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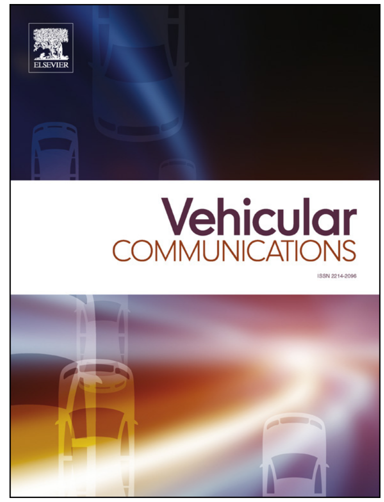

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Hazem Ahmed, Samuel Pierre, Alejandro Quintero

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A Flexible Testbed Architecture for VANET

Hazem Ahmed, Samuel Pierre, and Alejandro Quintero
Mobile Computing and Networking Research Laboratory
Department of Computer Engineering
Montréal, Canada
{hazem.ahmed, samuel.pierre, alejandro.quintero}@polymtl.ca

***Abstract*— Verification of VANET applications and protocols is a challenging task due to its unique mobility, driver behavior and networking requirements. Although network simulators are widely used for network performance evaluation, there is a lack of a realistic testbed that is capable of emulating the VANET environment, enabling user testing and evaluating both Quality of Service (QoS) and Quality of Experience (QoE). This article studies the requirements of such a testbed and introduces a flexible VANET testbed architecture that is tailored for VANET applications' needs. The implementation of this architecture is tested using standard VANET applications to evaluate its feasibility for vehicular applications. Our results confirm the suitability of the proposed testbed to meet VANET requirements. Furthermore, the effect of adding a caching entity is experimented and the results show its ability to mitigate the testbed's overhead.**

***Index Terms*— VANET; P2P; Testbed; Emulation; Simulation; WiFi; WiFi Direct; Android; Architecture; GPS; Experiment.**

I. Introduction

The world has more than 1 billion active Android users as of June, 2014[1], with more than one million devices being activated every day[1]. With the mass production of such smart technology (typically in the form of phones and tablets), the cost to manufacture these platforms is constantly getting cheaper even as devices become more powerful and capable.

With this dramatic growth in the number of portable wireless devices, there is a huge market for the development of smart applications that can interact with users' lifestyles and provide context-aware interactions. Mobile games markets are growing as well; it is expected to reach $23 billion by 2016[2].

In the last five years, automakers adopted integration platforms between the onboard devices and personal smartphones. Hence, the line between consumer electronic devices (e.g. smartphones) and onboard vehicles has become thinner. Furthermore, multiple applications are targeting consumer electronics for VANET applications.

The integration between onboard devices and consumer electronics offers more flexibility for applications that can be used on a vehicle and get best user experience of applications on the vehicle. Smart Device Link (SDL)[3] is one popular example that is adapted by Ford and Toyota. SDL enables running applications on smartphones on the vehicle's head unit. Other examples are Google's Android Auto and Apple's CarPlay that allow using the car's head unit to display and control applications on the consumer devices. Also, developers can develop VANET applications are that are suitable for Android Auto or Carplay.

Testing and validation of context-aware and mobile application is a huge market. ABI research firm mentioned that mobile testing tools generated $200 million of revenues in 2012. With the new mobile automated testing tools, this number will reach $800 million by the end of 2017[4].

Originally network simulators such as NS-2 and OMNET++ were enhanced by supporting both wireless interactions and basic mobility for simulated nodes. Although these simple mobility protocols work well for simple Mobile Ad-hoc Networks (MANETs), it failed to handle the VANET mobility requirements. VANET requires complex mobility models involves road topology, driver behavior and different traffic conditions and routes. This leads to the integration between network simulators and urban mobility simulators such as SUMO which is capable of simulating complex traffic scenarios and sophisticated driver behavior. This integration enriches the VANET simulation by using realistic road topology and mobility conditions.

Although the ability of network simulators integration with urban simulators to simulate complex VANET scenarios that are very difficult, if not impossible, to replicate in real environments, it fails to simulate complex user interactions, software application response, context-aware applications and on device testing. Furthermore, simulators can result in unrealistic scenarios and synthetic output[5].

Real testbeds are introduced as a solution for the simulation's problems, where a miniature of a real life scenario is implemented. This gives the ability to test applications on native environments and evaluate the Quality of Experience (QoE). Running costs of real testbeds are very high in addition it suffers from multiple problems such as scalability, limitation on specific scenarios, very long preparation and running time, lack of large scale evaluation and difficulty of repetition, profiling and modification of an experiment.

To solve the problems of real testbeds, emulation concept is introduced where parts of the hardware components are emulated. The emulation data could be an output of a simulator, real traces or event-based generator. For example, NS-2 and NS-3[6] provide and emulation extensions that enables using simulated nodes as if they are real network nodes. However, this technique could lead to unrealistic results due to simulators' overhead that is required to process the information[6].

Software emulators are usually provided by operating systems and hardware manufacturers to emulate several hardware profiles and supply visual tools on the developer's