SD2005-03

SD Department of Transportation
Office of Research

Use of Wireless Technology for Field Applications

Study SD2005-03

"Final Report"

Prepared by
Applied Research Associates, Inc.
7184 Troy Hill Drive, Suite N
Elkridge, Maryland 21075

July 31, 2006

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessary reflect the official views or policies of he South Dakota Department of Transportation, the State Transportation Commission, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGEMENTS

This work was performed under the supervision of the SD2005-03 Technical Panel:

Jon Becker...........Project Manager, Research
Dennis Johnson............………......Research
Dave Huft…………………………Research
Pat Sendelweck…………….………Research
Darin Charlson.…….Inventory Management
Brad Letcher.............…………..... Huron Area
Phil Clements..... ..…. Project Development
Dave Parker..........……………Right of Way
Leon Ellis...........… ……........................ BIT
Jerry Schaefer....……Materials & Surfacing
John Forman..........…… Operations Support
Eugene Thomas........... ……….…....... ... BIT
Bruce Hunt ..Federal Highway Administration
Tony Wieser......................... Internal Services
Todd Dravland.................... BIT - State Radio
Dan Martell…………………….……Road Design

The contribution of the following additional people are gratefully acknowledged:

Steve Wegman………South Dakota Public Utilities Commission
Bob Hart…………………..….Meridian Environmental Technology

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. SD2005-03	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

Use of Wireless Technology for Field Applications

5. Report Date

July 31, 2006

6. Performing Organization Code

7. Author (s) William A. Hyman, Jim Zeitlin, Harley Radin. Shawn Snellgrove, Edward Page

8. Performing Organization Report No.

9. Performing Organization Name and Address

Applied Research Associates, Inc.
505 West University Ave.
Champaign, IL 61820

10. Work Unit No.

11. Contract or Grant No.

Agreement No. 310936

12. Sponsoring Agency Name and Address

South Dakota Department of Transportation
700 E. Broadway Avenue
Pierre, South Dakota 57501-2586

13. Type of Report and Period Covered
Research Report, May 15, 2005 – June 30, 2006

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The South Dakota Department of Transportation (SDDOT) has many field applications that require data transfer with the state's computer network. These field applications include Road Weather Information Systems, the Maintenance Decision Support System, Automated Traffic Recorders, Weigh-in-Motion, Construction Management, Right-of-way Acquisition, Megatraks Fuel Consumption Reporting System, and Pavement Distress Identification. Phone lines are used for the vast majority of these applications. Monthly phone bills are high and so is the cost of upgrading phone lines. Furthermore, the time required to transfer data is often slow. If data resides on a laptop, rather than transfer data by phone, staff will often carry the laptop into an area or maintenance office for uploading, or they may use broadband services at home or, if traveling, in motels. This study examined the wireless communication and related requirements of the field applications listed above. Then a detailed examination of wireless technology was conducted. Wireless technology included personal, local, metropolitan and wide area networks (WPAN, WLAN, WMAN, and WWAN) and different generations of U.S. and overseas technology. Many other technologies were examined including Dedicated Short Range Communications, satellite communications; meteor burst communications, and extended range RF. A determination was made regarding whether each wireless technology was available in South Dakota, whether the data rates were sufficient, and if other characteristics could meet needs. Then for each set of requirements for each field application, alternative wireless solutions were identified and four recommendations were made to conduct pilot demonstrations. The project panel decided not to proceed with the recommended pilots for a variety of reasons. Instead SDDOT sought to identify additional field applications that might benefit from wireless communications and selected a traffic signal maintenance management application. Changes in the wireless market in South Dakota precluded carrying out this application in a timely fashion. Among the findings of the study were that many applications require a range of 20 to 40 miles -- possibly more with coverage expressed in square miles ranging from 400 to 1600 and under some circumstances 5625. Among the recommendations was a suggestion that the State upgrade the bandwidth of the wireline connections between the offices and headquarters to take advantage of high Wi-Fi data rates. Another recommendation was to implement a test bed for wireless communications.

17. Keywords
Wireless, Telecommunications, Data transfer, Field Applications, Technology

18. Distribution Statement

Unclassified – No Restrictions

19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No of Pages 92	22. Cost

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

PROBLEM DESCRIPTION

The South Dakota DOT (SDDOT) has many existing, evolving and emerging field applications. These include fixed and portable dynamic message signs, the fixed and mobile components of the Maintenance Decision Support System (MDSS), data inputs into the Road Condition Reporting System (RCRS), traffic counting and classifying using Automated Traffic Recorders (ATR) and Weigh-in-Motion (WIM), surveys to collect pavement distress data, right-of-way acquisition data collection necessary for the purchase of real estate, different facets of construction data collection (Mobile Contract Manager (MCM), Material Sampling and Testing (MS&T), Construction Measurement and Payment (CM&P)), the Megatraks fuel system, and a traffic signal maintenance management system.

SDDOT staff has concluded that existing telecommunications between many of these applications and their respective databases or servers is slow, inconvenient, costly, and that upgrading landlines would be expensive.

Recent successful experience using spread spectrum wireless communications between DOT offices and Dynamic Message Signs (DMS) prompted the SDDOT to conduct an in-depth inquiry regarding the feasibility and benefits and costs of using wireless communications with other field applications. SDDOT recognized the potential of inexpensive Wireless Fidelity (Wi-Fi) to satisfy many communication needs and that cellular or Personal Communications Services (PCS) such as Global System for Mobile Communications (GSM) might have a role to play in providing internet data transfer.

Consequently SDDOT contracted with Applied Research Associates Inc. (ARA) to investigate the suitability of different wireless technology for serving the various types of field applications listed above.

OBJECTIVES

There were two primary objectives of the study:

1. To assess the feasibility of various communications technologies to support field equipment, data collection, and maintenance and construction activities.
2. To perform pilot installations of communications to support data communications for SDDOT activities.

Given the problem statement for the research, we recast these objectives more broadly:

> The objective of the project is to investigate different wireless technology and identify those most appropriate and net-beneficial for different field applications. A related objective is to address field data transfer problems SDDOT has identified including wait time to upload data to the

Construction Management System from the construction project labs, rising costs for the current modes of data communication, and delays in communicating time-critical data. Another objective is to evaluate in one area of the state the implementation of the most appropriate wireless technology to support such applications as the construction management system, traffic data collection, right-of-way data needs, and pavement condition data collection. The ultimate objective is to use wireless technology to support field applications throughout the state where the benefits exceed the costs.

SCOPE OF WORK AND WORK PLAN

The essence of the scope of work called for ARA to identify user needs associated with different field applications, identify candidate wireless technologies that could meet different needs, make recommendations for one or two pilot installations, prepare specifications and plans for wireless transmissions with regards to the recommended field application(s), and conduct an evaluation that a third party contractor would implement in accordance with the specifications and plans.

More specifically the tasks we proposed to perform, which were based on those in the RFP are as follows:

1. Meet with the project's technical panel to review project scope and work plan.
2. Assess communication needs through interviews
3. Review literature relevant to other state transportation entities as well as those of Canadian Provinces
4. Assess the applicability of each technology to each of the user needs
5. Provide a general discussion of benefits, costs and feasibility of available wireless technology in South Dakota and indicate the impact on field computers and network hardware
6. Prepare a document that recommends communications technologies for each data need.
7. Recommend equipment specifications and plans for a pilot installation in one SDDOT area to be determined by the panel.
8. Evaluate the usefulness of the wireless data communication technology used in the installation(s)
9. Prepare a final report and executive summary of the research methodology, findings, conclusions and recommendations
10. Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project

WIRELESS OPTIONS FOR SELECTED TECHNOLOGIES

The ARA team conducted a substantial literature search regarding wireless technologies as well as drew upon the expertise of its team members. The wireless communications field is extremely complex and is rapidly evolving in response to technological change, competitive pressures, and new needs.

A convenient way to organize types of wireless technologies is to classify them by coverage area of increasing size: Wireless Personal Area Networks (WPAN), Wireless Local Area Networks (WLAN), Wireless Metropolitan Area Networks (WMAN), Wireless Wide Area Network (WWAN), and Wireless State and National Networks (WSNN).

Wireless telecommunications can be divided broadly into terrestrial and satellite systems—the former tends to evolve rapidly in response to both technological trends and market forces, and the latter more slowly owing to regulatory delays, high incremental capital costs, and the long satellite design and construction cycle.

Terrestrial wireless technology spent decades slowly emerging from the analog woodshed, but since wireless digital communications became technologically and economically feasible, it has developed at a rapid pace. Important sets of systems are designated in terms of generations (a number followed by G). In the time span of 15 years, we have progressed through 1G, 2G, 2.5G, and onto 3G. We are even starting to see 4G systems. The cellular data communications field is in enormous flux with technologies evolving along primarily two paths rooted in two different types of multiplexing, one adopted by the Americans (Code Division Multiple Access) and a second adopted by the Europeans and Japanese (Time Division Multiple Access). There are international efforts to bring these under one umbrella, using dual mode phones for example, to support cellular roaming throughout the world. At the same time, it seems there are countless other schemes for radio frequency communication, with new ones regularly becoming feasible and economically attractive because Moore's law every year brings processing power on chipsets across a new threshold.

Wireless systems can be summarized in terms of geographic coverage (from 8 inches to statewide or more), available data rate (from 10 bps to 40 Mbps, and potentially higher) and cost (from perhaps $20/mo to $80/mo for certain kinds of receiver units). It is probably safe to say that a user can choose to meet its requirements with any two of these elements (coverage area, data rate and cost), but may not be satisfied with the third.

Terrestrial wireless systems are reasonable in cost because they are typically deployed to serve the consumer market—the large potential customer universe enables manufacturers to achieve significant economies of scale so that equipment and services can be sold at an affordable cost. The reverse of this reasoning is also true: in areas or performance ranges where there is little private sector demand, a dedicated user will probably pay more, and the price is often perceived to be unaffordable.

Satellite communications technology is best adapted to wide geographic coverage needs (indeed, it is almost impossible to provide satellite services that do *not* have wide coverage). Thus the principal tradeoffs for these services are data rate and cost. Geostationary satellites (GEOs), which are about 22,240 statute miles above the earth, can be accessed using earth stations with fixed-pointed antennas and typically provide data rates up to roughly 40 Mbps. The satellite can broadcast identical data to multiple earth stations, or alternatively it can provide different data to particular earth stations. Relatively large diameter (2 feet in diameter or larger) earth station antennas are needed to capture sufficient downlink power. FCC regulations limit the permissible uplink transmitter power, so these large earth station antennas are also needed to focus sufficient uplink power on the satellite.

Satellites also operate in Medium Earth Orbit (MEO) and Low Earth Orbit (LEO). Fortunately, the combination of closer distances and higher satellite power (often coupled with lower operating frequencies) allows the earth stations to have portable, non-directional antennas. This makes it possible to provide convenient applications such as satellite telephone and data services. The user can buy whatever data rate or service may be needed, and can thus benefit from cost sharing with many other users of the satellite. Of course, the capabilities available are limited to those the satellite operator chooses to offer.

In addition to the above commercially available services, more specialized technologies and systems are available, such as meteor burst technology, low data rate transmitters embedded in widely dispersed sensors, and of course, dedicated systems such as the South Dakota State Radio System.

A myriad of wireless technologies are available today, and the new ones that will emerge in the next few years present a great opportunity to SDDOT to explore how to enhance its current communication systems. As a result, SDDOT should be able to provide application users more access, convenience, timeliness, speed, accuracy, and security.

In sorting through the various wireless technologies relevant to different field applications, the following were important considerations:

- A single wireless technology may serve multiple applications
- Some types of wireless technology can be regarded as low hanging fruit and be expected to yield medium to high benefits at relatively low costs
- There are high-value uses of wireless but they may be challenging to apply to an application, and thus relatively high cost
- Interesting or novel wireless technology may be worth investigating because of its future promise
- Valuable research can result from trying to implement certain types of wireless technology
- Certain technologies offer an opportunity to provide a national showcase or model deployment

- Proprietary technology, though it runs counter to the grain of open and interoperable systems, may offer compelling advantages
- The focus should be on the wireless application that provides the greatest benefits relative to costs.

Candidate field applications totaled eight:

1) Maintenance Decision Support System (MDSS)
   - Fixed in place component (RWIS)
   - Mobile component (Trucks with plows)
2) Traffic counting and classifying
   - Automated Traffic Recorders (ATR)
   - Weigh-in-motion (WIM)
   - Rest area traffic counters
3) Pavement distress data collection
4) Right-of-Way data acquisition for purchase of property
5) Dynamic Message Signs
6) Road Condition Reporting System
7) Construction data collection
   a. Mobile Contract Manager
   b. Material Sampling and Testing
   c. Construction Measurement and Payment
8) Megatraks fuel system

Of the eight field applications that were investigated, five were deemed the strongest candidates for field applications. The Tables 1 through 6 show various wireless technology that can serve specific field applications and satisfy the requirements described in the table heading.

Tables 1 through 6 present alternative communication technologies that can serve the following: fixed-in-place applications such as RWIS and ATR, mobile applications such as communicating with a truck that has a plow and spreader, and field applications requiring data transfer between a laptop and a server.

Fixed in-place applications, such as RWIS, ATR and WIM, can be served with various types of cellular data transfer, such as Radio Transmission Technology (1xRTT), which is available in South Dakota along I-90, I-29, east of the Missouri River, and a small extent west of the Missouri River. Spread Spectrum, which employs Code Division Multiple Access (CDMA) multiplexing, can be used for line-of-sight transmission of 20 miles or more. Spread spectrum communications has already been demonstrated in South Dakota with respect to with DMS. Another option is satellite communications.

Table 1. Maintenance Decision Support System – Fixed in Place Component (Needs: 20-40 miles or 400 – 1600 sq. mi. coverage; 400 bps for 60 sec and 4 to 32 kbps with video)

Technology	*Coverage*	*Data Rate*	*Cost*	*Feasibility/ Propagation*
1xRTT	I-90, I-29, 90% East of Missouri River and some West	60-80 kbps with bursts to 144 kbps (Verizon)	$40-$100/ month; PC card $50; telemetry equipment $600 (Verizon)	Yes/ No. of users affects bit rate
GPRS	Sioux City	9.6 kbps	N.A.	Can't buy in SD
CDMA SS; or OFDM	Varies; 30 miles +	Varies greatly	Varies	Yes/power, frequency, antenna, terrain
Satellite	Entire state	2.4-28.8 kbps narrowband; 64-256 kbps broadband	$2-$11/mo narrow band; $100-$500/mo broadband; $500-$5000 equip. cost	Yes/Rain can interrupt
Meteor Burst	1200-1500 miles	300-2400 bps	Similar to RWIS costs	Yes/already used in SD remote locations

Table 2. MDSS – Mobile Platform (Needs: 20-40 miles or 400 – 1600 sq. mi. coverage or within 330 feet of roadside; data rate of 13 bps for uplink and downlink)

Wireless Technology	*Coverage*	*Data Rate*	*Cost*	*Feasibility/ Propagation*
1xRTT	I-90, I-29, 90% East of Missouri River and some West	60-80 kbps with bursts to 144 kbps (Verizon)	$40-$100/ month; PC card $50; telemetry equipment $600 (Verizon)	Yes/ No. of users affects bit rate
DSRC or Wi-Fi (Spot or Serial)	330 feet to 10 miles	1 Mbps – 31Mbps	Cost of DSRC not known; Serial Wi-Fi inexpensive;	Yes/DSRC prototypes & Wi-Fi available; power, antenna, blockage, terrain, hops
CDMA Spread Spectrum	25 miles typical maximum for outdoors	40-1,000,000 kbps	Equipment cost varies from $50 to $45,000 depending on bandwidth and type of communication	Yes/ power, frequency, antenna; terrain, vegetation, curvature of earth, reflections, obstructions
Satellite	Entire state	2.4-28.8 kbps narrowband; 64-256 kbps broadband	$2-$11/mo narrow band; $100-$500/mo broadband; $500-$5000 equip. cost	Yes/rain can interrupt
Extended Range RF	100s or 1000s of miles	10 to 1000 kbps	Very low; simple COTS products	Yes/ vibration can be problem

Table 3. Automated Traffic Recorders & WIM (Needs: 20-40 miles or 400 – 1600 sq. mi. coverage; 9600 bps for hour; WIM 666 bps for 2 hrs)

Wireless Technology	*Coverage*	*Data Rate*	*Cost*	*Feasibility/ Propagation*
1xRTT	I-90, I-29, 90% East of Missouri River and some West	60-80 kbps with bursts to 144 kbps (Verizon)	$40-$100/ month; PC card $50; telemetry equipment $600 (Verizon)	Yes/ No. of users affects bit rate
CDMA Spread Spectrum	25 miles typical maximum for outdoors	40-1,000,000 kbps	Equipment cost varies from $50 to $45,000 depending on bandwidth and type of communication	Yes/ power, frequency, antenna; terrain, vegetation, curvature of earth, reflections, obstructions
Satellite	Entire state	2.4-28.8 kbps narrowband; 64-256 kbps broadband	$2-$11/mo narrow band; $100-$500/mo broadband; $500-$5000 equip. cost	Yes/Rain can interrupt
Meteor Burst	1200-1500 miles	300-2400 kbps	Similar to RWIS costs	Yes, already used in SD remote locations
Extended Range RF	100s or 1000s of miles	10 to 1000 bps	Very low; simple COTS products	Yes/vibration can be problem

Table 4. Pavement Distress Data Collection (Needs: 20-40 miles or 400 – 1600 sq. mi. coverage or within 330 feet at shop; 86.7 kbps for zipped file)

Wireless Technology	*Coverage*	*Data Rate*	*Cost*	*Feasibility/ Propagation*
Wi-Fi	330 feet	31 Mbps max throughput with fall back to as low as 1 Mbps	$0 to $50/mo operating cost and $20 to $120 for router; 802.11a router $225-$1500	Yes/ line-of- sight needed. No. of users affects bit rate
Satellite	Entire state	2.4-28.8 kbps narrowband; 64-256 kbps broadband	$2-$11/mo narrow band; $100-$500/mo broadband; $500-$5000 equip. cost	Yes/rain can interrupt

Table 5. Right-of-Way Data Collection (Needs: 20-40 miles or 400 – 1600 sq. mi. coverage or within 330 feet at shop; 1.1 to 1.6 Mbps)

Wireless Technology	*Coverage*	*Data Rate*	*Cost*	*Feasibility/ Propagation*
Wi-Fi	330 feet	31 Mbps max throughput with fall back to as low as 1 Mbps	$0 to $50/mo operating cost and $20 to $120 for router; 802.11a router $225-$1500	Yes/ line-of-sight needed. No. of users affects bit rate

Table 6. Construction Data Collection (Needs: 20-40 miles or 400 – 1600 sq. mi. coverage; 6.7 to 320 kbps)

Wireless Technology	*Coverage*	*Data Rate*	*Cost*	*Feasibility/ Propagation*
Wi-Fi Mesh (Serial Wi-Fi)	3 to 10 miles along corridor or network of many square miles	1 to 31 Mbps	$30-$50K	Yes/ line-of-sight needed, terrain, interference weather fading, antenna type, number of nodes, hops, access points
1xRTT	I-90, I-29, 90% East of Missouri River and some West	60-80 kbps with bursts to 144 kbps (Verizon)	$40-$100/ month; PC card $50; telemetry equipment $600 (Verizon)	Yes/ No. of users affects bit rate
Satellite	Entire state	2.4-28.8 kbps narrowband; 64-256 kbps broadband	$2-$11/mo narrow band; $100-$500/mo broadband; $500-$5000 equip. cost	Yes/Rain can interrupt

While ARA was obligated, based on its proposal, to recommend only one or two pilots, it recommended four:

1. ARA proposed to specify and evaluate a demonstration of Wi-Fi at an area or maintenance shop for transfer of data to/from a laptop that can be used for more than one field application (e.g. pavement distress data collection, right-of-way acquisition)
2. ARA would work with SDDOT to support a demonstration of Dedicated Short Range Communication (802.11p) for communication with a MDSS mobile platform such as a truck with snow plow. SDDOT had taken initial steps to explore federal funding
3. ARA proposed to orchestrate a second demonstration in Spring 2006 involving Wi-Fi mesh (or serial Wi-Fi) for construction inspection at a site to be mutually agreed upon by SDDOT and ARA. ARA would prepare the specifications. Also, ARA would incur the costs associated with its patented technology for field data acquisition. All other demonstration costs would be incurred by SDDOT and used to engage a third party to establish the Wi-Fi mesh and location-based technology required for the demonstration. It was recommended that an independent party should perform the evaluation.
4. ARA would explore with SDDOT a field demonstration of Extended Range RF, a patented ARA technology. SDDOT would work with ARA to obtain funding from a suitable source.

When ARA proposed four candidate projects for demonstrating wireless, the project panel rejected them because Wi-Fi at the shops could easily be implemented by the Bureau of Information and Telecommunications (BIT), there was ambiguity regarding whether prototype DSRC was available for a pilot demonstration, and there were proprietary features associated with two of the candidates.

When no projects were selected, the project panel decided that ARA should evaluate one or two projects already scheduled for implementation and focus on the reliability and effectiveness of wireless service. The project SDDOT ultimately selected involved wireless communications between a laptop supporting traffic signal maintenance management software and a headquarters database. The wireless carrier provider, Alltel, offered Radio Transmission Technology (1xRTT). During this time Alltel, merged with Cellular One, and began offering broader digital data services, including static IP addressing. SDDOT experienced delays in acquiring cellular equipment, implementing a database, installing hardware and collecting data that could be evaluated. Furthermore, there were scheduling difficulties and other project demands. Consequently the deadline for preparing a draft report for this project, *Use of Wireless Technology for Field Applications*, arrived prior to receiving the wireless data. The upshot was that no pilot wireless projects were field-tested and evaluated during this project.

FINDINGS AND CONCLUSIONS

The following are the findings and conclusions of this study:

- Numerous field applications can significantly be enhanced with the latest wireless communications available in South Dakota. Current communication methods are often more costly, slow, inconvenient, and have low bandwidth.
- Telecommunications is a very large field and so is wireless communications. The wireless field is rapidly evolving from one generation to the next due to technological innovations, competition, and demand for more and higher quality services. The dynamic nature of the wireless industry can suddenly result in a superior solution to a planned approach for communications with a field application.
- Many field applications require a communications range of 20 to 40 miles and possibly 75 miles or more under some circumstances. In terms of square miles of coverage, this translates into 400 to 1600 square miles or possibly even as much as 5625 square miles. Applications that appear to have coverage requirements within these magnitudes are Automated Traffic Recorders, Weigh in Motion, Construction Management, and Right-of-Way Acquisition.
- Public safety is the priority use of the State Radio System. This system is not an appropriate wireless solution for meeting SDDOT's needs to communicate with numerous field applications.
- Some wireless technologies can serve many different applications. For example Wi-Fi placed near the entrance of maintenance and area shops or at the fuel pumps could transfer data at very high rates between a laptop and a Wi-Fi local

area network. Throughput may be on the order of 31 MB per second. Thus it would be possible to quickly transfer data for such applications as fuel consumption tracking, construction inspection and materials testing, and right-of-way acquisition. However, an important finding of this study is wireline connections between the shops and the Becker-Hansen building have substantially less bandwidth. Consequently, there currently is a bottleneck that thwarts SDDOT from realizing the full benefits of Wi-Fi.

- Demonstrations and evaluations of wireless technology in conjunction with field applications can be justified if they satisfy any of the following criteria (1) they are "low hanging fruit" that yields moderate or significant benefits and are easy to implement for little cost (2) they are high-value and challenging uses of wireless communication and the value exceeds the costs and (3) they are interesting or novel wireless technology that involve valuable research or an opportunity to provide a national showcase or model deployment.
- SDDOT is uncomfortable with proprietary technology. Open systems, open standards, interoperability, and open source code promote competition and help keep costs low. However, in the communications field some of the most important advances in wireless communications are based on proprietary technology. In the United States every generation of native digital cellular technology is built upon Qualcomm's patented Code Division Multiple Access (CDMA) technology. Intellectual property rights provide incentives for innovation and can lead to economies of scale. However over time, there is a danger of becoming dependent on a source of proprietary technology and if the economies of scale are too great, decreasing costs can create conditions for a monopolist to emerge which may also result in reduced innovation in the future.

IMPLEMENTATION RECOMMENDATIONS

These recommendations resulted from this study:

- SDDOT has been actively exploring the use of wireless communications for some time. The success it has had using spread spectrum to communicate with Dynamic Message Signs (DMS) is an example. This research was prompted by a desire to accelerate the use of wireless technology for field applications. SDDOT should continue to move aggressively down this path.

- It is important to match communications and other requirements with those offered by particular types of wireless technology. Usually there are numerous options for satisfying a specific need and each realistic option should be investigated. Information in this report provides considerable insight regarding the applicability of alternative wireless solutions for specific field applications.

- SDDOT should work with the South Dakota's BIT to upgrade the wireline communications between SDDOT's area/maintenance shops and headquarters and address any internetworking issues that may be required to get the most benefits of a wireless local area network such as Wi-Fi.

- SDDOT should routinely monitor and seize the opportunities to implement wireless communications resulting from the dynamic and rapidly evolving telecommunications field. Services, products, prices, and quality of offerings such as reliability and coverage could change almost daily in South Dakota. Generally these rapid changes will benefit SDDOT but occasionally they will impede adding wireless communication to a field application. The Rand Corporation has proposed a novel initiative, Agnosco, that would provide broadband wireless communications to all rural America by using Wi-Fi and Wi-Max, incorporate Grid Computing into this network to allow rural residents to share computer resources (microprocessors, memory), to provide food security using Radio Frequency Identification (RFID) and other means, and to support important sectors such as education, agriculture, and forestry. The South Dakota Public Utilities Commission is evaluating Agnosco. SDDOT should be prepared to evaluate the ramifications of Agnosco for the transportation sector, both the users of the transportation network and the implications for SDDOT. To take but one example, Agnosco could have significant implications regarding the deployment of ITS and DSRC in rural areas. Also, South Dakota's Public Utilities Commission staff revealed that the Department of Defense is considering implementing a wireless information superhighway. Excess capacity could become available for civilian and government applications. This is another wireless deployment that could compete with various forms of wireless communication including DSRC.

- SDDOT should continue to tap the resources and expertise concerning wireless communications in BIT, the South Dakota Public Utilities Commission, and various vendors. These sources of expertise clearly prove valuable to SDDOT and were very useful to the ARA team.

- SDDOT in partnership with BIT should consider implementing a test bed for wireless communications. This test bed could have highly localized components and long distance, wide area features. SDDOT should begin by preparing a vision, a concept of operations, requirements, a technical architecture, and an analysis of the benefits and costs. SDDOT and BIT will have to explore alternative sources of funding.

PROBLEM DESCRIPTION

SDDOT has been faced with a variety of challenging problems regarding the transfer of data to and from applications in the field. These applications include fuel data collection, pavement condition and distress data collection, construction inspection and management, right-of-way acquisition, traffic signal maintenance management, Road Weather Information Systems (RWIS), Maintenance Decision Support Systems (MDSS), and Automated Traffic Recorders (ATRs). Recently SDDOT implemented spread spectrum wireless data communication between Dynamic Message Signs (DMS) and its headquarters in Pierre, South Dakota. The success in implementing wireless data communication with various DMS, suggested that the Department could benefit from using wireless data communications to serve these other applications.

There are a number of significant problems wireless data communications could potentially overcome. First, contractors are required to set up project labs for construction work. These project labs have telephones, but data transfer over the telephone is exceedingly slow, and so inspectors find it more convenient to carry the data back to the area shops to upload into a computer. More wideband and responsive wireless communication has the potential to overcome this problem. Another problem has been the increasing cost of phone service. Also, the cost of trenching and installing phone lines is quite high. Similarly, staff responsible for right-of-way acquisition must download into their computer planned roadwork, plats, and other information and upload data regarding rights-of-way acquisition. The amount of data can be very large. Rather than transferring the data from the field, often real estate agents transfer data using broadband connections in their homes and motels.

The original problem statement for this research conjectured that certain types of wireless communications might be very useful. One possibility was further application of spread spectrum data communication, whose practicality and reliability had already been established with DMS. Another was Wi-Fi, presumably because it had become fairly ubiquitous and easy to install.

A general challenge regarding wireless communications is the large number of existing and emerging technologies and the need to match the telecommunication requirements of a particular application to a wireless technology. For many of these wireless technologies coverage exists in part or nearly all of South Dakota. However, for other technologies coverage is non-existent.

OBJECTIVES

The Request for Proposal for the project entitled, *Use of Wireless Technology for Field Applications*, identified two objectives:

1. To assess the feasibility of various communications technologies to support field equipment, data collection, and maintenance and construction activities.
2. To perform pilot installations of communications to support data communications for SDDOT activities.

Our proposal cast these objectives more broadly in the following statement:

> The objective of the project is to investigate different wireless technology and identify those most appropriate and net-beneficial for different field applications. A related objective is to address field data transfer problems SDDOT has identified including: wait time to upload data to the Construction Management System from the construction project labs, rising costs for the current modes of data communication, and delays in communicating time-critical data. Another objective is to evaluate the implementation of the most appropriate wireless technology in one area of the state to support such applications as the construction management system, traffic data collection, right-of-way needs, and pavement condition data collection. The ultimate objective is to use wireless technology to support field applications throughout the state where the benefits exceed the costs.

With regards to the first RFP objective, the project team successfully assessed the feasibility of various communications technologies based on a combination of a literature search, the knowledge of team members, input from SDDOT staff, and contribution from experts on wireless communications in the BIT and the South Dakota Public Utilities Commission. We were able to identify communication requirements for different field applications and identify alternative wireless solutions. Feasibility included satisfying coverage and bandwidth requirements, reasonable costs, and successfully addressing other key issues such as propagation.

With regards to the second RFP objective, the SDDOT project panel concluded that none of the recommendations the ARA team made for field tests and evaluations were desirable to pursue. The reasons for rejecting ARA's recommendations are presented under Task 6 discussion of accomplishments.

Even after SDDOT decided not to pursue these recommendations, we worked with SDDOT to identify other candidates to develop specifications for field applications and/or to perform evaluations. These included (1) Serial Wi-Fi which Virginia Polytechnic Institute installed along a highway near its ITS test-bed and (2) an evaluation of wireless technology to serve a signal maintenance management application, CarteGraph's SIGNALView. SDDOT made a decision not to pursue either of these demonstrations/evaluations. Again, the reasons are discussed under Task 6.

There are four objectives embedded with the broad statement of project objectives in our proposal. Our research satisfied these objectives in the following manner:

1. The objective of the project is to investigate different wireless technology and identify those most appropriate and net-beneficial for different field applications. *We believe we successfully characterized those wireless technologies that have the greatest advantages in comparison to disadvantages for the various field applications under consideration.*

2. A related objective is to address field data transfer problems SDDOT has identified including wait time to upload data to the Construction Management System from the construction project labs, rising costs for the current modes of data communication, and delays in communicating time-critical data. *We gave serious consideration to the frustration SDDOT staff have transferring data, situations where there were rising costs, and the lag time in transferring data that is required in near-real time data collection processes. We assessed a wide range of wireless technology with the intent of overcoming these problems and recommended one possible solution to demonstrate.*

3. Another objective is to evaluate the implementation of the most appropriate wireless technology in one area of the state to support multiple applications such as the construction management system, traffic data collection, right-of-way needs, and pavement condition data collection. *We recommended that Wi-Fi be implemented and evaluated at an area or maintenance shop, especially if the bandwidth of the landline to headquarters could be upgraded. Wi-Fi would support multiple field applications. Despite the fact that Wi-Fi was identified as a candidate technology in the Problem Statement and that we identified it as highly net-beneficial "low hanging fruit," SDDOT decided that BIT could easily implement it and recommended against ARA preparing specifications and conducting an evaluation.*

4. The ultimate objective is to use wireless technology to support field applications throughout the state where the benefits exceed the costs. *The extensive literature search and the process of matching the requirements of different field applications with different types of wireless technology will help promote net-beneficial wireless telecommunications with SDDOT field application in the future.*

TASK DESCRIPTIONS

This chapter describes the tasks set out in the proposal and what we accomplished. For each task presented in the proposal, we stated the relationship to project objectives, the proposed work, the deliverable(s), and limits on scope. The funding for this project was modest yet the scope and number of activities were large. ARA and SDDOT concluded that the limits on scope were mutually agreeable.

The following are the proposal tasks and the nature of the work completed.

Task 1. Meet with Project Technical Panel to Review the Project Scope and Work Plan

Relationship to Project Objectives: Ensure that there is a full understanding both on the part of the Project Technical Panel and the ARA team regarding how the project scope and work plan will achieve the project objectives.

Proposed Work: ARA proposed to attend a kickoff meeting and make a PowerPoint presentation regarding ARA's work plan and the project scope. The Project Technical Panel was expected to provide feedback, suggestions, and offer direction. We said we would be responsive to the input SDDOT provided. However, because of the small budget for a project of potential great complexity, we proposed a tightly defined scope of work. The limitations on scope are presented in various tasks. We proposed that ARA and SDDOT agree to a change management procedure at the kickoff meeting to avoid scope creep.

We proposed that part of the kick-off meeting be allocated to discussing who to interview, the nature of the field applications for which they are responsible, the type of data communications currently used, and what concerns or issues they are known to have. This discussion would prime us for the interviews and enable us to ask more penetrating and relevant questions.

Deliverable: Minutes of meeting.

Limits on Scope: The kickoff meeting was to be followed immediately by the interviews, allowing the initial information gathering for Tasks 1 and 2 to be completed in two to three days.

Accomplishments: We completed Task 1 in the manner proposed. Two members of the ARA team attended the kickoff meeting, Bill Hyman, the ARA Project Manager, and a consultant expert on telecommunications. Eleven people attended and represented different interests of the SDDOT and BIT. Among them was SDDOT's Project Manager, Jon Becker.

Bill Hyman made a presentation that reviewed the research approach and work plan in ARA's proposal. There were only a few questions because the interviews under Task 2 commenced immediately afterwards. Of most interest was the possibility of providing wireless communications for MDSS. ARA's telecommunications consultant asked what were the most important motivation for interest in wireless communications. While panel members said there were a number of reasons, they stated landline connections were becoming very expensive, reaching $138,000 in one case and $20,000 in another.

Both ARA and SDDOT agreed to invoke the proposed change order procedures if deemed necessary.

The minutes of the meeting were incorporated into Deliverable #1 – Summary of Kickoff Meeting

Task 2. Assess communications needs through interviews

Relationship to the Project Objectives: Determine user perceptions and requirements regarding needs for wireless communications for field applications in South Dakota

Proposed Work: We requested that Jon Becker, the SDDOT Project Manager, or any staff he delegates, schedule the interviews for Task 2. We proposed to conduct interviews not to exceed two hours in length with staff from each of the following:

- Construction Management
- Right-of-way
- Inventory Management
- Internal Services
- Project Development
- Operations Support
- Bureau of Information and Telecommunications.

We said we would prepare an interview guide based upon the Framework in Figure 1 of the proposal and use it to summarize the meeting.

Information we requested in the proposal in advance of the interviews included the following:

1. The name, position, organizational unit, phone number and e-mail of each person we would be interviewing
2. Interview schedule and locations where each interview will be held (building, floor, office number, conference room number)
3. Any materials the Project Technical Panel or those being interviewed would like to provide us in advance – particularly valuable would be data collection forms, screen shots from field computers showing data inputs, and output reports from roadside equipment such as ATR's and RWIS. These would provide an indication of data transmission requirements.
4. BIT Standards
5. Any BIT strategic, business or program plan

6. Long range, policy, performance, strategic, business or program plans prepared by any other office whose staff we will be interviewing
7. Any ITS strategic or business plan. Also, the ITS architecture for South Dakota.

Accomplishments: SDDOT staff was very responsive and provided most of the advance materials we requested. We assume the material was not available or not easily acquired if it was not furnished to us. We prepared an interview guide and spoke with the following people listed in the table below regarding the wireless communication requirements. The field applications are listed on the left side of the Table 7.

Table 7. Application Needs and Issues

Application	Name and Position	Needs	Issues
Construction data collection 1. Mobile Contract Manager 2. Material Sampling and Testing 3. Construction Management Testing	Brad Letcher, Engineering Supervisor	200 users with laptops; need to download large data base. Central server stores every construction job in the state. Inspectors/ technicians/ engineers download the contractor name, dollar amount, letting name, and bid items (quantities and prices). As contractors install bid items, SDDOT inspectors enter the date and quantity of bid items installed into a laptop or desktop	Some inspectors when out for a week are forced to use telephone dial-up, which is a big problem. Policy requires payment of contractors within 2 weeks based on SDDOT inspections.
Road Condition Reporting System (RCRS)	Brad Letcher, Engineering Supervisor	SDDOT plans to install a touch screen terminal on board trucks with plows/spreaders. The operator would enter selected information on precipitation and other data. Automated Vehicle Location (AVL) using Global Positioning System (GPS) receivers would be used to establish location. Infrared surface pavement sensors would be installed; also sensors would detect whether the plow is up or down and the spreader off or on. The intent is to use wireless technology to	Vehicle operators are closest to the source of data and are therefore trusted to provide the most accurate information possible. Their input to the RCRS would not be filtered by a maintenance supervisor.

Application	Name and Position	Needs	Issues
		communicate data to the Road Condition Reporting System (RCRS).	
Megatraks fueling system	Brad Letcher, Engineering Supervisor	Megatraks is the state system that allows any state vehicle to fuel up at any shop with a gas pump. There is currently a data key that is used for identification to keep track of fuel taken from the pump. Outlying shops consolidate all fuel consumption by vehicle into a Megatraks key and then mail the key to the Area Office Secretary. SDDOT is looking for a wireless solution to transmit fuel consumption data.	
Right of Way Acquisition	Dave Parker Senior ROW Acquisition	There are three areas that would benefit from wireless communications: 1. Appraisers would benefit from being able to access central data bank (titles, plans, plats, and ownership) retrievable under combination of PSIM, county or Project ID codes 2. Title personnel would like all ROW info in the central database. It would be nice to upload and download title information from the central server. 3. ROW agents negotiate with property owners. Currently they take a stack of paper (plats, plans, appraisal book and	Data rates for reliable wireless can transfer 10 MB in a reasonable time Upload to the central data base is usually just a word document, but a combination of typed information, photos, and diagrams could reach 300 pages. Other factors to consider are: • Speed • Reliability • Access • Capacity to upload and download .pdf files • Ability to serve remote portions of the state Look at cellular data communications. Cell One and Verizon are

Application	Name and Position	Needs	Issues
		other information) to the field. These come from an electronic file; SDDOT would like to be able to get documents by e-mail	the major cell service providers in the metro areas and along the most heavily traveled corridors. Wi-Max could potentially address many areas in SDDOT. SDDOT offered the Black Hills as the location for a test and evaluation. Monitoring fires, Portable DMS, Road Construction, MDSS, and Traffic control at Mt. Rushmore are all potential field applications.
RWIS	John Forman Construction Maintenance Engineer	SSI Reviewing all RWIS – sensors, software, cameras Examining power needs; have solar panels for RWIS backup Could use antennas along heavily plowed, ice-controlled routes – basic equipment is relatively inexpensive Also, possibly could download RWIS data using 802.11 as one drives by a transceiver, similar to the Dedicated Short Range Communications component of Vehicle Integration Initiative	Accessing RWIS at least once an hour is important Approximately 6 to 8 out of 35 use state radio. Important to be able to allocate snow and ice control resources in an optimal fashion Virtually every RWIS phone data transfer is a long distance call.
MMDS	John Forman Construction Maintenance Engineer	MDSS relies on knowledge of snow/ice and weather conditions on/along the road whether derived from vehicles or RWIS. Currently use telephones and radios in vehicles to communicate information.	There is an ongoing MDSS pooled funded study to develop a functional prototype and improve MDSS. Meridian Environmental Technology is the Prime Contractor. Meridian has wireless under consideration.

Application	Name and Position	Needs	Issues
		All MDSS have MDS INET radio operating in the 902-928 MHz unlicensed spectrum. RF needs are customized based on terrain, etc. Interested in supporting MDSS with wireless data communication. Plows are attached to the front of dump trucks and spreaders to the back. SDDOT will contract for graders if needed. A Force America control head in trucks has 26 data interfaces (engine, spreader, plow up and down, GPS). Need an intermediate box or interface for wireless (Thomtech is one company that develops the interface). Desirable to obtain information from vehicles at least every 30 miles.	There are significant environmental benefits of RWIS and MDSS. Plow routes are a priority. MDSS data collection cannot interfere with safe operation of plows and spreaders It would be useful to have a download link every 25 to 35 miles. Getting power to an antenna would be an issue in many areas. Real time data transfer is not a requirement, but contact with a truck would be desirable at least hourly – it takes a long time for a truck to complete a snow route. Downloading at the shops would be too infrequent. Information needs to come from both roadway sensors and vehicle SDDOT is not a bare pavement state.
Portable Dynamic Message Signs	John Forman Construction Maintenance Engineer	Need to avoid going to a portable DMS to program a message.	Easier to do on the Interstate than on a secondary road. Some portables are diesel powered; most are solar powered. DMS with Light Emitting Diodes (LED) are power efficient and are better in most every respect than other types of DMS.
State Radio	Todd Dravland, System Engineer	Data communications were not available at the	Key question is to what extent can the State

Application	Name and Position	Needs	Issues
	BIT State Radio	time of the interview. State was in the early phase of implementing DataMax, which is optimized for public safety applications.	Radio System be used for communication between a plow and the maintenance shops or a Transportation Operations Center. Is there any reason that would prevent SDDOT from putting their own 9600 baud, full duplex transceivers on the state towers? Presumably public safety officials, highway patrol have priority use.
Construction Management System – Materials Sampling and Testing	Leon Ellis, Programmer Analyst; Gene Johnson, Cyber Project Manager; Ryan Claeys, System Architect and Lead Developer, Cyber; Mark Heier, Consultant	Contractors, field technicians, engineering supervisors, project engineers, material engineers, and central lab are all running tests. There are roughly 20 forms with about 20 tests per form. Some tests done every two hours; some done daily,; some are for Quality Assurance; and some are multiple tests. Rewriting Materials Sampling and Testing Application by using VB.NET and a little C#. Microsoft Sequel Server will be the database server. Older application is slow, especially the Citrix metaframe client that permits web access. Access throughout the vicinity of a project and anywhere tests are being run is needed.	Had not decided whether to run the new web server applications on laptops or else compile and connect DLLs. Size of typical replication is not a lot of data. MS&T application has 30 to 40 fields so there is about a 100 kilobyte daily transport requirement. However, if full CMP database is required, one may need to transfer on the order of 40 Mbytes. Central server has to build replication files every hour. The laptop has to replicate either over the phone in the construction lab or plug directly into the system in the office. Problem—when you are replicating, the system sometimes cannot synchronize and crashes. SDDOT has been working on the problem and most

Application	Name and Position	Needs	Issues
		Normally inspectors fill out a sheet of paper and take it back to their truck to enter the data into a laptop. It would be desirable to eliminate the step of having to fill out a sheet of paper.	issues have been smoothed out. Replicating/uploading is slow on the phone. You could put a server on each project, but would still need wireless connections throughout the site. BIT is opposed to VPN because of security issues. Consider using cellular in metropolitan areas and along main arterials. However, you can lose cell service on any major route in any direction.
Traffic Monitoring	John Whaley, Transportation Analyst; Noel Pothast, Senior Transportation Technician; Darin Charlson, Transportation Inventory Management; Pat Sandelweck, Research; Dennis Johnson, Assistant Project Manager	SDDOT has 50 Automated Traffic Recorders (ATR), 11 permanent Weigh-in-Motion (WIM) Units, and 10 permanent Rest Area Recorders. Equipment is polled twice per week, 2 hours for WIM and 1 hour for ATR. Polling of rest area monitors occurs for 15 minutes each. Bandwidth requirements are: ATR: 4 Kbytes/day WIM: 70-300 Kbytes/day Rest Area Recorders 2 Kbytes/day	Cost of long distance monthly phone bills is high. Installation cost plus usage cost is just under $30,000 per year for ATR and WIM permanent recorders. SDDOT uses Peek ATR and WIM equipment Factors to consider/requirements: • Cost of monthly phone bills • Weather, outdoor exposure, lightening • Terrain • Quality of connection – data retrieval, viewing traffic in real time • Quality of data transfer • Software compatibility

Application	Name and Position	Needs	Issues
			Maintenance of wireless equipment
Pavement Distress Identification	Phil Clements, Assistant Pavement Management Engineer	On several occasions have lost data and could potentially lose a week's worth. Would be desirable to transfer data to the DOT servers daily or twice a day at maintenance or area shops. Could use Wi-Fi while people filling up with gas. Description of data collection and transfer needs: • Use laptop to enter data • 4 types of distress for flexible pavements • 5 types of distress for rigid pavements • Collection condition data on rumble strips • Collect condition data on 75 miles of gravel roads • Examine pavements from white line to white line • Distress identification is based on SHRP manual. Main type of distress is transverse cracks typical of northern tier states. • Continuous visual survey where rater records data in quarter mile segments • Total good weather data uploads reach 10MB over 12 weeks or 0.83 MB/week	SDDOT uses Deighton PMS Transfer of data occurs once per week Factors to consider include: • Speed • Ease of data entry/retrieval • Security • Compatibility with Panasonic Toughbook • Ruggedness

Task 2 accomplishments are reflected in Deliverable #2 -- Documentation of Interviews

Task 3. Review Literature relevant to other state DOT's efforts as well as those of the Canadian Provinces.

Relationship to the Project Objectives: Learn what insight the literature can offer regarding wireless solutions for data communications regarding field applications

Proposed Work: We proposed to conduct a literature search to identify field applications of wireless technology by using the following resources:

- Transportation Research Information Service
- On-line search of three journals such as ASCE and IEEE
- Internet search
- Selected books we identified at Reiters Scientific Book Company

In addition, we proposed to write a letter to the office which is the equivalent of the South Dakota BIT in each State or Canadian Province and request reports, literature, or other information on any wireless technology for field applications.

We said we would prepare an annotated bibliography of the literature we identify. If any literature is particularly insightful or useful, we proposed to attempt to acquire it (if we have not already received it) and summarize it in a one page template.

Deliverable: Technical Memorandum consisting of an annotated bibliography and completed templates describing the most insightful or useful efforts to use wireless technology for field applications.

Limits on Scope: The literature search was limited to TRIS, an online service for searching journal articles, selected books from a technical bookstore, and material received in response to a letter mailed to State and Provincial DOTs. We proposed to review only a handful (of the most useful) applications in the literature in detail and summarize them using a template. We proposed that other potentially useful literature be presented as an annotated bibliography based on literature abstracts.

Accomplishments: We prepared an annotated literature search using all the sources described in the proposal except an online service to examine the contents of three journals. We found that this last source was somewhat redundant with respect to other sources of information (e.g. IEEE family of standards for 802.11) and too narrow in scope given the breadth and depth of important information on wireless communications we had to digest. Moreover, we found that the literature search could not be a task of predefined duration. Rather, it was necessary to continue the literature search after submission of the Task 3 deliverable. In fact the literature search continued throughout the project to stay abreast of rapidly changing technology, market conditions, and implementation in both South Dakota, the United States and the rest of the world. We ultimately compiled hundreds of articles, mainly from the Internet on the characteristics and status of different wireless technologies. Much of this information was reflected in later task deliverables, especially Tasks 5 and 6. Finally we found that the annotated bibliography was an adequate vehicle for recording information regarding the literature. The annotated bibliography included the two primary pieces of information we would normally incorporate into a literature review template: bibliographic information and a brief summary or abstract of the particular source.

Part of the literature search involved writing letters to the Chief Information Officers in State DOTs and Canadian Provinces. We requested examples of wireless communications they had implemented and which might useful to SDDOT. Only a small fraction of the organizations to which letters were sent responded. Respondents included the California Department of Transportation, the Rhode Island Department of Transportation, the Oklahoma Department of Transportation, and the Virginia Department of Transportation. We believe there were two reasons for the low response rate. First, the CIOs and their staff are very busy. Second, field applications of interest are managed thoughout a department and telecommunications would typically be managed within another organizational unit. It would be complicated task for an agency to gather information on wireless technologies relevant to the different applications addressed by this research. Caltrans provided the most useful information and referred us to Mitretek reports concerning wireless communications for Intelligent Transportation. Oklahoma DOT provided cutsheets regarding Motorola's Canopy broadband wireless Internet Solution. Virginia DOT described an application involving data transfer using Bluetooth.

As a part of the annotated bibliography, we identified numerous Internet resources, including on-line newsletters concerning wireless communications.

Task 3 accomplishments are reflected in Deliverable #3 – Bibliography and Other Resources.

Task 4. Assess the applicability of each technology to each of the user needs.

Relationship to the Project Objectives: Map wireless options to user needs to identify alternative ways of satisfying project objectives and to set priorities.

Proposed Work: We proposed to begin this task by listing the user needs identified from those we interviewed, the Project Technical Panel, and the RFP. We proposed to e-mail the list to the SDDOT Project Manager for distribution to the Project Technical Panel. We suggested there be a conference call with the Panel to identify 5 priority needs that would be the focus of this Task. We said we would make recommendations but we expected the priority list to change as a result of discussion with the Panel.

We proposed that once the priority needs were established, we would use the Framework in Figure 1 of the Proposal to guide the completion of our work under Task 4. For each priority need we proposed to do the following:

1. Identify the application(s)
2. Determine the communication factors to consider
3. Determine relevant wireless data communication options
4. Identify the system architecture for each option
5. Identify the requirements for user acceptance.

We proposed that part of this assessment would consist of determining if a particular wireless option or combination of wireless technologies can meet multiple user needs. We said we would identify other user needs that could be satisfied above and beyond the five that are the focus of this task, provided the same wireless option and architecture will work for all of them. Indeed, the implementation phase calls for installing communication equipment in one area of the state to support the construction management system, traffic data collection, right-of-way needs, and pavement condition data collection. It is possible that wireless data communication needs for most of these field applications could be met using just a few wireless technologies, for example Wi-Fi, some evolution of CDMA or GSM, or Wi-Max.

<u>Deliverable:</u> Technical memorandum assessing the applicability of each technology to the user needs.

<u>Limits on Scope:</u> We proposed to perform the Task 4 analysis for no more than 5 user needs jointly established as priorities by the ARA Team and the Project Panel. However, if wireless options clearly satisfy other similar user needs we will identify them.

<u>Accomplishments</u>: We conducted an assessment of user communication needs for the different field applications that wireless communications might serve. The applications we addressed were as follows:

1. Maintenance Decision Support System (MDSS)
    a. Fixed-in-place component (Road Weather Information System (RWIS))
    b. Mobile component (Truck with snow plow and/or spreader)
2. Traffic counting and classifying
    a. Automated Traffic Recorders (ATR)
    b. Weigh-in-Motion (WIM)
    c. Rest-area traffic counters
3. Pavement distress data collection
4. Right-of-way Acquisition data collection for purchase of property
5. Dynamic Message Signs (DMS)
6. Road Condition Reporting System (RCRS)
7. Construction data collection
    a. Mobile Contract Manager (MCM)
    b. Material Sampling and Testing (MS&T)

    c. Construction Measurement and Payment (CM&P)
8. Megatraks fuel system.

For each application we identified the following:

- Description of current equipment
- Current communication methods
- Current sensors, data storage
- Current number of sites
- Desired maximum communications distance needed
- Desired coverage (area or corridor length)
- Access points
- Desired frequency of communication
- Type of data
- File size needing transmittal
- Desired amount of time to transfer data
- Current bandwidth needs (uplink and downlink)
- Future upgrades
- Additional data transfer needs for upgrades or modifications
- Total transmission needs
- User acceptance factors
- Other issues (notes)

As we progressed through Task 4, we decided to defer to Task 5 examining alternative wireless technologies and assessing their relevance to South Dakota. We felt this was the logical way to proceed because Task 4 would cover user requirements of different field applications, Task 5 would address the ability of different technologies to satisfy the user requirements and the availability of those technologies in South Dakota, and Task 6 would offer recommendations on which demonstrations and evaluations to conduct that would match wireless technologies available in South Dakota to SDDOT field applications.

The Task 4 Deliverable, entitled "User Communication Needs for Applications," contains detailed tables describing user communication requirements for different field applications. Also, this deliverable identifies where multiple applications might be served by a single technology or combination of technologies. For example, we note that Wireless Local Area Networks (WLAN) involving high speed, broadband communication could potentially be installed inside or just outside maintenance and area shops and allow rapid uploading and downloading of data from laptops. As another example, some technologies that can serve Wireless Wide Area Networks (WWAN) might meet multiple needs involving MMDS (both the RWIS and mobile component), ATR and WIM, Construction Management, Right-of-Way Acquisition, and Pavement Distress Identification.

Task 4 accomplishments are reflected in Deliverable #4 – User Communication Needs for Applications

Task 5. Provide a general discussion of benefits, costs, and feasibility of available wireless technologies in South Dakota and indicate the impact on field computers and network hardware.

Relationship to the Project Objectives: Determine the feasibility, including economic, of a particular wireless approach satisfying the project objectives

Proposed Work: It was proposed that this task focus on wireless solutions for priority user needs and associated applications. We said we would provide a general discussion of each wireless technology's benefits, costs and feasibility. We proposed to focus on wireless options available in South Dakota and applicable to different types of field devices. Key considerations set out in the proposal were:

Benefits	• Time savings to personnel using wireless data communications in comparison to current data upload method • Reduction in the risk of losing data • Avoided delays in communicating time-critical data • Possible dollar imputation of the above
Costs	• Cost of hardware used in the field • Cost of network hardware (new equipment, upgrades/add-ons, maintenance) • Operating cost of wire data service (e.g. cost per month)
Feasibility	• User acceptance • Technical feasibility • Economic feasibility

To perform the benefit, cost, and feasibility assessment, we proposed to send the SDDOT Project Manager a brief questionnaire asking SDDOT to provide information on key parameters and answer key questions. For example, one question was likely to be how long does it currently take on average to upload construction inspection information from the construction project lab? Another question is likely to be how long does it take to enter the data into the CMS if the field computer is taken to the office and the data transferred there to the CMS? The answers to these questions would be compared with our estimate of how long it would take to upload the data from the field using a new wireless option. If there is a time savings, there would be a benefit.

One of our team members, though he is working as an independent consultant to ARA, normally works in a South Dakota office of a major telecommunications company. He is able to quickly determine the costs of different wireless data services that are provided by the larger wireless communication companies serving South Dakota.

Deliverable: A technical memorandum entitled "Deliverable #5, Wireless Options --Benefits, Costs, and Feasibility"

Limits on Scope: We proposed to provide a general discussion of each relevant wireless communication technology with regards to benefits, cost, and feasibility. This general discussion may be reduced to a matrix to make it easier for a reader to absorb the information and compare options.

The SDDOT Project Manager, Jon Becker communicated to us that, consistent with the "Limits on Scope," the Department wanted a general discussion – not a detailed analysis -- regarding benefits, costs and feasibility, and that this general discussion could be reduced to a matrix.

Accomplishments: Under Task 5, we prepared a technical memorandum on existing and emerging wireless technology in the United States and abroad. This is an exceedingly complicated field and it required in-depth research that drew on the literature we conducted in Task 3, compilation of much additional relevant information, and identification of a useful way to organize the material. This technical memorandum includes a discussion of different wireless technologies grouped according to whether they are Wireless Personal Area Networks (WPAN), Wireless Local Area Networks (WLAN), Wireless Metropolitan Area Networks (WMAN), Wireless Wide area Networks (WWAN), and Wireless Statewide and National Networks (WSNN). The technical memorandum also includes a series of summary matrices containing the following data for each type of technology addressed:

- Distance or coverage
- Availability in South Dakota
- Data rates
- Spectrum frequency
- Operating Cost
- Equipment Cost
- Comments (other benefits, costs, issues)

CLASSIFICATION OF WIRELESS

As we researched the various field applications of interest to SDDOT, it became apparent that was desirable to classify wireless communications by range or coverage. It then becomes quickly apparent which sets of wireless technologies can serve a specific field application that requires a certain range or coverage. Then one can determine whether the bandwidth and other characteristics of the technology can meet the needs of the application.

The five categories of wireless applications are as follows:

- **Wireless Personal Area Networks (WPAN).** These generally have a range of 8 inches to 30 feet although they can reach 300 feet under high power.
- **Wireless Local Area Networks (WLAN).** The range of WLANs is typically 100 to 300 feet although there are extensions up to 1000 feet and more.

- **Wireless Metropolitan Area Network (WMAN).** Provides coverage throughout a metropolitan area.
- **Wireless Wide Area Network (WWAN).** Provides coverage over a large area or long corridor and may encompass one or more a metropolitan areas, a large part of a state, or even many states.
- **Wireless Statewide and National Area Networks (WSAN).** Covers an entire state such as South Dakota or one or more countries, potentially including all the countries in a hemisphere. WWAN's may be a part of WSANs.

The following provides a brief description of various wireless technologies along with a general assessment of the benefits, costs, and feasibility of applying each in different in South Dakota. The discussion is organized by the categories of wireless technologies listed above.

WPAN

Bluetooth

Bluetooth -- which operates in the unlicensed 2.4 GHz Industrial, Scientific and Medical (ISM) frequency band, is a wireless Frequency Hopping Spread Spectrum (FHSS) technology for transferring data at very short ranges. Because of the high frequency, it can achieve high data rates of 1 Mbs on transceivers manufactured on small chips designed to sell for $5 or less, or better yet for under $1.[1] Bluetooth has practical applications for transferring data between PDAs and laptops to other computers such as a desktop. Furthermore, in South Dakota DOT, Bluetooth would be useful for transferring data from laptops to desktop computers at area and maintenance shops. The data would then be transferred to headquarters by Ethernet and a T1 line. If less than all the channels of a T1 line are available for data transmission (24 channels x 64 Kbps = 1.536 Mbps to headquarters), there could be a bottleneck in the transmission and the full bandwidth of Bluetooth could not be achieved from origin to destination.

IrDA

The Infrared Data Association (IrDA)has established a standard for wireless communications that uses infrared light (.003 - 4 x 10^{14} Hz) and can produce data rates of 4 Mbps at low power over very short distances (8 inches to 3 feet). IrDA also generates 75 kbps over roughly 300 feet at higher power.[2] Infrared light does not go through walls or other obstacles and so is limited to line-of-sight communication within a room. This technology has been in use for some time and allows communications between various personal devices such as laptops and Personal Digital Assistants (PDAs) at very short range. The technology can also communicate with up to eight peripheral devices such as

---

[1] Jim Geier, Wireless Networks, First-step, Cisco Press, Indianapolis, 2005, PP. 96-97. Andy Dornan, The Essential Guide to Wireless Communications Applications, 2nd Edition, Prentice Hall, Upper Saddle River, New Jersey, 2002, pp. 272-278.

[2] Jim Geier, Wireless Networks, First-steps, Cisco Press, Indianapolis, pp. 101-102.

a keyboard, mouse, or printer (often at longer range). This very inexpensive technology – in terms of cost per electronic device -- is routinely integrated into many kinds of consumer electronics.

Ultra-wideband (UWB)

This is a high frequency (from 3.1 to 10.6 GHz), very low power, high speed (40 Mbps to over 1000 Mbps), low range (3 to 30 feet) wireless technology that spreads very brief pulses over a broad swath of spectrum. It was designed to have no discernable interference with other devices or equipment licensed to use the same spectrum. UWB is viewed as a form of wireless technology that can communicate between multimedia devices such as digital cameras camcorders, TVs, PC's, DVD players, and flat panel video displays.

Although UWB is considered a WPAN technology, it could, with FCC approval, be allowed to use more power and therefore compete with WLAN. Some people have even advocated UWB as a solution to the problem of the last mile to the home/business, and thus it is a candidate for a WMAN technology. Many well-known companies are developing and testing chipsets to support UWB. These include Intel, Texas Instruments, and Motorola. The cost of UWB is likely to be cheap, like Wi-Fi, given that it will initially focus on communication among home and office electronics.

WLAN

Wi-Fi

The most prevalent form of WLANs is known as Wireless Fidelity (Wi-Fi) built in accordance with the family of IEEE standards known as 802.11. Different types of Wi-F- operate in the 2.4 GHz range, the same as Bluetooth, and in the 5 GHz range. Wi-Fi has real maximum throughput from 1 to 31 Mbps as follows:

- 802.11 has a data rate of 1 Mbps
- 802.11a communicates at 31 Mbps
- 802.11b data rate has 6 Mbps
- 802.11g has a data rate of 31 Mbps

Some of the standards have fall-back data rates depending upon distance and interference. For example, the 802.11a data rate of 31 Mbs can fall back to any of eight levels, the lowest being 3.4 Mbps.[3]

Wi-Fi hot spots are commonly found in coffee shops, airports, and university campuses but are increasingly present in businesses, hotels, and homes. The range of Wi-Fi is

---

[3] Andy Dornan, The Essential Guide to Wireless Communications Applications, 2nd Edition, Prentice Hall, Upper Saddle River, New Jersey, 2002, pp. 249-257.

about 300 feet but propagation can be disrupted by walls and multi-path effects from metal can significantly reduce range.

Local wireless access network cards are standard features in most new laptops sold today. Also, you can buy an inexpensive WLAN card that fits in the PCMCIA slot of computer. The cost of setting up a WLAN is very low now. A Wi-Fi wireless router is between roughly $20 and $120 and can be purchased at any large electronic outlet store such as Circuit City and Best Buy. The wireless router must be connected to an Internet access point such as DSL or Cable. In the past there have been serious concerns regarding the security of Wi-Fi but this has been addressed through effective encryption. Nonetheless, lingering concerns have caused individuals responsible for deploying Wi-Fi to be cautious.

Dedicated Short Range Communications

The Federal Communications Commission has allocated a 75 MHz band at the 5.9 GHz portion of the electromagnetic spectrum (5.850 GHz to 5.925 GHz) for the purpose of addressing transportation safety. The communications technology, known as Dedicated Short Range Communications (DSRC), lies within the family of IEEE 802.11 standards and has been designated 802.11p. It is intended to be the main form of communication for Vehicle Infrastructure Integration (VII) which involves vehicle-to-vehicle communications and vehicle-to-roadside communications. DSRC has seven channels. Data rates for DSRC are normally cited in the range of 6 to 27 Mbps and the communication range is given at 1000 meters or less. However, data rates and range vary depending on the performance envelopes for different applications. There are three regimes. The first is for general data transfer and internet access services (3 to 54 Mbps with a range of 0 to 1000 meters. The second consists of safety message services (roughly 5 to 20 Mbps with a range of 0 to 400 meters). The third consists of emergency services (roughly 5 to 8 Mbps with a range of 300 to 1000 meters).[4]

Probably well over 200 use cases have been developed by the private and/or public sector regarding potential applications of this technology, not all of which are safety oriented. The chipsets are intended to be compatible with those for 802.11a and the variable cost to users in terms of bits per second is expected to be near zero because the technology will already be built into vehicles. Depending upon the services offered and whether the public sector, the private sector, or public-private partnerships will install the DSRC beacons along the roads, variable costs could vary substantially. Cost for deployment of roadside units in rural areas is expected to be higher than urban areas. Roadside applications will need to provide power, an internet access point and protect the equipment from weather, vandalism, dust, and dirt.

During the last several years four firms, Sirit, Raytheon, Transcore, and Mark IV, have been working to together to develop the initial version of the DSRC standard and a

[4] Justin McNew, 5.9 GHz Dedicated Short Range Communications Overview, PowerPoint Presentation for the ISO TC294 WG16 and IEEE P1609 Working Group Joint Meeting, August 23, 2005.

prototype. In addition other firms have been testing similar transponders. Automobile and truck manufacturers have independently been conducting tests and evaluating potential applications. The general sense is that automobile manufacturers are seeking solutions using DSRC that do not depend upon waiting for the public sector to deploy DSRC, a process fraught with institutional challenges. Several announcements have occurred among pairs of automobile manufacturers to test and evaluate DSRC for safety and perhaps other applications. However, the forthcoming ITS World Congress in November 2005 will demonstrate a public sector application of DSRC or ersatz-DSRC on the streets of San Francisco. The FHWA has been trying to orchestrate DSRC deployment through the leadership of a consortium of State DOTs and automobile manufacturers. FHWA is fully aware of the chicken-and-egg problem regarding whether the private or public sector must deploy first and what types of business models are appropriate for rapid deployment along public rights-of-way.

From a practical point of view DSRC will not be deployed to a significant degree in the United States until automobile manufacturers begin installing DSRC in new models beginning around 2009 and a large amount of the fleet turns over. Certainly DSRC will not be available in time for this project unless SDDOT determines it wishes to conduct a pilot project, which would probably be expensive, but the costs might be defrayed through federal funding.

WMAN

A number of WMAN solutions are discussed here including 1G, 2G, 2.5G and 3G generation voice and data services. These include analog, cellular and Personal Communication Services (PCS), UMTS, wireless internet service providers (WISPs), Wi-Fi Mesh, Wi-Max, , and Flash-OFDM. Cellular and personal communication services could also be discussed in connection with WWANs and with regards to broader state, national or international communication networks. However, the characteristics of cellular and PCS do not vary significantly from WMANs to WWANs to some broader networks and thus may as well be introduced here.

Most important is to understand how mobile technology has been evolving. There are a number of distinct paths of evolution based primarily on the European standard, *Global System for Mobile Communications* (GSM) and Qualcomm's proprietary spread spectrum technology that uses Code Division Multiple Access (CDMA). GSM uses Time Division Multiple Access (TDMA) as its modulation scheme and is fundamentally incompatible with CDMA. However, GSM has become a world-wide standard with well over 1.5 billion users of GSM phones. A distinctive feature of GSM is the user must have a Subscriber Identify Module (SIM) Card that fits into digital phones or wireless data devices. The SIM card has all the information pertinent to a GSM subscriber including phone number, network operator, and the user's phone number/directory. Figure 1 shows the two primary paths of evolution of mobile wireless technology, one stemming from GSM and the other from CDMA.[5]

[5] Andy Dornan, pp. 122-125.

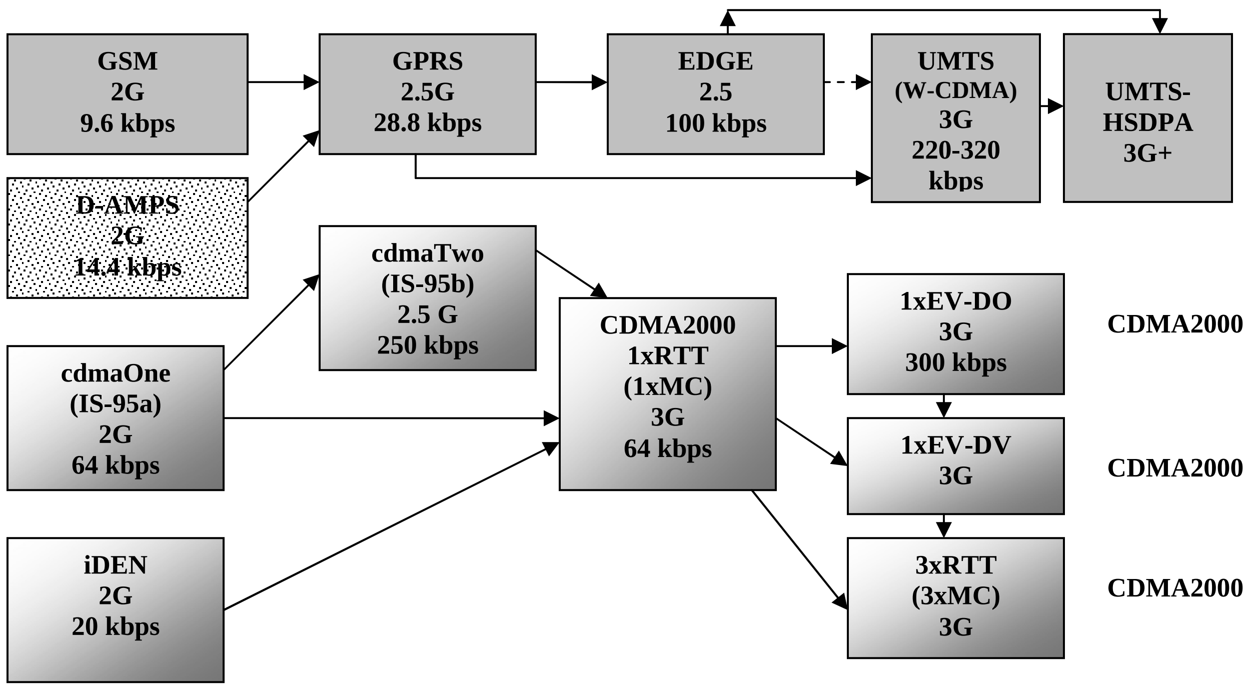

Figure 1. Wireless Evolutionary Paths

Because data communications continue to rapidly evolve, it is important for South Dakota DOT to be cognizant of new developments and the changes likely to occur so that wireless communication systems implemented in the future will be compatible with those implemented in the past, if a relevant consideration.

Cellular and Personal Communication Services are distinguished by generation. Briefly the definitions of different generations are as follows:

First Generation (1G). Provides for analog voice and data communications

Second Generation (2G). Mobile systems that convert speech to digital code and use digital cellular networks. Key advantages include clearer signals and the ability to compress data/voice and to provide security through encryption. Data transmission rates are typically below 10 kbps although data modems can handle 30 kbps.

Enhanced Second Generation Cellular and PCS (2.5G). Digital cellular networks have been enhanced to permit packet switching and have data rates similar to an analog

---

Carl Kain, Commercial Mobile Radio Systems, Applications in Public Transit, Mitretek, February 2003, p. 4-5.

modem. The Internet uses packet switching and therefore it is easier to make interconnections between 2.5G networks and the Internet. Operators of 2.5 G networks can transmit data at speeds consistent with a fast modem, 40 kbps, although the theoretical speed is 100 kbps.[6]

Third Generation (3G). Mobile systems that strive to provide performance similar to an Integrated Services Digital Network Line (ISDN). According to the International Telephone Union's definition of IMT-2000, three different data rates could be considered to be 3G depending upon how ISDN is construed. The lowest is 144 kbps, the same as an ISDN B-rate line. The next highest is 384 kbps, which would allow video conferencing and is considered the target operators should shoot for. The highest rate, 2 Mbps, equals the data rate a European P-rate ISDN line into a switchboard could achieve. As with most communications technologies, initial deployment of 3G technologies has not been able to achieve specified rates. Data rates originally did not exceed 64 kbps, more in line with a 2.5G technology.[7]

Fourth Generation (4G). 4G services envisioned in Japan and expected to be deployed in the 2006-2010 period, can serve as a benchmark for similar services in the United States. 4G download rates in Japan are projected to be 40 Mbps, sufficient for seamless video and quickly downloading music.

1G

Advanced Mobile Phone System (AMPS)

Analog cellular service, also known as AMPS, uses a circuit switched cellular technology in the 800 to 900 MHz band and was rolled out in the United States in the mid 1980's. AMPS has greater coverage in the United States than any other type of cellular system including digital. No new first generation analog cellular systems have been built in the United States for some time. Just a few years ago AMPS covered about 80 percent of the U.S. population. It more effectively served rural areas than urban areas. It will be phased out by 2008 so carriers are switching to other wireless systems as fast as possible. There still is analog service in South Dakota with reasonably good coverage along I-90 and even better coverage along I-29.[8]

Data rates are 9600 bps to 14400 bps, which depend on signal strength. Within a geographic area, two competing cellular operators divide the allocated spectrum, a downlink frequency of 869-894 MHz and an uplink frequency of 824 to 849 MHz. The number of users that can be accommodated equals the number of available channels less the number needed for signaling information, or just under 800.[9]

---

[6] Andy Dornan, p. 90.
[7] Andy Dornan, p. 126.
[8] Steve Wegman, South Dakota Public Utilities Commission
[9] Andy Dornan, p. 63.

A modem in a laptop or mobile device must be connected wirelessly to the modem of an Internet Service Provider (ISP). To make analog cellular data transmissions, the handset is cabled to the mobile device so the cellular network takes the place of a traditional wireline connection between a phone and a central switching facility. Data is transferred as a series of tones which the ISP modem interprets.

2G

The digital networks representing the second generation of cellular services are generally referred to Personal Communication Services (PCS). The FCC auctioned off the rights to provide these services.

***GSM (Global System for Mobile Communications*)**

This is a wideband TDMA communications technology able to handle voice and data. It was originally developed in Europe but is now used throughout the world and reached roughly 1.5 billion subscribers in 2005. The maximum data rate for GSM is 14.4 kbps but more realistic speeds for regular data service are 9.6 kbps. A distinguishing feature of GSM is each user must have a Subscriber Identify Module (SIM) smart card. The SIM card fits inside a wireless data device or digital phone and has all the information regarding a mobile subscriber such as phone number and network operator. AT&T (purchased by Cingular) offers limited coverage of GSM in South Dakota (e.g. Sioux City and possibly in spots along selected highway corridors). While GSM service is available in South Dakota, you cannot purchase it in the state.[10]

D-AMPS

D-AMPS is the digital upgrade to the first generation AMPS, the analog standard used in North and South America. D-AMPS has a data capacity of 14.4 kbps. D-AMPS uses the same analog frequencies as AMPS. Providers of analog service have sought an effective upgrade path to 2.5G and 3G wireless communications. As Figure 1 shows, upgrading to GPRS, which is backward compatible with GSM technology, has proven the most attractive route. D-AMPS is not available in South Dakota.

cdmaOne

This was the first wireless technology based on the Qualcomm's proprietary spread spectrum CDMA modulation technology. CDMA uses Direct Sequence Spread Spectrum. The signals are spread across a broad range of spectrum with little concentration of power in any one portion of the frequency band, thus limiting interference. Evolution of wireless technology based upon CDMA starts with this technology which has a maximum data capacity of 64 kbps. cdmaOne is not available in South Dakota.[11]

---

[10] Steve Wegman, South Dakota Public Utilities Commission
[11] Steve Wegman, South Dakota Public Utilities Commission

Integrated Digital Enhanced Network (iDEN)

iDEN is a proprietary wireless packet switching communication system developed by Motorola. As a 2G system it has no natural upgrade path to 3G. It has a throughput of roughly 20 kbps, comparable with the first GPRS phones. iDEN is one of the most widely used wireless systems in the United States. There have been a number of iDEN operators including Nextel. Even though iDEN is fundamentally a 2G system, Nextel claimed it provided the first nationwide 2.5 G system in the United States.[12] A distinguishing feature of Nextel's iDEN service is direct phone-to-phone communications. Phones do not have to communicate via a base station. Verizon Wireless provides iDEN coverage in certain areas, but you cannot purchase it in South Dakota.[13]

2.5 G

General Packet Radio Service (GPRS)

GPRS is intended for data communication and aims to provide users high capacity Internet access. GPRS uses TDMA for modulation and must work with GSM. Therefore modems for portable fixed-in-place equipment use SIM cards. GPRS uses packet switching, a significant improvement, and therefore requires bandwidth only when needed, leaving gaps in the data stream for others using the communication system. The data rates for GPRS are difficult to determine because they vary with the grade of handsets, the slot class (there are 29), capacities for uplink and downlink, and whether GPRS offers full duplex or not. GPRS offers each user up to eight 14.4 kbps channels. Slot class number 1 has a capacity of 14.4 kbps in both the uplink and downlink modes. Slot 18 provides the highest date rates 115.2 kbps in each direction. Because GPRS is on the evolutionary path from GSM, the most popular wireless platform in the world, it too is achieving substantial market penetration in Japan, Europe and now in the United States.[14]

The range of GPRS is 7 to 8 miles, but you can roughly double the transmission distance with an external antenna or amplifier. In South Dakota, GPRS coverage is available through Cingular along both the Interstate 29 and Interstate 90 corridors but you cannot buy Cingular service in South Dakota. Monthly costs for GPRS coverage, where it can be purchased, range from approximately $20 to $80. GPRS air cards for a laptop sell for about $75 to $100.[15]

[12] Andy Dornan, p. 117
[13] Steve Wegman, South Dakota Public Utilities Commission
[14] Andy Dornan, pp. 98-101
[15] Steve Wegman, South Dakota Public Utilities Commission

Enhanced Data for Global Evolution (EDGE)

EDGE is another wireless technology that has evolved from GSM. The channel bandwidth of EDGE is 200 kHz and it is based on TDMA, the same as GSM. EDGE gained cachet in the United States when the American TDMA industry figured out a way to migrate D-AMPS from GSM to GPRS and then to EDGE. In Europe, operators have been more focused upon obtaining and building out UMTS (W-CDMA) licenses. Touted data rates for EDGE are 384 kbps, but operators like Cingular and ATT indicate maximum data rates are 130 kbps and average actual speed is more like 100 kbps. EDGE service is available throughout much of the Northeastern U.S., the South, the Midwest, and the West and Southwest, but it does not appear to be currently available in South Dakota.[16]

cdmaTwo(IS-95b)

This represents an upgrade path for cdmaOne (IS-95A). cdmaTwo can generate a bit rate of 64 kbps.[17] This service is a way-station to 3G wireless communications. A 3G evolution of cdmaTwo can potentially reach speeds more than 1 Mbps although actual speeds are likely to be much lower. cdmaTwo is not available in South Dakota.[18]

3G and Above

As shown in Figure 1, the trail to 3G stemming from Qualcomm's patented CDMA spread spectrum technology stems from cdmaOne (a 2G technology) or cdmaTwo (a 2.5 G technology) to CDMA2000 (a 3G technology), also known as Radio Transmission Technology (1xRTT) or Multi Carrier (1xMC). This trail further evolves to Enhanced Version – Data Only (1xEV-DO), a 3G technology; Enhanced Version – Data and Voice (1xEV-DV), another 3G technology; and a higher data rate version of Radio Transmission Technology (3xRTT).

The trail to 3G that follows from the Japanese and European 2G GSM standard, which relies on TDMA, continues with GPRS (2.5 G), which uses packet switched data, and culminates in W-CDMA (3G), also known both as 3GSM and the better known UTMS. The new designation of 3GSM was designed to eliminate confusion but adding a third name for W-CDMA doesn't necessarily provide additional clarity. W-CDMA has little in common with CDMA2000 [although both use spread spectrum communications[19]]. The international Telecommunications union has an initiative called International Mobile Telecommunications – 2000 (IMT-2000) to create a global standard for 3G telecommunications involving UMTS/WCDMA, a version of EDGE and CDMA2000.

[16] Steve Wegman, South Dakota Public Utilities Commission
[17] Andy Dornan, 108
[18] Steve Wegman, South Dakota Public Utilities Commission
[19] Dornan, p. 68.

The goal is to provide 2Mbps for communication with stationary equipment and 384 kbps for mobile equipment, although practical data rates are likely to be far less. [20]

Radio Transmission Technology (1xRTT)/ Multi Carrier (1xMC)/IS-586

Verizon Wireless, Sprint PCS, Nextel and Alltel[21] are all committed to developing 1xRTT (1xMC) networks capable of realistic speeds of from 40 to 60 kbps, faster than GPRS. Indeed Verizon Wireless, Alltel and Sprint have already made substantial strides to build out their 1xRTT networks. Nextel, which has been committed to iDEN for some time, has a greater challenge and will have to make the investment to build an entirely new network. The 1xRTT technology is an upgrade to cdmaTwo (IS-95b) and is better than GPRS because it uses spectrum more efficiently. GPRS just adds packet switching to GSM and depends upon a limited number of fixed bandwidth channels (29) whereas 1xRTT, a CDMA technology, shares the entire band among all users.[22]

Verizon Wireless offers 1xRTT communications throughout much of South Dakota. It advertises slightly higher speeds than indicated above -- 60 to 80 kbps with bursts to 144 kbps (more typically 100 kbps). Verizon Wireless charges $39.99 for 20 MB of data and $59.99 for 60 MB of data. The unlimited access charge is $79.99. PC cards are $49.99 with a 2 year contract. For telemetry devices, the plans are offered in units of megabytes and range from $10 to $100 per month. Telemetry devices start around $600.[23] Alltel also offers 1xRTT service along I-90, I-29, east of the Missouri River, and to a much smaller degree, west of the Missouri River.

Enhanced Version –Data Only (1xEV-DO)

1xEV-DO is another logical extension of CDMA technologies, namely 1xRTT (CDMA2000). The maximum uplink rate of 1xEV-DO is 153 kbps while the maximum downlink rate is 2.4 Mbps. Average data rates are far less. According to a recent Mitretek study, Mobile Monet Networks offered 1xEV-DO in a few cities in Minnesota, North Dakota and South Dakota.[24] Unfortunately, the service provider filed for bankruptcy in 2004.[25]

Verizon Wireless now makes 1xEV-DO available in about 50 cities and 60 major airports (none are in South Dakota). Verizon Wireless says by the end of 2005 it will have the largest high- speed coverage in the United States, reaching 150 million people. Verizon Wireless will be testing a faster version of EV-DO service, dubbed Rev A EV-DO, in early 2006. The firm supports several EV-DO cards, including those from Audiovox, Novatel, and Kyocera. These cards can be found on Verizon Wireless's website. Unlimited data plans cost $80/month. Because 1xEV-DO is part of the CDMA family,

---

[20] 3G Americas website: http://www.3gamericas.org/English/Technology_Center/Qa/umtsqa.cfm (October 10, 2005)
[21] Alltel has two brands, Cellular One and Western Wireless
[22] Andy Dornan, p.140
[23] Verizon Wireless
[24] Carl Kain, p. 4-11
[25] Carl Kain, p. 4-13

1xEV-DO does not support international roaming. Also, published information suggests that Verizon Wireless does not currently offer hot-spot service.

Sprint offered 1x EV-DO in 2005 and initiated service in 34 downtown metro areas and airports. Again this service is not in South Dakota. Unlimited data plans, like those offered by Verizon Wireless, cost $80 per month. Sprint intends to cover 60 large metro areas by early 2006. Sprint also has a plan costing $40 per month for 40 MB with a cap of $90 if you go over in a given month. Sprint does not support international roaming but offers hotspot service at $49.95 per month. You can access the Sprint PCS website and find offers for two 1xEV-DO cards, the Sierra Wireless AirCard 580 and Novatel Merlin S620 which, at the time of this writing, were available for free with a 2-year contract until the offer expires.

Enhanced Version- Data and Voice (1xEV-DV)

This CDMA broadband mobile technology integrates data and voice over the same channel. 1xEV-DV supports remote access to the Internet and, according to the standard, provides typical throughput from 420 kbps to 1.7 Mbps and maximum data rates of 3.1 Mbps. The service is intended to support multimedia services such as streaming video, video conferencing, and on-line gaming. Ericsson tested the service in the United States in 2004, but it does not appear that any major service providers are currently offering it in this country. It will probably be rolled out in other countries first.[26]

3xRTT (3xMC)

3xRTT has been accepted by the International Telephone Union (ITU) as the CDMA2000 proposal that will provide functionality nearly the same as W-CDMA. 3xRTT can potentially provide IP communications of 384 kbps outdoors and 2 Mbps indoors.[27] The ITU would like phones to be produced with a dual mode chip that can handle both 3xRTT and W-CDMA.[28] However, compared to 1x technologies, 3x technologies use triple the spectrum, which operators in the U.S. find very unattractive due to very limited availability of spectrum. By mid-2004 this evolution of CDMA2000 had not appeared in the United States and does not seem to be available in 2005. Deployment in the U.S. is likely to accelerate if the FCC allocates additional spectrum for 3xRTT.

Wideband CDMA (W-CDMA)/Universal Mobile Telecommunications System (UMTS)/3GSM; UMTS TDD, UMTS FDD

W-CDMA or alternatively UTMS is a 3G broadband data and voice packet internet protocol (IP) technology. Thus it can handle large file transfers, music downloads, and

---

[26] Texas Instruments web page: http://focus.ti.com/docs/pr/pressrelease.jhtml?prelId=sc04134 (October 10, 2005)
[27] STMicroelectronics webpage: http://www.st.com/stonline/prodpres/dedicate/wireless/backgrds/cdma.htm (October 10, 2005)
[28] Andy Dornan, p. 142.

streaming video. W-CDMA/UTMS has average data rates of 220 to 330 kbps when a user is walking or in a car but theoretically could reach 2 Mbps for a stationary user.

W-CDMA/UTMS has a great deal of spectral efficiency since it uses both CDMA and TDMA. It works in a number of frequency spectrum bands including 1900 Mhz. W-CDMA/UTMS is an outgrowth of the widely used GSM technology, and hence the third name 3GSM. It is a straightforward upgrade from GPRS, because GRPS uses packet data. W-CDMA/UTMS can degrade to EDGE, GPRS or GSM where it is desirable to do so.

W-CDMA, like GSM, will be widely deployed around the world. Already 143 operators world-wide have selected W-CDMA/UTMS as their 3G wireless technology and 85% of world-wide 3G customers are projected to use W-CDMA/UTMS.[29]

This 3G technology was first deployed in Japan in 2001. AT&T deployed the first systems in the United States in Detroit, Phoenix, San Francisco and Seattle in 2004. Before the year was out, AT&T added service in Dallas and San Diego. Cingular, which acquired AT&T, deployed another variant of this 3G technology, UTMS-High Speed Downlink Packet Access (HSPDA) in Atlanta.

One of the reasons discussions regarding this 3G technology is so complex is writers often mention that both TDMA and CDMA is involved in UMTS, perhaps to promote truly universal 3G mobile communications that permits roaming in Americas, Europe, Japan and the rest of the world. It is quite likely that eventually that vast majority of phones sold around the world will be at least dual mode and accommodate various versions of W-CDMA/UMTS and CDMA2000.

There are two different types of W-CDMA/UTMS systems. One uses Frequency Division Duplex /Wideband Code Division Multiple Access (FDD/WCDMA), frequently referred to as UMTS FDD, which permits transmission and reception on two different frequencies. The other, Time Division Duplex/ Wideband Code Division Multiple Access (TDD/WCDMA), commonly called UMTS TDD, assigns different time slots within a single frame for both transmission and reception. Nextel, which is merging with Sprint, will be conducting a trial of UMTS TDD in the Washington D.C. region. UMTS TDD is considered an alternative to WiMax, discussed below.

W-CDMA/UTMS is not currently available in South Dakota. If it were, the cost would probably be competitive with other services in the state due to economies of scale and the ability of operators to build upon existing GPRS and EDGE networks. AT&T and Cingular appeared to have similar technical strategies for deployment of 3G systems before Cingular's purchased AT&T. The purchase was probably motivated by the likelihood of achieving significant economies of scale. Service plans for WCDMA/UMTS are about $80.00 per month.

---

[29] 3G Americas website: http://www.3gamericas.org/English/Technology_Center/Qa/umtsqa.cfm (October 10, 2005)

4G

Flash-OFDM

In the past the dividing line in wireless technology has largely been between those technologies based on GSM (TDMA) used mainly outside the United States and CDMA-based solutions deployed in this country. Flash-OFDM is emerging as a new fault-line in the wireless broadband business and is viewed as a direct threat to other wireless technologies that are being rolled out now (1xEV-DO) or that will be deployed in the future (wide area Wi-Fi Mesh and WiMax).

Flash-OFDM, originally developed at Bell Labs and based on Orthogonal Frequency Division Multiplexing (OFDM), is a 4G proprietary mobile, broadband, wireless end-to-end IP solution of Flarion Technologies. It operates in the frequency range of 400 MHz to 3.5 GHz. and uses a RadioRouter® which interfaces with an off-the-shelf edge router. Flash-OFDM will work on top of an operator's network and frequency spectrum and seamlessly interfaces with corporate LANs in a way that meets corporate requirements for speed and low packet latency while avoiding the need for various modifications such as applications and protocols.[30]

Nextel recently conducted a trial of Flash-OFDM in Raleigh, North Carolina. It is currently charging $35/month for its service. Flarion's PC card easily enables Laptop and other similar devices. Shortly Flash-OFDM devices will be able to interact with both Wi-Fi and WWANs. Flarion does not currently offer Flash-OFDM in South Dakota.

Wi-Fi Mesh.

Wi-Fi Mesh is a wide area, high-speed broadband, IP network built up from Wi-Fi base stations that adhere to IEEE 802.11 standards (a,b,g,i). Some of the Wi-Fi base stations connect to Internet Access Points (AP) while the others serve as repeaters. Achievable data rates for Wi-Fi Mesh are a function of the proximity to Internet Access Points and the degree a user is reached through a daisy-chained set of repeaters. The farther away from an access point and the more repeaters, the more the data rate declines. An interconnected web of routers or equipment that serves similar functions (e.g. Ethernet switches.) complements the Wi-Fi base stations, which can be very large in number. The Wi-Fi base stations may be viewed as public infrastructure because of public accessibility (though in fact they may be set up and operated by a private firm), whereas the routers and software that optimize traffic are proprietary. Since the Wi-Fi base stations, routers, and software must be fully integrated, in effect the Wi-Fi mesh is proprietary. The Wi-Fi Mesh can cover hundreds of square miles. It has a high degree of redundancy, is self organizing and self-healing, and software selects the optimal path for video, voice and data.[31]

[30] TMCnet webpage: http://tmcnet.com/usubmit/2004/Jun/1048599.htm (September 22,2005)
[31] http://www.tropos.com (August 18, 2005)

A Wi-Fi Mesh can cover a construction site, campus, a metropolitan area or even a wider region. At least 76 cities throughout the United States have plans for metropolitan Wi-Fi mesh, the largest implementation being Philadelphia. Tropos Networks landed a contract to deploy Wi-Fi Mesh in Oklahoma City which will have 600 fixed wireless base stations on light poles throughout the city and over 700 mobile Wi-Fi cells in police and fire vehicles.[32]

In the United States the major telecommunication carriers are fighting this bitterly and seeking legislation to prohibit it because they feel the responsibility for providing high 3G+ communications should be the responsibility of the private sector not the public sector. Obviously, if the public sector becomes a major competitor and deploys major communications systems for free or low cost, it can potentially do serious damage to parts of the telecommunications industry. [33]

Another major issue is that communications and cable television that require access to public property or public rights-of-way have historically been deployed under a franchise agreement. A franchise is defined as granting access to public property, including rights-of-way, in order satisfy a public interest obligation while being allowed to earn a profit. Franchise fees have been a significant source of revenues for municipalities and those who do not respect how telecommunications have been deployed in the past when ROW, lampposts along side the road or other public property has been required, will run into serious obstacles.[34]

Companies such as Motorola (Canopy Wireless Broadband Group), MeshNetworks, and Tropos Networks supply the ingredients for and build Wi-Fi meshes. No Wi-Fi Mesh network is known to exist in cities of South Dakota. In Philadelphia users may be charged $20.00 per month. It is possible that some cities will cover all the capital and operating costs because of the public benefits that accrue.

One way Wi-Fi mesh is deployed is through Wireless Internet Service Providers (WISP). These are small business that put a Wi-Fi transceiver on an antenna with a backhaul to the Internet. The transceivers broadcasts to 802.11 Wi-Fi devices in a microcell that may serve 200 users. The business may expand coverage to additional cells and eventually cover a large area whether it is urban or rural.

Currently there is no known wireless mesh in cities, colleges or universities, industrial campuses, or other sites within South Dakota.[35]

---

[32] Converage web page: http://www.convergedigest.com/WiFi/wlanarticle.asp?ID=15283
[33] FCM.COM web page: http://www.fcw/article90139-08-18-05-Web (September 9, 2005)
[34] William Hyman et. al., Overcoming Barriers to ITS, Lessons from Other Technologies, Final Report, prepared for Federal Highway Administration, December 1995, pp. 59-68.
[35] Steve Wegman, South Dakota Public Utilities Commission

Serial Wi-Fi

The Virginia Tech Transportation Institute (VTTI) worked with the Salem District Office of the Virginia Department of Transportation to implement Serial Wi-Fi in three directions from the VTTI Smart Road Control room near Blacksburg, Virginia. This serial Wi-Fi serves video cameras but could also serve DMS, Road Weather Information Systems (RWIS), and communications with a mobile platform. Serial Wi-Fi involves daisy-chaining Wi-Fi units and thus communicates in hops along point-to-point (P2P) connections. Serial Wi-Fi can provide communication over distances of 2.5 miles to 30 miles from a base node depending upon the length and number of hops, signal power, antenna gain, and height of the antennas. Serial-Wi-Fi requires clear line of sight between nodes and to achieve maximum distance must compensate for the curvature of the earth, and avoid intrusion of vegetation into the fresnal zone. High gain, narrow beam width, and directional antennas also tend to maximize transmission distance, everything else being equal. The FCC puts limits on the output power after an antenna amplifies the signal in order to minimize interference. Throughput can range from 1 MBs to 11 MBs depending upon antenna gain.

A typical serial Wi-Fi deployment would be a multi-hop system involving telephone poles with antennas placed one to three miles apart. An 8-hop system would have over 500 kbps of bandwidth at the most distant node.

Serial Wi-Fi supports mobile communication. VTTI experiments involving communication between the roadside units and a laptop in a moving vehicle at speeds between 5 and 60 mph, indicated the system functions well, although the throughput declines as the distance from the base node increases. Even at 60 miles per hour throughput ranged from nearly 1 MBs (furthest access point) to over 4 MBs (nearest access point).

As to costs, Serial Wi-Fi is substantially cheaper than optical fiber. Because Serial Wi-Fi uses Commercial-off-the Shelf (COTS) technology, installation costs appear to be an order of magnitude cheaper than optical fiber. Over time the savings in lifecycle costs of Serial Wi-Fi compared to wireline telecommunications increases and may reach 50 percent or more in the fourth and fifth years after installation.[36]

---

[36] See "Serial Wireless LANs Along DOT ROW," prepared by Ashwin Amanna, Assistant Director and Dr. Aaron Schroeder, Director, Center for Technology Deployment, Virginia Tech Transportation Institute. Also see Florida Department of Transportation, Wireless Technology for ITS Deployment, September 1, 2004. Useful websites are:
http://www.nawgits.com/itsa/ITS2004-000340.pdf;
http://www.dot.state.fl.us/trafficoperations/its/Telecommuncation/Wireless.htm
http://www.dot.state.fl.us/trafficoperations/its/Telecommuncation/Wireless/Wireless%20Technology%20for%20ITS%20Deployment.pdf.

Wi-Max

This is a broadband, wireless voice and data Ethernet IP communications technology that may be widely deployed in the 2007-2010 period. Already systems similar to Wi-Max are being demonstrated or deployed in Europe and the United States (e.g. Santa Clara, California[37]). Wi-Max would serve laptops, desktops, and PDA's; it would provide backhaul to IP networks, help move data downstream from Wi-Fi hotspots; and it can enhance quality of service or be invoked for broadband applications such as video. Wi-Max is based on the IEEE 802.16 standard and operates in the 2 to 11 GHz range. Specifications are being developed for both stationary and mobile Wi-Max. Original specifications for a different frequency range did not allow radio waves to penetrate or bend around buildings. The current 2 to 11 GHz range does allow partial penetration of buildings and waves to bend and reflect around obstacles. Consequently transmission between base stations and clients do not need clear line-of-sight. At low frequencies, transmission distance could reach 50 km but under most deployments the distance covered is more likely to be 6 to 10 kilometers.[38] The typical data rate per channel is expected to be 40 Mbps, compared with the theoretical rate of 32 to 135 Mbps. As with all Ethernet technologies, the users share the bandwidth for each channel, so as the number of users increase, the data rate declines. The Advanced Encryption Standard (AES) is expected to be part of the Wi-Max solution when the technology is rolled out.

The main obstacle to Wi-Max deployment is it may need a stronger business case. Wi-Max faces competition from many technologies and communications companies have already made huge investments in other types of wireless infrastructure. Nonetheless, Wi-Max is getting a large amount of attention in the telecommunications industry and it is likely to be widely deployed. For now, Wi-Max and similar proprietary networks do not exist in South Dakota.[39]

WWANs

All the technologies relevant to WMANS are also relevant to WWAN's. If a wireless technology can serve a 225 square mile area of a metro area 15 miles by 15 miles, it can potentially serve similar or larger areas in either urban or rural areas.

This section discusses some additional WWAN technology.

Spread Spectrum Radio Frequency Communication

A commonly used approach to wireless, which underlies a large number of communications technologies, is spread spectrum. Depending upon certain factors such

---

[37] 802.16 News web page: http://www.80216news.com/publications/page1299-3020152.asp (September 26, 2005)
[38] Unstrung web page: http://www.unstrung.com/document.asp?site=unstrung&doc_id=65348&page_number=7 (August 25, 2005)
[39] Steve Wegman, South Dakota Public Utilities Commission

as frequency range, power, gain, type of antenna, and impediments to propagation, spread spectrum communications can cover substantial distances, for example 15 to 50 miles, and thus clearly falls in the class of WWANs. Currently South Dakota is using spread spectrum to communicate with Dynamic Message Signs (DMS).

The two most well-known forms of spread spectrum are frequency hopping (FHSS) and direct sequence spread spectrum (DSSS). FHSS rapidly switches between narrowband FM channels in a pattern that seems random but which the receiver is capable of deciphering.

DSSS covers a wide swath of frequency and transmits over each part of the frequency band all at once. Each sending device codes its message slightly differently than the others and each receiving device must be able to decode the message so large numbers of users can transmit over the same frequency band. Codes must be known in advance; they are hardwired into transmitters and receivers such as phones and transceivers. Transmissions appear to be indistinguishable from noise, but because each receiver knows the code of the corresponding sender, each message can be extracted without others learning the content. Also, there is minimal interference from other RF transmissions. Because, of the similarity to encryption, DSSS is frequently referred to as Code Division Multiple Access (CDMA).[40]

Many spread spectrum RF systems operate over portions of the spectrum that do not require licenses. One vendor, for example, offers the following license free products:

	Frequency	**Speed**
MDS 5800	5.8 GHz	310 Mbps
MDS FIVE Series	5.3/5.8 GHz	200 Mbps
2.4 GHz Spread Spectrum		
MDS entraNET 2400	2.4 GHz	106 kbps
900 MHz Spread Spectrum		
MDS iNET 900	900 MHz	512 kbps
MDS iNET 900/ENI	900 MHz	512 kbps
MDS entraNET 900	900 MHz	106 kbps
MDS TransNET 900	900 MHz	115.2 kbps
MDS 9810 Transceiver	900 Mhz	19.2 kbps

Spread spectrum in the 900 MHz frequency range is already being used in South Dakota for investigation of Maintenance Decision Support System data communications. And as mentioned above, spread spectrum is being used to communicate with DMS.

Other potential applications are to complement the existing 9.6 kbps State Radio data communication network with 700 MHz Ultra High Frequency (UHF) spread spectrum. Currently this spectrum is allocated to UHF television, but as High Definition Television comes on line, the FCC will release this frequency for other purposes.

[40] Andy Dornan, pp. 67-68.

Orthogonal Frequency Division Multiplexing (OFDM)

The main attraction of OFDM is it avoids multi-path effects, a form of destructive interference. Different path lengths are increasingly likely to confuse a receiver when data rates become very high and each bit is represented by a shorter time interval. OFDM addresses this problem by slowing down the data rate by splitting the high-speed transmission into a number of slower channels. In fact the number of channels can be very high. OFDM also uses orthogonal carrier waves which cancel each other out as much as possible.

Many types of OFDM technology exist. These include technologies to improve the clarity of television broadcasting, and Flash-OFDM, developed by Flarion Corporation for 4G wide area mobile data.[41]

As discussed elsewhere in this report, Flarion Technologies has already demonstrated this technology in Raleigh, North Carolina. Flash-OFDM is not currently an option for South Dakota, but could become one if it proves highly competitive with other next generation technologies such as Wi-Max.

South Dakota State Radio System

The South Dakota Bureau of Information and Telecommunications (BIT) has been responsible for developing a statewide radio communication system intended for public safety functions. The initial deployment served just voice but beginning in September 2005, BIT started demonstrating and rapidly adding a capability to transmit data. Both the voice and data communications are supported by an infrastructure of 48 towers, though the initial deployment of the data network involves only 35 of these sites. The plan is eventually to provide wireless data communications at all sites. The maximum speed of the data network is 9.6 kbps, but typical speeds are expected to be 4 kbps.

The State Radio System has four channels, three exclusively dedicated to voice**.** The fourth is an APCO compliant 3600 bps control channel to support the trunking functions for voice communications. The State Radio voice network is a push-to-talk contention system. Furthermore, one can switch back and forth between voice and data which are two separate RF systems. Voice operates between 152 and 163 MHz whereas data is transmitted from 160 to 170 Mhz over a packet switched system. Voice moves over a Motorola ASTRO proprietary digital trunked radio system but data is transmitted on a Motorola ASTRO non-trunked system.

Voice equipment cost about $200,000 for four repeaters per site (3 voice & one control; a couple sites have four or five channels for voice). An additional repeater is required at each site for data. There is a T1 line from each tower to the Becker-Hansen DOT building; a 64 kilobyte DSO channel in each direction is available. Each T1 line cost

[41] Andy Dornan, pp. 72-73.

about $600/ month and is available from South Dakota Network. The costs cited above do not include buildings or land.

The State Radio System includes a Datamaxx middleware product called IntelliWare. This middleware functions like an IP bridge between the Motorola RF transceiver and a fixed-in-place or mobile terminal. IntelliWare enables one to switch between different networks, serve as a bridge between an application server with a public safety data base and a Windows based client, and provide compression and encryption.[42]

Multi-channel, Multi-point Distribution Service (MMDS)

This type of wireless service requires direct line-of-sight connections. It has a range of about 30 miles, operates around 2.5-2.7 GHz and has a data rate of 250 kbps. It is deployed in a number of rural South Dakota counties and communicates from tower to tower. The counties served are Lake, Moody, Minnehaha, McCook, Turner, Lincoln, Yankton, and Clay.[43]

Extended Range RF

Applied Research Associates, Inc. (ARA) is currently under contract with the Department of Defense to develop an innovative RF link concept, which offers the following dramatic benefits for applications in which low data rates (10-1000 bps) are sufficient:

Relative to available technology operating at the same power, it can achieve:
- 100 times the free space propagation range;
- 10 to 20 times the ground-to-ground range;

Simultaneous reception of hundreds of transmissions
- Very compact and low cost transmitter (COTS based); and
- High resistance to jamming and intercept;

This RF link is based on the well-understood fact that as the data rate is reduced, the receiver bandwidth can be reduced, which proportionally reduces the receiver noise floor, increasing the ability to detect longer range more highly attenuated transmissions. However, operating at these narrow bandwidths is extremely difficult because the normally present RF carrier frequency instabilities -- due to temperature, Doppler shift, and vibration -- are now much larger than the receiver bandwidth desired. ARA has solved this problem with a very practical design. This very low-cost, compact technology can be utilized for a range of potential applications including collecting information from ATRs, RWIS, strain gauges and vibration sensors on bridges. Figure 2 shows a variety of ways ERRF can be used to communicate between a sensor in the field (denoted by the ERRF transmitter) and a receiver (represented by the base station).

[42] Use of Wireless Technology for Field Applications, SDDOT2005-03, Deliverable #2, June 27, 2005, p. 12, conference call with SDDOT, BIT and Datamaxx representatives, and telephone interview with Derek Grant, Datamaxx. See also the description of the IntelliWare product at http://datamaxx.com
[43] Steve Wegman, South Dakota Public Utilities Commission

ERRF, when fully deployed and demonstrated, for the Department of Defense, will be available for civil applications such as those the South Dakota DOT. Components of the system are off-the-shelf, extremely inexpensive, and easy to install.

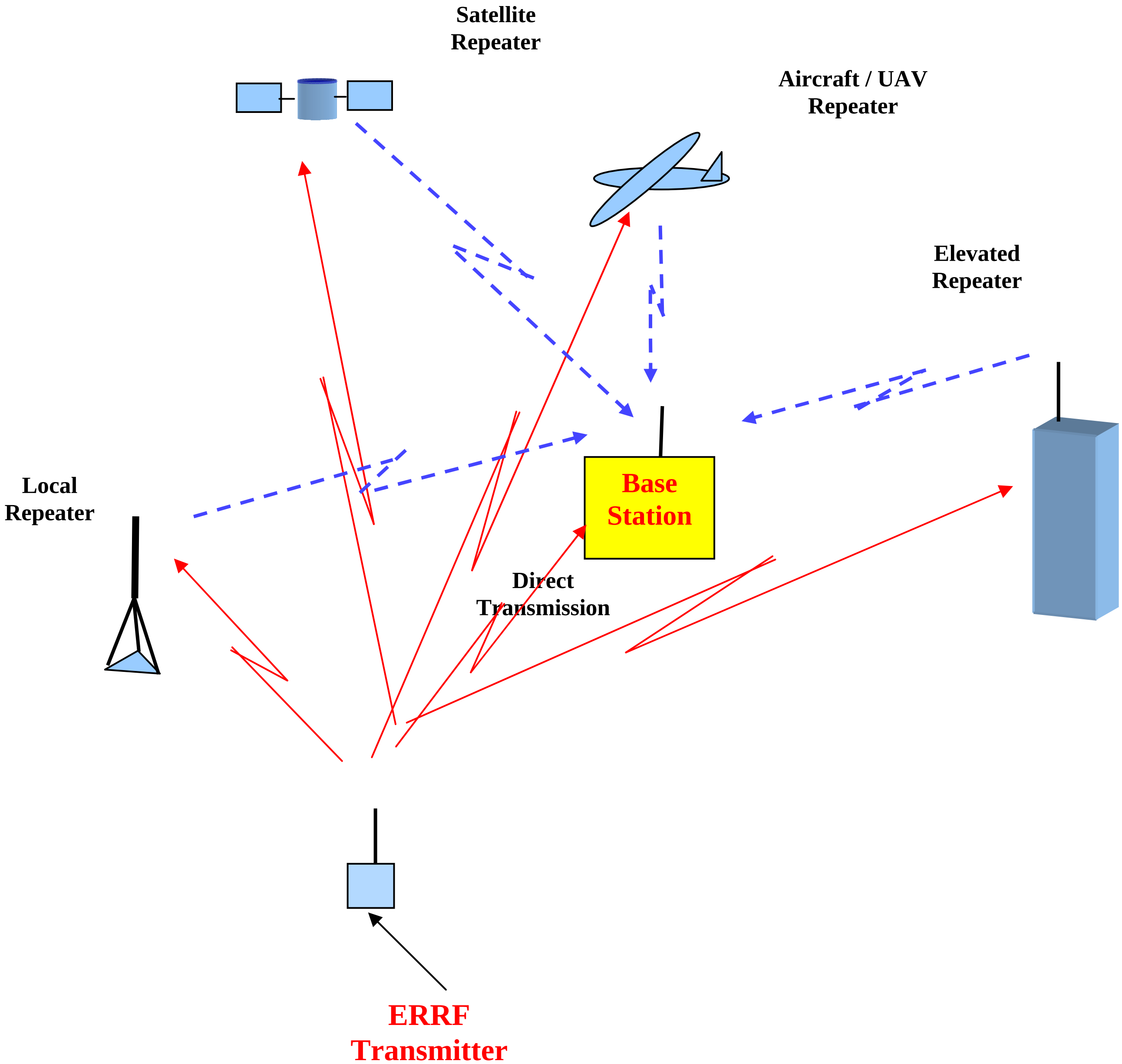

Figure 2. Extended Range RF

Indeed, this is an embedded system technology, meaning it is possible scatter hundreds of small sensors and integrated transmitters over a large area and monitor changes in conditions that can be communicated in a narrow bandwidth.

Meteor Burst Communications

When meteors enter the atmosphere, they are vaporized and ionized gases are formed. Radio waves can be reflected off either the trails of ionized gases left by larger meteors which arrive infrequently or they can be reflected off tiny ionized particles from the very small meteors which enter the atmosphere in large numbers. The intermittent arrival of meteors means that communications occur in bursts, although the bursts are frequent if the communication technology is exploiting the tiny meteors. Communication occurs using a radio wave in the 40 to 50 MHz range. Data rates are slow, roughly 300 to 2400 bps. Polling can occur several times a day.[44]

Meteor burst communications involve common features of RF transmission: noise filters, modulation and demodulation units, power amplifiers and antennas. The typical meteor burst communication network consists of a master station, a remote communication terminal and a remote data terminal. Meteor Burst Communications can send information line-of-sight or beyond line-of-sight. Typical transmission distances are 1200 to 1500 miles.

Meteor burst communication should be a candidate for sending data from remote portions of South Dakota that are not served by other forms of communications. The cost of meteor burst communication is quite low compared to satellite, making telemetry feasible.

The Canadians pioneered early meteor burst communication systems. NATO followed suit and in 1977 the Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture established a system to gather snow pack data from remote sites spread over a number of western states.

> In 1977, NRCS began modernizing its snow surveys by introducing meteor burst technology for acquiring snowpack data. The project, called SNOTEL (for SNOwpack TELemetry) measures and transmits snowpack, precipitation, and temperature data on a daily (or more frequent) basis throughout the West. A snow "pillow" serves as a hydraulic weighing platform to measure the snow water content.
>
> Over 700 SNOTEL sites are in operation. Most sites are powered by solar panels and are visited only a few times each year. Data are transmitted by meteor burst to a master station in Boise, Idaho, or Ogden, Utah, and then automatically

[44] Jim Geier, p. 164

> forwarded by telephone to a central computer in Portland, Oregon.
>
> Hydrologic data gathered from the SNOTEL system, snow course network, and other climatological stations are assembled in the computer system at the National Water and Climate Center in Portland, Oregon, for analysis and interpretation. A series of computer programs, known collectively as the Centralized Forecasting System (CFS), is the analytical tool used to generate streamflow forecasts, data summaries, and narratives that describe the current water supply outlook. This information is made immediately available to NRCS offices and other interested users via the Internet or by dial-up modem.[45]

South Dakota has two sites that are part of the SNOTEL network. Also, there are at least 80 United States Geological Survey sites in South Dakota that use Meteor burst communications to transmit streamflow and water temperature data to a processing center. In addition, the National Guard at National Guard Camps assembled in South Dakota has been observed to use meteor burst communications.[46]

WSNN

Satellite Communications

Data communication satellites serve as repeaters in the sky. They rebroadcast what they receive -- from one earth station to another earth station or to numerous earth stations/receivers (e.g. television antennas) located in one or more footprints on the earth's surface. The uplink is a point-to-point, low power (a couple hundred picowatts) microwave beam. The satellite typically has multiple transponders and electronics that take the incoming beam at one frequency and convert it to a downlink at another frequency. Thus communication satellites are frequently referred to as "bent pipes." The downlink can either cover a large area or it may have one or more spot beams that can be directed to cover specific regions on the earth. For the uplink, very sensitive earth stations with a large, high-gain parabolic antenna and an amplifier with a low carrier-to-noise ratio is required.

Satellites have a range of communication capabilities from narrow to broadband, and thus can communicate everything from data to voice to television images. Also, through internetworking, the data collected on other networks can be transmitted by satellite.

Communication satellites travel in circular or elliptical orbit and fall into one of three categories: Geosynchronous Orbit (GEO) where the satellite is 22,240 statute miles

---

[45] USDA, Natural Resource Conservation Service, http:/www.wcc.nrcs.usda.gov/factpu/wc_ss.html
[46] Steve Wegman, South Dakota Public Utilities Commission.

above the earth in a stationary position relative to a point on the earth, Medium Earth Orbits (MEO) in the range of 6,000 to 12,000 miles above the earth, and Low Earth Orbit (LEO), 100 to 300 miles above the earth. Users are assigned channels through a combination of time and/or frequency generally using one of four procedures ALOHA (or slotted ALOHA) a low efficiency procedure, Frequency Division Multiple Access (FDMA), TDMA and CDMA.[47]

GEOs can be accessed using earth stations with fixed-pointed antennas and typically provide data rates up to roughly 40 Mbps. The satellite can broadcast identical data to numerous earth stations, or alternatively it can provide different data to particular earth stations. Relatively large diameter (2 feet in diameter or larger) earth station antennas are needed to capture sufficient downlink power. FCC regulations limit the permissible uplink transmitter power, so these large earth station antennas are also needed to focus sufficient uplink power on the satellite.[48]

With regards to LEOs and MEOs, the combination of closer distances and higher satellite power (often coupled with lower operating frequencies) allows the earth stations to have portable, non-directional antennas. This makes it possible to provide convenient applications such as satellite telephone and data services.

Many applications involving a central facility and supporting offices can benefit from Very Small Aperture Terminal (VSAT). A DOT with a headquarters and Regions/Districts and areas/garages dispersed throughout the state is a good example. VSAT terminals are very small antennas (diameter as small as 1 meter). A weak signal would be transmitted from the VSAT terminal to the satellite, amplified, and then sent back down to the earth station at headquarters. VSAT terminals may also be placed on mobile equipment, such as snow and ice removal equipment.

Satellite communications is attractive because it can provide coverage throughout the South Dakota. It provides a means of reaching equipment located in remote or inaccessible areas that other communications, such as cellular, cannot reach.

Different satellite communication companies offer a range of dollar rates depending upon the service offered:

- Globalcom offers a variety of voice and data service plans through Globalstar. One pure data service is $9.95 month and another is $119.40 yearly.[49] The basic speed is 9.6 kbps, although Globalcom says it can reach data speeds up to 56 kbps. Requirements for using the service are a Globalstar phone, data kit, or vehicle kit, software, air time, pricing plan, and a subscription.
- Blue Sky Networks sells SATCOM portable voice and data kits, fixed installation voice and data kits and flight tracking kits with two-way messaging and telemetric

[47] Rizwan Mustafa Mir, http://www.cse.ohio-state.edu/~jain/cis788-97/ftp/satellite_data/index.htm (April 9, 2005)
[48] Harley Radin, DBSPrime.
[49] Globalcom. http://www.globalsatphone.com/satellite/services/globalstar.html (9/27/05)

data measurement. Portable kits, for both voice and data traffic, are Motorola and Iridium brands and cost from $1,695 to $3,995. Blue Sky Network offer a number of Iridium data service plans and rates vary by the unit of data transferred. Costs per month range from $75 to $499 per month for units ranging from 500 to 7000[50]

- The World Communication Center offers Hughes' DirecWay satellite data service. Monthly service fees that would support polling and Intranet connections are $43.99 and while the monthly fee for polling, Intranet and Internet connections are $89.99. Download speeds range from 1024 to 1544 kbps and upload speeds 128 to 256 kbps. This service allows a maximum of 2 concurrent users. A 0.98 meter satellite dish is required and standard installation fee is $400.[51]
- BigPond has broadband 2-way satellite data services with costs that range from $104.95 to $499.95 per month for monthly allowances that range from 500MB to 4GG, download speeds from 256 kbps to 800 kbps and upload speeds from 64 kbps to 128 kbps.[52]
- SatPhoneStore offers Inmarsat voice and data satellite communications. Inmarsat provides Public Switched Telephone Network (PSTN) services which include analog modem data throughput up to 28.8 kbps as well as a low speed data service of 2.4 kbps. SatPhoneStore rates are per minute and vary from roughly $4.00 to $11.30 for the higher speed service and from $2.30 to $2.85 for the lower speed service.[53]

SUMMARY OF BENEFITS, COSTS AND FEASIBILITY

Table 8 summarizes the information obtained through the investigation carried out under Task 5. The information in the Tables is organized according to the type of network that applies:

- Wireless Personal Area Network
- Wireless Local Area Network
- Wireless Metropolitan Area Network
- Wireless Wide Area Network
- Wireless State and National Networks.

As mentioned earlier the tables provide information on distance or coverage, service availability in South Dakota, spectrum frequency, operating cost, equipment cost, and other comments.

[50] Blue Sky Network. http://blueskynetwork.com/ServicePlans/DataPlans.shtml (9/27/05)
[51] World Communication Center. http://www.wcclp.com/index.php/phpmPage/Services_Satellite+Internet+Service_DIRECWAY+Service/page/7 (9/27/05)
[52] BigPond. http://www.bigpond.com/internet-plans/broadband/satellite/default.asp (9/27/05)
[53] SatPhoneStore. http://www.satphonestore.com/servprod/inmarsatm/rates.html (9/27/05)

Table 8. Comparison of Wireless Technologies

COMPARISON OF WIRELESS TECHNOLOGIES							
	Distance or Coverage	**Service Availability in South Dakota**	**Data Rates**	**Frequency**	**Operating Cost**	**Equipment Cost**	**Comment**
Wireless Personal Area Networks (WPANs) ***Range: 8 inches to 3 feet but sometimes to 35 ft.***							
Bluetooth	35 feet	Available	1Mbps	2.4 GHz	Essentially $0	See comment	Built into many types of home and business electronics
IrDA (Infrared)	8 inches to 3 feet	Available	4 Mbps	$.003 - 4 \times 10^{14}$ Hz	Essentially $0	See comment	Built into many types of home and business electronics
Ultra-wideband	30 feet	Chipsets being manufactured by major companies	40 Mbps	3.1 - 10.6 GHz	Essentially $0	See comment	Will be built into many types of home and business electronics

Table 8. Comparison of Wireless Technologies (cont.)

	Distance or Coverage	Service Availability in South Dakota	Data Rates	Frequency	Operating Cost	Equipment Cost	Comment
Wireless Local Area Networks (WLANs) ***Range: About 300 feet or less; up to 1100 yards for DSRC***							
Wi-Fi (IEEE 802.11)	N.A.	Obsolete	2 Mbps	2.4 GHz	N.A.	N.A.	
Wi-Fi (IEEE 802.11a)	100 feet outdoors; 50 feet indoors	Available (dual mode routers exist)	31 Mbps	5 GHz	$0 to $50/mo.	$225-$1500 for router	Will fall back to 48, 36, 24, 18, 12,.9 or 6 Mbps
Wi-Fi (IEEE 802.11b)	300 feet outdoors; 150 feet indoors	Available	6 Mbps	2.4 GHz	$0 to $50/mo.	$20-$120 for router	
Wi-Fi (IEEE 802.11g)	300 feet outdoors; 150 feet indoors	Available	31 Mbps	2.4 GHz	$0 to $50/mo.	$20-$120 for router	Will fall back to 5.5, 2 or 1 Mbps
Wi-Fi (IEEE 802.11n)d	1000 feet	Not available	100-500 Mbps	competing standards	$0 to $50/mo.	$120 for router	Standard expected to be ratified in 2007
Dedicated Short Range Communications (DSRC) (IEEE 802.11p)	1100 yards or less	Available 2008-15; prototypes being tested now	6-27 Mbps	5.9 GHz	$0 for vehicle-vehicle; vehicle-roadside TBD	low to moderate cost per unit	FCC allocated spectrum for public safety purposes

Table 8. Comparison of Wireless Technologies (cont.)

	Distance or Coverage	Service Availability in South Dakota	Data Rates	Frequency	Operating Cost	Equipment Cost	Comment
Wireless Metropolitan Area Networks (WMANs)							
Advanced Mobile Phone System (AMPS)	City and nationwide	Available, but being phased out by 2008	9600 to 14400 bps	800-900 MHz	low	low for modem	
Global System for Mobile Communications (GSM)	City and nationwide	Sioux City	9.6 kbps	450, 800, 1900 MHz for different systems in US	N.A. in SD	N.A. in SD	There is coverage in SD but cannot purchase service in SD
D-AMPS	City and nationwide	Not available	14.4 kbps		N.A. in SD	N.A. in SD	
cdmaOne	City and nationwide	Not available	64 kbps	824-894 MHz, 1850-1990 Mhz	N.A. in SD	N.A. in SD	
Integrated Digital Enhanced Network (iDEN)	City and nationwide	Verizon Wireless provides coverage in certain areas but you cannot purchase service in SD	20 kbps	800-900 MHz	N.A. in SD	N.A. in SD	
General Packet Radio Service	City and nationwide; 7 to 8 mi. from base station; can double with antenna or amplifier	Available along I-90 and I-29 Corridors	14.4 kbps to 115.2 kbps	900,1800,1900 MHz	$25-80/mo.	$75-$100 for air card	Cingular offers coverage but you cannot purchase it in SD
Enhanced Data for Global Evolution (EDGE)	City and nationwide	Not available	100-130 kbps down; 30 kbps up	900 MHz	N.A. in SD	N.A. in SD	May operate at other US GSM, GPRS frequencies
cdmaTwo(Is-95b)	City and nationwide	Not available	240 kbps	N.A. in SD	N.A. in SD	N.A. in SD	

Table 8. Comparison of Wireless Technologies (cont.)

	Distance or Coverage	Service Availability in South Dakota	Data Rates	Frequency	Operating Cost	Equipment Cost	Comment
Radio Transmission Technology (1xRTT)	City and nationwide	Verizon offers service throughout much of SD	60-80 kbps with bursts to 144 kbps		$40/mo. for 20 MB; $60/mo for 60 MB; unlimited $80/mo.; telemetry costs from $10 to $100/mo.	PC cards are $50 with 2 yr. contract. Telemetry devices start at $600.	Bit rate depends on signal strength and number of users
Enhanced Version -Data Only (1xEV-DO)	City and nationwide	Not available	Max 153 kbps up and 2.4 Mbps down	N.A. in SD	N.A. in SD	N.A. in SD	Bankrupt provider recently offered experimental service in SD city
Enhanced Version -Data and Voice (1xEV-DV)	City and nationwide	Not available	420 kbps to 1.7 Mbps	N.A. in SD	N.A. in SD	N.A. in SD	Service was tested in U.S. in 2004
3xRTT (3xMC)	City and nationwide	Not available	384 kbps outdoors; 2 Mbps indoors	N.A. in SD	N.A. in SD	N.A. in SD	Not deployed yet in US
Wideband CDMA/UMTS/3GSM	City and nationwide	Not available	220-384 kbps for mobile; 2 Mbps stationary	N.A. in SD	N.A. in SD	N.A. in SD	AT&T deployed in 6 US cities in 2004
Flash-OFDM	City and nationwide	Not available	300-500 kbps up; 1.5 Mbps down	400 Mhz-3.5 GHz	N.A. in SD	N.A. in SD	Nextel conducted trial in Raleigh, North Carolina; bit rates based on German trial
Wi-Fi Mesh	City, Corridor, Site	Not available; see comment	Max based on Wi-Fi bit rates	2.4, 5 GHz	N.A. in SD	N.A. in SD	Equipment and software commercially available and being deployed in many US cities
Wi-Max	30 mi. at low frequencies; 4-6 miles typical	Not available	40 Mbps typical	2-11 GHz	N.A. in SD	N.A. in SD	Similar system deployed in Santa Clara, CA

Table 8. Comparison of Wireless Technologies (cont.)

	Distance or Coverage	Service Availability in South Dakota	Data Rates	Frequency	Operating Cost	Equipment Cost	Comment
Wireless Wide Area Networks (WWANs)							
Spread Spectrum Radio Frequency Communication	Basic technology that can cover corridors or areas of varying sizes including WANs	Used in SD, for example with Dynamic Message Signs	Depends on radio and many factors	Depends on radio and many factors	Depends	Depends	
Orthogonal Frequency Division Multiplexing (OFDM)	A technology that can cover corridors or areas of varying sizes including WANs	Uses not known	Depends on radio and many factors	Depends on radio and many factors	Depends	Depends	
South Dakota State Radio System	Statewide except for some gaps	Voice available; data service being deployed in September 2005	9600 bps max; 4000 bps typical	160-170 Mhz	Free for government public safety applications	Large multi-million investment	
Multi-Channel, Multi-Point Distribution Service)	30 miles line-of-sight	7 rural counties	250 kbps	2.5-2..7 GHz	$150/mo	$1-1.5 million system cost; $250 to $500 subscriber cost	Costs may not apply to SD
Extended Range RF	100s or 1000's of miles	Not available	10-1000 bps	very narrow bandwidth	very low	very low	ARA holds patent; military applications under development
Meteor Burst Communications	1200 - 1500 miles	2 SNOTEL sites. Over 80 USGS sites to transmit streamflow and water temp data	300-2400 bps	40-50 MHz	low	moderate	SNOTEL network of 700 sites used to gather information on snow pack in western and other states
Wireless Statewide and National Networks (WSNNs)							
Satellite Communications --narrow band	Country or Hemisphere	Available	2.4 kbps-28.8 kbps	Varies	$2.30/mo-$11.30/mo	Equipment and installation costs are likely to be in $500-$5000 range	There are a large number of satelllite data service providers; bit rates are based on small sample
Satellite Communications -- broadband	Country or Hemisphere	Available	64-256 kbps upload;	Varies	$100-500/mo	Equipment and installation costs are likely to be in $500-$5000 range	There are a large number of satelllite data service providers; bit rates are based on small sample

Task 6. Prepare a document that recommends communication technologies for each data need.

Relationship to Project Objectives: Determine appropriate communication technologies for the data needs of each priority application.

Proposed Work: We proposed to combine the technical applicability of various wireless communications determined from Task 4 with the feasibility in Task 5 and make recommendations concerning which wireless options can meet the data needs for each priority application. Data needs consist of data rates that must be satisfied.

Deliverable: Technical Memorandum

Limits on Scope: This task focused on the priority needs (applications) identified in Task 4.

Accomplishments: We prepared Deliverable 6, "Recommendations," in the form of a PowerPoint handout. We felt that a deliverable in this form would be the easiest for the project panel to digest. The beginning of this deliverable set out ground rules and some convenient ways to think about demonstration options:

The key considerations were:

- Identify at least one demonstration of wireless technology for SDDOT field applications. This is consistent with the limitations of scope set out in Task 7.
- A single wireless technology may serve multiple applications
- The focus should be on the wireless application that provides the greatest benefits relative to costs.

We identified four categories of demonstrations from which a wireless demonstration and evaluation could be selected:

- A demonstration could be low hanging fruit – easy and inexpensive to implement and quick to generate significant benefits
- A demonstration could be a high-value use of wireless but challenging to apply to a field application and thus relatively high cost
- A demonstration might involve interesting or novel wireless technology
  - ➢ It could be valuable research
  - ➢ It could be an opportunity to provide a national showcase or model deployment
- Demonstration candidates could involve ARA proprietary technology.

We recommended that certain demonstrations and evaluations be ruled out for various reasons:

- Spread spectrum with (portable) dynamic message signs – Spread spectrum is already being applied.
- Road Condition Reporting System – this is a data base and not really a field application, although various field data collection procedures and technology feed RCRS.

- Megatraks Fuel System – we concluded SDDOT already has an adequate approach to data transfer.

We also recommended that the following field applications be the focus of any wireless communications and thus were the priority needs for wireless communication.

- Maintenance decision support system
- Traffic counting and classifying
- Pavement distress data collection
- Right-of-way acquisition data collection
- Construction management data acquisition

In a conference call with the project panel, selected guests, and two ARA team members, including the ARA Project Manager, we discussed the above items, examined the pros and cons of different wireless communications to serve the field applications listed above, and made recommendations. In particular, we identified wireless communication technologies that could satisfy the requirements for the field applications listed above:

- **Maintenance Decision Support System – Fixed in Place Component such as RWIS –** the requirements were to communicate at a rate of 400 bps for 60 seconds and possibly an additional 4 to 32 kbps for video over a distance or 20 to 40 miles or a coverage area of 400 to 1600 square miles. Wireless technologies that could satisfy this requirement include:

    - 1xRTT. This CDMA technology is currently provided by a mix of vendors along I-90, I-29, east of the Missouri River and to a small extent west of the Missouri River. One vendor offers data rates for 1xRTT of 60 to 80 kbps with bursts of 144 kbps. The number of users affects the bit rate. The service plans cost $40-$100/month. The PC card is about $50 and telemetry equipment costs $600. Other vendors offer different service plans and equipment packages. 1xRTT clearly is feasible in South Dakota.
    - GPRS is available in Sioux City, but can only be purchased outside South Dakota. The data rate is 9.6 kbps.
    - CDMA Spread Spectrum. The range, which can exceed 30 miles, and the data rate can vary greatly depending upon such factors as power, frequency, antenna, repeaters and terrain. This technology has already been demonstrated to be feasible for wireless communications in South Dakota with regards to DMS.
    - Flash-OFDM. This is a high bandwidth form of wireless communication recently introduced in the United States, but is not currently available in South Dakota. The range or coverage can satisfy the requirements for the fixed component of MDSS but data rates and propagation depends on such factors as distance, power, antenna, and terrain. OFDM exploits multi-path effects for a positive benefit.
    - Satellite. Services that can meet the requirements for the fixed-in-place component of MDSS cover all of South Dakota. Narrowband bit rates range from roughly 2.4 to 28.6 kbps while broadband data rates are more like 64 to 256 kbps. Service plans vary. Typical cost is $2 to $11 per month for narrowband and $100 to $500 per month for broadband. Equipment cost can range from $500 to $5000.

- **Maintenance Decision Support System – Mobile Platform Such as a Truck with Plow and Spreader –** the requirements were to communicate at a rate of 13 bps for the uplink and downlink over a distance of 20 to 40 miles or a coverage area of 400 to 1600 square miles. Wireless technologies that could satisfy this requirement include:

    - 1xRTT. This technology is currently provided by a mix of vendors along I-90, I-29, east of the Missouri River and to a small extent west of the Missouri River. One vendor offers a data rate for 1xRTT of 60 to 80 kbps with bursts of 144 kbps. The number of users affects the bit rate. The service plans cost $40-$100/month. The PC card is about $50 and telemetry equipment costs $600. Other vendors offer different service plans and equipment packages. 1xRTT clearly is feasible in South Dakota.
    - DSRC or Serial Wi-Fi. Both these technologies, part of the 802.11 family, can communicate serially along a road. The communication distance between a single roadside transponder and a vehicle is between roughly 330 feet (Wi-Fi) and 1000 feet (DSRC) but can extend for miles along a road if the transponders communicate with one another. Serial Wi-Fi has been demonstrated in Virginia and prototype DSRC transponders have been developed but neither have been implemented in South Dakota.
    - CDMA Spread Spectrum. The range, which can exceed 30 miles, and the data rate can vary greatly depending upon such factors as power, frequency, antenna, repeaters and terrain. This technology has already been demonstrated to be feasible for wireless communications in South Dakota with regards to DMS.
    - Satellite. Services that can meet the requirements for the mobile component of MDSS cover all of South Dakota. Narrowband bit rates range from roughly 2.4 to 28.6 kbps while broadband data rates are more like 64 to 256 kbps. Service plans vary. Typical cost is $2 to $11 per month for narrowband and $100 to $500 per month for broadband. Equipment cost can range from $500 to $5000. Rain can interrupt satellite transmissions.
    - Extended Range RF. This is an Applied Research Associates proprietary low data rate transmission technology, particularly useful for communicating sensor data. It is based on cheap commercial-off-the-shelf (COTS) products and is available for demonstration in South Dakota. Data rates are from 10 to 1000 bps for transmission over long distances such as 100 or 1000 miles.

- **Automated Traffic Recorders and Weigh-in-Motion –** the requirements were to communicate at a rate of 9600 bps for an hour for ATR and 666 bps for WIM over a distance of 20 to 40 miles or a coverage area of 400 to 1600 square miles. Wireless technologies that could satisfy this requirement include:

    - 1xRTT, Again, this technology is currently provided by a mix of vendors along I-90, I-29, east of the Missouri River and to a small extent west of the Missouri River. One vendor offers a data rate for 1xRTT of 60 to 80 kbps with bursts of 144 kbps. The number of users affects the bit rate. The service plans cost $40-$100/month. The PC card is about $50 and telemetry equipment costs $600. Other vendors offer different service plans and equipment packages. 1xRTT clearly is feasible in South Dakota.

- CDMA Spread Spectrum. The range, which can exceed 30 miles, and the data rate can vary greatly depending upon such factors as power, frequency, antenna, repeaters and terrain. This technology has already been demonstrated to be feasible for wireless communications in South Dakota with regards to DMS.
- Satellite. Services that can meet the transmission requirements for ATR and WIM cover all of South Dakota. Narrowband bit rates range from roughly 2.4 to 28.6 kbps while broadband data rates are more like 64 to 256 kbps. Service plans vary. Typical cost is $2 to $11 per month for narrowband and $100 to $500 per month for broadband. Equipment cost can range from $500 to $5000. . Rain can interrupt satellite transmissions.
- Meteor burst Communications. This technology is currently used in remote locations of South Dakota for low data rate sensor communications over long distances. Data rates range from 300 to 2400 kbps over distances of 1200 to 1500 miles.
- Extended Range RF. This Applied Research Associates proprietary technology is built from cheap commercial-off-the-shelf (COTS) products. It is available for demonstration in South Dakota. Data rates for communicating sensor data are from 10 to 1000 bps for transmission over long distances such as 100 or 1000 miles. Vibration can be a problem so this technology may not be practical on mobile platforms.

- **Pavement Distress Data Collection –** the requirements were to communicate at a rate of 86.7 kbps in a zipped file over either a distance of less than 330 feet or over a long distance of 20 to 40 miles with an equivalent coverage area of 400 to 1600 square miles. Wireless technologies that could satisfy this requirement include:

    - Wi-Fi. Provides high bandwidth communication at distances of around 330 feet or less. Requires line of sight. Data rates for some equipment are 31 Mbps with fallback to 1 Mbps and data rates decline with distance. 802 11b,g routers cost under $120 and can be easily purchased in such stores as Circuit City or Best Buy. 802.11a routers are in the $225 to $1500 range. Wi-Fi can easily be implemented in any South Dakota area shop although the wireline backhaul to the central office has much less capacity and is a bottleneck.
    - Satellite. Services that can meet the requirements for communicating pavement distress data from anywhere in South Dakota. Narrowband bit rates range from roughly 2.4 to 28.6 kbps while broadband data rates are more like 64 to 256 kbps. Service plans vary. Typical cost is $2 to $11 per month for narrowband and $100 to $500 per month for broadband. Equipment cost can range from $500 to $5000. Rain can interrupt transmission.

- **Right-of-Way Acquisition Data Collection –** The requirements were to communicate data at a rate of 1.1 to 1.6 Mbps within 330 feet at an area shop or over a longer distance of 20 to

40 miles with an equivalent coverage area of 400 to 1600 square miles. A technologies that can meet these requirements is the following:

- Wi-Fi. Provides high bandwidth communication at distances of around 330 feet or less. Requires line of sight. Data rates for some equipment are 31 Mbps with fallback to 1 Mbps and data rates decline with distance. 802 11b,g routers cost under $120 and can be easily purchased in such stores as Circuit City or Best Buy. 802.11a routers are in the $225 to $1500 range. Wi-Fi can easily be implemented in any South Dakota area shop although the wireline backhaul to the central office has much less capacity and is a bottleneck.

- **Construction Data Collection –** Data transmission requirements range from 6.7 to 320 kbps over a distance of 20 to 40 miles or a coverage area of 400 to 1600 square miles. Technologies that can meet these requirements include:

  - Wi-Fi mesh or Serial Wi-Fi. A Wi-fi mesh can be established throughout a construction site and if the construction site extends some distance along a road, the mesh can be augmented with serial Wi-Fi. While Wi-Fi mesh or serial Wi-Fi is not known to currently exist in South Dakota, such technology is being deployed in many places throughout the United States. Data rates are approximately 1 to 31 Mbps and a rough estimate of implementation cost is $30K to $50K. Direct line of sight communications between a laptop and Wi-Fi as well as between two Wi-Fi routers/receivers is required. Propagation is affected by such factors as power, terrain, antennas, weather, number of nodes, number of hops, and location of access points.
  - 1xRTT is currently provided by a mix of vendors along I-90, I-29, east of the Missouri River and to a small extent west of the Missouri River. One vendor offers a data rate for 1xRTT of 60 to 80 kbps with bursts of 144 kbps. The number of users affects the bit rate. The service plans cost $40-$100/month. The PC card is about $50 and telemetry equipment costs $600. Other vendors offer different service plans and equipment packages. 1xRTT clearly is feasible in South Dakota.
  - Satellite. Services that can meet construction data transmission requirements cover all of South Dakota. Narrowband bit rates range from roughly 2.4 to 28.6 kbps while broadband data rates are more like 64 to 256 kbps. Service plans vary. Typical cost is $2 to $11 per month for narrowband and $100 to $500 per month for broadband. Equipment cost can range from $500 to $5000. Rain can interrupt satellite transmissions.

Although we were obligated under our contract to identify and develop specifications for pilots of wireless communications regarding only one or two field applications, we recommended four. Each one satisfied selection criteria set out above:

- Low hanging fruit -- ARA stated it would specify and evaluate a demonstration of Wi-Fi at an area or maintenance shop for transfer of data to/from a laptop that can be used for more than one field application (e.g. pavement distress data collection, right-of-way acquisition). Note that the Problem Statement had identified Wi-Fi as a promising wireless candidate. This approach would use widely available commercial technology that is low-cost and easy to install. However, as stated earlier, the ARA team noted that the bandwidth of the landlines (T-1, etc.) connecting the area/maintenance shops with headquarters have a fraction of the bandwidth of Wi-Fi WLANs. Therefore the landlines represent a significant bottleneck relative to the Wi-Fi WLANs. We discussed the possibility of the State upgrading the wireline connections.
- Valuable Research – ARA stated it would work with SDDOT to support a demonstration of Dedicated Short Range Communications (DSRC/802.11p) for communication with a MDSS mobile platform such as truck with snow plow and/or spreader. SDDOT had taken initial steps to explore federal funding for such a demonstration and evaluation.
- ARA Proprietary wireless technology – ARA proposed to conduct a third demonstration involving Extended Range RF, a patented ARA technology. This low data-rate, long distance wireless transmission technology was included in ARA's proposal. We further proposed that SDDOT would work with ARA to obtain funding from a suitable source to provide resources to conduct the demonstration and perform the evaluation. This wireless technology was presented in our original proposal. SDDOT never provided feedback that it was uncomfortable with proprietary technology or that it was unacceptable.
- ARA proprietary wireless technology – ARA proposed to conduct a fourth demonstration in the Spring of 2006 involving Wi-Fi mesh (or serial Wi-Fi) and a novel Spatial User Interface in a Mobile Ad Hoc Network (MANET) for construction inspection at a site to be mutually agreed upon by SDDOT and ARA. ARA would prepare the specifications. Also, ARA would incur the costs associated with its technology for field data acquisition. All other demonstration costs would be incurred by SDDOT and used to engage a third party to establish the Wi-Fi mesh and location-based technology required for the demonstration. It was recommended that an independent party perform the evaluation.

The panel had a mixed reaction to the recommendations. Some felt one recommendation, installing Wi-Fi at an area or maintenance shop, was too simple, although it was pointed out that it would serve multiple applications (a main criterion for selecting a demonstration). The landline bottleneck and the need to increase its capacity also was acknowledged. Ultimately it was concluded that Wi-Fi could easily be implemented by BIT.

The panel seemed more receptive to the recommendation concerning a demonstration of a DSRC prototype for MMDS, but it was recognized that the feasibility of demonstrating DSRC would have to be investigated further. Bill Hyman, the ARA project manager, was about to go to the ITS World Congress where he had the opportunity to participate in a demonstration of DSRC technology. He rode in a bus that used some type of prototype DSRC communications to maintain a fixed headway with a bus a short distance ahead and to communicate amber alert information between a roadside unit and an onboard unit. He also talked to the vendors involved in the standards and prototype development process. He left the ITS World Congress with the impression that prototype DSRC technology could be obtained from Mark IV or TransCore. SDDOT received intelligence which indicated the contrary: that prototype DSRC technology was not ready for field tests. SDDOT's source further indicated that the prototype demonstrated at the ITS World Congress was based on the IEEE 802.11a standard, implying it was not really 802.11p technology. The fact is DSRC builds off 802.11a as can be seen under the IEEE 1609 Standard for Wireless Access in Vehicular Environment (WAVE).

The remaining two recommendations were rejected because they involved proprietary ARA technology even though ARA offered to demonstrate the part of the pilot involving its technology for free. ARA offered to demonstrate the other provided funding could be obtained from some other source besides SDDOT or ARA.

When no projects were selected, the panel decided that ARA should evaluate the reliability and effectiveness of one or two projects that SDDOT had already scheduled to implement or test in the field. The SDDOT project manager suggested to ARA that it should conduct an evaluation of wireless data transfer to support a signal maintenance management application introduced in Pierre, South Dakota. The application, SIGNALview developed by CarteGraph, is installed on laptops. Alltel provides CDMA 1xRTT cellular wireless data service. An Audiovox aircard allows data to be passed back and forth between the software application and the signal data base.

During this time, Alltel merged with Cellular One and began offering broader digital data services. Due to scheduling difficulties and SDDOT's other projects, there was a delay in the State acquiring cellular equipment, implementing a database, installing and collecting data that could be evaluated. The deadline for preparing a draft report arrived prior to receiving wireless data. As a result, the SDDOT Project Manager informed the ARA project manager that ARA should not conduct an evaluation of the wireless communication for the signal maintenance management application and proceed with preparing the final report.

However, in anticipation of proceeding with the evaluation, ARA completed most of the evaluation planning, discussed under Task 8.

The considerations, requirements for field applications, wireless options, and recommendations for demonstrations and evaluations appear in Deliverable #6 – Recommendations.

Task 7. Recommend Equipment Specifications and plans for a pilot installation in one SDDOT area to be determined by the panel.

<u>Relationship to Project Objectives</u>: Prepare specifications and plans in sufficient detail to test wireless data transfer to support an evaluation of the technology.

<u>Proposed Work</u>: We proposed that the ARA project team hold a conference call with the Project Technical Panel and select one or two priority user needs and associated field applications for which specifications and plans need to be developed.

SDDOT appeared to envision a test installation of wireless data communications to support the construction management system, traffic data collection, right-of-way needs, and pavement condition data collection. If all these applications are done with either a laptop or a pen-based computer, then a single wireless data communications technology would suffice. Indeed, it is possible that traffic counts in many parts of the state (low volume roads) are not performed using Automated Traffic Recorders but by individuals doing hand counts on a computer. Similarly, pavement distress data may be collected using laptops as a part of surveys and not using sophisticated automated equipment on expensive vans.

The purpose of the conference call was to establish what the pilot installation should consist of and whether it involves multiple applications with essentially the same or very different wireless data communication requirements.

We said we would recommend equipment specifications and plans for a pilot installation in one SDDOT area for one or two wireless solutions that may involve multiple applications.

In addition, we proposed to prepare an evaluation plan. Our Principal Investigator has a great deal of experience regarding evaluations of field operational tests and technology deployments. He served as the coordinator to help manage all the evaluations performed under two $24 million FHWA ITS Program Assessment Support (IPAS) task order contracts. Key elements of an evaluation plan are:

1. Background	6. Measures
2. Project description	7. Test Plan
3. Goals	8. Data collection plan
4. Objectives	9. Framework for findings, conclusions,
5. Hypotheses	recommendations

Consistent with good evaluation practices, we proposed to involve SDDOT and the installation contractor in a conference call in the early stages of the evaluation plan to define goals and objectives and ensure data for the evaluation will be collected. SDDOT and the installation contractor would have responsibility for furnishing data pertaining to the installation. Indeed language should be inserted into the contract of the installer stating explicitly what their data collection responsibilities will be. We proposed to help SDDOT develop the appropriate language. The type of data the evaluation contractor and SSDOT needed to collect was presented in the proposal and includes the type of application(s), data rates, bandwidth, frequency and interference, system architecture (e.g. hardware, software, sensors), and user acceptance (reliability, latency, ease of use, ergonomics).

Deliverable: A Technical Memorandum containing equipment specifications, plans, and an evaluation plan.

Limits on Scope: We proposed to prepare a document containing equipment specifications and plans, and an evaluation plan for one or two wireless data communication solutions to be mutually agreed upon by the Project Technical Panel and the ARA team. We said we will not collect the data for the evaluation. Indeed, SDDOT and/or the installation contractor will collect the data in accordance with the test plan and data collection plan we will prepare. We said the data collection plan would be likely to call for gathering such data as data rates, latency, and percent up-time, time savings of using wireless, reduction in wait time to upload data, perceived reduction in risk of loss of data (perhaps scored on a rating scale), installation costs, operating costs, maintenance costs, and various measures of user acceptance (based on ratings obtained through a questionnaire described in the test plan)

Accomplishment: This task was dropped from the project scope because no consensus was reached regarding what pilots and evaluations to conduct regarding wireless technology for field applications. A draft evaluation plan was prepared under Task 8.

Task 8. Evaluate the usefulness of the wireless data communication technology used in the installation(s).

Relationship to objectives: By applying a variety of technical and user acceptance criteria, assess the extent the pilot installation(s) of priority wireless communications can meet the project objectives.

Proposed work: We proposed to complete the evaluation in accordance with the evaluation plan. We understood that the evaluation should cover a period of at least sixty days after the new wireless data communication solution has been implemented. We said that we would ensure that data rates have been measured as a part of the evaluation.

Deliverable: Technical Memorandum containing the evaluation.

Limits on Scope: We limited the time period that the evaluation covers to little more than sixty days.

Accomplishments: As stated above, the SDDOT Project Manager requested us to evaluate wireless communications for a traffic signal maintenance management application. Under Task 8, the ARA team began preparing for the evaluation. We sought to confirm the objectives and hypothesis for the evaluation with the SDDOT Project Manager. In addition we drafted a detailed evaluation form for review by SDDOT staff. However, as noted above, shortly thereafter the SDDOT Project Manager instructed us to stop further work on the evaluation and prepare the draft final report. Consequently no formal deliverable was prepared under Task 8.

Task 9. Prepare a final report and executive summary of the research methodology, findings, conclusions, and recommendations.

Relationship to objectives: The research report will relate the findings, conclusions and recommendations to the objectives.

Proposed work: We said we would prepare a draft final report including an executive summary covering the elements requested in the RFP and submit the Draft Report to the Project Technical Panel for review and comment. Upon receipt of the comments, we said we would prepare a Final

Report taking the comments into account. We stated we would provide a point-by-point response regarding how we decided to handle the comments. The draft and final reports would be succinct and incorporate details by reference to the Technical Memoranda and other deliverables prepared in previous tasks, which would be incorporated into the final report as Appendices.

Deliverables: Draft Final Report followed by a Final Report accompanied by point-by-point response to the comments made on the Draft Final Report. In addition we proposed to provide an executive summary of the research methodology, findings, conclusions and recommendations. According to the instructions in *Guidelines for Performing Research for the South Dakota Department of Transportation*, both the draft and final reports and executive summary will be communicated to SDDOT in electronic form.

Limits on Scope: The final report will be brief and focus on research methodology, findings, conclusions, and recommendations.

Accomplishments: We prepared a Draft Final Report and a Final Report in accordance with the scope of work for this task.

Task 10. Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

Relationship to objectives: Communicate to SDDOT Executives and other managers options, effectiveness, efficiency, and user acceptance of wireless communications for field applications.

Proposed work: We proposed to make the executive presentation as required under Task 10.

Deliverable: Presentation and PowerPoint handout.

Limits on Scope: Focus on the research, conclusions, recommendations, and lessons learned.

Accomplishments: The ARA Project Manager prepared a 15 minute slide presentation and accompanying handout for the meeting of the SDDOT Research Review Board on June 14, 2006. The presentation that was made focused on the research, conclusion, recommendations, and lessons learned.

FINDINGS AND CONCLUSIONS

The following are the findings and conclusions of this study.

- Numerous field applications can significantly be enhanced with the latest wireless communications available in South Dakota. Current communication methods are often more costly, slow, inconvenient, and have low bandwidth.
- Telecommunications is a very large field and so is wireless communications. The wireless field is rapidly evolving from one generation to the next due to technological innovations, competition, and demand for more and higher quality services. The dynamic nature of the wireless industry can suddenly result in a superior solution to a planned approach for communications with a field application.
- Many field applications require a communications range of 20 to 40 miles and possibly 75 miles or more under some circumstances. In terms of square miles of coverage, this translates into 400 to 1600 square miles or possibly even as much as 5625 square miles. Applications that appear to have coverage requirements within these magnitudes are Automated Traffic Recorders, Weigh in Motion, Construction Management, and Right-of-Way Acquisition.
- Public safety is the priority use of the State Radio System. This system is not an appropriate wireless solution for meeting SDDOT's needs to communicate with numerous field applications.
- Some wireless technologies can serve many different applications. For example Wi-Fi placed near the entrance of maintenance and area shops or at the fuel pumps could transfer data at very high rates between a laptop and a Wi-Fi local area network. Throughput may be on the order of 31 MB per second. Thus it would be possible to quickly transfer data for such applications as fuel consumption tracking, construction inspection and materials testing, and right-of-way acquisition. However, an important finding of this study is wire-line connections between the shops and the Becker-Hansen building have substantially less bandwidth. Consequently, there currently is a bottleneck that thwarts SDDOT from realizing the full benefits of Wi-Fi.
- Demonstrations and evaluations of wireless technology in conjunction with field applications can be justified if they satisfy any of the following criteria (1) they are "low hanging fruit" that yields moderate or significant benefits and are easy to implement for little cost (2) they are high-value and challenging uses of wireless communication and the value exceeds the costs and (3) they are interesting or novel wireless technology that involve valuable research or an opportunity to provide a national showcase or model deployment.
- SDDOT is uncomfortable with proprietary technology. Open systems, open standards, interoperability, and open source code promote competition and help keep costs low. However, in the communications field some of the most important advances in wireless communications are based on proprietary technology. In the United States every generation of native digital cellular technology is built upon Qualcomm's patented Code Division Multiple Access (CDMA) technology. Intellectual property rights provide incentives for innovation and can lead to economies of scale. However over time, there is a danger of becoming dependent on a source of proprietary technology and if the economies of scale are too great, decreasing costs can create conditions for a monopolist to emerge which may also result in reduced innovation in the future.

IMPLEMENTATION RECOMMENDATIONS

These recommendations resulted from this study:

- SDDOT has been actively exploring the use of wireless communications for some time. The success it has had using spread spectrum to communicate with Dynamic Message Signs (DMS) is an example. This research was prompted by a desire to accelerate the use of wireless technology for field applications. SSDOT should continue to move aggressively down this path.

- It is important to match communications and other requirements with those offered by particular types of wireless technology. Usually there are numerous options for satisfying a specific need and each realistic option should be investigated. Information in this report provides considerable insight regarding the applicability of alternative wireless solutions for specific field applications.

- SDDOT should work with the South Dakota's BIT to upgrade the wireline communications between SDDOT's area/maintenance shops and headquarters and address any internetworking issues that may be required to get the most benefits of a wireless local area network such as Wi-Fi.

- SDDOT should routinely monitor and seize the opportunities to implement wireless communications resulting from the dynamic and rapidly evolving telecommunications field. Services, products, prices, and quality of offerings such as reliability and coverage could change almost daily in South Dakota. Generally these rapid changes will benefit SDDOT but occasionally they will impede adding wireless communication to a field application. The Rand Corporation has proposed a novel initiative, Agnosco, that would provide broadband wireless communications to all rural America by using Wi-Fi and Wi-Max, incorporate Grid Computing into this network to allow rural residents to share computer resources (microprocessors, memory), to provide food security using Radio Frequency Identification (RFID) and other means, and to support important sectors such as education, agriculture, and forestry. The South Dakota Public Utilities Commission is evaluating Agnosco. SDDOT should be prepared to evaluate the ramifications of Agnosco for the transportation sector, both the users of the transportation network and the implications for SDDOT. To take but one example, Agnosco could have significant implications regarding the deployment of ITS and DSRC in rural areas. Also, South Dakota's Public Utilities Commission staff revealed that the Department of Defense is considering implementing a wireless information superhighway. Excess capacity could become available for civilian and government applications. This is another wireless deployment that could compete with various forms of wireless communication including DSRC.

- SDDOT should continue to tap the resources and expertise concerning wireless communications in BIT, the South Dakota Public Utilities Commission, and various vendors. These sources of expertise clearly prove valuable to SDDOT and were very useful to the ARA team.

- SDDOT in partnership with BIT should consider implementing a test bed for wireless communications. This test bed could have highly localized components and long distance, wide-area features. SDDOT should begin by preparing a vision, a concept of operations, requirements, a technical architecture, and an analysis of the benefits and costs. SDDOT and BIT will have to explore alternative sources of funding.

ANALYSIS OF RESEARCH BENEFITS

The research we conducted provides a wide range of information that permits the matching of communication requirements of various field applications with a variety of wireless technology capable of meeting the needs. The problem statement indicated that the predominant method of data transfer using phone lines is often time consuming, inconvenient, and becoming more costly as phone rates increase. In the absence of quantitative information obtained from rigorous evaluations of field tests, we can make some rudimentary estimates of certain types of benefits of implementing wireless communications.

Table 9 provides some rough order of magnitude estimates of benefits of wireless communications for a few representative applications and technologies.

Table 9. Some Benefits of Wireless Communications

Application and Wireless Technologies	Time Saving	Convenience Indicator	Capital and Operating Cost
Technology: Wi-Fi at Area Offices **Applications:** • Construction Management • Right-of-way Acquisition	In regards to construction management, often inspectors travel to area offices to transfer data instead of using the phones in the project labs. Installation of Wi-Fi at area offices might save considerable time. Data transfer that sometimes take as long as 70 minutes in the lab could be reduced to minutes or less. This presumes the bandwidth of the wireline connections between the offices and headquarters are substantially increased. Transfer of data by cable would be roughly just as fast as Wi-Fi, but not as convenient, because data transfer could be accomplished anywhere in the office where there was a sufficiently strong Wi-Fi signal. Currently data transfer	Transferring data by phone at a project lab is slow and often frustrating. It is often more convenient to travel to an office to transfer data even though the traveling takes time. Data transfer or Right-of-Way acquisition data can also be very slow. Wireless communications with upgrades to the landlines connecting offices to headquarters is potentially much more convenient.	Low capital cost and virtually no operating cost for WLAN. Significant costs to upgrade landlines connecting offices to headquarters.

	of right-of-way acquisition data can take a long time. An extreme case would involve entering 50 to 100 plats which currently could take all day. Wi-Fi, with the bottlenecks removed, could enable right-of-way personnel to transfer the data in a fraction of the time.		
Technology: GPRS cellular data transfer **Applications:** • RWIS • ATR & WIM	Currently most RWIS communications involve a long distance call. Presently ATRs are polled two times per week. ATR sessions take 1 hour and WIM sessions take 2 hours. Rest area sessions take 15 minutes each. GPRS is faster than current telephone dial-up data transfer services.	Able to acquire RWIS data sooner for incorporation into the Road Condition Reporting System. This may have significant benefits both for SDDOT decision makers and road users during the winter. Also, faster transfer of ATR and WIM data. ATR is used for planning purposes, but WIM data may be used in real time to better manage commercial vehicle operations	There are costs to convert to GPRS data transfer at RWIS, ATR, and WIM sites. Need to check with service providers for monthly operating costs. One service provider was charging $75 to $100 per month.

REFERENCES

1. N. Randall and B. Sosinsky [2005]. Wireless Solutions, Build, Secure and Enhance the Perfect Wireless Network. Wiley Publishing, Indianapolis.

   Focuses on developing Wireless Local Area Networks (WLAN). Topics include building and using a wireless network, learning about the required gear, building ad hoc and infrastructure networks, wireless security solutions, expanding the wireless network, wireless mobile solutions, wireless home solutions, and troubleshooting.

2. Biesecker, Keith and Calvin Yeung [2003]. Mobile Internet Technologies and their Application to Intelligent Transportation Systems: Phase II – Prototyping and Field Assessment, Report MP 2003-21. Mitretek Systems, Falls Church, Virginia.

   Provides an overview of mobile Internet Technologies and their application to ITS. Examines 15 prototype technologies that Mitretek System evaluated in its labs. Eleven were further examined in the Northern Virginia Smart Transportation Center. A number of wireless technologies were used including PDAs, mobile units that support Wireless Application Protocols (WAP), and M-Mode. Substantial productivity gains were documented.

3. Kain, Carl and Calvin Yeung [2003] Commercial Mobile Radio Systems Applications in Public Transit Phase Two: Prototype Development and Testing of Data Services, Report MP 2003-20. Mitretek Systems, Falls Church, Virginia.

   Part of a three-part study that examines commercial mobile communications for the mass transit industry. Technologies examined included land mobile radio systems, commercial mobile radio systems, 3G wireless, GPRS, EDGE, and 1xRTT

4. Biesecker, Keith and Calvin Young [2003]. Mobile Internet Technologies and their Application to Intelligent Transportation Systems, Report MP 2003-02. Mitretek Systems, Falls Church, Virginia.

   This report introduces the new mobile Internet wireless technologies. Explains the wireless application environments for WWW and WAP technologies. Describes WAP protocol stacks and shows examples of WAP mobile phones and Internet enabled Personal Digital Assistants. Presents the evolution of various mobile technologies (e.g. those that derive from GSM and CDMA) and includes a useful appendix providing a brief summary of different types of wireless communications.

5. Carter, Todd W. [2005]. Wireless for Dummies. Wiley Publishing, Indianapolis.

   Provides an introduction to wireless communications and explains the basics of many different types of wireless technologies. Topics include planning your network, configuring your network, security and troubleshooting, mobile communications, networking technologies, home solutions, and integrating global positioning receivers. There is a useful list of internet resources at the back of the book which allows the reader to explore wireless topics in more depth or to find information on where to acquire equipment, services, information, and advice.

6. Engst, A. and G. Fleishman [2004]. The Wireless Networking Start Kit, Second Edition, Peachpit Press, Berkeley, California.

   This is a practical and introductory guide to setting up Wi-Fi networks. This book addresses understanding wireless networks; connecting your laptop and handheld gadgets, building your Wi-Fi network, working with Bluetooth and cell data, maintaining wireless security, using Wi-Fi while traveling, and extending your network.

7. Geier, Jim [2005]. Wireless Networks, First Step.Cisco Press, Indianapolis.

   This primer on wireless networks introduces the reader to basic concepts in wireless radio frequency communication, technology, architecture, services, and security.

8. Alexander, Bruce. E. [2005], 802.11 Wireless Network Site Surveying and Installation.. Cisco Press, Indianapolis.

   Book advocates that performing a Wireless Local Area Network (WLAN) site survey is important for a successful installation of a WLAN base station (hot spot). Each site is unique and it is desirable to address multi-path effects, reflection, absorption, radio wave interference, and the complexities and specifics of user demands. This book addresses the architecture of access points, cable routes, and electrical needs; the proper site survey technique and usage of appropriate utilities; structural installation obstacles such as building construction and transmission coverage area; documentation regarding needed parts and equipment; and diagrams showing the proper placement of equipment.

9. Ross, John [2003]. Wi-Fi, Install, Configure and Use 802.11b Wireless Networking, No Starch Press, San Francisco

   A straightforward, practical guide to setting up Wi-Fi in a home and office. The book addresses the best place to set up access points to improve network performance, extend the network beyond your own walls and provide the entire neighborhood with public or private wireless internet access, design and use point-to-point wireless network links to move data across several miles, find public networks at hotels, airports and so on, and provide security through the use of sniffer tools, encryption, password protection and virtual private networks.

10. Hoffman, John [2003]. GPRS Demystified. McGraw-Hill, New York.

   An accessible and thorough examination of GPRS, an evolution of Global System for Mobile (GSM) Communications. Discusses adoption of GPRS around world, market positioning and the GPRS business model, high speed data services, planning and dimensioning, implementation and testing, IP addressing, access point names, and GPRS security, WAP and lessons learned, M-services, M-commerce, applications in the GPRS environment, GPRS Roaming, eXchange, location based services, types of devices and how they grow, GPRS devices, environmental issues, testing and approvals, Enhanced Data Rates for GSM Evolutions (EDGE), GPRS evolution, and ALL-IP Networks.

11. Gralla, Preston [2002]. How Wireless Works. Que Corporation, Indianapolis.

    Highly graphical and attractive short tutorials on how wireless and specific wireless technology work.

12. Dornan, Andy [2002]. The Essential Guide to Wireless Communications Applications, From Cellular to Wi-Fi. Prentice-Hall PTR, Upper Saddle River.

    Covers a broad range of wireless technologies in some depth and includes useful tables describing such things as frequency and transmission capacity. Also includes internet resources and bibliographic material.

13. Reid, Neil P. [2001]. Broadband Fixed Wireless Networks. Cisco/Osborne, New York.

    Introduces the reader to the most commonly used types of Broadband Fixed Wireless (BBFW) technologies. Includes typical BBFW system block diagram for point-to-point communication consisting of the following elements: router/switch, wireless line card, intermediate cabling,, outdoor unit, and antenna. Includes table for key characteristics of MMDS, U-NII, WLAN, ISM, and LMDS. These characteristics include frequency, PTP bandwidth, PTM bandwidth, carrier equivalent PTP, PTP range (distance) LOS, over-the-air protocol, approximate cost per link, whether FCC license required, and preferred deployment. Discusses types of gear required, and also provides more in-depth discussion of Wi-Fi and WLAN.

14. Dobkin, Daniel M. [2005]. RF Engineering for Wireless Networks. Elsevier/Newnes, Amsterdam.

    Comprehensive, well-written treatment for planning and implementing indoor and outdoor wireless networks. Also, addresses theory and engineering principles regarding RF communications. Types of RF addressed include Wi-Fi, WiMax, Ultra Wideband, orthogonal frequency multiplexing (OFDM), Bluetooth and many others. The book addresses multiplexing, modulation, bandwidth, link budgets, network concepts, architectures, RF amplifiers, mixers, frequency conversion, filters, single-chip RF systems, antenna theory and designs, and signal propagation. The book includes a CD with software for making RF engineering calculations and analysis.

15. Coleman, Chris [2004]. Radio Frequency Engineering. Cambridge University Press, New York.

    This book focuses upon the practical side of radio engineering. The book addresses wireless systems, circuit design, antenna theory and design, propagation and digital methods.

16. Yang, Samuel C. [1998]. CDMA RF Systems Engineering. Artech House Publishers, Norwood, Massachusetts.

Code Division Multiple Access (CDMA) is a form of spread spectrum wireless communications used in mobile applications. This book provides a detailed discussion of engineering principles regarding CDMA. Topics addressed include fundamentals of digital RF communications, factors affecting propagation, principles of CDMA, link structure, call processing, CDMA design engineering, CDMA performance engineering, and CDMA noise management.

17. Schilling, Donald L. [1993]. Meteor Burst Communications: Theory and Practice. Wiley-Interscience, New York.

    Leading communications experts address research as well as military and commercial applications of meteor burst communications. Chapters provide an introduction, theory, modeling, an implementation method using FM, a comparison of experimental results with theory, and error correction.

18. Cookley, Todor [2004]. IEEE Wireless Communication Standards: A Study of 802.11, 802.15, and 802.16. Standards Information Network, IEEE Standards Press, New York.

    Provides an introduction to WLAN, WPAN, and WMAN standards. Discusses deployment of WLAN networks, business issues, future directions, and research problems.

19. Gutierrez, Jose A., Ed Callaway and Raymond Barrett [2003]. Low-Rate Wireless Personal Area Networks: Enabling Wireless Sensors with IEEE 802.15.4. Standards Information Network, IEEE Standards Press, New York.

    Provides a general and technical presentation of the low-rate wireless personal area technology and the IEEE standard for 802.15. In addition, addresses the network layer functionality for the planned applications, which the standard does not address. Finally addresses implementation and system design considerations, especially real world considerations.

20. Rappaport, Theodore S. [2002]. Wireless Communications: Principles and Practice (2nd Edition). Prentice Hall, Upper Saddle River, New Jersey.

    Comprehensive textbook on wireless communications, Begins with an introduction to mobile communications and then turns to modern wireless communications. Covers GMS, GPRS, EDGE,CDMA, UMTS, TDMA, FDMA, etc., the cellular concept, propagation issues, modulation, equalization and channel coding, speech coding, multiple access techniques, wireless networking, and wireless systems and standards.

21. Federal Highway Administration and Federal Motor Carrier Administration [2004]. CVISN Safety Information Exchange for Commercial Vehicles in Connecticut - A Case Study: Increasing Inspection Efficiency through Wireless Data Access at the Roadside. Washington D.C.

    This report describes the experience of the Connecticut Department of Motor Vehicles (DMV) in deploying a statewide wireless communication system to provide inspectors with real-time access to motor carrier safety information to help support electronic clearance and credentialing, Among the information that can be accessed through wireless communications is past truck and driver inspection records, numerical safety ratings, out-of-service orders, vehicle registration information and commercial driver license (CDL) information.

22. Sivalingam, K.M. [2004]. Wireless Sensor Networks.*IEEE Vehicular Technology Society News.* Volume: 51 Issue: 3, pp. 9-16.

Wireless sensor networks have attracted a great deal of interest in the past few years driven in part by development of low cost sensor devices with wireless network interfaces. This paper provides an overview of research and various issues that have been recently addressed, including architecture, protocols (access control, routing, and transport), followed by routing and transport protocols, energy efficient network operations, data dissemination protocols, localization methods, and network security.

23. Byrne, A, R.Grandhi, A. Manyazewal, and B. Tritter [2004], Test of Personal Communication Service (PCS) Data Services For Traffic Signal Control, prepared by Delcan Corporation for Transport Canada.

This project tested the next generation of PCS digital wireless technology to determine its utility for traffic signal control systems. Testing occurred in three phases: first characterize 1xRTT PCS to develop software for the test, second conduct bench tests, and third perform a field test with traffic signal controllers linked to a traffic control system. The project demonstrated that 1xRTT PCS can serve center-to-roadside communications for distributed traffic signal control systems. PCS proved not to be suitable for second-by-second traffic control systems or "non-distributed" traffic signal control systems. The authors recommended more work to assess the longer term reliability of the networks, support for ITS subsystems, and conformity with NTCIP.

24. Besl, D, B. Burkhard and B.Boggs [2004]. “Indianapolis Wireless ATMS” in Conference Proceedings, *At the Crossroads: Integrating Mobility Safety and Security. ITS America 2004,* 14th Annual Meeting and Exposition of ITS America, San Antonio, Texas.

Indianapolis is deploying an Advanced Traffic Management System covering 125 miles of expressway. A wireless communication system connects nearly all the sensors and roadside equipment including 200 detector stations, 100 cameras, 20 Dynamic Message Signs, 5 Highway Advisory Radios and 12 Flasher Signs. The system has been designed to operate as a virtual traffic management system to support Freeway Service Patrol vehicles and relies on open, fault-tolerant standards that use the Internet Protocol to send data from the various sensors.

25. Cicirello, Vincent, Maxim, Peysakhov, Gustave Anderson, Gaurav Naik, Kenneth Tsang, William Regli and Moshe Kam [2004]. “Designing Dependable Agent Systems for Mobile Wireless Networks,” *IEEE Intelligent Systems,* vol. 19, no. 5, pp. 39-45, September/October 2004.

Mobile Ad Hoc Networks (MANETs) are becoming increasingly important. MANETs permit rescue workers at natural disaster sites to provide their own network solutions, particularly relevant where communications infrastructure does not exist. MANETs include Multiagent Systems (MAS) that are environment-aware, able to reason given a nearly continuous flow of complex data, and be adaptive, responsive to feedback, and self-stabilizing to ensure robust operation.

26. Ferras, R and J. Hiebert [2004]. Straight Talk About Wireless For Traffic Applications. *IMSA Journal*,Vol. 42, Issue 2.

    Wireless applications must pay attention to potential interference in FCC's unlicensed portions of the spectrum, 902-928 MHz, 2.400-2.4835 GHz, and 5.7525-5.850 GHz. Spread spectrum uses several basic approaches to spread the transmission across a large portion of the electromagnetic spectrum and cause interference that is usually not noticeable.

27. Nookala, M and G. Crowson [2004]. Mobile Data Acquisition and Reporting For Traveler Information. In the proceedings: At the Crossroads: Integrating Mobility Safety and Security. ITS America 2004, 14th Annual Meeting and Exposition, San Antonio, Texas, April 26-28, 2004, 7 pages.

    The Minnesota Department of Transportation (Mn/DOT) started a pilot of a Mobile Data Acquisition and Reporting System (MDARS) in the winter of 2002. MDARS is an extension of Mn/DOT's Condition Acquisition and Reporting System (CARS). Seventy-five plow operators used internet cell phones to enter data concerning 500 situations regarding road condition into MDARS. Based on the success of this pilot Mn/DOT has decided to enter a second phase to further explore wireless communications and other issues.

28. Hourdakis, J, P.G. Michalopoulos and T. Morris [2004]. Deployment Of Wireless Mobile Detection And Surveillance For Data-Intensive Applications. *Transportation Research Record*, No. 1900, pp. 140-148.

    Wirelesss communication is portrayed as very attractive for many field applications especially traffic surveillance. However, there is a need to significantly reduce costs. This paper describes deployment of four wireless systems within a 1.7 mile site. The site can be viewed as a laboratory. The authors conclude that the technology can be deployed at the roadside or on mobile platforms.

29. Dobkin, Daniel M. [2005]. RF Engineering for Wireless Networks, Hardware, Antennas, and Propagation. Elsevier. Amsterdam.

    Provides a comprehensive overview of RF engineering for all types of wireless networks. Gives a review of electromagnetic theory followed by an explanation of key wireless concepts including multiplexing, modulation, bandwidth, link budgets, network concepts, radio system architectures, RF amplifiers, mixers, and frequency conversion, filters, single-chip radio systems, antenna theory and designs, signal propagation, and planning and implementing wireless networks for indoors and outdoors.

30. Hussain, Arshad [2005]. Advanced RF Engineering for Wireless Systems and Networks. John Wiley & Sons, Hoboken, New Jersey.

Provides in-depth and advanced treatment of key concepts to implement wireless communication systems. Addresses the design of filters, amplifiers, RF switches, and oscillators for 2G and 3G wireless; addresses essential aspects of WLAN, discusses GPRS service, clarifies the distinctions between 1G, 2G, and 3G technologies; offers ways to migrate from 2G to 3G; and discusses how to bridge engineering and network concepts.

31. Weisman, Carl J. [2002]. The Essential Guide to RF and Wireless. Prentice Hall, N.J, Upper Saddle River.

This book is a primer on the basic components and methods of wireless communications. Addresses such elements and concepts as receivers, antennas, modulators, mixers, and filters. Also provides an explanation of the basic wireless technologies ranging from Wi-Fi to Satellite Internet Delivery to the underlying techniques of TDMA, CDMA, FDMA, and OFDM as well as different types of spread spectrum, namely frequency hopping and direct sequence spread spectrum.

32. Smith, Clint and Daniel Collins [2002]. 3G Wireless Networks. McGraw-Hill, New York.

Describes third generation wireless technology and the anticipated migration from 2G to 2.5G to 3G. Address CDMA 2000, WCDMA/UMTS, network architectures and protocols, 3G network design methodologies and the air interface.

33. Salkintzis, Apostolis K. [2004]. Mobile Internet, Enabling Technologies and Services. CRC Press, Boca Raton.

Discusses the evolution toward mobile internet services and then discusses Internet access over Wireless LANs, GPRS, and Satellites. Also addresses mobility management, service quality multicast and security in mobile IP networks.

34. Callaway, Edgar H. Jr. [2004] Wireless Sensor Networks, Architectures and Protocols. Auerbach, Boca Raton.

Offers an in-depth discussion of how to design wireless sensor networks with a focus on architecture and protocols. Subjects covered include network design, partitioning of node functions into integrated circuits, low power systems, power sources, and the role of antennas in such systems. Also talks about the Mediation Device Protocol that enables communication between inexpensive devices with low duty cycle operation.

35. Finneran, Michael F. [2004] WiMax versus Wi-Fi, A Comparison of Technologies, Markets, and Business Plans. DBrn Associates.

This paper compares and contrasts WiMax, a rapidly emerging technology suitable suitable for wireless wide area networks, with Wi-Fi, which is a principally used for Wireless Local Area Networks (WLAN). The paper includes useful tables with comparative data.

36. Kain, Carl. [2003] Commercial Mobile Radio Systems Applications in Public Transit. Prepared for Federal Highway Administration. Mitretek, Center for Information and Telecommunications Technologies, Falls Church Virginia.

This report contains a comprehensive view of mobile radio systems. It provides a brief explanation of 1G, 2G, 2.5 and 3G services. It addresses Personal Communication Systems, IS-136 TDMA, CDMA, GSM and iDEN as well as Specialized Mobile Radio. The author has a good sense of the evolution of wireless cellular technologies and what types of mobile radio systems can serve mass transit.

37. Rand Corporation [2006]. Agnosco Overview.

The Rand Corporation has established and manages the Agnosco Institute to build a next-generation private communications and advanced information network for rural America. This network will use WiFi & WiMax to serve the "last mile', an optical long-haul network, a national grid computing system, an RFID tracking system and a variety of dedicated databases. Agnosco's initial focus will be on rural telecommunications and applications that support rural healthcare, education, and food security.

APPENDIX

ACRONYMS

1G	First generation wireless – analog voice
2G	Second generation wireless –digital voice, text messaging and some data services using an analog modem
2.5G	Upgraded Digital cellular networks that permit packet switching and data rates similar to those of an analog modem
3G	Third generation wireless with data rate transfer goals of 2 Mbs. In reality data transfer rates much lower.
1xRTT	Radio Transmission Technology; also known as Multicarrier. This is a narrow-band CDMA system
3xRTT	Radio Transmission Technology; also known as Multicarrier. This is a wideband CDMA system.
AES	Advanced Encryption Standard
AMPS	Advanced Mobil Phone System
AP	Access Points
ASP.NET	Implementation of Active Server Page in the Microsoft .NET framework
ATR	Automated Traffic Recorder
AVL	Automated Vehicle Locator
BBFW	Broadband Fixed Wireless
BIT	Bureau of Information and Telecommunications
CARS	Minnesota DOT's Condition Acquisition and Reporting System
CDL	Commercial Drivers License
CDMA	Code Division Multiple Access
cdmaOne	Second generation cellular based on CDMA. Also known as IS-95a.

cdmaTwo	Generation 2.5 cellular based on CDMA. Also known as IS-95b.
CDMA2000	A set of technologies that increase cdmaOne networks to data rates of more than 2 Mbps. These include such services as 1xMC and 3xMC
CFS	Centralized Forecasting System
CM&P	Construction Measurement and Payment
COTS	Commercial-off-the-shelf Software
CVISN	Commercial Vehicle Information System and Networks
DMS	Dynamic Message Sign
DMV	Department of Motor Vehicles
DSRC	Dedicated Short Range Communications
DSSS	Direct Sequence Spread Spectrum
EDGE	Enhanced Data Rates for GSM Evolution
EV-DO	Enhanced Version -- Data Only
EV-DV	Enhanced Version – Data and Voice
FCC	Federal Communication Commission
FDD	Frequency Division Duplexing
FDMA	Frequency Division Multiple Access
FHSS	Frequency Hopping Spread Spectrum
GEO	Geosynchronous Earth Orbit
GHz	Gigahertz
GSM	Global System for Mobile Communications
GPS	Global Positioning System
GPRS	General Packet Radio Service

HSPDA	High-Speed Packet Downlink Access
iDEN	A propriety wireless packet switching communication system Motorola developed
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISM	Industrial, Scientific, and Medical
ISP	Internet Service Provider
ITU	International Telecommunications Union
LED	Light Emitting Diode
LEO	Low Earth Orbit
LMDS	Local Multipoint Distribution Service
MANETs	Mobile Ad Hoc Networks
MAS	Multiagent Systems
MC	Multicarrier
M-commerce	Mobile e-commerce
MDARS	Minnesota DOT’s Mobile Data Acquisition and Reporting System
MDSS	Maintenance Decision Support System
MEO	Medium Earth Orbit
MHz	Megahertz
MMDS	Multichannel Multipoint Distribution Service
M-mode	Mobile mode
M-services	Mobile services
MS&T	Material Sampling and Testing
NTCIP	National Transportation Communications for Internet Protocol

NRCS	Natural Resources Conservation Service
OFDM	Orthogonal Frequency Multiplexing
PCS	Personal Communications Service
PDA	Personal Digital Assistant
PSTN	Public Switched Telephone Network
PTP	Picture Transfer Protocol
RCRS	Road Condition Reporting System
RF	Radio frequency
RFID	Radio Frequency Identification
RWIS	Road Weather Information System
SIM	Subscriber Identity Module
SS	Spread Spectrum
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
UHF	Ultra High Frequency
Ultrawideband	Very broad bandwidth technology for wireless local area network
U-NII	Unlicensed National Information Infrastructure
UMTS	A standard for 3G wireless networks that uses wideband CDMA and spectrum in the 5 GHz band
VII	Vehicle Infrastructure Integration
VSAT	Very Small Aperture Terminal
WAP	Wireless Application Protocols
WAVE	Wireless Access in Vehicular Environment

WCDMA Wideband CDMA which makes use of 5 GHz channels and is able to hand calls over to GSM

Wi-Fi Wireless Fidelity family of wireless local area networks that conform to the IEEE 802.11x set of standards

WIM Weigh-in-Motion

WISP Wireless Internet Service Provider

WLAN Wireless Local Area Network

WPAN Wireless Personal Area Network

WMAN Wireless Metropolitan Area Network

WWAN Wireless Wide Area Network

WSNN Wireless State and National Networks

XML Extensible Markup Language