US	United States	The United States of America, consisting 50 states and a federal district.
USD	US Dollars	
USDOT	US Department of Transportation	
V2C	Vehicle-to-Cloud or Vehicle-to-Centre	Transmission of information from vehicles to the Could, or vehicles to the control centre.
V2I	Vehicle-to-Infrastructure	Transmission of information from vehicles to the road infrastructure to enable a variety of safety, mobility and environmental applications.
V2V	Vehicle-to-Vehicle	Transmission of basic safety and other information between vehicles to facilitate warnings to drivers concerning traffic conditions and impending crashes.
V2X	Vehicle-to-anything (or other) communications	Communications between a vehicle and any external entity, including V2I, V2V, V2C or vehicle to any other device such as mobile phones.
ViCS	Vehicle Information and Communication System	A system to provide real-time information to car navigation systems in Japan.
VMS	Variable Message Sign	An electronic sign often used on roadways to display dynamic messages to inform, warn or guide travellers.
WA	Western Australia	The State of Western Australia
Wi-Fi		Wireless networking technology that uses radio waves to provide wireless high speed Internet and network connections
WLAN	Wireless Local Area Network	Wireless computer network that links two or more devices over short distances using radio or infrared signals.

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Appendix XXXVIII. Ministry of Land, Infrastructure, Transport, and Tourism, *ITS (Intelligent Transport System) Spot Services.*

ITS (Intelligent Transport System) Spot Services

Outline

ITS Spot services consist of three basic services that are made available as an all-in-one system by high speed, high volume road-to-vehicle communications. The first is Wide-Range Road Traffic Information. By transmitting road traffic information in real-time, car navigation systems can search wide-area expressways that cross prefectural borders, urban expressways and other roads, and select the fastest route based on the latest information. The second is safe Driving Support. ITS spots provide wide-area road traffic information on a regular basis including traffic safety issues for specific roads. In emergencies, they provide information that supports safe driving. The third is ETC. ITS spot services utilize the same technologies as ETC, therefore existing ETC services can be enjoyed with a compatible car navigation system. And other services are that information on tourist sites and updated maps are provided over the internet with some car navigation systems.

Backgound

Traffic accidents have increased, resulting in a death toll of about 5,000 persons per year. Additionally, traffic congestion in urban areas has caused economic losses amounting to 12 trillion yen, and time losses amounting to 5.6 billion person-hours. Major problems have surfaced with respect to transport safety and efficiency. Also, issues such as environmental deterioration along roads, disharmony with the global environment, and increased energy consumption are growing in severity and importance. Especially,
= In expressways in urban area, it is essential to guide the routes considered traffic information because of complex network of the roads.
= In the metropolitan expressway, 50,000 accidents of falling object per year have occurred.

Outcome

At the end of December 2011, there were about 34.24 million ETC-equipped vehicles. ETC users now account for 86.2% of all vehicles on expressways in Japan.
ITS spot services are available in about 1,600 places centering on expressways in Japan as of August 2011. With intercity expressways, an ITS spot is installed about every 10 to 15 km including about 90 locations before each junction, while with urban expressways, a spot is installed about every 4 km.
The number of accidents in the Sangubasi Curve, which is one of the highest numbers of traffic accident spots in the metropolitan expressway, has dropped by about 60% by providing congestion information ahead of the curve.

Key words

ITS, ETC, ITS Spot Services, expressways, congestion, environment, Information, Telecommunication, Toll booth

Inquiry point

Road Bureau, MLIT Japan

Appendix XXXIX. Kengo Kishimoto, et al., *Cooperative Inter-Infrastructure Communication System Using 700 MHz Band*, SEI TECHNICAL REVIEW, Number 78, (Apr. 2014).

Cooperative Inter-Infrastructure Communication System Using 700 MHz Band

Kengo KISHIMOTO*, Masaya YAMADA and Masayuki JINNO

In Japan, as part of the Intelligent Transport System (ITS), research, development and deployment of the Universal Traffic Management System (UTMS) have been promoted for the purposes of environmental preservation, safety support and traffic congestion reduction. For the application of UTMS, infrastructure-to-vehicle (I2V/V2I) and inter-infrastructure (I2I) communications are vitally important. As one of the possible solutions to these needs, we are studying the use of the 700 MHz radio band. This paper reports on our research and development for the practical application of UTMS using the 700 MHz band for I2V/V2I, I2I and vehicle-to-vehicle (V2V) communications. We have focused particularly on I2I communications for enhanced traffic signal control.

Keywords: I2I communication, cooperative system, wireless ITS, 700 MHz band, signal control

1. Introduction

In Japan, research and development for practical application of the Universal Traffic Management System (UTMS) are being carried out mainly by the UTMS Society of Japan aiming at environmental preservation, traffic safety and congestion reduction. Currently, diverse applications have become available of the system, and traffic control technologies have been increasingly sophisticated. Communications media are also making remarkable progress particularly for wireless broadband technology such as mobile phones and wireless LANs. The linkage of these technologies is essential for the advancement of the Intelligent Transport System (ITS) in the future. For instance, use of radio wave media allowing geographically widespread and seamless infrastructure-to-vehicle/vehicle-to-infrastructure (I2V/V2I) communications is being considered as a means of enhancing the Driving Safety Support Systems (DSSS) which reduce accidents by providing safe driving supporting information to drivers via infrared beacons.

Enhanced traffic control requires communications between roadside terminal units. However, in recent years, the installation of cables for transmitting information between terminals has become a problem in terms of landscape and maintenance, resulting in the difficulty of wired communication. For this reason, and for the further effective use of radio wave and installed facilities, we are studying the possibility of wireless communication between the roadside terminal units, i.e., infrastructure-to-infrastructure (I2I) communications by using wireless roadside units (hereinafter referred to as "RSU") for I2V/V2I communications installed at intersections.

This paper illustrates I2V/V2I, I2I, and vehicle-to vehicle (V2V) communications systems that use wireless 700 MHz ITS to enhance traffic signal control, and introduces the requirements of RSUs. Also, the paper presents experimental plans and discusses tasks to be reviewed in the future.

2. What Is 700MHz Band Wireless ITS

Recent years have seen remarkable advances in wireless broadband technologies such as mobile phones and wireless LAN, and progressing alongside with them are communication media. The Japanese government announced in December 2011 that 760 MHz band would be allocated for ITS. Later communication standards in compliance with this announcement were established (ARIB STD T-109. See **Fig. 1** and **Table 1**). For ITS, in accordance with these standards, the communication period is divided by time between I2V/V2I and V2V communications with the bandwidth of 10 MHz taken for one channel. RSU transmits the information during the I2V/V2I communications period by the time division multiple access (TDMA)

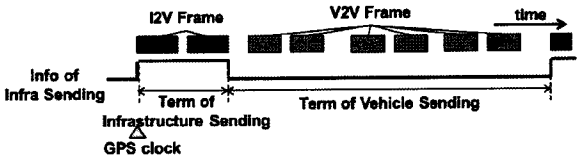

Fig. 1. Media access control of wireless 700 MHz band ITS

Table 1. Specifications of wireless 700 MHz band ITS

Conditions	Specifications
Center frequency	760 MHz (Single frequency)
Occupied bandwidth	9 MHz or lower
Error correction	Convolution FEC Rate1/2, 3/4
Modulation method	BPSK OFDM / QPSK OFDM / 16QAM OFDM
Transmission power	10 mW MRP or lower
Communication method	Broadcast
Media access control	SSMA/DA+TDMA

method*1 while the on-vehicle unit (hereinafter referred to as "OBU") transmits the information during the V2V communications period by the carrier sense multiple access/collision avoidance (CSMA/CA) method*2 to share the frequency channels.

Since the choices of media which can be used for ITS are thus increasing, building systems that make effective use of these media will lead to efficient realization of multiple applications.

3. V2V, I2V/V2I, and I2I Communications Systems

From the viewpoint of enhancing cost performance for spreading the equipment and devices, rational construction of systems is desirable. We therefore considered the possibility of having multiple systems share the 700 MHz band wireless ITS and link to each other. **Table 2** shows application examples of the systems and **Fig. 2** illustrates connection between the systems.

Table 2. Application examples of V2V, I2V/V2I, and I2I communications systems

	V2V communications	I2V/V2I communications	I2I communications
Kinds	-Driving Safety Support -Smooth driving	-Driving Safety Support, -Smooth driving	-Enhancement of signal control

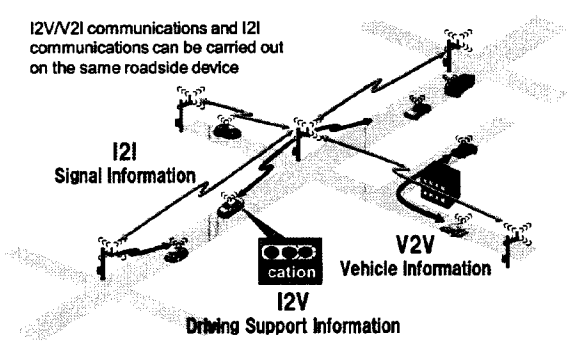

Fig. 2. Illustration of V2V, I2V/V2I, and I2I communications systems

Here, we focused on wireless I2I communications needs that have not been addressed to date. By sharing frequency resources and the RSUs for I2V/V2I communications installed at intersections with I2I communications, radio wave and facilities can be further effectively used. We also studied the possibility of using I2I communications by the methods that would have minimum effects on V2V and I2V/V2I communications. **Figure 3** shows the study flow.

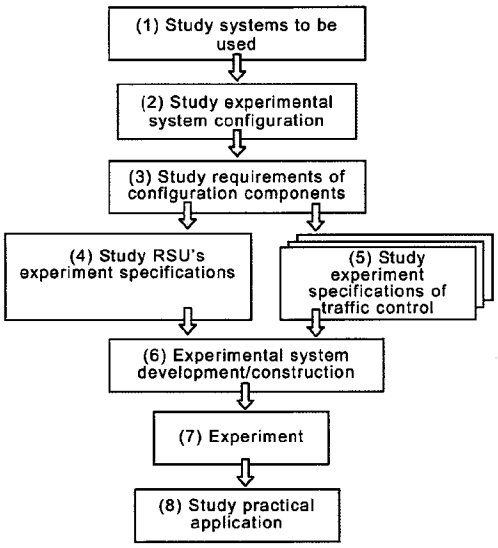

Fig. 3. Workflow

4. Applications Using I2I Communications

First, we selected applications using I2I communications which can enhance traffic control. **Table 3** shows the results.

Table 3. Applications using I2I communications

Type	Application	Outline
Emergency vehicle passage support	FAST	Perform signal control, etc. to give emergency vehicles driving priority.
Traffic flow control	Profile signal control	Predict traffic volume coming into intersection, and control signals to maximum number of vehicles which can pass through that intersection.
Disaster measures	Intelligent intersection	Carry out detour during intensification of terminal lines and when communications channels are cut off in disasters.

Figure 4 illustrates these applications.

We determined to clarify the communications requirements related to these applications and carry out field experiments on public roads to confirm the compatibility of wireless 700 MHz band ITS I2I communications for each application.

First, we set the priority order of the experiments, and decided to carry out demonstration experiments of applying I2I communications to FAST out of the applications given in **Table 3**. FAST is an advanced traffic signal control system designed to give driving priority to emergency vehicles. Information on the approach of an emergency vehicle exchanged in V2V communications is received by the infrastructure which in turn controls traffic signals ahead of the emergency vehicle to prioritize its passage.

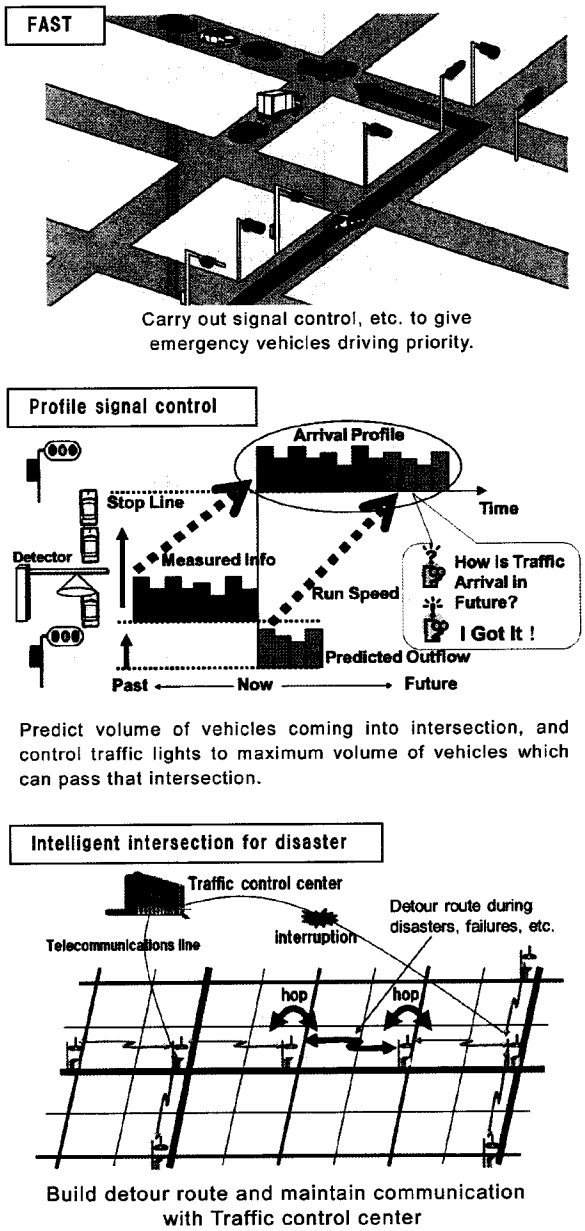

Fig. 4. Illustration of application

We studied the FAST system configuration using wireless 700 MHz band. **Figure 5** shows the system configuration.

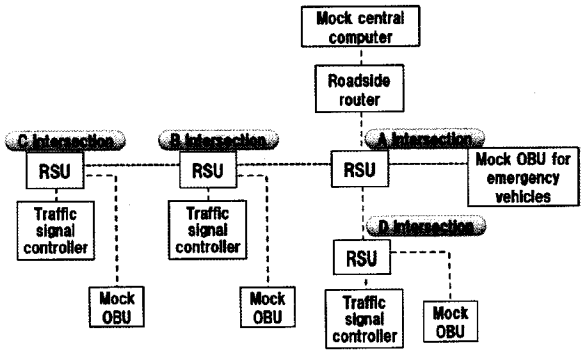

Fig. 5. FAST system configuration

5. Requirements of RSU

Next, we studied and summarized the main requirements for applying I2I communications to FAST such as the required communication method, quality and application functions. **Tables 4 and 5** show the results.

The study has confirmed that the requirements in **Table 4** are not independent of the application and common to the menus using I2I communications.

Table 4. Requirements of wireless communications

Item			Requirements
Communication	Communication method	Destination	Specific RSU
		Relay	Yes
	Communication quality	Packet arrival rate	90% or more (Visibility 300 m)
		Transmission delay allowable time	1895 ms or less
	Communication details	Security measures	Encryption, Authentication

Table 5. Requirements of application functions

Item		Requirements
FAST	Signal control	Communication of signal control application data must be possible between central computer and signal controller
	FAST signal control	Must be able to transmit detection information of emergency vehicle to central computer Must be able to instruct FAST signal control from central computer
	Provision of emergency vehicle approach information	Must be able to transmit approach information of emergency vehicle to OBU

In the demonstration experiments, based on the information from the mock OBU for emergency vehicles, information will be sent to terminal units from the central computer via I2I communications that meet the above requirements to verify that wireless 700 MHz band I2I communications can be applied to the existing FAST system's traffic signal control.

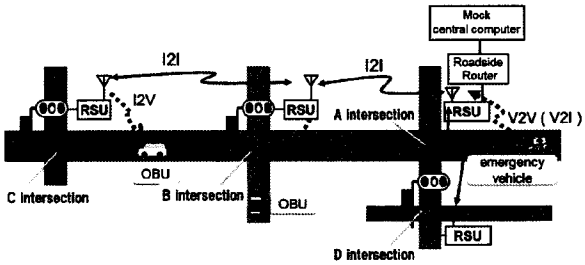

Fig. 6. Illustration of FAST demonstration experiment

Figure 6 illustrates FAST demonstration experiment. First, presence information is sent to the RSUs by V2V communications from the mock OBU for emergency vehicles to verify that emergency vehicle detection information is generated at the RSUs from the V2V communications information, and that the detection information is received by the mock central computer.

It will also be verified that the mock central computer having received the emergency vehicle detection information sends a FAST signal control command to the concerned signal controller to perform FAST signal control at the appropriate traffic lights.

Furthermore, it will also be confirmed that emergency vehicle approach information is sent from the concerned RSU and received by the mock OBU. The information transmission time (minimum/maximum/average value) via I2I communications will also be measured.

6. Experiment Schedule

Figure 7 shows the experiment schedule.

The system will be constructed in January 2014 to start experiments. Experiments on the sharing of frequency channels with I2V/V2I communications will also be conducted in FY2014.

For practical application of the system, our future tasks are to study the security, interoperability, and time-phased distribution of data for the sharing of frequency channels between I2V/V2I and V2V communications with the aim of applying communications standards for V2V and I2V/V2I communications to I2I communications.

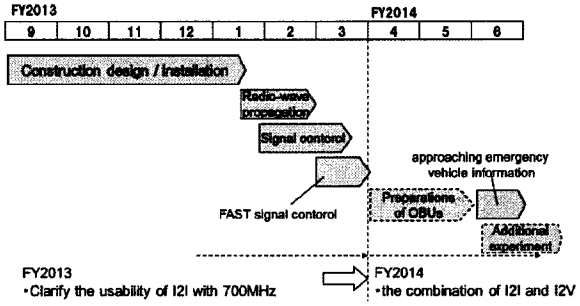

Fig. 7. Experiment schedule

7. Conclusion

This paper illustrated V2V, I2V/V2I, and I2I communications systems that use wireless 700 MHz ITS to enhance traffic signal control, and discussed the requirements of RSUs. Demonstration experiment plans and system configuration were also presented, and our future tasks were clarified.

For the future, we are planning to carry out demonstration experiments to evaluate the communication quality of I2I communications and verify compatibility to applications.

8. Acknowledgements

This paper summarizes the activities of the UTMS Society of Japan under the guidance of the National Police Agency. We would like to express our gratitude to the National Police Agency and UTMS Society of Japan for their helpful proposals and advice on technical reviews and experiment plans.

Technical Terms

*1 Time division multiple access (TDMA) method: One frequency channel is divided into several short timeslots and allotted to multiple communications devices to send data.

*2 Carrier sense multiple access/collision avoidance (CSMA/CA) method: Each communications device confirms that a channel is idle continuously for a certain period of time before sending data.

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(1) UTMS Society of Japan, "The activity report in 2012" (Jun. 2013)
(2) Association of Radio Industries and Businesses, "ARIB STD T-109" (02.14.2012)
(3) "UTMS Society of Japan" http://www.utms.or.jp/

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Appendix XXXX. Anna Lu, *Autonomous connected cars on their way*, SHANGHAI DAILY .COM (Jun. 8 2016).

Autonomous connected cars on their way

By Anna Lu | June 8, 2016, Wednesday |

Print Edition

EDITOR'S note:

INTERNET Plus, a concept highlighted in the government work report delivered by Premier Li Keqiang at the annual session of the National People's Congress in Beijing in March, is pushing the boundaries of China's traditional industries. Nowadays, enterprises across the country are embracing changes by incorporating advancements in the Internet and related technologies into their business models. In a series by Shanghai Daily, we explore how this concept is reshaping our world.

AUTONOMOUS connected cars are on their way to make intelligent transportation a dream come true for Shanghai residents but they are still a long way off before they actually hit the real roads from a sandbox.

As the first step towards the city's plan of filling a 100 square kilometer area with highly automated cars in three to five years, the National Intelligent Connected Vehicle (Shanghai) Pilot Zone yesterday invited reporters to an enclosed testing demonstration base — the first of its kind in China.

Loaded with various sensors, communication modules and electronic control units, the first batch of 25 self-driving cars set off on a journey of getting "street smart" in a 5 square kilometer area at Shanghai Auto Expo Park and Tongji University.

The trail blazers included Ford Transit, Chang'an CS75, Volvo XC90, Cadillac ATS-L, Roewe e50, Volkswagen Golf, and Range Rover Evoque. Foreign and domestic carmakers and technology suppliers sat behind the wheels as monitors. They were joined by experts from Chinese academic institutes like Tsinghua University, Tongji University and Shanghai Advanced Research Institute Chinese Academy of Science.

The country has just made "intelligent connected cars" a key direction of its 2025 roadmap to manufacturing upgrades. And this project called "a nice city" is set to take off in Jiading District, home to nearly 70 percent of the city's car manufacturing, and 80 percent automotive research and development.

Open platform

The test demonstration base was run like a virtual city for cars, though at this stage it was much smaller than the 32-acre Mcity set up in Michigan, the auto hub of US, and the industry's first.

"The driving situation in China is complicated. If an autonomous car can survive here, it will surely do well in the US but not necessarily the other way around. It is a challenge as well as an advantage to come up with better products," said Rong Wenwei, general manager of Shanghai International Automobile City that oversees the pilot zone.

"In Jiading, we want to build an open platform for all industry players to carry out their own tests."

At the first phase of the experiment, test cars will go through 29 challenges that simulate complex driving scenarios, with the help of its own artificial intelligence and special communication tools.

From intersections where traffic flow is complicated and mixed, to tunnels and boulevards where signals can get blocked, and to parking lots and electric charging spots that need real-time availability updates, cars will learn to understand and adapt to the environment information picked up by their own sensors and GPS, as well as given by infrastructure and shared between each other on a dedicated data exchange platform called V2X.

Together they will make a highly cooperative self-driving transportation system where even traffic lights and road signs can take initiatives to give cars the heads-up. Such team spirit is believed to give the system much more clairvoyance than mass deployment of sensor-based advanced driver assistance technology (ADAS) that focuses on every single car's ability to think and act like a human driver.

The latter is the current focus of many carmakers' research and development of autonomous vehicles and their commercialization since it is by comparison a much easier standalone project. The V2X application, which makes sense only when a large volume of cars are put on the same channel along with public facilities, is expected as a very visionary and faraway accomplishment.

While the US is taking the lead in making the equipment of V2X communication chips compulsory for cars as early as 2019, China's national standard for V2X technologies has long been absent.

Fu Yuwu, executive vice president of Society of Automotive Engineers China, said China will release its own roadmap for intelligent connected cars next month, and start its drafting of related standards first for active safety applications.

"An intelligent car cannot work without an intelligent transportation system for a safer, greener, more comfortable and efficient journey. But unfortunately in China the two studies are often separate," said Li Keqiang, key advisor to China's official roadmap to autonomous driving and automotive professor at Tsinghua University.

Only by fitting itself in the big picture of traffic can a car know how to change gear and plan fuel consumption by itself for higher economic performance. The test field will experiment with a green traffic belt that flows smoothly through traffic light changes without unnecessary braking and acceleration.

Holistic approach

And only by taking a holistic approach to predict environments beyond the sight of its artificial eyes can a smart connected car shorten its reaction time in an emergency situation where a fleeting second is a life-and-death matter. Safety issues, as a key focus of study at Shanghai's test field, now account for 19 of its 29 simulated scenes.

The complex encounters for test cars to face will be further diversified to 50 later this year to cover all the urban, rural and highway scenarios, and even grow over 100 to pave the way to much more ambitious tests in the next five years.

According to a blue print rolled out for the pilot zone, the test field will be extended this September to 27 square kilometers. Up to 1,000 test cars are expected to have some real-world experience in the core area of Anting Shanghai International Automobile City by the end of the year.

From 2018 to 2019, the expansion will cover the entire Anting Town, deploying a fleet of 5,000 automated cars in a 100 square kilometer area that includes highways. At the final stage till 2020, corridors with demonstration effect will be built up to connect Anting with Hongqiao Transportation Hub, with 10,000 self-driving cars running on 500 kilometers long roads.

Xie Fei, deputy general manager of China Automotive Engineering Research Institute, said China's advanced communication infrastructure, with its 5G era coming at the same pace as overseas highly developed markets, empowers the local auto industry to play some serious catch-up in the area of autonomous cars.

"Foreign carmakers have spent 30 years developing advanced driver assistance technologies, while we as a late starter have little such know-how of our own. But with V2X technologies on board, we can navigate to a highly automated future in a much more independent way," Xie said.

Shanghai's test demonstration zone will experiment with two mainstream V2X communication technologies, DSRC and LTE-V.

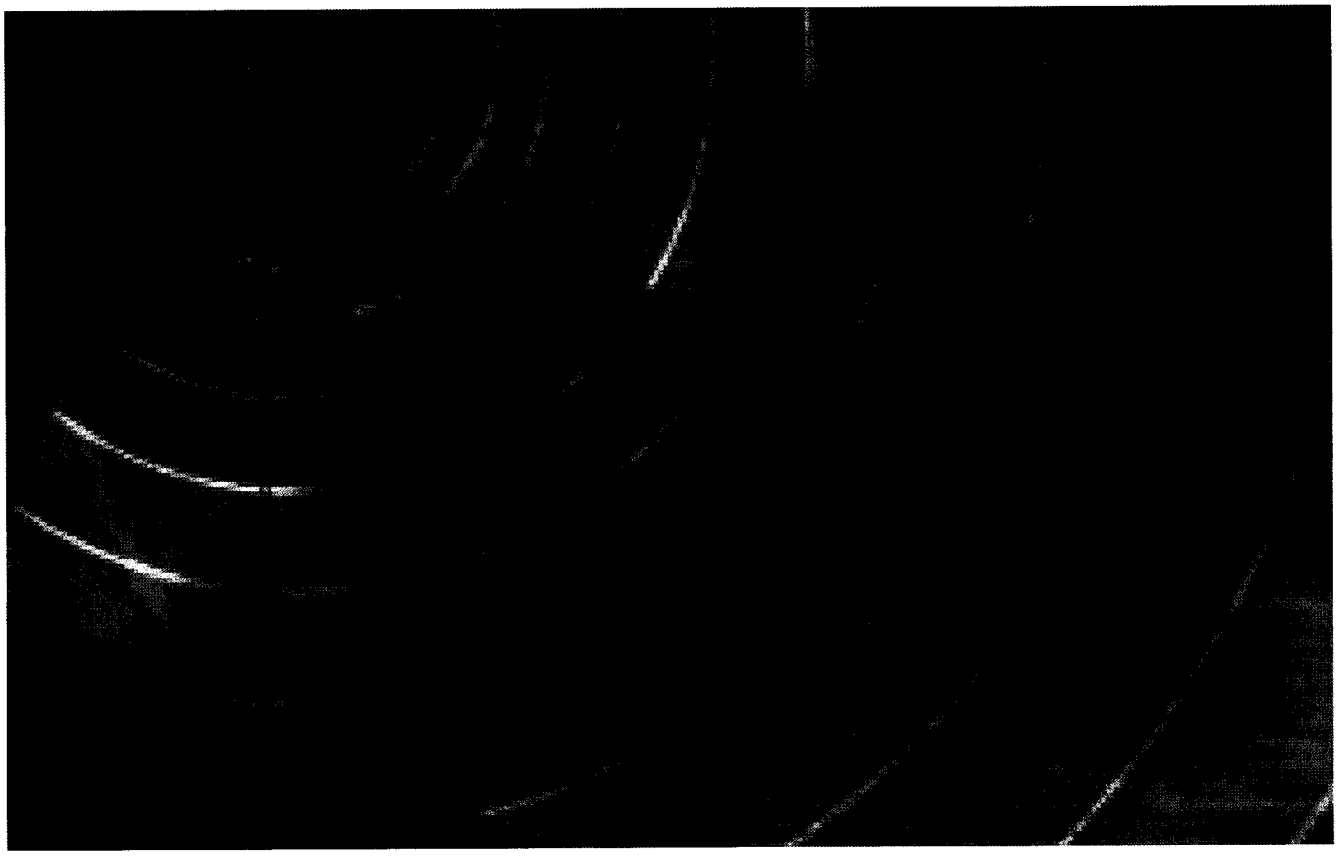
The first, which has been standardized by the US, responds fast, while the second, favored by China, features longer effective range, making the two highly complementary. And the gap between their response times will be narrowed to a point of being dismissible by the wide application of 5G, said Rong of Shanghai International Automobile City.

Appendix XXXXI. Larry Greenemeier, *Will Millimeter Waves Maximize 5G Wireless?*, SCIENTIFIC AMERICAN (June 23, 2015).

Will Millimeter Waves Maximize 5G Wireless?

Wireless companies want next-generation gadgets to download at rates of gigabits per second. The question is how to make it happen

- By Larry Greenemeier on June 23, 2015



5G: Next-generation wireless will have to deliver a huge leap in performance to handle surging mobile network traffic, much of which is multimedia content. *Credit: Courtesy of Getty.*

Advertisement

Every decade or so since the first cellular networks appeared the companies that make mobile devices and the networks linking them have worked out new requirements defining transmission speeds, capacity and other technical characteristics. Each new set of requirements is referred to as the latest "generation."

Today's fourth-generation, or 4G, wireless digital networks made it possible for smartphones and tablets to deliver voice and data communications with bandwidths measuring many millions of bits per second. Specific data speeds vary by carrier but most networks enable users to download a file containing a full-length movie—more than one gigabyte in size—in less than 10 minutes.

The next generation—5G wireless—will have to deliver a huge leap in performance to handle surging mobile network traffic, much of which will be large multimedia files. According to Cisco Systems' most recent Visual Networking Index (VNI), mobile data traffic will grow 10-fold globally between 2014 and 2019, reaching 24.3

exabytes per month worldwide in 2019. (An exabyte is one billion gigabytes.)

The details of 5G are a long way from being decided but it is expected to provide Internet connections 40 times faster and with at least four times more coverage worldwide than the current 4G Long Term Evolution (LTE) wireless communications standard. Even without a clear definition of 5G, testing is underway or in the works in places including Finland, Russia and South Korea.

One of the most promising potential 5G technologies under consideration is the use of high-frequency signals—in the millimeter-wave frequency band—that could allocate more bandwidth to deliver faster, higher-quality video and multimedia content. Other lines of research seek to enable a single mobile device to simultaneously connect to multiple wireless networks to boost connectivity and speed.

Mustafa Cenk Gursoy, an associate professor in Syracuse University's College of Engineering and Computer Science, and researchers at The Ohio State University have received about $678,000 in funding from the National Science Foundation to study ways to more efficiently access the radio spectrum over the next three years.* *Scientific American* spoke with Gursoy about the need for 5G and the role that millimeter-wave frequencies, in particular, could play.

[*An edited transcript of the interview follows.*]

Why do we need a new wireless standard?

The motivation behind a new standard is the exponential growth in wireless. We're talking about billions of users, billions of devices and billions of connections. That's something that a new standard has to address, because 4G is not going to be efficient enough to handle this much growth, much of it due to mobile video traffic. Smartphones, tablets, social networking sites and video-sharing sites have helped mobile video traffic become more than half of all mobile traffic.

On top of this, people have really high expectations for wireless services. They want a high level of reliability, low levels of latency [delayed uploading or downloading of content] and constant connectivity—anytime, anywhere. The Internet of Things, where new types of devices are connected digitally, as well as the increasing use of mobile technology for health care, smart power grid and vehicular networking create new expectations for wireless, especially when it comes to speed and reliability.

Any move to 5G wireless technology is still years away. What should we know about the standard at this point?

There's been an increase in interest in 5G within the past year, particularly from the research community. And telecom companies in the U.S., Europe, South Korea, China and Japan are interested in designing, testing and implementing these kinds of systems, so there's definitely some momentum building. It's not definite what 5G will be but people are talking about candidate technologies and what needs to be addressed in this next-generation wireless standard. And it might not be that far away—some companies are thinking they will have 5G systems up and running by 2020. That's not really a lot of time.

How will 5G differ from 4G?

One difference will be that 5G may move wireless signals to a higher frequency band, operating at millimeter-length wavelengths between 30 and 300 gigahertz (GHz) on the radio spectrum. That's going to open up a huge

amount of bandwidth and alleviate concerns about wireless traffic congestion. Radar, satellite and some military systems use this area of the spectrum currently but it's definitely less occupied than the spectrum currently in use. In addition, whereas 4G supports hundreds of megabits-per-second data rates, 5G is promising data rates in the gigabits-per-second range. It may not support those higher rates at all times in all places, but it will lower latency rates overall.

Are there drawbacks to wireless devices operating at such high frequencies?

Generally, as you move to higher frequencies, transmission range gets shorter—hundreds of meters rather than kilometers. And signals are unable to penetrate walls easily. Some hardware components, such as analog-to-digital converters, might also be expensive. We are still learning about millimeter wave and are testing its capabilities. Another challenge is if the transmitter and the receiver don't have a line-of-site connection, there is a lot of attenuation [loss] in the signal. We're conducting performance analyses to better understand the communication reliability and plan to publish a paper in the fall at the IEEE Vehicular Technology Conference in Boston.

What can be done to overcome these limitations?

There has been a trend toward small cells [portable base stations often called microcells, femtocells or picocells, depending on their ranges]. Millimeter waves can take advantage of these technologies, as they are better suited for transmission over relatively short ranges. High-frequency signals can also be reused across short distances by different cells in a network, meaning the available spectrum is used more efficiently. In addition, antenna size is inversely proportional to frequency size, so higher-frequency signals would require smaller antennas. You could pack more antennas into devices. That enables directional transmissions—you could actually steer the signal in a particular direction. This could overcome the loss of some of the signal transmission strength. More than one antenna operating in the same frequency range can also send multiple streams of data, increasing the data rate.

What research are you and your colleagues doing in the area of millimeter waves?

This first year we are learning the characteristics of communication in the millimeter range of frequencies and doing some performance analyses of millimeter-wave networks. For a short range, with devices in fixed positions, millimeter waves can connect devices to a network. The challenge is delivering this service to a user who is walking or driving. I also want to see networking scenarios where you can actually support multimedia traffic in a mobile environment using millimeter wave.

How does millimeter wave improve energy efficiency?

The use of directional transmission between the base station and a mobile device reduces signal interference, and that might account for the reduction in energy use we're seeing. When you establish a direct link and suppress interference, you can send data at higher rates for a given transmission energy level. Therefore, throughput per unit energy increases and hence energy efficiency improves. In such an analysis, it is also important to take into account possible increases in hardware energy consumption due to operation at high frequencies. Energy efficiency is very important here as well because of the growth in the number of users and devices—and efficiency should be considered with any new standard.

**Editor's Note (6/23/15): This sentence was edited after posting to correct the amount of NSF funding. The Ohio State researchers received about $460,000 in funding while Cenk's Syracuse team received more than $218,000*

in funding.

Appendix XXXXII. Press Release, USDOT, *Transportation Sec. Foxx Announces Steps to Accelerate Road Safety Innovation* (May 13, 2015).

Transportation Sec. Foxx announces steps to accelerate road safety innovation

NHTSA
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

DOT 49-15
Wednesday, May 13, 2015
Contact: Gordon Trowbridge, 202-366-9550, Public.Affairs@dot.gov

Pushing V2V forward, modernizing regulatory framework aimed at speeding up technologies that can save lives, reduce crashes

MOUNTAIN VIEW, Calif. – U.S. Transportation Secretary Anthony Foxx was at Delphi Labs @ Silicon Valley today to announce a series of steps to speed life-saving technology innovations to America's highways. He also pledged to work with the auto industry and technology companies to ensure that vehicle automation technologies with demonstrated safety benefits can come to market. Secretary Foxx was in California as part of his tour to highlight our nation's third annual Infrastructure Week, which brings together thousands of stakeholders across the country to highlight the importance of investing in America's infrastructure future.

"The Department wants to speed the nation toward an era when vehicle safety isn't just about surviving crashes; it's about avoiding them," Secretary Foxx said. "Connected, automated vehicles that can sense the environment around them and communicate with other vehicles and with infrastructure have the potential to revolutionize road safety and save thousands of lives."

The Department's National Highway Traffic Safety Administration will move ahead of its public time table for its proposal to require vehicle-to-vehicle (V2V) communication devices in new vehicles, and work to accelerate testing necessary to ensure that V2V and vehicle-to-infrastructure transmissions are free from radio interference.

The steps Secretary Foxx announced today include:

- **Accelerating the schedule of NHTSA's proposal to require V2V equipment on new vehicles.** Last year, the agency published an advance notice of proposed rulemaking and planned to send a proposed rule to the Office of Management and Budget (OMB) for review in in 2016. Foxx announced the Department has accelerated its goal and plans to send the proposal for OMB review by the end of this year.
- **Developing an expedited test plan on interference with V2V signals**. Members of Congress and the Federal Communication Commission, which controls radio spectrum, have expressed interest in testing whether the 5.9GHz spectrum reserved for V2V communications can be "shared" with unlicensed users. The Department is committing to complete a preliminary test plan within 12 months after industry makes production-ready devices available for testing.

- **Ensuring that the Department's regulatory framework accelerates safety innovations.** Innovation makes America's roads safer, and the Department is working to identify obstacles in the current framework to better understand where problems can be addressed internally and where we will need Congressional action.

Delphi Labs @ Silicon Valley is one of many research facilities working on connected automation technologies. Earlier this year, Delphi researchers drove an automated vehicle from California to New York.

Earlier this year, U.S. DOT released a landmark study titled "Beyond Traffic," that looked at the trends and choices facing American transportation over the next three decades. These included a rapidly growing population, demographic and migratory shifts in rural and urban areas, increasing freight volume, and innovations like V2V that will enhance safety and efficiency. To learn more about the study, please visit www.dot.gov/BeyondTraffic.

Stay connected with NHTSA: Search for open recalls with VIN look up I Download the Safercar Mobile App for Apple or Android devices I Receive recall alerts by email I Visit us on Facebook.com/NHTSA I Follow us on Twitter.com/NHTSAgov I Watch 5-Star Safety Ratings crash tests on YouTube.com/USDOTNHTSA I SaferCar.gov

Appendix XXXXIII. Ian Poole, *OFDM Orthogonal Frequency Division Multiplexing Tutorial*, Radio-Electronics.com.

What is OFDM | Orthogonal Frequency Division Multiplexing

OFDM Orthogonal Frequency Division Multiplexing Tutorial

- OFDM: Orthogonal Frequency Division Multiplexing, is a form of signal modulation that divides a high data rate modulating stream placing them onto many slowly modulated narrowband close-spaced subcarriers, and in this way is less sensitive to frequency selective fading.

Orthogonal Frequency Division Multiplexing or OFDM is a modulation format that is being used for many of the latest wireless and telecommunications standards.

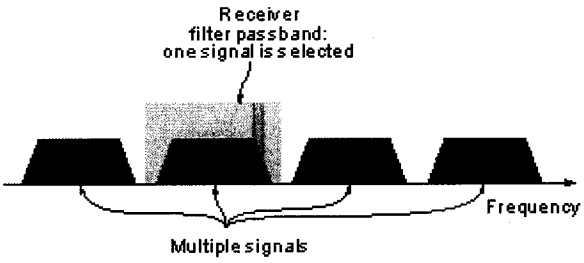
OFDM has been adopted in the Wi-Fi arena where the standards like 802.11a, 802.11n, 802.11ac and more. It has also been chosen for the cellular telecommunications standard LTE / LTE-A, and in addition to this it has been adopted by other standards such as WiMAX and many more.

Orthogonal frequency division multiplexing has also been adopted for a number of broadcast standards from DAB Digital Radio to the Digital Video Broadcast standards, DVB. It has also been adopted for other broadcast systems as well including Digital Radio Mondiale used for the long medium and short wave bands.

Although OFDM, orthogonal frequency division multiplexing is more complicated than earlier forms of signal format, it provides some distinct advantages in terms of data transmission, especially where high data rates are needed along with relatively wide bandwidths.

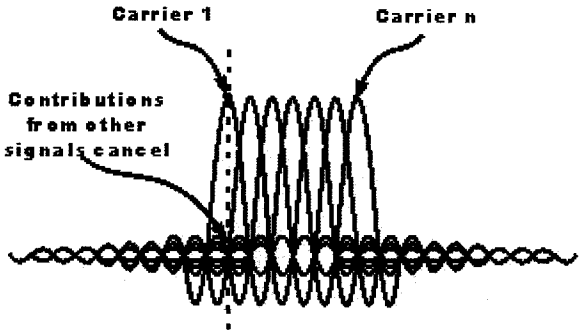
What is OFDM? - The concept

OFDM is a form of multicarrier modulation. An OFDM signal consists of a number of closely spaced modulated carriers. When modulation of any form - voice, data, etc. is applied to a carrier, then sidebands spread out either side. It is necessary for a receiver to be able to receive the whole signal to be able to successfully demodulate the data. As a result when signals are transmitted close to one another they must be spaced so that the receiver can separate them using a filter and there must be a guard band between them. This is not the case with OFDM. Although the sidebands from each carrier overlap, they can still be received without the interference that might be expected because they are orthogonal to each another. This is achieved by having the carrier spacing equal to the reciprocal of the symbol period.



Traditional view of receiving signals carrying modulation

To see how OFDM works, it is necessary to look at the receiver. This acts as a bank of demodulators, translating each carrier down to DC. The resulting signal is integrated over the symbol period to regenerate the data from that carrier. The same demodulator also demodulates the other carriers. As the carrier spacing equal to the reciprocal of the symbol period means that they will have a whole number of cycles in the symbol period and their contribution will sum to zero - in other words there is no interference contribution.



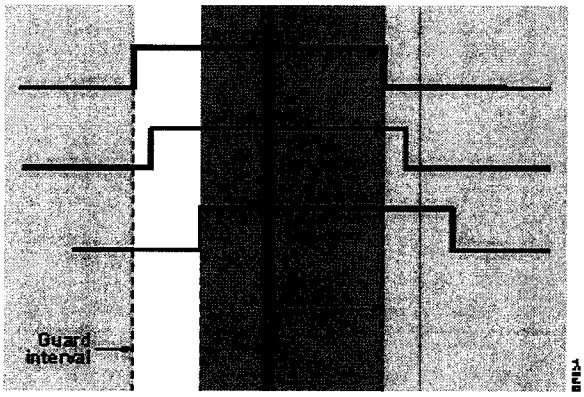
OFDM Spectrum

One requirement of the OFDM transmitting and receiving systems is that they must be linear. Any non-linearity will cause interference between the carriers as a result of inter-modulation distortion. This will introduce unwanted signals that would cause interference and impair the orthogonality of the transmission.

In terms of the equipment to be used the high peak to average ratio of multi-carrier systems such as OFDM requires the RF final amplifier on the output of the transmitter to be able to handle the peaks whilst the average power is much lower and this leads to inefficiency. In some systems the peaks are limited. Although this introduces distortion that results in a higher level of data errors, the system can rely on the error correction to remove them.

Data on OFDM

The data to be transmitted on an OFDM signal is spread across the carriers of the signal, each carrier taking part of the payload. This reduces the data rate taken by each carrier. The lower data rate has the advantage that interference from reflections is much less critical. This is achieved by adding a guard band time or guard interval into the system. This ensures that the data is only sampled when the signal is stable and no new delayed signals arrive that would alter the timing and phase of the signal.



Guard Interval

The distribution of the data across a large number of carriers in the OFDM signal has some further advantages. Nulls caused by multi-path effects or interference on a given frequency only affect a small number of the carriers, the remaining ones being received correctly. By using error-coding techniques, which does mean adding further data to the transmitted signal, it enables many or all of the corrupted data to be reconstructed within the receiver. This can be done because the error correction code is transmitted in a different part of the signal.

OFDM advantages & disadvantages

OFDM advantages

OFDM has been used in many high data rate wireless systems because of the many advantages it provides.

- ***Immunity to selective fading:*** One of the main advantages of OFDM is that is more resistant to frequency selective fading than single carrier systems because it divides the overall channel into multiple narrowband signals that are affected individually as flat fading sub-channels.
- ***Resilience to interference:*** Interference appearing on a channel may be bandwidth limited and in this way will not affect all the sub-channels. This means that not all the data is lost.
- ***Spectrum efficiency:*** Using close-spaced overlapping sub-carriers, a significant OFDM advantage is that it makes efficient use of the available spectrum.
- ***Resilient to ISI:*** Another advantage of OFDM is that it is very resilient to inter-symbol and inter-frame interference. This results from the low data rate on each of the sub-channels.
- ***Resilient to narrow-band effects:*** Using adequate channel coding and interleaving it is possible to recover symbols lost due to the frequency selectivity of the channel and narrow band interference. Not all the data is lost.
- ***Simpler channel equalisation:*** One of the issues with CDMA systems was the complexity of the channel equalisation which had to be applied across the whole channel. An advantage of OFDM is that using multiple sub-channels, the channel equalization becomes much simpler.

OFDM disadvantages

Whilst OFDM has been widely used, there are still a few disadvantages to its use which need to be addressed when considering its use.

- ***High peak to average power ratio:*** An OFDM signal has a noise like amplitude variation and has a relatively high large dynamic range, or peak to average power ratio. This impacts the RF amplifier efficiency as the amplifiers need to be linear and accommodate the large amplitude variations and these factors mean the amplifier cannot operate with a high efficiency level.
- ***Sensitive to carrier offset and drift:*** Another disadvantage of OFDM is that is sensitive to carrier frequency offset and drift. Single carrier systems are less sensitive.

OFDM variants

There are several other variants of OFDM for which the initials are seen in the technical literature. These follow the basic format for OFDM, but have additional attributes or variations:

- ***COFDM:*** Coded Orthogonal frequency division multiplexing. A form of OFDM where error correction coding is incorporated into the signal.
- ***Flash OFDM:*** This is a variant of OFDM that was developed by Flarion and it is a fast hopped form of OFDM. It uses multiple tones and fast hopping to spread signals over a given spectrum band.
- ***OFDMA:*** Orthogonal frequency division multiple access. A scheme used to provide a multiple access capability for applications such as cellular telecommunications when using OFDM technologies.
- ***VOFDM:*** Vector OFDM. This form of OFDM uses the concept of MIMO technology. It is being developed by CISCO Systems. MIMO stands for Multiple Input Multiple output and it uses multiple antennas to transmit and receive the signals so that multi-path effects can be utilised to enhance the signal reception and improve the transmission speeds that can be supported.
- ***WOFDM:*** Wideband OFDM. The concept of this form of OFDM is that it uses a degree of spacing between the channels that is large enough that any frequency errors between transmitter and receiver do not affect the performance. It is particularly applicable to Wi-Fi systems.

Each of these forms of OFDM utilise the same basic concept of using close spaced orthogonal carriers each carrying low data rate signals. During the demodulation phase the data is then combined to provide the complete signal.

OFDM, orthogonal frequency division multiplexing has gained a significant presence in the wireless market place. The combination of high data capacity, high spectral efficiency, and its resilience to interference as a result of multi-path effects means that it is ideal for the high data applications that have become a major factor in today's communications scene.

Appendix XXXXIV. USDOT, *ITS Research Fact Sheets – Connected Vehicle Certification Process.*

Intelligent Transportation Systems - Connected Vehicle Certification Program

ITS Research Fact Sheets - Connected Vehicle Certification Program

Introduction

Connected vehicle certification is a key research program of the Intelligent Transportation Systems Joint Program Office (ITS JPO), a program office within the U.S. Department of Transportation's (U.S. DOT) Research and Innovative Technology Administration (RITA).

Certification is the process of ensuring that system components, manufactured according to program requirements, perform as intended. Certification will ensure that users can trust that the components will work within the system.

Vision

The vision for the U.S. DOT connected vehicle certification research program is to work in close cooperation with public and private partners to establish appropriate certification requirements for equipment.

Research Plan

The ITS connected vehicle program deployment strategy will address the inherent risks to consumer safety, security, and privacy associated with a system breakdown. The system will have national interoperability, and, as such, national standards and criteria for certification of individual products that have access to the system, system processes, and operational procedures will need to be established. Since this is a new high-risk industry without an established consumer base, ITS JPO will work with industry to develop certification processes and procedures independently.

The ultimate form that a certifying entity would take, and the potential role of the Federal Government in oversight and enforcement of certification requirements is yet to be determined. Those two questions will be investigated as part of both the technical research program as well as the Policy and Institutional Issues research program.

Certification research will primarily be focused on understanding the needs for device compliance, system security, and privacy requirements.

ITS JPO will conduct the following research activities in support of certification:

- **Policy Research Related to Certification**–A forum will be established for solving policy-related issues, such as determining what is to be certified; the entity that will be responsible for certification; and the parties that will need to obtain certification. This research is included within the Policy and Institutional Issues research program, and it is envisioned that Federal, State, and local government stakeholders will provide input and direction in this area.
- **Technical Requirements for Certification**–The level of components within a device, or which interfaces need to be certified will be defined. Additionally, how this certification is to be accomplished will be determined. It is envisioned

that the responsibility for this area of work will be shared by Government and industry. However, the Government will have a primary role in funding development prior to the emergence of a consumer market for certified products. In that sense, the Government will serve as an enabler and coordinator of this function.

- **Implementation Support and Oversight**–A third party entity will likely conduct implementation of the planned certification process. The implementation process will include development of test tools and methods. The Federal Government may have a role in assisting with start-up, and in overseeing operation and adherence to standards. This implies an ongoing operational role for the Federal Government beyond the scope of research.

Research Goals

- To work with industry to define certification needs and develop supporting test methods and tools.
- To develop a future plan that will make certification activities self-sustaining through fees for testing shaped by the organizations seeking those requirements.

Research Outcomes

The results of this program are intended to deliver:

- Nationwide interoperability of system components.
- Reduction of inherent risks to consumer safety, security and privacy in the event of a whole or partial system breakdown.
- Establishment of an oversight structure (governance plan) that will provide the processes and procedures for system access, as well as system enforcement.
- An open, well-defined process that allows manufacturers to know the system requirements necessary to provide trustworthy components.

Certification ensures a common operational framework for critical components.

ITS connected vehicle certification research is ready to work in close cooperation with public and private partners to establish appropriate certification requirements for equipment.

The deployment strategy addresses inherent risks to consumer safety, security, and privacy.

Certified consumer products are instrumental to a reliable system-wide interface.

Testing new equipment is crucial to the certification process.

To learn more about this research, contact:

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Appendix XXXXV. USDOT, *Fact Sheet: Improving Safety and Mobility Through Connected Vehicle Technology.*

U.S. Department of Transportation

SAFETYPILOT

CONNECTED VEHICLE TECHNOLOGY

Fact Sheet: Improving Safety and Mobility Through Connected Vehicle Technology

The U.S. Department of Transportation is committed to improving safety and mobility on our nation's roadways. As we look ahead to the next stage of roadway safety in America, connected vehicle technology shows great promise in transforming the way Americans travel. Through wireless technology, connected vehicles ranging from cars to trucks and buses to trains could one day be able to communicate important safety and mobility information to one another that helps save lives, prevent injuries, ease traffic congestion, and improve the environment.

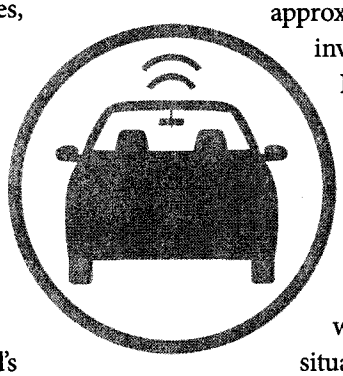
HOW CONNECTED VEHICLE TECHNOLOGY WORKS

The U.S. Department of Transportation is currently collaborating with some of the world's largest automobile manufacturers to research how wireless technology can enable vehicles to communicate with each other and with the infrastructure around them. Connected vehicle technology—vehicle-to-vehicle and vehicle-to-infrastructure communications—could one day alert motorists of dangerous roadway conditions, impending collisions, or dangerous curves. Connected vehicles could also "talk" to traffic signals, work zones, toll booths, school zones, and other types of infrastructure.

Connected vehicle systems are based on Dedicated Short Range Communications (DSRC)—a technology similar to Wi-Fi—which is fast, secure, reliable, and unlikely to be vulnerable to interference. Using either in-vehicle or after market devices that continuously share important safety and mobility information, vehicles ranging from cars to trucks and buses to trains would be able to "talk" to each other and to different types of roadway infrastructure.

IMPROVING SAFETY

Analyses by the U.S. Department of Transportation's National Highway Traffic Safety Administration show connected vehicle technology could potentially address approximately 80 percent of the crash scenarios involving non-impaired drivers. Specifically, NHTSA research shows that this technology could help prevent the majority of types of crashes that typically occur in the real world, such as crashes at intersections or while changing lanes.



- Through in-vehicle warnings, drivers would be alerted to imminent crash situations, such as merging trucks, cars in the driver's blind side, or when a vehicle ahead of them brakes suddenly.
- By communicating with roadside infrastructure, drivers would be alerted when they are entering school zones, if workers are on the side of the road, and if an upcoming traffic light is about to change.

IMPROVING MOBILITY

According to the Texas Transportation Institute, American drivers spent 4.8 billion hours stuck in traffic in 2010—the equivalent of nearly one full work week for every traveler on our roadways each year. Connected vehicle technology could enable drivers and transportation system operators to make smart choices to reduce travel delay.

- Anonymous signals in vehicles would help generate up-to-the-minute data on how, when, and where vehicles travel in real time. Informed travelers may be able to avoid congestion by taking alternate routes, using public transit, or by rescheduling their trip.
- Connected vehicles could one day also include buses, trains, and other forms of public transit. By providing real-time information, connected vehicle technology would give travelers a realistic idea of when transit vehicles will arrive while improving bus and train connections to make public transportation more appealing to everyone.
- This technology could also help pave the way to other innovations that improve the way Americans live and travel.

"Thanks to the efforts of automakers and the safety community traffic fatalities have reached historic lows. Despite these great strides though, more than 32,000 people are still killed on our nation's roads every year. That's why we must remain vigilant in our effort to improve safety. This research should bring us a step closer to what could be the next major safety breakthrough."

— U.S. Transportation Secretary ***Ray LaHood***

IMPROVING THE ENVIRONMENT

According to the Texas Transportation Institute, the total amount of wasted fuel topped 3.9 billion gallons in 2009, the latest year that this data is available. Connected vehicle technology could give motorists the real-time information they need to make "greener" transportation choices. Information about traffic conditions would help motorists eliminate unnecessary stops and let their vehicles reach optimal fuel-efficiency.

A COLLABORATIVE APPROACH TO CONNECTED VEHICLE RESEARCH

Working together with the automotive industry, the U.S. Department of Transportation's National Highway Traffic Safety Administration, Research and Innovative Technology Administration, and Federal Highway Administration—in coordination with other federal and state agencies—are conducting research to better understand how vehicle-to-vehicle and vehicle-to-infrastructure systems that use connected vehicle (DSRC) technology can improve safety and mobility—and whether they could be effectively applied in the real world. Current research efforts are focused on vehicle-to-vehicle safety applications that would operate alongside and in concert with sensor-based crash avoidance technologies that are already on the market and available to consumers. This research is being conducted through partnering agreements including the Vehicle Infrastructure Integration Consortium, University of Michigan Transportation Research Institute and the Crash Avoidance Metrics Partnership.

Eight major automotive manufacturers are providing support for the Department's research through partnering agreements: Ford Motor Company, General Motors LLC., Honda R&D Americas, Inc., Hyundai-Kia America Technical Center, Inc., Mercedes-Benz Research and Development North America, Inc., Nissan Technical Center North America, Toyota Motor Engineering & Manufacturing North America, Inc. and Volkswagen Group of America, Inc.

SAFETY PILOT OF CONNECTED VEHICLE TECHNOLOGY

The Safety Pilot program is a two-phase, joint research initiative led by NHTSA and RITA to examine connected vehicle technology and real-world applications. The Safety Pilot will lay the groundwork for understanding how this technology interacts in a real-world setting between vehicles and between vehicles and the infrastructure. By evaluating connected vehicle technology, the Department

expects to gather the information it needs to decide if these innovations are ready—and effective enough—to move forward with additional vehicle-to-vehicle communications programs, including potential rulemaking activities.

PHASE ONE – DRIVER ACCEPTANCE CLINICS

In August 2011, the Department began its first phase of research through a series of driver acceptance clinics. Driver clinics were designed to obtain driver acceptance data in cars equipped with "vehicle-to-vehicle" safety systems. The driver assistance applications that were tested included in-car collision warnings, "do not pass" alerts, warnings that a vehicle ahead has stopped suddenly, and other similar safety messages. The six-month program evaluated a total of approximately 700 drivers at the six driver clinics in Michigan, Minnesota, Florida, Virginia, California, and Texas and was completed in January 2012. The information gathered from the program showed that an overwhelming majority of drivers (9 out of 10) would like to have the vehicle-to-vehicle features included in their own vehicles and most believe the technology would be useful in improving driver safety.

> Nine out of 10 drivers agreed that they would like to have vehicle-to-vehicle safety features in their own vehicles and believe the technology would be useful in improving driver safety.

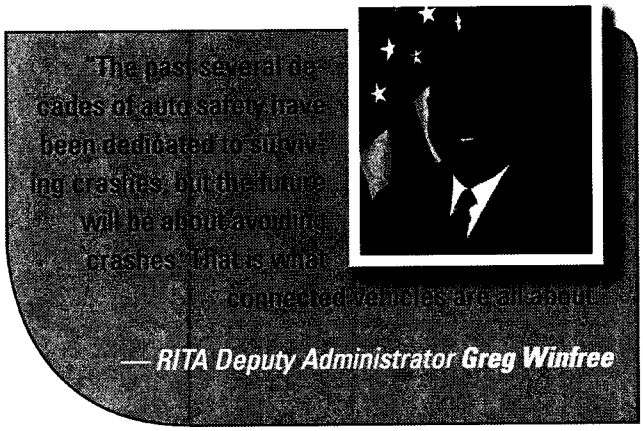
Dates and locations included:

- August 8–11, 2011: Michigan International Speedway in Brooklyn, MI
- September 23–29, 2011: Brainerd International Speedway, Brainerd, MN
- October 22–25, 2011 Walt Disneyworld Speedway, Orlando, FL
- November 7–10, 2011: Smart Road Virginia Tech Transportation Institute, Blacksburg, VA
- December 6–9, 2011: Texas Motor Speedway in Fort Worth, TX
- January 18–21, 2012: Alameda Naval Air Station, Alameda, CA

PHASE TWO – MODEL DEPLOYMENT

On August 21, 2012, the U.S. Department of Transportation and its research partners will launch the second part of the Safety Pilot with a model deployment to further test connected vehicle technology in a year-long effort from summer 2012 through summer 2013. Supported by a diverse team of industry, public agencies, and academia, the model deployment will operate on roads in Ann Arbor, Michigan, and test a limited number of vehicle-to-infrastructure safety applications in addition to continuing the research on vehicle-to-vehicle safety applications.

The U.S. Department of Transportation contracted with the University of Michigan's Transportation Research Institute to conduct the model deployment, which will use



connected vehicle technology in a real-world environment and gather extensive data about system operability, effectiveness, and security. The test site will create a highly concentrated environment of vehicles "talking" to each other using approximately 3,000 vehicles (including

cars, trucks, and buses) equipped with vehicle-to-vehicle communications devices. These vehicles will send and receive electronic data from other equipped vehicles at the site and translate the data into a warning to the driver if and when specific safety hazards occur.

The devices that will be tested include systems that are directly embedded in the vehicle, as well as aftermarket safety systems, and "simple" communications beacons that are brought into the vehicle. All systems and devices emit a basic safety message 10 times per second that forms the data stream that other in-vehicle devices use to determine when a potential traffic hazard exists. Combined with the vehicle's own data, this information provides highly accurate data that is used by the crash avoidance safety applications. The Safety Pilot Model Deployment will obtain empirical test data for determining the technologies' effectiveness at reducing crashes. These capabilities will also be extended to a limited set of applications in which vehicles will communicate with highway infrastructure (or "vehicle-to-infrastructure").

The information collected from both phases of the Safety Pilot, along with the results of other key research projects being conducted in the connected vehicle program, will be used by NHTSA to determine by 2013 whether to proceed with additional vehicle-to-vehicle communication activities, including possible future rulemakings.

RESEARCH & REPORTS:

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