Testing From V2X (Vehicle to Anything) Perspective

Point of View

Document Control

Revision History

Date	Version	Author	Description of the Change
June 2016	1		

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1 Introduction

This document presents possible test approaches for V2X applications and user scenarios. This article also outlines the points of consideration while choosing a right approach for testing, elaborates on different approaches and discusses corresponding case studies. Technology trends in connected car implementation and testing are also covered and a qualitative comparison is presented. Connected car is a broad spectrum where we talk about the Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I), Vehicle to Cloud and Vehicle to (Mobile) Device connectivity. Connected car business context covers a lot of other applications and features which encompass vehicle connectivity to the outer world in various possible ways as depicted in the below figure

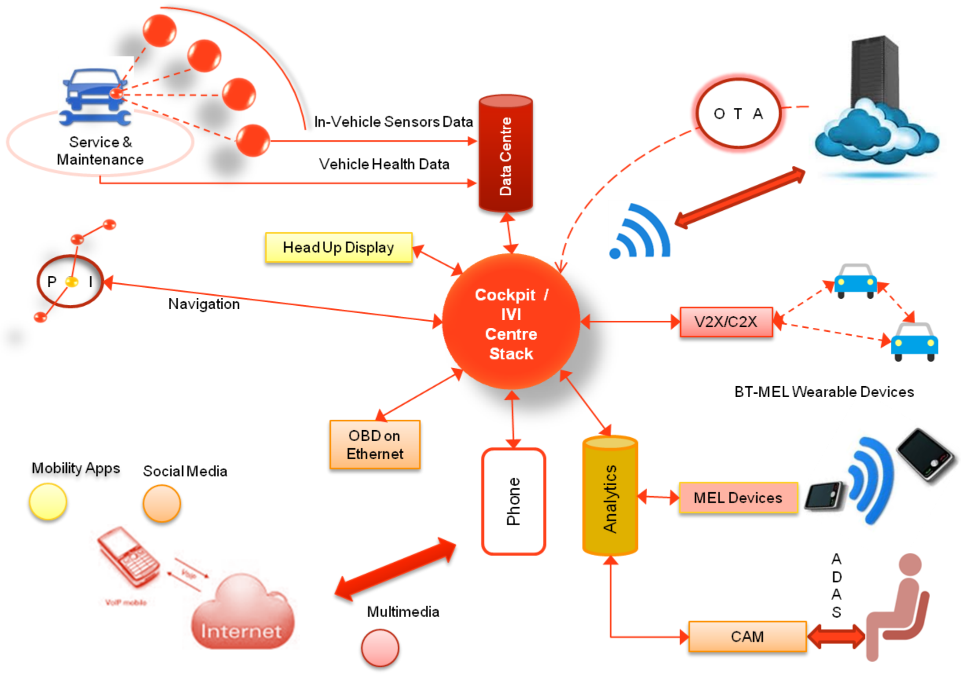

Figure 1.1 Connected Car Business Context

2 What Is V2X

V2X is commonly used terminology for addressing Cooperative Intelligent Transportation Systems (C-ITS). V2X specifies communication methodology between Vehicle-to-vehicle (V2V) and Vehicle-to-Infrastructure (V2I) to achieve optimization of various transportation parameters. Also referred to as (Car to Car) C2C / C2X in some scenarios. Depending on the technology used and data availability, various scenarios for connected car can be created. Some of them are: Vehicle health diagnostics, Driver information system, Advanced Driver Assistance System (ADAS) with Health monitoring using wearable devices, Social Media & Entertainment, Cloud connectivity for data intensive applications such as Insurance, Fleet management and Payment gateway.

3 V2X Architecture at a Glance

There are two main standards IEEE and ETSI being followed primarily in US and Europe respectively. IEEE developed IEEE 802.11p and the IEEE 1609.x series of standards to specify V2X communications operating at 5.9 GHz. This set of standards is called Dedicated Short Range Communication (DSRC) and Wireless Access in Vehicular Environment (WAVE).

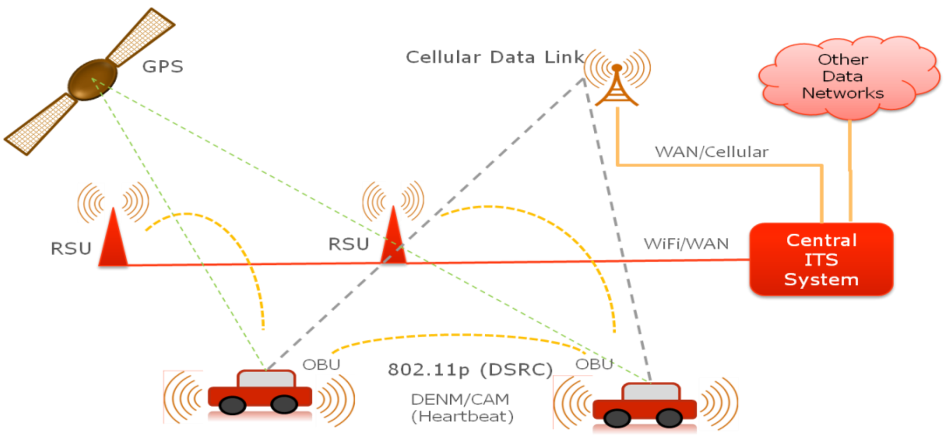

Figure 3.1 V2X Communication Infrastructure

Below architecture shows mapping of various standards related to V2X on a general device implementation. The other architecture (Figure 4) shows main functional components required for a V2X device. Apart from DSRC, GPS and 3G/4G connectivity is also required. The V2X hardware can be an integrated part of In Vehicle Infotainment system or an add on unit.

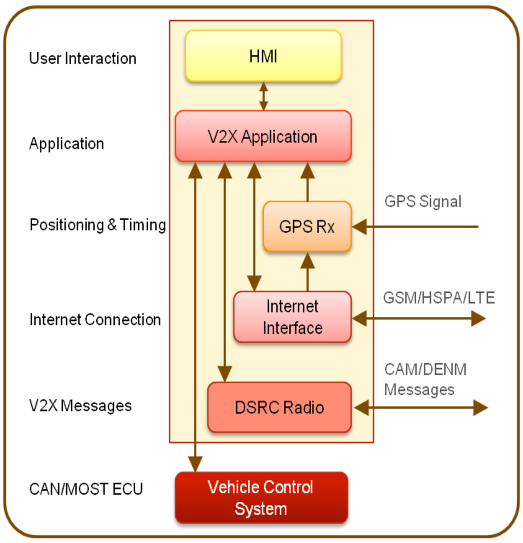

Figure 3.2 Vehicle V2X Node Functional Components

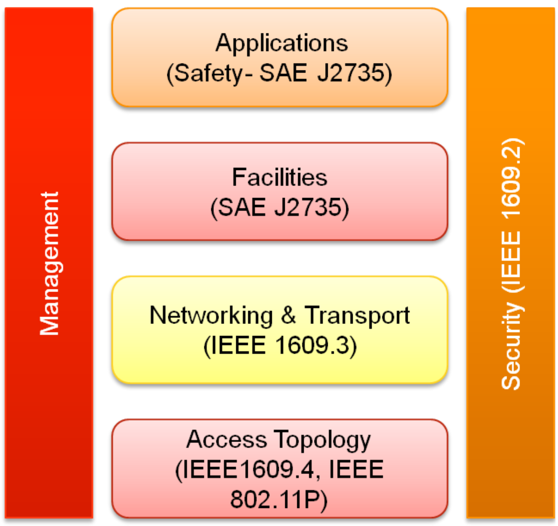

Figure 3.3 Standard V2X Node Reference Architecture

4 V2X Communication Protocols In Use

Technology	IEEE 802.11n (Wi-Fi / WLAN)	IEEE 802.11p (WAVE)	3G/HSPA (GSM)	LTE (Long-Term Evolution)
Channel	V2I	V2V	V2I	V2I
Capacity	50-100Mbps (MIMO)	3 to 5 Mbps	14Mbps	100Mbps in 20MHz channel (MIMO)
Speed	High speed capacity	High speed capacity (Doppler spread sensitive)	High speed capacity	High speed capacity
Coverage	A few km in open field	500 m	A few km in open field	A few km in open field
E2E delay	<250ms	<100ms	< a few hundreds of ms	100ms

The above table highlights suitability of IEEE 802.11p protocol as a basis of V2V communication because of its low latency and capability to perform in signal conditions which are produced by relative motion of signal transmitters and receivers. A detailed discussion on this is given in case studies at the end of this article.

Depending upon an application there could be various communication channels in use among the units. Interaction b/w (Road Side Units) RSUs and (On Board Units) OBUs Broadcasts MAP (Map Data) and SPaT (Signal Phase & Timing) messages, Receives and tracks BSMs (Basic Safety Message) from vehicles, receives Signal Request Messages from emergency vehicles and manages signal priority Broadcast of DENM (Decentralized Environmental Notification Message) and CAM (Cooperative Awareness Message) messages.

5 Drivers and Enablers

V2X is very vast and evolving field, a lot of technology variants are in Research & Development phase. So the testing approaches are also evolving. Here we are discussing about the factors which help us define scope of testing and prioritize testing approaches among the available options. We are emphasizing V2X testing here because the V2X applications have very wide scope of functionality and features so test setups also tend to be large scale and challenging to establish. The most popular approach is Field Operational Tests (FOTs) which are dedicated drive-ways for testing the applications in-vehicle and on-road (as shown in figure). These private test tracks are used to validate the technology to make it to the public roads. These are large-scale real world testing programs for comprehensive assessment of efficiency, quality, robustness, and acceptance of V2X technologies. Simulations are essential part of the FOT chain and need to be carried out during a field operational test.

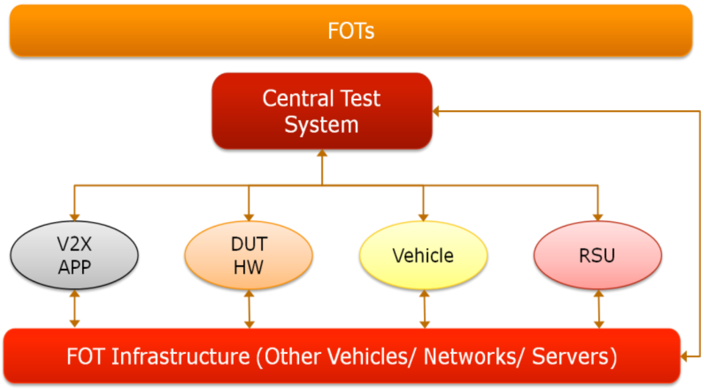

Figure 5.1 Field Operational Tests Architecture

But as the applications are scaling up and penetrating the market, there will be need for more commercially viable and optimized solutions which are discussed as alternative approaches later in this document.

6 Considerations for Test

There are some factors to be considered before choosing an approach for testing V2X applications. These factors may influence the choice of tools and test infrastructure. Some of the factors are important for understanding how much of test coverage can be achieved practically.

Real-life system behavior

Application's behavior in real life scenario should be considered and factors affecting its performance should be identified. Viz. Vehicle Features, Geography, Transport Infrastructure, Culture and Technology Adaptability.

Sensor performance

Since most of the V2X safety applications need reliable real time data from sensors to function adequately, the test set up must have capability to provide such data. There should be enough data or emulators for sensors role play with realistic interfaces.

Algorithm performance

Algorithm is the core of application which can be tested for functionality and performance. Test set up should have a framework to test algorithm as standalone or integrated with the platform.

System performance

There is a need of testing system as a whole to validate how pieces of hardware and software fit and perform together. There are various choices available to test the complete system which are discussed in the following sections.

Communication performance

Depending on the technical infrastructure and availability of support system, the choice of underlying technology and it's testing can be influenced. So it's important to consider the communication channels performance aspects while choosing a test system.

Security

Security is one of the most important aspects to be considered while testing a connected vehicle scenario. As most of the applications involve end user's personal data and sensitive information, the applications needs to be tested for security and integrity of data. Since vehicle control system is also exposed to the communication stack, safety concerns also need to be addressed in testing.

7 Test Parameters

A V2X system can have different parameters which can be potential candidates for testing, keeping in view the above discussed considerations.

Physical Layer Testing

Physical layer could be tested for signal fading, latency, processing time, routing efficiency, multipath propagation, reflections and diffractions of signals from car body or surroundings, interchannel interference and many more propagation effects.

Protocol Analysis

Validation of received message contents, To send individual CAM, DENM, SPaT or TOPO (Topology) messages correctly or as corrupted messages and verify the channel behavior, stress testing of firmware stack, data transmission efficiency and reliability.

Application Testing

Conformance of safety applications with standards, Overall behavior of application in communication model, Functional characteristics, Performance in different simulation scenarios/models.

8 Capgemini Point of View on Testing Approaches

With the above discussed test considerations and identified test parameters, we can derive the test system specifications and define V2X Test Bed as:

An infrastructure of Software & Hardware subsystems working coherently to achieve the following objectives:

- Automatic testing of complex V2X scenarios and protocols.
- Independence from proprietary interfaces and technologies by making use of abstract interfaces for simulations.
- Stimulations with dynamic data about the state of the vehicle e.g. velocity, position, lateral and longitudinal acceleration, etc.
- Support of different types of tests: functional, protocol, robustness, conformance and interoperability testing.
- Testing on different levels of integration: software, software/ hardware and system integration.

9 How can this be achieved?

Road tests for Validation and testing on real roads has to be performed in safe, repeatable conditions with full featured real infrastructure. It's very difficult to get access to such environment because of public safety and regulatory issues. Moreover the conditions are not controlled and repeatable to perform iteration and revalidation.

Other options are to do scenario and use case testing In a realistic environment; under full control; by making use of Lab based emulators and simulators, as described in the following approaches:

9.1 Lab Tests

Modular framework for V2X testing simulates other participating vehicles and nodes, generates and analyzes simulated signals and protocol messages reconstructing real life communication scenario. Custom application development and its testing is also possible. Case study at the end of this article shows how we can use a lab test system for V2X scenario testing.

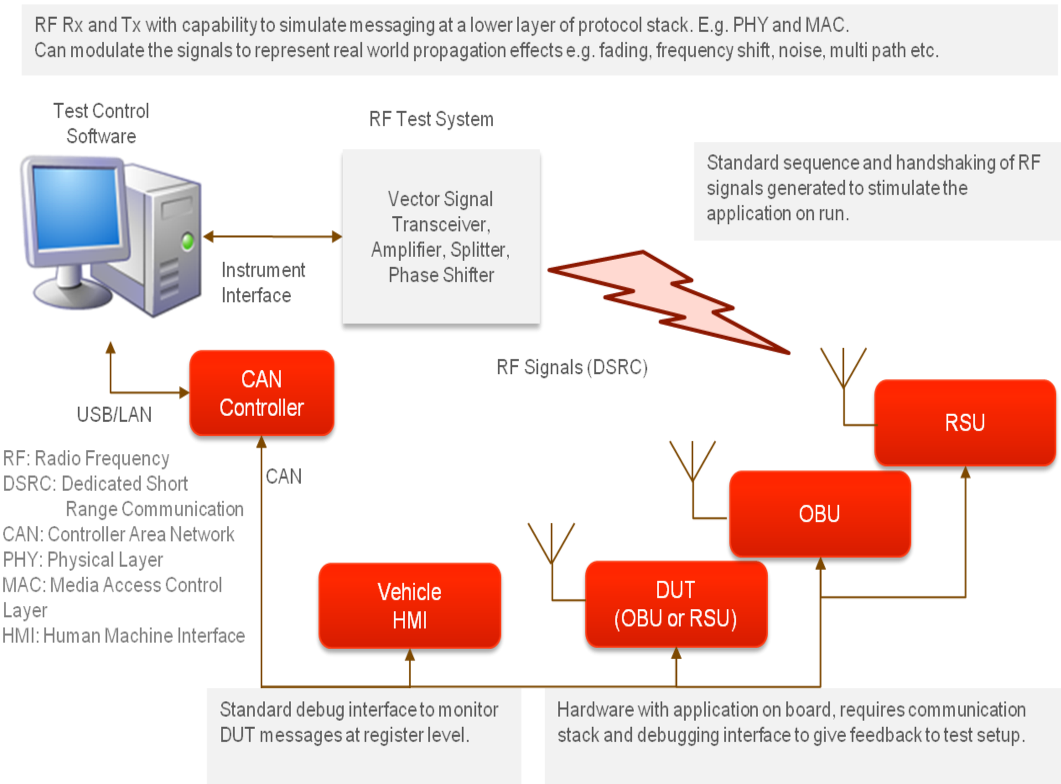

Figure 9.1 Lab Test Setup For V2X

9.2 Simulation

For conditions where a lab based system is too complex or expensive to set up, V2X scenarios can be comprehensively simulated on a desktop system to do testing excluding physical layers. This approach utilizes different simulators participating to test the application behavior from different aspects. The central system coordinates among the participants.

- Microscopic traffic simulator is used to simulate the movements of the vehicles
- A network simulator simulates the wireless communication among the vehicles or with the infrastructure
- An application simulator provides the environment for simulating a V2X application
- Run Time Infrastructure couples all these simulators and facilitates interaction among them at runtime of the simulation.

There are some vendors which offer simulator integration platform such as VSimRTI & iTETRIS. A feature list is given below for reference.

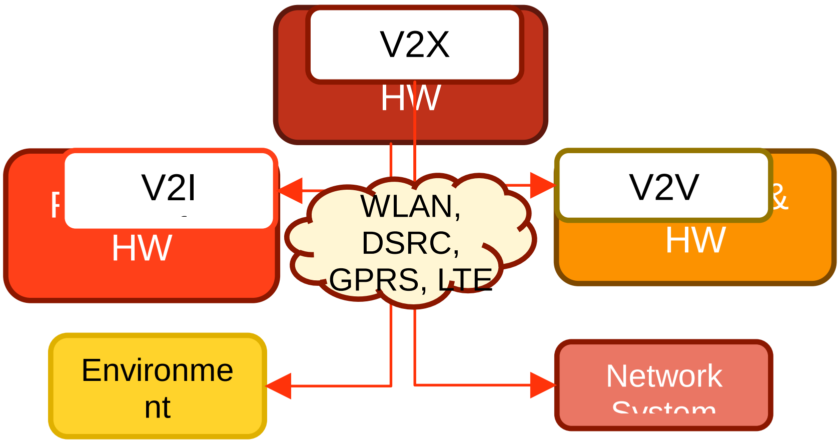

Figure 9.2 Real World Scenario

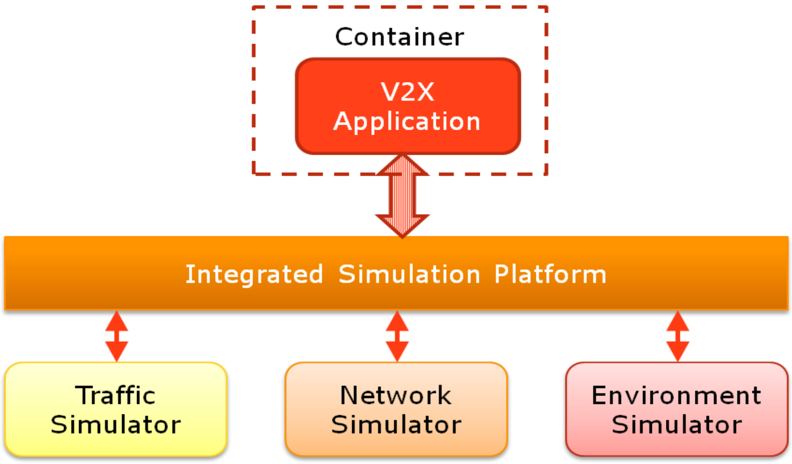

Figure 9.3 Simulation Scenario

Table 1 : Existing V2X Simulation Environments

System / Platform	Traffic Simulator	Communication Simulator	Application Simulator	Type of Coupling
iTETRIS	SUMO	ns-3	TraCI	Fixed
TraNS	SUMO	ns-2	TraCI	Fixed
Veins	SUMO	OMNeT++	TraCI	Fixed
Paramics & ns-2	Paramics	ns-2	Paramics	Fixed
VSimRTI	SUMO/VISSIM	JIST/SWANS/OMNeT++	VSimRTI_App	Flexible

The probable roadmap at the end of this article shows how we can achieve V2X testing with simulation. The selection of simulators and platform will depend on the simulation requirements and relevance to the test scenarios.

10 Summary

With all above analysis of facts and knowhow from various references we are presenting a comparison table of the three main approaches as a conclusion of our study. This table qualitatively compares the approaches w.r.t. different parameters which are significant from implementation perspective. Some of the international projects have worked on these approaches e.g. SimTD worked on Lab test setup and Drive-C2X has worked on Simulation approach as reported in some publications.

Table 2 Comparison Of Testing Approaches

Parameter	FOTs	Lab Test Bed	Simulation
Usage Effort	Not much extra effort for test set up once the infrastructure is established	Scenario description & definition of participating components is required	Simulation takes higher efforts in scenario description and set up
Dependencies	Most infrastructure and participating components are standardized	Dependent on communication model and driving behavior model used and instrument capability.	Dependent on communication model and driving behavior model and Simulator Efficiency
Volume	Physical assets are required to put infrastructure in place	Signal Generators, Simulator hardware, and physical communication links are required	Bench top system, has software components and models for physical components.
Scope	End to end testing of implementation in real life scenario .	End to end testing of implementation with simulated effects of field conditions on test parameters.	Behavioral & functional testing of application. Different algorithms/models can also be analyzed.
Relevance	For standardizing bodies, OEMs with products and services roadmap.	For OEMs, E2E service providers, Testing/Certification labs.	Startups, Research groups, Domain consultants.
Pros	Complete / Best Setup	Next Best Bet to FOTs	Can start with least physical Set Up
Cons	Huge setup, most complex & resource intensive	Cost can be overkill for some simpler implementations	Development & configuration, reconfiguration can be complex.

11 Proposed Roadmap For Testing Capability

Probable Roadmap 1: Evaluation of custom application using integrated simulation environment:

Problem Statement

V2X-based driver assistance system (such as GLOSA – Green Light Optimized Speed Advisory) suggests a speed which allows to pass the next traffic light at green. The requirement is to have simulative evaluations of GLOSA and Measurement of GLOSA’s effects on traffic efficiency.

Approach

The upcoming vehicular communication technology (V2X) promises to increase traffic safety and traffic efficiency by exchanging status messages between involved traffic participants and/or infrastructure.

Traffic lights send information about their programs and timings to vehicles. Knowing the distance to the traffic light from an internal road map and/or the GPS position, a vehicle which receives such a message can compute the speed needed to reach the traffic light on time

Proposed Tools: SUMO, Open Street Map, NS-3 Simulators

Simulation Model

The evaluations can be performed using the traffic simulation SUMO coupled to a network communication simulation and a model of the GLOSA application.

Traffic Simulation SUMO

SUMO (Simulation of Urban Mobility) is microscopic, that is each vehicle is simulated explicitly and has its own information about speed and position in the traffic network.

Communication Simulation

Communication can be simulated using an own communication model coupled to SUMO via TraCI. TraCI allows to receive information about simulation objects such as roads, vehicles, traffic lights, etc. – and to modify these objects online, e.g. to change the signals of a traffic light or a simulated vehicle’s speed.

Application Model

The application model consists of three parts: the first covers the technical realization of the GLOSA application, including message generation, sending, and retrieval. The second one is responsible for computing the speed that shall be presented to the driver. The last part is user acceptance and behavior.

The application can be implemented and embedded into the aforementioned communication model. The RSUs at simulated traffic lights will send information about their state with a frequency of 2Hz using SPAT (Signal Phase and Timing) messages.

Performance Metrics

The following performance indicators can be used: travel time (in s), waiting time (in s),

Following results are reported in reference [7] by performing 90 simulation runs with a single equipped vehicle, and 90 simulation runs with a single unequipped vehicle. For both (equipped/not equipped) settings, the vehicles' depart times were incremented by 1 s between each simulation run, respectively. The maximum communication range was set to 300 m. Figure shows the vehicles' movement through the network. It can be seen, that GLOSA helps vehicles to get through the network.

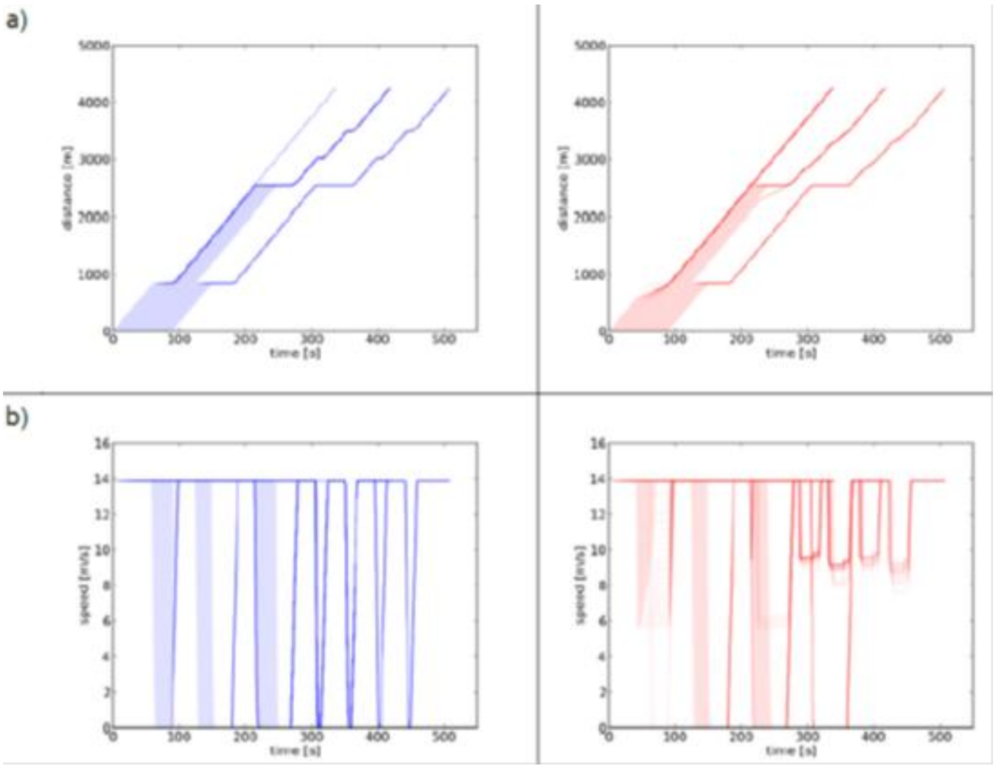

Figure 11.1 Differences between progressing through the network for 90 unequipped (left, blue) and 90 equipped (right, red, communication range of 300 m) vehicles; from top to bottom: a) distance over time; b) speed over time

It can be observed that the experiment with equipped vehicles represent a smoother vehicle movement and uniform speed by putting vehicles to stop less occasionally. Also the travel time tends to be lower. The experiments can be extrapolated to take driver behavior model and the adaptive traffic light model into account. Making this more complex but rendering more insightful results of V2X application behavior.

Probable Roadmap 2: Multipath Propagation Simulation Lab Test

Problem Statement:

Experimentally study how different design parameters of the multipath propagation simulator affect the received signals and data packets.

Approach

Define what special characteristics the simulation setup have for simulating realistic signal environments in a lab. Prepare minimum specifications required for the equipment and create architecture. Multipath signal emulator hardware shall take into consideration the following requirements for successful regeneration of test signals:-

- Over-the-air testing than using channel emulators only, allows vehicle antennas in the test loop.
- V2V channel is highly dynamic, having only a few dominant scatterers in open environments but a richer channel in urban environments.
- Channel statistics can change over time, scatterers move, phase in and phase out.

Proposed Tools: Vector Signal Transmitter and Receiver with RF Generation and Analysis Software Toolkit (Keysight or R&S), V2X On Board Unit as DUT (Cohda or Commsignia)

What can be tested for Application and OBU:-

- Effect of antenna positioning
- System environment
- Signal Propagation Parameters

The received signal at the car (OBU) has certain distributions over incident angle, polarization, delay, and Doppler shift. These characteristics should be simulated in a lab setup, since they represent the stress that the test object antennas and radio are subjected to. The ability of the radio receiver to handle low power levels, realistic delay spreads, and Doppler shifts, is tested. The antenna positioning and mounting affects radiation properties, because there will be reflection and diffraction.

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Multipath Simulation – Active Signaling Approach

Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths (e.g. Line-of-sight and Non-line-of-sight) due to reflection or diffraction from surroundings. Multipath causes interference, which causes fading and phase shifting of the signal. In digital radio communications multipath can cause errors and affect the quality of communications. The channel variability over time and the multipath propagation effect cause frequency dispersion or Doppler spread. These phenomena can be modeled with certain boundary conditions, in a lab setup to study their effect on the received signals.

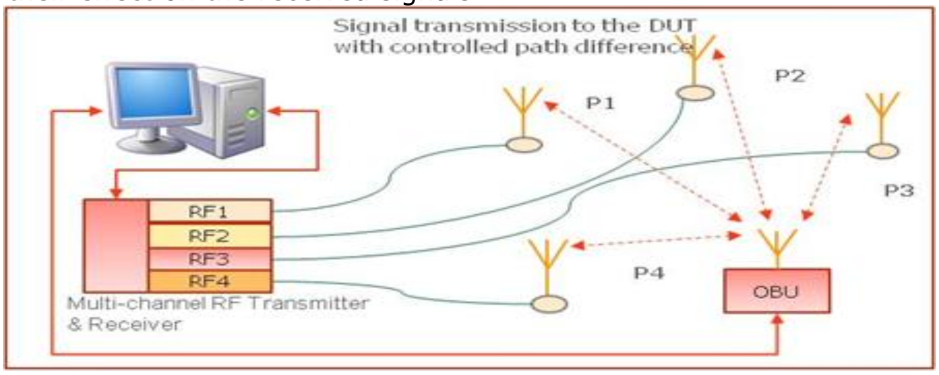

Figure 11.2 Multipath Simulation Set Up

To create a scenario of urban transport, the proposed setup consists of an array of antennas (getting signal feed from RF transceiver) encircling the test object (On Board Unit - OBU) with a radius of 5 m. Each antenna transmits signals with different precalculated phase shift to represent different paths of signal propagation

The challenge is to feed signals on different antennas in a way that those resemble real-life signals. This can be achieved by:-

- Position the antennas differently in order to vary the signal distribution over azimuth angle and polarization.
- Excess delays can be included in the feed network.
- Doppler shifts and attenuation can be set arbitrarily up to using the software

Software controls the transmitting OBU in the way that it sends a radio packet according to the standard 802.11p with fixed data length and unique PacketID at regular intervals around 100 times per second. On the other hand the software counts received packets from the receiver RSU/OBU and store the Received Signal Strength Indicator (RSSI) value for each packet hence Packet Error Rate (PER) can be calculated vs. the RSSI.

For Example: To identify the desired signal power vs. interference from the environment the time-domain impulse response is calculated using the inverse Fourier transform.

By conducting various experiments we can investigate the ability to simulate various realistic signal environments in terms of the desired signal vs. interference from the test setup and environment, and their effect on end result represented by PER. Further the application performance in different signal and packet reception conditions can be analyzed.

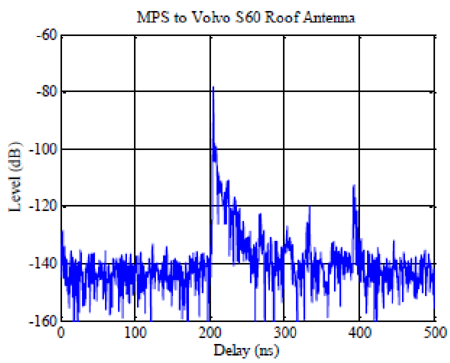

Figure 11.3 Example of measured impulse response, showing desired signal (first large peak) and interference (following lower peaks)

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