Use of Wireless Technology for Field Applications
Study SD2005-03

Executive Summary

Prepared by
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 necessarily reflect the official views or policies of the 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...........Operations Support
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
# Use of Wireless Technology for Field Applications

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.
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 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)

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

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)

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

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

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)

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

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)

<table>
<thead>
<tr>
<th>Wireless Technology</th>
<th>Coverage</th>
<th>Data Rate</th>
<th>Cost</th>
<th>Feasibility/ Propagation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wi-Fi</td>
<td>330 feet</td>
<td>31 Mbps max throughput with fall back to as low as 1 Mbps</td>
<td>$0 to $50/mo operating cost and $20 to $120 for router; 802.11a router $225-$1500</td>
<td>Yes/ line-of-sight needed. No. of users affects bit rate</td>
</tr>
</tbody>
</table>
Table 6. Construction Data Collection (Needs: 20-40 miles or 400 – 1600 sq. mi. coverage; 6.7 to 320 kbps)

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

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.