CTIT

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UNIVERSITY OF TWENTE.

2011 IEEE Vehicular Networking Conference (VNC): Demo Summaries

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Foreword

For the first time in its history, IEEE VNC has included this year's demonstrations in its program. Demonstrations play an important role to expose the research community to practical aspects of research and to foster cross-fertilization among researchers both in academia and in industry. Demonstrations of vehicular communication system solutions are considered very challenging, especially due to space constraints of conference venues. In its inaugural appearance, the contributors of this demonstration session took this challenge to the heart and managed to showcase their implementation work with both hands-on expositions and with recordings of larger scale outdoor testbeds. With topics ranging from applications to communication challenges, we hope that this demonstration session of IEEE VNC 2011 will spark new and interesting discussions.

Eylem Ekici
Demo Chair

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Cyber-Physical Systems Cooperative Vehicle Demonstration: Phase I

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Abstract— **The Cyber-Physical Systems Cooperative Vehicle Demonstration (CPS-CVD) is an evolving testbed for investigating and verifying a number of Cyber-Physical Systems related issues. In this, Phase I, we demonstrate basic aspects of cooperative, interacting autonomous and manual vehicles using vehicle to vehicle and vehicle to infrastructure DSRC communication along with map database technology.**

Keywords-cyber-physical systems, autonomous vehicles, urban driving

I. Introduction

The Cyber-Physical Systems Cooperative Vehicle Demonstration (CPS-CVD) is an evolving testbed for investigating and verifying a number of Cyber-Physical Systems related issues. In this, Phase I, we demonstrate basic aspects of cooperative, interacting autonomous and manual vehicles using vehicle to vehicle and vehicle to infrastructure DSRC communication along with map database technology.

The equipment shown in this demonstration includes:

- 1 fully automated (speed and steering control) passenger vehicle with DSRC
- 1 longitudinally automated (speed control) passenger vehicle with DSRC
- 2 human driven passenger vehicles with DSRC
- 1 Red-Green traffic light with DSRC broadcasting cycle timing, intersection geometry, and stop line positions
- 1 Stop sign (uninstrumented)
- Full road map database of the scenario layout

Figure 1. The Fullly and Partially Automated Cars

This work was sponsored by the National Science Foundation (NSF) under Cyber Physical Systems (CPS) Program (ECCS-0931669).

The goal of CPS-CVD, when all phases are completed, is to encompass all the activities and developments of our NSF supported CPS program. These include:

1. Illustration of the Cyber-Physical System design cycle.
2. Testing of various Cooperative Driving concepts.
3. Testing of V2V and V2I protocols and usage.
4. Further development of concepts from the GCDC.
5. Verification of robustness issues for hybrid systems.
6. Identification of the limits of lab-level and full-scale testing.
7. Verification of some driver intent modeling issues.
8. Initiation of system testing with virtual dense traffic.

II. Scenario

In this Phase 1 demonstration, a three vehicle convoy consisting of 2 autonomous vehicles which are led by a manual vehicle will continuously circle the figure-8 route shown in the diagram below. They will obey the traffic light, accelerating and decelerating simultaneously to maintain set inter-vehicle distances and to allow the convoy to clear the intersection as smoothly and rapidly as possible. They will also obey the stop sign and intersection precedence rules, determining the presence of a manually driven fourth vehicle using information obtained from its DSRC transmissions.

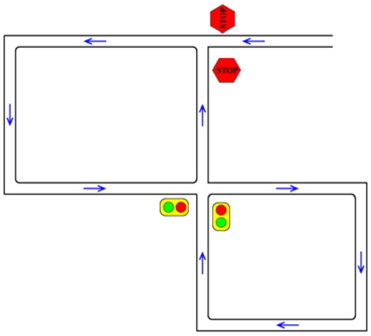

Figure 2. Schematic Sketch of Scenario Layout

Figure 3. Scenario Layout on Ackermann Parking Lots Test Site

The layout and scenario have been selected to provide a set of issues beyond those considered in the recent GCDC (Grand Cooperative Driving Challenge). In fact, the situations here are more in line with urban, stop-and-go driving.

III. Lab Based Testing

Figure 4. Lab Layout with Robots

Throughout the last 4 years the Control and Intelligent Transportation Research lab at OSU has developed an indoor testbed with mobile robots (called SimVille) used to verify decision making algorithms for autonomous vehicles. The laboratory is configured such that the same high level behavior management and planning software modules can be executed on both the passenger vehicles and the iRobot Create robots. The robots are equipped with onboard processing and WiFi communications, and the laboratory is configured with a traffic light that is also WiFi equipped. WiFi communication, operating in ad-hoc mode, substitutes for DSRC radios. The laboratory is also equipped with a ceiling mounted image processing tag localization system that provides GPS-equivalent information to the robots. A simulation environment that matches the laboratory configuration is also available, and can be employed to insert virtual vehicles into the physical tests.

SimVille has been used for our preparations for the DARPA Urban Challenge [1, 2], our current cyber-physical system research, and also for classroom educational activities.

The CPS-CVD demonstration was developed and tested using a topologically equivalent route in the urban layout of SimVille shown in Figure 4.

Utilizing SimVille also provides us with the ability to investigate more risky behavior than one would want to consider in a full-scale vehicular environment, even if it is in a test-bed. We will, for example, be able to consider different human-driver decisions interacting with autonomous or semi-autonomous vehicle controllers that can lead to unforeseen situations. (For full scale tests we have performed in modeling drivers running red-lights or stop signs, see [3].)

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Graph Visualization Tool for Vehicular Ad-Hoc Networks

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Abstract— **In this demo we describe VIVAGr, a graphical-oriented real time visualization tool for vehicular ad-hoc network connectivity graphs. This tool enables the effective synthesis of structural, topological, and dynamic characteristics of VANET graphs, with a variety of parameters that affect the shape and characteristics of a vehicular ad hoc network.**

Keywords- real-time graph visualization; VANETs; interference

I. Introduction

VIVAGr is a tool that allows the analysis of the structural, topological, and dynamic characteristics of Vehicular Ad-Hoc Networks (VANETs) using real time visualization of VANET connectivity graphs, based on nodes' mobility patterns and the underlying telecommunication system. VIVAGr allows researchers to explore and understand problems and issues related with vehicular networks that face today significant design challenges [1]. The tool is able to present all active connection of the network in real-time mode using mobility traces. A visual encoding syntax is used to represent semantic meanings and highlight the effect of mobility and topology on vehicular network specific properties.

Our design approach differs from known graph visualization tools by enabling the effective synthesis of structural and topological characteristics of VANETs with a variety of parameters that affect the shape and the characteristics of a wireless vehicular ad hoc network, wireless range, mobility models, network topology, market penetration ratio, signal propagation and exhibited interference.

II. Overview and Design

VIVAGr provides a link between formalism for representing network connectivity and graph visualization. It is a portable, multiplatform, and modular tool including various independent modules that could be used jointly or as separate functions, easily modified according to specific needs and requirements. In our design we give emphasis in three key areas for graph visualization: interactivity, visual encoding, and real-time representation of nodes' mobility patterns.

Our tool imports trace files describing the mobility patterns of nodes over time. At each time instance a connectivity undirected graph is created. Nodes are depicted as vertices and links as edges between two vertices. As nodes' positions change over, animation is used to show the transition of the newly created graph on canvas. It is able to collect and export specific statistical data for later analysis, focus and monitor the activity of a vehicle (or a group of vehicles) within the networking environment. The graph layout module is operating in real time mode. The user is able to select specific connectivity models allowing the creation of links between operating nodes. The user is also able to alter the viewing angle of the created graphs and to highlight specific link and node characteristics.

An important issue in vehicular networking is the time-evolving characteristics of the created communication graphs and the effect of the mobility patterns, using a geographical map, on the properties of the networking environment. With VIVAGr, the user is able to monitor in real time all corresponding changes in graph topology and connectivity during time as nodes follow a specific mobility pattern. The user can control the networking conditions under which a link can be formed, or not by, changing the properties of the underlying telecommunication system. In the current implementation we employ three different types of connectivity models, which can be enabled using the control panel, simple wireless range, interference limited range [3] and transmission rate mapping (see Figure 1).

Using VIVAGr the user is able for a specific mobility scenario to select different connectivity option and observe the effect of the corresponding graph in real time. For all these cases, during the real time graph visualization process, the user can: i) calculate and represent specific properties and attributes of all vertices and/or edges of the graph; ii) control the time frame of operation, described by the mobility scenario; iii) select the market penetration ratio of the network. Also, all the above graph visualization and animations processes, appearing on the drawing canvas, can be recorded and exported into a video file in order to be available for later studies.

For creating the connectivity graph we need to import information about the mobility pattern of the vehicles. This information is described in pre-processed mobility trace files on a regional or urban area. An animation of the nodes movement is created allowing the user to observe how and in what extend different topographical layouts influence the spatio-temporal characteristics of a VANET communication graph.

VIVAGr allows users to extract results on a number of metrics used to describe the shape and the properties of a vehicular network. These metrics [2] (i.e. Node degree, Effective Diameter, Density, Betweenness Centrality, Lobby

Index, Link duration, Connected periods, Link re-healing time, number of clusters and communities) can be used to identify the “highest-quality” vehicles in terms of connectivity (i.e., nodes with high betweenness centrality/lobby index values), as well as identify the laws that govern the temporal evolution of VANET-graph properties. The tool is able either to present them during the visualization process or to export structured data that could be analyzed in a later time, even using other graph analysis tools.

III. Use Case Study Scenario

We will demonstrate how VIVAGr can be used in order to get answers on critical issues about VANET design. The traces used describe the position of nodes in specific time intervals (of one second) and follow a steady state behavior where the number of vehicles in a given region remains constant over time. We will demonstrate VIVAGr using both real and realistic mobility traces over real-world, accurate, city maps. Real traces have been collected from taxis as these were traveling throughout Shanghai, China, in a 24-hour time period. Realistic traces have been generated using the VanetMobiSim vehicular mobility generator. Specifically, the data set include two vehicular mobility scenarios referring to central regions of two big US cities, namely a: 2Km x 2Km area in New York city (Manhattan area) and a 2Km x 2Km area in and around the city center of Los Angeles. These sets describe the mobility of 700, 7000 and 7000 vehicles for Shanghai, New York and Los Angeles respectively.

Initially, VIVAGr will translate the vehicular traces into a structured MATLAB vector form. Then, these data will be imported back to VIVAGr allowing the user to create and display, in real time, the corresponding connectivity graphs for these examples and observe the shape and the properties of the network.

With the navigation capabilities of VIVAGr, the user can change the viewing angle and position on the drawing graph canvas. Different models for network connectivity will be selected, observing how the underlying telecommunication networking system affects the corresponding connectivity graph and network topology. Using the control panel the user will define the networking conditions under which a link can be feasible or not (Figure 1). We will also see how node connectivity is affected by a) the road-map topology on which the vehicles move; b) the presence of Road Side units (RSUs); c) the market penetration.

Visualizing the vehicular networks using VIVAGr, we will try to provide answers to key questions about the shape and the large-scale behavior of vehicular communication network, such as: How the underlying telecommunication systems affect the vehicular network topology? How does the penetration ratio affect the networking shape of VANETs? Which are the “highest-quality” vehicles in terms of connectivity? What are the laws that govern the temporal evolution of VANET-graph properties? Can we identify communities in a VANET? How does the road-map topology affect the VANET graph properties? What is the best deployment strategy for RSUs in order to maximize information dissemination?

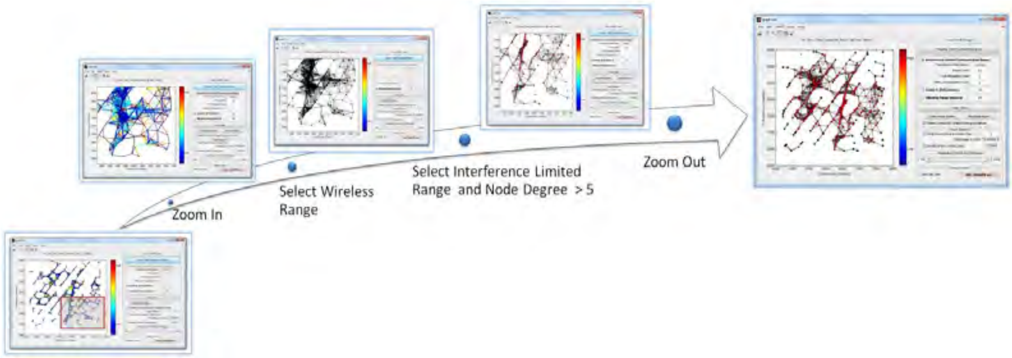

Figure 1. VANET Graph Visualization Tool: Road Side Units (RSUs) are highlighted with green color

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IEEE 802.11p / WAVE Implementation with Synchronous Channel Switching (DEMO)

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***Abstract*—This demo presents an implementation of the IEEE 802.11p and IEEE 1609 standards with the synchronous channel switching feature proposed in IEEE 1609.4. This feature is firstly demonstrated in a way that it can be perceived by the observer and then in the seamless normal operation state. Moreover, we show the operation in synchronous mode, with two and three nodes, one of them operating as a relay, and present measurements for the bandwidth achieved in real-time. The observer sees the operation of all the features of the demo over three scenarios.**

***Index Terms*—VANET, IEEE 802.11p, IEEE 1609, WAVE, Channel Switching.**

I. Introduction

The work shown in this demo has been performed in the framework of the DRIVE-IN project (http://drive-in.cmuportugal.org), which aims at investigating how vehicle-to-vehicle communication through the recently allocated 5.9 GHz band can improve the user experience and the overall efficiency of vehicle and road utilization. One of the outcomes of this project is the deployment of a 465 taxis testbed and a fleet of public buses in the city of Porto, Portugal, to be ready by the end of 2011. The fact that there are no affordable IEEE 802.11p / IEEE 1609 (WAVE) [1], [2] compliant network units, triggered the development of our own hardware setup and compliant driver based on the *ath5k* [3] linux driver. Therefore, this is one of the core tasks of the whole deployment.

The IEEE 802.11p / WAVE standards mandate that the network device must be able to switch periodically (in 50ms slots) between a control channel, which can only be used for control and safety-critical messages, and the service channels, used for all other purposes. This way, the driver of the vehicle can be timely informed of any safety-critical event, despite any other concurrent traffic. The time taken to switch between channels must be no longer than 4ms, according to the standard and, in our implementation, a maximum of 3ms is achieved.

II. Goals of the Demo

This demo aims at showing the following features of the IEEE 802.11p / WAVE devices that will be installed in each of the 465 node vehicular testbed to be deployed by the DRIVE-IN project by the end of 2011:

- Channel coordination
- Channel routing
- Channel access (alternate and continuous)
- Multi-channel synchronization (with estimator)

Along with the hardware that will be installed on the vehicles we will demonstrate in operation the driver that is being developed by IT Aveiro. Although we give special emphasis to the first scenario, described in Section III-A, since it shows the seamless channel switching property, we have two other scenarios, presented in Sections III-B and III-C. These two focus on the synchronization of all the participant nodes, and measurement in real-time of the achieved bandwidth.

III. Feature Demonstration

This section presents the three scenarios shown in our demo, along with an explanation of what can be experienced by the observer, as well as the features involved in each one.

A. Channel Switching

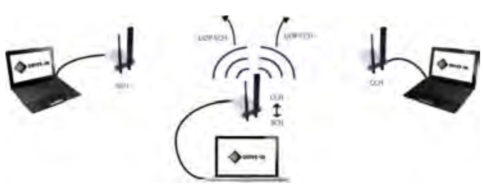

Fig. 1. Scenario 1 - Channel Switching

In this scenario, there are two video receivers connected to the top boards that are tuned to two different wireless channels. The bottom laptop is a video streamer connected to another board that is able to switch from the control channel (CCH) to a service channel (SCH), according to the IEEE 802.11p / WAVE specifications. The demo consists on observing that the streamer can communicate and transmit independently to each device (the video stops when the channel is switched) and then seeing that, if channel switching is issued at a high frequency, a user can seamlessly watch the video on the two receivers. Thus, our driver can seamlessly switch channels, therefore respecting the VANET standards by being able to alternate between a control channel and a service channel without disrupting the communication.

We have used video transmission in both the SCH and CCH so that the differences could be easily observed by everyone, but in real operation, no video can be transmitted over CCH, so that it's bandwidth remains free for safety-critical message exchange.

B. Synchronous Channel Switching

Fig. 2. Scenario 2 - Synchronous Channel Switching

Although the first scenario proves that the channel switching feature is working, it does not provide information about the synchronization among nodes. This synchronization is crucial, so that all the nodes in the network switch to the control channel at the same time and are able to communicate. In this scenario we show that both nodes switch to the control channel at the same time, being able to transmit information on two channels without significant packet loss. Also, we measure the bandwidth in real-time and present it to the observer.

The global synchronization is achieved by using the Global Positioning System (GPS) time, which provides a Pulse Per Second (PPS) signal, with an accuracy of up to nanosecond.

C. Synchronous Channel Switching with Relay

Fig. 3. Scenario 3 - Synchronous Channel Switching with Relay

In this scenario we introduce a third node, acting as a relay for the other two, in order to show that the synchronization is global and the solution is scalable. All the nodes are synchronously switching channels and it can be observed that the end nodes are able to communicate while the real-time bandwidth is shown to the observer.

D. QoS and Low-delay Emergency Message Transmission

In all the three scenarios we are able to demonstrate the operation of Quality of Service (QoS) mechanisms in the service channels, being able to provide lower delay to traffic marked as high priority, as well as low-delay emergency messages. The latter are transmitted seamlessly over the control channel, so that their delay is the lowest, regardless of the amount of traffic being sent in the service channels. This feature is essential in a VANET to guarantee that traffic from infotainment, content distribution and other applications does not interfere with safety-critical messages.

E. Low-delay Video Transmission for Overtaking Maneuvers

Fig. 4. Overtaking Maneuver Assistance

During the demo, an example of video transmission with low delay and emergency message dissemination over VANET is displayed. This feature is especially interesting for overtaking maneuvers in low-visibility situations, such as when a truck is in front of the vehicle in a single-lane road.

IV. Conclusion and Future Work

We show a working implementation of the IEEE 802.11p / WAVE standards, comprising some challenging features of the same. Although these features are already in testing phase, there is still need for interoperability tests between our solution and other commercial solutions.

We are currently working in the Wave Short Message Protocol (WSMP) implementation so that we can get closer to having full IEEE 802.11p / WAVE stack compliance.

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Integrated Simulation Platform for Vehicular Communication Evaluation

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I. Background

Inter-vehicular communication and coordination systems are being envisioned to enhance safety, efficiency and convenience of driving. However, large scale evaluation of such systems by means of field testing is extremely costly and time consuming. Simulation tools fill in the gap where the field testing suffers from scalability. On the other hand, development of such simulation tools requires integration of various separate simulators which is not a trivial task. Individual simulators include radio communication, roadway traffic, vehicle sensors, and vehicle application modules. Each simulator has its own intrinsic timing and relationship attributes. In this demonstration we plan to show our Integrated Simulation Platform (ISP) which coordinates multiple independent off-the-shelf simulators via a software interface.

II. Integrated Simulation Platform

ISP coordinates four simulators of roadway traffic, radio propagation, communication network, and vehicle application. Each simulator may communicate with each other directly through a TCP socket or indirectly through a shared database. Fig. 1 shows data flow among individual simulators. Traffic simulator generates vehicle objects in the simulation field. Based on vehicle locations, vehicle application executes communication with other vehicles. Radio propagation simulator computes the radio quality and communication network simulator determines success or failure of the communication. Subsequently, vehicle application determines the next action reflecting the communication result. This loosely-coupled architecture enables the use of up-to-date simulators right for the purpose.

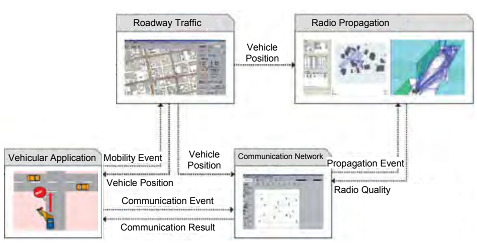

Figure 1. Data flow among individual simulators.

III. Demonstration

We demonstrate a simulation with over 1,500 units of vehicles in an urban area (Ginza, Tokyo) of 2 km square (Fig 2.) The demo application is intersection collision warning and we show how different the application works as a result of radio communication in case of 50% and 100% penetration. The demo visualizes received signal strength indications of any vehicle of interest. That leads radio reachability as well as radio interference including physical capture effect (Fig.3.)

Figure 2. Simulation of 1500 vehicles in Ginza, Tokyo.

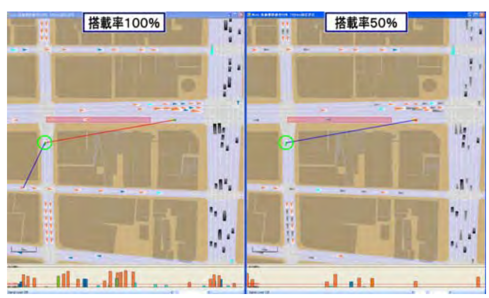

Figure 3. Visualization of received signal strength. (Penetration rate: Left 100%, Right 50%)

Robust IEEE802.11p Radio for ITS

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Abstract: **This document describes a demo of robust IEEE802.11p radio enabling car-to-car communication for active safety solutions. Two use cases for safe driving are shown. First is the so-called 'transparent truck', enabling the driver to receive warning on vehicles that are hidden from sight behind trucks. Second demo is the speed advice, where the speed advice communication between a roadside unit and a car is demonstrated.**

keywords: IEEE802.11p, ITS, safety, Vehicle-to-vehicle (V2V) / Vehicle-to-infrastructure (V2I) communication

I. ITS AT NXP

NXP has embraced ITS as a strategic business opportunity. In line with this ambition, NXP uses its radio technology and automotive knowledge to enable affordable miniaturized solutions for ITS equipment. NXP is working closely with leading OEMs and Tier 1 companies to define new products and market solutions.

During the Automotive week 2011 NXP gave a live demonstration of car-to-x (C2X) communication on a public road in the Netherlands (http://www.automotiveweek.nl). With this demo, NXP is the first semiconductor company to demonstrate software defined radio (SDR) solution for connected mobility in automotive domain (Figure 1). NXP has co-developed the C2X platform with Australian-based Cohda Wireless. Combined with telematics for location-based services and networking security, the platform enables the fully connected car and is therefore a major milestone towards mass deployment for safer road traffic.

Figure 1. NXP IEEE802.11p SDR Platform (MK3 board)

II. ROBUST WLAN 802.11P SDR TECHNOLOGY

C2X communication uses IEEE802.11p, a wireless standard designed specifically for automotive applications. This allows cars to communicate with each other (car-to-car) as well as with intelligent traffic infrastructure (car-to-infrastructure) around them. The newly developed C2X platform from NXP and Cohda is able to "see" around blind corners, through other vehicles, or even chat with traffic signals up to a mile away, in order to recognize traffic blocks or risks before they are visible to the human eye. Drivers therefore receive early warnings of cars hidden from sight behind trucks or approaching from around corners. Other use cases are warnings about emergency vehicles and traffic jams, or traffic light signals allowing drivers to adjust their speed and optimize driving.

The NXP C2X platform is able to meet the requirements of the automotive industry: reliable signal reception under highly mobile channel conditions, cost-efficient design, and flexible programming. It uses Cohda's Advanced IEEE802.11p radio and is based on NXP's multi-standard SDR reception platform. NXP's expertise as a global leader in car entertainment semiconductors and Cohda's patented reception algorithms are critical factors for successful development.

III. ITS DEMO DESCRIPTION

To demonstrate advantages of the innovative NXP-Cohda IEEE802.11p radio technology and to show an example application a combined technology and application demonstration is proposed. The demo consists of two parts

- Transparent Truck demo, showcasing superiority of NXP-Cohda IEEE802.11p radio technology in form of a Google Earth animation.
- Speed Advice demo, showcasing an example application in the form of an IEEE802.11p NXP transmitter and receiver communicating speed advice messages over-the-air.

IV. TRANSPARENT TRUCK DEMO

In order to showcase the superiority of the NXP-Cohda IEEE802.11p radio technology several tests on public roads were performed.

One of the demanding road trial scenarios is a transparent truck scenario where two cars equipped with NXP-Cohda IEEE802.11p radios were communicating with each other while being obstructed by a big truck in between and driving in urban and highway environment. In such conditions most of the time (except corners, curves, and roundabouts) there is no direct communication path as there is no line of sight between transmitting and receiving car. The non line-of-sight communication together with the movement of transmitter, obstructer and receiver causes a fast changing multipath channel (Figure 2). Under these severe channel conditions, NXP-Cohda's IEEE802.11p positively differentiates compared to Car2X modems using Commercial-of-the-Shelf WLAN technology.

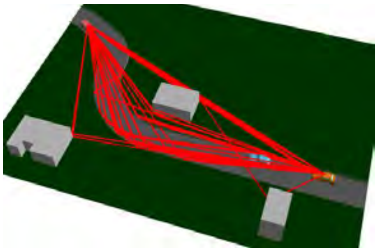

Figure 2. Channel Conditions

The cars in this scenario exchange messages, and the rate of correctly received packets against sent packets is measured and logged while driving (Figure 3).

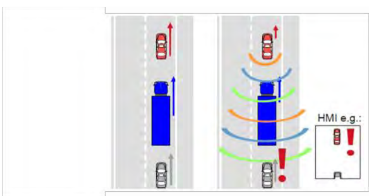

Figure 3. Transparent Truck Scenario

Since we cannot physically show this demo in a car, we display the Google Earth recoding of the actual drive. Therefore, using the logged data a Google Earth animation (Figure 4) is made showing the transparent truck drive in the test area, along with the received packet ratio. This received packet ratio is compared with the packet ratio of a commercial of the shelf (COTS) IEEE802.11p solution.

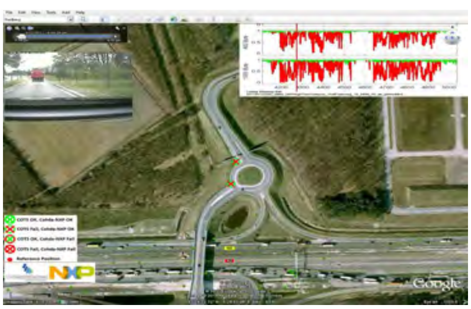

Figure 4. Google Earth animation of Transparent Truck scanario

There are also other scenarios demo-able in a similar way, e.g. the "Do Not Pass Warning" scenario and the "Intersection Collision Warning" scenario (Figure 5).

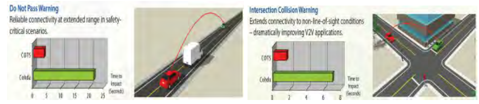

Figure 5. Other Test Senarios

V. SPEED ADVICE DEMO

An example application demonstrating use of reliable IEEE802.11p technology has been developed. In this application one NXP-Cohda board serves as road side unit (RSU) transmitting speed advice messages, and another board is used as car on-board unit (OBU) receiving the messages. We assume RSU will calculate speed advices per lane dependent on road conditions and traffic situations e.g. for green light wave, or to limit the speed in case of accidents. The transmitted messages are received by OBU over the air using IEEE802.11p communication and turned into speed limit messages. This speed limit messages are then displayed on an emulated Android-based device in an example advisory driver's car interface (Figure 6).

The demo shows the above described NXP SDR ITS platform in action namely working 802.11p receiver and transmitter communicating over-the-air in form of example ITS speed advice demo.

Figure 6. OBU Receiver and Driver's Speed Advice Application

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Vehicle to Vehicle Communications over TV White Space Demonstration

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Abstract—**Future vehicular communications systems are expected to utilize the vacant channels (white spaces) of the spectrum, otherwise allocated for specific designated use. One such candidate of white space comes from the TV broadcast band. In this demonstration, we will first present animated results of a TV spectrum measurement campaign along the entire portion of Interstate I-90 located in the US state of Massachusetts. Next, we will show a video of actual vehicle to vehicle communications field tests conducted in Japan using TV white space.**

I. Introduction

Vehicular communications is expected to become ubiquitous in the future resulting in a significant increase in the bandwidth required by various applications. Anticipating such a need for more spectrum, we have developed and tested a proof-of-concept version of vehicular dynamic spectrum access techniques. In this demonstration we will first present the animated results of a TV spectrum measurement campaign along the Interstate I-90 Highway in the US State of Massachusetts. Next we will demonstrate a video of actual V2V communications field tests conducted in Japan using TV white space.

II. Demonstrations

A. *TV White Space Measurement Campain*

Broadcast television spectrum is one possible candidate for DSA in vehicular environments due to its relatively static channel usage by the incumbents. In this part of the demonstration, we present the spectrum occupancy measurements collected over the digital television spectrum ranging from 470 MHz to 698 MHz. We used those measurements to characterize vacant TV channels along a major interstate highway (I-90) in the state of Massachusetts, USA. Figure 1 depicts the measurement set up together with the spectrum vacancy results. Figure 2 is a glimpse into the animated version of the TV spectrum measurements, where we show the trends in the availability of vacant channels from a vehicular dynamic spectrum access perspective.

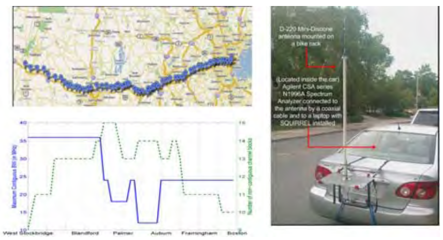

Figure 1. TV white space measurement campaign.

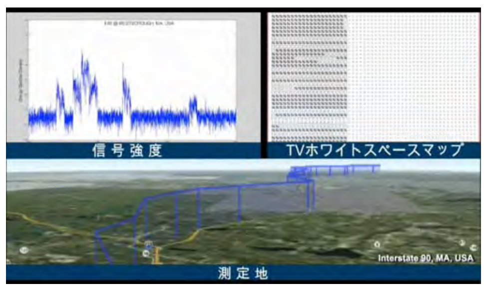

Figure 2. Animated version of the TV spectrum measurements.

B. *Field tests of V2V communications over TV white space*

In this part of the demonstration we will present a video of V2V communications field tests conducted in Miyazaki Prefecture of Japan using TV white space. Figure 3 shows a picture taken during the field tests showing the transmitting and receiving vehicles on public roads. The front vehicle transmits images taken from a video camera placed on the dashboard. The two vehicles agree on control and data channels, and switch to a vacant channel as soon as they detect an incumbent on the currently borrowed channel. Lower left portion of Figure 3 shows the video images received inside the following vehicle and the lower right portion depicts control (orange) and data (dark green) channels, together with a vacant channel (white) in between. For the field tests, we used the USRP2 platform and employed three USRP2s on each vehicle connected to a single PC. This configuration allowed us to have a full-time dedicated spectrum sensing module, and two full-duplex RF front-ends, one for the control channel and one for the data channel. Furthermore we emulated two incumbent users continuously emitting radio waves on TV channels, and placed them along the roadside.

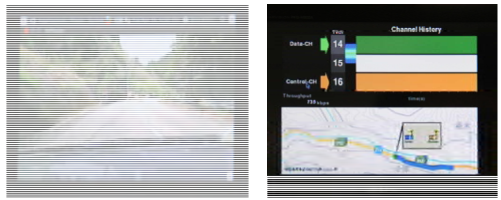

Figure 3. Field tests of V2V communications over TV white space.

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