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Short-Range Wireless Communications for Vehicular Ad hoc Networking

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Abstract

If upcoming traffic information were disseminated to drivers in a timely manner, the excessive cost of traffic collisions and congestion as well as the number of deaths and injuries could be significantly reduced. In order to forward the upcoming traffic information in a timely manner, wireless communication is a viable alternative. Upcoming traffic information can be forwarded in a vehicular network using Vehicle-to-Vehicle or Vehicle-to-Roadside (V2R) and Roadside-to-Vehicle (R2V) communications. Existing systems for forwarding upcoming traffic information introduce high delay which is not acceptable for time critical emergency messages. Our goal in this work is to develop an automatic information dissemination framework for vehicular ad hoc network. We also present a comparative study of different short range wireless technologies including Wi-Fi (IEEE 802.11a/b/g/n), Bluetooth (IEEE 802.15.1), ZigBee (802.15.4), and Dedicated Short Range Communication (IEEE 802.11p) through on board devices which are suitable for Vehicular Ad hoc Networks (VANETs). In order to compare these technologies, we will consider connection set-up time, data transfer rate, transmission range, processing delays, etc. as metrics. First, we will simulate VANET scenarios. Then, we will create a VANET prototype to test technologies in real world scenarios using cars and smartphones with applications. In this paper, we will present the results obtained from both simulations.

Keywords: Vehicular ad hoc network, Intelligent transportation system, Vehicle-to-vehicle communications

1. Introduction

Intelligent Transportation Systems (ITS) have been created as a convergence of modern mobile computing, wireless networks and transportation technologies. Within the next few years, highways will function as platforms for traffic safety, multimedia and commercial applications. The purpose of an ITS is to provide users with a reliable source of traffic information, warnings about upcoming road hazards, and commercial transactions amongst moving entities. The necessity of such systems has been promoted by the United States Department of Transportation (US-DOT), with the intention of seeing such technologies in all vehicles in the near future.

Vehicular Ad hoc Networks (VANETs) is emerging as the backbone of ITS. In VANETs, vehicles are capable of sending, receiving and routing the traffic information. Vehicles communicate with each other using either Vehicle-to-Vehicle (V2V) communication using single hop or multi-hop communications as shown in Fig 1, or Vehicle-to-Roadside (V2R) communications to cover wider area as shown in Fig 2. Due to the fast moving vehicles, VANET topology changes constantly and thus more research is needed to test the maturity of the emerging and existing wireless technologies and protocols.

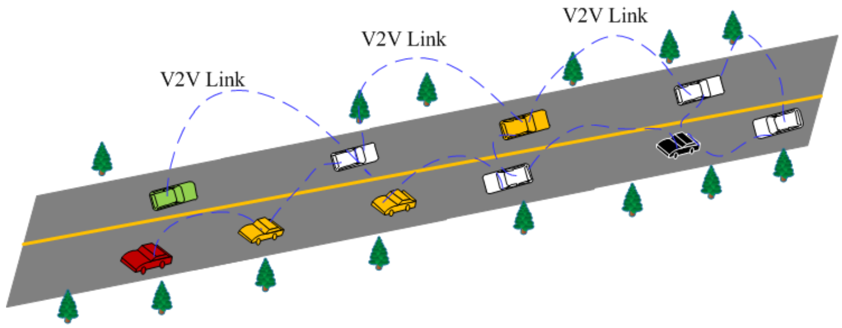

Fig. 1: Vehicle-to-Vehicle communications using single hop or multiple hops to forward messages in the VANETs

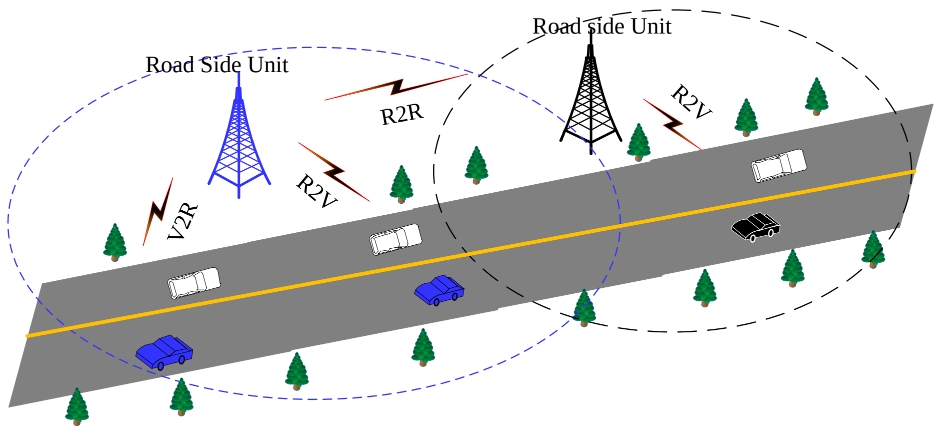

Fig. 2 Vehicle-to-Roadside, Roadside-to-Roadside, and Roadside-to-Vehicle communications

In this paper, we present the feasibility of different wireless technology suitable for vehicular networks. Especially, we consider short range wireless technologies such as ZigBee, Bluetooth and Wi-Fi/802.11 for V2V communications in VANET. Another important factor to consider these technologies is that they operate in free ISM (Industry, Scientific and Medical) bands. We study the feasibility of these technologies in terms of connection time, transmission distance, data transfer rates, data exchange time, amount of data transferred, etc.

ZigBee devices are based on the IEEE 802.15.4 physical radio standard. These devices operate in ISM bands at 2.4GHz and have transmission rates of 250 Kb/s at the 2.4 GHz band with 16 channels, 40 Kb/s at the 915 MHz band with 10 channels and 20 Kb/s at the 868 MHz band with 1 channel. Transmission range varies from 10 to 1,600 meters depending on the chosen transmission power.

Bluetooth devices are based on IEEE 802.15.1 radio standard and operate in the 2.4 to 2.485 GHz ISM bands. Maximum transmission range for Bluetooth devices is 100 meters, depending on device configuration. Bluetooth uses a spread spectrum, frequency hopping, full-duplex signal at a nominal rate of 1600 hops/sec. Maximum data transfer rate is 3Mbps in Bluetooth version 2 and 24Mbps for the version 4.

Wi-Fi is a trademark name for Wireless Local Area Networks (WLAN) and is defined by the Wi-Fi Alliance. There are 802.11a functions at the 5 GHz ISM band with a maximum transmission rate of 54 Mb/s, 802.11b (and 802.11g) operate at 2.4 GHz ISM band and have maximum data rate of 11 Mb/s (and 54 Mb/s) respectively. Typical approximate outdoor range of 802.11 technologies is 120 meters (for 802.11a) to 140 meters (for both 802.11b and 802.11g).

Wireless Access in Vehicular Environments (WAVE) is an amendment to the 802.11 standard and is defined as 802.11p. IEEE 802.11p standard uses channels of 10 MHz bandwidth in the 5.9GHz band (5.850-5.925 GHz). This is half the bandwidth, or double the transmission time for a specific data symbol, as used in 802.11a. The proposed 10 MHz bandwidth serves to make the signal more robust against fading and hence increases the tolerance to propagation effects [4]. The maximum data rate of an 802.11p device is 27 Mb/s with a transmission distance of 1000 meters [3].

1.1 Why Do We Care about Vehicular Networks?

The main goal of vehicular communications is to provide safety and comfort for passengers by forwarding upcoming traffic information in a timely manner. A special communication device will be mounted in each vehicle that is capable of receiving (and of processing if needed) along with forwarding to other vehicles through V2V and/or V2R communications. These wireless devices could also facilitate multimedia and Internet connectivity for passengers, provide lane merge assistance, receive information about road side facilities (such as roadside restaurants, gas stations and price, shopping and entertainment centers), and pay automatic parking fees or tolls. In mobile vehicular communications, sending timely traffic updates is important. For instance, vehicles should not forward information about road closures after the road has re-opened. In a broad sense, vehicular communication has two applications: safety and comfort.

1.2 Emergency and safety applications

Primary purpose of vehicular communication is to forward the upcoming traffic information in timely manner to the drivers so that they could make a wise decision to avoid accidents and/or delays. The emergency and safety related applications include collision alert, emergency vehicle approaching, deceleration alert, road conditions warnings, merge assistance, etc. In these applications, central emphasis is to timely disseminate the safety related messages to nearby vehicles. In other words, safety applications require messages to be propagated from the point of occurrence to the target vehicles with very low latency (less than a half-second).

1.3 Information and Entertainment (Infotainment) Applications

Infotainment applications (multimedia and comfort applications) aim to improve passenger comfort and traffic efficiency and include information about road side facilities (such as shopping malls, fast foods, hotels, parking spots, gas station/price, etc. etc.), electronic payments, weather condition, and interactive multimedia communications. These applications may require high speed continuous connectivity and thus are bandwidth-hungry, but they are typically not delay-sensitive like safety-related applications. In these applications, connectivity with high bandwidth is the main concern. In these applications, latency is not very important like in safety applications.

In this paper, we present the feasibility study of short-range wireless technologies for V2V communication in VANET. This scenario is presented in Fig. 1 where each vehicle is equipped with an on-board wireless device that is capable of computing, receiving, forwarding, and routing the traffic information so that drivers would be able to received upcoming traffic information make wise decision to avoid traffic accidents and congestions.

1.4 What is the relevance of the proposed research in this paper?

With the assumption that there are over 346 million vehicles and 16 million built each year, Michael Cops [7,8], Program Manager of Vehicle infrastructure integration Consortium, has predicted that by 2020, 50% of vehicles on the road will have computing and communication equipment, and that by 2030 all vehicles will have the equipment and will be able to participate in vehicular communications. There are several challenges that still need to be addressed before fully realizing the capabilities of vehicular communication for intelligent transportation systems.

The rest of this paper is organized as follows. Section II presents proposed methodology to evaluate the performance of different technologies. Section III presents the numerical results obtained from simulations. Section IV concludes the paper along with future work.

2. Methodology

In order to study the feasibility of short range wireless technologies 802.11/Wi-Fi, Bluetooth and ZigBee, we simulated different VANET scenarios for different wireless technologies using MATLAB [5]. We assume that each vehicle is equipped with devices that have short transmission range and examine the functionality of these devices. We consider the following metrics to study the feasibility and evaluate the performance of these technologies, we consider following three parameters:

- **Association time** (*a.k.a.* connection setup time): Each technology has its own unique time requirements for connecting to new nodes in the network. Different wireless technologies have different association time to establish a link before they exchange the actual information. In short-range based V2V communication, the performance of the network heavily depends on this parameter.

- **Data rate**: Note that the different wireless technologies have different data transfer rates. Higher data rate results in bigger amount of data exchange between two vehicles for a given amount of time.

- **Transmission Range**: The transmission range determines the coverage of communication over which vehicle could be linked to exchange their information. When the vehicles are not within the transmission range of each other, they cannot communicate and exchange the messages. Thus choosing suitable value of transmission range is very important. Note that when we choose too large of a value for the transmission range which covers the large area of off-road, malicious users who are sitting along the roadside can inject and mislead the vehicular communication. Thus, short-range wireless technologies are considered for V2V based communication in vehicular networks in this paper.

In vehicular networks, there are two different VANET scenarios for V2V communications:

1. **One-way-traffic where all vehicles move in the same direction**:In this case, relative speed of vehicle is very small. When vehicles move with same speed in a given direction, theiur relative speed it zero and thus vehicles see stationary with respect to other vehicles. Note that smaller the relative speed, longer the time they will have for connection setup and information exchange using wireless devices for a given transmission range.

2. **Two-way-traffic where vehicles move in both directions**: In this case, relative speed of vehicles moving in opposite directions will be sum of the speeds of two vehicles and thus it will be greater. The larger the speed, the shorter the time for connection setup and data exchange using wireless devices for a given transmission range.

In order to study the feasibility of different wireless technologies for both VANET scenarios, we consider above mentioned metrics and evaluate the technologies. First, we calculate the total time duration available for V2V communication using relative speed and given transmission range as:

$$Total\ duration\ = \frac{Transmission\ Range}{Relative\ Speed} \tag{1}$$

This total time duration is used for connection setup and exchanging the actual data in vehicular networks.

$$Time\ left\ after\ successful\ connection\ setup\ =\ Total\ duration - conection\ setup\ time \tag{2}$$

Note that the ‘connection setup’ time of different wireless technologies is different and thus ‘time left after successful connection setup’ will be different for different wireless technologies. For instance, Wi-Fi devices take about 600 milliseconds, Bluetooth devices take between 1 and 4 seconds, and ZigBee devices take about 30 milliseconds [6]. Using ‘Time left after successful connection setup’ and data rates, vehicles exchange the traffic information. Thus, the size of the message that is exchanged between vehicles can be calculated as

$$Message\ size\ = \frac{Time\ left\ after\ successful\ connection\ setup}{Data\ Rate\ of\ a\ given\ technology} \tag{3}$$

Note that the (maximum) data rates of different wireless technologies have different values as mentioned in the introduction section. Thus, size of the message exchanged in vehicular network using different technologies will be different. When the ‘Time left after successful connection setup’ is zero then size of the exchanged message will be zero that means no vehicles would be able to communicate with other vehicles.

3. Numerical Results

In order to properly discern a resolution it is our objective to compare the different mediums through the process of MATLAB simulation. During these simulations we recreate the situation in which two nodes are equipped with matching appropriate technologies. In these instances each vehicle is only equipped with one of these devices at a time. For the purpose of simulation we assume that these vehicles are moving with a maximum relative speed of 180 miles per hour (80.476 meters per second). This allows us to provide simulations for vehicles when they range in relative speeds from stagnant (vehicles are not moving or are moving together at identical speeds) to assumed maximums while moving in opposite directions (90 miles per hour is the assumed maximum for any given vehicle moving in one direction).

By using the formula provided in section II of this paper we are able to determine a total time for the given scenario. If we assume, for instance, the relative speed between two vehicles is s = 100 miles per hour (44.704 meters per second) and both vehicles are equipped with devices which have a transmission distance of d = 80 meters (this value is chosen based on the abilities of the devices as well as referencing the physical size of vehicles and there relation to each other on a standard highway) then we can compute that the total time allotted for communication is approximately 1.78 seconds or 1,780 milliseconds. By introducing the parameter of new association time for each device (30 milliseconds for ZigBee, 4 seconds for Bluetooth and 600 milliseconds for Wi-Fi) we can derive the total allotted time window for each device to communicate within. The values for new association time have been derived from information provided in [6].

We take a look at the simulations that were run in order to better understand the effect that this new metric has on the overall performance of each type of technology. This coupled with the also proceeding simulations dedicated to maximum message size will be utilized to further compare each technology for the purpose of judging their effectiveness in a mobile network.

The simulation results shown in Figure 3 provide record of the total avaibalble time and time duration left for data transfer within each technology after successful data transfer. The base time refers to data derived from equation (1), not incorporating the parameter for association time that the rest of the mediums provide. The remaing three sets of data incorporate the association time value and are processed using equation (2). Notice that the trend for ZigBee devices matches very closely to the control data, or base time. This is due to the incredibly small association time of Zigbee (30 milliseconds). Due to the high transmission distance WLAN is able to create connections within the range of all the provided relative speeds even after accounting for its half second new association time. Bluetooth, however is not able to maintain connections at a certain speed due to its much larger association time of 4 seconds.

Using the information seen in Figure 3, we can now take note of the total time allowed for two devices to communicate and the effects of the device's innate new association time parameter. Using a range of relative speeds from the value of 0 miles per hour to 180 miles per hour and a transmission distance of 80 meters we can derive appropriate functionality for each device. As shown in Figure 3, two vehicles using Bluetooth technologies lose feasibility for communication after exceeding a speed of 43 miles per hour. However, both ZigBee and all permutations of 802.11 are appropriate for application regardless of relative speed.

Based on the simulation results above we can begin to denote applications for each technology. However, before we can precisely ascertain the most appropriate medium for a vehicular ad hoc network we must look closely at the data transfer capabilities of each of these devices.

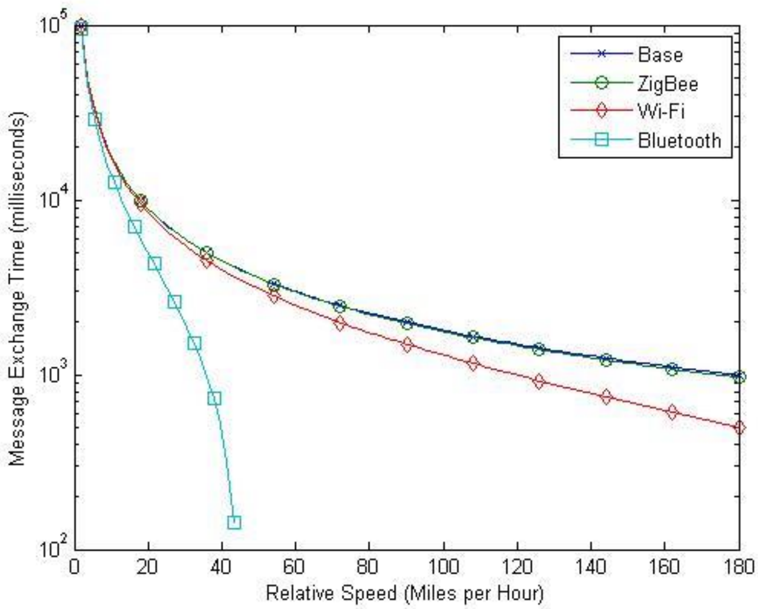

Figure 3: Total time duration and time left for data exchange after association for Zigbee, Bluetooth and Wi-Fi

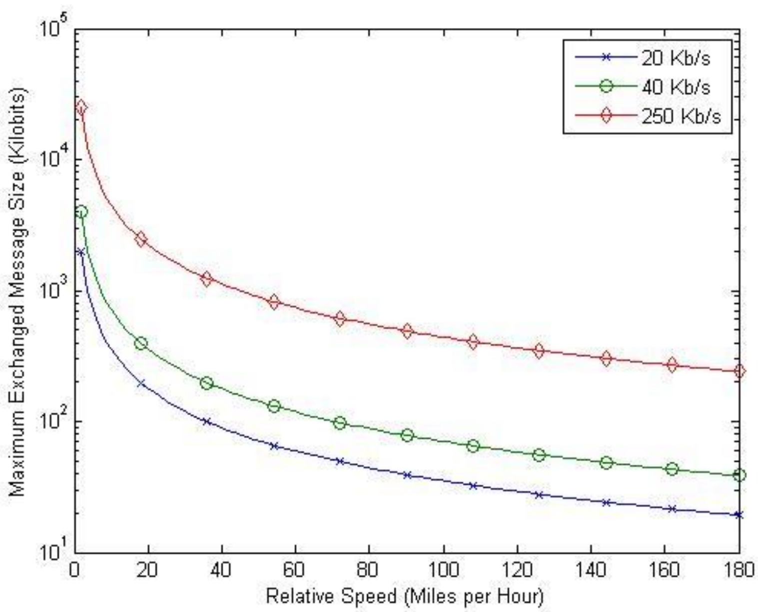

Figure 4: Variation of data exchange for ZigBee technology in V2V communication

Knowing the ZigBee technology has the capabily to properly transmit when the relative speeds of two vehicles is high (e.g., 180 miles per hour) from Figure 3, we can now look at the devices abilities to transmit data. The data rate of a ZigBee device is listed to have a maximum of 250 Kbps [6]. For our simulations we assume that the device can infact transfer with this capacity. We also include simulations for ZigBee when it is operating under two different data rates, 20 Kbps and 40 Kbps. Increase in speed results in lower data exchange time and hence the size of the message size as shown in Figure 4.

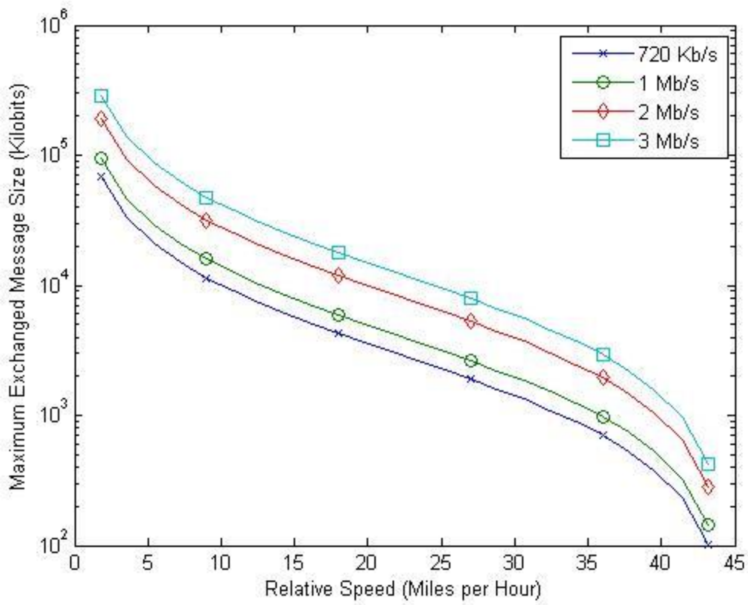

Figure 5: Variation of data exchange for Bluetooth technology in V2V communication

Figure 5 shows that the data rates of Bluetooth greatly exceed that of ZigBee device, especially with the addition of Enhanced Data Rate (EDR) available in Bluetooth version 2.0 and above. However, Bluetooth devices can only function in a scenario where two vehicles are moving at relative speed of a maximum of 43 miles per hour. This typically limits the functionality of Bluetooth in a VANET to vehicles that are moving with each other in the same direction. Simulations for this device were conducted using the maximum data rate of Bluetooth with EDR which is approximately 3 Mbps, but typically available in 2 Mbps data rate. The addition of a 1 Mbps value, much like with the ZigBee simulations was to analyze Bluetooth amongst other potential data rates.

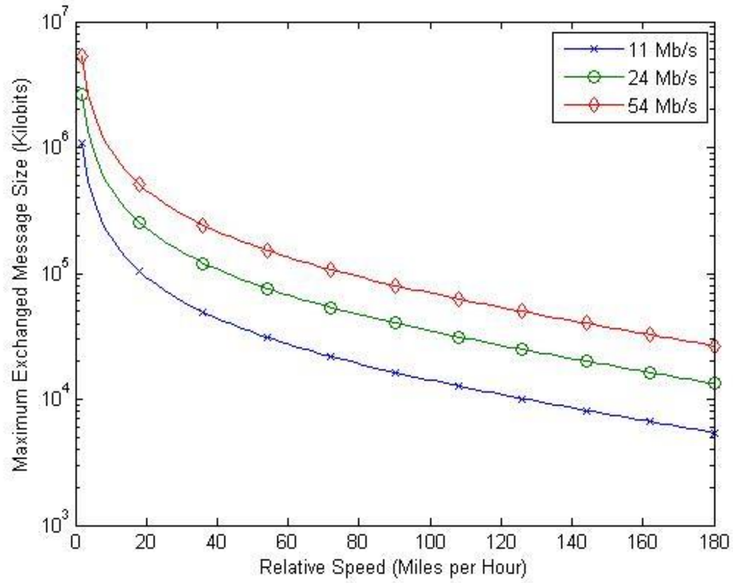

Figure 6: Variation of data exchange for 802.11 technologies in V2V communication

Figure 6 show the variation of data size exchanged for IEEE 802.11/Wi-Fi technology. 802.11 devices are capable of competing with ZigBee for connection time as they are applicable to vehicles moving with the maximum relative speeds that are being used. As described above, Wi-Fi provides several unique data rates that can be utilized for various purposes.

Based on the information ascertained from these simulations we can begin to draw conclusions on the viability of various technologies in vehicular ad hoc networks. Wi-Fi and ZigBee technologies show promising application for vehicles moving at the high speeds. However, Wi-Fi provides the benefit of a significantly greater data transfer rate, making it a more suitable environment for various applications. The primary advantage of ZigBee, its incredibly small association time, is irrelevant due to the large transmission range that we are assuming for our simulations. Bluetooth, while having acceptable values for data transfer rate, is clearly ill-fit for a network with the quickly changing topology that comes with a vehicular ad hoc network.

4. Conclusion and Future Work

Integration of real-time wireless communication with vehicular network in intelligent transportation system could help to reduce traffic accidents and deaths on the highways, and could prevent billions of dollars in fuel and lost work hours because of congestions. Numerical results obtained from simulation suggest that the ZigBee technology is better for higher relative speeds and smaller message sizes. Wi-Fi technology is suitable for high volume of data as it offers high data transfer rates. Bluetooth technology is suitable only for smaller relative speed. Again, choice of wireless technology for V2V communications depends on the applications that are envisioned to be supported.

Future considerations for our research will include, but are not limited to, development of VANET prototypes for V2V communications using above mentioned technologies which will be used as proof of concept in real traffic scenarios. Additionally, as part of the ongoing research, we plan to design a prototype using 802.11p based On-Board-Unit to compare the performance. This will allow us to create better model for VANETs with real world environment.

5. Acknowledgments

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