especially footnote 21.

[36]Under growing competitive pressure, INMARSAT, too, has established plans for a new LEO network to serve people with portable satellite phones. INMARSAT's LEO proposal is seen by some analysts as a blow to the highly-publicized Iridium project—Motorola's effort to create an expansive LEO network. Iridium will be discussed in more detail later in this report. See: Sylvia Dennis and Steve Gold, "Ericsson Teams With INMARSAT on Satellite Phones," Newsbytes News Network, 18 October 1993.

communications techniques to commercial ventures that could benefit the civilian population.[37] With regulatory barriers falling, space became the new business frontier for many companies eager to participate in this new "gold rush." Add to this scenario the problem of congestion in the Clarke Belt, and one can understand why service providers were refocusing their attention on the promise of low-earth-orbit satellites.

As the low-earth-orbit market has begun to develop, operators have come to differentiate themselves as either "little LEO's" or "big LEO's." The term "little LEO" refers to those low-earth-orbit systems being established specifically for the provision of data services; the "big LEO's" will carry both voice and data.[38] The two classes of LEO service can also be distinguished by the frequencies they have been allocated. During the World Administrative Radio Conference (WARC) held in 1992, frequencies above 1 GHz were set aside for use by the big LEO's (around 1.6 GHz and 2.5 GHz).[39] At the same time, VHF frequencies around 140 MHz were earmarked for the little LEO's.[40] In Europe, the little LEO's were granted only secondary status in the 140 MHz band, which drastically limits their usefulness there.

A surprising number of programs are presently underway to establish low-earth-orbit satellite networks within the next decade, and it seems unlikely that all will succeed, given their tremendous expense. Two little LEO projects sponsored by Orbital Sciences Corporation and Starsys have already begun aggressively moving ahead and deserve attention from the DOT. Both systems have already been granted experimental licenses by the FCC and announce that commercial service will commence in 1995 or 1996.

Orbital Sciences has named its network ORBCOMM. This system may eventually have as many as 36 small satellites traveling in a circular low-earth-orbit at an altitude of 425 miles.[41] Although ORBCOMM satellites will not always be within range of ground transceivers, the company claims that most regions of the world will have access to a passing satellite at least 95 percent of the time.[42] ORBCOMM will make possible four different levels

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[37]The Teledesic LEO project being supported, in part, by Bill Gates and Craig McCaw is just one example. "McCaw and Gates Team Up In Space," The Seattle Times, 21 March 1994, pp. A1-A2.

[38]David B. Crosbie, "The New Space Race: Satellite Mobile Communications," IEE Review, May 1993, p. 112.

[39]Those frequencies (between 1.610 and 1.6265 GHz, and between 2.4835 and 2.5 GHz) have since been allocated by the FCC for domestic use by big LEO operators. 33 MHz in all was established for big LEO systems. Dana Blankenhorn, "FCC Allocates Spectrum for Low Earth Orbit Satellites," Newsbytes News Network, 14 December 1993.

[40]Crosbie, "The New Space Race," p. 112.

[41]Ibid.

[42]As an example, if a remote terminal has access to the ORBCOMM network 97 percent of the time, that means that during each 24 hour period the various isolated moments when a satellite will be out of reach will total 43 minutes. According to ORBCOMM's calculations, "90 percent of the outages will last for less than 2 minutes." Orbital Sciences Corporation, ORBCOMM: Virtual Communications Absolutely Anyplace on Earth (Informational Packet) (Dulles, VA: Orbital Sciences Corporation, 1992), no page number given.

of service: a remote emergency alert option providing simple notification of distant machinery malfunctions or trespass on private property; a radiolocation function that can be used to track vehicle movements; a data relay component that will permit remote sensor readings to be forwarded to a centralized office; and a two-way data messaging capability. Orbital Sciences also claims that customers on corporate computer networks using common communications protocols (X.400, X.25, and others) will be able to forward data messages through gateway earth stations and satellite relays to remote users. The associated handset sports a cellular-type omnidirectional antenna, a data screen, and a simple keypad, and it weighs just 10 ounces. It is expected to cost between $100 and $400 depending on the level of service required.[43]

Starsys plans to offer many of the same satellite-based services following a similar pricing structure.[44] Until both companies are able to launch about 24 satellites, their U.S. coverage may be inconsistent. But following full deployment, they should be able to provide nearly continuous coverage. Both little LEO networks will use VHF frequencies to carry their data transmissions.

Technical and operational specifics for seven of the more extensive big LEO projects are included in Table 8.5. One of the most ambitious of these projects is called Iridium and is being championed by Motorola. Since it is beyond the scope of this report to outline the history and technological particulars of each of the satellite systems noted in Table 8.5, the background and potential of the Iridium project will be reviewed as a representative sample of work in the field.

Iridium has received more press attention than any of the other projects combined, so copious amounts of information on the proposed system are readily available (and public interest has been sparked as a result). Also, while once considered ridiculous for its most ambitious project design employing 66 LEO satellites, Iridium has gained increasing respect from analysts as Motorola has brought more investors on board and pushed ahead with its launch plans.[45] Finally, Iridium intends to reach a mass market with its satellite phones, so it may eventually offer airtime rates that are reasonable—considering the service's reach into isolated rural areas. For all these reasons—its vast publicity, its growing likelihood of success, and its anticipated affordability—Iridium should be of interest to the State DOT and is worthy of further investigation.

The Iridium Project

The proposed Iridium satellite system was originally named for the chemical element Iridium which has 77 electrons spinning around its nucleus; Motorola's Iridium, too, was to

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[43]Philip Chien, "Telecommunications: Letter to a Beeper," Popular Mechanics, April 1994, p. 51.
[44]Crosbie, "The New Space Race," p. 112.
[45]"McCaw and Gates Team Up In Space," p. A2.

	IRIDIUM	GLOBALSTAR	ODYSSEY	ARIES	ELLIPSO	PROJECT 21	TELEDESIC
Sponsors	Motorola, Brazilian Government, United Comm. of Thailand, Raytheon	Loral, Qualcomm, Aerospatiale Alenia, Alcatel, DASA	TRW Inc., Matra Marconi Space	Defense Sciences, International Microspace, Pacific Comm. Sciences	Mobile Comm. Holdings Inc. Matra Group, Fairchild, IBM, Westinghouse	International Posts, Telephone, & Telegraph authorities (PTT's)	Bill Gates, Craig McCaw, Edward Tuck, McCaw Cellular Comm.
Operator	Iridium, Inc.	Globalstar	TRW	Constellation Comm.	Ellipso	INMARSAT	Teledesic
Constructor	Lockheed	sponsors	sponsors	sponsors	Westinghouse	undecided	not known
Launcher	conventional	conventional	conventional	Defense Sciences	undecided	undecided	not known
Service	voice, radiopaging, 2.4 kbps data	voice, GPS, radiopaging	voice, GPS	voice, data, radiopaging	voice, data, radiopaging for US only	voice, data, radiopaging	16 kbps voice & data
Satellites	66	48	12	48	14	undecided	840
Orbit	polar circular, 765 km inclined 87°	circular, 1,389 km inclined 52°	elliptical, 10,000 km inclined 55°	polar circular, 1,000 km inclined 90°	elliptical, 429 km to 2,903 km inclined 64°	undecided	circular, 700 km
Switching & Processing	onboard cellular switching, inter-satellite links	ground-based switching	ground-based switching	ground-based switching	ground-based switching	undecided	not known
Multiplexing	FDMA/TDMA	CDMA	CDMA	CDMA	FDMA/CDMA	undecided	not known
Investment	$3.4 billion	$1.8 billion	$800 million	$500 million	$280 million	$1 billion	$9 billion
Operational	1998	1998	1997	1998	1997	2001	2001

Table 8.5: Primary Big LEO Mobile Satellite Systems in Progress

(Primary Source: David B. Crosbie, "The New Space Race: Satellite Mobile Communications," IEE Review, May 1993, p. 112.)

boast 77 satellites orbiting the earth along 11 evenly-spaced polar orbits. Engineers later came to the conclusion that the project would work with only 66 satellites—saving a fair amount of money—but the name had already stuck.[46] Project designers have been able to save additional dollars when compared with the cost of launching a comparable number of geosynchronous satellites because the LEO satellites are relatively small, weighing about 1,100 pounds each. That will prove to be a plus, since smaller rockets can be used to boost the Iridium satellites up into their circular orbits. The greater number of satellites deployed should also lead to some efficiencies of scale that will bring down the manufacturing costs for each individual bird. Even so, Iridium requires 66 satellites to cover the planet whereas three geosynchronous satellites can accomplish much the same feat. The cost of creating the Iridium network will be at least $3.4 billion; that is substantially more than the $600 million it would cost to launch three typical geostationary satellites.[47]

So, why are Motorola and the other Iridium supporters establishing such an elaborate satellite web? In a word: capacity. By generating 37 overlapping, highly-focused spot beams, each Iridium satellite will be able to reuse transmission frequencies and, thereby, carry more calls. Also, by setting up these spot beams to share frequencies according to a modified seven-cell reuse pattern (see Figure 2.1 in Chapter Two), the system will create 283,000 50 Hz-calling-channels across the globe. As a result, the Iridium system will be able to carry ten times as many phone calls as any current satellite systems.[48] By purposely designing the satellite network to support increased levels of voice traffic, Motorola expects it will be able to dramatically undercut the price associated with satellite calls on INMARSAT-A. (See Table 8.6.) Then, too, by making satellite voice channels available at a much cheaper cost, Iridium's managers are hoping to attract a global mass audience on the go in isolated territories that have no wired or cellular telephone infrastructure.

The actual workings of Iridium's planned equipment have drawn on the experience of satellite <u>and cellular</u> operators to produce an innovative hybrid system. As one Motorola manager explains:

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[46]Some useful sources of information on Iridium include: Jerry L. Grubb, "The Traveller's Dream Come True," <u>IEEE Communications Magazine</u>, November 1991, pp. 48-51; Joanie Wexler, "Gates-McCaw Network Plan Met With Skepticism," <u>Network World</u>, 28 March 1994, pp. 1, 58; Crosbie, "The New Space Race," pp. 111-114; Lois Therrien, "It's a Mad, Mad, Mad Wireless World," <u>Business Week</u>, 29 November 1993, pp. 128, 132-133; Robert X. Cringely, "Who, What and Why of Wireless," <u>Forbes</u>, 13 September 1993, pp. S84-S85, S88, S92; and Jim Foley, "Iridium: Key to Worldwide Cellular Communications," <u>Telecommunications</u>, Oct. 1991, pp. 23-24, 26, 28.

[47]The manufacturing and launch costs associated with the orbital placement of a geosynchronous satellite were gleaned from: Albrecht, "Satellites," p. 225.

[48]Foley, "Iridium: Key to Worldwide Cellular Communications," p. 23.

	Consumer Equipment	Airtime Prices
Cellular Phone	$200-$1,000 (In reality, many phones are given away for free—or nearly free—to encourage subscribers)	38¢ to 99¢ per minute
INMARSAT-A (real-time voice & high-speed data communications)	$30,000-$45,000	$7 to $10 per minute
INMARSAT-C (low-speed, store-and-forward packet data service)	$10,000	1¢ per byte
Iridium (Digital voice, data, facsimile, paging, and geopositioning)	$3,000[49]	$2-3 per minute $50 monthly subscriber fee
Globalstar (Digital voice, GPS, and radiopaging)	$600	65¢ per minute (plus long distance charges)
ORBCOMM (Emergency alert, radiolocation, remote sensing, and two-way data messaging)	$100 - $400 (depending on included transceiver functions)	19¢ per 250-character message[50] (There will be no limit on message length. Airtime charges will vary depending on message size, priority, and time of day.)

Table 8.6: Cellular and Satellite Cost Comparisons[51]

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[49]Iridium insiders predict the cost of an Iridium satellite phone "may" drop to $1,000 by early in the twenty-first century. Foley, "Iridium: Key to Worldwide Cellular Communications," p. 24.

[50]Chien, "Telecommunications: Letter to a Beeper," p. 52.

[51]Sources include: Wood, "Mobile Satellite Services for Travellers," p. 33; Crosbie, "The New Space Race," 111; John P. Mello, Jr., and Peter Wayner, "Wireless Mobile Communications," BYTE, February 1993, p. 154; Joanie Wexler, "Satellites Galore," Network World, 28 March 1994, p. 58; and Orbital Sciences Corporation, ORBCOMM: Virtual Communications Absolutely Anyplace on Earth, no page number given.

> The Iridium system's digital cellular design is essentially a mirror image of present-day cellular telephone systems. The cell pattern is fixed relatively to each of the constellations [66] satellites, but moves rapidly relative to the earth's surface. As a subscriber unit is operated, handoffs occur from cell to cell, similar to today's cellular telephones. However, unlike the case of terrestrial cellular telephones, Iridium's cells would be moving across the user, rather than requiring the user to move through the cells.[52]

With earth-based cellular systems, mobile travelers have their calls passed between cells about once a minute, and that same time frame would hold true for Iridium's hand-offs, too. That's about the amount of time it will take an Iridium bird, moving at over 16,714 miles-per-hour, to pass overhead from horizon to horizon.[53] About the time the first satellite is ready to disappear, the second will follow in its path and the hand-off will take place. The entire network of satellites will be joined together in the sky by a series of microwave links. On-board signal processing and switching intelligence will reduce the need for gateway earth stations and simplify the hand-off procedure.

Despite its similarities with terrestrial cellular systems, Motorola insists that its space-based network will not replace the present duopoly service but will extend telephone links to those outlying areas where conventional cellular can't afford to go. In fact, the cheaper airtime rates for traditional cellular connections will ensure that it holds its attraction for mobile urban dwellers. But much as PCS should threaten terrestrial cellular with its greater capacity and lower prices, Iridium is expecting to steal customers away from INMARSAT-A with its cost advantages.

Another key difference between the early INMARSAT-A mobile voice service and the system planned by Iridium will be the operating equipment. As was mentioned earlier, the portable INMARSAT terminals were each as big as an attaché case and required awkward antennae. But Motorola's satellite phones will not be much bigger than a standard cellular phone and will use a small-profile antenna that stays fastened to the transceiver. Because Iridium satellites will fly in a low-earth-orbit 484 miles above the earth (about one-fifth the altitude of fixed satellites), customers' handsets can be compact and their power requirements will be greatly reduced. It's expected that they will operate on only 600 milliwatts, much like today's cellular models.

Because Iridium is a big LEO, it will be able to do everything a little LEO can do—including radiolocation, paging, and short data messaging[54]—but it will also be able to provide

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[52]Foley, "Iridium: Key to Worldwide Cellular Communications," p. 24.

[53]Lodge, "Mobile Satellite Communications Systems," p. 30.

[54]Motorola is producing a modem to work with Iridium satellites that will transmit at 2.4 kilobits-per-second. Iridium will also support facsimile transmissions. Grubb, "The Traveller's Dream Come True," pp. 50-51.

high-quality, two-way voice connections. In that respect, it is quite similar to all the other big LEO projects outlined in Table 8.5. Another characteristic that each of these big LEO systems will share is the challenge of convincing international departments of Posts, Telephone, and Telegraph (PTT's) to grant them service privileges abroad. Since each of the foreign PTT's stands to lose revenue to LEO systems if the LEO's drain telephone business from these government-run communications utilities, it stands to reason that the PTT's will have to be convinced of their own financial security before any LEO networks can achieve complete global coverage.

Geopositioning Services

One important feature of many of the big and little LEO projects in progress is their ability to help customers pinpoint their latitudinal and longitudinal coordinates on the earth and, thereby, reveal their location. Some of these systems provide information on the user's altitude, direction of travel and speed of travel, too. As one might well imagine, such vital data can be of great service to commercial ocean vessels, pleasure craft, cross-country truckers, package delivery companies, pilots, and recreational hikers, among others. A whole chapter could be written on the development of radiolocation technology and its dramatic improvements in accuracy over the past decades. Instead, Table 8.7 has been provided to outline some of the main global positioning networks and summarize their leading characteristics.

In reviewing Table 8.7, special attention should be paid to the details of the Global Positioning System (GPS), which now offers highly accurate radiolocation satellite service around the world and free of charge. By using hand-held or dash-mounted GPS receivers, travelers can pinpoint their whereabouts with an accuracy to within an amazing 17.5 yards (16 meters). The GPS system employs 24 satellites and a triangulation process to make its fine-tuned calculations.[55]

Established at a cost of $13 billion to aid the U.S. military in the guidance of ballistic missiles, some details on the system were made available to civilian manufacturers so that they could make receiving units and positioning software available to the global public. GPS devices have now been reduced in size to allow for handsets that can make the necessary readings in a matter of just seconds; GPS receivers have also been installed on thin PCMCIA cards that can plug easily into current laptop computers. As one reviewer explains: "If coupled with two-way communications, this positioning information can be fed back to a central data-collection site and integrated with a geographical-information system to present real-time position mapping and similar services."[56]

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[55]"GPS—What Is It?" (Tiger Software Catalog) (Coral Gables, FL: Tiger Software, January 1994), p. 9.

[56]Don Fitzwater, "Wherever You Go, There You Are—Really," <u>Puget Sound Computer User</u>, March 1994, p. 26.

System	Position Accuracy	Range of Operation	Comments
Global Positioning System (GPS)	16 meters	Worldwide	24-hour, all-weather coverage; specified position accuracy available to authorized users.
Long-range Navigation (LORAN), LORAN-C	180 meters	U.S. coast & continental regions; selected areas overseas	Localized coverage; limited by skywave interference.
Omega	2,200 meters	Worldwide	24-hour coverage; subject to very low frequency propagation anomalies.
Standard Inertial Navigation Systems	no more than 1,500 meters after first hour	Worldwide	24-hour, all-weather coverage; degraded performance in polar areas.
Tactical Air Navigation (TACAN)	400 meters	Line-of-sight (present air routes)	Position accuracy is degraded mainly by azimuth uncertainty, which is typically on the order of 1.0 degree.
Transit	200 meters	Worldwide	90 minute intervals between position fixes suits slow vehicles (better accuracy available with dual frequency measurements).

Table 8.7: Primary Radiolocation Systems[57]

Applications

Satellites have proven that they have the technological capability to handle most any task that the more pedestrian wireless communications systems can accomplish. Even so, there traditionally have been three main handicaps for satellite systems: the burdensome size of the "portable" transceivers; the limitations on the number of radio channels that fixed satellites could make available using their global beam transmission approach; and the big-budget expense of satellite phone calls costing at least $10 a minute. With the marketplace being reshaped by technological change and regulatory revisions, those problems should be less imposing in the years ahead.

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[57] Adapted from: Ivan A. Getting, "The Global Positioning System," IEEE Spectrum, December 1993, p. 38.

Satellites have commonly been used in the past to carry long distance phone calls and relay television signals from coast-to-coast and over international borders. As the technology evolves, however, new applications are being explored. As the Iridium system takes shape, its engineers claim that their low-earth-orbit birds will be able to handle multiple tasks: high-quality voice communications, two-way data messaging, facsimile transmissions, paging, automatic vehicle location service, and the relay of remote sensing data. Most of the other LEO's and geosynchronous satellites can do these same things with varying degrees of efficiency and according to different cost schedules.

Even so, it seems unlikely that modern satellite networks will ever be able to compete head-to-head with ground-based wireless systems in providing mobile communications around metropolitan hubs. The cost of designing, building and launching these complicated satellites simply raises the expense of the whole network, and those costs have to be recovered through higher service fees. However, it's the remaining locations where cellular and paging systems are not cost effective—like through the Cascade mountain passes or in the wide open spaces north of Moses Lake—that satellite communications excels as an affordable solution. None of the conventional wireless providers would consider placing transmission towers in these less-densely populated places where many people still travel for work and play. That is the niche market that satellite operators can satisfy so well. This rural focus shines through in one newspaper report on the Teledesic project, which explains:

> More than half the world's population lives more than two hours from a telephone, according to Teledesic documents. Nearly 58,000 villages in Indonesia and 151,000 villages in Africa have no telephones. Teledesic officials argue that sophisticated communications networks will be necessary for the economic development of the rural areas.[58]

Although this quote focuses on the effect of satellites on foreign lands, their impact could be no less dramatic for rural areas of the United States. As The Economist concurs: "A farmer's call for advice could save a whole crop; access to a small handset could help a small business sell its wares."[59] Certainly a driving force behind each of these new satellite endeavors is the goal of profitability to satisfy all of their investors; they are, of course, private businesses and not government-run development programs. But their foundation as commercial enterprises does not preclude the chance that they might also provide modern telecommunication services to regions that would otherwise remain disadvantaged. It is too early to tell whether these satellite links will prove cost effective for bringing urban health and

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[58] "Satellite Network Goes Where No Peer Has Ventured Before," (Washington Post and Los Angeles Times reports) The Seattle Times, 21 March 1994, p. A3.

[59] "Phones Into Orbit," The Economist, 28 March 1992, p. 15.

educational expertise to isolated towns—or whether they might serve as a commercial lifelines for rural cooperatives and agricultural start-ups. Indeed, we may find, once the market shakes out, that the technology's main use is generated by urban businessmen who are just passing through.

Transportation-Specific Applications

As satellite airtime becomes more reasonable and the phones get more portable, their usefulness is growing—especially in transportation-related affairs. For instance, thanks to the seamless network that satellites can provide across the vast farmlands and mountains of America's mid-section, more trucking companies are turning to satellite operators for assistance. As one satellite service provider has outlined:

> Mobile [satellite] data communications can be used to monitor the safety of rigs. Most of the larger national truck fleets have some sort of monitoring system. But instead of information being transmitted via satellite [or some other technology], the data is stored on-board, and is only delivered when the rig reaches the company freight yard. Since data is received as past history rather than in real time, opportunities for en route efficiencies are therefore lost.
>
> The more sophisticated mobile data systems rely on portable PCs for each truck, sometimes with a fax, and with a modem link up to...the satellite...network. By typing into their computer, truckers can send messages to one another or to headquarters. A visual monitor can notify them of in-bound messages.[60]

Satellites can perform the same sorts of tasks for the Washington State DOT. Regional offices in Spokane or Seattle could follow the movement of snow plows through the Cascades; those same trucks could be outfitted with sensors telling dispatchers if an engine is about to overheat or if a dump truck needs repairs. The value of satellite communications is that mobile workers anywhere outside urban centers can still maintain contact with mangers and can address transportation emergencies most effectively.

The usefulness of satellite communications to mobile employees is substantiated by researcher John Hamilton, who conducted a study of the technology and its application by national freight carriers.[61] While the shipping industry and the DOT may have different emphases for satellite telecommunications, the DOT can learn from the experience of truckers who like the technology for the efficient mobility it permits. Drivers, especially, found the satellite network to be useful, Hamilton writes:

> Drivers receive value from the TSS [transportation support system, i.e. satellite link] in several ways. One, through the AVL and communications capabilities, when

[60]Guy Wallin, "'Heavenly' Data is Keeping Truckers 'Just-in-Time,'" Puget Sound Business Journal (Special Report: Telecommunications), 1-7 July 1994, p. 19.

[61]John W. Hamilton, "Wireless Communication Systems: A Satellite-based Communications Approach for Competitive Advantage in Logistic and Transportation Support Services," Computers in Industry 21 (1993): 273-278.

breakdowns or emergencies occur the driver simply notifies the dispatch department of the problem. Dispatch then uses the AVL feature of the system to send the needed support to the driver. Additionally, the use of a TSS eliminates the need for routine check-calls. The TSS provides immediate location information and the driver can be contacted using data communications. The driver is saved time by not having to stop for check-calls. Also, actual driving time productivity is increased.[62]

Orbital Sciences agrees that satellite-based communications can earn its keep through more effective fleet management. In the promotional literature for its ORBCOMM system, Orbital Sciences cites the added usefulness of its satellite data system for the unattended relay of sensor readings on such things as machinery performance or meteorological changes (like freezing levels or snowfall accumulations).[63] In response to in-coming data readings, operators can trigger remote events, such as the opening or closing of water reservoir gates. Although not directly related to transportation issues, the company's illustrations suggest that satellite connections can reliably carry data transmissions that may be used, in turn, to activate devices at the place of interest. Obviously, the same type of satellite configuration could be used to manage traffic patterns and highway conditions from afar.

Satellites are even being tested for their potential to lead lost travelers to their destinations. In New York State, the regional telephone company (Nynex) is using a satellite-based relay to connect people in their autos with directional assistance.[64] Lost drivers push a button and an operator comes on-line via satellite to talk customers through their journey. Back at the control center, each operator has an electronic map that shows the driver's present location. As part of the experiment for Project Northstar, the operators have also guided participants around traffic jams and connected callers directly with the state police. Admittedly, this is a futuristic application. But it suggests one scenario for how the DOT might employ satellite radio channels to reach the driving public and influence the flow of traffic. It also illustrates how satellites can be of benefit by offering seamless statewide coverage using a single communications technology.

Another author promotes the potential of the solar-powered satellite phone booth.[65] Placed along remote stretches of highway, such distress stations could act like safety sentinels, ready to bring help to stranded motorists. Such call boxes already exist using cellular technology. But these satellite booths would allow the concept to be extended into other areas beyond the reaches of the suburbs.

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[62]Ibid., p. 277.

[63]Orbital Sciences Corporation, ORBCOMM: Virtual Communications Absolutely Anyplace on Earth, no page number given.

[64]"Help with Directions as Close as Car Phone," The Seattle Times, 10 April 1994, p. A3.

[65]Grubb, "The Traveller's Dream Come True," p. 48.

A final illustration of how satellites might be put to productive use in transportation matters stems from the FAA's testing of "pilotless airplanes." During September of 1993, the FAA ran a demonstration outside Washington, DC of a computer-controlled twin-engine jet that guided itself to a landing site using GPS technology. The Associated Press reported that "...officials of the Federal Aviation Administration were positively gleeful as they unveiled a new satellite-based air traffic control system that can land a jetliner, in good weather or bad, without human help."[66] The GPS trial proved its worth by demonstrating its ability to land a plane with a margin of error of just a few feet. Such a system would seem equally applicable in the case of Washington State ferries as they try to find their way through banks of Puget Sound fog. The technology would not replace ferry boat captains, but could help them to navigate during times of bad weather. If satellites were used for ship-to-shore communications, as well, the GPS data could be piggybacked on those same radio channels.

Conclusion

Compared to many of the other technologies discussed in this report, satellite communications systems can not only do all the same tasks accomplished by cellular and radio data networks, for example, but they can do them better. Satellites like INMARSAT-A and INMARSAT-B offer fast and reliable data connections; as we all know firsthand from making long distance phone calls, satellites provide high-quality voice connections, as well (distinguishable by the slight delays one experiences during conversations). Fixed satellite systems like OmniTRACS and Geostar make possible reliable two-way messaging; they can also automatically include AVL tracking data along with their messaging signals. Add paging to their capabilities and you have a complete mobile communications package. So why all the bother with earth-bound personal communications services, radiopaging, and private land mobile radio when satellite links can do it all?

First, while satellite systems can support mobile communications, they have been, until recently, just barely portable. The first generation of satellite transceivers has been as bulky to carry as a piece of luggage—and the antennae have been inconvenient to lug around and a problem for some to set-up. Only recently have satellites begun to deliver handsets comparable to the larger cellular handsets that first accompanied that technology. Clearly, satellite transceivers have far to go to catch up with the cellular flip phones on the market today.

Second, satellite telephone and data service has been an oddity, of sorts. The limited channel capacity of geostationary satellites virtually insured that only the biggest accounts would have access to this somewhat eccentric mobile network. The number of satellite

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[66] James H. Rubin, "Pilotless Planes? Satellites Move Us One Step Closer," The Seattle Times, 15 September 1993, p. A3.

operators was small and their circle of customers was equally limited—confined to clients like cruise lines, television networks, and scientific expeditions—and beyond the reach of the ordinary person.

Third, satellite equipment and airtime were prohibitively expensive. It took deregulation to open the skies to increasing competition, both in the number of suppliers and in the technological approaches pursued. The rush of new operators with their innovative satellite deployment schemes should work to drive down customer service charges. Although satellite telephony will probably never match cellular phone service for price, it will provide a more reasonable alternative for travelers out of sight of cellular transmitter towers. If analyst predictions hold true, mobile satellite telephony will become commonly accepted as a cost effective option for professionals traveling into rural or undeveloped areas.

With the advances expected for satellite communications, it might initially seem reasonable for the Washington State DOT to switch all of its mobile telephony needs to satellite in order to establish a seamless, statewide departmental network. But such a change would be ill advised, since the advantages gained by creating a single mobile communications system for the DOT would be heavily out-weighed by the financial burden of higher network costs. As the Iridium planners have stressed repeatedly, even the best satellite systems can only serve as extensions of the terrestrial wireless infrastructure since they will never be able to directly compete on airtime costs. Yet satellite systems do have a special niche in their ability to provide the DOT with convenient communications links to rugged areas of the state in which field workers would otherwise remain isolated.

At present, the DOT must look to existing fixed satellite systems for providing mobile communications to outlying regions. Store-and-forward packet data satellites are in place and can offer two-way data messaging links along with AVL options. But DOT managers must decide whether pauses of several minutes would be a hindrance for departmental wireless communications or for relays of data from remote sensing devices. If the time lag is not a problem, then the store-and-forward systems might prove useful. Such services are also receiving solid competition from an alternative technology known as meteor burst, which will be covered in the next chapter. Meteor burst is limited, too, by transmission delays that can last seconds or minutes, but it is considerably cheaper than any satellite service.

Real-time voice and data communications to rural areas can also be established using fixed satellites that are already in place. A series of INMARSAT satellites have proven themselves to be reliable wireless carriers. Competition from newer entrants to the satellite field, like MSAT, will give the DOT the option of choosing among various providers and should help to lower the cost of instantaneous voice service to remote areas. An even stronger competitive threat will come from the new generation of low-earth-orbit satellites, if their ambitious programs can ever get off the ground.

Well publicized projects like Iridium and Teledesic—and lesser known efforts such as Globalstar and Ellipso—have made bold promises of pocket satellite phones (Pocsats) and reasonable airtime rates for everyday customers. Nets of little LEO's offering data relays and big LEO's adding voice channels are about to be cast over the heavens, delivering seamless worldwide communications grids. But some of these LEO systems are extremely ambitious. Teledesic, for instance, will involve the launch of 840 "smart" satellites at a cost of $9 billion (in 1994 dollars)! Whether any of the claims made for these satellite innovations will hold true is anyone's guess. <u>But if even one should come to fruition and make good on its service promises, it would offer the DOT a very attractive wireless network for providing instantaneous voice and data links to the far-flung reaches of the state</u>.

Chapter IX

Meteor Burst

Introduction

One author has described it as "Buck Rogers Technology."[1] Another calls it "exotic, bordering on magic."[2] Indeed, meteor burst communications is one of the more unorthodox technologies described in this report. In fact, its modus operandi is so unusual that it may actually have discouraged broad interest in its own application. But during the last two decades, meteor burst technology has experienced a renaissance, of sorts, and organizations frustrated with the high cost of satellite communications and the limitations of other localized communications networks have given "magical" meteor burst another look.

This chapter will emphasize the many advantages of meteor burst communications, as well as its few significant limitations. In the process, the reader should come to understand that the very factors that make meteor burst so unusual also make it very special. Meteor burst technology may have operational characteristics that push it beyond the comfort level of many potential customers. But the Washington State Department of Transportation must not dismiss it before giving it serious consideration. To quickly cast aside the potential of meteor burst would be a sorry mistake in that it would mark a missed opportunity to dramatically improve the DOT's state-wide wireless communications service.

Background

Meteor burst (MB) communications, which is sometimes also called meteor scatter, takes advantage of the fact that a million million (10^{12}) meteors stream through the earth's upper atmosphere every day. Many of these meteors are small—about the size of a grain of sand. As they enter the more dense air of earth's atmosphere they burn up, leaving brief ionized gas trails. As researchers noticed during the early 1930's, these ionized trails will reflect or re-radiate radio signals. It would take another twenty years, however, before the first operational meteor burst system would be constructed.

There are some regularly occurring meteor showers that intersect earth's orbital path at the same time each year. But it is the random meteor showers that strike with different intensities depending on the time of day and the time of year that are of greatest use for meteor burst communications. Scientists have detected that the heaviest influx of meteors takes place

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[1]Les Dennis, "Buck Rogers Technology—A Step in the Right Direction," in Meteor Burst Communications, ed. Donald L. Schilling (New York, NY: John Wiley & Sons, Inc., 1993), p. 1.

[2]Mark Hewish, "Meteor-burst Gets a Boost," Defense Electronics and Computing (Supplement to IDR), October 1990, no page number given.

each day at around 6 AM, making this the best time to send meteor burst messages; meteor showers reach their nadir about 6 PM. This important difference in the availability of usable meteor trails is plainly evident in a series of tests conducted by the U.S. Army's Communications-Electronics Command (CECOM), the results of which are contained in Table 9.1. Additionally, the summer months mark the annual height of the meteor shower season, with the best period running from May through November, peaking in July. On the other hand, the months of December through April exhibit relatively less meteor activity. (Note that the tests reflected in Table 9.1 were conducted in April.) The challenge, of course, is for operators to identify usable meteor trails in all seasons and use them to relay radio transmissions during the microseconds the trails sweep across the sky at the proper location—clearly, no simple task.

message length	messages sent	mean wait-time (minutes)	average number of transmissions per message	average throughput (words-per-minute)
Morning Tests				
50 characters	1,477	.10	3.23	105.9
150 characters	986	.16	5.10	179.7
250 characters	771	.22	6.56	229.6
Afternoon Tests				
50 characters	487	.46	3.28	22.5
150 characters	330	.69	5.07	43.6
250 characters	220	1.00	6.45	51.0

Table 9.1: Meteor Burst Test Performance Summary (April 1990)[3]

Meteor showers deposit their trails across the lower ionosphere, at altitudes between 50 and 71 miles above the earth.[4] This is fortunate because it frees MB communications from terrestrial weather disturbances. However, since it places the relay of radio signals at an altitude lower than that of geosynchronous satellites, MB messages cannot be transmitted quite as far. Limited by the curvature of the earth, MB transmissions can cover a maximum distance of about 1,200 miles. When the mobile and base stations are less than 100 miles apart, the

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[3]Source: Ibid.

[4]Information on the typical behavior of meteor showers and their usefulness as "natural satellites" can be found in works by : Bhushan Rele and Lee Han, "Meteor Burst Communication for Advanced Rural Transportation," (IVHS Preprint) (Blacksburg, VA: Virginia Polytechnic Institute and State University, 1993 IVHS America), no page number given; Davras Yavuz, "Meteor Burst Communications," IEEE Communications Magazine, September 1990, pp. 40-48; and Mark Hewish, "Meteor-burst Propagation," Defense Electronics and Computing (Supplement to IDR), October 1990, no page number given; among others.

groundwave component of the meteor burst radio signal eliminates any need to bounce transmissions off meteor trails. At that point, mobile and base units communicate much as they would using private land mobile radio signals, or any other line-of-sight (LOS) radio service.[5]

Most meteors leave initial trails about 15 miles long and a yard wide, but they begin to expand almost immediately due to diffusion. Atmospheric wind shear and turbulence also distort the straight-line patterns of meteor trails into serpentine shapes. Since the integrity of meteor trails is not long lived, meteor burst equipment must perform quickly to locate usable meteor paths and relay data bursts:

> The duration during which the electron density is high enough to support communications varies from a fraction of a second to several seconds. Trails with densities below 10^{14} electrons/m are described as "underdense," while those above this level are referred to as "overdense." The cross-section of an overdense trail is such that radio signals are reflected. With underdense trails, the radio signal passes through rather than being reflected. This excites the electrons, which act as antennas and re-radiate the signal. Underdense trails are more common, but overdense trails generally last longer and can provide high [data] throughput. Both types of trail acts as directional antennas, with the signal's angle of reflection being equal to the angle of incidence. The area of reception (footprint) of a typical trail is an oval up to 40 km [25 miles] long, with the major axis being along the line between the two stations.[6]

The unique operational features of MB provide the service with some performance advantages over more conventional radio networks. For example, decades of testing have shown that the most suitable carrier frequencies for meteor burst are between 30 and 50 MHz;[7] (although usable MB signals have been employed between 30 and 90 MHz, the fringe frequencies do not provide optimum data throughput). Falling as they do between the high frequency (HF) and very high frequency (VHF) radio services, the optimum meteor burst frequencies between 30 and 50 MHz are more readily available for licensing by the FCC than frequencies found at other places in the radio spectrum.

The specific location of the meteor region in the earth's atmosphere is fortunate because it avoids many of the natural ionospheric disturbances that disrupt other radio services, like AM radio, for example. The 25-mile reception footprint characteristic of meteor burst is another plus. Since this footprint is so small, it is conducive to frequency reuse. When combined with the fact that mobiles separated by at least 25 miles will use different meteor trails occurring at different times in order to communicate with base stations, these peculiarities of MB create a

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[5]Telephone interview with Tom Donich, vice president of engineering, Meteor Communications Corporation, Kent, WA, 22 July 1994. Phone: (206)251-9411.

[6]Hewish, "Meteor-burst Propagation," no page number given.

[7]See, for example: Rele and Han, "Meteor Burst Communication for Advanced Rural Transportation," no page number given; Hewish, "Meteor-burst Gets a Boost," no page number given; and Yavuz, "Meteor Burst Communications," p. 40; among others.

sort of natural time-division multiplexing that increases channel efficiency.[8] In sum, the random nature of MB transmissions reduces electromagnetic "pollution," or interference.

Early on, the advantages of MB for military communications were obvious. MB transmissions were difficult for opposing forces to intercept because of the small reception area that is supported. In addition, the small footprint made MB messages hard to electronically jam, since any jamming system would have to be near the MB transceiver to be effective. The naturally occurring random variations in meteor arrival also aided clandestine communications. Meteor burst signals are not as susceptible as other radio signals to the distortions caused by the effect of nuclear radiation on ionospheric propagation. Perhaps most obvious, there is no external hardware—like a satellite or permanent earth station—that can be disabled by enemy fire. Improvements in solid state electronics made MB equipment increasingly mobile. As a result, MB transmitters could be deployed to remote regions and connected to remote sensing devices, thereby providing friendly "eyes and ears" in dangerous or foreign regions.

Finally, MB equipment has been simplified to the point where it is more readily affordable. At least one estimate indicates that MB mobile transceivers cost half that of mobile satellite transceivers.[9] These features provide today's civilian MB conversations the same security and reliability they have long offered to military dispatches.

Obviously, meteor burst is not without its drawbacks, however. One hindrance is the fact that there is no agreed-upon MB standard. There is reportedly an effort by the military to establish its own standard,[10] but currently all MB operating systems and equipment are proprietary. As a result, customers become permanently tied to one equipment supplier whenever they make a decision on which vendor to support; equipment available from different vendors is not interchangeable.

For most potential users, an even greater handicap is the wait-time that occurs whenever a message is to be transmitted by a base station or a mobile. Meteor burst communications are not instantaneous like satellite transmissions but have to wait for the proper meteor trail to appear before radio contact can be made. The wait-time is commonly longer for the mobile unit than it is for the base station because the mobile operates on a much lower transmitter power, which limits the number of suitable meteor trails. This difference is clearly evident in the results of a meteor burst test conducted by Bhushan Rele and Lee Han. (See Table 9.2.) When using a carrier frequency of 50 MHz, the base station incurred an average wait-time of 1.49 minutes; the mobile, however, had to wait an average of 9.21

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[8]Hewish, "Meteor-burst Propagation," no page number given.

[9]Ira Brodsky, "Wireless Data Networks and the Mobile Workforce," Telecommunications, December 1990, p. 34.

[10]The draft U.S. military standard is known as MIL-STD-188-135. See: Yavuz, "Meteor Burst Communications," p. 47.

minutes to complete its transmission. The longest wait-time recorded for the mobile was 17.27 minutes—a hefty delay, indeed. Clearly, meteor burst is not an appropriate communications technology to be used in emergency situations, when seconds matter most. However, there are a host of other communications tasks, such as the forwarding of remote sensor readings, for which time is not of the essence.

Another disadvantage for meteor burst is its relatively slow data transmission rate, especially in comparison with satellite communications. Meteor burst transceivers can transmit using variable rates from 2 kilobits-per-second to 32 kilobits-per-second; the transmission rate can be dynamically assigned based on an evaluation of the highest rate any single meteor trail will support. However, the window available for any transmission depends on the decay rate of the meteor trail, and that limits the number of data packets that can be sent at any one time. For longer messages, the data packets can be transmitted over subsequent meteor trails and then joined together at the receiving end, but this will entail even longer delays. Nevertheless, as Table 9.1 displayed, the average throughput possible over a MB channel can range from 22.5 words-per-minute to 229.6 words-per-minute; and those are figures gathers from a test in April when meteor shower activity is quite low. Again, while this low data rate is limiting in some situations, it is totally adequate for many other tasks.

	Central Base Station 1,000 W			Mobile Unit 10 W		
	30 MHz	40 MHz	50 MHz	30 MHz	40 MHz	50 MHz
Best	0.714	0.11	0.154	0.716	1.105	1.55
Worst	0.79	1.212	2.09	8.127	12.56	17.27
Average	0.709	1.07	1.49	5.526	7.271	9.21

Table 9.2: Sample Waiting Times for Meteor Burst Transmissions (in minutes)[11]

One final shortcoming for meteor burst communications is that it is limited to data transmissions. There are some MB systems designed for the military that do permit what is called Near-Real-Time-Speech (NRTS), which makes use of voice synthesizers.[12] However, all commercial MB equipment is optimized for data transmission only. For some customers this drawback is only an inconvenience, while for others it is enough to discourage further consideration of meteor burst altogether.

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[11]Source: Rele and Han, "Meteor Burst Communication for Advanced Rural Transportation," no page number given.

[12]Yavuz, "Meteor Burst Communications," p. 46.

Broadcast, Channel Probing, and ARQ Meteor Burst Systems

There are two general approached that have been taken in the design of functional meteor burst systems: one is a broadcast protocol and the other is a channel probing protocol. A third protocol, known as the Automatic Retransmission Request (ARQ) process, is a cross between the two more generic systems and has similarities with both.[13]

With a broadcast system, equipment at the transmitting end does not search for usable meteor trails but, instead, repeatedly broadcasts message packets for a long enough duration as to ensure a likely probability that the complete information was received. Identical software configurations at the transmitting and receiving stations guarantee that message packets are deciphered correctly.

Channel probing MB systems are more common than broadcast systems. Under this protocol, the transmitter sends a brief probing signal of between 5 to 20 microseconds at frequent intervals until it elicits a response from a network receiver. This response will only occur if a meteor trail is at the proper angle to relay the message to the desired receiver. This process is referred to as the "handshake" or as "trail acquisition." Once the handshake has been established, a certain amount of message data is transmitted depending on the system's estimation of the meteor trail's useful life. Most meteor trails will support between 100 and 300 microseconds of transmitted data. If there is more data to be sent after that meteor trail has vanished, the initiating transmitter begins the process anew with another probing signal. Since the data is packetized, any subsequent transmissions simply pick up where the last transmission link was cut short.

If the radio signals from the transmitter and receiver employ different frequencies, the meteor burst system supports duplex communications and is, thereby, able to relay more information in the limited time available. If a single frequency is used by both the transmitter and receiving equipment, the system is simplex and is not able to transmit as much data over a comparable meteor trail.

There is a third type of MB system which is a sort of hybrid between the broadcast and channel probing protocols. This ARQ system uses the first packet of data as a sort of probing signal. While rapidly sending this first packet of data, the transmitter also listens for acknowledgment of a clear connection from a receiving device. Once the transmitter is signaled an acknowledgment, it starts sending the rest of the message packets until the transmission is complete.

According to one researcher, the ability of the channel probing and ARQ protocols to identify and harness the productive potential of passing meteor trails before they fully dissipate

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[13]This description of the three different types of MB systems is gleaned from a discussion by Davras Yavuz in his article "Meteor Burst Communications," pp. 41-42.

offers a 20 percent improvement in communications efficiency by either boosting throughput or decreasing waiting times.[14]

Meteor Burst History

It has already been mentioned that the earliest awareness of meteor burst phenomena came during the early 1930's. While scientists had recorded evidence of MB activity, they did not yet understand it. It was not until after World War II, as the VHF and ultra-high frequencies (UHF) came into common use, that scientists came to appreciate the productive potential of MB transmissions for beyond-line-of-sight (BLOS) communications.[15] Inquiries into the process of meteor burst went forth worldwide. Researchers came to quickly appreciate the small reception footprint associated with MB communications, which lent the transmissions a certain degree of privacy. As a result, their military usefulness took precedence and much of the research on the topic in the U.S. remained classified until the end of the 1950's.

Gradually experimental meteor burst networks were established as different organizations probed the useful application of this newly discovered phenomenon. One of the first was the JANET system (named for the Roman god Janus, who could see in two directions at once), which was developed by the Radio Physics Laboratory of the Canadian Defense Research Board in 1953. JANET provided a point-to-point teletype link between Ottawa and Port Arthur. In the United States, similar meteor burst systems were established by the National Bureau of Standards (NBS) (1953) and the Stanford Research Institute (SRI) under contract with the U.S. Air Force (early 1950's); Hughes Aircraft, also under contract with the Air Force, conducted some research into meteor burst, too. But in 1957, with interest in meteor burst at an all-time high, the Sputnik satellite was launched and attention quickly turned to the development of space satellites rather than meteor burst communications.

Interest in meteor burst did not disappear altogether, however. During the 1960's the NATO SHAPE Technical Center established the first meteor burst system intended to carry military communiqués. Known as the COMET system, it was used to shuttle teletype messages between The Hague, Netherlands and southern France. During the 1970's, a major meteor burst network was developed to measure and relay meteorological and snow depth data from hundreds of remote sensing stations across the western U.S. The transmitters used solar collectors to provide them with the little power they needed to operate. The network, known as SNOTEL for SNOwpack TELemetry, was designed by the Meteor Communications

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[14] Ibid., p. 42.

[15] Historical accounts concerning the development of meteor burst technology can be found in: Dennis, "Buck Rogers Technology—A Step in the Right Direction," in Meteor Burst Communications, pp. 1-7; and Jay A. Weitzen, "Meteor Scatter Communication: A New Understanding," in Meteor Burst Communications, ed. Donald L. Schilling (New York, NY: John Wiley & Sons, Inc., 1993), pp. 10-12.

Corporation (MCC) in Kent, WA and was operated by the U.S. Department of Agriculture.[16] Although meteor burst had been pushed into the background, useful applications were still being created.

Some of the earliest meteor burst equipment had been hindered by its reliance on vacuum tube technology, which made it bulky and less reliable. The development of the transistor and improved microprocessors would prove to be vital to the health of meteor burst technology. Jay A. Weitzen explains how several developments converged to renew scientific interest in MB applications:

> By the early 1980s the perceived vulnerability of satellite and terrestrial land line communication for military applications stimulated a revival of meteor scatter communication as a backup communication media....Networks with multiple interconnected master stations capable of intercontinental range were fielded. Advanced coding techniques were incorporated into terminals to improve their performance on weak scatter channels.
>
> Theoretical work showed that by using techniques that match information transfer rate to the dynamic capacity of the channel, large increases in throughput could be achieved....Improvements in antenna technology allowed meteor scatter to compete with more conventional techniques such as HF [high frequency radio services].[17]

Despite its operational limitations, the relatively low cost and simple design of meteor burst technology is providing an attraction that is helping it to compete with satellite communications. New applications are appearing on the scene to lift MB out of the purely military realm and establish it as the centerpiece for a host of commercial communications services. Some of the most ambitious meteor burst systems to date—including JANET and SNOTEL—are listed in Table 9.3 along with their most pertinent features.

Applications

The growing number of meteor burst applications can be grouped broadly into three main categories: mobile communications, global positioning, and remote sensing. This section will describe some of the real-world applications of meteor burst that fall into each of these categories, or some combination of the three. Military uses will not be discussed since much of the information on that topic is classified and is less applicable than current commercial applications.[18]

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[16] In addition to MCC, other leading meteor burst system suppliers include: Hadron Communications Product Division, ITT Defense Communications Division, Pegasus Message (Herndon, VA), and Broadcom. See: Hewish, "Meteor-burst Propagation," no page number given; and Brodsky, "Wireless Data Networks and the Mobile Workforce," p. 34.

[17] Weitzen, "Meteor Scatter Communication: A New Understanding," in Meteor Burst Communications, p. 12.

[18] Military organizations using meteor burst communications equipment include: the Chinese People's Liberation Army, the Royal Australian Air Force, the United Kingdom's Ministry of Defense, the U.S. Navy in

Characteristic	JANET	SNOTEL	AMBCS[19]	BLOSSOM[20]
date	1954	1967	1976	1986
test/service	test	service	service	test
type	point-to-point	network	network	point-to-point
simplex/duplex	duplex	simplex	simplex	simplex
transmit power	500 W	2 kW	0.3-5 kW	650 W
frequency	40 MHz	40-50 MHz	40-50 MHz	37-72 MHz
antenna/transmit	4 x Yagi (5)	Omni	Omni	Yagi (4)
antenna/receive	4 x Yagi (5)	4 x Yagi	6 x Yagi	Yagi (4)
modulation	AM/PM	2PSK	2PSK	FSK
rate	650 bits/sec	2,000 bits/sec	2,000 bits/sec	2,400 bits/sec
coding	n/a	Manchester CRC	Manchester CRC	Various

Table 9.3: Key Characteristics of Past and Current Meteor Burst Systems[21]

Mobile Communications

Despite its shortcomings of low data transmission speeds and moderate-to-long wait-times, MB is still a viable mobile communications technology in many situations. Of course, MB is not a good system choice for those instances that require instantaneous, fully-interactive radio communications. But in a large number of cases, the slight inconvenience caused by meteor burst's transmission peculiarities is far outweighed by the cost savings and ease of MB equipment operation. Although MB cannot provide voice communications like the satellite services, it can match most data intensive tasks—even if it is a little slower. Guy Wallin, the executive vice president and chief operating officer of MCC, tells of the usefulness of MB for mobile communications:

> Trucking companies can tell customers exactly where each of their shipments are [sic] located on the road [using Automatic Vehicle Location, AVL, incorporated into the MB service]. They can send and receive faxes, accurately transmit detailed

the Mediterranean, the U.S. Army's Southern Command, the U.S. Coast Guard in Alaska, and NORAD (as a back-up to its regular communications network). Hewish, "Meteor-burst Propagation," no page number given.

[19]A meteor burst network designed to perform much the same tasks as SNOTEL was the Alaska Meteor Burst Communications System, or AMBCS. Built a decade after SNOTEL, AMBCS has reportedly performed well and proven to be a cost effective system for relaying remote environmental data. Yavüz, "Meteor Burst Communications," p. 46.

[20]BLOSSOM is an acronym for Beyond Line Of Sight Signaling Over Meteors. It is a meteor burst application being developed by the Royal Aircraft Establishment in the United Kingdom to serve various air-to-ground functions. Ibid.

[21]Adapted from: Ibid.

> messages, send proof of signature, record pick-ups and deliveries, perform computer-aided dispatch, and constantly monitor fleet safety conditions like oil pressure and valve temperature—all with on-board computers that speak directly to computers at headquarters.[22]

Of course, in the past much of this information was gathered by truckers en route and passed on when they arrived at their destinations to make pickups and deliveries. The big advantage now is that MB makes it possible to inexpensively relay such data in real time, which improves performance efficiencies and facilitates "just-in-time" manufacturing schedules. In addition to facilitating mobile communications between control centers and field employees, MB can also be used for communications between mobile units.

Global Positioning

The advantages of AVL should be obvious: it allows dispatch centers to know the location of all company vehicles at any time.[23] This information makes it possible to reroute the vehicle closest to an emergency scene, saving precious minutes. It also makes it possible for controllers to spot vehicles that are disabled or misdirected. In at least one case, AVL aided police in their efforts to recover a stolen semitrailer with all its contents still inside.[24]

According to Fred Anderson, a systems engineering manager with MCC, an AVL device can be interconnected with an on-board meteor burst transceiver to automatically relay vehicle position coordinates every ten minutes using MB radio channels.[25] Global Positioning System (GPS) devices from Motorola, for example, cost only $400 apiece. Such AVL equipment picks up latitude and longitude coordinates from either a satellite GPS or a LORAN network. Using these coordinates, the AVL technology can calculate the vehicle's location with an error margin of about six city blocks.[26]

Remote Sensing

One of the most touted applications for MB has been in the area of remote sensing. The technical abilities of MB fit well the demands associated with the unmanned monitoring and relay of environmental data. In such instances, another key feature of MB has been put to productive advantage: that is, the low-power requirements of meteor burst field transceivers. Since these transceivers consume little electricity, it has been possible to power them using batteries that are continuously recharged by solar cells. In fact, this is just the design that was

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[22]Guy Wallin, "'Heavenly Data is Keeping Truckers 'Just-in-Time,'" Puget Sound Business Journal (Special Report: Telecommunications), 1-7 July 1994, p. 19.

[23]Gary Stix, "Meteoric Messages: Keeping Tabs on Trucks, Volcanoes and the Nile," Scientific American, September 1990, p. 167.

[24]Ibid.

[25]Telephone interview with Fred Anderson, systems engineering manager, Meteor Communications Corporation, Kent, WA, 18 July 1994. Phone: 1-800-503-3062, or (206) 251-9411.

[26]Wallin, "'Heavenly Data is Keeping Truckers 'Just-in-Time,'" p. 19.

employed with the SNOTEL network—one of the world's largest meteor burst communications systems. This system ties together the environmental readings supplied by 700 data terminals distributed across ten western states. Using a star network configuration, these remote stations feed their findings to two master stations; the collected data is later consolidated in a computer database maintained in Portland, OR. Over the twenty years that SNOTEL has been in operation, its managers claim a reporting reliability of more than 99 percent.[27]

An equally impressive application of MB's remote sensing abilities is evident in the $300 million project to track the water levels of the Nile and ensure that the river meets the Egyptian population's demands for water without violating water sharing agreements with other African nations.[28] The Irrigation Management System (IMS) is being overseen by Egypt's Ministry of Public Works and Water Resources (MPWWR) and should be completed sometime in 1995. Using 560 data collection sites along the Nile, irrigation canals, and water drains, the IMS meteor burst network will establish an historical database including information on: 1) water levels; 2) water quality; 3) regulator gate positions; 4) pump station status; and 5) climatological factors. The resulting database will help public works officials to better manage Egypt's water resources. Like the SNOTEL system, the Egyptian MB network is being designed by MCC.

Closer to home, remote sensors attached to MB transceivers are being used to relay information on the status of the snow base atop Mount St. Helens.[29] Rapidly melting snow inside the mountain's crater might signal an imminent eruption, so the condition of snow deposits are continuously monitored and relayed along meteor burst radio channels. Likewise, a meteor burst system is being used in the Himalayas to monitor snow levels.[30]

Transportation-Specific Applications

It doesn't take much imagination to envision the wide variety of applications meteor burst communications could have in transportation-related situations. Clearly, MB could provide a useful back-up system to the DOT's existing private land mobile radio network. Its robust performance in the face of ionospheric disturbances, as well as its inherent security from eavesdroppers, would make it a useful adjunct radio service, especially in times of public emergency. Additionally, meteor burst could provide the DOT with a relatively inexpensive yet reliable technology for providing wireless communications to workers in some of the outlying regions of the state. Admittedly, MB technology would not support the type of interactive voice

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[27]Hewish, "Meteor-burst Propagation," no page number given.

[28]Cheryl Hohenstein, "Computers in Agriculture: Managing the Nile with Computers," Business Computer User, August 1991, pp. 14-15.

[29]Stix, "Meteoric Messages: Keeping Tabs on Trucks, Volcanoes and the Nile," p. 167.

[30]Wallin, "'Heavenly Data is Keeping Truckers 'Just-in-Time,'" p. 19.

messaging common on the DOT's highway maintenance channels. Nevertheless, its potential usefulness for the relay of short dispatch messages, followed by brief acknowledgments from mobile units, should not be overlooked.

A MB system enhanced with AVL capabilities would have obvious advantages. DOT dispatch centers would be able to track the changing locations of road crew vehicles and snow plows, practically in real time. As a result, the Department's manpower and mobile resources could be deployed most effectively. Ferries, too, could be tracked and their positions pinpointed on an electronic map showing regularly updated boat positions.[31]

In addition to its mobile communications and AVL capabilities, MB could offer the DOT a flexible remote sensing link of tremendous value, as it has proven in many other situations around the globe. Two researchers, Bhushan Rele and Lee Han, suggest that meteor burst could provide the technological foundation for an Advanced Traveler Information System (ATIS) to serve rural areas, which are much less readily accessible by DOT road crews than are urban freeways.[32] Remote sensors on hazardous sections of country roads could signal a centralized control center when water begins freezing on road surfaces, for example. Control center personnel could then respond over MB channels to activate electronic warning displays along the roadway; an historical database of our state's highway conditions could be assembled at the same time, they explain. In situations like this, the low data rate and minute-long wait-times associated with meteor burst are inconsequential.

The State has two options should it decide to employ meteor burst technology to assist DOT communications: it could construct its own MB network at a relatively low cost, or it could contract with a radio common carrier to use a privately-owned MB system. According to Fred Anderson, with MCC, a State-built meteor burst network would probably require the establishment of two base stations—one in Spokane and the other in Vancouver, WA—as well as a mini base station sited in Seattle, in order to ensure blanket coverage. DOT vehicles would have to be outfitted with radio frequency (RF) modems, data terminals, and special antennae; AVL devices would cost extra. Before such a project could even be attempted, the State DOT would have to obtain an operating license from the FCC, but, according to Anderson, licenses for that portion of the spectrum are not terribly hard to procure. The primary costs of developing such a MB network are outlined in Table 9.4.

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[31] This application was suggested during a telephone interview with Tom Donich, MCC, 22 July 1994. Donich noted that the Canadian Coast Guard is already using AVL data transmitted over MB technology to track Chinese fishing boats in Canadian waters.

[32] Rele and Han, "Meteor Burst Communication for Advanced Rural Transportation," no page numbers given.

	Operator Equipment	Airtime Prices
State-built and Operated Meteor Burst System	Two base stations & one mini base station:[33] $510,000 Modems for 50 vehicles: (@ $3,000 ea.)[34] $150,000 Optional positioning devices for 50 vehicles: (@ $400 ea.) $20,000 Data terminals for 50 vehicles: (@ $2,000 ea.)[35] $100,000 Vehicle antennae for 50 vehicles: (@ $200 ea.) $10,000 **TOTAL COST: $790,000**	Only the cost of securing frequencies from the FCC[36]
Meteor Communications Corporation, Kent, WA Meteor Burst Radio Common Carrier	Modems for 50 vehicles: (@ $3,000 ea.) $150,000 Optional positioning devices for 50 vehicles: (@ $400 ea.) $20,000 Data terminals for 50 vehicles: (@ $2,000 ea.) $100,000 Vehicle antennae for 50 vehicles: (@ $200 ea.) $10,000 **TOTAL COST: $280,000**	$50-$75/month/mobile

Table 9.4: Primary Meteor Burst Costs[37]

[33]Base stations supplied by MCC cost $250,000 apiece; a mini base station would cost $10,000. Although one base station alone would be sufficient to provide meteor burst coverage of the entire state, the additional base stations suggested in this table would help to reduce wait-time and would boost system performance. If the DOT envisions the primary application of meteor burst as a technology to support the relay of remote sensing data, then wait-time becomes less important and a single base station is all that would be necessary. Telephone interviews with: Fred Anderson, MCC, 18 July 1994; and Tom Donich, MCC, 22 July 1994.

[34]Fred Anderson anticipates that prices for MCC-supplied RF modems will soon drop to $2,500 each as design changes are incorporated into current equipment. Telephone interview with Fred Anderson, MCC, 18 July 1994.

[35]Prices for data terminals can range anywhere from $400 to $3,000. The $2,000 price listed in the table was selected as a middle-of-the-road estimate intended to facilitate cost comparisons between MB and other mobile technologies. Telephone interview with Fred Anderson, MCC, 18 July 1994.

[36]Fred Anderson has indicated that frequency allocations between 30 MHz and 50 MHz are not as difficult to obtain from the FCC as are other more desirable spectrum slots. Telephone interview with Fred Anderson, MCC, 18 July 1994.

[37]Source: Telephone interview with Fred Anderson, MCC, 18 July 1994.

As a second option, the State could still purchase MB equipment for its trucks but could avoid the major expense of constructing base stations by purchasing airtime from a private supplier, like MCC, which has excess capacity on its own MB network. (See Table 9.4.)

Conclusion

That a technology like meteor burst functions at all certainly does seem "magical." Yet it does work effectively and, as its track record with the SNOTEL project demonstrates, it can work very well when used in those situations that best take advantage of its capabilities.

MB is a data-only technology, and a low-data-rate technology at that. It cannot support real-time interactive messaging, since there are delays of several minutes while the system controller locates suitable meteor trails for relaying radio signals. Plus, MB is a medium BLOS technology, and, as such, does not have the geographic reach of geosynchronous satellites. Despite these handicaps, meteor burst does fill an important mobile communications niche and could prove to be of substantial value to the Washington State DOT.

While it is true that MB transmissions can take several minutes to complete, it is important to remember that the delay for messages originating from the base station is commonly much shorted than for signals coming from mobile units. Since many dispatch situations only require simple acknowledgments from employees in the field, the brevity of such replies increases the likelihood that responses from mobile workers will be forwarded quickly. Also, in a dispatch situation, the predominant requirement of the communications situation is to forward commands from a centralized control center, with less time-sensitive value placed on inquiries from remote crews. Hence, the faster relay time associated with base station messages is a positive feature.

Although the short life of ionized meteor trails limits the length of messages that can be transmitted over the temporary "circuit" they support, network software does permit the transfer of longer messages, which are simply a string of shorter messages assembled at the receiving end. Additionally, some customers create internal codes that make shorter messages easy to create.

Meteor burst channels have proven that they are more robust than conventional radio services that are disrupted by daily fluctuations in the ionosphere, so they can be counted on for reliable communications in most emergency situations. MB networks are also inherently more private and secure, due to the small area of the reception footprint associated with the technology and the random pattern of MB radio connections. Over forty years of strong military interest in MB from governments around the world attests to the functionality and reliability of this specialized radio service. Meteor burst remote transceivers have also become increasingly mobile and durable thanks to improvements in solid state engineering.

It has been mentioned previously that meteor burst systems cannot transmit messages as far as geosynchronous satellites. That is not a problem when considering the technology's possible application by the DOT, since the 1,200 mile range is more than enough to provide blanket coverage of Washington State, which is approximately 350 miles wide at its broadest point.

Perhaps foremost among meteor burst's qualifications are its reasonable equipment costs and elimination of airtime costs, for self-owned MB networks. As an executive with MCC has commented: "Meteors are free—you don't have to worry about leasing a satellite channel."[38] When one notes the small number of base stations required to provide statewide radio coverage—especially in comparison with other competing technologies like cellular telephony, paging, and private land mobile radio—the cost advantages of meteor burst stand out as one of its most attractive features. When compared with the only other wireless technology able to provide true long-distance mobile coverage—satellites—the smaller price tag associated with initiating and maintaining a meteor burst system demands serious consideration from prospective mobile communications users. Some of the key characteristics that differentiate MB from satellite communications are summarized in Table 9.5, which concludes this chapter.

Technology	Data Throughput	Range	Bandwidth Supported	Initial Cost	Operating Cost
Geosynchronous Satellite	6,400 bps to 19,200 bps	6,200 miles	hundreds of MHz	$200 million	high
Big LEO (estimated figures)	2,400 bps to 16,000 bps	3,000 miles	10-15 MHz	$280 million to $9 billion	high
Meteor Burst	600 bps to 2,400 bps	1,200 miles	up to 1 MHz (during bursts)	$750,000 to $1 million	low to moderate

Table 9.5: Primary Satellite and Meteor Burst Performance Comparisons[39]

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[38]Quote from Donald Sytsma, president, MCC, as cited by: Stix, "Meteoric Messages: Keeping Tabs on Trucks, Volcanoes and the Nile," p. 167.

[39]Based on information from: Yavuz, "Meteor Burst Communications," p. 42; and Rele and Han, "Meteor Burst Communication for Advanced Rural Transportation," Table 1, no page numbers given. Geosynchronous and LEO satellite data adapted from previous chapter.

Appendix A:

Digital Cellular: Top Markets and Plans

DIGITAL CELLULAR: TOP MARKETS AND PLANS[1]

Carrier	TDMA	N-AMPS	CDMA	Activation Date
<u>BALTIMORE</u>				
Cellular One	•			6/94
Bell Atlantic Mobile	•			2/94
<u>ATLANTA</u>				
AirTouch Cellular			•	TBD
BellSouth Mobility	•			12/96 at latest
<u>BOSTON</u>				
Cellular One	•			6/94
NYNEX			•	TBD
<u>CHICAGO</u>				
Cellular One	•			7/93
Ameritech	?			
<u>CLEVELAND</u>				
Cellular One	?			
GTE Mobilnet	?			
<u>DALLAS/FT. WORTH</u>				
MetroCel	•			TBD
Southwestern Bell	•			1/94
<u>DENVER</u>				
Cellular One	•			TBD
US West Cellular		•		7/93
<u>DETROIT</u>				
Cellular One	?			
Ameritech	?			
<u>HOUSTON</u>				
Houston Cellular	•			TBD
GTE Mobilnet	?			
<u>INDIANAPOLIS</u>				
Cellular One	•			TBD
GTE Mobilnet	?			

? = undecided

TBD = to be decided

[1]Adapted from a table included in an article written by: Connie Brown, "Do You Need Digital?" <u>Cellular Buyers' Guide</u>, Summer 1994, p. 21.

Carrier	TDMA	N-AMPS	CDMA	Activation Date
MIAMI/FT. LAUDERDALE				
Cellular One	•			2/93
BellSouth Mobility	•			12/96 at latest
LOS ANGELES				
LA Cellular	•			11/93
AirTouch Cellular			•	Early '95
MINNEAPOLIS				
Cellular One	•			TBD
US West Cellular		•		8/93
NEW YORK				
Cellular One	•			4/94
NYNEX			•	Early '95
PHILADELPHIA				
Comcast Metrophone	?			
Bell Atlantic Mobile	•			2/94
PHOENIX				
Bell Atlantic Mobile	•			TBD
US West Cellular		•		TBD
PITTSBURGH				
Cellular One	•			TBD
Bell Atlantic Mobile	•			4/94
SAN DIEGO				
US West Cellular		•		3/94
AirTouch Cellular			•	TBD
SAN FRANCISCO/SAN JOSE				
Cellular One	•			10/93
GTE Mobilnet	?			
SEATTLE				
Cellular One	•			**7/93**
US West Cellular		•		**6/93**
ST. LOUIS				
Cybertel	?			
Southwestern Bell	•			9/93
TAMPA				
Cellular One	•			2/93
GTE Mobilnet	?			
WASHINGTON, DC				
Cellular One	•			3/94
Bell Atlantic Mobile	•			2/94

? = undecided

TBD = to be decided

Appendix B:

FCC Highway Maintenance VHF Radio Allocations

FCC HIGHWAY MAINTENANCE VHF RADIO ALLOCATIONS

FREQUENCY (MHz)	ASSIGNED SERVICE
33.020	Special Emergency/Highway Maintenance
33.040	Special Emergency
33.060	Special Emergency/Highway Maintenance
33.080	Special Emergency
33.100	Special Emergency/Highway Maintenance
37.900	Highway Maintenance/Special Emergency
37.920	Highway Maintenance
37.940	Highway Maintenance/Special Emergency
37.960	Highway Maintenance
37.980	Highway Maintenance/Special Emergency
45.680	Highway Maintenance
45.700	Police
45.720	Highway Maintenance
45.740	Police Mobile
45.760	Highway Maintenance
45.780	Police Mobile
45.800	Highway Maintenance
45.820	Police Mobile
45.840	Highway Maintenance

FREQUENCY (MHz)	ASSIGNED SERVICE
47.020	Highway Maintenance
47.040	Highway Maintenance
47.060	Highway Maintenance
47.080	Highway Maintenance
47.100	Highway Maintenance
47.120	Highway Maintenance
47.140	Highway Maintenance
47.160	Highway Maintenance
47.180	Highway Maintenance
47.200	Highway Maintenance
47.220	Highway Maintenance
47.240	Highway Maintenance
47.260	Highway Maintenance
47.280	Highway Maintenance
47.300	Highway Maintenance
47.320	Highway Maintenance
47.340	Highway Maintenance
47.360	Highway Maintenance
47.380	Highway Maintenance
47.400	Highway Maintenance

150.995	Highway Maintenance
151.010	Highway Maintenance
151.025	Highway Maintenance
151.040	Highway Maintenance
151.055	Highway Maintenance
151.070	Highway Maintenance
151.085	Highway Maintenance
151.100	Highway Maintenance
151.115	Highway Maintenance

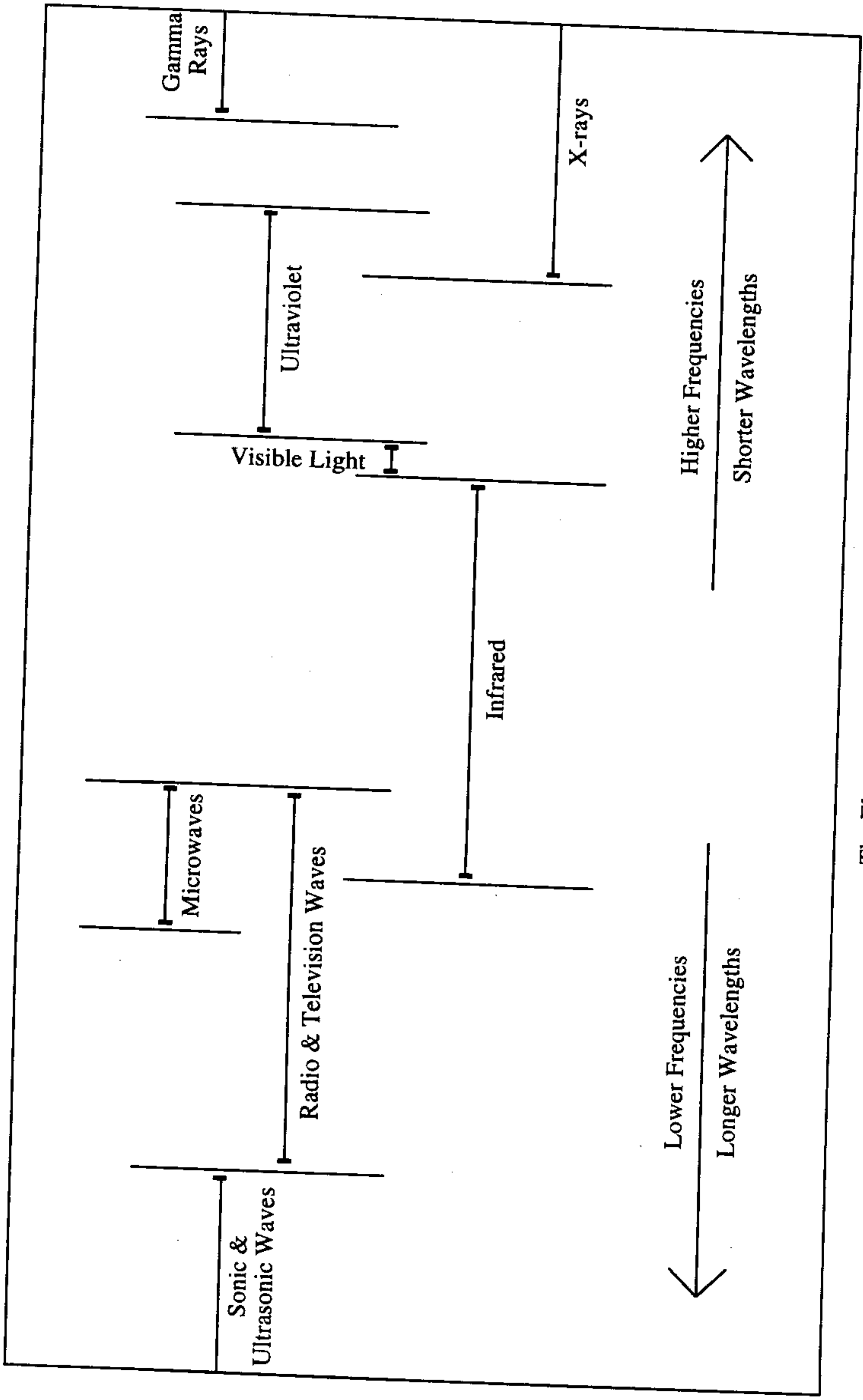
151.130	Highway Maintenance

FREQUENCY (MHz)	ASSIGNED SERVICE
156.045	Highway Maintenance Mobile
156.060	Highway Maintenance Mobile
156.075	Highway Maintenance Mobile
156.090	Police Mobile
156.105	Highway Maintenance
156.120	Highway Maintenance
156.135	Highway Maintenance
156.150	Police Mobile
156.165	Highway Maintenance
156.180	Highway Maintenance
156.195	Highway Maintenance
156.210	Police
156.225	Highway Maintenance
156.240	Highway Maintenance

FREQUENCY (MHz)	ASSIGNED SERVICE
158.970	Police
158.985	Highway Maintenance
159.000	Highway Maintenance
159.015	Highway Maintenance
159.030	Police
159.045	Highway Maintenance
159.060	Highway Maintenance
159.075	Highway Maintenance
159.090	Police
159.105	Highway Maintenance
159.120	Highway Maintenance
159.135	Highway Maintenance
159.150	Police
159.165	Highway Maintenance
159.180	Highway Maintenance
159.195	Highway Maintenance
159.210	Police

Appendix C:

The Electromagnetic Spectrum



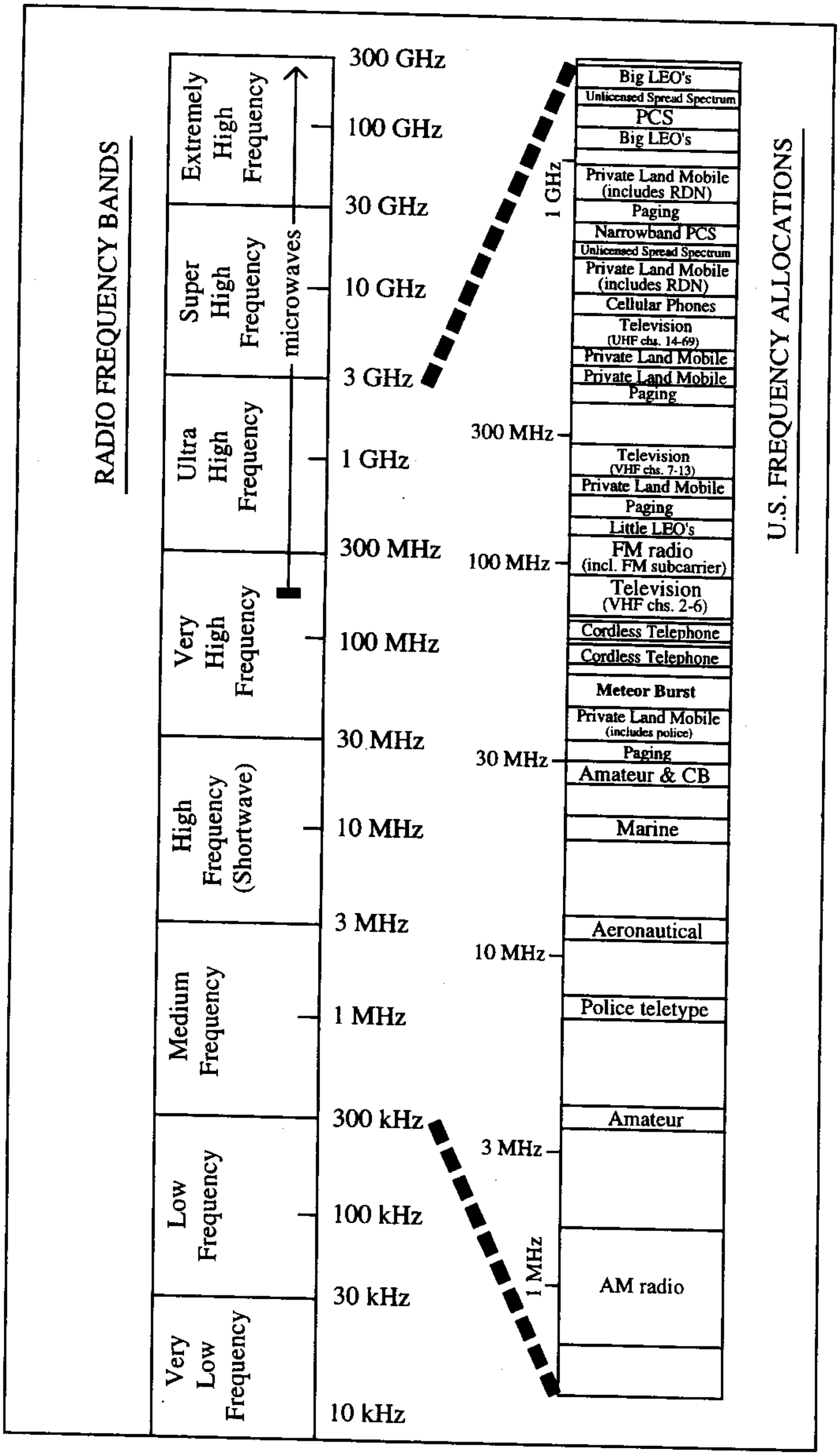
The Electromagnetic Spectrum

(Adapted from chart: Electromagnetic Spectrum, "Infrared Technology: Moving at Light Speed," PC Novice, April 1994, p. 83.)

(relative scale is not exact)

Appendix D:

Radio Frequency Bands & U.S. Frequency Allocations



Radio Frequency Bands & U.S. Frequency Allocations

(Adapted from charts: Radio-Frequency Bands and U.S. Frequency Allocations, in The Encyclopedia Americana, International Edition, Vol. 23. Danbury, CT: Grolier Incorporated, 1993, p. 160.)

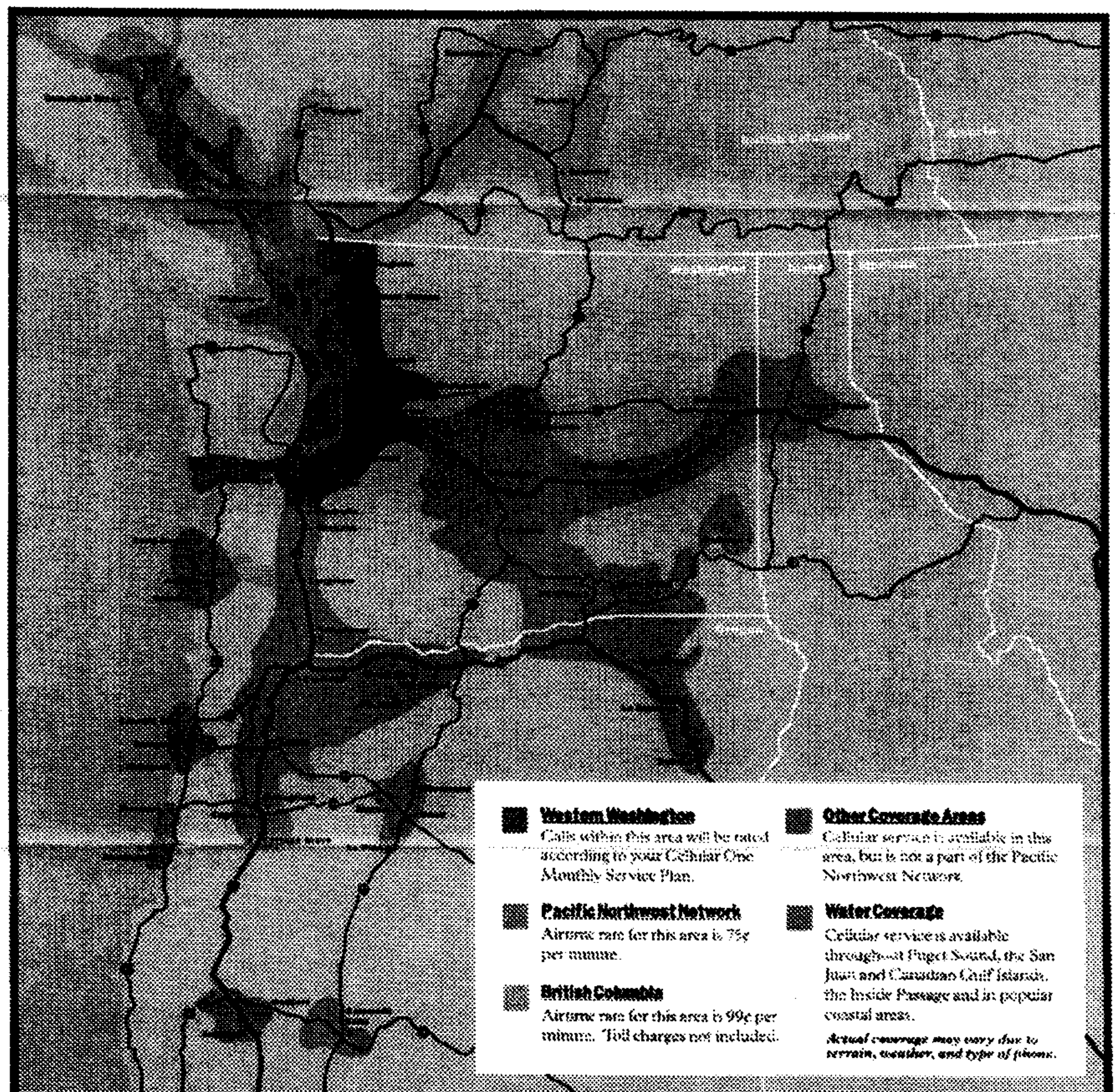
(only key frequency allocations are shown in their approximate spectrum locations)

Appendix E:

Washington State Coverage Maps for Selected Wireless Technologies

CELLULARONE

Pacific Northwest Network



CELLULARONE

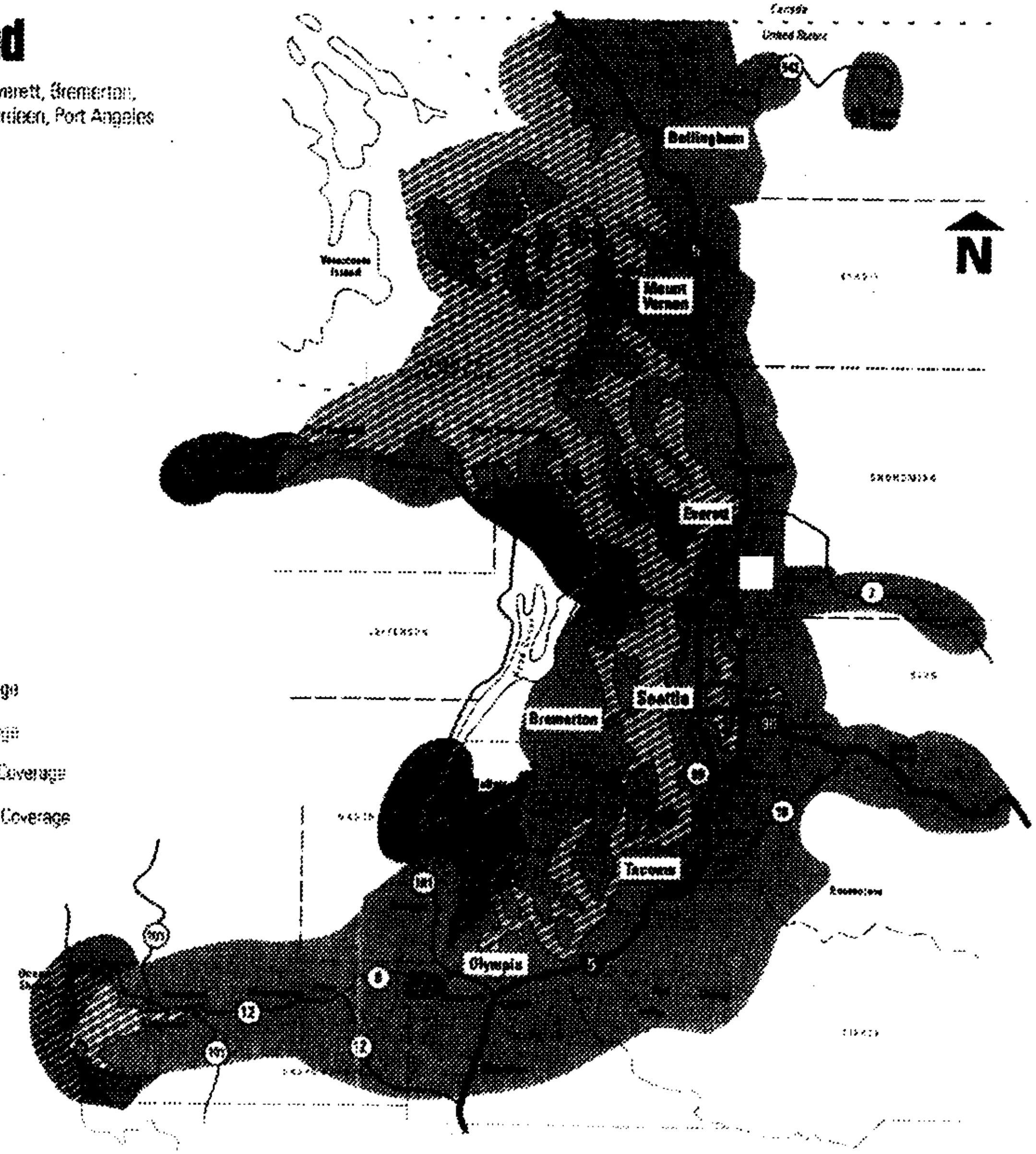
Western Washington Coverage

WITH COMMUNITY CALLING ZONES

At U S WEST Cellular, we have the Puget Sound area covered.

ʼuget Sound

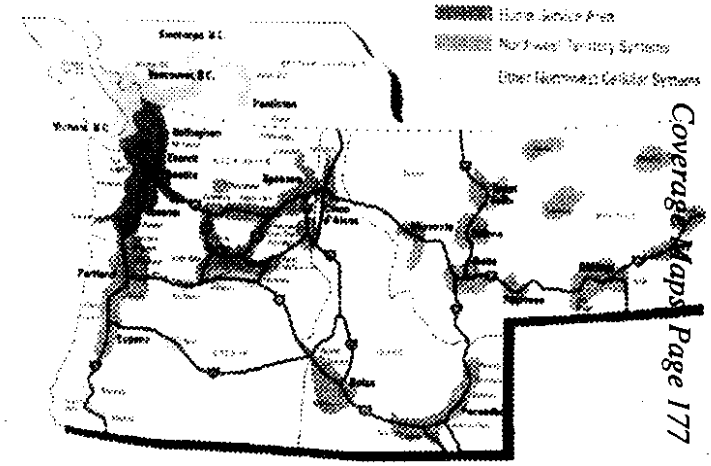
;attle, Tacoma, Olympia, Everett, Bremerton,
;llingham, Mt. Vernon, Aberdeen, Port Angeles



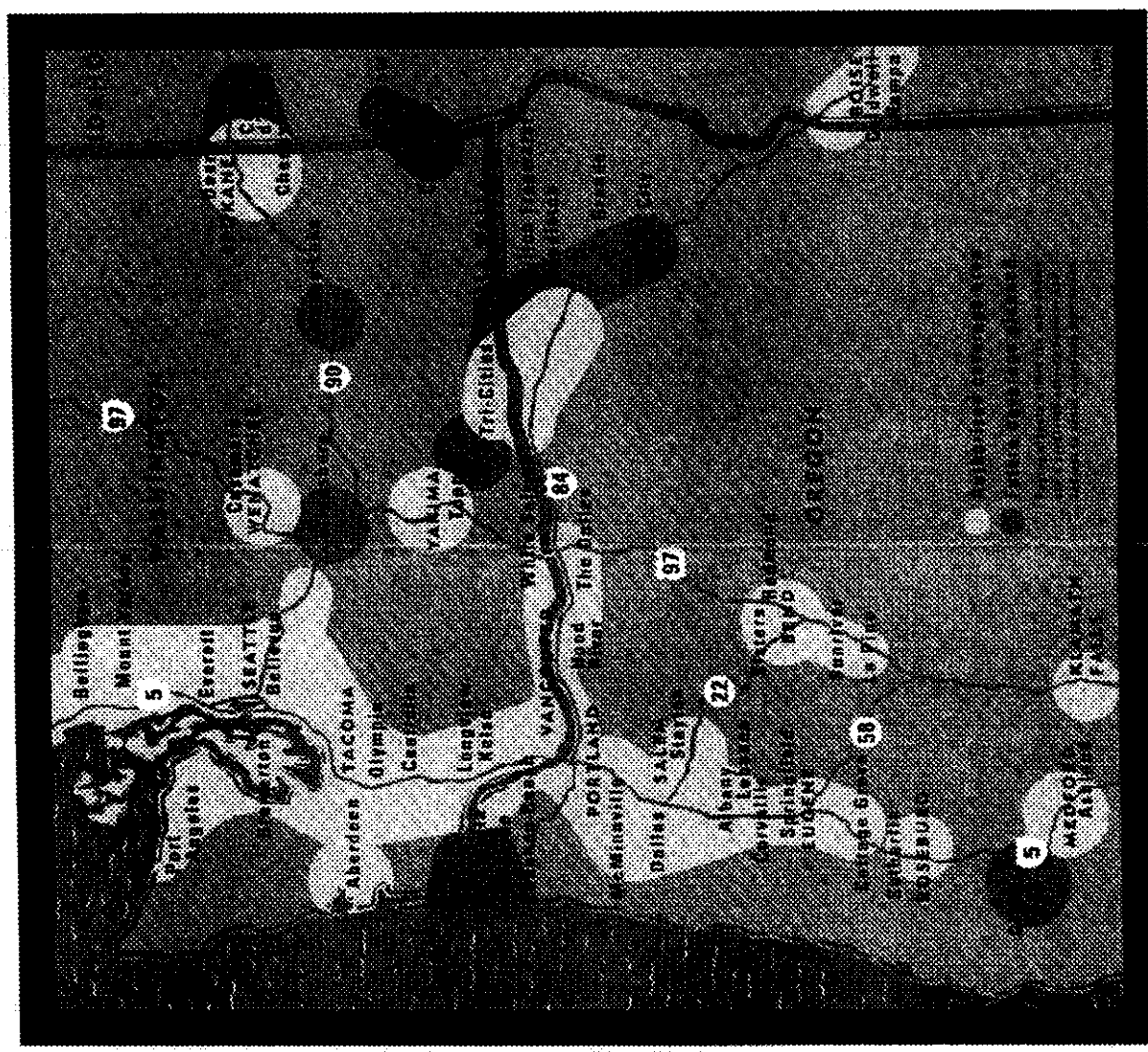
Legend

- Primary Coverage
- Pending Coverage
- Primary Water Coverage
- Pending Water Coverage

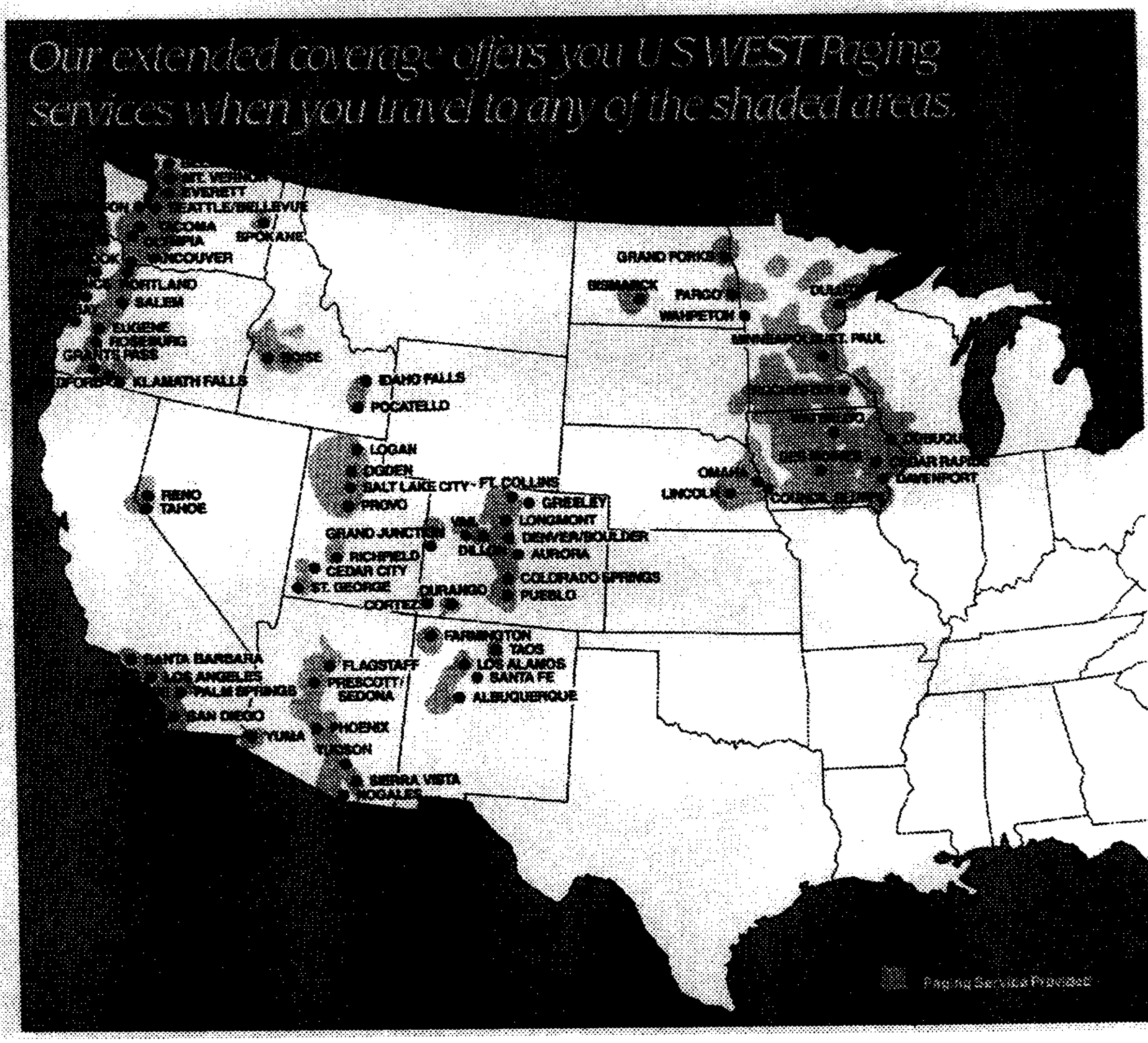
Legend



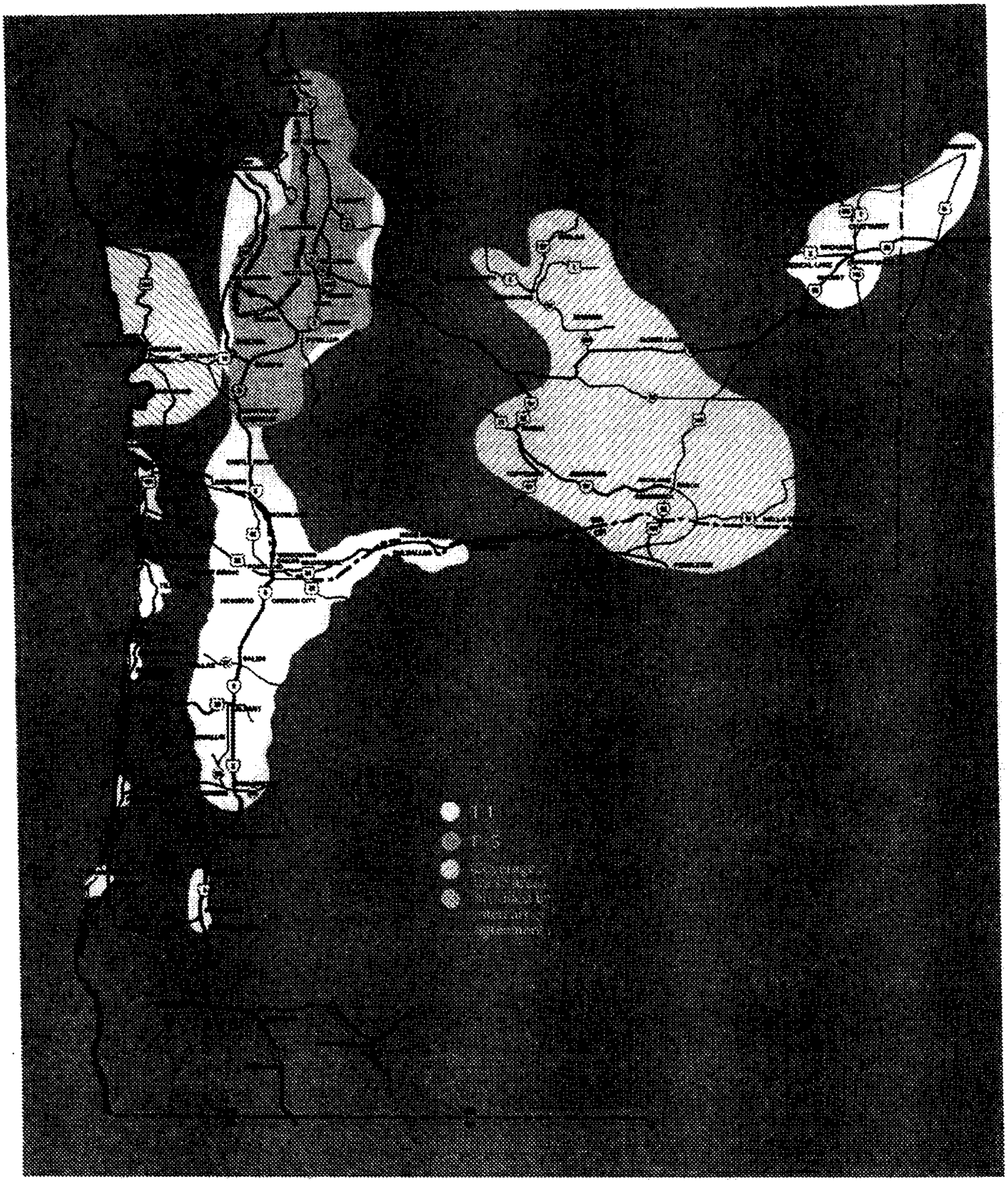
PAGE WEST

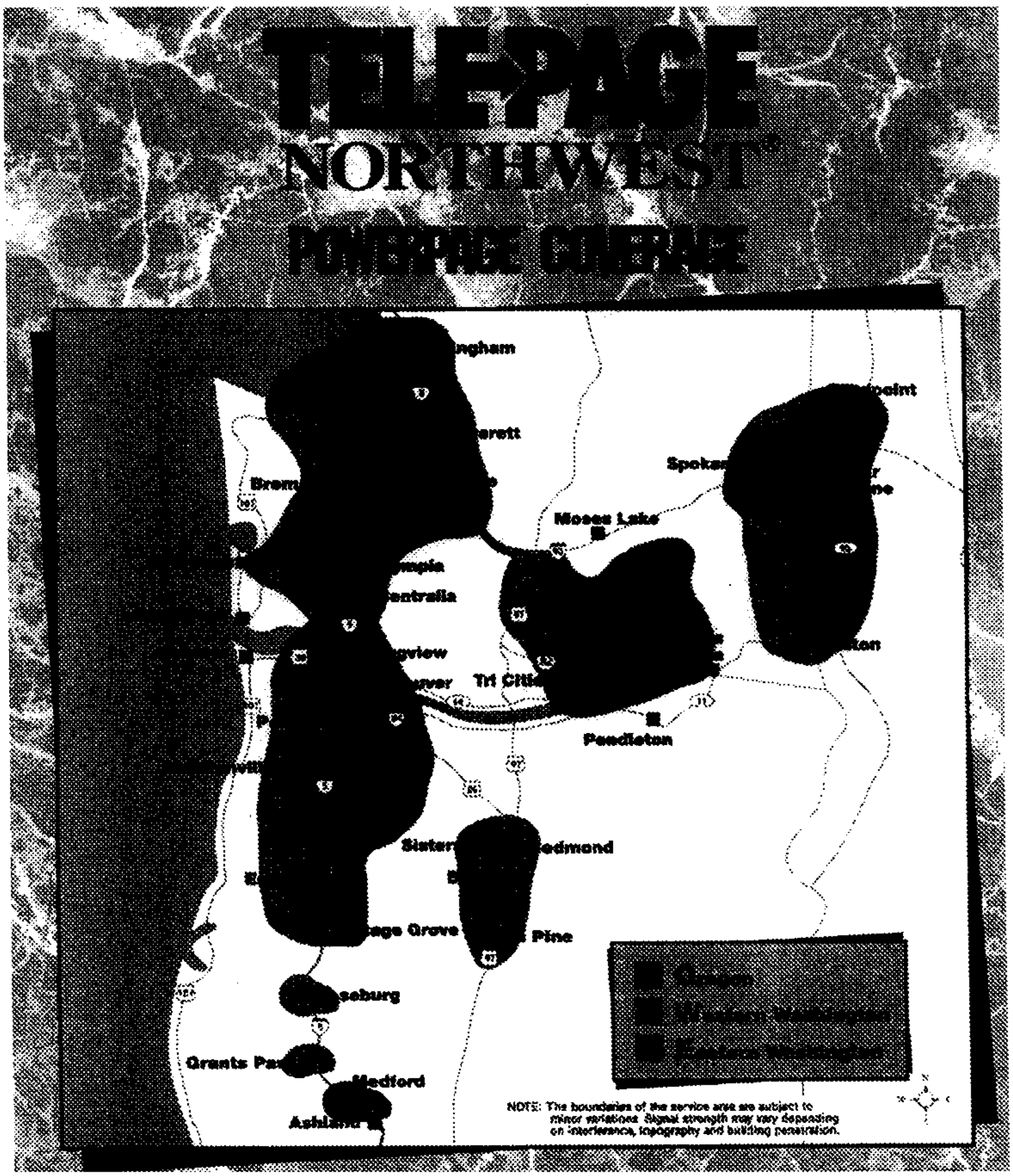

SEATTLE
TACOMA
Olympia
Aberdeen
PORTLAND
SALEM
Albany
EUGENE
MEDFORD
YAKIMA
Tri-Cities
The Dalles
Hood River
OREGON
5
90
97
84
22
58

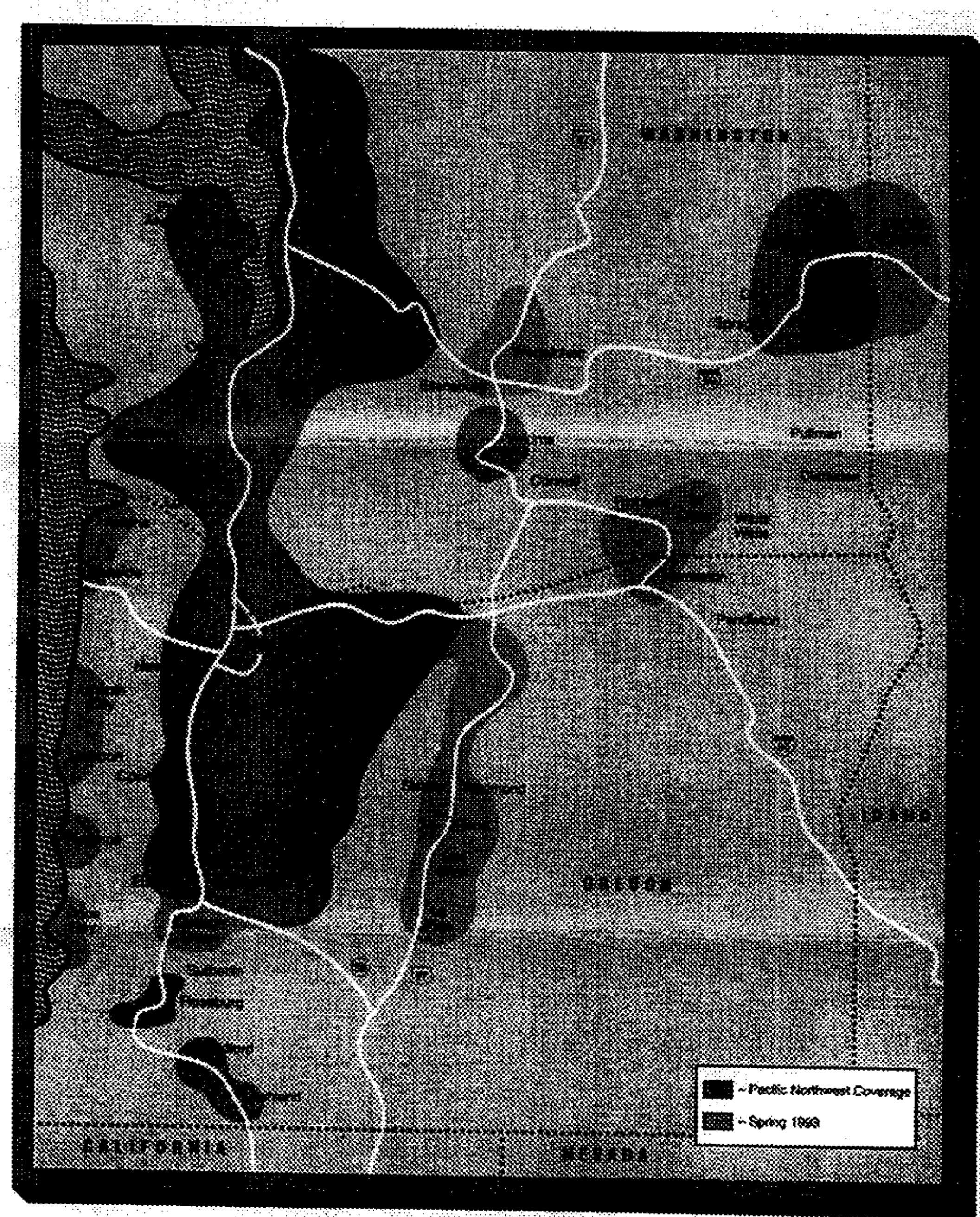
Become a part of the U S WEST Paging Network.



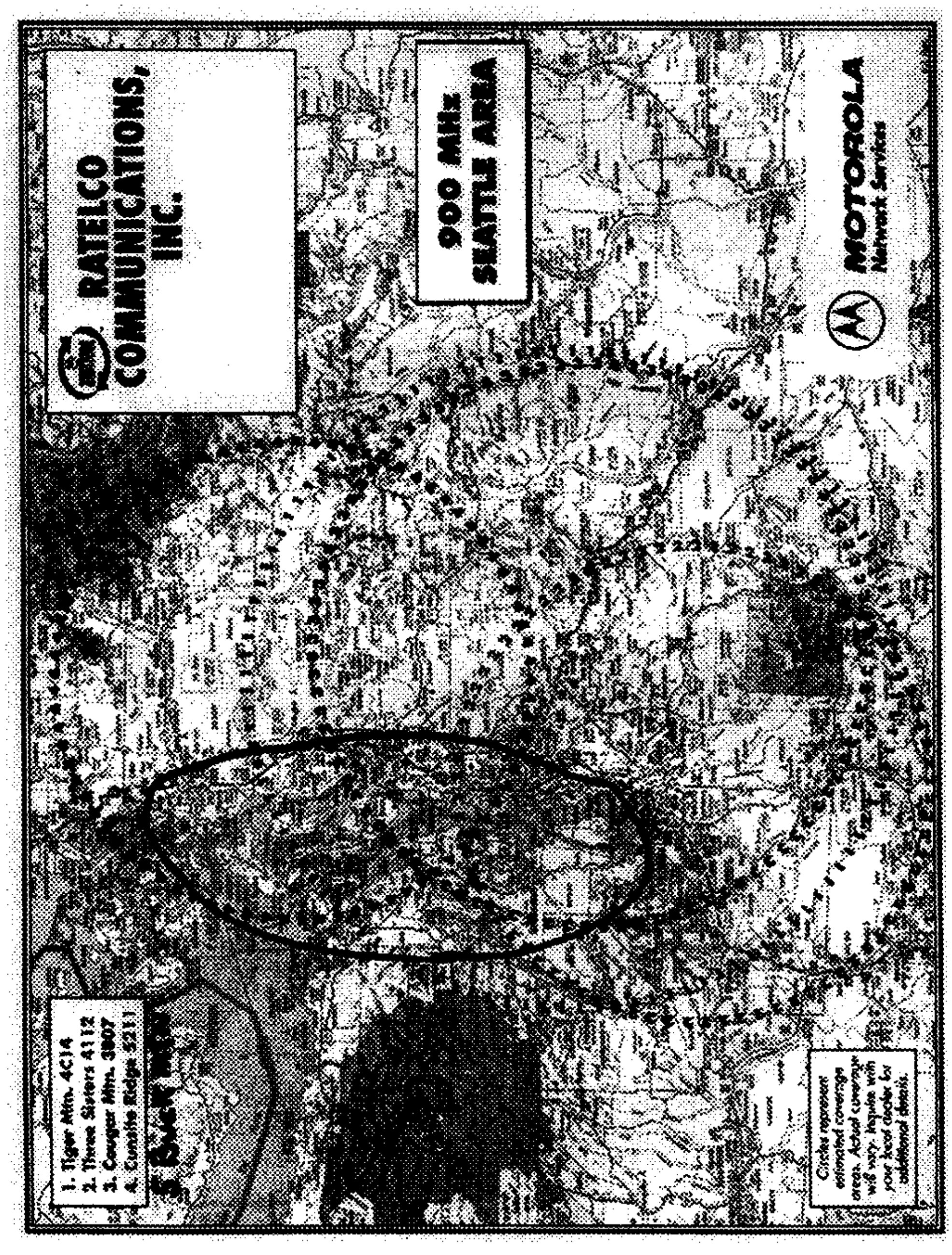
USWEST
PAGING

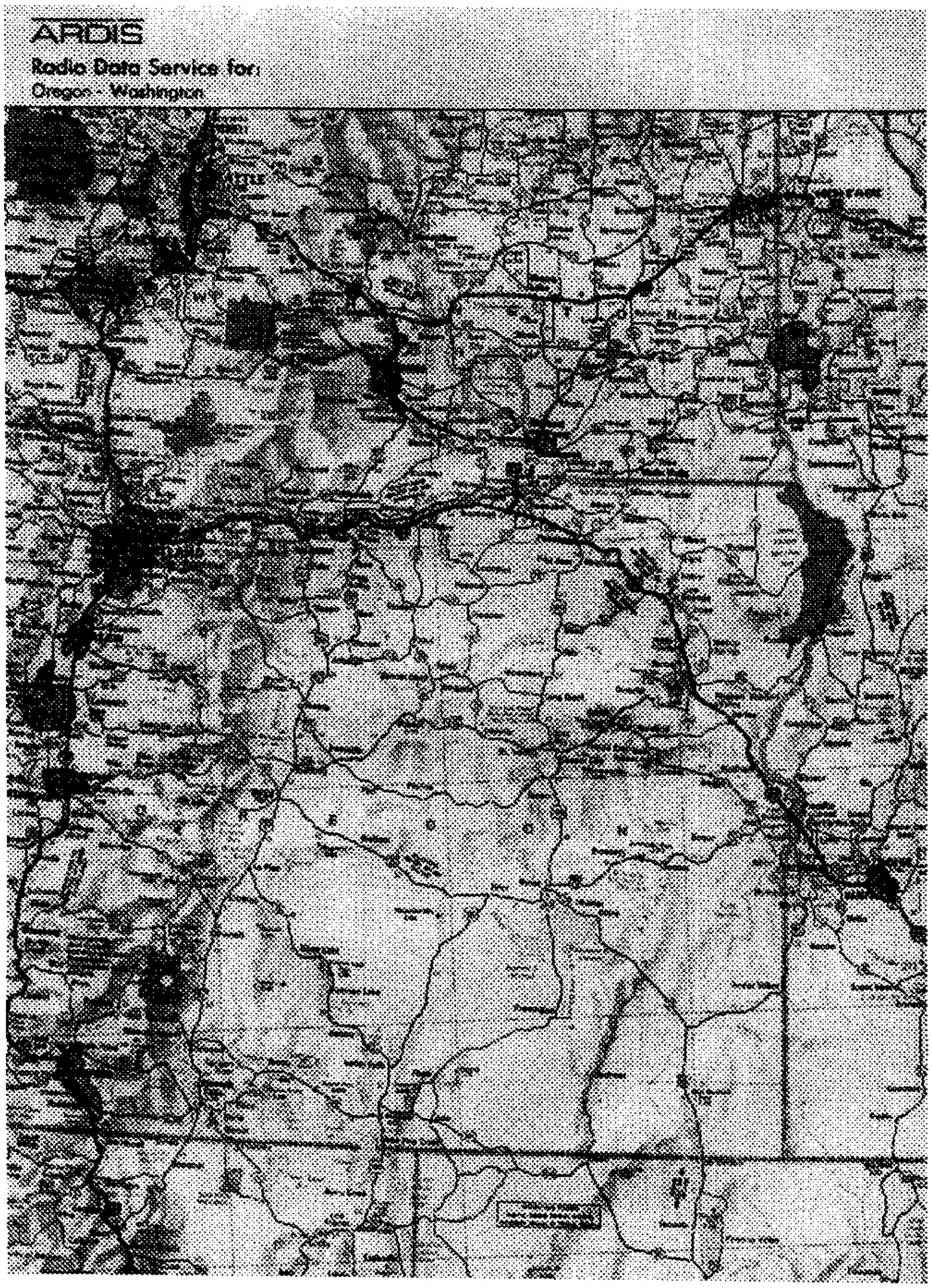


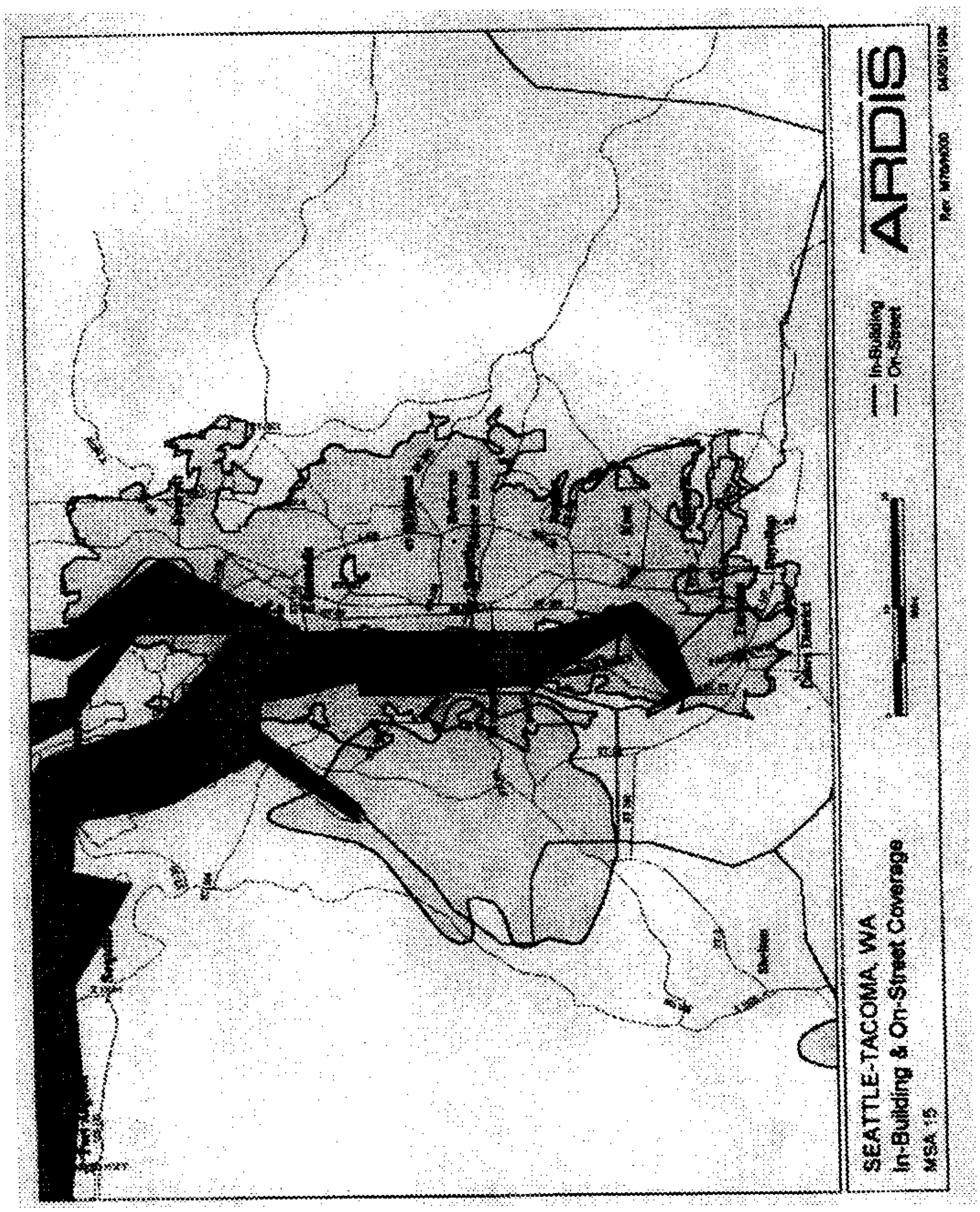

TELE-PAGE
NORTHWEST
POWERPAGE COVERAGE
Moses Lake
Tri Cities
Pendleton
Sisters
Redmond
Pine
Grants Pass
Medford
NOTE: The boundaries of the service area are subject to minor variations. Signal strength may vary depending on interference, topography and building penetration.



PAGENET


RATELCO COMMUNICATIONS, INC.
900 MHz SEATTLE AREA
MOTOROLA
Network Services

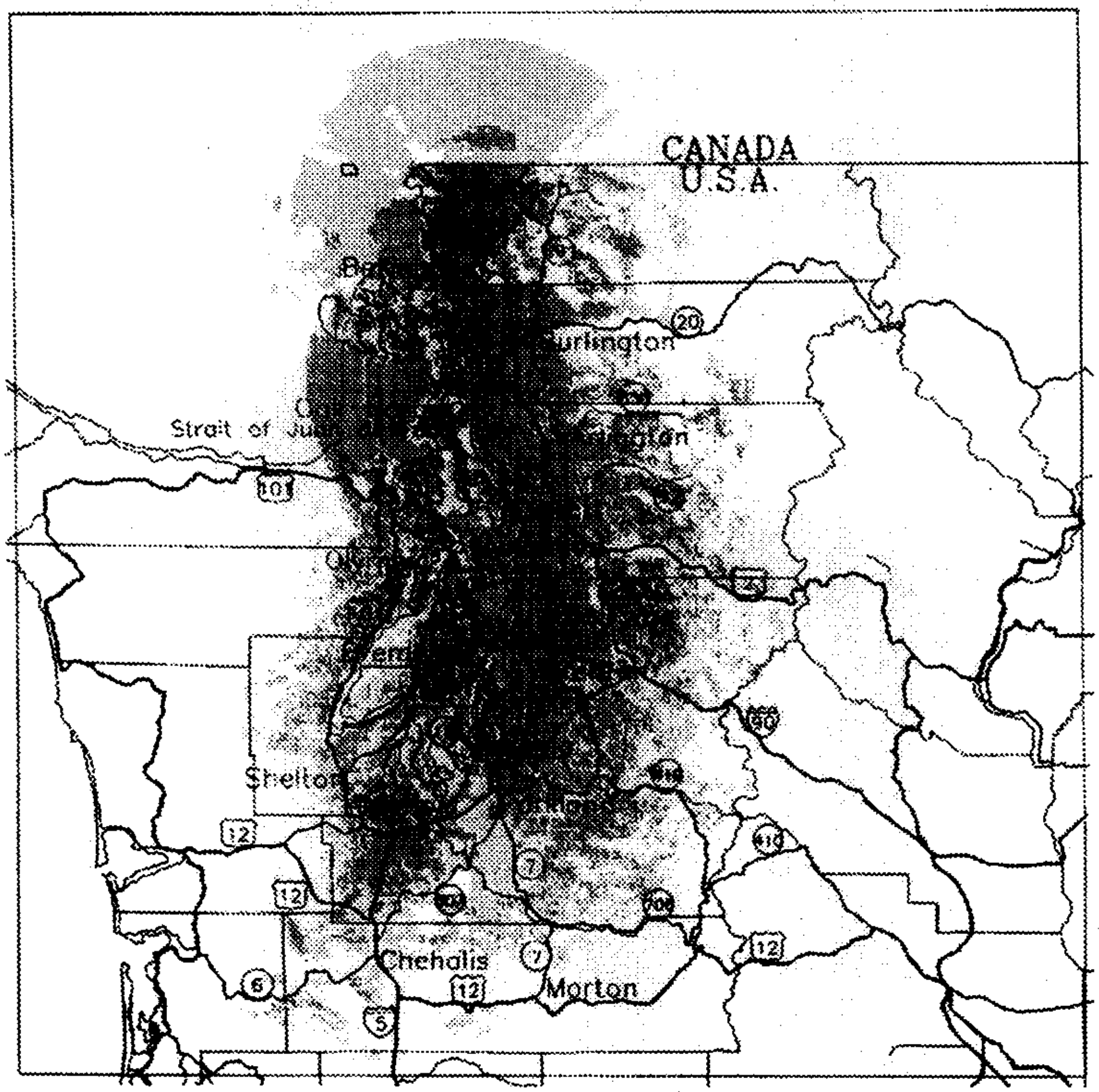

ARDIS
Radio Data Service for:
Oregon - Washington


SEATTLE-TACOMA, WA
In-Building & On-Street Coverage
MSA 15
In-Building
On-Street
ARDIS

RAM Mobile Data
Seattle Service Area

As of January 1994

PORTABLE
MOBILE
EXTENDED MOBILE



Interexchange company service is required for messaging outside of Local Access and Transport Area (LATA). Actual coverage may vary due to topography and environmental conditions. 1/94

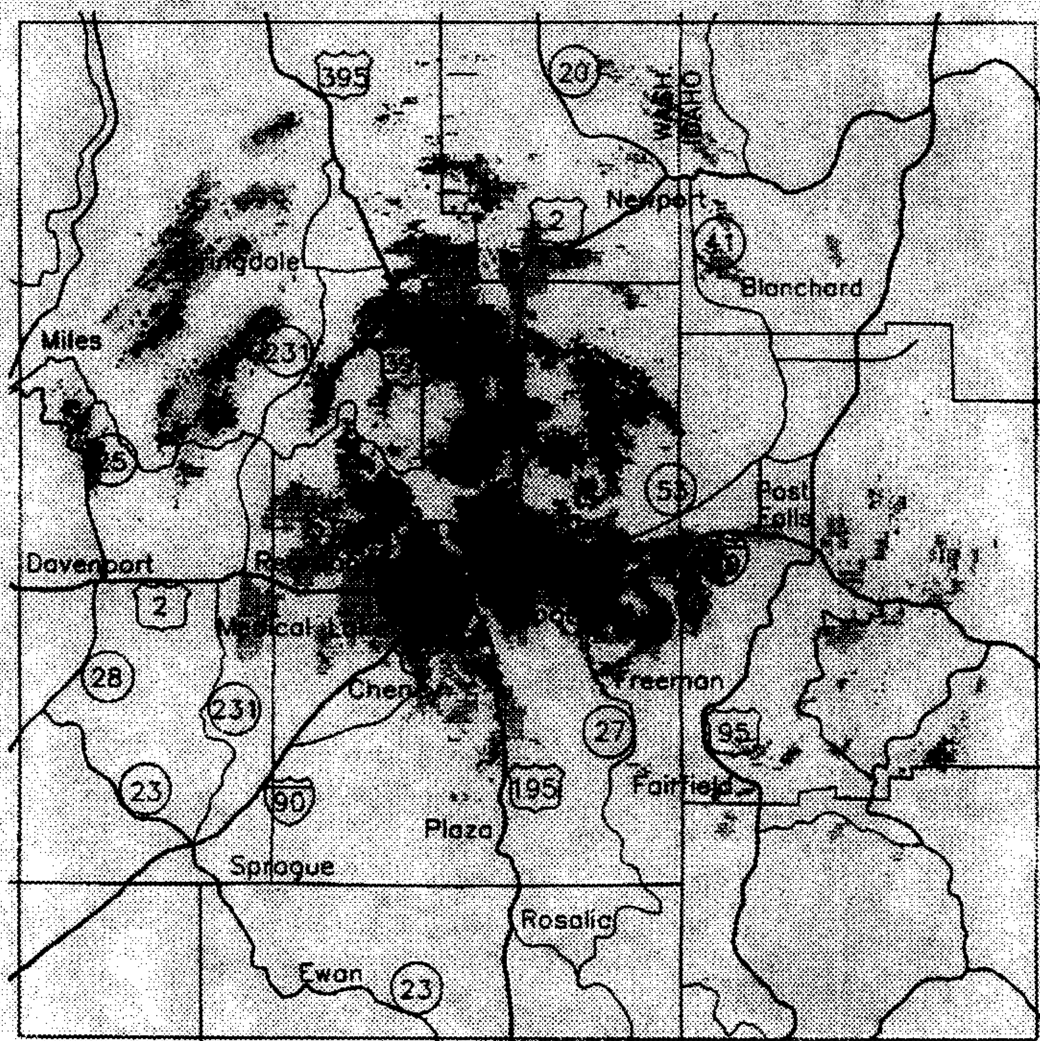
Mapping Services Provided By:
RAM
COMMUNICATIONS CONSULTANTS
[illegible]

RAM Mobile Data is a business venture between RAM Broadcasting and BellSouth.

Spokane Service Area

PORTABLE
MOBILE
EXTENDED MOBILE

As of January 1994



Interexchange company service is required for messaging outside of Local Access and Transport Area (LATA). Actual coverage may vary due to topography and environmental conditions. 1/94

Mapping Services Provided By

RAM

COMMUNICATIONS CONSULTANTS

RAM Mobile Data is a business venture between RAM Broadcasting and BellSouth.

Appendix F:

U.S. Frequency Allocations

United States Frequency Allocations (kHz)

United States table		
Government Allocation (kHz)	Non-government Allocation (kHz)	Special-use frequencies
Below 9 (Not allocated).	Below 9 (Not allocated).	
9-14 RADIONAVIGATION.	9-14 RADIONAVIGATION.	
14-19.95 FIXED. MARITIME MOBILE.	14-19.95 Fixed.	
19.95-20.05 STANDARD FREQUENCY AND TIME SIGNAL.	19.95-20.05 STANDARD FREQUENCY AND TIME SIGNAL.	20 kHz: Standard Frequency
20.05-59 FIXED. MARITIME MOBILE.	20.05-59 FIXED.	
59-61 STANDARD FREQUENCY AND TIME SIGNAL.	59-61 STANDARD FREQUENCY AND TIME SIGNAL.	60 kHz: Standard Frequency
61-70 FIXED. MARITIME MOBILE.	61-70 FIXED.	
70-90 FIXED. MARITIME MOBILE. Radiolocation.	70-90 FIXED. Radiolocation.	
90-110 RADIONAVIGATION.	90-110 RADIONAVIGATION.	
110-130 FIXED. MARITIME MOBILE. Radiolocation.	110-130 FIXED. MARITIME MOBILE. Radiolocation.	
130-160 FIXED. MARITIME MOBILE.	130-160 FIXED. MARITIME MOBILE.	
160-190 FIXED. MARITIME MOBILE.	160-190 FIXED.	
190-200 AERONAUTICAL RADIONAVIGATION.	190-200 AERONAUTICAL RADIONAVIGATION.	
200-275 AERONAUTICAL RADIONAVIGATION. Aeronautical Mobile.	200-275 AERONAUTICAL RADIONAVIGATION. Aeronautical Mobile.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)

Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (kHz)	Non-government Allocation (kHz)	Special-use frequencies
275-285 AERONAUTICAL RADIONAVIGATION. Aeronautical Mobile. Maritime Radionavigation (radio beacons).	275-285 AERONAUTICAL RADIONAVIGATION. Aeronautical Mobile. Maritime Radionavigation (radio beacons).	
285-325 MARITIME RADIONAVIGATION (radio beacons). Aeronautical Radionavigation (radio beacons).	285-325 MARITIME RADIONAVIGATION (radio beacons). Aeronautical Radionavigation (radio beacons).	
325-335 AERONAUTICAL RADIONAVIGATION (radio beacons). Aeronautical Mobile. Maritime Radionavigation (radio beacons).	325-335 AERONAUTICAL RADIONAVIGATION (radio beacons). Aeronautical Mobile. Maritime Radionavigation (radio beacons).	
335-405 AERONAUTICAL RADIONAVIGATION (radio beacons). Aeronautical Mobile.	335-405 AERONAUTICAL RADIONAVIGATION (radio beacons). Aeronautical Mobile.	
405-415 RADIONAVIGATION. Aeronautical Mobile.	405-415 RADIONAVIGATION. Aeronautical Mobile.	
415-435 AERONAUTICAL RADIONAVIGATION. MARITIME MOBILE.	415-435 AERONAUTICAL RADIONAVIGATION. MARITIME MOBILE.	
435-495 MARITIME MOBILE. AERONAUTICAL RADIONAVIGATION.	435-495 MARITIME MOBILE.	
495-505 MOBILE (distress and calling).	495-505 MOBILE (distress and calling).	500 kHz: Distress and calling frequency.
505-510 MARITIME MOBILE.	505-510 MARITIME MOBILE.	
510-525 AERONAUTICAL RADIONAVIGATION (radio beacons). MARITIME MOBILE (Ships only).	510-525 AERONAUTICAL RADIONAVIGATION (radio beacons). MARITIME MOBILE (Ships only).	518 kHz is used for international NAVTEX in the Maritime Mobile Service.

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (kHz)	Non-government Allocation (kHz)	Special-use frequencies
525-535 MOBILE. AERONAUTICAL RADIONAVIGATION (radio beacons).	525-535 MOBILE. AERONAUTICAL RADIONAVIGATION (radio beacons).	530 kHz: Travelers' information.
535-1705 kHz: Travelers' Information.	535-1605 ORIGINAL AM BROADCASTING.	
1605-1615 MOBILE.	1605-1615 EXTENDED AM BROADCASTING.	1610 kHz: Travelers' information.
1615-1625	1615-1625 EXTENDED AM BROADCASTING.	
1625-1705 Radiolocation.	1625-1705 EXTENDED AM BROADCASTING. Radiolocation.	
1705-1800 FIXED. MOBILE. RADIOLOCATION.	1705-1800 FIXED. MOBILE. RADIOLOCATION.	
1800-1900	1800-1900 AMATEUR.	
1900-2000 RADIOLOCATION.	1900-2000 RADIOLOCATION.	
2000-2065 FIXED. MOBILE.	2000-2065 MARITIME MOBILE.	
2065-2107 MARITIME MOBILE.	2065-2107 MARITIME MOBILE.	
2107-2170 FIXED. MOBILE.	2107-2170 FIXED. MARITIME MOBILE. LAND MOBILE.	
2170-2173.5 MARITIME MOBILE.	2170-2173.5 MARITIME MOBILE.	
2173.5-2190.5 MOBILE (distress and calling).	2173.5-2190.5 MOBILE (distress and calling).	2182 kHz: Distress and calling.
2190.5-2194 MARITIME MOBILE.	2190.5-2194 MARITIME MOBILE.	
2194-2495 FIXED. MOBILE.	2194-2495 FIXED. LAND MOBILE. MARITIME MOBILE.	
2495-2505 STANDARD FREQUENCY AND TIME SIGNAL.	2495-2505 STANDARD FREQUENCY AND TIME SIGNAL.	2500 kHz: Standard frequency.

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (kHz)	Non-government Allocation (kHz)	Special-use frequencies
2505-2850 FIXED. MOBILE.	2505-2850 FIXED. LAND MOBILE. MARITIME MOBILE.	
2850-3025 AERONAUTICAL MOBILE.	2850-3025 AERONAUTICAL MOBILE.	
3025-3155 AERONAUTICAL MOBILE.	3025-3155 AERONAUTICAL MOBILE.	
3155-3230 FIXED. MOBILE except aeronautical mobile.	3155-3230 FIXED. MOBILE except aeronautical mobile.	
3230-3400 FIXED. MOBILE except aeronautical mobile. Radiolocation.	3230-3400 FIXED. MOBILE except aeronautical mobile. Radiolocation.	
3400-3500 AERONAUTICAL MOBILE.	3400-3500 AERONAUTICAL MOBILE.	
3500-4000	3500-4000 AMATEUR	
4000-4438 MARITIME MOBILE.	4000-4438 MARITIME MOBILE.	
4438-4650 FIXED. MOBILE except aeronautical mobile.	4438-4650 FIXED. MOBILE except aeronautical mobile.	
4650-4700 AERONAUTICAL MOBILE.	4650-4700 AERONAUTICAL MOBILE.	
4700-4750 AERONAUTICAL MOBILE.	4700-4750 AERONAUTICAL MOBILE.	
4750-4850 FIXED. MOBILE except aeronautical mobile.	4750-4850 FIXED. MOBILE except aeronautical mobile.	
4850-4995 FIXED. MOBILE.	4850-4995 FIXED.	
4995-5005 STANDARD FREQUENCY AND TIME SIGNAL.	4995-5005 STANDARD FREQUENCY AND TIME SIGNAL.	5000 kHz: Standard frequency.
5005-5060 FIXED.	5005-5060 FIXED.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)

Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (kHz)	Non-government Allocation (kHz)	Special-use frequencies
5060-5450 FIXED. MOBILE except aeronautical mobile.	5060-5450 FIXED. MOBILE except aeronautical mobile.	
5450-5680 AERONAUTICAL MOBILE.	5450-5680 AERONAUTICAL MOBILE.	
5680-5730 AERONAUTICAL MOBILE.	5680-5730 AERONAUTICAL MOBILE.	
5730-5950 FIXED. MOBILE except aeronautical mobile.	5730-5950 FIXED. MOBILE except aeronautical mobile.	
5950-6200 BROADCASTING.	5950-6200 BROADCASTING.	
6200-6525 MARITIME MOBILE.	6200-6525 MARITIME MOBILE.	
6525-6685 AERONAUTICAL MOBILE.	6525-6685 AERONAUTICAL MOBILE.	
6685-6765 AERONAUTICAL MOBILE.	6685-6765 AERONAUTICAL MOBILE.	
6765-7000 FIXED. Mobile.	6765-7000 FIXED. Mobile.	6780 kHz ± 15 kHz: Industrial, scientific, and medical frequency.
7000-7300	7000-7100 AMATEUR. AMATEUR SATELLITE.	
	7100-7300 AMATEUR.	
7300-8100 FIXED. Mobile.	7300-8100 FIXED. Mobile.	
8100-8815 MARITIME MOBILE.	8100-8815 MARITIME MOBILE.	
8815-8965 AERONAUTICAL MOBILE.	8815-8965 AERONAUTICAL MOBILE.	
8965-9040 AERONAUTICAL MOBILE.	8965-9040 AERONAUTICAL MOBILE.	
9040-9500 FIXED.	9040-9500 FIXED.	
9500-9900 BROADCASTING.	9500-9900 BROADCASTING.	

LEGEND
Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (kHz)	Non-government Allocation (kHz)	Special-use frequencies
9900-9995 FIXED.	9900-9995 FIXED.	
9995-10005 STANDARD FREQUENCY AND TIME SIGNAL.	9995-10005 STANDARD FREQUENCY AND TIME SIGNAL.	10000 kHz: Standard frequency.
10005-10100 AERONAUTICAL MOBILE.	10005-10100 AERONAUTICAL MOBILE.	
10100-10150	10100-10150 AMATEUR	
10150-11175 FIXED. MOBILE except aeronautical mobile.	10150-11175 FIXED. MOBILE except aeronautical mobile.	
11175-11275 AERONAUTICAL MOBILE.	11175-11275 AERONAUTICAL MOBILE.	
11275-11400 AERONAUTICAL MOBILE.	11275-11400 AERONAUTICAL MOBILE.	
11400-11650 FIXED.	11400-11650 FIXED.	
11650-12050 BROADCASTING.	11650-12050 BROADCASTING.	
12050-12230 FIXED.	12050-12230 FIXED.	
12230-13200 MARITIME MOBILE.	12230-13200 MARITIME MOBILE.	
13200-13260 AERONAUTICAL MOBILE.	13200-13260 AERONAUTICAL MOBILE.	
13260-13360 AERONAUTICAL MOBILE.	13260-13360 AERONAUTICAL MOBILE.	
13360-13410 RADIO ASTRONOMY.	13360-13410 RADIO ASTRONOMY.	
13410-13600 FIXED. Mobile except aeronautical mobile.	13410-13600 FIXED.	13560 kHz ± 7 kHz: Industrial, scientific, and medical frequency.
13600-13800 BROADCASTING.	13600-13800 BROADCASTING.	
13800-14000 FIXED. Mobile except aeronautical mobile.	13800-14000 FIXED.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (kHz)	Non-government Allocation (kHz)	Special-use frequencies
14000-14350	14000-14250 AMATEUR. AMATEUR SATELLITE.	
	14250-14350 AMATEUR	
14350-14990 FIXED. Mobile except aeronautical mobile.	14350-14990 FIXED.	
14990-15010 STANDARD FREQUENCY AND TIME SIGNAL.	14990-15010 STANDARD FREQUENCY AND TIME SIGNAL.	15000 kHz: Standard frequency.
15010-15100 AERONAUTICAL MOBILE.	15010-15100 AERONAUTICAL MOBILE.	
15100-15600 BROADCASTING.	15100-15600 BROADCASTING.	
15600-16360 FIXED.	15600-16360 FIXED.	
16360-17410 MARITIME MOBILE.	16360-17410 MARITIME MOBILE.	
17410-17550 FIXED.	17410-17550 FIXED.	
17550-17900 BROADCASTING.	17550-17900 BROADCASTING.	
17900-17970 AERONAUTICAL MOBILE.	17900-17970 AERONAUTICAL MOBILE.	
17970-18030 AERONAUTICAL MOBILE.	17970-18030 AERONAUTICAL MOBILE.	
18030-18068 FIXED.	18030-18068 FIXED.	
18068-18168	18068-18168 AMATEUR. AMATEUR SATELLITE.	
18168-18780 FIXED. Mobile.	18168-18780 FIXED. Mobile.	
18780-18900 MARITIME MOBILE.	18780-18900 MARITIME MOBILE.	
18900-19680 FIXED.	18900-19680 FIXED.	
19680-19800 MARITIME MOBILE.	19680-19800 MARITIME MOBILE.	
19800-19990 FIXED.	19800-19990 FIXED.	

LEGEND
Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (kHz)	Non-government Allocation (kHz)	Special-use frequencies
19990-20010 STANDARD FREQUENCY AND TIME SIGNAL.	19990-20010 STANDARD FREQUENCY AND TIME SIGNAL.	20000 kHz: Standard frequency.
20010-21000 FIXED. Mobile.	20010-21000 FIXED.	
21000-21450	21000-21450 AMATEUR. AMATEUR SATELLITE.	
21450-21850 BROADCASTING.	21450-21850 BROADCASTING.	
21850-21924 FIXED.	21850-21924 FIXED.	
21924-22000 AERONAUTICAL MOBILE.	21924-22000 AERONAUTICAL MOBILE.	
22000-22855 MARITIME MOBILE.	22000-22855 MARITIME MOBILE.	
22855-23000 FIXED.	22855-23000 FIXED.	
23000-23200 FIXED. Mobile except aeronautical mobile.	23000-23200 FIXED.	
23200-23350 AERONAUTICAL MOBILE.	23200-23350 AERONAUTICAL MOBILE.	
23350-24890 FIXED. MOBILE except aeronautical mobile.	23350-24890 FIXED.	
24890-24990	24890-24990 AMATEUR. AMATEUR SATELLITE.	
24990-25010 STANDARD FREQUENCY AND TIME SIGNAL.	24990-25010 STANDARD FREQUENCY AND TIME SIGNAL.	25000 kHz: Standard frequency.
25010-25070	25010-25070 LAND MOBILE.	
25070-25210 MARITIME MOBILE.	25070-25210 MARITIME MOBILE.	
25210-25330	25210-25330 LAND MOBILE.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (kHz)	Non-government Allocation (kHz)	Special-use frequencies
25330-25550 FIXED. MOBILE except aeronautical mobile.	25330-25550	
25550-25670 RADIO ASTRONOMY.	25550-25670 RADIO ASTRONOMY.	
25670-26100 BROADCASTING.	25670-26100 BROADCASTING.	
26100-26175 MARITIME MOBILE.	26100-26175 MARITIME MOBILE.	
26175-26480	26175-26480 LAND MOBILE.	
26480-26950 FIXED. MOBILE except aeronautical mobile.	26480-26950	
26950-27540	26950-26960 FIXED.	
	26960-27230 MOBILE except aeronautical mobile.	27120 kHz ± 160 kHz: Industrial, scientific, and medical frequency.
	27230-27410 FIXED. MOBILE except aeronautical mobile.	
	27410-27540 LAND MOBILE.	
27540-28000 FIXED. MOBILE.	27540-28000	

LEGEND

Primary Services: in capitals (i.e. MOBILE)

Secondary Services: normal characters (i.e. Radiolocation)

United States Frequency Allocations (MHz)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
28.0-29.7	28.0-29.7 AMATEUR. AMATEUR SATELLITE.	
29.7-29.89	29.7-29.8 LAND MOBILE.	
	29.8-29.89 FIXED.	
29.89-29.91 FIXED. MOBILE.	29.89-29.91	
29.91-30.0	29.91-30.0 FIXED.	
30.0-30.56 MOBILE. Fixed.	30.0-30.56	
30.56-32.0	30.56-32.0 LAND MOBILE.	
32.0-33.0 FIXED. MOBILE.	32.0-33.0	
33.0-34.0	33.0-34.0 LAND MOBILE.	
34.0-35.0 FIXED. MOBILE.	34.0-35.0	
35.0-36.0	35.0-35.19 LAND MOBILE.	
	35.19-35.69 LAND MOBILE.	
	35.69-36.0 LAND MOBILE.	
36.0-37.0 FIXED. MOBILE.	36.0-37.0	
37.0-37.5	37.0-37.5 LAND MOBILE.	
37.5-38.0 Radio Astronomy.	37.5-38.0 LAND MOBILE. Radio Astronomy.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)

Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
38.0-38.25 FIXED. MOBILE. RADIO ASTRONOMY.	38.0-38.25 RADIO ASTRONOMY.	
38.25-39.0 FIXED. MOBILE.	38.25-39.0	
39.0-40.0	39.0-40.0 LAND MOBILE.	
40.0-42.0 FIXED. MOBILE.	40.0-42.0	40.68 MHz ± .02 MHz: Industrial, scientific, and medical frequency.
42.0-46.6 PRIVATE LAND MOBILE.	42.0-43.19	
	43.19-43.69 LAND MOBILE.	
	43.69-46.6 LAND MOBILE.	
46.6-47.0 FIXED. MOBILE.	46.6-46.98 CORDLESS TELEPHONE.	
47.0-49.6	47.0-49.6 LAND MOBILE.	
49.6-50.0 FIXED. MOBILE.	49.66-50.0 CORDLESS TELEPHONE.	
50.0-54.0	50.0-54.0 AMATEUR.	
54.0-72.0	54.0-72.0 TV BROADCASTING (VHF 2-4).	
72.0-73.0	72.0-73.0 FIXED. MOBILE.	
73.0-74.6 RADIO ASTRONOMY.	73.0-74.6 RADIO ASTRONOMY.	
74.6-74.8 FIXED. MOBILE.	74.6-74.8 FIXED. MOBILE.	
74.8-75.2 AERONAUTICAL RADIONAVIGATION.	74.8-75.2 AERONAUTICAL RADIONAVIGATION.	75 MHz: Marker Beacon.

LEGEND
Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
75.2-75.4 FIXED. MOBILE.	75.2-75.4 FIXED. MOBILE.	
75.4-76.0	75.4-76.0 FIXED. MOBILE.	
76.0-88.0	76.0-88.0 TV BROADCASTING (VHF 5-6).	
88.0-108.0	88.0-108.0 FM BROADCASTING.	
108.0-117.975 AERONAUTICAL RADIONAVIGATION.	108.0-117.975 AERONAUTICAL RADIONAVIGATION.	
117.975-121.9375 AERONAUTICAL MOBILE.	117.975-121.9375 AERONAUTICAL MOBILE.	
21.9375-123.0875	21.9375-123.0875 AERONAUTICAL MOBILE.	
123.0875-123.5875 AERONAUTICAL MOBILE.	123.0875-123.5875 AERONAUTICAL MOBILE.	123.1 MHz: SAR (scene-of-action) communication.
123.5875-128.8125 AERONAUTICAL MOBILE.	123.5875-128.8125 AERONAUTICAL MOBILE.	
128.8125-132.0125	128.8125-132.0125 AERONAUTICAL MOBILE.	
132.0125-136.0 AERONAUTICAL MOBILE.	132.0125-136.0 AERONAUTICAL MOBILE.	
136.0-137.0	136.0-137.0 AERONAUTICAL MOBILE.	
137.0-138.0 SPACE OPERATION (space-to-earth). METEOROLOGICAL SATELLITE (space-to-earth). SPACE RESEARCH (space-to-earth).	137.0-138.0 SPACE OPERATION (space-to-earth). METEOROLOGICAL SATELLITE (space-to-earth). SPACE RESEARCH (space-to-earth).	
138.0-144.0 FIXED. MOBILE.	138.0-144.0	
144.0-146.0	144.0-146.0 AMATEUR. AMATEUR SATELLITE.	
146.0-148.0	146.0-148.0 AMATEUR.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
148.0-149.9 FIXED. MOBILE.	148.0-149.9	
149.9-150.05 RADIONAVIGATION SATELLITE.	149.9-150.05 RADIONAVIGATION SATELLITE.	
150.05-150.8 FIXED. MOBILE.	150.05-150.8	
150.8-156.2475	150.8-152.0 LAND MOBILE.	
	152.0-152.255 LAND MOBILE.	
	152.255-152.495 LAND MOBILE.	
	152.495-152.855 LAND MOBILE.	
	152.855-156.2475 LAND MOBILE.	
156.2475-157.0375	156.2475-157.0375 MARITIME MOBILE.	
157.0375-157.1875 MARITIME MOBILE.	157.0375-157.1875	
157.1875-157.45	157.1875-157.45 MARITIME MOBILE.	
157.45-161.575	157.45-157.755 LAND MOBILE.	
	157.755-158.115 LAND MOBILE.	
	158.115-161.575 LAND MOBILE.	
161.575-161.625	161.575-161.625 MARITIME MOBILE.	
161.625-161.775	161.625-161.775 LAND MOBILE.	
161.775-162.0125	161.775-162.0125 MARITIME MOBILE.	
162.0125-173.2 FIXED. MOBILE.	162.0125-173.2	
173.2-173.4	173.2-173.4 FIXED. Land Mobile.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
173.4-174.0 FIXED. MOBILE.	173.4-174.0	
174.0-216.0	174.0-216.0 TV BROADCASTING (VHF 7-13).	
216.0-220.0 MARITIME MOBILE. Aeronautical Mobile. Fixed. Land Mobile. Radiolocation.	216.0-220.0 MARITIME MOBILE. Aeronautical Mobile. Fixed. Land Mobile. Radiolocation.	
220.0-222.0 Land Mobile. Radiolocation.	220.0-222.0 Land Mobile.	
222.0-225.0 Radiolocation.	222.0-225.0 Amateur.	
225.0-328.6 FIXED. MOBILE.	225.0-328.6	
328.6-335.4 AERONAUTICAL RADIONAVIGATION.	328.6-335.4 AERONAUTICAL RADIONAVIGATION.	
335.4-399.9 FIXED. MOBILE.	335.4-399.9	
399.9-400.05 RADIONAVIGATION-SATELLITE.	399.9-400.05 RADIONAVIGATION-SATELLITE.	
400.05-400.15 STANDARD FREQUENCY AND TIME SIGNAL-SATELLITE.	400.05-400.15 STANDARD FREQUENCY AND TIME SIGNAL-SATELLITE.	400.1 MHz: Standard frequency.
400.15-401.0 METEOROLOGICAL AIDS (radiosonde). METEOROLOGICAL SATELLITE (space-to-earth). SPACE RESEARCH (space-to-earth). Space Operation (space-to-earth).	400.15-401.0 METEOROLOGICAL AIDS (radiosonde). SPACE RESEARCH (space-to-earth). Space Operation (space-to-earth).	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
401.0-402.0 METEOROLOGICAL AIDS (radiosonde). SPACE OPERATION (space-to-earth). Earth Exploration-Satellite (earth-to-space). Meteorological Satellite (earth-to-space).	401.0-402.0 METEOROLOGICAL AIDS (radiosonde). SPACE OPERATION (space-to-earth). Earth Exploration-Satellite (earth-to-space). Meteorological Satellite (earth-to-space).	
402.0-403.0 METEOROLOGICAL AIDS (radiosonde). Earth Exploration-Satellite (earth-to-space). Meteorological Satellite (earth-to-space).	402.0-403.0 METEOROLOGICAL AIDS (radiosonde). Earth Exploration-Satellite (earth-to-space). Meteorological Satellite (earth-to-space).	
403.0-406.0 METEOROLOGICAL AIDS (radiosonde).	403.0-406.0 METEOROLOGICAL AIDS (radiosonde).	
406.0-406.1 MOBILE SATELLITE (earth-to-space).	406.0-406.1 MOBILE SATELLITE (earth-to-space).	
406.1-410.0 FIXED. MOBILE. RADIO ASTRONOMY.	406.1-410.0 RADIO ASTRONOMY.	
410.0-420.0 FIXED. MOBILE.	410.0-420.0	
420.0-450.0 RADIOLOCATION.	420.0-450.0 Amateur.	
450.0-460.0	450.0-451.0 LAND MOBILE.	
	451.0-454.0 LAND MOBILE.	
	454.0-455.0 LAND MOBILE.	
	455.0-456.0 LAND MOBILE.	
	456.0-459.0 LAND MOBILE.	
	459.0-460.0 LAND MOBILE.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
460.0-470.0 Meteorological Satellite (space-to-earth).	460.0-462.5375 LAND MOBILE.	
	462.5375-462.7375 LAND MOBILE.	
	462.7375-467.5375 LAND MOBILE.	
	467.5375-467.7375 LAND MOBILE.	
	467.7375-470.0 LAND MOBILE.	
470.0-512.0	470.0-512.0 TV BROADCASTING (UHF 14-20). LAND MOBILE.	
512.0-608.0	512.0-608.0 TV BROADCASTING (UHF 21-36).	
608.0-614.0 RADIO ASTRONOMY.	608.0-614.0 RADIO ASTRONOMY.	
614.0-806.0	614.0-806.0 TV BROADCASTING (UHF 38-69).	
806.0-902.0	806.0-821.0 LAND MOBILE.	
	821.0-824.0 LAND MOBILE.	
	824.0-849.0 CELLULAR TELEPHONE (reverse).	
	849.0-851.0 LAND MOBILE.	
	851.0-866.0 LAND MOBILE.	
	866.0-869.0 LAND MOBILE.	
	869.0-894.0 CELLULAR TELEPHONE (forward).	
	894.0-896.0 AERONAUTICAL MOBILE.	
	896.0-901.0 LAND MOBILE.	
	901.0-902.0 NARROWBAND PCS.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
902.0-928.0 RADIOLOCATION.	902.0-928.0	915 MHz ± 13 MHz: Industrial, scientific, and medical frequency.
928.0-932.0	928.0-929.0 FIXED.	
	930.0-931.0 NARROWBAND PCS.	
	931.0-932.0 COMMON CARRIER PAGING.	
932.0-935.0 FIXED.	932.0-935.0 POINT-TO-MULTIPOINT. POINT-TO-POINT.	
935.0-941.0	935.0-940.0 LAND MOBILE.	
	940.0-941.0 MOBILE	
941.0-944.0 FIXED.	941.0-944.0 POINT-TO-MULTIPOINT. POINT-TO-POINT.	
944.0-960.0	944.0-960.0 FIXED.	
960.0-1215.0 AERONAUTICAL RADIONAVIGATION.	960.0-1215.0 AERONAUTICAL RADIONAVIGATION.	
1215.0-1240.0 RADIOLOCATION. RADIONAVIGATION-SATELLITE (space-to-earth).	1215.0-1240.0	
1240.0-1300.0 RADIOLOCATION.	1240.0-1300.0 Amateur.	
1300.0-1350.0 AERONAUTICAL RADIONAVIGATION. Radiolocation.	1300.0-1350.0 AERONAUTICAL RADIONAVIGATION.	
1350.0-1400.0 RADIOLOCATION. Fixed. Mobile.	1350.0-1400.0	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
1400.0-1427.0 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	1400.0-1427.0 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
1427.0-1429.0 SPACE OPERATION (earth-to-space). FIXED. MOBILE except aeronautical mobile.	1427.0-1429.0 SPACE OPERATION (earth-to-space). Fixed (telemetering). Land Mobile (telemetering and telecommand).	
1429.0-1435.0 FIXED. MOBILE.	1429.0-1435.0 Land Mobile (telemetering and telecommand). Fixed (telemetering).	
1435.0-1530.0 MOBILE (aeronautical telemetering).	1435.0-1530.0 MOBILE (aeronautical telemetering).	
1530.0-1535.0 MARITIME MOBILE-SATELLITE (space-to-earth). Mobile (aeronautical telemetering).	1530.0-1535.0 MARITIME MOBILE-SATELLITE (space-to-earth). Mobile (aeronautical telemetering).	
1535.0-1544.0 MARITIME MOBILE-SATELLITE (space-to-earth).	1535.0-1544.0 MARITIME MOBILE-SATELLITE (space-to-earth).	
1544.0-1545.0 MOBILE SATELLITE (space-to-earth).	1544.0-1545.0 MOBILE SATELLITE (space-to-earth).	
1545.0-1549.5 AERONAUTICAL MOBILE-SATELLITE (space-to-earth). Mobile-satellite (space-to-earth).	1545.0-1549.5 AERONAUTICAL MOBILE-SATELLITE (space-to-earth). Mobile-satellite (space-to-earth).	
1549.5-1558.5 AERONAUTICAL MOBILE-SATELLITE (space-to-earth). MOBILE-SATELLITE (space-to-earth).	1549.5-1558.5 AERONAUTICAL MOBILE-SATELLITE (space-to-earth). MOBILE-SATELLITE (space-to-earth).	
1558.5-1559.0 AERONAUTICAL MOBILE-SATELLITE (space-to-earth).	1558.5-1559.0 AERONAUTICAL MOBILE-SATELLITE (space-to-earth).	

LEGEND
Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
1559.0-1610.0 AERONAUTICAL RADIONAVIGATION-SATELLITE (space-to-earth).	1559.0-1610.0 AERONAUTICAL RADIONAVIGATION-SATELLITE (space-to-earth).	
1610.0-1626.5 AERONAUTICAL RADIONAVIGATION.	1610.0-1626.5 AERONAUTICAL RADIONAVIGATION.	
1626.5-1645.5 MARITIME MOBILE-SATELLITE (earth-to-space).	1626.5-1645.5 MARITIME MOBILE-SATELLITE (earth-to-space).	
1645.5-1646.5 MOBILE-SATELLITE (earth-to-space).	1645.5-1646.5 MOBILE-SATELLITE (earth-to-space).	
1646.5-1651.0 AERONAUTICAL MOBILE-SATELLITE (earth-to-space). Mobile-Satellite (earth-to-space).	1646.5-1651.0 AERONAUTICAL MOBILE-SATELLITE (earth-to-space). Mobile-Satellite (earth-to-space).	
1651.0-1660.0 AERONAUTICAL MOBILE-SATELLITE (earth-to-space). Mobile-Satellite (earth-to-space).	1651.0-1660.0 AERONAUTICAL MOBILE-SATELLITE (earth-to-space). Mobile-Satellite (earth-to-space).	
1660.0-1660.5 AERONAUTICAL MOBILE-SATELLITE (earth-to-space). RADIO ASTRONOMY.	1660.0-1660.5 AERONAUTICAL MOBILE-SATELLITE (earth-to-space). RADIO ASTRONOMY.	
1660.5-1668.4 RADIO ASTRONOMY. SPACE RESEARCH (passive).	1660.5-1668.4 RADIO ASTRONOMY. SPACE RESEARCH (passive).	
1668.4-1670.0 METEOROLOGICAL AIDS (radiosonde). RADIO ASTRONOMY.	1668.4-1670.0 METEOROLOGICAL AIDS (radiosonde). RADIO ASTRONOMY.	
1670.0-1690.0 METEOROLOGICAL AIDS (radiosonde). METEOROLOGICAL-SATELLITE (space-to-earth).	1670.0-1690.0 METEOROLOGICAL AIDS (radiosonde). METEOROLOGICAL-SATELLITE (space-to-earth).	
1690.0-1700.0 METEOROLOGICAL AIDS (radiosonde). METEOROLOGICAL-SATELLITE (space-to-earth).	1690.0-1700.0 METEOROLOGICAL AIDS (radiosonde). METEOROLOGICAL-SATELLITE (space-to-earth).	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies *
1700.0-1710.0 FIXED METEOROLOGICAL-SATELLITE (space-to-earth).	1700.0-1710.0 METEOROLOGICAL-SATELLITE (space-to-earth). Fixed.	
1710.0-1850.0 FIXED. MOBILE.	1710.0-1850.0	
1850.0-1990.0	1850.0-1970.0 PCS.	
1990.0-2100.0	1990.0-2100.0 Fixed. MOBILE.	
2100.0-2200.0	2100.0-2130.0	
	2130.0-2150.0 PCS.	
	2150.0-2180.0	
	2180.0-2200.0 PCS.	
2200.0-2290.0 FIXED. MOBILE. SPACE RESEARCH (space-to-earth) (space-to-space)	2200.0-2290.0	
2290.0-2300.0 FIXED. MOBILE except aeronautical mobile. SPACE RESEARCH (space-to-earth) (deep space only).	2290.0-2300.0 SPACE RESEARCH (space-to-earth) (deep space only).	
2300.0-2310.0 RADIOLOCATION. Fixed. Mobile.	2300.0-2310.0 Amateur.	
2310.0-2390.0 MOBILE. RADIOLOCATION. Fixed.	2310.0-2390.0 MOBILE.	
2390.0-2450.0 RADIOLOCATION.	2390.0-2450.0 Amateur.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
2450.0-2483.5	2450.0-2483.5 FIXED. MOBILE. Radiolocation.	2450 MHz ± 50 MHz: Industrial, scientific, and medical frequency.
2483.5-2500.0	2483.5-2500.0 RADIODETERMINATION SATELLITE (space-to-earth).	
2500.0-2655.0	2500.0-2655.0 FIXED. BROADCASTING-SATELLITE.	
2655.0-2690.0 Earth Exploration-Satellite (passive). Radio Astronomy. Space Research (passive).	2655.0-2690.0 FIXED. BROADCASTING-SATELLITE. Earth Exploration-Satellite (passive). Radio Astronomy. Space Research (passive).	
2690.0-2700.0 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	2690.0-2700.0 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
2700.0-2900.0 AERONAUTICAL RADIONAVIGATION. METEOROLOGICAL AIDS. Radiolocation.	2700.0-2900.0	
2900.0-3100.0 MARITIME RADIONAVIGATION. Radiolocation.	2900.0-3100.0 MARITIME RADIONAVIGATION. Radiolocation.	
3100.0-3300.0 RADIOLOCATION.	3100.0-3300.0 Radiolocation.	
3300.0-3500.0 RADIOLOCATION.	3300.0-3500.0 Amateur. Radiolocation.	
3500.0-3600.0 AERONAUTICAL RADIONAVIGATION (ground-based). RADIOLOCATION.	3500.0-3600.0 Radiolocation.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
3600.0-3700.0 AERONAUTICAL RADIONAVIGATION (ground-based). RADIOLOCATION.	3600.0-3700.0 FIXED-SATELLITE (space-to-earth). Radiolocation.	
3700.0-4200.0	3700.0-4200.0 FIXED. FIXED-SATELLITE (space-to-earth).	
4200.0-4400.0 AERONAUTICAL RADIONAVIGATION.	4200.0-4400.0 AERONAUTICAL RADIONAVIGATION.	
4400.0-4500.0 FIXED. MOBILE.	4400.0-4500.0	
4500.0-4800.0 FIXED. MOBILE.	4500.0-4800.0 FIXED-SATELLITE (space-to-earth).	
4800.0-4990.0 FIXED. MOBILE.	4800.0-4990.0	
4990.0-5000.0 RADIO ASTRONOMY. Space Research (passive).	4990.0-5000.0 RADIO ASTRONOMY. Space Research (passive).	
5000.0-5250.0 AERONAUTICAL RADIONAVIGATION.	5000.0-5250.0 AERONAUTICAL RADIONAVIGATION.	
5250.0-5350.0 RADIOLOCATION.	5250.0-5350.0 Radiolocation.	
5350.0-5460.0 AERONAUTICAL RADIONAVIGATION. RADIOLOCATION.	5350.0-5460.0 AERONAUTICAL RADIONAVIGATION. Radiolocation.	
5460.0-5470.0 RADIONAVIGATION. Radiolocation.	5460.0-5470.0 RADIONAVIGATION. Radiolocation.	
5470.0-5600.0 MARITIME RADIONAVIGATION. Radiolocation.	5470.0-5600.0 MARITIME RADIONAVIGATION. Radiolocation.	
5600.0-5650.0 MARITIME RADIONAVIGATION. METEOROLOGICAL AIDS. Radiolocation.	5600.0-5650.0 MARITIME RADIONAVIGATION. METEOROLOGICAL AIDS. Radiolocation.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
5650.0-5850.0 RADIOLOCATION.	5650.0-5850.0 Amateur.	5800 MHz ± 75 MHz: Industrial, scientific, and medical frequency.
5850.0-5925.0 RADIOLOCATION.	5850.0-5925.0 FIXED-SATELLITE. (earth-to-space). Amateur.	
5925.0-7125.0	5925.0-6425.0 FIXED. FIXED-SATELLITE (earth-to-space).	
	6425.0-6525.0 FIXED-SATELLITE (earth-to-space). MOBILE.	
	6525.0-6875.0 FIXED. FIXED-SATELLITE (earth-to-space).	
	6875.0-7075.0 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE.	
	7075.0-7125.0 FIXED MOBILE.	
7125.0-7190.0 FIXED.	7125.0-8450.0	
7190.0-7235.0 FIXED. SPACE RESEARCH (earth-to-space)		
7235.0-7250.0 FIXED.		
7250.0-7300.0 FIXED-SATELLITE (space-to-earth). MOBILE-SATELLITE (space-to-earth). Fixed.		

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
7300.0-7450.0 FIXED. FIXED-SATELLITE (space-to-earth). Mobile-Satellite (space-to-earth).		
7450.0-7550.0 FIXED. FIXED-SATELLITE (space-to-earth). METEOROLOGICAL-SATELLITE (space-to-earth). Mobile-Satellite (space-to-earth).		
7550.0-7750.0 FIXED. FIXED-SATELLITE (space-to-earth). Mobile-Satellite (space-to-earth).		
7750.0-7900.0 FIXED.		
7900.0-8025.0 FIXED-SATELLITE (earth-to-space). MOBILE-SATELLITE (earth-to-space). Fixed.		
8025.0-8175.0 EARTH EXPLORATION-SATELLITE (space-to-earth). FIXED. FIXED-SATELLITE (earth-to-space). Mobile-Satellite (earth-to-space) (no airborne transmissions).		

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (MHz)	Non-government Allocation (MHz)	Special-use frequencies
8175.0-8215.0 EARTH EXPLORATION-SATELLITE (space-to-earth). FIXED. FIXED-SATELLITE (earth-to-space). METEOROLOGICAL-SATELLITE (earth-to-space). Mobile-Satellite (earth-to-space) (no airborne transmissions).		
8215.0-8400.0 EARTH EXPLORATION-SATELLITE (space-to-earth). FIXED. FIXED-SATELLITE (earth-to-space). Mobile-Satellite (earth-to-space) (no airborne transmissions).		
8400.0-8450.0 FIXED. SPACE RESEARCH (space-to-earth) (deep space only).		
8450.0-8500.0 FIXED. SPACE RESEARCH (space-to-earth).	8450.0-8500.0 SPACE RESEARCH (space-to-earth).	
8500.0-9000.0 RADIOLOCATION.	8500.0-9000.0 Radiolocation.	
9000.0-9200.0 AERONAUTICAL RADIONAVIGATION. Radiolocation.	9000.0-9200.0 AERONAUTICAL RADIONAVIGATION. Radiolocation.	
9200.0-9300.0 MARITIME RADIONAVIGATION. RADIOLOCATION.	9200.0-9300.0 MARITIME RADIONAVIGATION. Radiolocation.	
9300.0-9500.0 RADIONAVIGATION. Meteorological Aids. Radiolocation.	9300.0-9500.0 RADIONAVIGATION. Meteorological Aids. Radiolocation.	
9500.0-10,000.0 RADIOLOCATION.	9500.0-10,000.0 Radiolocation.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States Frequency Allocations (GHz)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
10.0-10.45 RADIOLOCATION.	10.0-10.45 Amateur. Radiolocation.	
10.45-10.50 RADIOLOCATION.	10.45-10.50 Amateur. Amateur-Satellite. Radiolocation.	
10.50-10.55 RADIOLOCATION.	10.50-10.55 RADIOLOCATION.	
10.55-10.60	10.55-10.60 FIXED.	
10.60-10.68 EARTH EXPLORATION-SATELLITE (passive). SPACE RESEARCH (passive).	10.60-10.68 EARTH EXPLORATION-SATELLITE (passive). FIXED. SPACE RESEARCH (passive).	
10.68-10.70 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	10.68-10.70 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
10.7-11.7	10.7-11.7 FIXED. FIXED-SATELLITE (space-to-earth).	
11.7-12.2	11.7-12.2 FIXED-SATELLITE (space-to-earth). Mobile except aeronautical mobile.	
12.2-12.7	12.2-12.7 FIXED. BROADCASTING-SATELLITE.	
12.7-12.75	12.7-12.75 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
12.75-13.25	12.75-13.25 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE.	
13.25-13.40 AERONAUTICAL RADIONAVIGATION. Space Research (earth-to-space)	13.25-13.40 AERONAUTICAL RADIONAVIGATION. Space Research (earth-to-space)	
13.40-14.0 RADIOLOCATION. Standard Frequency and Time Signal-Satellite (earth-to-space). Space Research.	13.40-14.0 RADIOLOCATION. Standard Frequency and Time Signal-Satellite (earth-to-space). Space Research.	
14.0-14.2 RADIONAVIGATION. Space Research.	14.0-14.2 FIXED-SATELLITE (earth-to-space). RADIONAVIGATION. Space Research.	
14.2-14.3	14.2-14.3 Fixed-Satellite (earth-to-space). Mobile except aeronautical mobile.	
14.3-14.4	14.3-14.4 Fixed-Satellite (earth-to-space). Mobile except aeronautical mobile.	
14.4-14.5 Fixed. Mobile.	14.4-14.5 FIXED-SATELLITE (earth-to-space).	
14.5-14.7145 FIXED. Mobile. Space Research.	14.5-15.35	
14.7145-15.1365 MOBILE. Fixed. Space Research.		
15.1365-15.35 FIXED. Mobile. Space Research.		

LEGEND
Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
15.35-15.40 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	15.35-15.40 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
15.40-15.70 AERONAUTICAL RADIONAVIGATION.	15.40-15.70 AERONAUTICAL RADIONAVIGATION.	
15.70-16.60 RADIOLOCATION.	15.70-17.20 Radiolocation.	
16.60-17.10 RADIOLOCATION. Space Research (deep space) (earth-to-space).		
17.10-17.20 RADIOLOCATION.		
17.20-17.30 RADIOLOCATION. Earth Exploration-Satellite (active). Space Research (active).	17.20-17.30 Radiolocation. Earth Exploration-Satellite (active). Space Research (active).	
17.30-17.70 Radiolocation.	17.30-17.70 FIXED-SATELLITE (earth-to-space).	
17.70-17.80	17.70-17.80 FIXED. FIXED-SATELLITE (space-to-earth) (earth-to-space). MOBILE.	
17.80-18.60	17.80-18.60 FIXED. FIXED-SATELLITE (space-to-earth). MOBILE.	
18.60-18.80 EARTH EXPLORATION-SATELLITE (passive). SPACE RESEARCH (passive).	18.60-18.80 EARTH EXPLORATION-SATELLITE (passive). FIXED. FIXED-SATELLITE (space-to-earth). MOBILE except aeronautical mobile. SPACE RESEARCH (passive).	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
18.80-19.70	18.80-19.70 FIXED. FIXED-SATELLITE (space-to-earth). MOBILE.	
19.70-20.20	19.70-20.20 FIXED-SATELLITE (space-to-earth). Mobile-Satellite (space-to-earth).	
20.20-21.20 FIXED-SATELLITE (space-to-earth). MOBILE-SATELLITE (space-to-earth). Standard Frequency and Time Signal-Satellite (space-to-earth).	20.20-21.20 Standard Frequency and Time Signal-Satellite (space-to-earth).	
21.20-21.40 EARTH EXPLORATION-SATELLITE (passive). FIXED. MOBILE. SPACE RESEARCH (passive).	21.20-21.40 EARTH EXPLORATION-SATELLITE (passive). FIXED. MOBILE. SPACE RESEARCH (passive).	
21.40-22.00 FIXED. MOBILE.	21.40-22.00 FIXED. MOBILE.	
22.00-22.21 FIXED. MOBILE except aeronautical mobile.	22.00-22.21 FIXED. MOBILE except aeronautical mobile.	
22.21-22.50 EARTH EXPLORATION-SATELLITE (passive). FIXED. MOBILE except aeronautical mobile. RADIO ASTRONOMY. SPACE RESEARCH (passive).	22.21-22.50 EARTH EXPLORATION-SATELLITE (passive). FIXED. MOBILE except aeronautical mobile. RADIO ASTRONOMY. SPACE RESEARCH (passive).	
22.50-22.55 FIXED. MOBILE.	22.50-22.55 BROADCASTING-SATELLITE. FIXED. MOBILE.	

LEGEND
Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
22.55-23.00 FIXED. INTER-SATELLITE. MOBILE.	22.55-23.00 BROADCASTING-SATELLITE. FIXED. INTER-SATELLITE. MOBILE.	
23.00-23.55 FIXED. INTER-SATELLITE. MOBILE.	23.00-23.55 FIXED. INTER-SATELLITE. MOBILE.	
23.55-23.60 FIXED. MOBILE.	23.55-23.60 FIXED. MOBILE.	
23.60-24.0 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	23.60-24.0 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
24.0-24.05	24.0-24.05 AMATEUR. AMATEUR-SATELLITE.	
24.05-24.25 RADIOLOCATION. EARTH EXPLORATION-SATELLITE (active).	24.05-24.25 Amateur. Radiolocation. EARTH EXPLORATION-SATELLITE (active).	24.125 ± 125 GHz: Industrial, scientific, and medical frequency.
24.25-25.25 RADIONAVIGATION.	24.25-25.25 RADIONAVIGATION.	
25.25-27.00 FIXED. MOBILE. Earth Exploration-Satellite (space-to-space). Standard Frequency and Time Signal-Satellite (earth-to-space).	25.25-27.00 Earth Exploration-Satellite (space-to-space). Standard Frequency and Time Signal-Satellite (earth-to-space).	
27.0-27.5 FIXED. MOBILE. Earth Exploration-Satellite (space-to-space).	27.0-27.5 Earth Exploration-Satellite (space-to-space).	
27.5-29.5	27.5-29.5 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE.	

LEGEND
Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
29.5-30.0	29.5-30.0 FIXED-SATELLITE (earth-to-space). Mobile-Satellite (earth-to-space).	
30.0-31.0 FIXED-SATELLITE (earth-to-space). MOBILE-SATELLITE (earth-to-space). Standard Frequency and Time Signal-Satellite (space-to-earth).	30.0-31.0 Standard Frequency and Time Signal-Satellite (space-to-earth).	
31.0-31.3 Standard Frequency and Time Signal-Satellite (space-to-earth).	31.0-31.3 FIXED. MOBILE. Standard Frequency and Time Signal-Satellite (space-to-earth).	
31.3-31.8 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	31.3-31.8 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
31.8-32.0 RADIONAVIGATION.	31.8-32.0 RADIONAVIGATION.	
32.0-33.0 INTER-SATELLITE. RADIONAVIGATION.	32.0-33.0 INTER-SATELLITE. RADIONAVIGATION.	
33.0-33.4 RADIONAVIGATION.	33.0-33.4 RADIONAVIGATION.	
33.4-36.0 RADIOLOCATION.	33.4-36.0 Radiolocation.	
36.0-37.0 EARTH EXPLORATION-SATELLITE (passive). FIXED. MOBILE. SPACE RESEARCH (passive).	36.0-37.0 EARTH EXPLORATION-SATELLITE (passive). FIXED. MOBILE. SPACE RESEARCH (passive).	
37.0-38.6 FIXED. MOBILE.	37.0-38.6 FIXED. MOBILE.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
38.6-39.5	38.6-39.5 FIXED. MOBILE. FIXED-SATELLITE (space-to-earth).	
39.5-40.0 FIXED-SATELLITE (space-to-earth). MOBILE-SATELLITE (space-to-earth).	39.5-40.0 FIXED. FIXED-SATELLITE (space-to-earth). MOBILE. MOBILE-SATELLITE (space-to-earth).	
40.0-40.5 FIXED-SATELLITE (space-to-earth). MOBILE-SATELLITE (space-to-earth).	40.0-40.5 FIXED-SATELLITE (space-to-earth). MOBILE-SATELLITE (space-to-earth).	
40.5-42.5	40.5-42.5 BROADCASTING-SATELLITE. /BROADCASTING/. Fixed. Mobile	
42.5-43.5 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE except aeronautical mobile. RADIO ASTRONOMY.	42.5-43.5 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE except aeronautical mobile. RADIO ASTRONOMY.	
43.5-45.5 FIXED-SATELLITE (earth-to-space). MOBILE SATELLITE (earth-to-space).	43.5-45.5	
45.5-47.0 MOBILE. MOBILE-SATELLITE (earth-to-space). RADIONAVIGATION. RADIONAVIGATION-SATELLITE.	45.5-47.0 MOBILE. MOBILE-SATELLITE (earth-to-space). RADIONAVIGATION. RADIONAVIGATION-SATELLITE.	
47.0-47.2	47.0-47.2 AMATEUR. AMATEUR-SATELLITE.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Permitted Services: in capitals between slash marks (i.e. /FIXED/)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
47.2-50.2 FIXED. FIXED-SATELLITE. (earth-to-space). MOBILE.	47.2-50.2 FIXED. FIXED-SATELLITE. (earth-to-space). MOBILE.	
50.2-50.4 EARTH EXPLORATION-SATELLITE (passive). FIXED. MOBILE. SPACE RESEARCH (passive).	50.2-50.4 EARTH EXPLORATION-SATELLITE (passive). FIXED. MOBILE. SPACE RESEARCH (passive).	
50.4-51.4 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE. MOBILE-SATELLITE (earth-to-space).	50.4-51.4 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE. MOBILE-SATELLITE (earth-to-space).	
51.4-54.25 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	51.4-54.25 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
54.25-58.2 EARTH EXPLORATION-SATELLITE (passive). FIXED. INTER-SATELLITE. MOBILE. SPACE RESEARCH (passive).	54.25-58.2 EARTH EXPLORATION-SATELLITE (passive). FIXED. INTER-SATELLITE. MOBILE. SPACE RESEARCH (passive).	
58.2-59.0 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	58.2-59.0 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
59-64 FIXED. INTER-SATELLITE. MOBILE. RADIOLOCATION.	59-64 FIXED. INTER-SATELLITE. MOBILE. RADIOLOCATION.	61.25 GHz ± 250 MHz: Industrial, scientific, and medical frequency.

LEGEND

Primary Services: in capitals (i.e. MOBILE)

Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
64-65 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	64-65 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
65-66 EARTH EXPLORATION-SATELLITE. SPACE RESEARCH. Fixed. Mobile.	65-66 EARTH EXPLORATION-SATELLITE. SPACE RESEARCH. Fixed. Mobile.	
66-71 MOBILE. MOBILE-SATELLITE. RADIONAVIGATION. RADIONAVIGATION-SATELLITE.	66-71 MOBILE. MOBILE-SATELLITE. RADIONAVIGATION. RADIONAVIGATION-SATELLITE.	
71-74 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE. MOBILE-SATELLITE (earth-to-space).	71-74 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE. MOBILE-SATELLITE (earth-to-space).	
74.0-75.5 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE.	74.0-75.5 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE.	
75.5-76.0	75.5-76.0 AMATEUR. AMATEUR-SATELLITE.	
76-81 RADIOLOCATION.	76-81 RADIOLOCATION. Amateur. Amateur-Satellite.	
81-84 FIXED. FIXED-SATELLITE (space-to-earth). MOBILE. MOBILE-SATELLITE (space-to-earth).	81-84 FIXED. FIXED-SATELLITE (space-to-earth). MOBILE. MOBILE-SATELLITE (space-to-earth).	

LEGEND

Primary Services: in capitals (i.e. MOBILE)

Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
84-86 FIXED. MOBILE.	84-86 FIXED. MOBILE. BROADCASTING. BROADCASTING-SATELLITE.	
86-92 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	86-92 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
92-95 FIXED. FIXED-SATELLITE (earth-to-space) MOBILE. RADIOLOCATION.	92-95 FIXED. FIXED-SATELLITE (earth-to-space) MOBILE. RADIOLOCATION.	
95-100 MOBILE. MOBILE-SATELLITE. RADIONAVIGATION. RADIONAVIGATION-SATELLITE. Radiolocation.	95-100 MOBILE. MOBILE-SATELLITE. RADIONAVIGATION. RADIONAVIGATION-SATELLITE. Radiolocation.	
100-102 EARTH EXPLORATION-SATELLITE (passive). SPACE RESEARCH (passive).	100-102 EARTH EXPLORATION-SATELLITE (passive). SPACE RESEARCH (passive).	
102-105 FIXED. FIXED-SATELLITE (space-to-earth)	102-105 FIXED. FIXED-SATELLITE (space-to-earth)	
105-116 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	105-116 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
116-126 EARTH EXPLORATION-SATELLITE (passive). FIXED. INTER-SATELLITE. MOBILE. SPACE RESEARCH (passive).	116-126 EARTH EXPLORATION-SATELLITE (passive). FIXED. INTER-SATELLITE. MOBILE. SPACE RESEARCH (passive).	122.5 GHz ± 5 GHz: Industrial, scientific, and medical frequency.

LEGEND

Primary Services: in capitals (i.e. MOBILE)

Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
126-134 FIXED. INTER-SATELLITE. MOBILE. RADIOLOCATION.	126-134 FIXED. INTER-SATELLITE. MOBILE. RADIOLOCATION.	
134-142 MOBILE. MOBILE-SATELLITE. RADIONAVIGATION. RADIONAVIGATION-SATELLITE. Radiolocation.	134-142 MOBILE. MOBILE-SATELLITE. RADIONAVIGATION. RADIONAVIGATION-SATELLITE. Radiolocation.	
142-144	142-144 AMATEUR. AMATEUR-SATELLITE.	
144-149 RADIOLOCATION.	144-149 RADIOLOCATION. Amateur. Amateur-Satellite.	
149-150 FIXED. FIXED-SATELLITE (space-to-earth). MOBILE.	149-150 FIXED. FIXED-SATELLITE (space-to-earth). MOBILE.	
150-151 EARTH EXPLORATION-SATELLITE (passive). FIXED. FIXED-SATELLITE (space-to-earth). MOBILE. SPACE RESEARCH (passive).	150-151 EARTH EXPLORATION-SATELLITE (passive). FIXED. FIXED-SATELLITE (space-to-earth). MOBILE. SPACE RESEARCH (passive).	
151-164 FIXED. FIXED-SATELLITE.	151-164 FIXED. FIXED-SATELLITE.	
164-168 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	164-168 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
168-170 FIXED. MOBILE.	168-170 FIXED. MOBILE.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
170.0-174.5 FIXED. INTER-SATELLITE. MOBILE.	170.0-174.5 FIXED. INTER-SATELLITE. MOBILE.	
174.5-176.5 EARTH EXPLORATION-SATELLITE (passive). FIXED. INTER-SATELLITE. MOBILE. SPACE RESEARCH (passive).	174.5-176.5 EARTH EXPLORATION-SATELLITE (passive). FIXED. INTER-SATELLITE. MOBILE. SPACE RESEARCH (passive).	
176.5-182.0 FIXED. INTER-SATELLITE. MOBILE.	176.5-182.0 FIXED. INTER-SATELLITE. MOBILE.	
182-185 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	182-185 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	
185-190 FIXED. INTER-SATELLITE. MOBILE.	185-190 FIXED. INTER-SATELLITE. MOBILE.	
190-200 MOBILE. MOBILE-SATELLITE. RADIONAVIGATION. RADIONAVIGATION-SATELLITE.	190-200 MOBILE. MOBILE-SATELLITE. RADIONAVIGATION. RADIONAVIGATION-SATELLITE.	
200-202 EARTH EXPLORATION-SATELLITE (passive). FIXED. MOBILE. SPACE RESEARCH (passive).	200-202 EARTH EXPLORATION-SATELLITE (passive). FIXED. MOBILE. SPACE RESEARCH (passive).	
202-217 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE.	202-217 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE.	
217-231 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	217-231 EARTH EXPLORATION-SATELLITE (passive). RADIO ASTRONOMY. SPACE RESEARCH (passive).	

LEGEND

Primary Services: in capitals (i.e. MOBILE)

Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government Allocation (GHz)	Non-government Allocation (GHz)	Special-use frequencies
231-235 FIXED. FIXED-SATELLITE (space-to-earth). MOBILE. Radiolocation.	231-235 FIXED. FIXED-SATELLITE (space-to-earth). MOBILE. Radiolocation.	
235-238 EARTH EXPLORATION-SATELLITE (passive). FIXED. FIXED-SATELLITE (space-to-earth). MOBILE. SPACE RESEARCH (passive).	235-238 EARTH EXPLORATION-SATELLITE (passive). FIXED. FIXED-SATELLITE (space-to-earth). MOBILE. SPACE RESEARCH (passive).	
238-241 FIXED. FIXED-SATELLITE (space-to-earth). MOBILE. Radiolocation.	238-241 FIXED. FIXED-SATELLITE (space-to-earth). MOBILE. Radiolocation.	
241-248 RADIOLOCATION.	241-248 RADIOLOCATION. Amateur. Amateur-Satellite.	245 GHz ± 1 GHz: Industrial, scientific, and medical frequency.
248-250	248-250 AMATEUR. AMATEUR-SATELLITE.	
250-252 EARTH EXPLORATION-SATELLITE (passive). SPACE RESEARCH (passive).	250-252 EARTH EXPLORATION-SATELLITE (passive). SPACE RESEARCH (passive).	
252-265 MOBILE. MOBILE-SATELLITE. RADIONAVIGATION. RADIONAVIGATION-SATELLITE.	252-265 MOBILE. MOBILE-SATELLITE. RADIONAVIGATION. RADIONAVIGATION-SATELLITE.	
265-275 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE. RADIO ASTRONOMY.	265-275 FIXED. FIXED-SATELLITE (earth-to-space). MOBILE. RADIO ASTRONOMY.	

LEGEND

Primary Services: in capitals (i.e. MOBILE)

Secondary Services: normal characters (i.e. Radiolocation)

United States table		
Government	Non-government	Special-use frequencies
Allocation (GHz)	Allocation (GHz)	
275-300 FIXED. MOBILE.	275-300 FIXED. MOBILE.	
Above 300. (Not allocated).	Above 300. (Not allocated).	

LEGEND

Primary Services: in capitals (i.e. MOBILE)
Secondary Services: normal characters (i.e. Radiolocation)

GLOSSARY

Absorption: The attenuation of a light wave signal by impurities or fiber core imperfections, or of a microwave signal by oxygen or water vapor in the atmosphere.

Access: The capability of devices on a network to be interconnected with one another.

Addressing: The process of sending digits over a telecommunications circuit to direct the switching equipment to the station address of the called number.

ADPCM: Adaptive Differential Pulse Code Modulation, where an error between a locally regenerated signal (formulated by an adaptive predictor) and an input signal is adaptively quantized and transmitted. A method approved by CCITT for coding voice channels at 32 kb/s to increase the capacity of T-1 to either 44 or 48 channels.

AF: Audio Frequency; a range of frequencies, normally 20 Hz to 20 kHz, that the human ear can hear.

Air Interface: A set of parameters (such as frequencies, access methodologies, information coding schemes, and the like) that defines the behavior of the wireless connections within a communications network.

Alerting: The use of signals on a telecommunications circuit to alert the called party or equipment to an incoming call.

Allocation: in the National Table of Frequency Allocations, the entry of a band of frequencies describing its allowed use by one or more radio services.

AMSS: Aeronautical Mobile Satellite Service;

ASCII: American Standard Code for Information Interexchange; a seven-bit (plus one parity bit) coding system used for encoding characters for transmission over a data network.

Analog: A transmission mode in which information is transmitted by converting it to a continuously variable electrical signal.

Answer Supervision: A signal that is sent from a switching system through the trunking network to the originating end of a call to signal that a call has been answered.

Antenna Gain: The increase in radiated power from an antenna compared to an isotropic antenna.

Asynchronous: A means of transmitting data over a network wherein each character contains a start and a stop bit to keep the transmitting and receiving terminals synchronized.

ATM: Asynchronous Transfer Mode; a connection-type transmission system carrying information in the form of headers followed by information blocks. Recurrence of blocks depends on instantaneous bandwidth requirements.

Atmospheric Loss: The attenuation of a radio signal because of absorption by oxygen molecules and water vapor in the atmosphere.

Balanced Modulator: An amplitude modulating circuit that suppresses the carrier signal, resulting in an output consisting of only upper and lower sidebands.

Band: A range of radio frequencies.

Bandpass: The range of frequencies that a channel will pass without excessive attenuation.

Bandwidth: The range of frequencies a communications channel is capable of carrying without excessive attenuation.

Baseband: A form of modulation in which data signals are pulsed directly on the transmission medium without frequency division.

Baud: The number of signal events on a circuit per unit of time.

Bearer Channel: A 64 kb/s information-carrying channel that furnishes integrated services digital network (ISDN) services to end users.

BER: Bit Error Rate; the number of error bits in a signal expressed as a fraction of the number of transmitted bits.

Big LEO's: Low Earth Orbiting satellites that offer services using radio frequencies above 1 GHz. Big LEO's are most commonly used for providing voice-grade telephony, global positioning, paging, messaging, and data transfer.

Binary: A numbering system consisting of two digits: 0 and 1.

Bit: The smallest unit of binary information; a contraction formed from the words BInary digIT.

Bit Rate: The number of bits per second a communications system carries.

Bit Robbing: The use of the least significant bit per channel in every sixth frame of a T-1 carrier system for signaling.

Bit Stream: A continuous string of bits transmitted serially in time.

Blocking: A switching system condition in which no circuits are available to complete a call, and a busy signal is returned to the caller.

BPSK: Binary Phase Shift Keying, where the phase of the transmitting carrier changes by 180° whenever the logical value of the binary data changes.

Branching Filter: A device inserted in a waveguide to separate or combine different microwave frequency bands.

Break: An interruption in transmission on a circuit.

Broadband: A form of modulation in which multiple channels are formed by dividing the transmission medium into discrete frequency segments.

Broadband PCS: Personal communications services to be offered in the United States in the 2-GHz spectrum.

Broadcast Address: A network address that includes all stations on the network that are intended to receive a transmission.

Bypass: Routing circuits around the facilities of a local exchange carrier by some form of technology such as lightwave or microwave.

Byte: A set of eight bits of information equivalent to a character. Also sometimes called an octet.

Carrier: (1) A company that carries telecommunications services for a fee. (2) A signal that can be modulated to carry intelligence from another signal. (3) A type of multiplexing equipment used to derive several channels from one communications link by combining signals on the basis of time or frequency division.

Carrier to Noise Ratio: The ratio of the received carrier to the noise level in a satellite link.

CCIS: Common Channel Interoffice Signaling; the AT&T common channel signaling system used North America.

CCITT: Consultative Committee on International Telephone and Telegraph; an element of the International Telecommunications Union, which establishes international telecommunications standards.

CC (n,k,K): A Convolutional Code where n is the number of encoded bits for each k information bit, and K is the constraint length. The $(n - k)$ parity bits depend on K previous information bits, and the correcting power of the code is dependent on the coding rate $R = k/n, K$, and the decoding algorithm.

Cell: A hexagonal subdivision of a mobile telephone service area containing a cell-site controller and radio frequency transceivers. Also, a group of bytes conditioned for transmission across a network.

Cell-Site Controller: The cellular radio unit that manages radio channels within a cell.

Cellular Telephone: A mobile and portable radio telephone service that uses networked base stations or "cells." The U.S. service is offered in the 800-MHz band by two competing licensees in each market. Elsewhere in the world it is offered at 800 MHz and other bands and under a variety of commercial arrangements.

CELP: Code Excited Linear Prediction; a speech encoding algorithm that enables speech to be digitized at 8.0 kb/s with quality approximately equal to that of analog FM systems.

CEPT: Conference European on Post and Telecommunications; the European telecommunications standards-setting body.

CGSA: Cellular Geographic Serving Area; a metropolitan area in which the FCC grants cellular radio licenses.

Channel: A electronic communications path that is capable of carrying a signal.

Channel Bank: An apparatus that converts multiple voice frequency signals to frequency or time division multiplexed signals for transmitting over a transmission medium.

Circuit: A transmission path between two points in a telecommunications system.

Clear Channel: The elimination of bit-robbed signaling in a digital channel to enable use of all 64 kb/s for digital transmission.

Coherence Bandwidth: The bandwidth of a range of frequencies that are subjected to the same degree of frequency-selective fading.

Commercial Mobile Radio Service: A new category of mobile radio service that is provided for profit, interconnected with the public switched network, and available to all or much of the public. It groups traditional mobile communications common carriers with licensed narrowband and broadband PCS, as well as other types of private carriers that provide mobile communications services to business and industrial users. (Unlicensed PCS is not considered a mobile radio service, whether commercial or private.)

Common Carrier: A company authorized by the United States Federal Communications Commission to provide communications services (either by wire or radio) to the general public for profit within an assigned territory. Common carriers are regulated by Title II of the Communications Act of 1934.

Critical Rain Rate: The amount of rainfall where the drops are of sufficient size and intensity to cause fading in a microwave signal.

Cross Polarization: The relationship between two radio waves when one is polarized vertically and the other horizontally.

Crosstalk: The unwanted coupling of a signal from one transmission path into another.

CRSO: Cellular Radio Switching Office; the electronic switching system that switches calls between mobile and wireline telephones, controls hand-off between cells, and monitors usage. This equipment is known by various trade names.

DAMA: Demand Assigned Multiple Access; a method of sharing the capacity of a communications satellite by assigning capacity on demand to an idle channel or time slot from a pool.

Data Compression: A data transmission system that replaces a bit stream with another bit stream having fewer bits.

Data Link: A circuit capable of carrying digitized information.

dB: Decibel; a measure of relative power level between two points in a circuit.

dBm: A measure of power level relative to the power of 1 milliwatt.

DBS: Direct Broadcast Satellite; a television broadcast service that provides television programming services throughout a country from a single source through a satellite.

Delta Modulation: A system of converting analog to digital signals by transmitting a single bit indicating the direction of change in amplitude from the previous sample.

Demodulation: The process of extracting intelligence from a carrier signal.

Digital: A mode of transmission in which information is coded in binary form for transmission on a network.

Diplexer: A device that couples a radio transmitter and receiver to the same antenna.

Dipole: An antenna that has two radiating elements fed from a central point.

Dispersive Fade Margin: A property of a digital microwave signal that expresses the amount of fade margin under conditions of distortion caused by multipath fading.

Distortion: An unwanted change in a waveform.

Diversity: A method of protecting a radio signal from failure of equipment or the radio path by providing standby equipment.

Diversity Reception: Where a receiver enhances the reliability of transmission by suitable combining the reception from a number of independent fading paths that each carry the same message.

Downlink: The radio path from a satellite to an earth station.

DPM: Digital Phase Modulation, where the shaped data signals are applied directly to a phase modulator.

DOV: Data Over Voice; a device that multiplexes a full duplex data channel over a voice channel using analog modulation.

DTMF: Dual Tone Multifrequency; a signaling system that uses pairs of audio frequencies to represent a digit. Usually synonymous with the AT&T trademark Touchtone.

Earth Station: The assembly of radio equipment, antenna, and satellite communication control circuitry that provides access from terrestrial circuits to a satellite.

Echo: The reflection of a portion of a signal back to its source.

Emerging Technologies: A generic term describing new radio communications technologies and applications. In the United States, the FCC has reallocated 220 MHz of fixed service spectrum in the bands 1850-1990, 2110-2150, and 2160-2200 MHz to these new technologies and applications.

EMI: Electromagnetic Interference; an interfering signal that is radiated from a source and picked up by a telecommunications circuit.

Enterprise Network: A private network of both switched and dedicated facilities that enables users to connect to services wherever they are located without concern about how to establish the session.

Envelope Delay: The difference in propagation speed of different frequencies within the pass band of a telecommunications channel.

Erlang: A unit of network load. One Erlang equals 36 CCS and represents 100 percent occupancy of a circuit or piece of equipment.

Facility: Any set of transmission paths that can transport voice or data. Facilities can range from a cable to a carrier system or a microwave radio system.

Fade: A reduction in received signal level in a radio system caused by reflection, refraction, or absorption.

Fade Margin: The depth of fade, expressed in dB, that a microwave receiver can accommodate while still maintaining acceptable circuit quality.

Fast Packet Switching: A packet switching system intended for voice, data, and video transmission. Fast packet eliminates many of the time consuming link-by-link flow control and error correction procedures that delay the flow of packets.

FDMA: Frequency Division Multiple Access; a method of sharing the capacity of a communications satellite or cellular telephone transmitter by frequency division of the transponder.

FEC: Forward Error Correction; a method of correcting errors in a data channel by transmitting overhead bits that enable the receiving end to correct error bits.

Filter: A device used to remove unwanted signals from the pass band of a circuit.

Fixed Service: A generic term describing point-to-point microwave telecommunications and telemetry for industrial and common carrier uses. The gradual conversion of these bands to new uses, including personal communication services (PCS), is an international trend.

Footprint: The earth's area that is illuminated by the RF output signal of a satellite.

FPLMTS: Future Public Land Mobile Telecommunications Services; a proposed global system that includes the functions of cordless telephony, paging, cordless pay phones, private branch exchanges, and rural radio and telephone exchanges among terminals on land, at sea, and in the air. A search for a new acronym is under way.

Frame: A complete television picture consisting of two field of interlaced scanning lines. Also, a group of bytes conditioned with header and error correction fields for transmission across a data link.

Frame Alignment: The state in which the frame of the receiving equipment is properly phased with respect to the transmitting equipment.

Free Space Attenuation: The amount of loss, expressed in dB, that a radio signal encounters between the transmitting and receiving antennas.

Frequency: The number of time per second that an alternating current signal changes state through one complete cycle.

Frequency Agility: The ability of a cellular mobile telephone to shift automatically between frequencies.

Frequency Diversity: Protection of a radio signal by providing a standby radio channel on a different frequency to assume the load when the regular channel fails.

FSK: Frequency Shift Keying, where the instantaneous carrier frequency is dependent on the value of the input signal. If the phase is continuous at symbol boundaries, Continuous Phase FSK (**CPFSK**) results.

Full Duplex: A data communication circuit over which data can be sent in both directions simultaneously.

Gain: (1) The increase in electrical power that results from amplification. (2) The increase in power radiated from an antenna compared to the power that would radiate from a dipole antenna.

Gateway: Circuitry used to interconnect networks by converting the protocol of one network to that used by the other.

gb/s: Gigabits Per Second; a unit of data transmission speed measured in billions of bits per second.

Geosynchronous: An orbit that positions a satellite at a constant point with respect to a point on the earth's surface.

GHz: Gigahertz; a unit of frequency measured in billions of cycles per second.

GMSK: Gaussian Minimum Shift Keying is CPFSK with a Gaussian-shaped premodulation filter. It has a narrower bandwidth than the equivalent unfiltered CPFSK signal.

GOS: Grade of Service; the percentage of time or probability that a call will be blocked in a network. Also a quality indicator used in transmission measurements to specify the quality of a circuit based on both noise and loss.

GPS: Global Positioning System; satellite systems which allow users on the ground to pinpoint their location on the earth's surface.

Ground Wave: A radio wave that is guided by the earth's surface.

Guard Band: A frequency band that separates the voice channels of circuits from one another.

Half Duplex: A data communications circuit over which data can be sent in only one direction at a time.

Hand-off: The process of changing radio channels when a mobile unit moves from the coverage area of one cell to another.

Handset: A telephone transmitter and receiver that are mounted as a single piece.

Handshaking: The exchange of signals between two devices preparing to initiate or terminate communications.

Hang-On Queuing: A trunk queuing system in which the switching system signals users that all trunks are busy and allows them to remain off-hook while they are held in queue until the call can be completed.

Heterodyning: The process of shifting a radio frequency by mixing it with another frequency and selecting the desired frequency from the resulting modulation products.

Holding Time: The time period that a call occupies a telecommunications channel.

Hot Standby: A method of protecting a radio system by keeping a duplicate system tuned to the same frequency but decoupled from the antenna.

Hybrid Network: A network that consists of multiple facility ownership, uses, architectures, or other such mixtures of characteristics that take it away from the traditional discrete networks of the past.

Hz: Hertz; the unit of frequency, in cycles per second.

I and Q Signals: Inphase and Quadrature signals are vector components of the baseband information carrying signal.

Impedance: The ratio of voltage to current along a transmission line or circuit.

IMTS: Improved Mobile Telephone Service; a type of mobile telephone service that allows direct dialing between wireline and mobile units without operator intervention.

Inband Signaling: Signaling transmitted within the pass band of the circuit that is used for the transmission.

INMARSAT: International Maritime Satellite Service; a satellite system that provides satellite services to ships at sea.

Interframe Encoding: A method of video compression that transmits only changed information between successive frames.

Interleaving: A process whereby data, in either bit or symbol form, are distributed over a time frame in order to disperse error bursts at the receiver after de-interleaving has occurred.

Intraframe Encoding: A method of video compression that divides the picture into blocks and transmits only changed blocks between successive frames.

Interoperability: The capability of a wireless technology to communicate with the receiving equipment and networks of other manufacturers and licensees.

ISDN: Integrated Services Digital Network; a set of CCITT standards that provides for an integrated set of voice and data services over an end-to-end digital medium.

Isochronous: The timing characteristics of an event or signal recurring at known intervals. Digitized voice and video are examples of isochronous signals.

Isotropic Antenna: An antenna that radiates equally in all directions.

Jitter: The phase shift of digital pulses over a transmission medium.

kb/s: Kilobits Per Second; a unit of data transmission speed measured in thousands of bits per second.

kHz: Kilohertz; a unit of frequency measured in thousands of cycles per second.

Latency: The elapsed time between transmission from one device and its reception by the addressee.

LEO: Low Earth Orbiting satellite;

Little LEO's: Low Earth Orbiting satellites that offer services using radio frequencies below 1 GHz. Little LEO's are most commonly used for providing low-rate data transfer and radiolocation services.

LMSS: Land Mobile Satellite Service;

LMX: L Multiplex; a system of analog multiplex consisting of combinations of groups, super groups, master groups, and jumbo groups to form a hierarchy of channels that can be transmitted over radio or coaxial cable.

Loss Budget: The sum of all factors that introduce loss between the transmitter and receivers.

mb/s: Megabits Per Second; a unit of data transmission speed measured in millions of bits per second.

MHz: Megahertz; a unit of frequency measured in millions of cycles per second.

Microwave: A radio frequency in the range of 1 GHz to 30 GHz.

Milliwatt: One one-thousandth of a watt. Used as a reference power for signal levels in telecommunications circuits.

Mixed Mode: A system that is capable of encoding data in both alphanumeric and facsimile form for integrating text and graphics.

MMSS: Maritime Mobile Satellite Service;

Mode: The different paths light waves can take through a transmission medium.

Modulation: The process of imposing information on a carrier signal.

MSK: Minimum Shift Keying is CPFSK with a modulation index of 0.5.

Multipath Fading: A radio system fade caused by reflection of a portion of the transmitted signal so that it takes a longer path to the receive antenna and arrives slightly out of phase. The phase difference results in a reduced receive signal level.

Multiplexer: A device used for combining several lower speed channels into a higher speed channel.

Multiplexing: The process of combining multiple signals into a single channel.

Narrowband: A radio system that operates in a bandwidth that is less than the coherence bandwidth.

Narrowband PCS: Personal communications services to be offered in the United States around 900 MHz by services such as advanced paging and data messaging.

Noise: Any unwanted signal in a transmission path.

Nonwireline: A term describing cellular radio service providers that are not operating telephone companies.

Octet: A group of eight bits; also known as a byte.

Open Network Architecture: A telephone architecture that provides the interfaces to enable service providers to connect to the public switched telephone network.

OSI: Open Systems Interconnect; a seven-layer data communications protocol model that specifies standard interfaces that all vendors can adapt to their own design.

Out-of-Band Signaling: Signaling within the pass band of a single circuit by tones that are separated from the voice channel by filters.

Overhead: Any non-information bits, such as headers, error checking bits, and start and stop bits, that are used for controlling a network.

Packet: A unit of data information consisting of header, information, error detection, and trailer records that is transmitted across the network layer.

Packet Switching: A method of allocating network time by forming data into packets and relaying it to the destination under control of processors at each major node. The network determines packet routing during transport of the packet.

PAD: Packet Assembler/Disassembler; a device used on a packet switched network to assemble information into packets and to convert received packets into a continuous data stream.

PAM: Pulse Amplitude Modulation; a digital modulation method that operates by varying the amplitude of a stream of pulses in accordance with the instantaneous amplitude of the modulating signal.

Parity: A bit or series of bits appended to a character or block of characters to ensure that either an odd or an even number of bits are transmitted. Parity is used for error detection.

PBX: Private Branch Exchange; a switching system dedicated to telephone and data use in a private communication network.

PCC: Punctured Convolutional Codes are CC (n,k,K) codes where certain code bits are periodically deleted prior to transmission. The coding rate R is increased, but the complexity of the decoder is reduced.

PCM: Pulse Code Modulation; a digital modulation method that encodes a PAM signal into an eight-bit digital word representing the amplitude of each pulse.

PCN: Personal Communications Network; a form of PCS that offers metropolitan-area portable radio telephony that could compete with cellular and public telephone networks.

PCS: Personal Communications Services; an Emerging Technology and a generic term describing mobile, portable, and ancillary fixed radio communications systems that could provide services to individuals and businesses and be integrated with a variety of competing networks. Around the world, PCS allocations will be made in the 800-3000 MHz range.

Picture Element (Pixel): A single element of video information.

Pilot: A single frequency that is transmitted on an L carrier line or microwave radio system to regulate amplifier stability and to actuate alarms.

Ping Pong: A method of obtaining full duplex data transmission over a two wire circuit by rapidly alternating the direction of transmission.

RSL: Received Signal Level; the strength of a radio signal received at the input to a radio receiver.

Sampling: The process of periodically examining the amplitude of an analog signal.

Satellite Delay Compensator: A device that compensates for absolute delay in a satellite circuit by communicating with data terminal equipment with the data terminal equipment's own protocol.

SBC: Sub-Band Coding, where the speech signal is partitioned into frequency sub-bands, and each sub-band signal is [illegible]

Plesiochronous: The situation that exists when two digital networks are independently timed and no synchronizing signal is passed between them.

Private Mobile Radio Service: One that falls outside the statutory definition of a commercial radio service, being principally used for the licensee's internal communications.

Propagation Delay: The absolute time delay of a signal from the sending to the receiving terminal.

Propagation Speed: The speed at which a signal travels over a transmission medium.

Pulse: A short signal used to transmit information.

PSK: Phase Shift Keying; a method of digitally modulating a radio signal by shifting the phase of the transmitted carrier.

Public Switched Network: Any common-carrier switched network, whether wire or radio, that uses the North American Numbering Plan and routes calls by switching (such as telephone networks or mobile service providers).

QAM: Quadrature Amplitude Modulation; a method of digitally modulating a radio signal by combining sine and cosine carrier signals in quadrature.

Quantizing: The process of encoding a PAM signal into a PCM signal.

Quantizing Noise: Noise that results from the inability of a PAM signal to represent each gradation of amplitude change.

Quasi-Synchronous: A system of enabling multiple radio transmitters to operate simultaneously on frequencies that are slightly offset. Also known as simulcast.

RDSS: Radiodetermination Satellite Service; involves tracking, locating, and direction-finding operations on the earth and in space using satellites.

Receiver Sensitivity: The magnitude of the received signal level necessary to produce objective BER or channel noise performance.

Regenerator: An electronic digital signal repeater that reshapes incoming pulses into undistorted square waves.

Repeater: An electronic device that reshapes pulses or adds gain or amplification to a circuit.

Resistance: The property in an electrical circuit that opposes the flow of electricity.

rn: Reference Noise; the threshold of audibility to which noise measurements are referred, -90 dBm.

Roamer: A mobile telephone user who initiates service in an area other than the one to which the customer was originally assigned.

Routing: The path selection made for a telecommunications signal through the network to its destination.

Spot Beam Antenna: A satellite antenna that is capable of illuminating a narrow portion of the earth's surface.

SSB: Single-Sideband; an amplitude modulation method in which the carrier is suppressed and one sideband is filtered out so that only one sideband is amplified and transmitted.

SSTDMA: Spacecraft Switched Time Division Multiple Access; a method of sharing the capacity of a communications satellite by on-board switching of signals aimed at earth stations.

Station Keeping: The process on board a satellite for keeping it at its assigned longitude and inclination.

Statistical Multiplexing: A form of data multiplexing in which time on a communications channel is assigned to terminals only when they have data to transport.

Sun Transit Outage: Satellite circuit outage caused by direct radiation of the sun's rays on an earth station receiving antenna.

System Gain: The amount of free space path loss that a radio can overcome by a combination of transmitted power and receiver sensitivity.

Talk-Through: The ability of a full duplex mobile radio unit to talk to another mobile unit through the base station.

TDM: Time Division Multiplexing; a method of combining several communication channels by dividing a channel into time increments and assigning each channel to a time slot. Multiple channels are interleaved when each channel is assigned the entire bandwidth of the backbone channel for a short period of time.

TDMA: Time Division Multiple Access; a method of sharing the capacity of a communications satellite by allotting access to the satellite to earth stations transmitting on the same frequency.

Telepoint: A generic term for a form of PCS that provides cordless pay phone service to customer-owned handsets within limited range of base stations in public places.

Three-Axis Stabilization: A method of preventing a satellite from tumbling by use of a gyroscope inside the satellite.

Throughput: The effective rate of transmission of information, excluding non-information (overhead) bits, between two points.

Traffic: The volume of demand on a telecommunications system.

Transceiver: A single device that can both transmit and receive.

Transmitter Output Power: The amount of radio frequency energy, usually expressed in dBm, that a transmitter delivers to the antenna.

Transponder: A satellite-mounted radio repeater that amplifies and converts the uplink frequency to the downlink frequency.

Tropospheric Wave: A radio wave at VHF frequencies or above that is reflected or scattered by the troposphere.

Trunking Radio: A mobile radio station in which multiple mobiles share a group of frequencies. The idle mobiles all tune to a control channel to receive signals and then shift frequency to an assigned channel or trunk.

Unfaded Received Signal Level: The signal level measured at the input to a radio receiver. It is the sum of all gains and losses in the signal except losses due to fading.

Uplink: The radio path from an earth station to a satellite.

User-PCS: A term used by U.S. manufacturers for a form of PCS that is unlicensed and user-owned, such as wireless local area networks, cordless telephone systems, and portable information devices.

VF: Voice Frequency; an audio frequency in the range of 300 to 3000 Hz.

Video Compression: A method of transmitting analog television over a narrow digital channel by processing the signal.

Voice/Data Multiplexer: A device that compresses voice and integrates it with a data signal for transmission on a digital channel.

Voting Receivers: A group of mobile base station receivers operating on the same frequency with a control unit to pick the best signal from among them.

WARC: World Administrative Radio Conference;

Waveguide: A rectangular or circular metallic tube capable of coupling a microwave signal from radio equipment to an antenna.

White Noise: Noise frequencies that are equally distributed across all frequencies of a pass band.

Wideband: (1) A channel that has enough bandwidth to carry more than one voice channel. (2) A radio bandwidth that is greater than the coherence bandwidth.

Wireline: A term describing cellular radio service providers who are operating telephone companies. Also used to distinguish between mobile radio users and conventional telephone users in a standard telephone-to-mobile call.

XPD: Cross-Polarization Discrimination; the amount of decoupling between radio waves that exists when they are cross polarized.

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