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Analyses and Evaluation of Wireless Local Area Network in Vehicular Mobility Scenarios

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***Abstract*—Vehicle-to-infrastructure (V2I) communication based on wireless local area network (WLAN) technology can provide users in-motion to obtain Internet connectivity. In this paper we present an experimental study of IEEE802.11n with diminished settings compared to the legacy system using off-the-shelf devices in V2I small scale scenario. In order to evaluate the V2I the type of communication in the large scale scenario, in this paper we propose an analytic model to characterize the goodput of WLAN-based networks using Markov process.**

***Index Terms*—Vehicular communication, Markov process, Wireless LAN.**

I. INTRODUCTION

The urgent need for the diminishing of road traffic accidents, traffic jams, CO_2 emission and environmental impact are a major challenge for academics and industry. Researchers in both parties have been linked to develop vehicular communication and networking technology in two basic ways vehicle to vehicle (V2V) in ad hoc mode and vehicle to infrastructure (V2I) with fixed nodes along the road. The potency to exchange information wirelessly V2X is a major backbone of powerful Intelligent Transport Systems (ITS). In connection with those in Europe, USA and Japan are great efforts made from automakers and governments to reach single standards through the several and common projects. Result from common effort is an international standard, IEEE802.11p [1] with raw data rate up to 27Mbps. This standard is able to provide a short message communication to enhance safety on the road and traffic flow, but it does not have the capacity to ensure the comfort of the passengers and drivers with appropriate INTERNET access. In this case, new initiatives are offered to develop wireless network solutions with low costs and high throughput.

A nowadays disposition of WLAN-based access technologies are predominantly to stationer indoor and outdoor users who are most slowly moving and in range limited. Despite the fact that the standard has been developed not for fast dynamic usage, nothing limits it to be evaluated for vehicular communication systems. The main motivation is to understand the interaction between the vehicle speed and goodput of WLAN-based network. In our case, Goodput is defined [2] as the application throughput, i.e. the number of bits per unit of time excluding protocol overhead and retransmission packet.

Realizing field trials for goodput evaluation of vehicular wireless communication systems is very difficult and costly because many vehicles and communication equipment need to be purchased or rented, and also many experimenters need to be employed. Given such problems, it is highly desirable to obtain a mathematical description of process with real data from small scale scenarios of practical measurement results and perform an evaluation prior conducting field trials as it is made in this work.

This paper constructs as follows: After introduction the problem in Section II, Section III provides some background issue about the vehicular traffic. Then in Section IV provides V2I small scale scenario trial test description and results. After then, in Section V describes a queuing model of V2I communication with one wireless access point and variable amount of mobile clients (vehicles). After demonstrating the analysis results in Section 4B. Section V summarize and concludes this paper.

II. VEHICLE MOBILITY MODELS

The mobility model that will be utilized in the remainder of this paper is introduced briefly in this section.

In general, traffic engineers distinguish two major classes of mobility models which have both spatial extension and temporal duration of traffic flow.

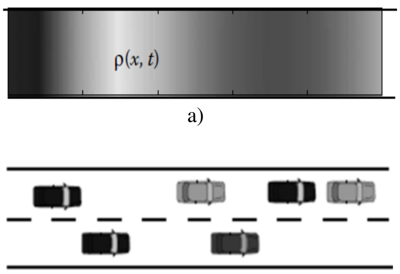

Fig. 1. Illustration of two main traffic modeling options: a – Macroscopic model; b – Microscopic model.

Macroscopic traffic flow models describe the vehicular mobility as a hydrodynamic phenomenon or a physical flow of some fluid. By way of contrast, microscopic traffic models describe the motion of each individual vehicle. In

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few research papers [3], [4] are discussed different microscopic traffic models in terms of their analytical description and verified their realism. Based on those studies, car-following models are the appropriated approach for studies of vehicular networks. Car-following models describe the behavior of each driver in relation to the vehicle ahead so called the leading vehicle.

A microscopic traffic model called Intelligent Driver Model (IDM) belongs to the type of deterministic car-following models, which is based on follow-the-leader concept.

Working out with defined parameters and simplified IDM was achieved that the traffic density vs. speed relations can be approximated as follows

$$\rho(v) \approx \frac{d}{(l+s_0)} e^{-0.0349v} \quad (1)$$

where s_0 – minimum traffic congestion distance (m); l – average vehicle length (m) ~ 4.12 meter; d – WLAN access point production phase or a certain window of useful connectivity distance during which effective communication can be taken place; v – balanced speed of vehicles.

However, vehicular traffic is an extremely complex dynamic process due to nonlinear interactions between travel decision behavior, routing of vehicles in a traffic network and traffic congestion occurrence within the network [5]. Finally one can be used (1) related for analyses of wireless communication performance with finite customer quantity N(v), which can be mapped into Markov birth-death system.

III. V2I SMALL SCALE SCENARIO

Evaluations of a low-cost WLAN in different scenarios are currently a topic research area in academia and industry [6]–[12]. Remarkable efforts in the research field are achieved to provide comprehensive test results which are off-the-shelf technologies mostly based on the widely deployed IEE 802.11a/b/g standards.

The main contributions to this section are to give an overview of the latest standard like IEEE802.11n improvements and experimental results from trial test. The field test was performed in the absence of other conventional wireless signals in order to be able to perform WLAN root cause analysis in a mobile environment.

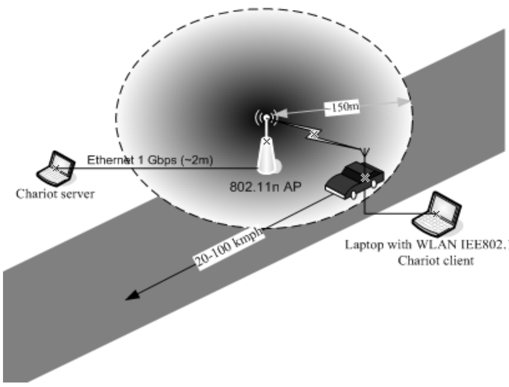

Fig. 2. Field trial measurement test setup – V2I scenario.

A. Measurement tools and scenarios

The main goal of practical test is to investigate the possibility of 802.11n standard in vehicular to infrastructure mode using cost effective and off-the-shelf equipment, and available software.

In order to reach the aim has been performed set of measurements with one access point (AP) and a mobile user's device which was located in a moving vehicle at a constant speed and velocity has been maintained using cruise control.

The access point has been directly connected to the fixed station. Off-the-shelf laptop with WLAN based on IEEE802.11n standard was used as a mobile user's device without external antenna and the similar laptop for fixed station is wired to an off-the-shelf WLAN AP (ASUS RT-N16). This multi-functional Gigabit wireless N router is a cost effective AP supporting 802.11n standard draft data rate up to 300 Mbps and operating licenses free frequency band (2.4 GHz) and has a transmit power rating at 15.8~19.5dBm. The network topology and system configuration depict in Fig. 2 and main measurement setup parameters are summarized in Table I.

TABLE I. TRIAL TEST SETUP.

Item	Setting
Wireless technology	802.11n only
Channel	fixed
Channel wide	20MHz
Frequency band	2.4GHz
Tx power	17mW
Maximal data rate	up to 130 Mbps
MIMO Transmission fixed rate	Auto
OFDM Guard Interval	0.8μs
Preamble	Long
Size of sending file	100000 Bytes
Transport protocol	TCP
IP address	Fixed
Velocity	20/40/60/80/100 kmph

For establish wireless connectivity quickly, the AP and the mobile user's device WLAN adapter were configured to use the same frequency channel and ESSID, the encryption has been deactivated. IP addresses for all connections have been entered in prior do to highly variable performance.

The network throughput was taken to estimate the TCP performance. For this have been used a client and a server of The IxChariot program (Version 6.7) with the client residing on the mobile user's device, i.e., in vehicle and server running on a fixed station with Ethernet based connection to AP router interface. By entering a WLAN the throughput of WLANs depends heavily on the environment, including the distance between the client and the access point. The throughput generally falls off as distance increases, but obstacles and signal interference from different signal sources also have a significant effect. Therefore, prior to the test was conducted a scanning of existing access points that could interfere with testing signals.

During the trial test which was deployed over a straight and the 1400m long runway of the airfield "Rumbula" performed a total of 16 runs. Each configuration was tested more than twice, to get better results.

B. TCP measurement results

The results of the outdoor performance test for IEEE802.11n WLAN at various speeds of vehicles is shown Fig. 3. The throughput is plotted versus elapsed time by different velocity of the car. The figures show that the throughput is increased by approaching the access point contrary while moving away is decreasing due to the adaptive data rate. An access point adaptive data rate which impact of the subsequent uses of the different primary modulation type received by the testing car is dependent on its distance (here expressed in elapsed time) from the access point. The throughputs have floating effect which can be also explained by variations of channel conditions due to fading.

The throughput versus velocity of the car is variable and clearly shows at every velocity the phases of oncoming to and moving away from the access point. In the both phases derive low throughput rates. The transition to the peak throughput phase occurs relatively quickly. At lower velocity the transitional form is gently sloping. This affirm the case where the access point transmission bit rate received by the testing vehicle changes as the vehicle passes through the access point's coverage range.

In our case, goodput is calculated by multiplying the size of sending files by transferred file rate and dividing by a useful connectivity window.

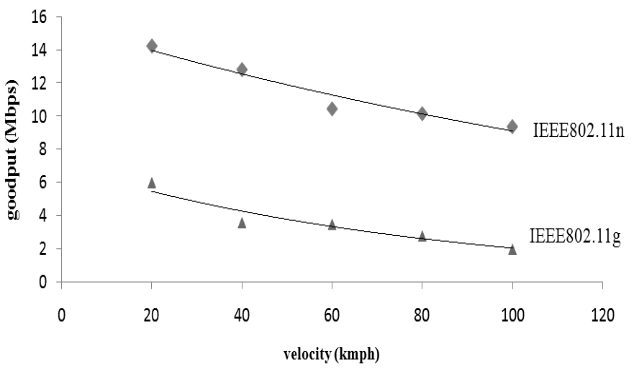

Fig. 3. Comparison of basic performances goodput vs. velocity over IEEE802.11 g and n.

In fact, goodput rate is dependent on the vehicle speed and decreasing proportionally with the vehicle speed. Fig. 7 shows the goodput of the IEEE802.11n standard in comparison with IEEE802.11g. Improved standard presents a 2 ½ time preferably performance of goodput in mobile environment then legacy.

Calculating the results from field trial with IEEE802.11n standard devices was obtained that the average goodput vs. velocity relations and can be approximated as follows

$$goodput(v) = 15.517 \cdot e^{-0.005 \cdot v}. \quad (2)$$

In this section were obtained the results from the small scale of practical tests to be able to continue to use the data for further analysis. With this small test we've got the wireless network maximum performance indicators, which can get highly mobile user with the appropriate network configuration.

IV. V2I LARGE SCALE SCENARIO

Realizing field trials for goodput evaluation of vehicular wireless communication systems is very difficult and costly. Numerous vehicles and communication equipment need to be involved, and also many experimenters need to be employed. In this case, it is highly desirable to obtain theoretical analysis with real data from small scale scenarios of practical measurement results and perform an evaluation prior conducting field trials. In terms of analyses methods, were mapped previous approximations of vehicle mobility (1) and goodput (2) into Markov M/M/1//N chain model. Use of Markov model is novel for evaluation of IEEE802.11n standard in a mobile environment comparing with legacy standard (i.e. IEEE802.11g).

A. System model description

For this model computation, was considering the case where the access point's transmission data rate is variable through the access point coverage range.

Primitive packets flow from finite wireless mobile users N and arrive to an infinite buffer of the system and are served by the server or wireless router.

In this case our system is expressed by the Kendall notation like M/M/1//N [13], where first M – defines exponential inter arrival times between packet distribution (Poisson process), second M – defines exponential data packets transmission time distribution, next number defines the transmission channel and N – represents the number of packet sources. Processes in M/M/1//N system are birth-death process. Queuing models for M/M/1//N systems are very elegant in analysis of wireless data networks in transmission channel with no packet loss and vehicles simultaneously under the coverage of the access point v. speed – $N(v)$ (i.e. ρ(v) from (1)). Based on this M/M/1//N queuing model the average goodput by a vehicle can be computed as follows:

$$goodput(v)_N = goodput(v) \cdot (1 - \pi_0) / N(v), \quad (3)$$

where π_0 represent probability of idle system.

$$\pi_0 = \left[\sum_{j=0}^{N(v)} \frac{N(v)!}{(N(v)-j)!} \cdot \frac{\lambda}{\mu}^{j} \right]^{-1}, \quad (4)$$

where $j=1,2,3....N(v)$, μ – the data packet transmission rate of the channel between vehicular and base station, λ is packet arrival rate in the coverage range of the access point.

B. Results

In the computation of the analytical model in the previous subsection, was constructed a topology with an access point sending file data to all vehicles within coverage range of an access point. In the computation, each vehicle maintains its speed as it drives through the access point coverage range as shown in Fig. 4. The computations compare the results derived from trial field tests with analytical model for the single-lane vehicle traffic.

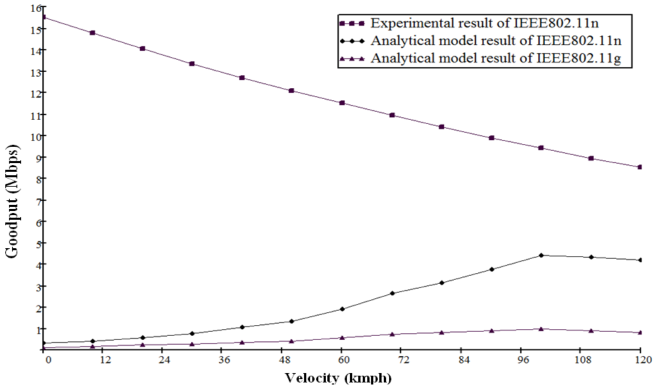

Fig. 4. An average goodput for user in-motion at different speed.

The range of values was investigated for goodput that a vehicle can obtain from access point.

From the Fig. 11 can make the following observation at low traffic density corresponding to high vehicle speed, there are few vehicles and as such there is a few connections using the access point resource and the value of goodput is close to maximum. It is about two times less than plausible maximum goodput. On low velocity increase value of vehicles and bandwidth connections increases leading to lower values of goodput for a vehicle. Despite reduction of maximum goodput due to mobility at velocity from 50 kmph to 100 kmph improves the goodput value of a vehicle.

V. CONCLUSIONS

In this article was presented field trial evaluations together with theoretical analyses of the IEEE802.11n standard comparing with legacy standard in the vehicle environment. The numbers of test were performed in the context of simple scenario of one vehicle and access point. At various velocities has been tested the goodput of WLAN. Wireless network under fluent number of vehicles respectively active users simultaneously realizing such field trials for goodput evaluation is very difficult and costly. Therefore a simple mathematical model for goodput evaluation of vehicular communication systems in V2I scenario was presented and analyzed for understanding the basic processes in wireless data networks prior to conducting larger field trials. And it is also important to note that results were showed here serve as information for future analyzes and vehicle wireless information for network systems designers.

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