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2012 IEEE Vehicular Networking Conference (VNC): Demo Summaries

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Preface

Last year's edition of IEEE VNC in Amsterdam included a very successful demonstration session in its program. Therefore, demonstrations are again part of the program of IEEE VNC 2012 in Seoul, Republic of Korea. 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. 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 2012 will spark new and interesting discussions.

O. Altintas, W. Chen, G. Heijenk, H.S. Oh,
J.-M. Chung, F. Dressler, F. Kargl, G. Pau, and E. Schoch
General and TPC Co-Chairs

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Full-HD wireless connection using 60 GHz

Chul Woo Byeon, Seong Jun Cho, In Sang Song, Hong Yi Kim, Chaejun Lee, Chong Hyun Yoon, Joongho Lee,
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***Abstract*—A 60 GHz full HD wireless connection for an intra-vehicular multimedia wireless network is demonstrated. The 60 GHz HDMI wireless connection consists of a serializer, a deserializer, a 60 GHz transmitter, and a receiver. The 60 GHz full-HD wireless connection supports a data rate of more than 3 Gb/s covering a 1080p full-HD display.**

***Keywords*—60GHz, wireless, Intra-vehicular multimedia, Full HD**

I. INTRODUCTION

Modern automobiles often deploy high-definition (HD) cameras at more than six points, including two cameras on each of the front and rear sides and one camera on the left and the right sides for safety, as shown in Fig. 1 [1]. There are many types of cables in the intra-vehicle network for data transmission for the thousands of automotive sensors in use. These types include the one-wire, twist wire, coaxial cable, and optic cable types depending on the interface, whether it is a CAN (Controller Area Network), LIN (Local Interconnect Network), FlexRay (X-By-wire), or AMI-C (Automotive Multimedia Interface-Component) interface. The CAN, LIN and FlexRay interfaces are generally defined by the carmaker. Automotive data is physically shared via a twisted wire between the ECU (Electronic control unit) and the sensor through the CAN and FlexRay types of interfaces. The LIN interface, which is normally attached to the end point of a CAN interface, easily and simply transmits data to a sensor via one wire. The status of the car can be monitored through a diagnostic connector with scanning tools supporting ISO 15031-5.

However, AMI-C uses optic cable for the transmission of wide-bandwidth data covering multimedia signals. The installation of the wiring requires considerable engineering work because an optic cable is generally rigid. Using a radio-on-fiber (RoF) system at the end point of an AMI-C interface largely reduces the harnesses loads during the installation process by providing wireless connections among devices. In this demonstration, a 60 GHz transceiver is designed to cover multimedia data for a HD camera where the bandwidth is allocated up to several GHz.

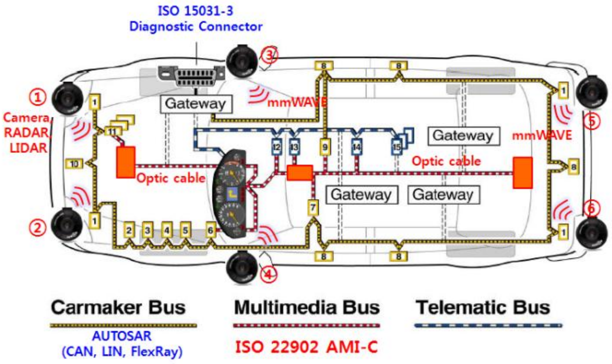

Fig. 1. Intra-vehicle network [1].

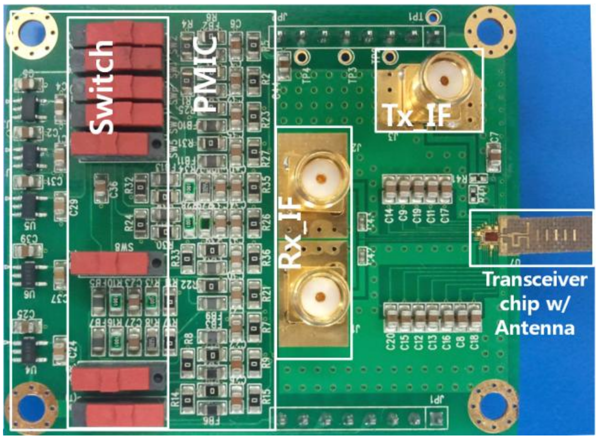

Fig. 2. 60 GHz OOK transceiver module. (Where PMIC is the Power Management Integrated Circuit, 60 GHz transceiver Chip Size: 1.6 x 1.2 mm^2, 60 GHz transceiver Module size: 5.8 x 4.4 cm^2)

II. 60 GHZ WIRELESS CONNECTION

The demand for millimeter-wave frequency band has increased due to prevalence of high-quality video content. The emerging 60 GHz band is a great candidate for high data rate

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wireless HD video transmission. A multi-gigabit data rate can easily be achieved with a simple modulation scheme using 60 GHz unlicensed band.

Fig. 2 shows the fabricated 60 GHz OOK transceiver module. The OOK modulation scheme is adopted for its low power consumption, high integrity, and simplicity. The key building blocks of the transceiver are the OOK modulator and demodulator, which are based on those in earlier work [2], [3]. In the transmitter, the modulator modulates OOK input signal and at the same time generates high output power. Furthermore, this modulator consumes DC power only on-state of OOK input signal. In the receiver, the demodulator uses gain-boosting technique. This technique helps to increase conversion gain and to recover high data rate OOK signal. Implemented in 90 nm CMOS technology, the transceiver consumes a DC power of less than 70 mW. The 60 GHz OOK transceiver targeted inter-vehicular multimedia, which supports full-HD video data rates that exceed 3 Gb/s. A Yagi-Uda antenna is mounted on the PCB. Finally, the 60 GHz transceiver module is fabricated with the power management circuit, the 60 GHz transceiver chip, and the antenna on the PCB. The size of the module is 5.8 x 4.4 cm^2.

III. DEMO DESCRIPTION

The 60 GHz wireless connectivity demonstration for intra-vehicular multimedia is depicted in Fig. 3. The camera sends parallel digital data to a serializer, and the serializer converts the parallel date to serial data. The 60 GHz transmitter sends raw HD data to the 60 GHz receiver through the air. The 60 GHz receiver demodulates OOK modulated signal from transmitter to the serial digital signal. Finally, the monitor displays the HD video. Fig. 4 shows the demonstration picture of the intra-vehicular multimedia using the fabricated 60 GHz transceiver modules. The proposed 60 GHz intra-vehicular multimedia solution transmits 1080p wireless full-HD video over a distance of 60 cm.

IV. CONCLUSION

We proposed a 60 GHz full-HD wireless connection for an intra-vehicular multimedia wireless network. The proposed connection consists of a CMOS-based transmitter and receiver and communicates 1080p full-HD video data through the air. The proposed solution is inexpensive and offers high reliability for a HD camera network in a modern automobile.

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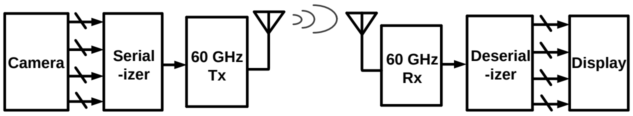

Fig. 3. The proposed 60 GHz wireless connectivity demonstration for intra-vehicular multimedia.

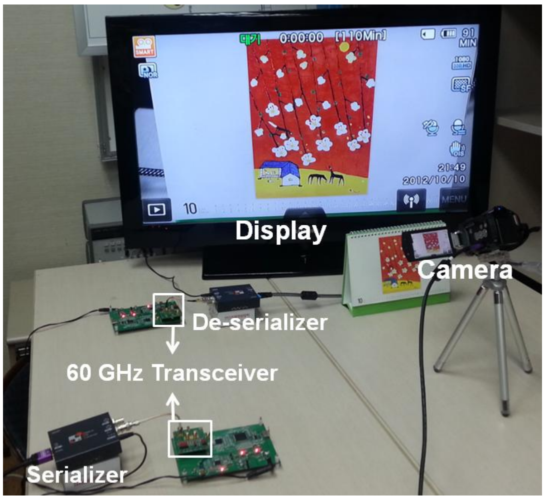

Fig. 4. Demonstration of the wireless video data transmission as an example of the intra-vehicular multimedia.

Microscopic Simulation-based Validation of Scalability and Data Quality for a Dynamic Vehicular Ad-Hoc Networks Algorithm

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***Abstract*—Many applications of *connected vehicles* entail a constant need for vehicles to connect to the communication infrastructure. This could result in the congestion of the network. In this demonstration we evaluate an algorithm to build such a hybrid VANET for better use of the communication infrastructure. This algorithm for dynamic grouping of instrumented vehicles is implemented in a realistic and well-calibrated microscopic traffic simulation test bed of the New Jersey Turnpike and Jersey City. We illustrate the algorithm using a video extracted from one such run of the simulation model. We show that this algorithm reduces communication load and is very scalable. We demonstrate that the algorithm not only performs better but there is only a negligible loss in data quality as compared to using only V2I. The quality of reported data is validated using metrics such as error in speed, travel time during normal and incident conditions, and extent of vehicular network coverage. We show that the average error in reported speed is consistently within 8% despite varying the market penetration and DSRC radio communication ranges. Travel time along different paths is shown to be within 5%. The travel times in case of non-recurrent congestion such as an accident are also within 10%. The network coverage is also shown to be 89-97%. This data quality is achieved using far lesser bandwidth using the dynamic grouping algorithm. Thus we establish that the dynamic grouping algorithm is very effective in many real-world traffic scenarios.**

I. INTRODUCTION

Connected vehicles can provide the drivers with better mobility, safer travel and improved driving experience. However, the widespread use of mobile computing results in increase in the number of applications of *connected vehicles* as well as the bandwidth usage. Each car passes on its location, speed and possibly other information, constantly leading to the communication network being overwhelmed. Hence it is important to find means to reduce the communication load for more efficient ways of information exchange among *connected vehicles*.

A scalable mechanism to manage communication network load is required. Additionally, in order to evaluate the load on the communication network, it is imperative to use a realistic test bed to measure the load. Applications of probe data involve collecting real-time information on travel time and speeds along different routes during normal and during occurrence of non-recurrent congestion events such as accidents, etc. Hence it is essential that any mechanism to aggregate data should not only reduce bandwidth usage but also maintain the quality of data.

In this study we achieve the objective of vehicle information aggregation by forming hybrid VANETs of autonomous and dynamic groups of equipped vehicles. During the demonstration, we illustrate the algorithm using a video extracted from one such run of the simulation model. Extensive evaluation for the maintenance of quality of reported data is performed using, travel times and speeds during normal incident conditions along various routes. Scalability of the algorithm for dynamic formation of disjoint collections of VANET nodes is evaluated using a realistic well-calibrated microscopic traffic simulation of the New Jersey Turnpike (NJTPK).

II. MODELING METHODOLOGY

In order to make optimal use of vehicular communication and to ensure a better spread of information, V2I has to be combined with V2V communication. For applications such as probe vehicle data, integrating V2V with V2I is very useful. Also, unlike in other type of communication such as location-based services and advertising, the frequency of vehicles accessing the RSU infrastructure is much higher for probe data.

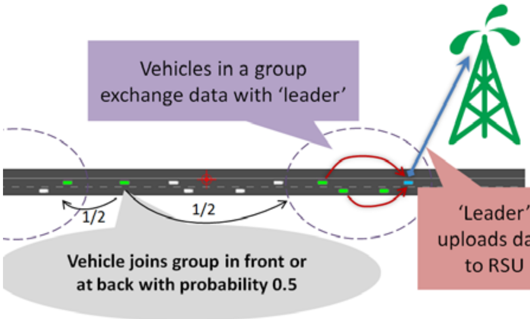

Figure 1 Illustration of Dynamic Grouping Methodology

Since the objective is to reduce the number of vehicles that access the RSUs, groups of equipped vehicles are formed dynamically. The vehicles within a group exchange information with one another and only one chosen vehicle (called the leader) exchanges the information with the communication network. The procedure involved in grouping equipped vehicles is the forest forming algorithm proposed by (Li et al, 2012). A pictorial illustration of the grouping algorithm is shown in Figure 1. A 50-mile section of a much larger calibrated microscopic simulation model of the New Jersey Turnpike (NJTPK) in PARAMICS has been used during the PM peak period to implement the algorithm.

III. SIMULATION RESULTS

Average and maximum channel usage in the PM peak period for 5% and 15% market share were found to have a significant reduction with the dynamic grouping algorithm. The reduction is between 68-85% for 5% market penetration and 72%-91% for 15% market penetration.

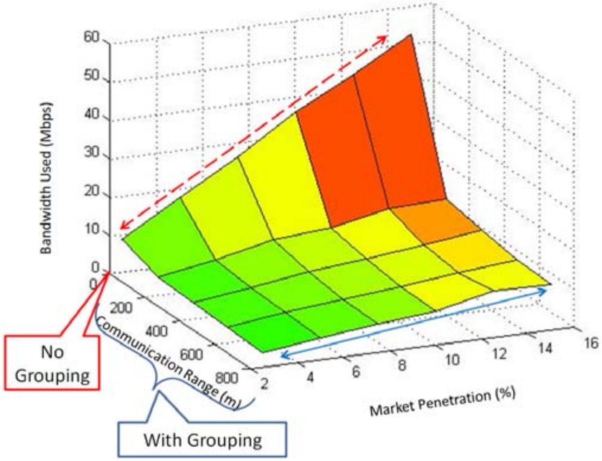

Figure 2 Response Surface for Bandwidth usage for average speed estimation over the whole network

In order to investigate the scalability of the algorithm, it is implemented for different market penetration of technology (2.5%, 5%, 7.5%, 10%, 12.5% and 15%) and communication ranges of the DSRC radios (200m, 400m, 600m, and 800m). The bandwidth used to estimate average link speed for a 15-minute time interval from the speed data reported by instrumented vehicles over the whole network (23,000 vehicles per hour) without grouping (extreme left) and with dynamic grouping are shown in Figure 2. The increase in bandwidth can be quantified as 3.51 Mbps/% increase in market penetration without grouping (red dotted line), and 0.66 Mbps/% increase in market penetration using dynamic grouping (blue solid line), which is 81% reduction when compared to the scenario where every instrumented vehicle reports data..

Despite the bandwidth reduction, the quality of reported data should also be maintained in order to conclude that the dynamic grouping methodology has a clear advantage over independent probe vehicle data collection. Quality of data represents how closely the aggregated data represents the actual traffic conditions. Speed and travel time data that are reported between 3:30PM-5:00 PM are compared for: (a) data reported to RSU with individual probe vehicles, and (b) data reported by the group leader with dynamic grouping.

The average speed estimated using each approach is compared and mean absolute percent error (MAPE) is estimated. The average error using the dynamic grouping methodology is between 5.5-8.0%.

An important application of probe vehicle data is to estimate travel time between origins and destinations, which may have more than one path. The speed profiles (Figure 3) using data from dynamic grouping methodology closely follow that from individual probe data. The travel time using dynamic grouping approach is less than 4.5% within the travel time from individual vehicles' probe data, however, using 80-90% less bandwidth.

Probe data is also useful to estimate travel times in the event of non-recurrent congestion such as inclement weather or an accident. To replicate a non-recurrent congestion scenario, an incident of 20 minute duration at 3:45 PM. It can be seen from Figure 3 that the speed profile from dynamic grouping methodology closely follows that from individual probe data before, during and after the accident. Estimated travel times on each path from dynamic grouping are almost always less than 10% and less than 5% on an average within the individual probe vehicle travel times. Probe data collected using dynamic grouping approach can be used to estimate incident clearance times and queue spillback.

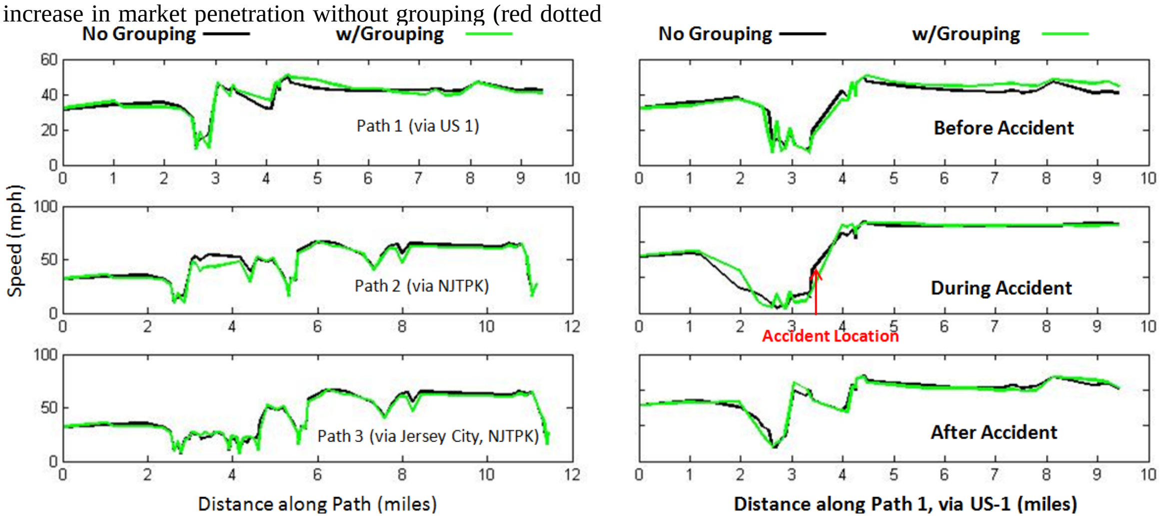

Figure 3 Speed profile along a path during normal conditions (left) before, during and after accident (right)

Secure Communication in Vehicular Networks

PRESERVE Demo

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***Abstract*—Security and privacy are fundamental prerequisites for the deployment of vehicular communications. The near-deployment status of Safety Applications for Intelligent Transport Systems (ITS) calls for strong evidence on the applicability of proposed research solutions, notably close-to-reality situations and field-operational trials. The contribution of our work is in this direction: We present a demonstration of the integration and the interoperability among components and security mechanisms coming from different Research and Development projects, as per the PRESERVE project. In fact, we show that the components of the SeVeCom and EVITA projects with the PRESERVE architecture lead to strong and practical security and privacy solutions for Vehicular Ad-hoc Networks (VANETs).**

***Index Terms*—Security, privacy, ITS, interoperability, PRESERVE, EVITA**

I. INTRODUCTION

For Intelligent Transport Systems (ITS), vehicles and road-side infrastructure are equipped with on-board sensor devices, computers, and wireless communication modules. ITS rely on Vehicular Communications (VC), i.e. Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication, to enable transportation safety and efficiency and other applications [1].

Strong but also practical security enhancing mechanisms need to be integrated in the VC [2]. Privacy requirements need also to be addressed [3], especially with the frequent broadcasting of positioning information. This led to the Secure Vehicle Communication (SeVeCom) [4] and the Privacy Enabled Capability in Co-operative Systems and Safety Applications (PRECIOSA) [5] projects, as well standardization efforts by European Telecommunications Standards Institute (ETSI) [6], IEEE 1609 WG [7] and the institution of the Car2Car Communication Consortium (C2C-CC).

Nevertheless not only the VC have to be secured, but also the vehicle internal communication buses should be protected against tampering attacks [8]. The objective of the E-safety Vehicle Intrusion protected Applications (EVITA) project was to develop a secure automotive on-board network [9].

Based on the conclusions of past and on-going Field Operational Tests (FOTs), such as Système COopératif Routier Expérimental Français (SCORE@F), safety applications have reached a near-deployment maturity state. The Preparing Secure Vehicle-to-X Communication Systems (PRESERVE) research project [10] plays a crucial role in this direction, bringing in strong and practical security and privacy protection, notably in field testing. With all the above efforts, an integrated, comprehensive solution, and a practical evaluation, i.e. FOTs, towards deployment of an overall secure architecture for automotive networks.

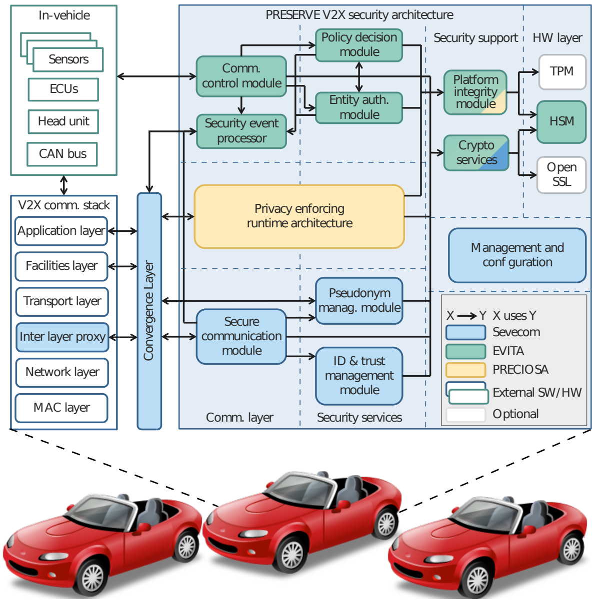

Figure 1: Illustration of the various components involved in the demonstration.

In this paper we briefly describe the overall integration of components in Sec. II, notably to achieve interoperability between EVITA on-board system and the PRESERVE architecture. In Sec. III we describe the demonstration setup.

II. SYSTEM DESCRIPTION

The system architecture for this demonstration is derived from the PRESERVE project. We have components from the vehicle on-board network plus secure communication capabilities. Figure 1 shows the relationships among components from the involved project [10].

A. On-Board Network

Modern cars are equipped with several embedded Electronic Control Units (ECUs), which are interconnected via various vehicular buses. The exchanged information can be critical for the safety of the car itself or nearby vehicles. The EVITA project defines an architecture for automotive on-board networks, where security-relevant components are protected against tampering, and sensitive data are protected against compromise. To achieve this degree of security, a trusted Hardware Security Module (HSM) that provides generation and verification of Message Authentication Codes (MACs), is attached to each ECU.

B. On-Board Unit

The vehicles are also equipped with an On-Board Unit (OBU) that runs the ITS applications, the communication facilities (i.e. radio, communication stack), and it is connected to the on-board network. The OBU is responsible for transmitting packets according to the ETSI GeoNetworking (GN) protocol, and it also integrates the IEEE 1609 standard. The OBU includes also the VC Security Subsystem (VSS) that provides security services to protect on-board communication and external VC.

C. Hardware Security Modules

The embedded ECUs and the VSS use a Hardware Security Module (HSM) to accelerate cryptographic primitives and securely store cryptographic credentials. Different HSMs attached to each ECU are defined in the EVITA project. The HSM dedicated to the VSS has been developed within the PRESERVE project in a form of Field-Programmable Gate Array (FPGA).

III. DEMONSTRATION SETUP

The proposed demonstration includes different devices, standing for two ITS vehicles acting as a transmitter and a receiver, respectively. We demonstrate the overall security and notably the the secure V2V communication.

One vehicle is represented by: (i) a Laptop, running the on board network, (ii) a 802.11p modem with the GN communication stack and the PRESERVE module, to which (iii) the PRESERVE FPGA is connected, to enable the hardware accelerated cryptographic functions and secure storage.

Laptops run a generic GNU/Linux operating system, and they host all the EVITA components, and interconnected internally. Each Laptop also hosts a Graphic User Interface (GUI) that displays the data and the related MAC, generated from the sensor and verified by the ECU, always using the EVITA HSM in software version. It also displays the vehicle's signature generation and verification. Figure 2 shows a screenshot of the GUI window.

Each Laptop is connected to a 802.11p modem via ethernet cable. Those modems are usually x86, ARM, or PPC based devices, running a modified version of the GNU/Linux operating system. We included in the modems the GN protocol stack for VC, implemented by Hitachi Europe in the context of SCORE@F. The ECU will transmit the internally verified message to the GN stack, where it will be signed under the vehicle's current pseudonym and broadcasted over the 5.9 GHz wireless band. The ECU and the modem together constitute the OBU.

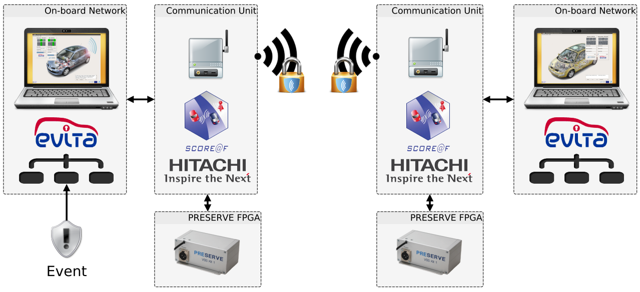

Figure 2: The whole demo setup and GUI that shows the triggered events and their transmission and reception.

The message is then received by the second vehicle's modem and it is verified by the other FPGA, while going upstream in the GN stack. If the verification is successful, the message is forwarded to the ECU where a new MAC is attached, and it finally reaches the actuator that verifies the integrity. The overall setup is illustrated in Figure 2.

In conclusion, we provide a milestone towards the integration between multiple projects, to achieve a single consistent implementation of a secure and privacy-aware ITS architecture.

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An Online Recommendation System for the Taxi Stand choice Problem

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I. PROBLEM OVERVIEW

The taxi driver mobility intelligence is one of the keys to mitigate the excessive concentration of vacant vehicles in the main town centers. The knowledge about where the services (i.e. the transport of a passenger from a pick-up to a drop-off location) will actually emerge can truly be useful to the driver – especially where there are more than one competitor operating. Recently, the major taxi fleets are equipped with GPS sensors and wireless communication devices. Typically, these vehicles will transmit information to a data center about their location and the events undergoing like the passenger pick-up and drop-off. These historical traces can reveal the underlying running mobility patterns. Multiple works in the literature have already explored this kind of data successfully with distinct applications like smart driving [1], modeling the spatiotemporal structure of taxi services [2-4], building passenger-finding strategies [5, 6] or even predicting the taxi location in a passenger-perspective [7]. Despite their useful insights, the majority of the techniques reported are offline, discarding the main advantages of this signal (i.e. a streaming one).

In our work, we focus on the online choice problem about which is the best taxi stand to go to after a passenger drop-off (i.e. the stand where we will pick-up another passenger quicker). Our goal is to use the vehicular network communicational framework to improve their reliability by combining all drivers' experience. In other words, the idea is to forecast how many services will arise in each taxi stand based on the network past behavior to feed a recommendation model to calculate the best stand to head to. An illustration about our problem is presented in Fig. 1 (the five blue dots represent possible stands to head to after a passenger drop-off; our recommendation system outputs one of them as the best choice at the moment).

The **smart stand-choice problem** is based on **four key decision variables**: the expected price for a service over time, the distance/cost relation with each stand, how many taxis are already waiting at each stand and the passenger demand for each stand over time. The taxi vehicular network can be a ubiquitous sensor of taxi-passenger demand from where we can continuously mine the reported variables. However, the work described here will just address the decision process based on the last three variables.

Figure 1. Taxi Stand choice problem.

In this Demo, we will present a Recommendation System to help the taxi driver about which **is the most profitable stand in each moment** based not only in its own experience but on a combination of them all. This system will account not only the current day type and daytime, but also the number of vehicles already parked in each stand, the distance to each stand and a live prediction about the demand in the next few minutes. A full description of this model is also presented in this conference as a full research paper with this same title.

II. DEMO DESCRIPTION

The Demo will consist in a video projection containing part of our experiments. They consisted on a simulation of a competitive scenario of two fleets operating in urban area where the demand is largely inferior to the number of vacant taxis. This simulation recreates a real scale scenario: the case running on the city of Porto, Portugal. One of the fleets follow a standard behavior while the other uses the recommendation model hereby proposed. The two fleets are fed with live service logs containing real information about the services demanded. The travel times and distances are simulated using the DIVERT traffic simulator [8].

In this video, we will be able to observe not only the real behavior of the vehicles and its navigation through the city' road network, but also the impact of the recommendation system using three distinct performance metrics: (1) the *Waiting Time* (WT) and (2) the *Vacant Running Distance* (VRD) and the number of *No Services* (NS). The *Waiting Time* is the total time that a driver takes between a drop-off and a pick-up (i.e. to leave a stand with a passenger or to get one in his/her current location). The *Vacant Running Distance* is the distance that a driver does to get into a stand after a drop-off (i.e.: without any passenger inside). Independently on the time measured on the simulation, we always consider a maximum threshold of 120 minutes to the *Waiting Time*. The *No Service* metric is a ratio between the number of times that a taxi parked on a stand had a waiting time greater than the 120 minutes threshold and the number of services effectively dispatched by the respective fleet.

Along with the video reproduction, the presenter will talk about some particular aspects, causes and side effects of this recommendation model. Questions and/or other comments will also be welcome.

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Vehicular Robotic Test Bed for ITS Applications

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I. DEMO PROPOSAL

Intelligent Transportation System (ITS) applications are proposed on nearly a daily basis through conferences, journals, and ad hoc discussions of people within and outside the field of vehicular technologies. Many applications are purely theoretical because they lack the funding or support to test the application in live vehicles. Further, many applications require a high penetration rate of vehicles equipped with specific hardware or software, and this is nearly impossible to achieve as part of a research project. To obtain stakeholder acceptance, a proof of concept must be developed. Although this could be accomplished through installing hardware in vehicles, it can also be accomplished through a vehicular test bed with scaled vehicles. In addition, any applications that could have potential damage to vehicles or cause potential harm to drivers and passengers can be tested in an environment where the cost of a crash is nothing more than the cost of a scaled vehicle. The potential of causing harm to people is completely removed in this environment.

At the University of Alaska Anchorage, we have developed a 1:24 scaled vehicular robotic track to allow testing of intelligent transportation system algorithms and vehicular communication. The vehicles are 1:24 scale model cars that we have modified to contain wireless transceivers, microcontrollers, motors, turning ability, and extensibility for sensors, as shown in Figures 1 and 2.

An overall architecture of the system is shown in Figure 3. The vehicles communicate using either 802.15.4 or 802.11. There is a router that is connected to a server monitoring all of the communication activity. The communication can be vehicle-to-infrastructure by communicating with the router and the server or vehicle-to-vehicle by two vehicles communicating directly with each other. The V2V communication can be accomplished by vehicles communicating in ad hoc mode or utilizing the router as a pass-through that merely bounces the signal back to the destination vehicle. A discussion on which of these communication methods would be utilized practically was provided during a riveting panel at VNC 2011.

Since many ITS applications assume that vehicle location is given, we have created a video processing application that determines the location of a vehicle from a video camera mounted above the test track. The location is then transmitted to the server for forwarding along to the specific vehicle. This process is similar to receiving a location from a GPS satellite, though the camera is not communicating directly with the vehicle. This is a possibility for the future, but at this point we did not feel it was necessary to add this additional communication channel into the test bed.

Although we have complete network coverage in our environment, we can simulate disconnected operation through the server not forwarding along messages to vehicles that are within a “dead zone.” The vehicle will then operate on its own during that time period without any communication from the server, though other vehicles that are within the range we allow will still be able to communicate with it.

One of the goals of this project is to provide autonomous operation of the vehicles on the track. Since it is infeasible to assume that we will have 100% penetration rate of autonomous vehicles in the foreseeable future, we have provided a mechanism for having a mix of driven and driverless vehicles. We have developed an iPhone/iPod Touch application that can be used to control individual vehicles. We then will be able to have any number of vehicles autonomously driven and the remaining ones controlled by humans.

The track that we use is created using whiteboard markers on an erasable surface. This allows us to change the lane markings throughout our testing. Another application we have created reads the lane markers through a video camera and determines the corners and roadway sections. This is then sent to the central server to be used for directing the vehicles along paths that do not cross over lane markings or curbs.

Traffic signals and stop signs have been added in as well. Although we do not currently have video cameras installed on the vehicles, it is an enhancement we are planning in the near future. The traffic lights are wired back to the central server and can be controlled synchronously or asynchronously with the other ITS applications we are testing. Platooning traffic can easily be achieved or dynamic signal timing algorithms can be tested with little configuration.

There is a web interface that has been created to stream the simulation results directly to anyone viewing the URL. One of our future steps will be to allow researchers from anywhere in the world to upload code onto the server and the vehicles and test their own applications remotely using our test bed. There will be a specific API for controlling the vehicles and all of the different parameters that will exist, but we are currently in the works of that.

Further, all of this data will be tied into the real-time traffic simulator FreeSim [1], which has been developed by one of the authors of this proposal. FreeSim has been working quite well at receiving data in real-time from live vehicles that have GPS receivers and cellular transceivers connected to the on-board diagnostics port on a vehicle. A number of

FIGURE 1. 1:24 SCALE VEHICLE USED IN TEST BED

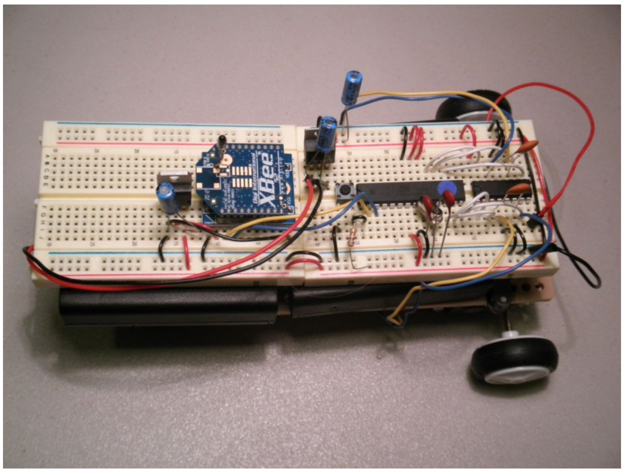

FIGURE 2. MODIFICATIONS MADE TO VEHICLE

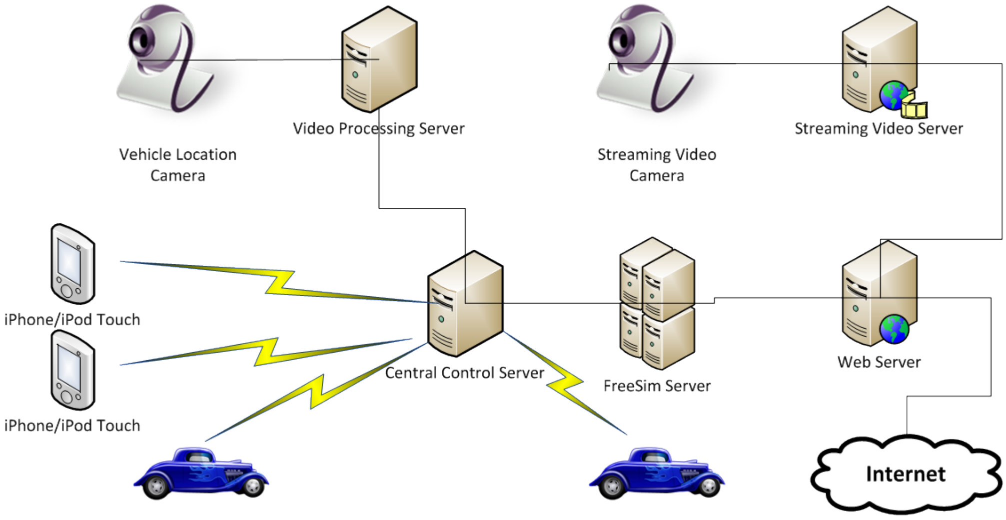

FIGURE 3. ARCHITECTURE OF VEHICULAR ROBOTIC TEST BED

parameters are transmitted back in real-time to a central server we host, and real-time traffic conditions are reported through a web site. Instead of only operating on live data, FreeSim is being modified to operate on simulated data from the vehicular test bed. The data will be forwarded to FreeSim for processing, and the real-time conditions and locations of the vehicles will be displayed in the FreeSim interface. This will provide researchers the ability to watch a live video feed and then see a simulated execution within FreeSim. All of the data from the execution will be stored in a database so that it can be recalled for review purposes.

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