TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. WA-RD 360.1	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE IVHS DATA AND INFORMATION STRUCTURE		5. REPORT DATE May 1995 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Daniel J. Dailey, Mark P. Haselkorn, and Scott D. Elliott		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State Transportation Center (TRAC) University of Washington, JD-10 University District Building; 1107 NE 45th Street, Suite 535 Box 354802 Seattle, Washington 98105-4631		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. Agreement T9903, Task 11
12. SPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation Transportation Building, MS 7370 Olympia, Washington 98504-7370		13. TYPE OF REPORT AND PERIOD COVERED Final Summary Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

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.

17. KEY WORDS Analog cellular, digital cellular, cellular digital packet data, personal communications services, cordless, radiopaging, wireless, mobile radio, ARDIS, RAM, geostationary satellites, meteor burst, CT-2, DECT, paging, data networks, global positioning, remote sensing	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	20	

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

IVHS DATA AND INFORMATION STRUCTURE

by

Daniel J. Dailey, Mark P. Haselkorn, Scott D. Elliott
ITS Research Program
College of Engineering, FT-10
University of Washington
Seattle, Washington 98195

Washington State Transportation Center (TRAC)
University of Washington, JD-10
University District Building
1107 NE 45th Street, Suite 535
Box 354802
Seattle, Washington 98105-4631

Washington State Department of Transportation
Technical Monitor
Morgan Balogh
ITS Engineer

Prepared for

Washington State Transportation Commission
Department of Transportation
and in cooperation with
U.S. Department of Transportation
Federal Highway Administration

May 1995

DISCLAIMER

Table of Contents

List of Tables

Executive Summary

Introduction

Wireless communications technologies are rapidly growing in their variety and popularity. For instance, along our state's freeways it is now commonplace to see drivers talking on their cellular phones while traveling to work. Paging devices are even more widespread, as greater numbers of employees stay "on-call" with their supervisors through pager messaging. High school students have adopted pagers, too, and are using "beepers" (in "day-glo" colors) to stay in touch with parents and friends. Satellites have become an ordinary part of rural life as farmers and townsfolk use the technology to improve their television viewing options. Now smaller satellite dishes and low-earth-orbit satellites are on the verge of bringing vast improvement in voice and data communications to those same isolated regions. The State Department of Transportation, too, has used designated highway maintenance frequencies for years to link mobile workers with base dispatchers. But even traditional private land mobile radio technology is taking on new tasks and more customers as it goes digital and as commercial competition is encouraged.

This explosion of wireless communications options can be seen as both a bane and a blessing. The increase in service providers and in available technological choices practically ensures that there is a mobile communications solution for most any wireless need. The challenge, however, has increasingly become one of sorting through all the jumbled, competing claims to make sense of the marketplace. Only then can the proper technology be matched with the customer's communications demands. This executive summary is a condensed version of a research report that has been developed to provide the Washington State Department of Transportation with a more complete and coherent understanding of today's wireless communications environment.

Request for the Study

The research effort that has produced this executive summary 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 executive summary—and its associated, comprehensive research report—have 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. Considering that a recent workshop on 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 as part of this process.

The Scope of the Study and Research Methods

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 DOT officials.

Attention was given to those wireless technologies offering moderate to long-range communications capabilities. As a result, those mobile systems designed to provide signal coverage primarily within buildings—such as that offered by wireless local area networks (WLAN's)—were not included in this study. Wireless technologies that are able to support either simplex (one-way) or duplex (two-way) communications were examined; also, both analog and the newer digital transmission systems were reviewed. 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 extensively in separate chapters that make up the body of the full research report.

This research effort has borrowed from work done previously by scholar Steven Bell, who has identified some of the key characteristics for comparing the performance of competing

---

[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).

wireless networks.[2] Bell spotlights the following parameters as key factors for evaluating the potential of mobile communication equipment:

1) The reliability of the radio service;
2) The coverage area provided: urban or rural;
3) The maximum transmission speeds possible, which can impact the cost of service;
4) Equipment and airtime costs; and
5) The security of associated messages.

In addition to these somewhat generic qualifications, the technologies reviewed have been evaluated as to their suitability for carrying out specific DOT communications functions. Five general classes of departmental service have been identified as being of primary importance. First, and perhaps most obvious, is the DOT's need for wireless links to handle internal communications between managers and dispatchers 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 commuters in their cars to 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 service to be provided by wireless networks. Third is the need for some sort of flexible and inexpensive relay system for transmitting data measurements from remote sensors to urban offices, from which the DOT can monitor changing traffic and meteorological conditions across the state. 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 devices that could be used to instantaneous react to emergency situations that are inaccessible or which demand prompt and decisive action by centrally-located transportation managers. Distant control of highway reader boards or traffic signals are obvious examples of how such wireless relays might be applied.

Key Findings

The generic and DOT-specific communications features listed above have been used as reference points for comparing the functionality of today's leading wireless technologies. The following summaries of these mobile technologies reflect the key findings of the main report that accompanies this executive summary. In addition, Table 1.1 provides a basic overview of

---

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

	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

specific mobile communications services that are most promising and are available now or expected within the next decade. Each of these particular services fits within one of the broader wireless categories, such as cellular telephony or paging.

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. 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. It must be emphasized that this matrix is intended only as a quick reference to the leading wireless technologies that should be considered by the DOT. Readers wanting more in-depth evaluations of certain technologies should refer to the extensive companion report which discusses the different wireless systems in much greater detail.

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. 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.

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, 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.) Alternative standards like code-division multiple-access (CDMA) and Enhanced-TDMA (E-TDMA) promise the potential of even greater system capacity, and, therefore, lower costs for airtime. But their technical viability is still very much in question. 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.

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.

Another cellular-based technology that can be used to transmit data has been created by Cellular Data, Inc. (CDI) of Palo Alto, California. The CDI system uses the 3 kHz "guardband" in between each conventional cellular radio channel to carry low-power data transmissions. CDI can support a slower data transfer speed of 2.4 kilobits-per-second. 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. Nevertheless, CDI has gotten much less publicity than CDPD, and it remains to be seen whether this technology can carve out its own niche in today's competitive wireless environment.

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

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.

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.

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.

Cordless Telephony

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. In addition to voice communications, the DECT system supports data transmission of 32 kilobits-per-second.

A Japanese cordless offering known as the Personal Handy Phone System (PHS) has many performance similarities with the DECT standard. U.S. West and Bell Atlantic are reportedly testing the potential of PHS for introduction in the United States. PHS is a digital system employing a light-weight handset which allows the user to both make and receive calls when in the vicinity of a telepoint station. PHS equipment faces an uphill battle since it lags behind both CT-2 and DECT in development. It is gaining ground quickly, however.

There are currently no telepoint networks in the U.S., although some Canadian and American firms are showing interest in importing the technology. The value of DECT, PHS, or CT-2 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. 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.

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. 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 short 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. 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[3] cards even when the computer is powered down.

---

[3]PCMCIA is an acronym for Personal Computer Memory Card Industry Association.

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 high-definition television (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 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.

Whenever a technology, like paging, has a prominent weakness, it's a sure bet that someone will come along with a "new and improved" version 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 novel 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.[4] 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.

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 for highway maintenance support. The DOT currently uses those radio channels for voice communications with workers located 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. For instance, 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. Switching from the current configuration that supports voice communications to one allowing data messaging could also 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, it must be remembered that 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 conventional voice communications. The data transmitted on these frequencies could be used for most any

---

[4]Other companies, like American Paging, Inc. and Nexus Telecommunications Systems Ltd., are also testing advanced two-way paging systems.

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.

Because private land mobile radio has built on the experience of foundational 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.

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.[5] A company called OneComm previously held the specialized mobile radio licenses covering Washington State, but OneComm announced a merger with NEXTEL during the summer of 1994.

The only ESMR network up and running is in Los Angeles, but OneComm (NEXTEL) 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

[5]The ESMR standard is formally known as the Motorola Integrated Radio System, or MIRS.

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.

Radio Data Networks

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 technicians, 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. At least for the near future in Washington State, RAM will provide a data transfer speed of 8 kilobits-per-second and ARDIS will relay data messages at 4.8 kilobits-per-second.[6] To their credit, 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.

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

[6]ARDIS can provide a data transmission rate of 19.2 kilobits-per-second in some larger markets, but not in the metropolitan Seattle area.

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.

Satellites

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.

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 systems offering continuous communications have yet made it from the drawing board 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.

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 heated competition from an alternative technology known as meteor burst, which will be discussed in the next section. 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.

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 example—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, there would never be any airtime costs, 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 using meteor burst to relay meteorological readings from 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.)

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 shorter 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.

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. 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.

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. 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.

Additionally, MB networks are inherently more private and secure, due to the small diameter of the reception area (called the "footprint") associated with the technology and the random pattern of MB radio connections. Meteor burst remote transceivers have also become increasingly mobile and durable thanks to improvements in solid state engineering. Joined with radiolocation equipment, meteor burst technology could help DOT dispatchers track and direct highway work crews across the state. Over forty years of strong military interest in MB from governments around the world attests to the functionality and reliability of this specialized and unique radio service.