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Dedicated Short Range Communications (DSRC) between automobiles and the road side stations can be accomplished in a special 75 MHz band at 5.9 GHz frequency that has been set aside for transportation use by the Federal Communications Commission (FCC). The Intelligent Transportation Society of America and the United States Department of Transportation are promoting the development of the Wireless Access in a Vehicular Environment (WAVE) IEEE 1609 protocols, which have been adopted for trial use, and the IEEE 802.11p WAVE amendment, which is being considered by the IEEE 802.11 Working Group. In the first part of an on-going California Partners for Advanced Transit and Highways (PATH) project, UCLA and UC Berkeley researchers collaborated under Task Order 5214 to develop a DSRC/WAVE test bed for testing and evaluation of the radio and communication protocol standards in the context of high-value Intelligent Transportation Systems (ITS) applications.

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ITS Band Roadside to Vehicle Communications in a Highway Setting: Interim Summary

Final Report for Task Order 5214

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Final Report for Caltrans Contract 65A0161, Task Order 5214 and Interim Report for Contract 65A0208, Task Order 6214 which continues 5214 under the new master interagency agreement.
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Abstract

Dedicated Short Range Communications (DSRC) between automobiles and the road side stations can be accomplished in a special 75 MHz band at 5.9 GHz frequency that has been set aside for transportation use by the Federal Communications Commission (FCC). The Intelligent Transportation Society of America and the United States Department of Transportation are promoting the development of the Wireless Access in a Vehicular Environment (WAVE) IEEE 1609 protocols, which have been adopted for trial use, and the IEEE 802.11p WAVE amendment, which is being considered by the IEEE 802.11 Working Group. In the first part of an on-going California Partners for Advanced Transit and Highways (PATH) project, UCLA and UC Berkeley researchers collaborated under Task Order 5214 to develop a DSRC/WAVE test bed for testing and evaluation of the radio and communication protocol standards in the context of high-value Intelligent Transportation Systems (ITS) applications.

Executive Summary

The Intelligent Transportation Systems (ITS) program is a worldwide initiative to add information and communications technology to transport infrastructure and vehicles. It aims to manage factors such as vehicles, loads, and routes to improve safety and reduce vehicle wear, transportation times and fuel consumption.

The development of the Dedicated Short Range Communications (DSRC) Wireless Access in a Vehicular Environment (WAVE) technology provides many exciting opportunities for improving safety and efficiency on roads and highways. To help California leverage this promising technology, UCLA and UC Berkeley researchers collaborated under Task Order 5214 to develop a DSRC/WAVE test bed for testing and evaluation of the radio and communication protocol standards in the context of high-value ITS applications.

Applications under development to make use of this enriched communication for transportation problem solving includes: (1) Public safety: emergency vehicle notification, accident warnings (2) Traffic management: traffic signal control, adaptive route selection (3) Electronic payments: toll collection, drive-through services (4) Consumer services: internet access for local service information and (5) Future applications: collision avoidance, adaptive cruise control.

A COTS-based test bed for rapid algorithm development, implementation, and test of the DSRC physical layer was developed at UCLA in the first phase of this project to provide a platform for DSRC-oriented research and testing. The DSRC test bed consists of a set of simulation models along with a programmable hardware platform for implementation and testing. To ensure that this project stays in compliance with the Federal Highway Authority's Vehicle Infrastructure Integration (VII) effort, as well as with future commercial implementations of DSRC technology, we have participated in the standards process for the IEEE 802.11p WAVE lower layers and IEEE 1609 WAVE trial use upper layers. UC Berkeley researchers have participated in the standards development process and are developing open source implementations of the layers of the network stack above the physical layer, in conformance with the developing standards.

In the second phase of this project, under Task Order 6214, we plan to implement the 802.11p MAC and 1609.3 networking services protocols, install the radio test bed at the site of the I405

Detector Test Bed in Irvine (Caltrans), and, in conjunction with vehicle manufacturer researchers, demonstrate a safety applications, like a collision warning, a toll-type transaction, and a multimedia download while two vehicles travel at high-speed.

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1. Introduction

The development of the Dedicated Short Range Communications (DSRC) Wireless Access in a Vehicular Environment (WAVE) technology provides many exciting opportunities for improving safety and efficiency on roads and highways. To help California leverage this promising technology, UCLA and UC Berkeley researchers collaborated under Task Order 5214 to develop a DSRC/WAVE test bed for testing and evaluation of the radio and communication protocol standards in the context of high-value ITS applications.

Applications under development to make use of this enriched communication for transportation include: (1) Public safety: emergency vehicle notification, accident warnings (2) Traffic management: traffic signal control, adaptive route selection (3) Electronic payments: toll collection, drive-through services (4) Consumer services: internet access for local service information and (5) Future applications: collision avoidance, adaptive cruise control

See Figure 1 for a conceptual diagram of a variety of WAVE use cases.

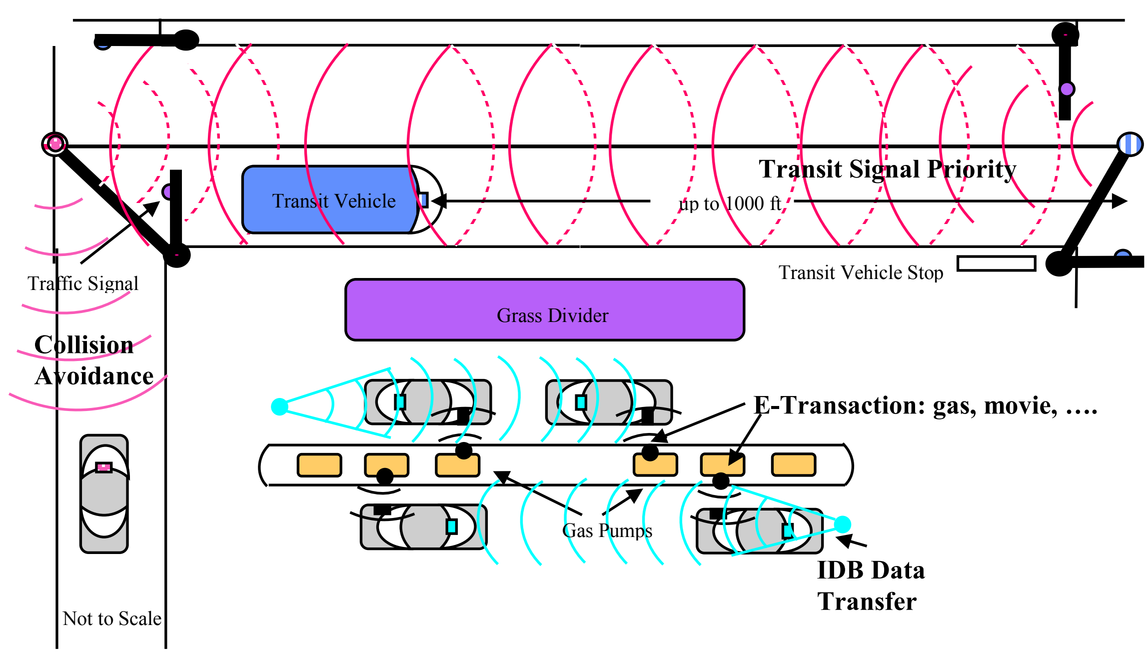

Figure 1: WAVE Concepts and Use Cases

2. Radio Test Bed

A COTS-based test bed for rapid algorithm development, implementation, and test of the DSRC physical layer was developed in the first phase of this project, under Task Order 5214 to provide a platform for DSRC-oriented research. Details of the implementations are described in (Dulmage 2006). A channel model is presented in (Dulmage 2007). The test bed can be used for (1) algorithm design, implementation, and tests in the high mobility wireless environment (2) conformance testing of 3rd party DSRC devices (3) physical layer interface for network and/or application layer testing and (4) channel sounding and signal measurement

The DSRC test bed consists of a set of simulation models along with a programmable hardware platform for implementation and testing. These models facilitate algorithm development following the general evolution illustrated in Figure 2.

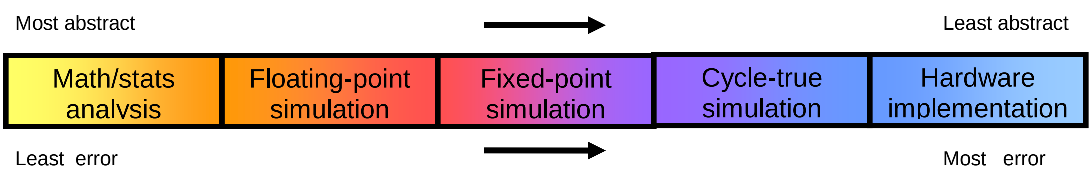

Figure 2: DSRC Test Bed Evolution for Analysis and Test

The hardware components of the radio test bed are shown in Figure 3. These include a Xilinx FPGA board by Nallatech and a RF front end with a custom built IF to 2.4GHz converter by E-Monitoring and a custom built 2.4GHz to 5.9GHz converter by Tomany Consulting. The floating-point model consists of an IEEE 802.11p draft standard conformant transmitter and receiver algorithms that include frequency offset tracking, simplified soft-output demapper, and a soft-input viterbi decoder.

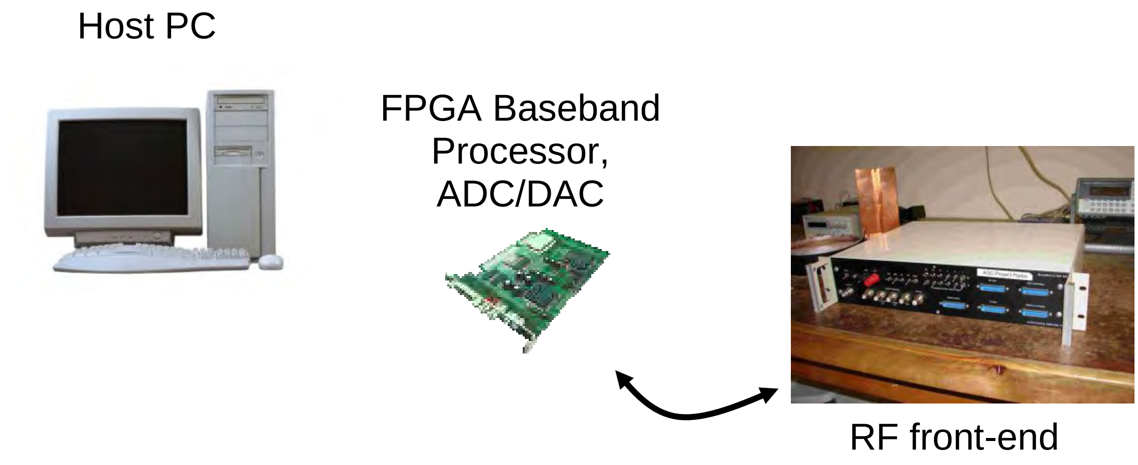

Figure 3: Components of the Radio Test Bed

The hardware and software components of the test bed were chosen to satisfy the following criteria: (1) Low-cost: COTS and/or low-cost custom subsystems (2) Portable: largest component is 19” box; further size reductions possible (3) Reprogrammable: FPGA is primary processing device (4) Modular: loosely coupled subsystems with intuitive interfaces (5) Highly parameterized: flexible simulation setups and (6) High performance: efficient frame-based implementation, optional hardware-in-the-loop acceleration

A variety of signal visualizations and data error statistics are available from the test bed, as shown in Figure 4. Displayed are received and equalized constellation plots. received and equalized signal spectra, actual channel and estimated channel responses, BER, PER, SNR vs. time, and BER vs. SNR plots.

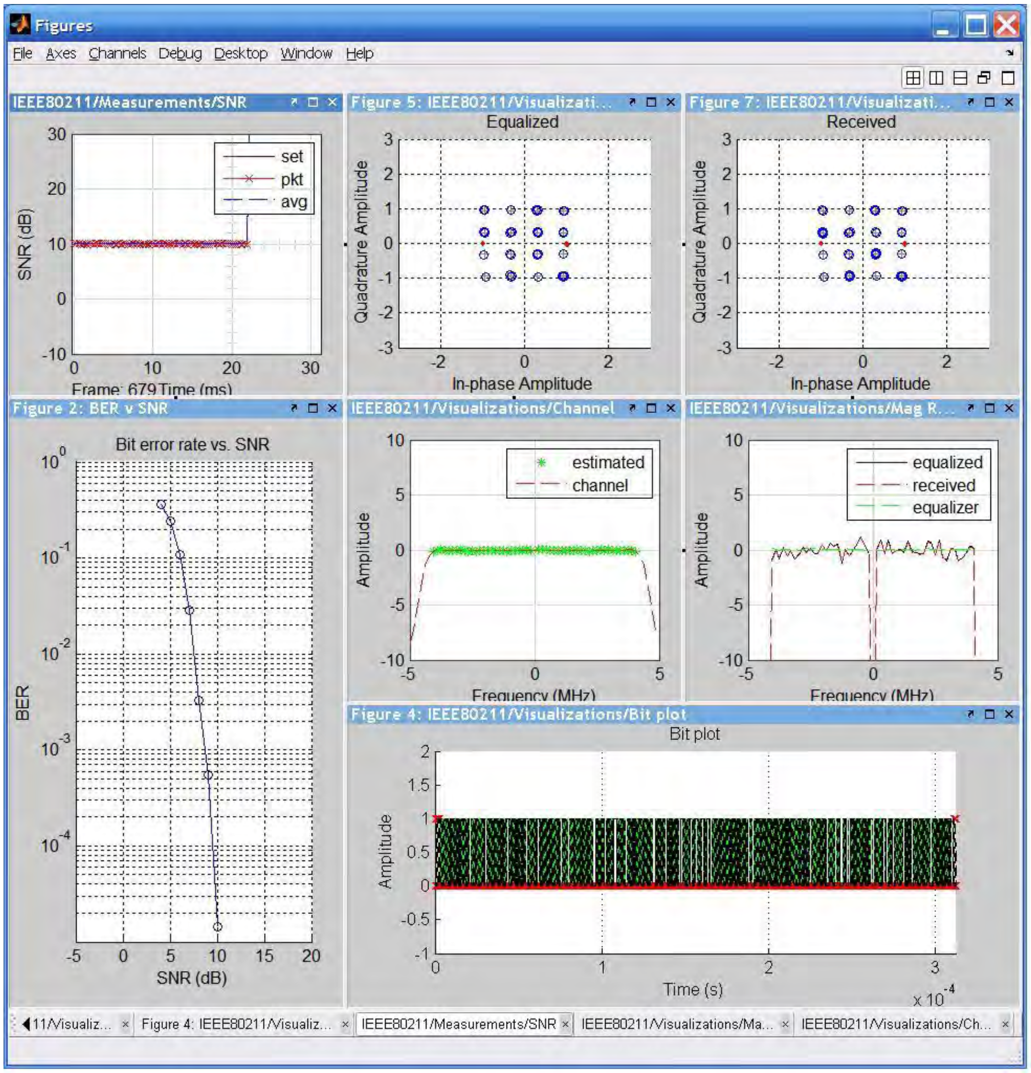

Figure 4: ITS Band Test Bed Visualizations and Statistics

3. Standards Compliance

To ensure that this project stays in compliance with the Federal Highway Authority's Vehicle Infrastructure Integration (VII) effort, as well as with future commercial implementations of DSRC technology, we have participated in the standards process for the IEEE 802.11p WAVE lower layers and IEEE 1609 WAVE trial use upper layers. Ideally, the same on-board equipment used for toll collection should also be available for use by roadway safety applications such as vehicle collision avoidances, and for other applications such as traffic management, traveler information, emergency services or private sector transportation related data services. Some of these applications may require extremely short times, on the order of 50 to 100 milliseconds, to complete a transaction, while for other applications, extremely high data rates or long operating ranges may be required.

Since the mid-1990s, transportation researchers and the US Department of Transportation have been working towards future use of DSRC in a spectrum dedicated for transportation purposes only. A standard for the physical and medium access control layers in this DSRC band, *E2213-02 - Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems*, was defined by the American Society for Testing and Materials (ASTM) International in 2002, and in 2004 the FCC published rules and standards for use. See Figure 5 for the FCC defined bandplan.

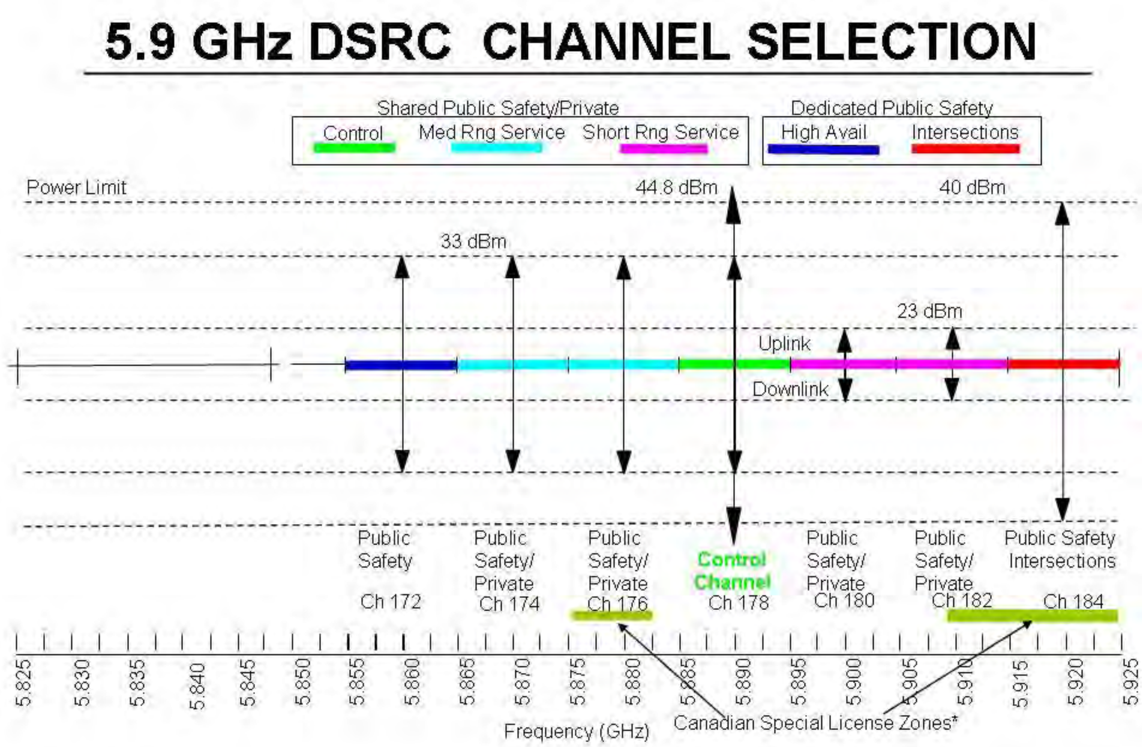

Figure 5: FCC-Defined DSRC Bandplan

The FCC rules stated that DSRC frequencies should be used "primarily" for public safety purposes, but left the eligibility requirements for licensing open in order to encourage development of new services. The DSRC band lies between 5.850 and 5.925 GHz, and includes 7 available 10 MHz wide channels. Both public safety and non public-safety users are eligible for licensing on all channels, with limited geographical coverage for each roadside installation.

The new WAVE/DSRC technology is being designed to support general Internet access and special low-latency short messages for vehicle safety applications, as well as the existing command-response applications. A further difference is the open architecture and standard protocol being developed for WAVE devices, compared to the custom chip sets of previous systems. Figure 6 shows a comparison of WAVE technology with other common wireless technologies.

	DSRC	**Wi-Fi**	**Cellular**	**Mobile WiMAX5**
Data rate	3-27Mbps	6-54Mbps	< 2 Mbps	1-32 Mbps
Latency	< 50ms	Seconds	Seconds	?
Range	< 1km	< 100m	< 10km	< 15km
Mobility	> 60 mph	< 5mph	> 60 mph	> 60 mph
Nominal Bandwidth	10MHz	20MHz	< 3MHz	< 10MHz
Operating Band	5.86-5.92GHz (ITS-RS)	2.4GHz, 5.2GHz (ISM)	800MHz, 1.9GHz	2.5 GHz
IEEE std.	802.11p (WAVE)	802.11a	N/A	802.16e

Figure 6: Comparison of Wave Technologies

The IEEE 802.11p WAVE amendment is currently in letter ballot and is expected to be adopted by 2008. The IEEE 1609 higher layer WAVE standards were approved for trial use last quarter 2006 and first quarter 2007. These include the 1609.1 WAVE Resource Manager draft standard for application level services and interfaces, the 1609.2 WAVE Security Services standard defining secure message formats and processing of secure messages, the1609.3 Networking Services standard which includes a WAVE Short Message protocol (not based on the IP suite of Internet protocols), that can be used for low-latency vehicle-to-vehicle communication, and the P1609.4 Multi-channel Operations to ensure interoperability for WAVE channel switching applications. For more information about developing WAVE technology and vehicle communications, see (DSRC), (National ITS), (National VII), and (California PATH 2005).

At levels above the network and transport layers, the SAE J2735 committee is working on a DSRC message set dictionary (US DOT)

4 Conclusions

In a collaboration between UCLA and the Path Lab at the University of California at Berkeley, we have started developing a DSRC test bed. UCLA developed the DSRC physical layer in the first phase of this project to provide a platform for DSRC-oriented research and testing. The DSRC test bed consists of a set of simulation models along with a programmable hardware platform for implementation and testing. UC Berkeley is developing the MAC layer which will be open source (as much as possible) to allow easy modification with new ideas from the standards committee. In the second phase of this project, under Task Order 6214, we plan to implement the 802.11p MAC and 1609.3 networking services protocols, install the radio test bed at the site of the I405 Detector Test Bed in Irvine (Caltrans), and, in conjunction with Daimler Chrysler, demonstrate a safety applications, like a collision warning, a toll-type transaction, and a multimedia download while two vehicles travel at high-speed.

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National VII Coalition http://www.vehicleinfrastructure.org/

US DOT ITS Standards Program, ITS Standard SAE J2735 http://www.standards.its.dot.gov/fact_sheet.asp?f=71