Performances Evaluation study of VANET Communication Technologies for Smart and Autonomous Vehicles

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Abstract— **The amazing advanced in high technologies allows Intelligent Transportation Systems (ITS) to become an integral part of our daily life. Smart and autonomous vehicles illustrate these new transportation structures. The interaction and communication between vehicles in such systems are considered the key elements and illustrated by the different V2X (Vehicles to Vehicle and Vehicle to Infrastructure) technologies proposed in the market place. The Vehicular ad-hoc networks(VANETs) and LPWA technologies as the fifth generation mobile communication(5G) and IEEE 802.11p protocol could be a proper solution. In this paper, the architecture of these standards were analysed. The key parameters of IEEE 802.11p were implemented in Veins Framework combined with Omnet++ network simulator and SUMO Mobility simulator, to accurately simulate VANETs. The performance of this standard was measured in Veins Framework using realistic vehicular mobility models. Then, the main performance metrics; Timeliness, Throughput and Packet Loss Ratio were analyzed when varying the different messages sizes in the scenario. and Then a rebroadcasting process was analysed when varying the number of nodes.**

I. INTRODUCTION

Nowadays, mobility and transport have become an integral part of our daily life, owning a car is not even a luxury anymore. With the fast development of highways and roads which make a crucial contribution to economic development and growth, we face many serious socio-economic problems and huge financial costs because of the increased number of traffic accidents, causing more and more injuries and deaths amoung drivers . Every year more than 1.25 million people die as a result of a road traffic crash as reported by the World Health Organization (WHO). That is why in the recent year Intelligent Transportation Systems (ITS) are exceedingly getting more intrest due to their ability of reducing traffic accidents and traffic jams as well as assisting the passengers with important and useful informations. A blizzard of new technologies has emerged, all arguing that they have the key to the future of Intelligent Vehicles (IV). But, when dealing with a critical machine type communication (MTC) [1], there are many factors to be considered such as: traffic safety messages should have maximum end-to-end latency of 100ms, messages generation frequency is up to 10 messages per second (10Hz), high communication reliability as high as 99.999 %, high positioning accuracy (cm) in a high mobility environment, etc. [2]. From this emerged technologies for Intelligent Vehicles we have LPWA technologies, the IEEE802.11p standard and the cellular vehicle-to-everything (5G C-V2X).

LPWA technologies are already hitting the market such as the proprietary technologies LoRa and Sigfox, with a novel communication paradigm, which complement existing cellular mobile network and short range technologies, enabling long battery life (up to 10 years) and wide area connectivity at a low cost chipsets and networks.

With its very long range, devices can spread and move over large geographical areas. Vehicles connected by LPWA technologies can sense and interact with their environment anywhere and at anytime, more details will be provided about this new technologies in section II.

When talking about the IEEE 802.11P it is the physical (PHY) and datalink (MAC) layer of the wireless access for vehicular environment (WAVE) standard, which is composed of the IEEE 1609 protocol family and IEEE 802.11P as PHY and MAC layer, together are called WAVE standard, used for automotive wireless standard. It is designed to meet every V2X application requirement with the most stringent performance specification, without the need to establish a basic service set (BSS). In section II we will talk about some details of the IEEE 802.11p PHY and MAC layer and how it is designed for the sake of Intelligent Vehicle communication.

A bigger challenger to these technologies has emerged from the cellular industry called C-V2X providing Vehicular-to-Everything (V2X) communication which is essential in enabling safe, reliable and efficient transportation services which can be deployed both near- and long-term and can meet the vehicular use case requirements of today and tomorrow (higher throughput and a range that exceeds one mile) [3]. In section II we discuss more about the 5G C-V2X technology. In section III we provide an overview of the wireless requirement for VANETs, by explaining the Quality Of Service (QOS), dependability and the security in the intelligent vehicles communication (IVC), and a performance analysis of the IEEE802.11p standard using a simulation. In section IV we analyze the result obtained from the simulation and section V is a conclusion, we provide an analysis and a prediction for the future of VANETs.

II. RELATED WORKS AND TECHNOLOGIES OVERVIEW

Most of the previous works on the VANET broadcast performance analysis is based on the 802.11 DCF. Yuan et al. [4] considered a bidirectional highway with one lane per direction. this typical highway scenario is abstracted into a 1-D VANET model. proposed two Markov chain models for ACs with different priorities to analyze the performance and reliability of the safety-critical data broadcasting on the CCH under both non saturated and saturated conditions in VANETs using the NS-2 simulator.They concluded that the 802.11p standard broadcast on the CCH in a typical highway scenario can easily satisfy the delay constraints; however, it is difficult to meet the reliability requirements. To increase the reliability of the 802.11p broadcast, system parameters has to be adjusted. Vinel et al. [5] leveraged a periodic broadcast model to compute the successful reception probability and the mean transmission delay in the WAVE.

Diogo et al. [6] analyzed using the NS-2 simulator the performance of two major optimization parameters in VANETS, packets delay and data throughput, for vehicular networks that implements direct communication between the nodes, IVC. They concluded that increasing vehicles average speeds and keeping the average distance constant, for a given number of nodes, the impact on delay and throughput was low. It was also found that keeping the nodes average speed, the impact on data throughput and packets delay is given directly by the network topology, that is the number of nodes and average distance between them.

A suitable wireless medium access technology can significantly improve the performance of applications. In this section, the two major access technologies are compared in term of key performance indicators, to facilitate the analysis of their performance in VANETs applications. Usman et al. [7] mentioned that LPWA technologies achieve long range and low power operation at the expense of low data rate (typically in order of tens of kilobits per seconds) and higher latency (typically in order of seconds or minutes). Therefore it is clear that LPWA technologies are considered for those use cases that are delay tolerant, do not need high data rates, and typically require low power consumption and low cost. Critical MTC are definitely out of the remit of LPWA technologies because their stringent performance requirements such as up to five nines (99.999%) reliability and up to 1-10 ms latency cannot be guaranteed with a low cost and low power solution.

In fact, Lora & Sigfox are extremely out of the remit, because of the high latency and the duty cycle restriction.

We concluded that LPWA technologies are not well suited for VANETs and are excluded from our study.

Festag et al. [8] provides an overview of the key C-ITS and DSRC protocols from a standardization perspective. It also analyzes automated driving as the potential new application domain for vehicular communication, discusses its requirements on communication, and derives potential directions for future releases of the vehicular communication standards.

IEEE 802.11p is a short range peer-to-peer communication protocol for wireless access in vehicular environments. A new potential access technology has emerged, the 5G C-V2X, will be presented for the future best performance and long range communication.

A. 5G C-V2X

Cellular-V2X which was initially defined as LTE-V2X is an improvement over 802.11p providing a better alert latency and 2X the range. It is designed to operate in 2 modes:

- Device-to-Device(D2D): This means Vehicle-to-Vehicle (V2V), Vehicle-to-(Roadway) Infrastructure (V2I) and Vehicle-to-Pedestrian (V2P) direct communication on "PC5" interface, operating in ITS bands (5.9 GHz), meaning that it can work in the absence of a cellular network.
- Device-to-Network(D2N): This is vehicle-to-Network (V2N) communication operating in the traditional mobile broadband licensed spectrum on the "Uu" interface. Primarily, to enable cloud services to be a part and parcel of the end-to-end solution.

Collectively, the cellular-V2X is composed of a shorter-range direct communications (V2V, V2I, V2P) and longer-range network-based communications (V2N) as transmission modes, 3GPP should clearly specify the spectrum that needs to be utilized by this emerged technology. As the 5.9 GHz ITS spectrum is used for vehicle safety and mobility applications, it is of major importance that the use of C-V2X direct communication in 5.9 GHz is secured in order to guarantee that the superior C-V2X technology advantages can be used for both near- and long-term for the public good. As mentioned before C-V2X communication can be supported by over the PC5 interface introduced in the new feature known as Proximity Service (ProSe) or D2D communication in Release12 and Release13 of the specification, also known as "sidelink" communication, in contrast to the conventional up- and downlink in cellular network. It has been enhanced to address the network requirement for vehicular safety applications (high speed (up to 250kph) and high density (thousand of nodes)) [9], and also by over LTE-Uu, which is the radio interface between UE and the Evolved Node B (eNodeB). A UE might use unicast and/or Multimedia Broadcast or Multicast Service (MBMS) for transmitting and receiving messages.

Beside positioning, C-V2X also uses GNSS for time synchronization without relying on cellular network.

The primary purposes of V2X are safety and efficiency, they can be achieved through sending realtime alerts to drivers, pedestrians and Road side units (RSUs), including road hazards, Forward Collision Warning, Emergency Vehicle Warning, Warning to Pedestrian against Pedestrian Collision etc. All through the PC5 interface which is a point to multipoint communication so the transmitter does not know in advance the recipient of the message, and a security association establishment between UEs is not necessary in an advanced setting. Thus, no security mechanism is used in this layer. For LTE-Uu communications, the LTE security mechanism for air interface confidentially should be used, and the privacy may be supported using credentials and identifiers. [10]

B. IEEE 802.11p

The ultimate vision of Dedicated Short Range Communication (DSRC) is an allocation of bandwidth for different regulatory organizations around the world to allow V2V and V2X, their aspect being primarily: Safety. DSRC utilizes IEEE 802.11p which is part of the WAVE protocol in VANETs, an amendment that improved the 802.11 standard for vehicular communication. This standard defines a way to exchange data without the need to establish a basic service set (BSS), and so, without any delays in waiting for authentications procedures before sending the message, it is a peer to peer communication, the network contains no access points or base stations, this will reduce enormously the delay as it is mentioned in [11] that the traffic safety messages should have a maximum end-to-end latency of 100 ms. In addition, the broadcast and the multicast of IEEE 802.11p do not have the acknowledgment process, the RTS/CTS mechanism and the MAC-level recovery mechanism. As a result, the transmission delay continues to be reduced, but the reliability of transmissions cannot be guaranteed. The IEEE 802.11p equivalent in Europes C-ITS stack covering PHY and MAC is termed ITS-G5.

The IEEE 802.11p amendment allows the use of the 5.9 GHz band (5.850 - 5.925) GHz with channel spacing equal to 20 MHz, 10 MHz and 5 MHz and lays down the requirements for using this band in Europe and US. It operates on seven 10 MHz wide channels. 5 MHz in the beginning of the band at 5.85 used as guard band (GB). CH172-5.860 GHz and CH184-5.920 GHz both are safety dedicated channels. Channel CH178-5.890GHz is a control channel responsible for controlling the transmission broadcast and link establishment. The four other service channels are allocated for bidirectional communication between different types of units [12].

Even though the physical layer of the 802.11p is adopted from the 802.11a standard there was some modifications in order to keep abreast the requirement of vehicular ad-hoc network (VANET): 802.11a uses 48 sub-carriers to transmit data and 4 for pilot carriers so a total of 52 sub-carriers with a 20 MHz bandwidth per channel. 802.11p uses the same number of sub-carriers, but a 10 MHz bandwidth per channel. So that implies doubling of all OFDM timing parameters used in the regular 802.11a transmissions. the result to this is that Doppler spread decreases (due to the smaller frequency bandwidth), inter-symbol interference is also decreased due to the longer guard times, but these doubled parameters in the time domain halve the effective data rate (3 to 27 Mbps against 6 to 54 in 802.11a).

IEEE 802.11p MAC Layer unlike the 802.11 standard that uses Distributed Coordination Function (DCF), it uses an enhanced version of it which is the Contention-Based Channel Access named Enhanced Distributed Channel Access (EDCA). EDCA uses Carrier Sense Multiple Access (CSMA) with Collision Avoidance (CSMA/CA) meaning that whenever a node is transmitting any other node that overhears this transmission should remain silent and wait for it to finish before attempting to access the medium again. Frames are classified into four Access Categories (ACs): Background traffic (BK or AC0), Best Effort traffic (BE or AC1), Video traffic (VI or AC2) and Voice traffic (VO or AC3). In EDCA: Arbitration Inter-Frame Space Number (AIFSN) is used instead of DIFS in 802.11 standard. AIFSN and Contention Window values are chosen for different ACs as illustrated in TABLE I, aCWmin and aCWmax are equal to 15 and 1023, respectively [13].

TABLE I
DEFAULT EDCA PARAMETERS IN IEEE P802.11P

AC	AIFSN	CWmin	CWmax
AC0	9	aCWmin	aCWmax
AC1	6	(aCWmin+1)/2 - 1	aCWmax
AC2	3	(aCWmin+1)/4 - 1	aCWmin
AC3	2	(aCWmin+1)/4 - 1	(aCWmin+1)/2-1

When the data comes from the upper layer to the MAC Layer it is classified into 4 different ACs groups according to its priority (AC) [14].

EDCA will calculate its AIFS[AC] according to the data AC as follow:

$$AIFS[AC] = aSIFSTime + AIFSN[AC] \times aSlotTime$$

Where: aSIFTime = 13 s and the aSlotTime = 32 s.

Before transmitting, the node senses the medium. If the channel is free for greater or equal to AIFS[AC], the data will be sent, else, a random back-off time is selected as follow: (i) the node selects a backoff time uniformly at random from the interval [0,CW +1] where the initial CW (Contention Window) value equals CWmin; (ii) the interval size will increase (double), if the subsequent transmission attempt fails, until the CW value equals CWmax; (iii) If the channel is idle, the backoff time will be decremented (iv) Once the backoff timer expires, the data will be sent.

III. WIRELESS REQUIREMENTS FOR VANETS

The main aim of VANETs is to serve a safe and high quality experience for humanity. Due to the sensitivity of this market, correctly choosing the wireless standard according to the performance aspects in regards to the system requirements, is a big challenge for all designers. In addition to the traditional QoS properties such as : Timeliness & Energy-consumption , that measure the performance of the system. Kumar et al. [15] add two new aspects which had been neglected in wireless communication research :

- Dependability : is defined as the ability to provide trustable services within a given period of time. From VANETs system's side, a measure of their reliability, maintainability, integrity, availability and safety.

- Security : the authentication system for wireless standards should not leak information associated. Hence, communications must support an online security to ensure privacy.

This three dimensional space, is very complex to manage. The goal is to find the set of coordinates, which make the QoS balance better, with a reasonable level of security and dependability [16].

In one hand, VANETS need Real-time communications, when a deadline must be respected, the system must ensure the latency/delivery to guarantee the bound time.VANETs require ultra-low latency and ultra-high reliability.

TABLE II
KEY PERFORMANCE INDICATORS (KPIS) FOR LORA, SIGFOX, 5G C-V2X, IEEE 802.11P

KPIs	LoRA	Sigfox	5G C-V2X	IEEE 802.11p
Extended coverage	+++	+++	+++	+
Reliability	+	+	+++	+++
Network scalability	+	+	+++	+++
Timeliness	+	+	+++	++
Safety	+++	+++	+++	+++
Mobility support	+	+	+++	+++

The unpredicted interruption of the communication between the different nodes causes a negative impact in the safety of VANETs. In fact, the wireless standard should have a strong mechanism of defense against erasure, and must be able to handle a potential interference or a Cyber-attack without loss of main functionality. The data exchanged between nodes must be prevented from unauthorized access, by encrypting the wireless communications.

As explained in Section II, IEEE 802.11p & 5G C-V2X are the two standards with the most adapted characteristics that respond adequately to VANETs requirements. The TABLE II resumes the KPIs for VANETs for each of the four technologies [17].

A. IEEE 802.11p SIMULATION

VANETs are very difficult and expensive, to be implemented and deployed in the real world, because they require a lot of resources and a wide infrastructure. In fact , most researchers refer to the simulation in this domain, as an alternative solution.

Veins, the Open Source vehicular network simulation framework, is selected for this paper because of its flexibility and real world maps, Full IEEE 802.11p implementation. This simulation is executed by an event-based network simulator (OMNeT++) while interacting with a road traffic simulator (SUMO). The simulation is performed by executing the two simulators in parallel, connected via a TCP socket [18]. The trace generated by SUMO simulator is fed to the Omnet++ simulator which defines the realistic position of each vehicle during the network simulation. The Omnet++ simulator implements the VANET protocols and produces a trace file that contains the complete information about the scenario taking place. IEEE 802.11p performance, is then evaluated by analyzing this generated information.

N.Balon et al. [19] mention that Broadcast transmissions are the predominate form of network traffic in a VANET. However , the IEEE 802.11p performance can be measured in function of its broadcast messages reception QoS.

The scenario is a highway of 400 meters long with three lanes in Oran-Algeria obtained from OpenStreetMap [20], with 4 meters width each one, in one direction, and 16 vehicles moving in these two lanes. The maximum speeds of the two lanes are 80, 60 and 40 Km/h resp.In the scenario, a Red car carrying a sick person is in an emergency situation traveling in the same direction at the speed of 100 Km/h. The Red car is located behind the last car over 120 meters apart. The Veins Framework generates realistic vehicular model. The Red car transmits one periodic broadcast every 0.4 seconds with a payload of 300 bytes, so other vehicles clear the road for it. We implemented another scenario, in which the ambulance transmits a broadcast messages with the payload of 600 and 1500 bytes, in addition , we tested the rebroadcasting process when changing the number of nodes. To make our results more robust, we did every scenario ten times, the obtained results are the average of the different experiences.

Veins does not use the concept of a fixed transmission range that vehicles can communicate. Instead, Veins compares different parameters(Tx Power, sensitivity, SNR, path loss coefficient, frequency), then derives the probability of reception. In this simulation, Txpower was set to 10 mW, sensitivity to -80 dBm and path loss coefficient to 2, which conclude a transmission range of 127 meters. This transmission range gives us the possibility to see the different results in a short distance of 400 meters, instead of using a bigger distance that requires more hardware resources.

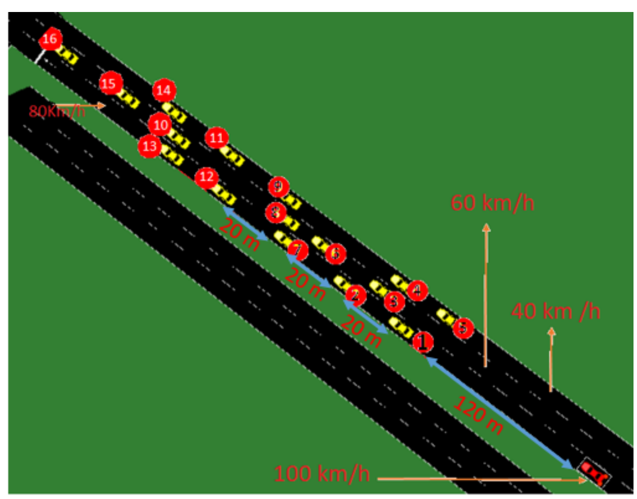

Fig. 1. Case study scenario

IV. RESULTS

The simulation results obtained from the previously described scenario, packet loss ratio, Throughput and End-to-

End delay were calculated for sixteen vehicles as shown in Fig.3 during a run-time simulation of 22 seconds.

TABLE III
DISTANCE BETWEEN THE RED CAR AND DIFFERENT VEHICLES

Vehicle / Time(sec)	0	5	10	15	20
V-1	120	92.5	65	37.5	10
v-2	140	112.5	85	57.5	30
v-7	160	132.5	105	77.5	50
v-12	180	152.5	125	97.5	70
v-9	170	87	4	79	162
v10	210	154.5	99	43.5	12

TABLE III shows the distance between the red car and vehicles 1, 2, 7, 12, 9, 10 during the simulation. In addition, Packet loss between the red car and these vehicles during the simulation is illustrated in Fig.2 .its mentioned in Fig.2 that there is no packet loss between the red car and vehicles 7 & 12 after 10 seconds of the simulation time.According to TABLE III , the distance between the red car and the vehicles 7 & 12 is less than 127 meters after 10 seconds. Accordingly, the vehicles can receive the broadcast message when their distance from the sending node i.e(the red car) is less than 127 meters.

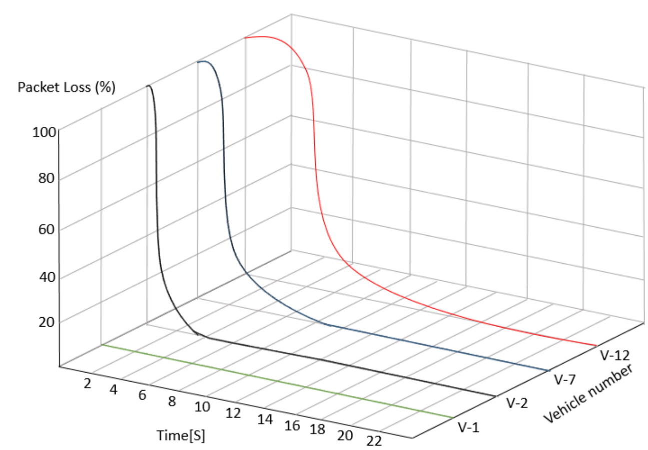

Fig. 2. Path loss between the red car and other vehicles during the simulation

Fig.3 shows the throughput of vehicles 1, 2, 7 and 12 with the message size of 300 bytes. The throughput of vehicles 2,7 and 12 variate between 2.1 and 2.5 Kbps, when the distances between the vehicles and the Red car are less than 127 meters. It is obvious that all the vehicles share the same throughput when the distances between the red car and other vehicles are less than 127 meters. In fact, the throughput and packet loss are not affected by the varying speed.

End-to-End delay between the red car and vehicles 1, 2, 7 and 12 with a payload of 300 bytes are illustrated in Fig.4. A correlation between Fig.4 and TABLE III is noticed, above the threshold distance which is 127 meters, no packet is exchanged. End-to-end delay is affected by

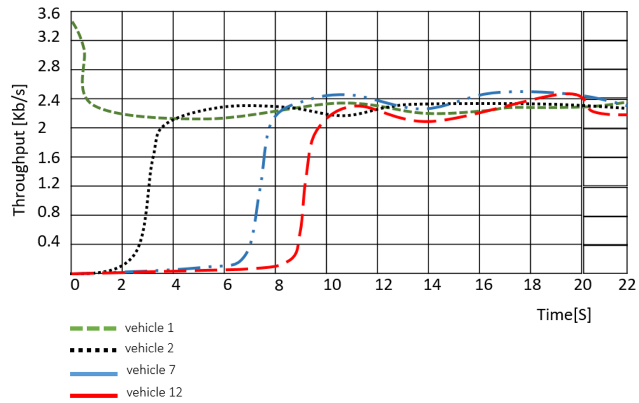

Fig. 3. Throughput of vehicle 1,2,7 and 12 (message size 300 bytes)

the distance between the sender and the receiver, as the distance increases below the threshold value, End-to-End delay increases consequently.

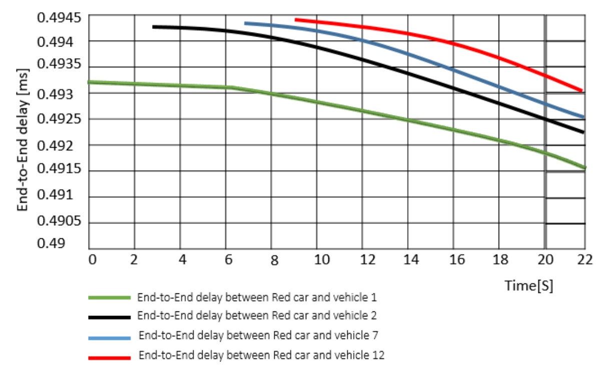

Fig. 4. End-to-End delay between the red car and other vehicles

The message size affects directly on the End-end-End delay (see Fig.5).

TABLE IV
SIMULATION RESULTS FOR DIFFERENT NODES NUMBER

Nodes	16	20	50	100
Retransmissions	14.2	16.1	43.7	92.8
Sent packets	33.6	166	898	2786
% received packets	100	89	70	58
% lost packets	0	11	30	42
delay[ms]	0.497	2.203	2.124	2.677
% reached nodes	82	91	95	98

TABLE IV shows that as the number of nodes increases, as the network performance decreases . In fact, IEEE 802.11p works better in the Urban scenario than in the Highway scenario.

V. CONCLUSION

In this paper, We studied the different communication technologies used or candidate to be used for ITS and

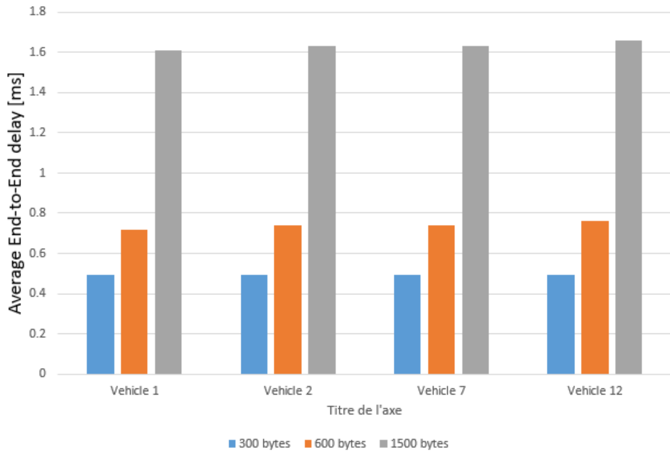

Fig. 5. Average End-to-End delay between the red car and other vehicles with different payload size

autonomous vehicles. Technologies like LoRa, Sigfox, 5G C-V2X and IEEE802.11p VANETs standards are studied with a focus on the two last ones (5G C-V2X and IEEE802.11p). We implemented the 802.11p in Veins simulation Framework using realistic vehicular mobility model obtained from OpenStreetMap around ORAN city area (Algeria).Based on our results, we observed that the performance metrics (Packet Loss Ratio, End-to-End delay) are affected by the distance between the sender and the receiver, and the size of the broadcast messages. We can say that the IEEE 802.11p enables direct V2V communications within short distances (up to 150m), but possible obstacles in the line of sight could reduce the communication range significantly.

On the other hand, 5G C-V2X offers superior performance over IEEE802.11p in term of range and hight traffic capacity. We expect that the future VANETs architecture will be based on 5G as a backbone solution because it can provide ubiquitous geographical coverage, high data rates, reliable communication and QoS support, in coexistence with IEEE 802.11p and 5G C-V2X in D2D mode for V2V communication, to best satisfy the requirements of VANETs.

It has not escaped our notice that a group of leading companies in automotive and telecommunication industries such as : AT&T, AUDI, BMW, China Mobile, HUAWEI, QUALCOMM etc. formed the 5G Automotive Association (5GAA) in September 2016 in order to accelerate the development and deployment of C-V2X, to prepare the next-generation vehicular communications towards connected and autonomous driving.

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