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Research Article

Performance Comparison of IEEE 802.11p and IEEE 802.11b for Vehicle-to-Vehicle Communications in Highway, Rural, and Urban Areas

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Communication between vehicles has recently been a popular research topic. Generally, the Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Infrastructure-to-Infrastructure (I2I) communications applications can be divided into two sections: (i) safety applications and (ii) nonsafety applications. In this study, we have investigated the performance of IEEE 802.11p and IEEE 802.11b based on real-world measurements and radio propagation models of V2V networks in different environments, including highway, rural, and urban areas. Furthermore, we have investigated the most used V2V mobility models and simulation tools. Comparative performance evaluations show that the IEEE 802.11p achieves higher network throughput, low end-to-end delay, and higher delivery ratio compared to IEEE 802.11b. Overall, our main objective is to describe potential advantages, research challenges, and applications of V2V networks and show how IEEE 802.11p and IEEE 802.11b will perform under different radio propagation environments.

1. Introduction

Vehicle-to-Vehicle (V2V) communication has recently become a hot topic in both academy and automotive industries [1–3]. The communication between vehicles helps to improve road safety. In these networks, vehicles act like sensors and transmit the warning messages to other vehicles in communication range or receive the messages from other vehicles. Drivers can easily detect any abnormal or potentially dangerous situations, such as traffic accidents and traffic jam, by receiving telematics information, including location and speed information.

The main applications of V2V technology include road safety applications, including accident warning, and blind spot warning, lane change warning, intersection warning, emergency vehicle warning [1–6]. Also there are efficiency and commercial applications, including route guidance systems, transportation congestion systems, tolling payment, and fleet control.

The key factor in V2V communication networks is the mobility of nodes. In addition to mobility challenges, in these networks vehicles should also obey the traffic specific rules and follow the available roads. Therefore, a special form of an ad hoc network for V2V systems has emerged, which has been called vehicular ad hoc network (VANET). Some of the issues that affect the performance of VANETs are high mobility, signal fading, packet collisions, radio interferences on transmitting data, and so forth.

The illustration of V2V communication is shown in Figure 1. In general, there are three types of V2V communications [5]. The first one is communication between vehicles (V2V), in which vehicles can share information about road, can transmit accident or collision information, and so forth. The second one is communication between vehicles and infrastructures (V2I), in which, road side units (RSU) can transmit commercial advertisements, vehicles can pay toll or parking payments, and so forth. The third one is communication between infrastructures (I2I), in which the

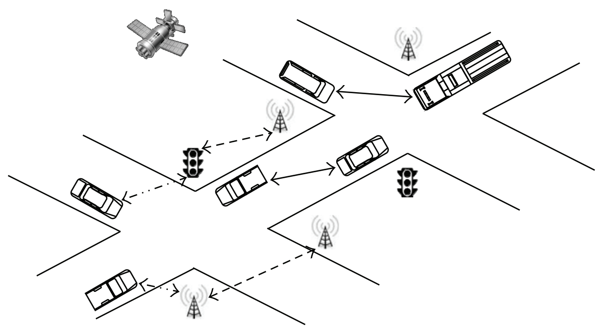

Figure 1: Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Infrastructure-to-Infrastructure I2I networks.

RSUs can exchange important data that is received from the vehicles with each other.

The communication standards in vehicular communication are dedicated short range communication (DSRC) and IEEE 1609 [3, 5]. DSRC is used for short range communication in V2V and V2R applications. The features of DSRC are low communication delay and high data transfers. DSRC has 7 channels, and they have been allocated in this order: first channel is used for safety communications, second channel is used for critical safety communications, third channel is used for high power public safety communications, and the rest of the channels are used for either safety or nonsafety communications. The standards of DSRC are different in Japan, Europe, and USA. In each of the three regions DSRC has different features. For example, communication range is 30 meters in Japan, 15–20 meters in Europe, and 1000 meters (max) in USA. The data rate in Japan is 1–4 Mbps, 250 Kbps in Europe, and 3–27 Mbps in USA. The comparison of regional differences in DSRC has been summarized in Table 1.

IEEE 802.11b protocol may be used for wireless communication in V2V. However, some challenges such as vehicle speed, traffic patterns, and high mobility, affect the communication, that is, establishing communication between vehicles that approach from opposite direction. To address these challenges, IEEE 1609 standards for wireless access in vehicular environments (WAVE) have emerged. IEEE 1609 has resource manager protocols, security services protocols, networking protocols, and multichannel operation protocols. IEEE 802.11p is the updated version of IEEE 802.11b standard that works on data link and physical layers and enables communication between high speed vehicles. WAVE protocol works on the rest of the OSI layers. The physical layer values of the IEEE 802.11b and IEEE 802.11p have been summarized in Table 2.

Since real-time field tests are very expensive and topology of network is difficult to construct due to requirements of high number of vehicles, detailed performance evaluations are very important to develop protocols for V2V applications. In this paper, we have compared the IEEE 802.11b and IEEE 802.11p protocols in different environments, including rural, urban, and suburban areas using MObility model generator for VEhicular networks (MOVE) simulator tool. We have evaluated the performance of IEEE 802.11p and IEEE 802.11b in terms of average delay, delivery ratio, and network throughput. In this work, we also introduce simulators, and mobility models that are widely used in VANET simulations. Here, our objective is to describe potential advantages and applications of V2V networks and show how IEEE 802.11p and IEEE 802.11b will perform under different propagation environments.

The remainder of this paper is organized as follows. In Section 2, an overview of the related work on V2V communications is presented. In Section 3, V2V applications and requirements are summarized, and research challenges are presented. In Section 4, V2V simulators and mobility models are summarized. In Section 5, comparative performance results are shown. Finally, the paper is concluded in Section 6.

2. Related Work

In the related literature, there are some studies about measuring propagation channels for V2V communications [4, 9–11]. Reliable V2V communications require accurate propagation channel models. This section provides an overview of V2V propagation channel measurements. The propagation of V2V is not the same as cellular channels. The time and frequency selectivity in V2V are different compared to cellular communication [1].

In [9], the authors have made some empirical measurements for V2V communications. They have used prototype of IEEE 802.11p equipment. Two vehicles are equipped with CVIS OBU with a microwave communication module (MCM). Their experiment environments are highway, rural, and urban areas. They consider different speeds and distances in their measurements.

In [12], the authors have measured the channel by using log-normal shadowing path loss model for highway, rural, and urban environments at 5.9 GHz. Different vehicle movement simulation scenarios such as driving opposite direction and driving in same direction have been considered. They also have considered LOS and NLOS conditions. After the measurements, they give the path loss and shadowing deviation parameters for three environments.

In [13], the authors have made channel measurements in highway and rural driving environments by using on-road vehicular test bed equipment. They have also used programmable laboratory instruments in their measurements. Their studies include the narrow-band measurements, Doppler-delay measurements, antenna pattern's effects, and variations of passing vehicles. Frequency spectrum of signals has been used to compute the received signal strength. Based on the channel measurements, they have reported dual-slope log-normal shadowing path loss parameters.

In [14], the authors have measured the V2V propagation channel in realistic suburban environments in Pittsburgh, Pennsylvania, at 5.9 GHz. To enable the dynamic measurements, they include differential global positioning system

Table 1: Regional differences in DSRC.

Features	Japan	Europe	USA
Radio band	80 MHz	20 MHz	75 MHz
Data rate	1–4 Mbps	250 Kbps	3–27 Mbps
Communication range	30 m	15–20 m	1000 m (max)
Radio frequency	5.8 GHz	5.8 GHz	5.9 GHz

Table 2: PHY layer values of IEEE 802.11b and IEEE 802.11p [7].

Parameters	IEEE 802.11b	IEEE 802.11p
Channel bandwidth	20 MHz	10 MHz
Data rates	1 to 11 Mbps	3 to 27 Mbps
Slot time	20 μs	16 μs
SIFS time	10 μs	32 μs
Preamble length	96 μs (short), 192 μs (long)	32 μs
Air propagation time	<2 μs	<4 μs
CWmin	31	15
CWmax	1023	1023

(DGPS). To allow dynamic measurements when the vehicles are on way, they include GPS receivers into their measurements. They have used log-normal shadowing path loss model to obtain large scale path loss models. They introduce both empirical data for V2V wireless channel modeling and encourage the research community for theoretical modeling studies in V2V.

Although all these studies are valuable for VANET, there is no comprehensive study that compares performance of IEEE 802.11b and IEEE 802.11p in different environments, including rural, urban, and suburban areas in terms of average delay, delivery ratio, and network throughput. Overall, our main objective is to describe potential advantages, research challenges, and applications of V2V networks and show how IEEE 802.11p and IEEE 802.11b will perform under different radio propagation environments.

3. V2V Applications and Challenges

3.1. V2V Applications. This section introduces the available and potential applications of V2V. Basically, there are two types of V2V applications, that is, road safety applications and traffic efficiency applications. An overview of V2V applications can be summarized as follows.

3.1.1. Road Safety Applications. The objectives of the road safety applications are to decrease the number of traffic accidents and to help the drivers increase their safety. These applications provide information to drivers about collisions that have occurred on that way [8]. Furthermore these applications warn driver when another driver makes immediate break or tries to decrease traffic accident at the road intersections to increase the safety of drivers.

3.1.2. Traffic Efficiecny Applications. The aims of the traffic efficiency applications are improving the traffic flow and coordination of traffic by providing instant traffic information between vehicles and RSUs. These applications try to balance the speed of vehicle and inform the drivers when they try to reach the destination.

The V2V applications have been summarized in Table 3.

3.2. V2V Challenges

3.2.1. Routing Challenges. Determining the possible routes in VANETs is hard due to mobility of nodes. The direction, position, and speed of vehicles always change. In this case, even though the source and destination nodes are stable, the location of intermediate nodes changes, which can create packet losses along the path.

3.2.2. Doppler Effect. When two vehicles approach each other due to the Doppler effect, the frequency may be different on the receiver and transmitter side. Therefore, frequency should be regulated on the receiving side.

3.2.3. Hidden Terminal Problem. When there is no centralized communication coordination, the hidden terminal problem occurs in VANETs. This causes collisions when two nodes that are not in same communication range try to transmit data to the same node.

3.2.4. Data Security. The privacy of data may be important in some applications. To increase the security, some encoding mechanisms may be used. However, this causes extra overhead on the data and may affect the system performance.

3.2.5. Delay Constraints. In emergency situation, the warning messages have to be forwarded immediately. Due to mobility of nodes and changing in network topology, latency may increase.

4. V2V Simulators and Mobility Models

Since real-time field tests are very expensive and topology of network is difficult to construct due to requirements of

Table 3: V2V applications and requirements [8].

Application name	Description	Application type	Communication mode	Minimum transmission frequency
Emergency Brake Light Warning	Informs vehicles when driver brakes	Safety application	Periodic permanent message broadcasting	10 Hz
Forward Collision Warning	Detects moving vehicles directly ahead	Safety application	Cooperation awareness between vehicles associated with unicast	10 Hz
Intersection Movement	Warns the drivers when they approach intersections	Safety application	Periodic message broadcasting	10 Hz
Blind Spot & Lane Changing Assistance	Decreases lateral collisions by disabling the lane changing	Safety application	Periodic message broadcasting	10 Hz
Do Not Pass (Overtaking) Warning	Warns the driver not to overtake or disable lane changing	Safety application	Broadcasting when overtaking	10 Hz
Head On & Rear End Collision Warning	Warns the drivers that are coming from opposite lane when a traffic accident occurs	Safety application	Broadcasting when collision occurred	10 Hz
Collision Risk Warning	Detects vehicles that have risk of collision	Safety application	Broadcasting when a risk occurred	10 Hz
Hazardous Location Notification	Informs the drivers when some obstacles are discovered on the road	Safety application	Broadcasting when road is slippery	10 Hz
Emergency Vehicle Warning	Broadcasts to all vehicles and RSUs to open the lane when an emergency vehicle is detected	Safety application	Broadcasting when an emergency vehicle is detected	10 Hz
Speed Management	Balances the speed of vehicle	Traffic efficiency application	Cooperation awareness	2 Hz
Route Guidance & Transportation Congestion Systems	Informs the drivers when they try to reach the destination	Traffic efficiency application	Cooperation awareness	2 Hz
Fleet Control	Informs the fleet companies about their vehicles	Traffic efficiency application	Cooperation awareness	2 Hz

high number of vehicles, detailed performance evaluations through simulations are very crucial to develop protocols for V2V applications [9]. In the following two subsections, we introduce the widely used VANET simulator tools and mobility models that are used in simulations.

4.1. VANET Simulators. This subsection introduces the simulators for VANET study. There are two types of simulator for VANET.

(i) Network simulators that are related to network applications and protocols studies: in these simulators, trace files that have been generated by traffic simulators are evaluated.

(ii) Traffic simulators that are related to traffic and transportation studies: in these simulators, initial positions, speeds, and type of vehicles are defined.

4.1.1. MOVE. The MObility model generator for VEhicular networks (MOVE) is a Java based VANET simulator and runs commands of Simulation of Urban MObility (SUMO) at background with GUI support [15]. In this simulator, maps can be defined in three different ways. Researchers can manually define the map, maps can be generated automatically by researchers, and real maps from topologically integrated geographic encoding and referencing (TIGER) and Google Earth can be imported. The movement of vehicles can also be created manually or automatically. MOVE also generates trace files for network simulators, including NS-2 and QualNet to simulate the movements of vehicles.

4.1.2. TRANS. Traffic and network simulator (TRANS) is Java based VANET simulator with GUI support. It combines NS-2 and SUMO [16]. SUMO generates trace files and parses them to NS-2 simulator. TraNs has a light version called TraNs Lite that just generates mobility models without generating trace files for NS-2.

4.1.3. SUMO. SUMO is C++ based microscopic and open source traffic simulator with GUI support [17]. It can generate

Table 4: Simulators Comparison.

Simulator name	Language	Network simulator support	GUI support	Map support	Movement Of vehicles	Simulation scale
MOVE	Java	NS-2, QualNet	Yes	TIGER, Google Earth	Manually, automatically	No information
TRANS	Java	NS-2	Yes	TIGER, Shapefile Maps	No information	Up to 3000 vehicles
SUMO	C++	NS-2, QualNet, Ansim	Yes	OpenStreetMap, TIGER	Manually	Up to 100000 vehicles and 10000 edges
VanetMobiSim	Java	NS-2, Glosim, QualNet	Yes	TIGER	No information	No information

mobility trace files to NS-2, QualNet, and Ansim. Network maps can be generated manually, or real-world maps from OpenStreetMap and TIGER. It is also compatible with network maps that are generated by other traffic simulators such as MATsim, OSM, RoboCup, Shapefiles, VISUM, and Vissim. SUMO also supports different vehicle types and way rules. 100,000 vehicles and 10,000 edges can be managed in simulations. Each vehicle has its own route in simulations.

4.1.4. VanetMobiSim. Vanet mobility simulation (VanetMobiSim) is Java based micromobility and macromobility VANET simulator with GUI support [4]. It is the extension version of CanuMobiSim. Networks maps can be generated manually and randomly. It can generate trace files for network simulators, including NS-2, Glosim, and Qualnet. VanetMobiSim also considers road topology, road structure, and traffic signs.

Table 4 summarizes the comparison of the most used V2V simulators in terms of programming language, network simulator support, GUI support, map support, movement of vehicles, and simulation scale.

4.2. Mobility Models. This subsection introduces the mobility models that are used in VANET simulations. Each model uses different parameters to create the path of vehicles. In mobility models concept, there are two important levels.

(i) Macroscopic mobility refers to streets, traffic lights, speed limits, number of lanes, building, traffic signs, and so forth.

(ii) Microscopic mobility refers to vehicle movements and behavior of drivers according to their age, mood, and sex.

There are some factors that significantly affect vehicles' mobility pattern. Some of these factors are as follow:

(i) vehicle speed,

(ii) streets layout,

(iii) traffic signs (stop signs, lights).

4.2.1. Freeway Model. In this model, movement pattern of mobile nodes in freeways is simulated [18]. There is no intersection in this model. In other words, there are vertical or horizontal lanes on the map. Nodes are randomly distributed and use this speed formula:

$$V(t+1) = V(t) + \text{rand}(-1,1) * a(t), \quad (1)$$

where $V(t)$ represents the speed of vehicle at time t, $a(t)$ represents the vehicle's acceleration at time t, and rand $(-1,1)$ means a random number between -1 and 1. Nodes cannot change their lane and a node cannot pass another node that is ahead of itself in this model.

4.2.2. Manhattan. In this model, movement pattern of mobile nodes in urban environments is simulated using a grid road topology [10]. This mobility model contains horizontal and vertical roads. Nodes are randomly placed on map at the beginning of simulation and they are allowed to change their lanes. When a node reaches the intersection, it can continue by turning left, turning right, or going straightforward randomly with 0.25, 0.25, and 0.50 probability, respectively.

4.2.3. City Section Model. In this model, movement pattern of mobile nodes in a part of city is simulated [10]. All nodes and streets have particular speed limit in this model. Initial positions of nodes are defined before the simulation beginning. Each node chooses random destination, and a node moves from current location to the destination using shortest travel time between two locations. When the node reaches the destination, node stays there for a specific time and then selects a new random destination by repeating the same process.

4.2.4. Synthetic Model. In this model, movement pattern of mobile nodes is simulated using mathematical equations [19]. In most of the simulations, this model is preferred and the simulation results are compared with real mobility models. This model has some categories, including behavioral models that investigate the movements of driver according to the social interactions, car following model that investigates the car-to-car interaction behavior, stochastic model that creates random motion, and queue model that considers roads as buffer and vehicles on lane as in queue. The most known synthetic models can be summarized as follows.

4.3. Car Following Model. In this model, movement pattern of mobile nodes is simulated according to behavior of each driver [20]. CFM is microscopic mobility models. The current speed, length, and current position of cars are used to compute the speed or acceleration of a car. A common equation is used in this model as follows:

$$X = L + Tv_i + \mu(v_i)^2, \tag{2}$$

where L represents the length of the vehicle, T represents the safe time headway, v_i represents the velocity of vehicle, μ represents the adjusting parameter for deceleration.

4.4. Intelligent Driver's Model. It is a microscopic mobility model and extension of CFM model [21]. IDM is used for freeway and urban traffic as time continuous car following model. Dynamics of the positions and velocities of single vehicles are described in this model. In this mobility model, free acceleration and interaction deceleration are calculated as follows:

$$\frac{dv}{dt} = \alpha\left[1 - \left(\frac{v}{v_0}\right)^{\delta} - \left(\frac{s*(v,\Delta v)}{s}\right)^2\right]$$
$$s*(v,\Delta v) = s_0 + vT + \left(\frac{v\Delta v}{2\sqrt{(\alpha b)}}\right), \tag{3}$$

where v_0 represents desired velocity, Δv represents the velocity difference, s represents minimum spacing, α represents acceleration, T represents the desired time headway, and b represents the comfortable breaking deceleration.

5. Performance Evaluations

The simulation studies of IEEE 802.11p and IEEE 802.11b have been performed in NS-2 network simulator [22]. Since Log-normal shadowing path loss model provides more accurate results compared to the other models, that is, Nakagami and Rayleigh models for wireless environments, we have selected it as the channel model [23]. In log-normal shadowing path loss model, the signal to noise ratio $\gamma(d)_{\text{dB}}$ at a distance d from the transmitter is given by

$$\gamma(d)_{\text{dB}} = P_t - \text{PL}(d_0) - 10_\eta \log_{10}\left(\frac{d}{d_0}\right) - X_\sigma - P_\eta, \tag{4}$$

where P_t represents the transmit power in dBm, $\text{PL}(d_0)$ represents the path loss at a reference distance d_0, η means the path loss exponent, X_σ represents a zero mean Gaussian random variable with standard deviation σ, and P_η represents the noise power in dBm.

Table 5 summarizes the comparison of the radio propagation models in terms of the assumed propagation condition, line-of-sight (LOS), and communication range. Free space and two-ray ground models assumed that propagation condition is ideal and communication range is circle. On the other hand, due to fading effects, received power is randomly variable in real life. The mean of received power is predicted and reflected in shadowing model. Therefore, the ideal circle is extended to a richer statistic model in shadowing model that gives more realistic results.

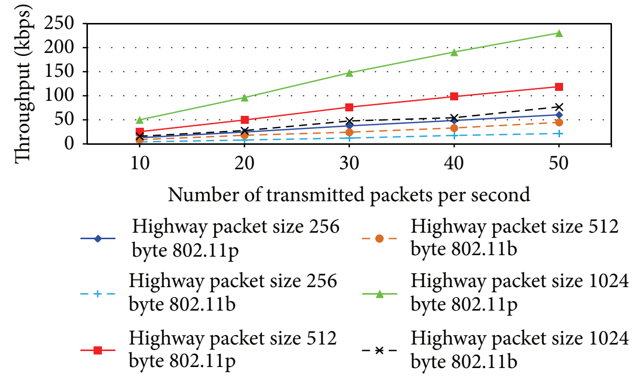

Figure 2: Throughput of IEEE 802.11p and IEEE 802.11b in highway environment.

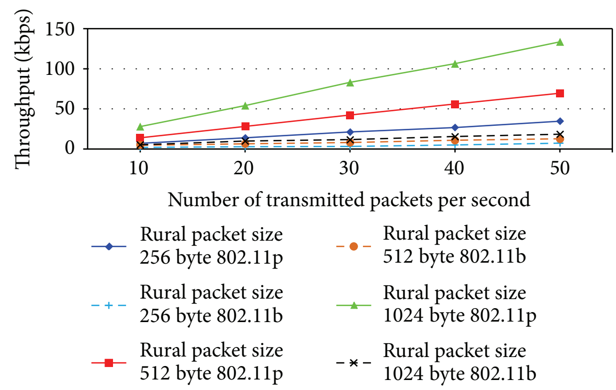

Figure 3: Throughput of IEEE 802.11p and IEEE 802.11b in rural environment.

In this study, we have used MOVE traffic simulator tool with NS-2 network simulator and log-normal channel parameters for different traffic environments, that is, highway, rural, and urban areas for performance evaluations. The reason that we used NS-2 and MOVE in our simulations is that both of them are publicly available. Furthermore there are several useful tutorials on web for these simulators. Constant bit rate is selected for traffic type, and different packet sizes are used, including 250, 512, and 1024 bytes with different inter-packet gap (IPG), including 0.1, 0.05, 0.033, 0.025, and 0.02 second. To statistically analyze the system, we run each simulation 10 times with different seeds and take the average of the measured values. In our simulations, we have used AODV as a routing protocol. The movements of vehicles in simulations are in the same direction with different speed up to average maximum speed. All parameters used in our performance evaluations are listed in Table 6.

The log-normal channel parameters that we used in our performance evaluations are based on the study [12], where parameters have been obtained with set of field tests at 5.9 GHz on highway, rural, and urban environments. The parameters that we used in our simulations for the three environments are given in Table 7. These environments can be explained as follows:

(i) Highway is an environment that has at least 3 lanes in each direction with no obstacles such as houses, trees, and vehicle speeds are permitted up to 120 km/h.

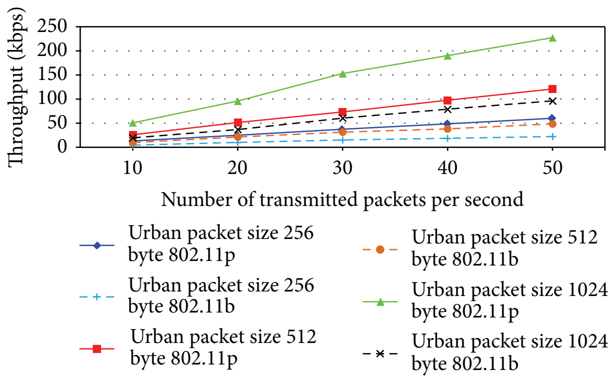

Figure 4: Throughput of IEEE 802.11p and IEEE 802.11b in Urban Environment.

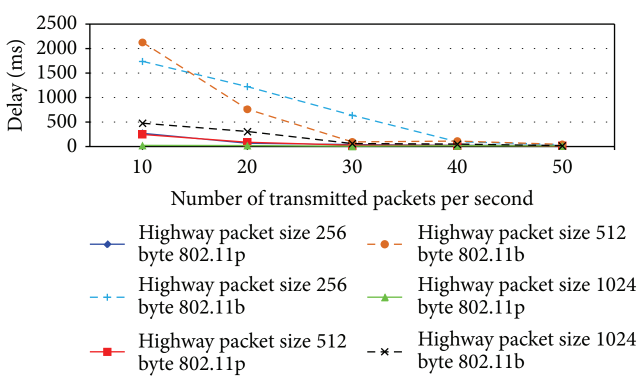

Figure 5: End-to-End Delay of IEEE 802.11p and IEEE 802.11b in Highway Environment.

(ii) Rural is an environment that has 1 lane in each direction with trees and hills, and vehicle speeds are permitted between 50 and 90 km/h.

(iii) Urban is an environment that has 2 lanes in each direction with dense traffic, many traffic lights, junctions and obstacles such as many houses and few trees, and vehicle speeds are permitted between 50 and 70 km/h.

In these performance evaluations, we have compared the IEEE 802.11p and IEEE 802.11b according to the following performance metrics.

(i) Average Delay means the average time to receive all data on the destination side.

(ii) Delivery Ratio means ratio between the number of successful packets and the total number of transmitted packets.

(iii) Network Throughput means the amount of data transmitted between transceivers in a specific time period.

In our simulations vehicles travel from one point to another point with different speeds up to the maximum speed that is defined previously. There are some traffic lights on ways that vehicles stop at when they returned to red. Furthermore, there are some flows and turn definitions that help the vehicles to reach their final destination. Based on these metrics, we present the performance results from Figure 2 to Figure 12 when different packet size, vehicle speeds, and data rates are employed in different traffic environments. Throughput performance results of IEEE 802.11p and IEEE 802.11b have been shown in Figure 2 to Figure 4. Then, end-to-end delay results of IEEE 802.11p and IEEE 802.11b have been shown in Figure 5 to Figure 7. After that delivery ratio results of IEEE 802.11p and IEEE 802.11b have been shown in Figure 8 to Figure 10. Finally, the throughput and delivery ratio results of IEEE 802.11p and IEEE 802.11b with different vehicle speeds and different IPG values have been shown in Figure 11 and Figure 12.

Figure 2 shows the network throughput versus number of transmitted packets per second for IEEE 802.11p and IEEE 802.11b in highway environment. When IEEE 802.11p is used as MAC layer protocol, the throughput results are approximately three times better compared to IEEE 802.11b. At the same time, the throughput values are increasing when the number of transmitted packet increases for both IEEE 802.11p and IEEE 802.11b. Since there are no obstacles that affect the V2V communication in highway environments, compared to the other environments, that is, rural and urban environment, the throughput results are better in highway environment.

Figure 3 shows the network throughput versus number of transmitted packets per second for IEEE 802.11p and IEEE 802.11b in rural environment. When IEEE 802.11p is used as MAC layer protocol, the throughput results are approximately five times better compared to IEEE 802.11b. There is no big differences on throughput results in IEEE 802.11b protocol. The obstacles, such as trees and hills near the road, affect the V2V communication, and this causes lowest throughput ratios compared to the highway and urban environments.

Figure 4 shows the network throughput versus number of transmitted packets per second for IEEE 802.11p and IEEE 802.11b in urban environments. The throughput results for IEEE 802.11p are better than IEEE 802.11b. When we increase the packet size in both MAC protocols, throughput results increase significantly. When we compare the throughput results with highway and rural area, it is obviously seen that throughput results of urban area are better than rural area. On the other hand it is worse than highway areas.

Figure 5 shows the end-to-end delay versus number of transmitted packets per second for IEEE 802.11p and IEEE 802.11b in highway environment. When IEEE 802.11p is used as MAC layer protocol, the delay is approximately ten times shorter compared to IEEE 802.11b. At the same time, the delay between transmitter and receiver is decreasing when the number of transmitted packet increases for both IEEE 802.11p and IEEE 802.11b. For IEEE 802.11p, we got the highest delay for 10 transmitted packets per second when we applied 256 bytes data, and we got the lowest delay when we applied 1024 bytes data.

Figure 6 shows the end-to-end delay versus number of transmitted packets per second for IEEE 802.11p and IEEE 802.11b in rural environment. In rural environment,

Table 5: Comparison of Radio Propagation Models.

Propagation model	Assumed propagation condition	LOS	Communication range
Free space	Ideal	1 clear LOS between transmitter and receiver	Circle
Two-ray ground	Ideal	1 Los between 2 mobile nodes	Circle
Shadowing	Realistic	Los and Nlos	Extended ideal circle

Table 6: Simulation Parameters.

Network Simulator	NS-2
Traffic Simulator Tool	MOVE
Channel Model	Log-Normal Shadowing
Number of Vehicles	100
Avg. Max. Vehicle Speed	40–60–80
Packet Size	256–512–1024 Bytes
Traffic Type	CBR
IPG	0.1, 0.05, 0.033, 0.025, 0.02 second
Queue Type	Drop Tail
Traffic Environments	Highway-Rural-Urban
Routing Protocol	AODV
Vehicle Movements	Same direction with different speed

Table 7: Log-normal shadowing channel parameters.

Environments	Path loss	Shadowing deviation
Highway	1.85	3.2
Rural	1.79	3.3
Urban	1.61	3.4

end-to-end delay between transceivers is too much for IEEE 802.11b protocol, and compared to IEEE 802.11p protocol. Like highway environment, delay between transceivers is decreasing when the number of transmitted packet increases for both IEEE 802.11p and IEEE 802.11b. For IEEE 802.11p, the highest delay for 10 transmitted packets per second is calculated when we applied 1024 bytes data for both protocol, and the lowest delay is calculated when we applied 512 and 1024 bytes data for IEEE 802.11p and IEEE 802.11b, respectively.

Figure 7 shows the end-to-end delay versus number of transmitted packets per second for IEEE 802.11p and IEEE 802.11b, in urban environment. In urban environment IEEE 802.11p has lower end-to-end delay compared to IEEE 802.11b. Like highway and rural environment, delay between transceivers is decreasing when the number of transmitted packet increases for both IEEE 802.11p and IEEE 802.11b. When we compare the three environments, urban environment has higher communication delay than both highway and rural environment for two MAC protocols. The highest delay for 10 transmitted packets per second is calculated when we applied 512 and 256 bytes data for IEEE 802.11p and IEEE 802.11b, respectively. The lowest delay is calculated when we applied 512 bytes data for IEEE 802.11p and IEEE 802.11b, respectively.

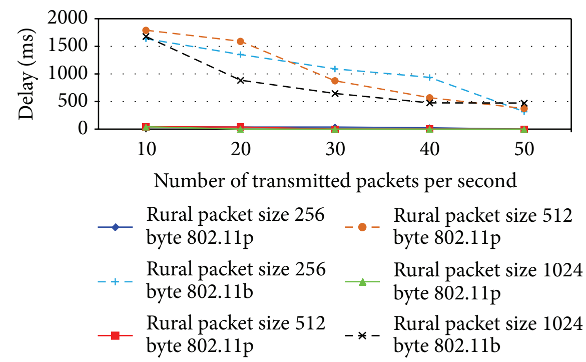

Figure 6: End-to-End Delay of IEEE 802.11p and IEEE 802.11b in Rural Environment.

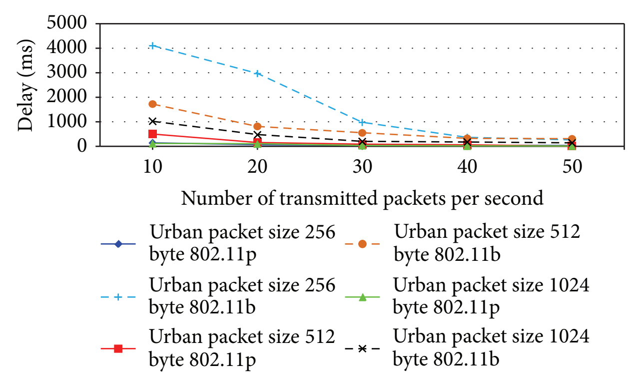

Figure 7: End-to-end delay of IEEE 802.11p and IEEE 802.11b in urban environment.

Figure 8 shows the delivery ratio versus number of transmitted packets per second for IEEE 802.11p and IEEE 802.11b in highway environment. When we use IEEE 802.11p as MAC layer protocol, we achieve a delivery ratio between 90% and 78%. On the other hand delivery ratio is between 31% and 23% when IEEE 802.11b is used. At the same time, the delivery ratio is decreasing when the number of transmitted packet increases for both IEEE 802.11p and IEEE 802.11b. Compared to the other two environments' delivery ratios, highway has lower delivery ratios. The vehicle speeds and the distance between vehicles may decrease the delivery ratio.

Figure 9 shows the delivery ratio versus number of transmitted packets per second for IEEE 802.11p and IEEE 802.11b in rural environment. The delivery ratio of IEEE 802.11p is between 99% and 94%, and the delivery ratio of IEEE 802.11b is between 34% and 10%. At the same time, the delivery ratio is decreasing when the number of transmitted packet increases for both IEEE 802.11p and IEEE

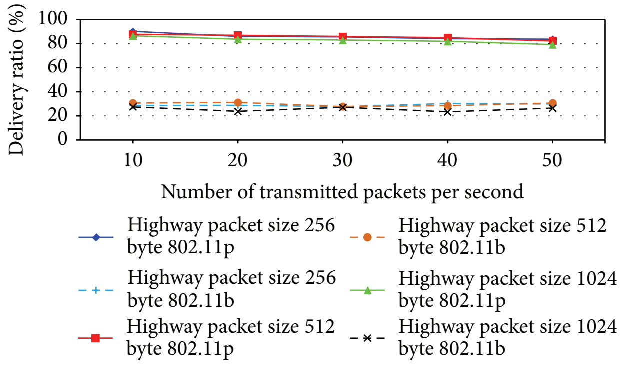

Figure 8: Delivery ratio of IEEE 802.11p and IEEE 802.11b in highway environment.

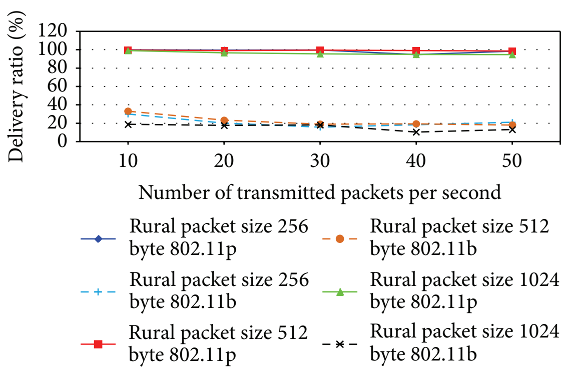

Figure 9: Delivery ratio of IEEE 802.11b and IEEE 802.11b in rural environment.

802.11b. Although there are some obstacles, such as trees and hills, the highest delivery ratios have been obtained in rural environment compared to the other two environments.

Figure 10 shows the delivery ratio versus number of transmitted packets per second for IEEE 802.11p and IEEE 802.11b in urban environment. In urban environment IEEE 802.11p has a delivery ratio between 91%, and 78% and IEEE 802.11b has a delivery ratio between 37% and 30%. At the same time, the delivery ratio is decreasing when the number of transmitted packet increases for both IEEE 802.11p and IEEE 802.11b. Urban environment has higher delivery rate compared to the highway environment. On the other hand, it has lower delivery rate compared to rural environment.

Figure 11 shows the throughput versus packet size for IEEE 802.11p and IEEE 802.11b in urban environment with different vehicle speeds. Although there are no significant throughput differences between two speeds as shown in Figure 11 when we applied 40 km/h and 60 km/h with 0.1 IPG, lower speed vehicles have little higher network throughput. When we apply the different vehicle speeds for IEEE 802.11b, the throughput differences start to increase after applying data packets that have 1024 bytes.

Figure 12 shows the delivery ratio versus packet size for IEEE 802.11p and IEEE 802.11b in urban environment with different vehicle speeds. As shown in Figure 12, vehicles with 40 km/h speeds have the highest delivery ratio and vehicles

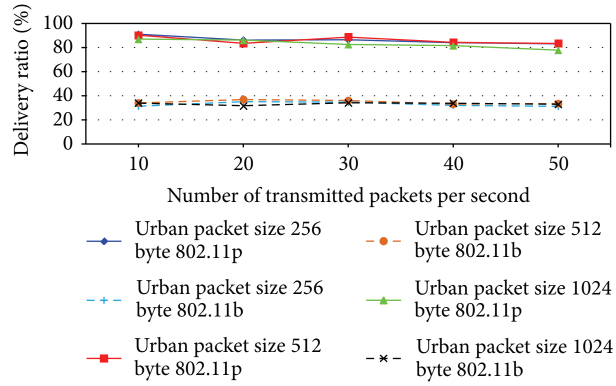

Figure 10: Delivery ratio of IEEE 802.11p and IEEE 802.11b in urban environment.

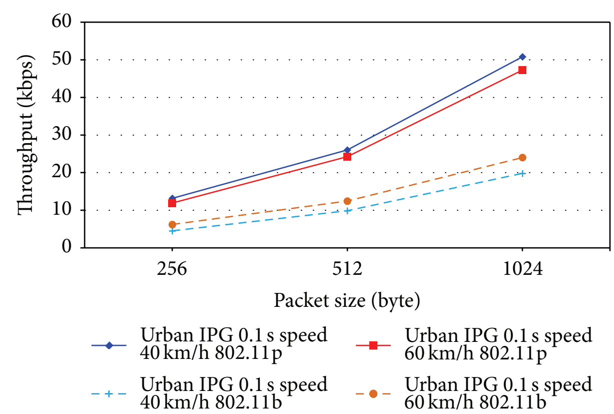

Figure 11: Throughput of IEEE 802.11p and IEEE 802.11b in urban environment with different vehicle speeds.

with 60 and 80 km/h speeds have almost the same delivery ratio for IEEE 802.11p. On the other hand, the delivery ratio of vehicles is increasing when the vehicle speed is increased for IEEE 802.11b. Also, in IEEE 802.11b protocol vehicles with the same speed have almost the same delivery ratio even if the packet size has been increased.

6. Conclusion

In this paper, the performance of 802.11p and 802.11b has been compared for different environments, for example, highway, rural, and urban area. We also introduce some simulators that used for VANET simulations and mobility models that are used for these simulators. In our studies, we have used different packet sizes, different interpacket gaps, and different vehicle speeds. Here, our goal is to introduce VANET simulators, research challenges, and mobility models and encourage the research community to explore this promising research area. Overall, comparative performance evaluations show that IEEE 802.11p MAC layer protocol has better results for V2V communications compared to the IEEE 802.11b MAC protocol in terms of network throughput, end-to-end delay, and delivery ratio. Furthermore, the network throughput results of IEEE 802.11p and IEEE 802.11b can be ordered

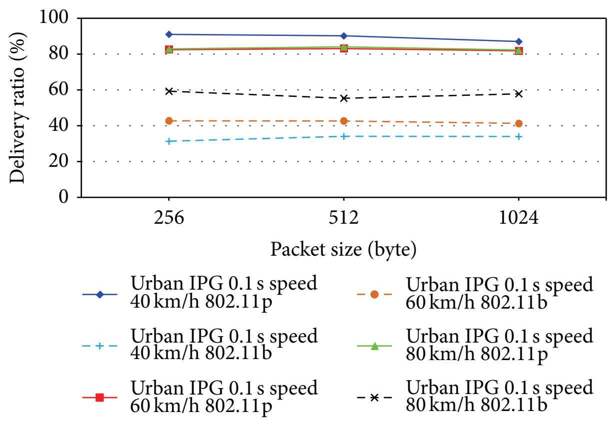

Figure 12: Delivery ratio of IEEE 802.11p and IEEE 802.11b in urban environment with different vehicle speeds.

from higher throughput to lower throughput as highway > urban > rural areas. Certainly, there are many important open research issues on V2V communications and applications. The development of cross-layer and adaptive protocols for V2V communications and applications may be the future work for the researchers.

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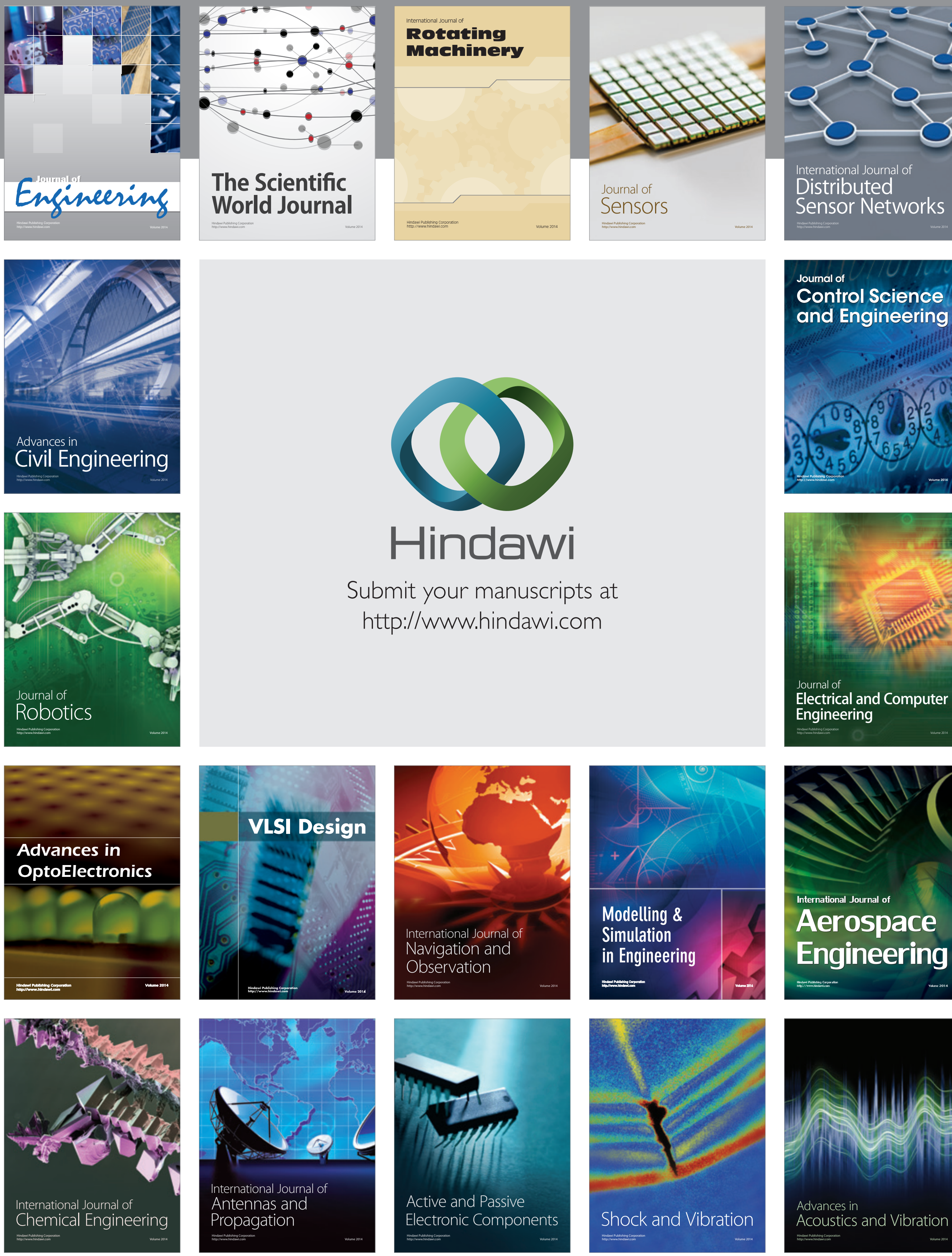
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