Performance Evaluation of IEEE 802.11p for Vehicular Communication Networks

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Abstract—IEEE 802.11p is an emerging standard which provides vehicular safety communication through wireless networks. In this paper, we will study the architecture of Wireless Access for Vehicular Environment (WAVE) and IEEE 802.11p standard. The key parameters of this standard are implemented in ns-2 network simulator to accurately simulate vehicular ad hoc networks (VANETs). The performance of this standard will be evaluated in the network simulation environment using realistic vehicular mobility models. Throughput, End-to-End delay, and packet loss metrics will be analysed for our scenario, since they are the main performance metrics for vehicular safety communication. In addition, the effect of varying vehicle speed and different message sizes on the performance metrics will be examined.

Keywords—IEEE 802.11p, WAVE, Vehicular Communication Networks

I. INTRODUCTION

Intelligent Transportation System (ITS) is one of the information and communication technologies which has attracted a lot of attention recently. This technology enhances transportation safety, reliability, security and productivity by integrating with existing technologies. Wireless data communication between vehicles is one of the technologies which has improved the deployment of ITS applications. This communication is divided into two types: Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I). Vehicles are equipped with short-range wireless communication technology (approximately 100 to 300 meters) acting as computer nodes on the road. This is known as vehicular ad hoc network (VANET) technology. The major objectives of VANET technology can be stated as follow: broadcast warning messages to neighbouring vehicles in case of car accidents, help emergency vehicles to pass other vehicles quickly, provide drivers with latest real-time traffic information, assist drivers to find accessible parking space.

In 1997, the United States Federal Communications Commission (FCC) allocated 75MHz of spectrum in the 5.9 GHz band, 5.850-5.925 GHZ, for the exclusive use in vehicular applications. The spectrum became known as Direct Short-Range Communications (DSRC). Furthermore, in 2008, the European Union (EU) dedicated a 30 MHz spectrum, 5.875-5.905 GHz, for ITS communication [1].

A wide range of project activities have initiated around the world in order to improve vehicular communication networks. In 2004, IEEE 802.11 task group p developed an amendment to the 802.11 standard in order to enhance the 802.11 required to support VANETs. This standard is known as 802.11p, it defines physical and medium access control layers of VANETs. In addition, The IEEE 1609 working group defined IEEE 1609 protocol family which developed higher layer specification based on 802.11p. This protocol consists of four documents: IEEE 1609.1, IEEE 1609.2, IEEE 1609.3, and IEEE 1609.4. IEEE 1609 protocol family and 802.11p together are called WAVE standard. This system architecture is used for automotive wireless communications [2].

The specific nature of VANET makes this network different from other kinds of networks; some of its characteristics are high mobility, short communication periods, dynamic topology and limited bandwidth. Communication in VANETs is based on event-driven messages or broadcast messages which are exchanged between surrounding vehicles. Due to the characteristics of VANET and limited bandwidth, periodic broadcast messages can consume the entire available bandwidth. Furthermore, emergency messages need to be disseminated quickly and efficiently. Consequently, there is a need to prioritise important and time-critical messages and use quality of services. The IEEE 802.11p MAC layer implements a priority scheme in a similar way to IEEE 802.11e Enhanced Distributed Channel Access (EDCA) function. EDCA mechanism was proposed in 802.11e in order to support quality of service and prioritize messages.

The overall aim of this paper is to evaluate the IEEE 802.11p PHY/Mac standard. A study will be made of the structure of the WAVE architecture for VANETs. We will, subsequently, set up one real scenario which will help us to analyse the performance metrics of the IEEE 802.11p (throughput, End to end delay, and packet loss). This scenario is implemented and modelled using ns-2 network simulator and VanetMobiSim traffic simulator. One of the most important points in the vehicular network simulation is that the nature of vehicular communication is based on the movement, so it is necessary to implement a realistic vehicular movement in the simulation. In other words, all of the important parameters should be implemented accurately in the VANET simulation. The main novelty of this paper is to implement the key parameters of 802.11p standard in ns-2, and prepare the realistic vehicular mobility model by VanetMobiSim.

Several publications ([3], [4], [5]) have studied the performance of 802.11p, however they do not support realistic vehicular mobility simulation. In [6], the authors present a comprehensive evaluation and simulative review of the performance of 802.11p and WAVE standards. They use Qualnet network simulator for the simulation portion. In terms
of modelling accuracy. A new model of IEEE 802.11 MAC and PHY, which support IEEE 802.11P, is designed and implemented in ns-2 network simulator version 2.34 [7]. This version of ns-2 network simulator is used for this paper [8].

The remainder of this paper is organized as follows. In section II we clarify the WAVE and IEEE802.11p structure. The simulation scenario is conducted in section III. Results from the simulation and the analyses of the performance metrics of the IEEE 802.11p are presented in section IV. Finally, this paper is concluded in Section V.

II. VEHICULAR COMMUNICATION BASED ON THE IEEE 802.11P AND WAVE SYSTEM

In this section we briefly present an outline of WAVE architecture system and IEEE 802.11p protocol for VANET.

A. Physical and MAC Layers

The physical and MAC layers of WAVE are based on IEEE 802.11p standard. The physical layer of IEEE 802.11P consists of seven channels in 5.9GHz band which is similar to IEEE 802.11a design, but the main difference is that the IEEE 802.11p use 10MHZ bandwidth for each channel instead of 20MHZ bandwidth in IEEE 802.11a. The physical layer of 802.11p uses OFDM technology which is used for increasing data transmission rate and overcoming signal fading in wireless communication. One of the specifications of IEEE 802.11p is that the management functions are connected with the physical and MAC layers which are called physical layer management entity (PLME) and MAC layer management entity (MLME), respectively [3]. The IEEE 802.11p uses CSMA/CA to reduce collisions and provide fair access to the channel.

B. Multichannel operation

IEEE 1609.4 is one of the standards of the IEEE 1609 protocol family, which manages channel coordination and supports MAC service data unit delivery. This standard describes seven different channels with different features and usage (six service channels (SCH) and one control channel (CCH)). In addition, these channels use different frequencies and transmit powers. Eichler [3] mentions that each station continuously alternates between the control channel and one of the service channels; however the different channels cannot be used at the same time. According to [9], the control channel is used for system control and safety data transmission. On the other hand, non-safety messages are exchanged by the six service channels.

The IEEE 802.11p MAC layer is based on multichannel operation of WAVE architecture and 802.11e EDCA. This mechanism defines four different access categorizes (AC) for each channel. The access categories are indicated by AC0-AC3, and each of them has an independent queue [3]. The EDCA mechanism provides prioritization by assigning different contention parameters to each access category. AC3 has the highest priority to access medium, and AC0 has the lowest priority. Therefore, service channels and one control channel and each of them has four different access categories. Consequently, during data transmission, there are two contention procedures to access the medium: Internal contention procedure which occurs inside each channel between their access categories by using the contention parameters (Arbitrary InterFrame space (AIFS) and Contention Window (CW)), The contention procedure between channels to access the medium is supported by different timer settings based on the internal contention procedure.

Throughout data transmission, each frame is categorized into different access categories, depending on the importance of the message. Then the selected frames contend to access the medium using their contention parameters [10].

Logical link control (LLC) is another element of WAVE structure which is similar to upper sub-layer of OSI layer two. LLC provides the communication between upper layers and the lower layer.

C. Network and transport layers

The IEEE 1609.3 defines the operation of services at network and transport layers. Moreover, it provides wireless connectivity between vehicles, and vehicles to roadside devices. The functions of the WAVE network services can be separated into two sets:

- Data-plane services: they transmit network traffics and support IPv6 and WSMP protocols. WAVE short-message-Protocol (WSMP) provides this capability that applications can send short message to increase the probability of receiving the messages in time.

- Management-plane services: Their functions are to configure and maintain system, for instance: IPv6 configuration, channel usage monitoring, and application registration. This service is known as WAVE management entity (WME).

The devices which use WAVE architecture should implement UDP as specified in RFC 768, and TCP as defined in RFC 793 [10].

D. Resource Manager

There are two kinds of wireless access in VANETs:

- Roadside unit (RSU) which are the static stations located along the roadside,
- On-board unit (OBU) mounted on a vehicle and can operate while moving.

IEEE 1609.1 standard defines a WAVE application known as resource manager (RM) which should allow communication between applications runs on RSUs and OBUs. The RM resides on either OBUs or RSUs [10].
E. Security Services

The IEEE 1609.2 standard defines security services for the WAVE architecture and the applications which run through this architecture. This standard defines the format and the processing of secure messages; furthermore, it describes the core security functions [2].

III. Simulations

Implementing and deploying VANETs in a real world can be prohibitively expensive and difficult. Consequently, most of the research in the area of Vehicular communication network is based on simulation for evaluation [11].

Simulation in VANET consists of two components: traffic simulation and network simulation. Traffic simulation focuses on vehicular mobility and it generates a trace file which provides realistic vehicles movement. This trace file is fed into the network simulator which defines the realistic position of each vehicle during the network simulation. The network simulator then implements the VANET protocols and produces a trace file which prepares complete information about the events taking place in the scenario. Information will, subsequently, be analysed to evaluate the performance metrics of the IEE 802.11p in VANET.

VanetMobiSim [12] has been selected as a traffic simulator for this paper, since it is an open source and is validated against commercial simulators. This simulator supports Intelligent DriverModel with Intersection Management (IDMIM) which generates realistic vehicular mobility model [13].

Jiang et al. [14] mention that vehicular safety communications based on IEEE 802.11p consist of safety broadcast messages between neighbouring vehicles. Consequently, the overall IEEE 802.11p performance is related to broadcast messages reception performance. PBC agent is a broadcast message generator which is implemented in ns-2 version 2.34. We use this agent in order to define the broadcast message generation behaviour in our simulation scenario.

One scenario has been implemented in our simulation. The scenario is a highway of 1500 meter length with three lanes in one direction and nine vehicles moving in these three lanes. The maximum speeds of the lanes are around 80, 100 and 130 km/h respectively and the speed limit for each lane is 60 km/h. The distance between each lane is 4 metres. In this scenario an ambulance is in the emergency situation traveling in the same direction as other vehicles at the speed of 150 km/h. The ambulance is located behind other cars which are 100 metres apart. The IDMIM generates realistic vehicular mobility model. Ambulance transmits one periodic broadcast message with a payload of 250 bytes in every 0.2 seconds. In order to evaluate the effect of different message sizes on the performance metrics we implement another two network simulations in which the ambulance transmits period broadcast messages with the payload of 500, 1000 bytes respectively. Each network simulations run twenty times with the same mobility trace to obtain an average and get a notion of statistical significance.

IV. Results

Results which have been obtained from the scenario previously described will be presented in this section. Throughput, End-to-End delay, and packet loss have been calculated for nine vehicles as numbered in fig. 2 during the simulation run-time (65 seconds). In addition, the impact of various speeds on different performance metrics will be evaluated.

Fig. 3 shows the distances between the ambulance and vehicles 2, 4, and 10; in addition packet loss between the ambulance and these vehicles during simulation time are illustrated in fig. 4. It is clearly shown that the packet loss between the ambulance and vehicle 4 is 100% for 38 seconds but after this time there is no packet loss. According to fig. 3 the distance between ambulance and vehicle 4 is less than 138 metres after 38 seconds. It provides similar results for vehicle 10 and after 58 seconds when the distance between ambulance and vehicle 10 is less than 138 metres the packet loss is 0%. Accordingly, the vehicles can receive the broadcast message when their distance from ambulance is less than 138 metres.
Fig. 4. Packet loss between the ambulance and other vehicles

Fig. 5 demonstrates the throughput of vehicles 2, 4, and 10 with the message size of 250 bytes. The plot shows that the throughputs of vehicle 4 and 10 fluctuate between 1.8 and 2.2 Kbps, when their distance from ambulance is less than 138 meters. It can be seen from fig. 5 that all of the vehicles have nearly similar throughput when the distance between vehicles and ambulance is less than 138 metres. In other words, throughput of all the vehicles which are not 138 metres far from ambulance is the same and there is no packet loss between these vehicles and ambulance. The most important point is that each vehicle has different speed, as a result the throughput and packet loss are not affected by the varying speed.

Fig. 6. End-to-End Delay between vehicle 1 and other vehicles (message size 250 bytes)

The End-to-End delay between the ambulance and vehicles 2, 4, and 10 with the message size of 250 bytes are calculated in fig. 6. A comparison between fig. 3 and fig. 6 shows that as soon as the distance between vehicle and the ambulance is below 138 metres, these two plots look similar. It is observed that End-to-End delay is significantly influenced by the distance between sender and receiver of the message. As the distance between sender and receiver increases, the End-to-End delay increases as well. Based on our findings, various vehicle speeds do not have any impact on End-to-End delay.

Fig. 7 illustrates the average throughput of all vehicles; in addition fig. 8 and fig. 9 demonstrate the average distance and packet loss between these vehicles and the ambulance respectively. This shows that the probability of message reception for vehicles 4, 7 and 10 is less than other vehicles and they have the highest average packet loss, since their average distance is more than other vehicles and at the beginning of simulation their distance from the ambulance is more than 138 metres. However other vehicles, which are at a max of 138 meters from the ambulance during simulation time, has the equal and highest rate of average throughout without any packet loss. This is another reason which indicates that throughput and packet loss are not influenced by different vehicle speed.

Fig. 8. Average Distance between the ambulance and other vehicles (message size 250 bytes)
Fig. 9. Average Packet loss between the ambulance and other vehicles (message size 250 bytes)

Fig. 10 and fig.11 illustrate the average throughput and End-to-End delay with three different message sizes (250, 500, 1000 bytes). According to these figures the average throughput and End-to-End delay are increased by increasing the message size, but the increment of throughput of vehicles 4, 7, and 10 is not as high as other vehicles.

V. CONCLUSION

In this paper we studied details of the WAVE architecture and IEEE 802.11p standard for vehicular ad hoc networks (VANET). We implemented the key parameters of 802.11p in ns-2 network simulation using realistic vehicular mobility model generated by VanetMobisim traffic simulation. One scenario was implemented in the simulation and we analysed three important metrics in order to evaluate the performance of IEEE 802.11p standards. Based on our findings, we have observed that the performance metrics (throughput, End-to-End delay, and packet loss) are not affected by varying vehicle speed. Analysis of throughput for the all vehicles showed that the probability of successful message reception is same for all the vehicles when the distance between sender and receiver of the message is less than 138 metres. In addition, the End-to-end delay metric is directly related to the distance between the vehicle transmitting the broadcast messages and its neighbouring vehicles. Results of scenarios with different message sizes demonstrated that the average throughput and End-to-End delay metrics are increased by increasing message sizes.

REFERENCES