Advanced Wireless Communication for the Transportation Sector

A Roundtable Discussion

May 22, 2008

SUMMARY REPORT

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Preface

On May 22, 2008, the U.S. Department of Transportation's Research and Innovative Technology Administration (RITA) convened the "Advanced Wireless Communication for the Transportation Sector Roundtable." It brought together 40 leading experts in the field of wireless communications and filled a conference room with a vast amount of intellectual capacity in the area of communications technology. Experts represented the private sector, academia, State and local Governments, and the research and advocacy community. Appendix A provides a full list of participants.

The roundtable was structured to accommodate presentations, discussion, and dialogue among participants. Its goal was to share with thought leaders in the field of wireless communications critical information about the U.S. Department of Transportation (DOT) vision, interest, and applications to the transportation sector. The complete agenda is listed in Appendix B.

The roundtable provided a forum to discuss how to enable internet and wireless communications technologies to better allow vehicle-to-vehicle, vehicle-to-infrastructure, and infrastructure-to-system manager communications in order to avoid crashes and enable improved situational awareness (including dynamic rerouting and improvements in signal timing and synchronization based on real time and evolving traffic and weather conditions). Other applications of advanced communications technologies include electronic tolling and fare collection for all modes of transportation, and developing mobility devices for remote monitoring of bridges, roads, rails, and other critical infrastructure.

It should be noted that while the DOT currently engages in a number of activities across all modes that can or do make use of wireless communications (e.g. aviation, marine, etc.), much of the roundtable discussion centered on the surface transportation arena.

The session was opened with remarks by Vice Admiral Thomas J. Barrett (USCG - ret.), Deputy Secretary of Transportation. Having noted the enormity of the transportation sector – including its economic impacts and its relationship to global, not merely domestic issues – Barrett offered comments that centered on three key concepts:

- Importance of the enterprise approach to innovation;
- Shift in focus on current applications, rather than future ones; and
- Critical role of openness and open networks.

The enterprise approach adopted by DOT leverages the intellectual capabilities of experts in the field – those in the private sector, researchers in academia, and proponents and advocates throughout the industry. These experts can enable and energize new ideas and systems. The approach requires considerable outreach and an ability to "get people to the table" to share information, transfer knowledge, and develop strategies for moving forward.

The DOT focus in the area of wireless communications is on safety, innovation, and identification of 21st Century solutions for challenges. Vice Admiral Barrett recognized that the field is dynamic and ever-changing, and powerful tools are being developed. Notably, Vice Admiral Barrett's purview extends to the next-generation of airspace management system (i.e., GPS, satellite-based systems). That work involves shifting the focus on technology from "NextGen" to current applications. The goal is to identify those technologies and innovations that can be applied and implemented now, rather than well into the future.

Significant opportunities exist to make use of expertise in wireless communications and related technologies. The new language of technology (including wiki collaboration, mash-ups, and MANETs) is emblematic of challenges, but more importantly, of potential opportunities for growth.

This growth can be achieved by encouraging openness. As a strong proponent of open networks, Vice Admiral Barrett is concerned with spurring innovation and entrepreneurial creativity without "locking it up." However, standards for open networks are needed, and U.S. DOT looks forward to continuing the dialogue about open networks with industry experts.

Finally, Vice Admiral Barrett noted that his participation on a committee tasked with addressing the civilian side of Precision, Navigation, and Timing (PNT) issues has allowed him to learn about astonishing advancements in the area, including the impact on many different fields i.e., the increase in productivity through use of precision farming techniques that employ the Global Positioning System (GPS).

Vice Admiral Barrett offered an anecdote about a recent trip to Ghana: while visiting locales where the transportation network is minimal or simplistic, the prevalence of cell phones and wireless systems was impressive. The U.S. has always been a leader in technology innovation, but it needs to show real leadership in this particular area.

Vice Admiral Barrett's opening remarks inspired and encouraged participants to offer their knowledge, thoughts, and opinions about advanced wireless communication in the transportation sector and provided a foundation for RITA Administrator Paul R. Brubaker to share the DOT viewpoint on the topic.

1.0 Overview of Department of Transportation Viewpoint

RITA Administrator Paul R. Brubaker was introduced by Volpe National Transportation Systems Center Acting Director Robert E. Suda. Suda also provided an overview of the roundtable agenda (Appendix B). Brubaker offered a framework for the discussion by laying out current challenges and exploratory/demonstration projects currently underway. His comments highlighted several key points:

- Measurable improvements and outcome-based objectives are critical to successful deployment of new and advanced wireless communication technologies in the transportation sector;
- The U.S. DOT and State DOT perspectives should be broadened to "open the aperture" to make use of technologies that are not currently being utilized; and
- Exploration in partnership with State DOTs and other entities can reveal new opportunities, functions, and applications that can improve the surface transportation system.

Administrator Brubaker's emphasis on "measurable improvements and outcome-based objectives" pervades RITA and reflects the *Transportation Vision for 2030*'s "lofty goals" in the areas of ITS, environmental stewardship, and reduction of greenhouse gas and NOx emissions.

It was noted that there are six million vehicular crashes each year, which claim 42,000 lives. Although not an official DOT goal, Administrator Brubaker is a proponent of a "bold, hairy, audacious goal" to reduce crashes by 90 percent by the year 2030 as a way to spur innovation and creative thinking. Meeting this goal can potentially save 34,000 lives, but it can also reduce the economic impact of crashes and the recurring congestion that causes them. It is estimated that more than $200 billion in medical bills, loss of productivity, etc., can be attributed to those crashes.

> *"Nothing encompasses [mobility, safety system performance, and 21st century solutions] more than Intelligent Transportation Systems."*
> *- Paul Brubaker, RITA*

The safety and system performance applications of advanced wireless communication technology are an essential piece of the Department's path towards 21st Century transportation solutions. While there may be useful "convenience applications" of advanced wireless technologies, the safety applications are of paramount importance to the DOT.

In order to meet these goals and objectives, and to successfully leverage emerging technologies in the transportation sector, it is crucial that transportation decision-makers be open to innovation and investigation of these new technologies. Transportation leaders must take an in-depth look at the technology requirements of the Vehicle Infrastructure Integration (VII) system to determine which technological developments can be utilized to more efficiently achieve the program's stated objectives.

> *"We [want to] figure out the technological developments that are out there today [that we can] leverage to help us achieve our objectives faster."*
> *- Paul Brubaker, RITA*

While Dedicated Short Range Communications (DSRC) radio technology has been the preferred communications solution for VII, it is important to look beyond DSRC to consider, for example, how to enable mobile ad-hoc networks to achieve safety and mobility goals. For instance, it is now possible to layer crash data in GIS maps to provide information to drivers to warn them about crash-related congestion. New systems could supply drivers with audible warnings via in-car devices to alert them to treacherous bends in roadways. These are but a few of the potential safety applications that leverage advanced wireless communication technologies.

Finally, Brubaker shared information about exploratory and demonstration projects in the U.S., noting that Michigan DOT's Director Kirk Steudle oversaw the successful development of a wireless mesh network for transportation use. It was suggested that transportation leaders raise their level of thinking to leverage mobile ad-hoc networks (to enable tolling, road usage fees, etc.). Doing so can facilitate the creation of self-healing transportation networks that transmit high value information to drivers and system managers.

Administrator Brubaker's remarks were followed by a presentation on current technology trends and perspectives.

2.0 Wireless Communication Technology Trends

David Reed, Professor in the Media Lab and Communications Futures Program at the Massachusetts Institute of Technology (MIT), presented an overview of trends in the wireless communications arena, and perspectives from the academic and private sectors. Reed's comments were organized around two primary topics:

- Open systems versus closed systems
- Technology architecture and the business ecosystem

2.1 Open Systems vs. Closed Systems

Reed opened with an anecdote about the business aspects of technology development. Reed recently talked with leaders at Texas Instruments (TI), one of the industry's foremost suppliers of CPUs for cellular phones. The primary business problem cited was the cycle between concept and delivery, which is approximately five years.

Due to the amount of time to get through requirements development, product development, marketing, and other required business activities, it becomes difficult to predict the needs of customers five years hence. TI is intrigued by open platforms because it has been proven with empirical evidence that "when you create an open platform with the intent of creating an industrial sort of ecology around it, all of a sudden, the business development cycle typically shifts from about five years down to about three months."

At the start of the PC revolution in 1980 Apple had the Apple II, but by 1985, there were millions of PCs running on a standard set of platforms. IBM lost the market because competitors shared platforms. The next five-year cycle ran from 1992-1998 from the onset of use of the Internet and e-commerce. These activities had long technology development cycles. Contrast these cycles with the advance of social networking applications such as Facebook, which experienced huge market penetration in approximately one year.

Thus, an open platform allows for more rapid innovation and deployment of those innovations as consumer and business needs evolve. The common theme is to build an application on a platform or host that can be reused and invested in by other vendors, and to create incentives for this model.

Reed noted that cellular telephones have the highest rate of adoption of any digital device over a period of three years. Other devices continue to ride on the coattails of cellular phones (like tablet computers and iPhones).

From a technology perspective, the devices are driven by the processing power you can put in a chip – for a cell phone, this could include a mesh repeater that operates on low-power, can cover long distances, and has a 2.4 GHz antenna on board. The chip implements Wi-Fi radio functions and MAC layer functions, and features a fully reprogrammable microprocessor. In addition, the antennae can be quite small and do not have to be proportional to wavelength.

The One Laptop per Child initiative leveraged an open platform for its product precisely in the interest of innovation. Similarly, Linux-based cell phones work the same way: a developer can write code for any device, download applications to the phone, and use its 802.11x network connectivity.

2.2 Technology Architecture and the Business Ecosystem

One of Reed's key themes was that advanced wireless communication technologies are progressing extremely rapidly, and this has serious implications for the business ecosystem: at the 2003 ISART[1] conference, only a small handful of participants knew about or were using Wi-Fi or 802.11 networks. DSRC was the prominent technology, and Wi-Fi was "under the radar." Today, Hewlett-Packard (HP) manufactures 48 million laptops per year, each with an 802.11 chip in the device. Reed predicts that soon all cellular phones will have 802.11 chips, and potentially even cameras. This cycle is driven by consumer technology and cannot be replicated in other markets. There are four interesting issues that contributed to these developments:

1. **Wireless technologies had previously been limited by hardware legacy and regulation.** In the past, a new frequency band was needed to release a new technology (and it takes quite a long time to get a new band). Legacy devices were barriers as it was costly to replace physical hardware. This is no longer the case now, as today digital systems are used to modulate waveforms. Users do not have to replace hardware, but simply download software. Industry and Government leaders realized that old analog technologies are very inefficient (these use a loud signal to broadcast far away). This results in computing capability that allows systems to be updated and adapted to one another.
2. **Digital modulation improved efficiencies.** In the past, radio systems were blind to one another; new devices negotiate dynamically for the bandwidth – these talk to and negotiate with one another, improving efficiencies in the process.
3. **Dynamic protocols increase the speed with which devices can be added.** As the Internet emerged it invented protocol design to manage the higher level space in which negotiation between systems happens. In the past there were protocols (e.g., IBM's SNA) but these were static and unchanging and were improved by appending information to these protocols. This made the addition of new devices rather slow. New dynamic protocols increase the speed with which you can add devices within existing systems.
4. **Virtual computing environments can now be constructed.** Virtual computing environments are not bound to original technology on which these were originally based. Users can run legacy applications on new hardware that virtually emulates the original environment.

While discussing the business ecosystem, Reed cited Iridium, the low earth orbit satellite communications system that was designed to provide voice communications in developing countries around the world. What went wrong? Nothing, technically, since it delivered every feature and function it was supposed to, except that it was designed as a 10-year project. By the end of the 10-year development cycle, the market had evolved beyond the capabilities of Iridium's fixed design.

[1] ISART stands for International Symposium on Advanced Radio Technologies. It hosts an annual conference that serves the government radio and technology market.

2.3 A New Technology Development Ecosystem

Reed's assessment was that the "game needs to be changed." Key characteristics of the new technology business game are:

- **A platform that evolves** and co-evolves with standards at a rate appropriate for the market. This does not mean that, for example, the standard wave form of a chip set is eliminated, but that standards evolve along with requirements.
- **An industry structure that cooperates.** As long as there is a market that is wide open, it will be able to do more things in less time, and it will be easier to be innovative. Ideally, the transportation marketplace includes this element of "coopetition" (cooperation plus competition) and expectations for growth throughout the industry.
- **Interoperability is essential** for an industrial ecosystem that involves specialist companies to implement systems.
- **Protocol-based negotiations** of what activities are allowed and possible. The negotiations style can change over time as protocols evolve, but the essential philosophy must be present.

The core trend is towards platforms that are open enough to be capable of evolving based on protocols. **Such an environment can drive investment in innovation that leads to progress.**

> *"Almost no radio system before 1990 had any capability of adapting to the other radio systems around it. They were blind to the other radio... it didn't matter because they didn't listen before they talked... Now radios are perfectly happy to share, to build models of their environment..."*
> *- David Reed, MIT*

Reed's assessment for the transportation sector is that add-on electronics will be key for automobiles. In-car communication for entertainment already exists, but devices that allow for communications between cars can spark innovation in safety and other applications.

Following Prof. Reed's presentation, the floor was opened for questions and discussion. Note that the dialogue is organized by topic areas, not by speakers' names or chronological order of questions. Discussants' affiliations are noted in parentheses.

Participants discussed the role of open source mesh wireless networks. Sascha Meinrath (New America Foundation's Wireless Futures Program) noted that many of the issues raised during the early part of the roundtable are the same ones raised before 2000. He made four key points about trends in advanced wireless communication technologies:

- There have been advancements in the use of multiple frequencies in software defined-radios. Common nomenclature and agile transceivers are also on the horizon. Such 802.11 devices can operate on multiple different frequencies, pointing to open platforms and devices.
- Some wireless industry players have challenged the FCC to drive innovation back to the network, and remove it from "the central authorities" (i.e., allowing cell phones to be network-independent).
- Smart antennae are being developed, but they are not yet fully implemented or utilized.
- Policy reform is critical for R&D efforts. For example, white space devices are making more efficient use of spectrums. These devices are critical to advances, but policy reforms can encourage implementation and further innovation.

Meinrath asserted that there will never be a full-scale roll-out of advanced wireless technologies unless there is substantial investment in innovative projects, not continued investment in "the usual suspects." DOT should take advantage of new opportunities to work with private sector players who are driving these innovations.

Rich Howard (Rutgers University and PnP Networks) is a former Vice President for Wireless technology at Bell Labs. Howard agreed that roll-out remains an important issue. A large Wi-Fi network may include 400 nodes (just a few blocks in Manhattan); any tests deployed on a small trial scale would be irrelevant. Rather, huge scale tests are required. Many participants agreed with this sentiment. Later in the discussion, Tim Krout (CENGEN) noted that a mesh of 5,000 nodes would be an adequate test size to prove functionality of a given mesh platform that would successfully accommodate massive scaling.

Additional issues related to testing and roll-out were raised by Ferdinand Milanes (CALTRANS). He noted that interoperability in today's systems remains a significant challenge. Public safety users are on low-band and high-band systems, with the result that frequently first responders cannot talk to one another directly. Gateways and other expensive workarounds may not be feasible. Milanes noted that there are not a lot of options for public safety radio platforms, but asked the group to consider if wireless mesh networks could support not only data but voice communications.

2.4 Applications for the Transportation Sector

Christopher Wilson (Tele Atlas) noted that all participants agree on the goal of interoperable radio, but the real question is how to get into the automotive environment. What is the one application that will drive people to use an application or in-car device? What is the "killer app"[2] that drives this technology into the vehicle?

There was agreement from Douglas Sicker (University of Colorado-Boulder) who asked participants how the vehicular market differs from existing markets. He noted that it will be important to identify new risks, especially in terms of licensing and patenting.

Tim Krout, a former DoD engineer, offered a response and some suggestions for transportation applications. From Krout's perspective, there are three primary applications for advanced wireless communication in the transportation sector:

- Dissemination of **safety** information;
- Use of traveler information for **convenience** of system use; and
- Improvement of **situational awareness** (e.g., monitoring of bridge conditions, in-vehicle fuel consumption, congestion pricing opportunities)

Krout noted that a wireless communications system cannot be "all things to all people." Krout suggested that DOT approach the problem differently and identify the problem transportation network is trying to solve. Is it necessary to have one radio that serves all functions or solves all

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[2] A killer application (commonly shortened to killer app), in the jargon of computer programmers, has been used to refer to any computer program that is so necessary or desirable that it provides the core value of some larger technology, such as a gaming console, software, operating system, or piece of computer hardware. Simply put, a killer app is an application so compelling that someone will buy the hardware or software components necessary to run it.

problems? The fundamental policy centers on whether or not an “80 percent solution” is appropriate.

3.0 Mobile Ad-Hoc Networks (MANETs)

3.1 Overview of Trends

MIT's David Reed presented an overview of trends in the area mobile ad-hoc networks (MANETs) and their potential to provide alternatives to existing approaches. Mobile ad-hoc networks have emerged in response to mobility and networking challenges faced by traditional networks, including the "command and control" architecture model found in many Department of Defense systems.

Reed's expertise is in an area that might be referred to as "slightly mobile ad-hoc social networks." Due to the inexpensive nature of radio technology and the extensive adoption of wireless devices by general users, it is reasonable to project that there will be a great deal of radio communication in the human centered network. The "out of the box" view of vehicular networks assumes the perspective that users will be carrying in-car radios. Thus, the "killer app" may not be about cars, but about the cars talking to the users; however, can the car talk to the user intelligently?

> *"If you use a lot of short distance radio, you get a lot more capacity...Even the cellular space is starting to use handset-to-handset handoffs and packets...to blend systems together."*
> *- David Reed, MIT*

An important observation about the history of MANETs is that radios can send signals multiple hops further than they can point-to-point. There are advantages to eliminating points of failure and inefficiencies in order to achieve more capacity. If a system is deployed with a lot of short distance links, you get more capacity in the system. Currently, with cell towers there is only so much coverage available, such that cell networks are using handset-to-handset signaling to maximize available cell tower capacity. According to Reed, in terms of the transportation sector, when we talk about MANETs (based on radios that adapt and cooperate) we can provide a map of the environment around us. Industry leaders and researchers are already starting to build integrated systems in the indoor communications space; this can also happen in the vehicular space.

3.2 Role of Standards

Systems with a reasonable amount of standards can take advantage of the increased capability afforded by MANETs. In places like Intel labs and Motorola labs, there is a lot of work being done to make systems that basically exploit all of the radios in the space, and also use other systems, whether they are broadband, Wi-Fi, or traditional resources. A system that has a reasonable amount of intelligence can actually take advantage of these resources. What makes this work are radios that can understand each other.

The minimum capability of either standardizing on analog wave form or standardizing some form of capability that can be adapted to each other is what is called software-defined radio. The advantage of software-defined radio is, in fact, all of these modern radios are being pulled that way, whether they expose it or not. Although they may be defined in terms of analog wave form, they are generating waveforms digitally. So, you can take advantage of those, for example, to adapt to rapidly changing populations. For programmers this means that the digital realm gets programmable access to the (analog) radio spectrum. In that sense a wealth of new applications can evolve around the principle of software-defined radios.

> Cyrus Behroozi (TROPOS) asked **What does open mean?** These definitions are compiled from Behroozi's comments and online sources:
> **Open source:** Software application source code is practically accessible to developers, and can be copied or modified.
> **Open platform:** Software source code may not be available, but external programming interfaces have been published, which allows third parties to integrate with the platform to add functionality without requiring modification of the source code.
> **Open network:** This might be closed source, but users with a Wi-Fi device with encryption open are allowed to access the network and benefit from it.

The crucial element of packet-systems is that the links can be short-distance. This is extremely different from the traditional radio problem of establishing channels. Much of the work on fixed wireless mesh networks and new adaptable systems shows that they can work well for many kinds of short distance applications. For many of those applications, "you'd have to stand on your head to use traditional radio systems." The result is that the safety element can be extremely dynamic with short packets.

The field is starting to see users deploy add-on devices in cars that use Wi-Fi (i.e., Dash Express GPS[3], although they are not very useful because they only function with a connection. An issue with Dash and other Wi-Fi devices (which are like memory chips with Wi-Fi antennae) is that they are missing critical standards. Reed's assessment is that it is worth considering options beyond command-and-control networks, but for vehicle applications, it is important to understand channels and standards necessary for safety-specific applications.

An important note about packet systems is that the need for a consistent channel is very short. A microsecond or two has been read into packet systems to make them work; this actually establishes a channel condition that stays stable for a reasonable period of time. This is very easy and quite normal for a Wi-Fi radio that is flying past another Wi-Fi radio. If the right processor is available, there is enough time to exchange a fairly large amount of data with multiple packets going through it.

Packet-based radio systems that dynamically build connections on a type of opportunistic connectivity can be built today. This is one reason Reed is concerned about the confusion with the term "mesh." There has been a lot of work on fixed wireless, but vehicular communication "hop by hop" can actually work quite well for many kinds of naturally "ad-hoc" applications for short distances (such as measuring traffic, interacting with a parking meter, etc.).

3.3 Advanced Wireless Applications for the Transportation Sector

Reed's overview provided a foundation for three important speakers to discuss advances in and uses of mesh networks and MANETs. The discussants (Robin Chase, L. Aaron Kaplan, and Tim Krout) provided new perspectives and details on different aspects of advanced wireless technologies and potential transportation applications. The discussion summary has been organized around several broad topic areas and includes an overview of presentations and question-and-answer sessions.

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[3] Dash Express touts itself as the first two-way, Internet-connected GPS navigation system. Its GPS unit leverages the SIRFstarIII satellite signal processor, the Wi-Fi receiver and antenna connects to networks from a car using a high gain antenna, and the cellular radio and antenna uses cellular (GPRS) network to keep the device connected at all times. See www.dash.net.

3.3.1 The Business Case for Open Platforms and Open Networks

Robin Chase (Meadow Networks and ZipCar founder) offered her perspective on strategies for leveraging wireless communications technologies for transportation safety financing, congestion mitigation, and innovative commercial applications. Chase noted that in terms of the transportation sector, applications will be adopted in a piecemeal fashion in specific geographies across the country and rely on after-market devices.

Furthermore, she believes there is an opportunity to change the outcome of DOT transportation investments by ensuring that technical investments use open platforms that can then be multi-purposed and accessible to others to build upon. Open platforms also support innovation: new ideas can be tried, tested, and improved upon at lower cost and with lower stakes (because no entity would have to build the entire set of applications or the entire infrastructure on their own). In a rapidly changing technology environment, Chase believes the desired DOT outcomes can be financed and achieved at a lower cost and at a faster pace of both innovation and adoption if open platforms and open networks are used.

In a positive trend, there are large scale wireless network experiments underway in Minnesota, Ft. Lauderdale, and other metropolitan areas, with the expectation that billions of dollars will be spent on these projects over the next several decades. The vast majority of the larger markets have deployed (or are considering deploying) closed proprietary solutions on closed networks. The result will be expensive single purpose devices and networks that have little likelihood of connectivity with others being built around the country, and enormous amounts of embedded excess capacity in the devices and infrastructure. These types of closed systems will not make use of the latest technologies because of the lengthy time cycle between development and deployment to the market. Additionally, one can anticipate no innovation on such systems. The system provider has little incentive to innovate or improve systems since they have built to initial specifications; and other companies cannot get into these systems in order to improve or update their capabilities.

The transportation sector now has an opportunity to change the outcome by making multi-purpose investments and leveraging open platforms to spark innovation. This strategy can result in rapidly improved environments and identification of the "killer app" (according to Chase, this is congestion and road pricing). Strategies for leveraging advanced wireless communication systems must include discussion of privacy issues, an issue at the forefront of the conversation about platforms, software, and hardware.

Chase identified several historical and current barriers to enabling advanced wireless communication for transportation safety, financing, and congestion applications:

- *Centralized, top-down, massive scale projects* – London's congestion pricing initiative used existing technologies, drew a cordon around the central business district (CBD), and used cameras to capture license plates. While there was a 90 percent positive license capture rate, there was a 10 percent error rate, which had a huge negative impact on the cost-effectiveness of the system. The city had spent approximately £400 million on the original system, but would now like to expand the cordon around the city (at a cost of several hundred million more pounds). Had London used a vehicle-based open mesh platform, their initial investment would have more cost-effective transactions (no camera system generating high error rates), accommodated the expanded cordon with little incremental cost, and would have provided the foundation for a "wireless London" built on the back of the congestion pricing infrastructure. Instead, because an open platform did not exist, London chose traditional closed proprietary systems for its first congestion pricing build, and opted to maintain the status quo in its expansion plans.

- *A hardware environment that prevented improvements* – New York City modeled its congestion pricing initiative after London's. As New York City considered congestion pricing, it became clear that it would also be politically easier to leverage the installed base of EZ pass transponders (a closed proprietary system). This promise immediately eliminated opportunities for innovative solutions that are newly possible since EZ pass was first created more than a decade ago. It also alienated the 25 percent of New Yorkers who have not adopted EZ pass because of privacy concerns (EZ freely gives location information of specific cars to those who ask) and the system's requirement for cameras.

- *Political barriers and jurisdictional issues.* Chase used New York City's recent nine-month long political discussion as an example. While there are many reasons for the city's inability to ultimately gain support for congestion pricing, the rigid technology constraints, posed by the closed proprietary systems proposed, were major contributors: a system that required flat fixed rates along a cordon surrounding downtown Manhattan alienated the other boroughs and made the system appear unfair. The camera technology was much contested by those seeking to protect the geographic privacy of drivers circulating in the city. Adoption of an open mesh-based platform in the car would have also reduced jurisdictional friction raised by installation of fixed hardware throughout the city; it was also considered operationally risky since such a platform had not yet been built and used at the scale required for Manhattan. This is the opportunity that can be corrected and addressed by the DOT.

> *"One of the barriers for getting innovation into the transportation sector is that…closed proprietary platforms require a huge amount of infrastructure – fixed and mobile – to be built…"*
> *- Robin Chase*

Chase also noted that open platforms can be "a magnet of opportunity for the business realm." For example, if New York City established a mobile communications system, not only could it enable safety applications, but also other types of convenience or commercial transactions.

British Telecom offers a good example of this type of openness when it told broadband buyers that if business users opened their broadband access points to other BT users within reach of their access points, they too could be able to roam and use the wireless networks of other BT business users. This offering improves BT's network efficiencies (see www.BTFON.com). Ultimately, the planned expectation is that users will be switching networks to use the most cost-effective network for a given activity. Doing this requires an open system.

Closed platforms typically associated with huge fixed/mobile systems (e.g. bus rapid transit (BRT) in Los Angeles, HOT lanes in Florida, etc.) cannot test new ideas or be platforms for innovation. An open standard platform is needed for trials that can scale with less risk, and an open platform with flexible open architecture allows the private sector to enter into the space. (Another example of a missed opportunity for a large-scale open platform trial is in New Jersey. Rather than attempt to use an open platform, New Jersey Transit (NJT) is opting, conservatively, to explore possibilities based on "tried and true" devices and networks, which limit NJT's opportunities for future innovation and interconnectivity.)

Chase closed by reviewing the handout she provided to the group, pointing out the benefits in terms of costs and time to implementation that could be gained by pursuing standards-based, open access points and ad-hoc networks that leverage both existing and new devices and infrastructure.

3.3.2 Technical Options and Considerations

Both L. Aaron Kaplan (Funk-Feuer Initiative, www.olsr.org) and Tim Krout (CenGen) offered their viewpoints on technical considerations for enabling advanced wireless communication in the transportation network. Kaplan, whose connection to this field started when he retrofitted a laptop for Wi-Fi in Vienna, now oversees a mesh network that uses the Optimized Link State Routing Protocol[4] (OLSR) consisting of more than 400 nodes (still a relatively small network compared to the other existing mesh networks in Europe).

Larger networks exist in Athens (2,000 nodes, fully meshed), around Barcelona (~5500 nodes, Wi-Fi but non-meshed), and in the Czech Republic, which has a wireless network covering the whole country (www.czfree.cz – Czech language site). Kaplan asserted that it is a myth that Wi-Fi networks need to be small in size. There are density issues, but the Czech Republic experience shows that it is possible to have a national network. However, Kaplan noted that complete mesh networks will be available only "in the distant future" as large mesh segments may be a more promising approach. In Vienna, the network Kaplan created is a Wi-Fi mesh network, based on inexpensive off-the-shelf 802.11x Wi-Fi equipment, reprogrammed with open source code (openwrt) and feeding off of one single fiber uplink. The uplink provides bandwidth for approximately 400 nodes. The average operational expenditure (OPEX) costs for this network are a few hundred Euros/month (~1-2 Euro per user per month). The bandwidth in the Vienna mesh network goes up to 30 mbit/sec netto. Uplink is 100 Mbit/sec netto.

Kaplan clarified that he also directs the current research and development of the open source OLSR.org project.[5] Current trends in OLSR research include integrating GPS into routing decisions (relative speed of vehicles will be used to adapt the rate of routing packets), reducing the number of packets in the air in order to conserve bandwidth, and reducing the complexity of fast and dynamic route changes.

The OLSR.org Project has recently demonstrated that the routing daemon scales well in an 800 node mesh network on an embedded web camera with only 20 MHz CPU power (roughly equivalent to an Intel 286 processor from 1982). Scalability of OLSR to thousands of nodes is currently a reality.

Kaplan later noted that in Europe many of the community networks use standard Wi-Fi equipment and the available 2.4 GHz frequencies. One major obstacle of current Wi-Fi technology is the scarcity of the spectrum. Based on his own experience building real world Wi-Fi mesh networks, Kaplan believes that self-interference of nodes and interference with neighboring nodes is the

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[4] OSLR is a proactive link-state routing protocol that floods a topology table of its neighbors to all nodes in the network, which then compute optimal forwarding paths locally.

[5] Kaplan offered comments in the next several paragraphs after the roundtable took place, in order to provide additional detailed information about the OLSR project and his experiences with mesh networks.

main stumbling block for successful deployment of any kind of Wi-Fi network (meshed or non-meshed). More and better spectrum will be needed.

Overall, Kaplan agreed with Ramming's assessment of the state of the current technology. Network coding, better layer 1 support, MIMO, more spectrum and advances in routing metrics and algorithms all combined show that very large mobile mesh networks can now be feasible.

Tim Krout (CenGen) offered an overview of the Department of Defense (DoD) innovations, including a MANET based in Iraq that includes approximately 100,000 nodes. CenGen's vision is to serve the tactical high mobile user with the "pointiest end of the spear," including "killer apps" to improve situational awareness and provide vehicle-based video feeds.

There are several radios available in the DoD environment, including:

- JTRS – Joint Tactical Radio System
- WINT project – War Fighter Information Network-Tactical
- EPLAR – Enhanced Position Location and Reporting in-vehicle radios
- HNS – High Beam Networking System
- SRWF – Soldier Radio Wave Form (uses and open platform)
- Blue Force Tracker

DoD and specifically Defense Advanced Research Projects Agency (DARPA) have "pushed the envelope" in terms of next-generation radio communications technologies. Advances in EPLAR will make it easier to configure and program, will be dynamic and meant to be operated and maintained by the average soldier. Within the next two to three years, Krout expects to see small JTRS radios available for use in robotic vehicles, while CenGen is currently developing an open source version of a JTRS radio.

At the same time, HNS technology is an in-vehicle system delivering 50mbps per sec and has been deployed in "a few hundred vehicles." The primary research developer for the network is Cisco Systems, which suggests that there is a larger commercial market available outside of DoD.

> *"...[In] vehicle MANETs, you really need to care about the 100 millisecond, 50 millisecond kind of timing within a few vehicle lengths."*
> *- Tim Krout, CenGen, Inc.*

Blue Force Tracker, which uses an I-band, is a satellite communications based device that leverages the same technology as Iridium phones. There are currently thousands of vehicles being tracked with the device. Prior to the Iraq effort, EPLAR was the preferred system, however, approximately six weeks into the Iraq war production of Blue Force Trackers was increased in order to outfit more vehicles. While not used predominantly in Iraq, the device uses a commercial-off-the-shelf (COTS) cellular card with a Wi-Fi chip. There is no transparency to the user regarding which network is functioning (cellular or Wi-Fi). DoD has been encouraging MANETs in order to expand connections to vehicles. Krout noted the importance of understanding network coding, which is a new way of passing information between nodes.

J. Christopher Ramming (Consultant) presented a detailed look at some of the technological considerations related to mesh networks and advanced wireless communication technology. Ramming recently finished a term of service at DARPA, which is attempting to make mesh networks a reality. His work asked key questions such as "is the technology ready," "what are obstacles, risks, etc."?

DARPA is part of DoD and has a razor sharp focus to take results and accelerate them into practice; DARPA solves point problems, but it does not build huge networks.

"Did DoD finish the job of building the Internet?"

According to Ramming, "not really" – there is still a lot of work to do and support for mobility is currently missing. There is an exciting opportunity to create the mobile Internet and to use it for driving applications. In the transportation sector, there are problems to solve that force us to take the next step.

Ramming then described several known technical challenges and the evolution of the technology:

Mesh networks and cellular systems are quite similar, but meshes do not rely on fixed infrastructure. The intended benefits are identical: both try to achieve ubiquitous computing ("anytime, anywhere" solutions). This goal forces a shift to a wireless medium.

Importantly, the wireless medium is challenging and very different from traditional wired infrastructure. First, "the network abstraction may not be a perfect fit for the wireless systems that are in development." Nodes and links do not adequately represent interacting electromagnetic fields. Second, Ramming cited Tim Krout's observation that MANETs routinely experience more than 10 percent packet loss. And third, Ramming suggested that participants recall that in designing IP technologies, latency or efficiencies are not a high priority – a single wire will provide 12,800 GHz of bandwidth relative to at most 3 GHz of useable mobile spectrum. The wireless medium forces a look at efficiencies in design stage, and this is difficult to handle from a systems architecture perspective.

The Internet is one line of development that allows interconnectivity; its common packet format has been transformational and has sparked a great deal of innovation. However, it is important to remember that the Internet has not fully addressed mobility. Ramming suggested a look at how the cellular industry has gone beyond interconnectivity to support mobility. DoD MANETs are another line of development in support of mobility. "Killer apps" include hard real-time control, but this is challenging in terms of data security and data assurance.

> *"The Internet…allows interconnectivity; its common packet format has been transformational and has sparked a great deal of innovation."*
> - J. Christopher Ramming

In terms of moving forward, Ramming asserted that DOT can select its own timeline, but it will face challenges similar to DoD. Some challenges may be "postponable." He suggested developing an evolutionary approach based on prioritizing "a taxonomy of applications that can include many dimensions: vehicle-to-vehicle, comfort and convenience, hard safety versus soft safety, scheduled versus event-driven versus on-demand, location aware versus location independent, unicast and multicast, elastic traffic streaming, public sector applications versus private sector applications, latency sensitive versus latency insensitive, and single hop versus multi-hop versus completely arbitrary, point-to-point, and point-to-any-point."

Support for Mobility – Ramming discussed several ways in which the original Internet design did not include support for mobility. The seven-layer OSI model[6] differs from the four-layer Internet model in important ways, and in particular the four-layer model does not include rich support for wireless mobility. For example, there is no formal session layer that allows for temporary suspension of a session if there is some kind of mobility event. In addition, many protocols including Transmission Control Protocol (TCP) were designed for a regime with low packet error and latency (had wireless mobility been an earlier requirement for the Internet design certain important protocols might have evolved differently). And finally, Internet Protocol (IP) addresses represent both locations and identity, with the impact that topological mobility is challenging to implement.

> *"At extremely challenged mobility time scales…intelligent flooding becomes the key enabler of mesh networks."*
> *- J. Christopher Ramming*

However, mobility is increasingly understood and the Internet Engineering Task Force (IETF) is now exploring solutions to these challenges. Example solution elements include Mobile IP for global mobility via a home agent concept, which is similar to approaches used in cellular networks but that can involve high handoff latency (up to two seconds have been reported). To address fast handoff, various approaches to local mobility are being explored, including as Hierarchical Mobile IPv6 (HMIPv6), Fast-Handovers for Mobile IPv6 (FMIPv6), and work in the IETF Network-based Localized Mobility Management working group (NETLMPP) to minimize latency and packet loss in local handoff.

With respect to routing, traditional single-path wide-area Internet routing protocols are not very appropriate for wireless MANET. However, there has now been a huge amount of work on MANET routing protocols. Ramming pointed out that there is a good deal of mesh networking using OLSR that is appropriate for fairly static regimes. Efforts like Ad hoc On-Demand Distance Vector (AODV) routing assume much higher rates of mobility; at the extreme mobility time scales where the solution is not routing, intelligent flooding becomes the key enabler of mesh networks.

Finally, NACK-oriented reliable multicast (NORM), backpressure-based transport algorithms, Disruption Tolerant Networking, and the recommendations for TCP tuning in RFC3481 are all a step toward transport protocols that are wireless-friendly. With respect to wireless mobility, Ramming's recommendation is that DOT chooses a set of initial protocols and put an architectural "stake in the ground." While this may be controversial, it seems important for progress in this area to have a specific "straw man" architecture for community consideration. Ramming believes that "no other Federal agency appears to have the specific challenge or the responsibility that DOT has."

L. Aaron Kaplan (Funk-Feuer Initiative) noted in a later clarification that link state algorithms were integrated into the Vienna OLSR network. Additional practical experimentation will integrate GPS-based devices so that intelligent flooding based on relative speeds of vehicles can occur. In a later clarification, Kaplan also explained that there are two aspects of the term "mobility": (1) mobility for small mobile devices such as cell phones or PDAs. These require AODV since AODV

[6] The Open Systems Interconnection Basic Reterence Model (OSI Reference Model or OSI Model for short) is a layered, abstract description for communications and computer network protocol design. It was developed as part of the Open Systems Interconnection (OSI) initiative and is sometimes known as the OSI seven-layer model.

saves battery life, however, AODV does not permanently send packets, and, (2) mobility in terms of vehicular networks where fast handovers are a strict requirement. In these settings, AODV is not suitable since it needs to (reactively) determine the complete route before sending the first packet. Subsequent requests will also be quick, but if the topology changes rapidly (as in car meshes), it starts a new cycle of asking for the best route.

Kaplan believes that this is why CenGen is using OLSR for vehicular networks rather than AODV: they are more mobile (in the second meaning). For saving battery life, AODV is the optimal solution. And thus it is the algorithm of choice for some scenarios, like the $100 laptop that tries to save power. Additional information can be found at folk.uio.no/kenneho/studies/essay/.

Sascha Meinrath pointed out that link state work was undertaken 2001 and 2002, and that DoD is now rediscovering these routing protocols that are "half a decade old." He noted that by 2004 or 2005, developers working with OLSR+Fisheye (Fisheye is HSLS ported into Linux) began to merge it with the best of AODV and HSLS. This presents a classic example of where open source is far ahead of real world implementation.

> *"How [do we] deliver very sensitive and critical information in an interference-rich environment?"*
> *- Babak Daneshrad, UCLA*

Babak Daneshrad (University of California – Los Angeles) noted that it is important to remember layer 1– the physical layer, which is "subservient to everything else above it." In terms of Bluetooth, Wi-Fi, and cellular, the physical layer is different in each scenario for a reason because usage scenarios are different.

Daneshrad noted that participants need to address these issues of different types of usage scenarios (from in-car video to the passing of tiny messages back and forth between vehicles and infrastructure). For example, if a system operated on 2.4 GHz band, interference mitigation could happen at the physical layer but also at higher communications layers. He asked, "Can we look at interference mitigation and layer 1?" If Wi-Fi is ubiquitous, how does the field deal with delivering very sensitive and critical information in an "interference-rich environment?"

Daneshrad asked participants to think about notion of "elastic links" – stretching out a link until the network catches up and then performs the crossover. For example, a link can be stretched from 100 megabits per second in a room, to 100 kilobits per second on long distance links stretching several kilometers.

Richard Howard (Rutgers University) echoed Daneshrad's comments and noted that users can move from texting on typewriter to YouTube because there was so much additional capacity available on the network. However, with radio (GSM), users cannot move from data or audio to video without using the entire spectrum from one channel. Howard considers this more than an "engineering problem" and a fundamental issue.

Ramming believes that mobility as a whole is an "addressable problem" with the technology available today, though difficult choices will have to be made. However, he offered that the "fully connected mobile ad-hoc network" is a myth and that wireless-friendly reliable transport protocols (for example Disruption Tolerant Networking) will need to replace or augment TCP in certain future mobile environments and applications.

Transport Protocols for Sparse and Dense MANET Deployments – Ramming went on to discuss two important regimes:

1. Sparse and partial MANET deployments (early stages)
2. Dense deployments (later evolutionary stages)

Ramming noted that in the early days of deployment and currently, there is always downtime in DoD's MANETs. Even on I-80 in LA *[sic]* at night, the potential for disconnection in a fully equipped vehicular network could be as much as 35 percent. Disruption-tolerant networking can be an enabler of applications in these sparse regimes. Disruption tolerance allows a shift away from the idea that there needs to be a link from the source to the destination at all times in order to make communications work. Systems do not merely copy-and-forward at intermediate nodes; rather, the model is copy-carry-store-forward. This approach can vastly improve situational awareness application discussed earlier and is even used in developing countries to enable communications. DOT could consider using similar protocols for certain delay-insensitive applications.

The dense regime is also important to consider and is equally interesting. In an extremely heavily loaded network, it is important to look at network coding (the primitives for networking: first there were circuits in a telephone network, then packets in the Internet; network coding is the next step operating on bits and information). The network coding concept is not link oriented but broadcast oriented and allows information to be transmitted even with unreliable connections. This is a form of intelligent flooding that may allow for improved reliability in the future for certain safety applications but should be viewed as a "bleeding edge."

Information Security – An additional issue is information assurance and security. Wireless networks are changing the cyber-defense paradigm because there is no perimeter to defend. This transforms the problem of defense from perimeter to insider threat. DARPA has several programs underway to address this, but the problem is challenging. The key approach may be to focus on the security solutions that are available now, rather than attempting to address every possible threat. For example, protocol leashes, watchdogs, and reputation systems allow parts of the network to police each other and identify harmful behavior. These solutions force all parts of the network to "stay within the rules." Some ideas for dealing with network integrity and cyberattack are not completely ready to deploy, but this may be tolerable in the short run because some of the "soft safety" applications that are being considered by DOT may not require extreme assurances.

Krout (CenGen) agreed, noting that security issues are not only present in vehicular networking, but that the problem is being addressed in the commercial world. The available techniques approach the solution by making problems visible and transparent, such as policing cars. Once harmful actions are visible, the problem can be reduced.

Ramming offered that authentication, authorization, and accountability are other issues to consider. There have been advances in ideas like proof-carrying authorization, physical layer authentication and fingerprinting that allow system administrators to determine if information is coming from the node that is broadcasting (making it much more difficult to spoof an automobile or some other center of information). However, there is no complete solution, and many vulnerabilities lie with human error and misconfiguration. System administrators must take some risks, and complete security may not be achievable.

Michail Bletsas (One Laptop per Child) framed security issues in terms of encryption and privacy, not information integrity. He cited the effectiveness of end-to-end approaches, and noted that users do not rely on the layer 2 encryption for credit card transactions; rather users rely on Secure Sockets Layer (SSL)—the end-to-end encryption approach.

He continued with a word about MANETs: if they are married to network coding at the application level, one "killer app" is social situational awareness. This allows users to make intelligent decisions about traffic, but does not require the user to know his or her own position, only those of others around them. He posited that there is no efficient way to use cellular technology to propagate that information down the network, so MANETs have advantages. He suggested that participants refrain from attempting to use MANETs to replace solutions that already exist and work well. MANETs can extend or augment what is available.

> *"…I think we could team up with the commercial or consumer [market] for telematic services…"*
> *- Kevin Lu, Telecordia, Inc.*

Scalability – Ramming noted that the field has only have seen small deployments of MANETs, and that there is a pernicious assumption that MANETs will be used like a telephone network (where users can call anywhere, anytime and use all of the multiple hops). This results in dismal scaling results in research papers. On the other hand, many of the DOT applications only need to have communications within a few hops. So long as DOT does not try to create a MANET-based general-purpose cellular network, there is hope that current scaling laws will not be problematic.

Latency and Other Recent Developments – Ramming noted that DARPA's Tactical Targeting Network Technology (TTNT) tries to achieve 2 millisecond packet transfer at 100 nautical miles (very low latency). He further noted that MIMO and directional networking may also provide benefits for DOT applications, and that emerging hop-by-hop protocols may resolve problematic interactions between MAC scheduling and congestion management techniques in protocols like TCP.

Ramming underscored the need for standardized protocols for mobility applications and consideration of dynamic network coding (like DTN) to improve robustness in the short term.

Following the technical presentations, the floor was opened for questions and discussion. Note that the dialogue is organized by topic areas, not by speakers' names or chronological order of questions. Discussants' affiliations are noted in parentheses.

Kevin Lu (Telecordia) observed that his company realized it would have been too costly to install optical fiber in every house, and shifted the focus to cable and DSL modems. Lu noted that The Telecommunications Industry Association is ready to work with DOT to develop standards for vehicular telematics. Some examples of relevant technologies and industry players include OnStar, ATX, Connexis, CrossCountry, and Qualcomm. Lu suggested that there may be opportunities to team up with automakers for commercial applications, such as the way Ford partnered with OnStar (the deployment took 10 years, but there were 4.5 million calls from active subscribers last year alone.

Robin Chase noted that given the long time to turn over the fleet in America (25 years), innovation will necessarily be in after-market devices being installed in the existing 240 million vehicles already on the road.

In terms of ITS solutions available today, Francois Simon (ARINC) asked, "Is MANET safe for safety messages?" and how can the number of nodes required be minimized? These questions remained unresolved (see Section 4.2). Simon posited that perhaps layers can be identified and separated to use different systems, so that you separate the DSRC layer from the MAC layer and put everything above DSRC on a MANET. The concept is that applications are placed in separate "buckets" that can leverage different types of systems.

> *"There are a lot of problems with MANETs... when you break the path...It doesn't seem to me that this is a very safe way [to deliver] safety messages..."*
> *- Francois Simon, ARINC*

Cisco Systems' Howard Lock agreed and suggested that DOT should be looking for scalable physical systems and radios that can be isolated from the upper architecture. He further suggested separating the routing layer from the stack, and isolating the service layer.

Lock then pointed out that security remains a key concern, and that open systems like MANETs are potentially vulnerable to malicious code and mischievous behavior. As an anecdote, he noted that he would not want to rely on a mesh network to transmit safety information or personal critical data.

3.3.3 Business Models

Krout discussed various business models and opportunity areas for leveraging advanced wireless communication technologies:

- *Hard and soft safety applications* – What makes the transportation applications unique in terms of vehicular applications is the small amount of time relevant to situations, for example, only 50 milliseconds between a few vehicles can avoid a crash.
- *Singe radio systems* – These may be viable where the "80 percent solution" is acceptable.
- *Wi-Fi approach for safety applications* – Safety applications in a few thousand vehicles could be deployed fairly quickly using a Wi-Fi based approach using two, three, or four-hop communications. A MANET could be technologically feasible in an application that requires quick reaction and low latency, but it is probably not workable for safety applications.

> *Howard Lock (Cisco Systems) noted that there is increased sophistication in communication devices. For the first time, consumers have more power than enterprises. For example, the hospitality industry is struggling to keep up with guests' capabilities. One possible approach for vehicles is to consider the automobile simply a platform for user-selected applications.*

There were several comments from participants related to business models and the business ecosystem.

While discussing the services approach to vehicle-based technologies, Dennis Govoni (Sun Microsystems) offered that the automobile is not an open system, and that it will be challenging (if not impossible) for open source communications to get into the automobile market. Govoni suggested leveraging private sector resources to help solve technology problems.

He noted that the Internet can serve as a model for solving problems for two key reasons: first, the Internet has a very simple protocol (packet protocol), and second, the Internet "doesn't remember anything" – it is a fluid system, and it does not matter if the network is Wi-Fi, copper wire, fiber, etc. Thus, vehicles must have an open interface to map to this.

Govoni pointed out that recently purchased vehicles include a "maintenance minder" that connects to a network. "Automakers are already thinking about solutions, and a potential next step for [the group] is to select several good use cases and see what infrastructure is really required as a platform for selected applications."

Howard Lock also pointed out that as DOT moves towards demonstration and deployment, small scale test are not relevant for large scale roll-out. His suggestions for moving forward include:

- Broaden the conversation to include other industries (such as hospitality, building trades);
- Involve other Federal departments who can participate through governance or funding; and
- Pursue innovation through a business model; do not approach the issue as a technology problem.

Lock also suggested an interesting approach to use: "the consumer carries their devices and the auto builder simply produces a platform [the user] plugs into." This leverages the "increased sophistication of consumer devices" and shifts the risk and responsibility for communications tools from automakers to consumers.

> *"This is the first time in the history of technology that the consumer has more power... than [established] enterprises."*
> *- Howard Lock, Cisco Systems*

From a local government perspective, some municipalities have benefitted from extensive fiber optic and Wi-Fi infrastructure. Dana McDaniel (City of Dublin, Ohio) noted that the surge towards Wi-Fi being successfully deployed uses an anchor-tenant model based on departments like DOT, State DOTs, or cities to determine whether or not to use Wi-Fi to deliver efficient service. He offers central Ohio as a test site, as Dublin owns 25 percent of its network.

Howard Lock (Cisco Systems) offered some final advice on business models:

1. *Avoid technology religion:* There are many different perspectives on the issue, and players should be open to many solutions. For example, when asked about security, Lock said it needs to be pervasive in the network on a end-to-end basis. It's less important to be "stuck" on a particular technology, but to focus instead on the business model.
2. *Do not be too far ahead of the curve:* Cisco recognized that a company or application may fail if too far ahead of the curve. If DOT is making investments in VII and the timing is right, he suggests a small-scale investment and a focus on "ruthless execution."
3. *Connect the dots:* Steve Jobs (Apple, Inc.) talks about connecting the dots, meaning, "killer apps" are almost never clear looking forward, only looking back. They will appear after a system is built, so it is important to rethink the need to identify the "killer app" before launching the system.

3.3.4 Practical Considerations for Field Applications

The group as a whole raised many practical considerations for field applications of advanced wireless technologies. Tim Krout (CenGen) noted that actionable steps are important. He identified five to six cities that received large amounts of research dollars to investigate these technologies.

Krout agreed that DOT could put a "stake in the ground" in terms of mobility protocols. From a deployment perspective, he suggested a model where 5,000 transceivers are installed in vehicles to create a test bed in a small-sized city. This could allow for advancement and innovation. A generic Linux processor could be used in a shoe-box-sized system to create a test bed with "amazing results" and substantial improvement in all areas.

Stan Pietrowicz (Telecordia) asked participants to consider Paul Brubaker's opening remark about how to accelerate deployment of mobility and safety applications in this space. He noted that mobility and safety may not be served by the same platform, system, or same radio. Safety applications for vehicle-to-vehicle operations are different from mobility applications. Safety requires communications between strangers, low latencies, and features privacy issues. The first mandate for safety applications is that at least two cars have to have the system in place. At the normal rate of vehicle attrition, that equates to a 20- to 25-year fleet turnover cycle.

He continued that in-vehicle message signage indicating a crash two cars ahead is shortsighted, and privacy considerations create unique requirements and authentication challenges. It is not desirable to transmit inaccurate data, especially if vehicles (not only their drivers) are reacting to that information. Thus, intrusion detection systems will be important – not necessarily for encryption but for authentication (with the complex follow-on issue of determining how to remove intruders from the system). With regard to mobility, vehicle routing and traffic information, these could be subscriber-based "opt-in" information services. This would complement mandatory safety applications.

> *"Mobility and safety [applications] may not be served by the same platform, system, or radio."*
> *- Stan Pietrowicz (Telecordia)*

Christopher Wilson (TeleAtlas) offered an idea regarding authentication: ranging signals built into the communications signals either on OFDM, 802.11, or on top of DSRC systems. David Reed (MIT) noted that OFDM ranging is not a current challenge, but questions remain about how to extract data from the MAC layer off of a Wi-Fi card. He asserted that if you can measure the time, you can measure the phase. Professor Reed agreed that this approach might be possible, and noted that ranging, not at speed, is something some vendors are looking at.

Practical Procurement and Maintenance Issues – Ferdinand Milanes (CALTRANS) offered a sobering perspective on procurement and maintenance, stating that it is difficult for public entities (such as CALTRANS) to purchase a product through sole-source procurement when only one vendor exists. This scenario can present barriers to implementation.

Next, Milanes suggests considering the maintenance back-end. Field staff with minimal knowledge or expertise in communications technology would be responsible for maintaining state-of-the-art equipment. This needs to be factored into system design. Furthermore, it would be important to minimize field staff exposure to safety hazards of working near busy roadways and reduce the need for roadside equipment. Alternative energy also might be necessary as often there is no AC power on the roadside.

Milanes suggested partnering with the private sector where possible. California has a wireless right-of-way (ROW) agreement with several cellular companies, which offer CALTRANS space on their towers. The State DOT installs repeaters on the ROW instead of geographically challenging areas (like mountaintops). Finally, he asked if major telecoms like Nextel and Cingular might ask for the DSRC bands that the FCC has allocated (the 5.9 GHz ITS and 4.9 GHz public safety bands) if public entities opt not to use these.

Kirk Steudle (Michigan DOT) offered some background about Michigan's two mesh networks which are fully functional. Steudle indicated he took part in a seminar with Shelly Rome and Richard Paul, and realized the importance of installing a mesh-based Wi-Fi network on a bridge. Thus, the DOT was challenged to install a system on the Mackinac Bridge in three weeks to monitor the structure during the annual bridge walk that has attracted up to 85,000 participants. The system is Wi-Fi based and functional. Steudle is willing to give others a demonstration of the system in Michigan, if interested. It is being replicated for other bridges and exemplifies how wireless communications can be used for purposes of interest to State DOTs beyond traffic safety and congestion management.

Lastly, in terms of practical considerations, Barry Einsig (Tyco) suggested that separating security-dependent safety applications from commercial applications can avoid legal issues. He suggests deploying experimental projects in confined areas (e.g., the island of Hawaii) in order to reduce intrusion or contamination by other users. The demonstration project could have two parts: one that features all safety applications and one that features all of the commercial applications.

4.0 The Path Forward

4.1 Strategic Alignment with DOT Vision and Mission

The DOT Transportation Vision for 2030, published by RITA in 2008, lays out many broad goals for the transportation sector. RITA Administrator Paul Brubaker recommended that participants review the document, and noted the importance of not waiting until 2025 to talk about how to achieve the vision. **The key question is, "How do you reverse engineer the program to get on path to success?"**

Brubaker noted that Moore's law[7] is alive and well, and there continue to be advances like nano-sensor road coatings. DOT spends approximately $100 million each year on ITS activities, and as the transportation authorization bill comes up for consideration, it will be important to leverage the expertise of the roundtable group to open the aperture and identify ways to reverse engineer a plan based on the goals.

Brubaker cautioned that the group should not "let the perfect be the enemy of the good." Rather, as U.S. DOT has defined three phases of VII (near-term, mid-term, and long-term), priorities will need to be established and requirements developed. The hope is to funnel the group's energy and turn it into actionable results in order to save lives, improve mobility, improve the environment, and expand modal choice.

4.2 Implementation and Action Steps

According to Robin Chase (Meadow Networks), DOT has a unique opportunity because of the power of ubiquity (the agency's influence is greater than any one company). The DOT perspective comes from a network of roads, bridges, and highways, and has a history of providing a basic generic platform for individuals and companies to "get their jobs done." There is now an opportunity to provide that same generic open platform in the mobile space. Chase's expectation is that this will be a mixed network, relying on a number of different but interoperable networks, devices, and applications.

Chase recommends that DOT require open standards and open networks for its major infrustructure investments, increasing the likelihood of long-term interoperability and inclusion of rapidly evolving new wireless standards, as well as providing opportunity for innovation. She further recommends that U.S. DOT support the creation of an open platform and an open network, and conduct some experiments using these tools. Outside of DOT, she sees ancillary benefits of leveraging the mobile Internet for homeland security, energy efficiency and sustainability, congestion pricing, economic development, and private sector involvement.

Since DOT is committed to its "enterprise approach" to innovation, the Department will continue to learn from experts in the private and public sectors. In order to maintain dialogue and information exchange, Volpe Center Acting Director Robert Suda will establish a ***community of practice*** on this topic. The Web-based community of practice will allow roundtable attendants to consider key issues and questions, share new ideas, and foster connections among leaders in the

[7] Moore's Law: the number of transistors that can be inexpensively placed on an integrated circuit is increasing exponentially, doubling approximately every two years. The observation was first made by Intel co-founder Gordon E. Moore in a 1965 paper.

technology, communications, and transportation sectors. Presentations on this topic from roundtable participants will be posted for review and download on the community of practice Web site.

Appendix A: List of Participants

John Augustine
Deputy Director
Intelligent Transportation Systems (ITS) Joint Program Office (JPO)
DOT

Vice Admiral Thomas Barrett
Deputy Secretary of Transportation
DOT

Cyrus Behroozi
Chief Scientist
TROPOS

Michail Bletsas
Founder/Connectivity Officer
One Laptop Per Child (OLPC)

Paul R. Brubaker
Administrator
Research and Innovative Technology Administration
DOT

Robin Chase
CEO
Meadow Networks, Inc.

Max Coffman
Senate Appropriations Subcommittee on Transportation, Housing and Urban Development and Related Agencies

Babak Daneshrad
Professor
University of California – Los Angeles

Sunil Daluvoy
New Business Development
Google

Barry Einsig
Director of Marketing/Research
Tyco Electronics

Paul Feenstra
Director, Government, International & Public Affairs
Research and Innovative Technology Administration
DOT

Dennis Govoni
Chief Scientist
Sun Microsystems Federal

Richard E. Howard
Professor
Winlab, Rutgers University

Richard R. John
Director Emeritus
Volpe National Transportation Systems Center
DOT

Leon (L.) Aaron Kaplan
Founder
Funk-Feuer Initiative (Vienna/Graz wireless network)

Tim Krout
Vice President for Engineering
CenGen, Inc.

Gregory Kreuger, PE
Project Manager for ITS
State of Michigan DOT

Howard Lock
Transportation Sector Director
CISCO Systems

Kevin W. Lu
Chief Scientist of Vehicular Telmatics at Advanced Technology Solutions
Telecordia Technologies, Inc.

Dana McDaniel
Deputy City Manager &
Director of Economic Development
City of Dublin, Ohio

Cheryl McQueary
Deputy Administrator
Research and Innovative Technology Administration
DOT

Sascha Meinrath
Research Director
New America Foundation

Ferdinand Milanes
Chief, Office of Radio Communications
Division of Maintenance
California Department of Transportation

David Napoliello
Majority on the House Appropriations Subcommittee on Transportation, Housing and Urban Development and Related Agencies

Suzanne Newhouse
Transportation Counsel for the Senate Committee on Commerce, Science and Transportation (Minority Side)

Stan Pietrowicz
Principal Consultant to Government & Public Sector Business Unit
Telecordia Technologies, Inc.

Scott Propp
Director of MOTODRIVE
Motorola, Inc.

J. Christopher Ramming
Consultant

David P. Reed
Adjunct Professor
Massachusetts Institute of Technology

Gary Ritter
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Paul Schmid
Legislative Assistant
U.S. Representative Ellen Tauscher (CA-10; Co-Chair of the Congressional ITS Caucus)

Douglas Sicker
Professor
University of Colorado-Boulder

Francois Simon
Senior Researcher/Engineer
ARINC

Kirk Steudle
Secretary of Transportation
Michigan Department of Transportation

Robert Suda
Acting Director
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Appendix B: Roundtable Agenda

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Oklahoma City Room
1200 New Jersey Avenue, S.E., E33-461
Washington, DC 20590

1:00pm	**Welcome**	Paul R. Brubaker, Administrator, Research and Innovative Technology Administration
1:05pm	**Introductory Remarks**	Vice Admiral Thomas J. Barrett, USCG (ret.) Deputy Secretary of Transportation
1:15pm	**Overview of Today's Agenda**	Robert E. Suda, Acting Director John A. Volpe National Transportation Systems Center U.S. DOT/Research and Innovative Technology Administration
1:20pm	**U.S. DOT Viewpoint** • Historical Approach: DSCR • Current Challenges: Timeline, technical, political, budgetary • U.S. DOT/State and Local Strategic Exploration: Open standards, after market, engage with consumer market	Paul R. Brubaker
1:30pm	**Technology Trends and Perspectives** • Open systems vs. closed systems • Architecture and the business ecosystem • Discussion: What are the implications for DOT?	David Reed, Professor Massachusetts Institute of Technology
1:50pm	**Mobile ad hoc networks (MANETS) as a potential alternative to existing approaches**	David Reed
	• Technical aspects	Robin Chase, Chief Executive Officer, Meadow Networks
	• Financial, economic, business model advantages	Leon Aaron Kaplan, Co-Founder, Funk-Feuer Initiative
	• Current Implications: ➢ Large Fixed, open source, muni wifi ➢ Military, mobile	Tim Krout, Vice President for Engineering, CenGen
3:00pm	**BREAK**	

3:10pm	**Technical Issues (Discussion and Synthesis)** • Known technical challenges • *Discussion:* What are the degrees of difficulty, priorities, and time requirements? • Synthesis	J. Christopher Ramming, Consultant
4:00pm	**The Path Forward (Next Steps)** Discussion: What are the barriers to increasing scale of implementation; what are benchmarks? How do we engage the public and private sectors and enable experimentation?	Paul R. Brubaker Robert E. Suda
4:45pm	Summary Remarks	Robin Chase
5:00pm	Closing Remarks and Adjournment	Paul R. Brubaker

Appendix C: Questions and Issues for Further Discussion

A roundtable such as this one, which brought together participants with widely varying background and perspectives, is sure to spark an assortment of questions and discussion items. This appendix offers some questions and issues for ongoing dialogue. Some of these questions were raised by participants and discussants during the event, while others were identified after informal discourse and ongoing dialogue about the topic with key attendees after the event. These questions are important to DOT's understanding of this issue.

- ***What are the advantages and disadvantages of using a single system (e.g. DSRC, MANETs, mesh, etc.), and, is a mesh wireless network appropriate for safety applications?***
  It was clear that there are many different opinions about the capabilities and characteristics of mesh networks or MANETs vis-à-vis DSRC and other existing technologies. There is no simple answer to this question, but additional dialogue among experts and leaders in the field can help DOT managers move towards an appropriate solution. There is a series of related questions surrounding goals, objectives, and technical requirements that will inform the dialogue about the usefulness and appropriateness of mesh networks for safety-critical applications.

- ***What are the advantages of open platforms and systems versus closed or fixed systems?*** Many discussants noted the effect open platforms and systems can have on the technology development and deployment cycle. The transportation sector is unique and is not simply another business or industry sector. Because technology applications may be used to protect and enhance public safety on roadways, there may be arguments for closed, fixed, or static systems. A full investigation of the advantages and disadvantages of open platforms and systems should be valuable to DOT leaders.

- ***Is the 80 percent solution acceptable?***
  Tim Krout (CenGen) discussed the "80 percent solution" early in the day. The reference speaks to the idea that no single system can perform all required functions for all parties in all scenarios, and instead, there may be a technology solution that meets 80 percent of desired objectives. In terms of the transportation network in general, and specifically safety critical applications, it will be important for DOT to determine if an "80 percent solution" is acceptable in this environment.

- ***How vulnerable are mesh networks to human interference, natural disasters, and security breaches?***
  As DOT evolves its requirements for safety applications that leverage advanced networking capabilities, it will be instructive to assess the level of vulnerability for mesh networks compared to other networks, and contingencies in place to handle system interference, assure reliability, and maintain appropriate levels of latency.

- ***Who has control or jurisdiction over the transportation network?***
  There was brief discussion towards the end of the roundtable about the opportunity for DOT to carry out large-scale deployment tests. However, if partnerships with private sector hardware and software providers are cultivated, it will be critical for those private sector entities to fully understand the range of jurisdictional and institutional issues associated with

the roll-out of an advanced wireless communication system for safety applications in the transportation network. Some applications may be more complex than others – from a technology standpoint, from an institutional standpoint, or from a public relations standpoint. It will be important to address these issues early on, and to ensure that all parties understand roles and capabilities.

- ***What are the unintended consequences of leveraging advanced wireless communication technologies in the transportation sector?***
  Any policy decision, business process, or technology application will undoubtedly have unintended consequences – sometimes positive, sometimes negative. In this case, there are unresolved questions about unintended consequences – especially as they relate to hard safety applications and liability for public safety and security.

- ***In terms of workforce transition, how would a new system be installed and maintained?***
  There is a transition period for the adoption of any new technology application, including advanced wireless communication technologies. There are multiple questions related to implementation and deployment, including how to manage demands on the transportation workforce, and how to predict the length of time for users to transition to using vehicle-to-infrastructure and vehicle-to-vehicle communication systems.

- ***How can current mobile technologies be leveraged to accelerate deployment of a variety of safety applications, many of which were originally designed to use 5.9GHz DSRC technology?***
  There are a range of safety and mobility applications that can use different communications technologies with different infrastructure requirements. It will be important for key stakeholders, including Federal transportation leaders, to have ongoing dialogue about how to leverage currently-available advanced wireless technologies to support applications originally conceived to use 5.9 GHz DSRC radio technology.

- ***What is the role of public education in improving communication between vehicles and infrastructure?***
  As DOT considers deploying applications that may use advanced wireless technologies to create a fully connected transportation network, the agency should also consider the role of education and communication with the public. There are related questions and issues surrounding user needs and expectations, and public use and acceptance of new technologies.

- ***What are the implications of a multi-application vehicle communications solution that extends beyond safety functions?***
  Because technology requirements for transportation applications will differ, it will be important to explore how to use existing advanced wireless technologies and other communications technologies to develop a solution that includes multiple applications and that can be deployed in a timely manner.

- ***How can advanced wireless technologies contribute to national interoperability and deployment of a fully connected transportation system?***
  National interoperability is essential to widespread deployment regardless of the technology employed (DSRC, MANET, etc.). Mobile ITS and electronic communications technologies are advancing rapidly, but an important issue for ongoing discussion is the extent to which multiple and different technologies can be leveraged now or deployed over time in order for drivers and transportation system managers to realize safety and other benefits.

- ***Continue to discuss the full spectrum of technologies and applications that are being considered.*** Consumer electronics devices such as cellular telephones, personal navigation devices, and mobile Internet devices are some of the enabling technologies that can provide vehicle and infrastructure communications applications. DSRC wireless communications capabilities are another important means of delivering a range of mobility and "safety beneficial" applications. It will be important to continue to discuss available technologies and applications that can be deployed to meet DOT's objectives.

- ***How might the political and financial context impact the use of advanced wireless technologies to enable safety and other benefits through vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-system manager communications over a 10 to 20 year period?***
  DOT hopes to make use of traditional and advanced wireless technologies to connect the transportation network over a fairly long-term period, with several phases of deployment. It will be helpful to reflect on the political and financial implications of deploying such a network over time, especially as commercial partners begin to play a role in deploying complementary technologies, devices, and applications.

Appendix D: List of Acronyms

AODV	Ad-hoc On-Demand Distance Vector Routing Protocol
BHAG	Bold, hairy, audacious goal
BRT	Bus rapid transit
CALTRANS	California Department of Transportation
COTS	Commercial-off-the-shelf [application]
CPU	Central processing unit (or "processor")
DARPA	Defense Advanced Research Projects Agency (part of DoD)
DoD	United Stated Department of Defense
DOT	United States Department of Transportation
DSL	Digital subscriber line
DSRC	Dedicated short range communications
DTN	Delay Tolerant Networking
EPLAR	Enhanced Position Location and Reporting
FCC	Federal Communications Commission
GHz	Gigahertz unit of frequency
GIS	Geographic information systems
GPS	Global Positioning System
GSM	Global System for Mobile communications
HNS	High Beam Networking System
HOT	High-occupancy toll
HSLS	Hazy Sighted Link State Routing Protocol
IP	Internet Protocol
ISART	International Symposium on Advanced Radio Technologies
ITS	Intelligent Transportation Systems
JTRS	Joint Tactical Radio System
LMTP	Local Mail Transfer Protocol
MAC	Media Access Control
MANETs	Mobile ad-hoc networks
MIMO	Multiple-input multiple-output
NOx	Generic term for nitrogen oxides produced during combustion
OFDM	Orthogonal frequency-division multiplexing
OLSR	Optimized Link State Routing Protocol
OSI	Open Systems Interconnection Basic Reference Model
PNT	Precision, Navigation, and Timing
RITA	DOT's Research and Innovative Technology Administration
ROW	Right-of-way
SNA	Systems network architecture developed by IBM
SRWF	Soldier Radio Wave Form
SSL	Secure Sockets Layer
TCP	Transmission Control Protocol
TTNT	DARPA's Tactical Targeting Network Technology
VII	Vehicle Infrastructure Integration
WINT	War Fighter Information Network-Tactical