DSRC Applicability in Cameroon Road Traffic: A Simulation Study

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Abstract

The IEEE 802.11p standard has been amended in the 5.9GHz band in 2010 to provide road safety by enabling vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. V2V communications evolve the exchange of Wave Short Messages (WSM) between vehicles for safety advertisement, either in one hop or multi-hop broadcasts. However, previous DSRC evaluations have shown that this protocol is highly sensitive to transmission conditions, making it difficult to predict its performance. We are interested in finding the best configuration parameters for safety messages broadcasting over DSRC in typical African urban environments. Extensive simulations through the widely used network simulator OMNeT++, Veins, and SUMO show that only a very small fraction (around 30%) of the WSM reach the neighboring vehicles on time. Furthermore, the rebroadcasting of WSM further deteriorates the performances. Thus, the protocol as it is needs to be improved for its application in our environment.

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1. Introduction

Intelligent Transportation Systems (ITS) and Vehicular Ad-hoc Networks (VANETs) have been introduced to help solve the problems caused by increasing traffic on our roads. A VANET is a class or an application of a Mobile Ad hoc Network (MANET) that enables communications between vehicles and road infrastructures such as radars and traffic lights. The substantial difference between Mobile Ad-hoc Network and Vehicular Ad-hoc Network is the predictability of movement. Unlike the random movement in Mobile Ad-hoc Network, vehicles in Vehicular Ad-hoc Network must follow the routes and traffic rules [1]. In VANETs, vehicles, of variable density in an area, exchange information of different types. As vehicles are constantly moving, the environmental conditions of the transmission (such as the transmission range, the data packet size, distance between vehicles, interferences with other vehicles, etc.) change, and have to be taken into account carefully, in order to successfully reach each other and meet the required quality of service.

Dedicated Short-Range Communications and Wireless Access in Vehicular Environment (DSRC/WAVE) have been proposed as a wireless communication protocol for use in VANETs. Indeed, the desire to improve road safety information between vehicles to prevent accidents and also improve road safety was the main motivation behind the development of vehicular networking [2]. To date, the 5.9 GHz band has not been able to meet all the expectations to support widespread deployment of systems that would improve efficiency and promote safety within the Nation's transportation infrastructure. The US Federal Communications Commission (FCC) has then decided to realize the maximum value from this 75 MHz by initiating a Notice of Proposed Rulemaking (NPRM) to access the 5.9 GHz band rules and propose appropriate changes to ensure the spectrum supports its highest and best use, enabling the coexistence of DSRC with orther devices in the 5.9 GHz band.

In this study, we have used the DSRC in its european version for two main reasons. The first reason is that European standards are mostly those accessible in Sub saharan Africa and the second reason is because the coexistence is not yet at its mature exploitation and in developing countries, the unlicensed devices sharing the 5.9 GHz band are not yet accessible.

In developing countries, the rapid growth of urban population driven by rural exodus has triggered rapid growth in transport-related challenges, including CO_2 emission, congestion, accidents, environmental degradation, to just name a few. Official reports[†] state that 70% of all car accidents are due to human factors, i.e. speeding, drunkenness, parking violations, and lack of signaling of vehicles in distress. 20% are due to infrastructural causes, such as the poor state of the roads or plant invasion of

pavements, and finally, 10% are due to the bad condition of vehicles and other problems. While these issues are known world-wide, in Cameroon and other Sub-Saharan countries they are more severe. Figure 1 shows an example in Yaounde, the capital city of Cameroon. It presents the Carrefour Acacia junction, one of the most trafficked junctions in Yaounde. One can see the slope of the street, the low buildings, the parking and pedestrian situation, and the different traffic conditions at different times of the day.

In this paper, we explore the applicability of deploying an infrastructure-less IEEE 802.11p for vehicle-to-vehicle communication in Cameroonian (or Sub-Saharan African in general) conditions.

We focus on packet reception ratio (PRR) and the delay of accident warning messages with and without re-broadcast. We focus on a safety application only, as this is considered the most realistic and needed in our conditions and can save lives [3]. We explore a large parameter space to find which setting serves the application scenario best and how well. We use the well-known OMNeT++ simulator with its extension frameworks Veins and SUMO for vehicular communications.

Figure 1. Examples of traffic conditions in Yaounde

The rest of the paper is organized as follows: Section 2 gives a background study of safety applications in the WAVE standard with a note on the coexistence between DSRC and unlicensed devices in the 5.9 GHz band; Section 3 discusses previous relevant research; Section 4 presents the evaluation scenario (the above mentioned Acacia junction) and describes in detail the evaluation methodology; Section 5 shows and discusses the results, while finally Section 6 concludes the work.

2. Background on WAVE Protocol and safety applications

WAVE is an amendment to the IEEE 802.11 standard, also known as IEEE 802.11p, aiming at supporting ITS applications for short-range communications. The goals of WAVE among many others is providing real-time traffic information, improving safety in transportation, and reducing traffic congestion [4]. Two types of applications are used in WAVE: safety and comfort. Safety applications, which are highly delay sensitive and require a high level of

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†By the official spokesperson of the Cameroonian government during a press conference in September 2017

QoS, are mainly associated with emergency packet broadcast. Comfort applications on the other hand are less delay-sensitive and associated with infotainment and convenience. WAVE has been defined by the IEEE working group as the core of DSRC and ensures the traffic information collection and their immediate and stable transmission as well as keeping the security of information. Technically, according to [4], DSRC uses IEEE 802.11p for wireless access for vehicular environments (WAVE) based on IEEE 802.11 standard at the PHY and MAC layers. In upper protocol layers, DSRC makes use of a suite of IEEE 1609 standards: 1609.2 for security service, 1609.3 for network and transport services, and 1609.4 for multichannel operation. WAVE is a modified version of the Dedicated Short-Range Protocol (DSRC) with less overhead. From the implementation point of view, WAVE works at both Phisical (PHY) and MAC layers. The DSRC/WAVE architecture is presented in Figure 2.

2.1. Physical layer and Channel management

(a) DSRC before coexistence with other standards in the 5.9 GHz band

In order to enable Vehicle-to-Vehicle (V2V) and Vehicle-to-infrastructure (V2I) communications, the US Federal Communication Commission (FCC) has exclusively allocated 75 MHz in the 5.9 GHz frequency spectrum (5.850 GHz to 5.925 GHz band) for DSRC. The main objective was to enable public safety applications in vehicular environment to prevent accidents and improve traffic flow. In Europe, the European Telecommunications Standards Institute (ETSI) allocated the spectrum for cooperative safety communications in the 5.855 - 5.925 GHz band divided as follows [23]:

- 30 MHz of spectrum in the range 5.875-5.905 GHz for ITS restricted to safety-related communications, referred to as ITS G5A;
- 20 MHz of spectrum in the range 5.905-5.925 GHz for future extension, referred to as ITS G5D;
- 20 MHz of spectrum in the range 5.855-5.875 GHz for non safety communications, referred to as ITS G5B.

In Figure 2 below, the channel used is detailed.

ETSI ITS – G5B	ETSI ITS – G5A	ETSI ITS – G5D
Non safety related communications	EU-Wide available Safety-related communications	ITS future use

SCH 4	SCH 3	SCH 1	SCH 2	CCH	SCH 5	SCH 6
5860	5870	5880	5890	5900	5910	5920 MHz
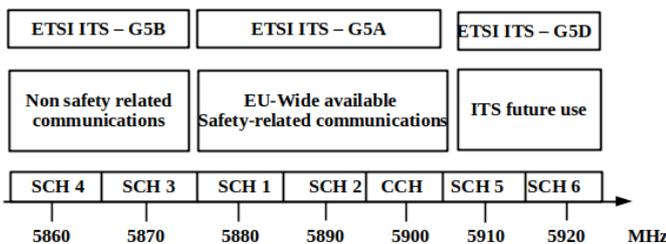
Figure 2. ITS carrier frequencies in the European Union (EU)

Because the regulations in Cameroon are the ones used in Europe, this study is based on the regulations specified by ETSI. At the bottom of the IEEE 802.11p protocol suite, the physical layer shown in Figure 2 is almost the same we have in 802.11a, with some modifications to conform to vehicular environments; namely:

- The division by 2 of the bandwidth (20 Mhz in 11a, 10 Mhz in 11p) to increase the tolerance according to propagation effects of the multiple trajects of signals. Globally, 11p OFDM uses the half-clock of 11a original OFDM;
- The MAC layer of 802.11p, which does not integrate the extended MAC sublayer (IEEE 1609.4), adds to the original MAC layer of 802.11 the mandatory management of the Quality of Service;
- Instead of using the traditional Distributed Coordination Function (DCF), it utilizes a new coordination function called Hybrid Coordination Function (HCF). HCF uses, as the fundamental access to the medium method, the Enhanced Distributed Channel Access (EDCA) which is based on the DCF mechanism but improved with a priority attached to each data packet according to its QoS constraints;
- The Extended MAC layer, defined by IEEE 1609.4 defines the organization, scheduling and use of the different channels of DSRC. Its goal is to provide mechanisms that allow multiple devices to tune in to a single channel for communication purposes.
The LLC layer layer is the traditional Logical Link

Control defined in IEEE 802.2.
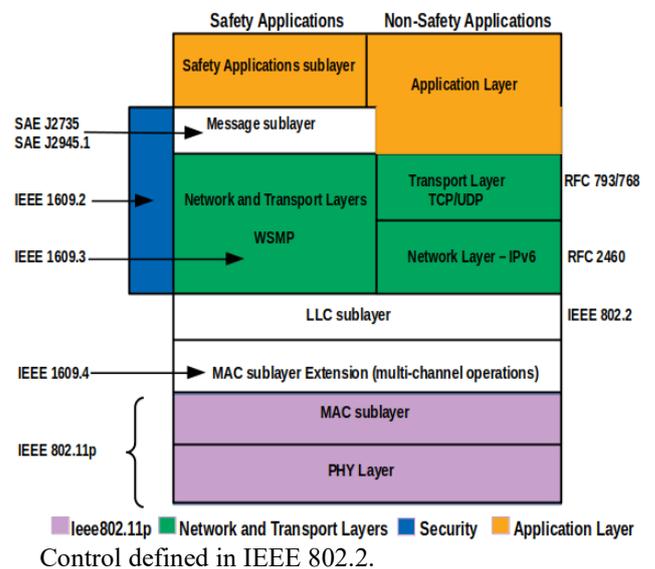
Figure 3. DSRC/WAVE architecture

(b) DSRC and U-NII devices coexistence on 5.9GHz band

The United States Federal Communications Commission (US FCC) has originally allocated 75 MHz spectrum in the 5.850 GHz to 5.925 GHz band to the mobile

service for DSRC. Many years after DSRC adoption, it has barely been deployed meaning this spectrum has been largely unused. In December 2020, the FCC has published a new document for the 5.850-5.925 GHz band usage. In this document, 30 MHz of spectrum in the 5.895-5.925 GHz (upper 30 MHz) was retained for ITS radio service and sunset the current technological standard in favor of Cellular-Car to Everything (C-C2X); and DSRC and Unlicensed National Information Infrastructure (U-NII) devices share the lower 45 MHz [24], enabling the coexistence between DSRC and U-NII devices in the 5.9 GHz band.

The initiated NPRM proposes to adopt rules reducing the amount of spectrum available for vehicular-related communications through two interference mitigation approaches:

- the Detect and Vacate (DAV or D&A);
- Re-channelization (Re-Ch).

The re-channelization process is an allocation process where safety-related applications use the upper 30 MHz (CH180, 182 and 184) and, while non-safety-related DSRC and Unlicensed National Information Infrastructure (U-NII) devices share the lower 45 MHz (CH172, 174, 176 and 178). The primary unlicensed devices considered in NPRM uses a signal based on IEEE 802.11 ac, some LTE-based systems as well, just to name a few. This is referred to as the concept of coexistence of DSRC and unlicensed devices in the 5.9 Ghz band.

Even if the coexistence between DSRC and unlicensed devices in the 5.9 GHz band is out the scope of this study, we have yet made a comparison between our results and those obtained by some existing studies in an environement where DSRC coexists with other standards in section 5.4.

2.2. WAVE Application layer and QoS requirements for safety

At the top of the WAVE protocol stack, according to vehicular environments, IEEE 1609.3 defines an efficient mechanism to manage safety. The IEEE 1609.3 standard manages the addressing and routing services in the network. Technically, it defines the WAVE Short Message (WSM) and WAVE Short Message Protocol (WSMP), both of which provide network and transport layer functionality for road safety applications. Due to its low latency, the use of WSMP is adequate for safety applications. The standard also defines the WAVE Service Advertisement (WSA), used to announce the availability of DSRC services. DSRC services allow the control of some applications by announcing their technical characteristics at a given location.

WSMP represents bandwidth-efficient small messages exchanged between vehicles or Road-Side-Units (RSU) to provide road safety. Then come SAE J2735 and SAE 2945.1. In fact, in cooperation with IEEE 1609 standards, the Society of Automotive Engineers (SAE) International

has standardized SAE J2735 for Message Set Dictionary used by WSMP and J2945.1 draft for minimum performance requirements [4].

The SAE J2945/1 standard specifies the minimum performance requirements for on-board vehicle-to-vehicle (V2V) safety communications and is in charge of transmitting and receiving Basic Safety Messages (BSMs) over a DSRC wireless communication. Finally, the safety application sublayer is found at the most top of WAVE/DSRC stack.

VANETs have a wide range of applications going from safety of life to comfort. Efficiency and safety are two important requirements that can be used to classify VANET applications based on their primary purpose [5]. The study of Chen, Xianbo and Refai, Hazem H and Ma, Xiaomin in [6] has defined Safety-related applications in VANET as a broad term for applications that are able to predict, prevent, and report safety-related events on the roads. The authors have classified Safety-related applications into two classes according to the level of urgency of the events and the latency that the applications can sustain:

- Safety-general applications that natively handle post event transactions and allow relatively longer latencies (1-10s);
- Safety-critical applications that can run either before the events such as traffic signal violation warning, lane change warning and pre-crash warning or after the events such as accident severity amelioration. They have very stringent real-time requirements in terms of delays (lower than 100ms).

From [7], we have combined informations to classify safety applications as shown in Figure 3. Due to the critical aspect of the safety of lives, the reliability of the packet transmission is of great concern. Thus, the protocol used for the transmission has to ensure a good level of packet reception rate to be considered as reliable.

According to [8] and [9], the requirements for the two safety applications this study deals with are summarized in Table 1.

Table 1. Safety application requirements compiled from [8] and [9]

Safety applications	Frequency	Latency req.	Dissemination range
Head on collision warning	10 Hz	100 msec	200 m
Emergency vehicle warning	10 Hz	100 msec	300 m

The layered transmission from the application layer to the wireless medium goes through Wave Short Message Protocol (WSMP) - IEEE 1609.3, the MAC sublayer - IEEE 1609.4 (optional and not used for this study), and finally IEEE 802.11p PHY and MAC

layers. Through this transmission, the impact of data rate transmission, data size of packets transmission, transmission and received power, the path loss models to be used etc, should be clearly presented.
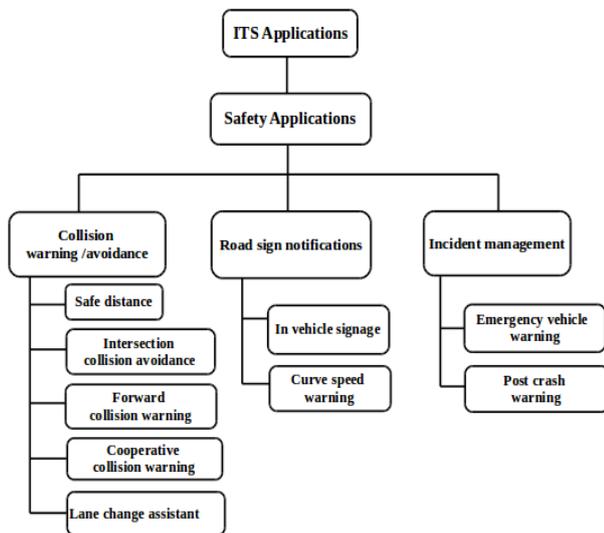
Figure 4. Classification of safety applications, compiled from [7]

Multiple applications exist in order to take advantage of the safety benefits of V2V. In [10], it is said that the exchange of traffic related informations (BSMs) between On-Borad-Units (OBUs) and/or RSUs allow drivers to take adequate proactive actions according to the nature of received alerts. Despite the spread of DSRC, its "short range" aspect makes it highly sensitive to the environmental conditions of the transmission (traffic density, sorrounding buildings, speed of the cars etc). Many studies have evaluated its field applicability, with different results. Some of them are presented below.

3. Related work

Evaluating performances of the IEEE 802.11p has been an attractive area of research in the past ten years. The study made by the authors of [11], [12], [13], [14],and [15] are good examples.

Below is a short description of some research work really close to what we did; but with significant differences.

In [6], Chen et al. have studied various enhancements of the 802.11 standard to meet the requirements of vehicular applications. They focus on a large number of applications using both V2I and V2V applications and conclude that none of the available enhancements fully support all applications and all requirements. However, they base their conclusions on theoretical analysis and not on simulation experiments with concrete scenarios.

In [16], Hernandez-Jayo et al. analyze the performance of IEEE 802.11p vehicular networks used as communication media to warn drivers about hazardous situations on the road. In particular, they focused on three typical active safety applications which are based on the cooperation among vehicles and intelligent elements placed on the road. The authors have analysed the performance of the protocol for V2V and V2I/I2V scenarios. They conclude that larger packets (1400 Bytes) achieve better delivery ratios for distance below 60 meters and speeds below 50km/h. However, they consider mostly highway and city center scenarios and do not evaluate the complete parameter space we are interested in.

In [17], Lupi et al. explore the question how the number of RSUs and their density impacts the network performance. Differently from our study, they do not measure the packet delivery ratio and only consider the delay in the presence of RSUs. Not surprisingly, they conclude that higher traffic combined with a dense deployment of RSUs affects the performance positively. However, they do not explore the suitability of these settings for safety warning dissemination.

In [12], Rashdan et .al have evaluated the performance of the ITS-G5 802.11p (European profile of IEEE 802.11p) based V2V communication for a cooperative collision avoidance system at urban intersections during the detection phase of the collision. They have used the Update Delay (UD), which is the time elapsed between two consecutive successfully received Cooperative Awareness Messages from a specific transmitter at a specific receiver. Extensive simulations conducted in OMNeT++ / Veins / SUMO have shown that the higher the traffic density the higher the UD. After showing in their simulations that the main reason for packet loss is the interference, they have found that buildings at intersections can reduce interference between cars by strongly attenuating the signal. They have concluded by recommending to increase the data rate by using higher order modulation to increase robustness and achieve a better reliability for the application. While this recommendation probably holds also in our scenario, it remains unclear whether a WAVE setting exist, which can serve our application.

Another question we pose is whether re-broadcasting of the warning messages can improve the performance.

To the best of our knowledge, none of the existing works gives an answer to our question: can we apply the WAVE standard in a Sub-Saharan-like large city without the use of road side units? With other words, can we comply to the requirement of informing all vehicles in a radius of 300 meters in less than 300 msec? If yes, what are the optimal settings to achieve best performance? If not, can we use re-broadcast of messages to increase the performance and meet the requirements?

4. Problem statement and simulation environment

In this section we define the exact application scenario and give details about the simulation environment and

the metrics we use.

4.1. Problem description and area of interest

As already mentioned in Section 1, we explore one particular crossing in Yaounde (Carrefour Accacia) and use this to parametrise our simulation scenario. The Accacia crossing (GPS Coordinates 3.840882, 11.488631) is depicted in Figure 4. This crossing is particularly congested in rush hours and is typical for Sub-Saharan cities: steep streets, low buildings, almost no pedestrian paths and few lanes.

The area of interest is a rectangular zone (1500m x 1500m) around Carrefour Accacia. This area is composed of two main streets (SW,NE : N,E) intersecting at one point (3.840882, 11.488631). Each of these streets has four lanes, two in each direction, but the delimitation is not clear and is often violated. The intersection (the circled part in Figure 4) is on top of a small hill, with three of the adjacent roads sloping. Road (SW,NE) has a vertical drop of 22 m at point A, and is about 1 km long. Whereas road (N,E) has a vertical drop of 25 m from A to East, with a total length of 501 m.

In the following experiments, we would like to explore this intersection with various traffic conditions and different WAVE parameters to evaluate whether WAVE can serve the application requirements: Disseminate the warning to all vehicles in a radius of 300 meters in less than 100 ms (as specified in Table 1).
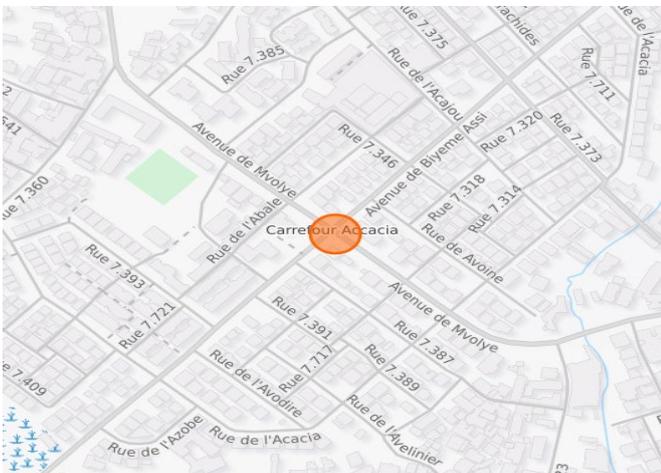
Figure 5. Experiment location: *Carrefour Accacia* in Yaounde, Cameroon

Two metrics are of interest in this work:

- The Packet Reception Rate (PRR) within the required time; This is the same as the information rate: how many vehicles were informed about the accident warning;
- The time a message takes from the source to the destination (latency). Recall that we have a hard deadline for the messages, 300 msec.

4.2. Simulation environment

The simulation environment is summarized in Figure 5. It consists of three simulators:

- Objective Modular Network Testbed in C++ (OMNeT++): an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulations [18];
- Vehicles in Network Simulation (Veins): an open source Inter-Vehicular Communication (IVC) simulation framework composed of an event-based network simulator (OMNeT++) and a road traffic simulator (SUMO), using cosimulation [19];
- Simulation of Urban MObility (Sumo): the traffic simulator designed to handle large road networks [20].
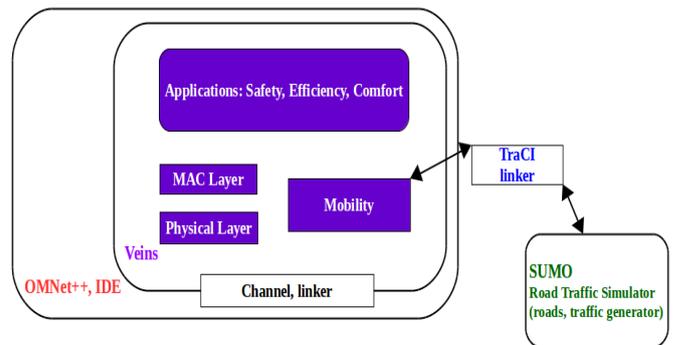
Figure 6. OMNeT++, Veins, SUMO

While OMNeT+ is the general simulation framework, Veins provides the required physical, MAC and application layers, including the WAVE standard. SUMO is used to create the vehicle traffic and to move it along the predefined streets.

In our model, a node is made up of an application layer and a wireless interface. The exact interaction between the individual components is also depicted in Figure 7.

The final scenario setup in OMNeT++/Veins is shown in Figure 8 with all buildings and streets as per our Accacia intersection scenario.
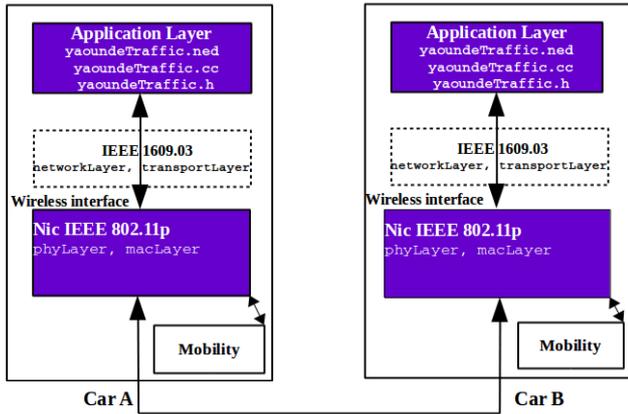
Figure 7. Direct communication between two cars in Veins
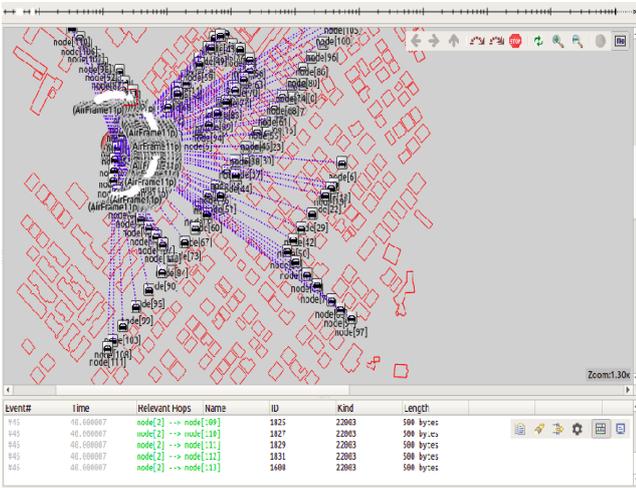
Figure 8. Simulation environement in OMNeT++

4.3. Parameter study

Table 2 shows the network configuration of OMNeT++ and Veins.

Table 2. General configurations for all experiments

General parameters	
Parameters	Values
Area of interest	1500x1500 m
Travel road length	400m x 400m
Antennas Transmit power	20mW
Physical sensitivity	-94
Maximum Interference distance	1500 m
Antennas position	On the roof
Channels used	CCH180-5.900
Frequency	10 MHz

These general parameters have been chosen according to preliminary studies:

- Area of interest: Accacia crossroad problem extends in just 450 m and thus, this is the area of interest. 1500m x 1500m has been defined as the area of testing which includes all the 450 m of the crossroad and shown above in order to present all the alternative roads;
- Transmission power: according to DSRC literature, channels between 172-183 use various transmission powers in the world from 23dBm to 44.8dBm. In Europe and Cameroon, 33dBm (20mW) is used;
- For the Physical sensitivity of antennas, we have conducted preliminary studies on the possible values. The results reveal that only values of physical sensitivity below -90 (-94 and -95) allow us to reach neighboring cars.
- Antennas can be placed either on the roof of cars or left/right mirrors. Better results have been observed only when the antennas are located on the roof.
- Channel used: for the sake of simplicity, we have assumed the Service Channel Interval is set to 0 to have a base line of 100% usage of CCH for safety messaging.

In our experiments, we explore a wide range of parameter values, shown in Tables 3 and 4.

Table 3. Model specific configurations

Specific NIC and application layer	
Parameters	Values
Data rates	$\{3,6,9,27\}$Mbps
Data packets size	$\{300,400,500\}$B
Max. Data packets size	$\{36.5,72.76,108.77\}$KB

The choice of parameter values in Table 3 is made to cover all plausible possibilities, based on our own preliminary studies and conclusions from related works:

- For the data rates, [21] and [22] have shown that 6Mbps is not only the default but also the best data rate in non overloaded environment because it performs the best PRR and for slightly loaded to overloaded environment, 4.5 and 9 Mbps are better in terms of PRR. We have extended the study to include data-rates between 3 and 27 Mbps.
- Concerning the data packets size, knowing that safety messages are very short packets, we have taken into account all the acceptabe possible small sizes and we went further by looking for the maximum data packet size that could be transmitted within the required travel time (100 ms).

Table 4. SUMO settings, MinGap is the minimum distance between cars

Mobility settings	
Parameters	Values
Number of vehicles	$\{50..300\}$ step 50

Max. speed	${20..70}$km/h step 10
MinGap between cars	${1..20}$m step 5

Table 4's values are chosen according to the traffic patterns generally observed at the area of interest. During rush hours, more than 300 vehicles can be found within this area. And during normal traffic hours, the number of vehicles vary between 50 and 150. Thus, the number of vehicles is closely related to the MinGap, which is the minimum distance between cars and the maximum speed of vehicles.

5. Results and discussion

After extensive simulations on OMNeT++, Veins and SUMO, the results we have obtained are classified into two categories, which are the two metrics we have defined in the previous section; namely the PRR of safety messages and their latency.

5.1. Evaluation of the PRR for Wave Short Message (WSM) Broadcast and Re-Brodacast

Figures 9a and 9b presents our experimental results in terms of PRR for various data rates and different number of vehicles. Furthermore, we have explored here the possibility to re-broadcast the message to reach more vehicles. However, our hypothesis was not confirmed. Re-broadcasting of messages creates a broadcast storm, resulting in very high interference, leading to even lower PRR.
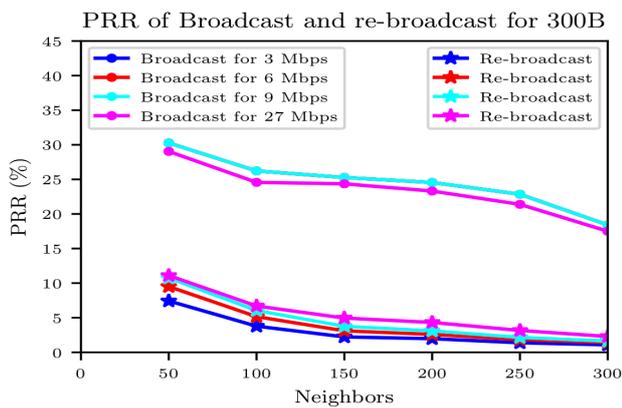
Figure 9(a). PRR for 300B data packet size
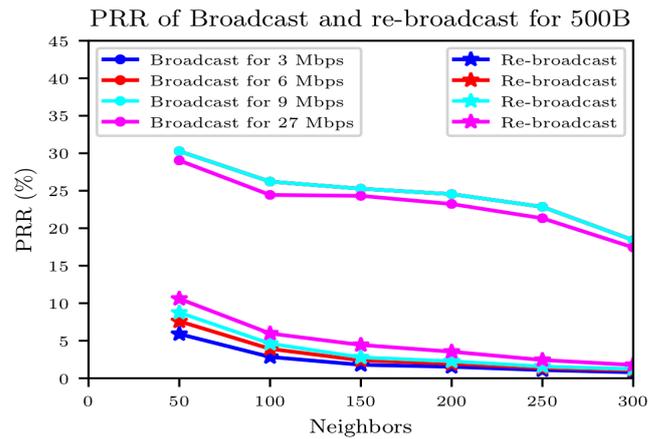
Figure 9(b). PRR for 500B data packet size

The data for 400 B is omitted for space reasons, since it shows the same behaviour as for 300 and 500 B.

In general, the achieved PRR is very low: not enough to serve the application requirements. This is due to the very high interference and high attenuation in the environment. Higher data rates do not make any difference in our experiments, as this does not contribute to the final PRR.

With increasing number of vehicles, the PRR decreases, as it can be expected.

5.2. Latency evaluation with different data sizes and data rates

Regarding the second metric, which is the latency of a safety message, following are the observations. As already stated in the SAE J2945/1 standard, a safety message is only useful to the recipient if its travel time from the source to the destination is lower or equals to 100 milliseconds (Table 1). After measuring all the travel times of received messages using different data packet size and data-rate, we have noticed that they are all far below the 100 millisecond. And for the same data packet size, sent using the same data-rate, the travel time is exactly the same no matter the number of vehicles. This is seen in Figure 10a and Figure 10b.
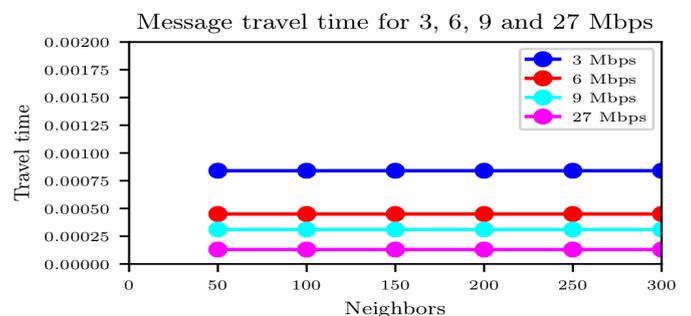
Figure 10(a). Message travel time for 300B data packet size
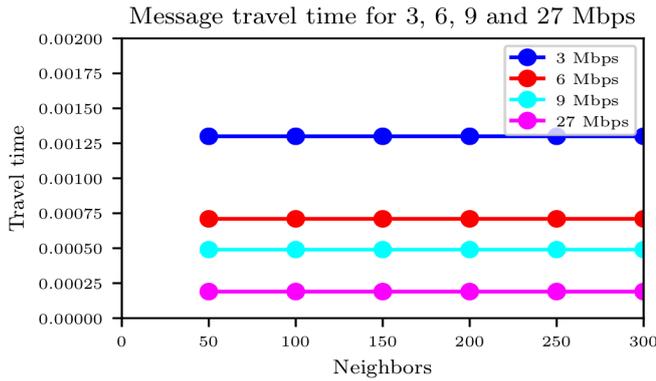
Figure 10(b). Message travel time for 500B data packet size

The data for 400 B is omitted for space reasons, as it shows a behaviour between 300 B and 500 B.

These results show that all the nearby vehicles receiving the safety message are warned early enough to take adequate action. This could help the intended cars to change their initial route to avoid the emergency situation upstream and thus reduce the risk of traffic jams

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Figure 11. PRR for different data packet sizes and data rates.

5.3. Maximum data packet size for 3, 6 and 9 Mbps

In this section we explore what is the maximum data size for different data rates, so that the emergency message is extended with more details, status information, etc. For each data rate (3, 6, 9 and 27 Mbps) we have calculated the theoretically maximum data packet size.

For example, for 3 Mbps and 100 msec maximum transmission time to keep the delay restriction, the maximum packet size is 36.5 KB. Figure 10 shows that with increasing data sizes, the delivery rates for lower data rates drops to 0. For example, the PRR for 36.5 KB and 3 Mbps is around 30% , but drops to 0 when sending a 72.76 KB packet. This is because the packet was too large to be sent in the requested 100 ms slow.

Thus, we can see that with 3Mbps the maximum usable data packet size is 36.5 KB, with 6 Mbps it is 72.76 KB and for 9 and above it is 108.77 KB. This is very important for practitioners, since it shows that only small data packets have any chnace of being delivered at the neighboring vehicles.

5.4. Comparison to related works

Compared to the results obtained by Chen et al. In [6], we actually find significant differences. However, these differences might be coming from the parameter spaces explored: Chen et al. explore up to 50 terminals (vehicles) and our analysis starts with 50 and extends to 300 neighboring vehicles. Comparing only the results for 50 vehicles, we again observe differences: our obtained delay is significantly lower (below 1 msec) against around 600 msec in [6]. Furthermore, the packet delivery ratio in [6] is below 10%, while ours is around 30%. These variations are probably due to the theoretical methodology used in [6] against our experimental analysis and to the used scenarios.

Experimental results in [16] show more similar results to ours, even if the application scenario is different. There, Hernandez et al. report delays below 100 msec (similar to ours) and deteriorating PRRs for larger distances, again similar to ours. The results from both studies (ours and the one in [16]) are complementary. The same holds for the results in [12].

Our results combined with the results from previous studies, show that WAVE is only applicable in certain scenarios. With increasing distance from the accident and increasing traffic, performance decreases dramatically. Re-broadcasting messages (multi-hop communication) has also a negative effect, as well as

less interference from the environment (e.g. lower buildings like in our case). Furthermore, higher data rates help reaching more vehicles on time, but is more susceptible to interference, which at the end results in lower performance. However, higher data rates are able to transfer more data, if this is required by the application.

Next, we discuss the results obtained by some recent studies with scenarios where DSRC coexists with others 5.9 GHz band unlicensed standards. Sathya et al. have conducted various in-depth studies on the coexistence on the 5.9 GHz band of Wi-Fi and other unlicensed standards such as LTE Assisted Access and LTE systems in [25], [26], [27] with meaningful results that have led to standardization advances for some and to advices to push researches in the field further.

In terms of discussion, the coexistence of DSRC with other unlicensed 5.9 GHz standards, we have notice, with the results of the authors of [28] and [29], that the new DAV approach does not affect the DSRC, while the most challenges are found in the re-channelization. In fact, experiments conducted by the authors of [27] and [28] on Wi-Fi/DSRC adjacent channel interference show that DSRC performances drop for certain scenarios where the transmitter power setting is set to 20dBm and devices are at a distance lower than 7 m.

For these scenarios, the Packet Error Rate is high. The parameters chosen in our study are in lign with their results because our results are still acceptable for a power transmission of 33 dBm and sparse vehicles.

6. Conclusion

In this paper we have explored the question whether the DSRC protocol can be successfully deployed in Sub-Saharan large city environment. In such an environment, we cannot use road side units, the interference is high and the traffic is mostly congested. We have used the OMNeT++ network simulatior with its extension frameworks Veins and SUMO to answer this question. Unfortunately, our results show clearly that the DSRC protocol is not suited to work in such an environment. While the latency of messages is satisfactory, the best achieved packet reception ratio (PRR) was only about 30%. Also our hypothesis of using re-broadcast to achieve better PRR was not confirmed.

In future, we will focus on the identified problems to develop a solution to increase the PRR and thus the penetration of safety warning messages. We are planing to explore the version of DSRC coexisting with U-NII devices, with Re-channelization and see how to implement it in our future work.

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