Performance Evaluation of Inter-Vehicle Communications Based on the Proposed IEEE 802.11p Physical and MAC Layers Specifications

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***Abstract*—Traffic control, accidents prevention, vehicles automation and useful services to the drivers have always been goals of an intelligent traffic system. With this objective, the IEEE is finalizing its new standard: the IEEE 802.11p, which defines the vehicular ad-hoc networks physical and medium access control layers characteristics. This paper presents simulations to evaluate the performance of these networks operating according to the new standard, at different scenarios, using the most recent version of the well-known network simulator NS-2. The results show that the transmissions quality impact is directly linked to dynamic changes in the network topology.**

***Keywords*—*IEEE 802.11p*; *Vehicular Networks*; *NS-2.34*.**

I. Introduction

Big cities all over the world are suffering, or can suffer in the near future, with the uncontrolled growth of their road systems, making the search for solutions that lead to this improvement becomes a challenge [1], [2], [3]. Linked to this, there is a lack of traffic information to drivers, what prevents them to make decisions that could avoid traffic jams. In this scenario, the concept of intelligent transportation system (ITS) was created, where essential data are exchanged by the vehicles, such as: track and weather conditions, levels of traffic jams and accidents emergency announcements. These and other measures would be relevant to the planning of routes and safety of drivers and pedestrians [3], [4], [5], [6].

From this situation came the necessity for the criation of vehicular ad-hoc networks (VANETS), which are able to supply the demand for inter-vehicle communications (IVC) and road-to-vehicle communications (RVC). Such technology is getting lots of attention by both the automotive industry and world research centers [4], [7].

To VANETS's standardization, the IEEE is finalizing a new standard: the IEEE 802.11p, which defines the rules for wireless access in vehicular environment (WAVE) [3], [8], [9], [10]. The new model comes as an alternative to the currents wi-fi standards, being developed to support the vehicular networks features, where the main difficulty is keeping the transmission rates due to the network topology dynamism and nodes high speed, besides low latency in security applications [3], [6].

As this proposed standard is not finished, computer simulations to evaluate its performance are very important to both researchers and industry, being the focus of this work. With this target, experiments were performed using the network simulator NS-2.34, applying the IEEE 802.11p support, where it was observed two main performance parameters of VANETS: packets delay and data throughput.

Some related works can be highlighted, such as [11], [12], [13]; however, in all of this works, the simulations was performed using old NS-2 versions and different VANETS implementations, developed by each one of these authors. This work uses the newer NS-2 version and its native VANETS modules, developed by [14], being different from the latter by the analyzed metrics: packets delay and data throughput.

The paper is organized as follows. First, Section II describes the IEEE 802.11p physical and medium access control layers characteristics. Continuing, Section III describes the IEEE 802.11p implementation in NS-2.34. Then, Section IV presents experiments and results of vehicular networks simulations, using NS-2.34, at different scenarios. Finally, Section V shows the work final considerations and conclusions.

II. IEEE 802.11p Standard

Due to studies, none of the currents wireless standards are completely adapted to VANETS [6]. So, the IEEE is developing a new standard in order to follow vehicle networks requirements with safety and quality, ensuring data transmission in unstable networks. The IEEE 802.11p, with its drafts, defines the operation mode settings of VANETS's physical and medium access control (MAC) layers [3], [8], [9], [10].

The goal of this new proposal is to ensure robust and quality communications when dealing with networks whose nodes have high mobility and fast topology changes, beyond the necessity of low latency and immunity to interference. The IEEE 802.11p definitions are described in Subsections II-A and II-B.

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TABLE I
IEEE 802.11P AND IEEE 802.11A MAIN PARAMETERS COMPARISON

Parameter	IEEE 802.11p	IEEE 802.11a
Rate (Mbps)	3, 4.5, 6, 9 12, 18, 24 and 27	6, 9, 12, 18 14, 36, 48 and 54
Modulation	BPSK, QPSK 16-QAM and 64-QAM	BPSK, QPSK 16-QAM and 64-QAM
Codification Rate	1/2, 1/3 and 3/4	1/2, 1/3 and 3/4
Sub-carriers Number	52	52
OFDM Symbol Duration	8μs	4μs
Guard Interval	1.6μs	0.8μs
FFT Period	6.4μs	3.2μs
Preamble Duration	32μs	16μs
Sub-carriers Spacing	0.15625 MHz	0.3125 MHz

TABLE II
CONTROL CHANNEL EDCA PARAMETERS.

AC	CWmin	CWmax	AIFS
0	CWmin	CWmax	9
1	(CWmin+1)/2-1	CWmin	6
2	(CWmin+1)/4-1	(CWmin+1)/2-1	3
3	(CWmin+1)/4-1	(CWmin+1)/2-1	2

TABLE III
SERVICE CHANNELS EDCA PARAMETERS.

AC	CWmin	CWmax	AIFS
0	CWmin	CWmax	7
1	CWmin	CWmax	3
2	(CWmin+1)/2-1	CWmin	2
3	(CWmin+1)/4-1	(CWmin+1)/2-1	2

A. Physical Layer

The IEEE 802.11p physical layer implementation specifies the use of dedicated short range communications (DSRC), defined by the Federal Communications Commission (FCC) [11].

The DSRC technology operates at a 75 MHz bandwidth, positioned in the spectrum range of 5.9 GHz. These 75 MHz are divided in seven 10 MHZ channels each, being the center channel the control channel and the rest of the channels the service channels [4], [11], [12], as illustrated in Fig. 1.

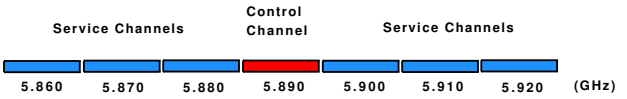

Figure 1. DSRC spectrum.

Different channels can not be used simultaneously, thus, each station can make the constant change between the control channel and the service channels. To ensure the requirement of low delay, especially when safety data are sent, the changing time can not be higher than 100 *m*s [4].

During transmissions, signals are sent using orthogonal frequency division multiplexing (OFDM) technique, which divides each channel in several sub-carriers spaced by 0.15625 MHz from each other [3].

To illustrate the differences, Table I compares the IEEE 802.11p and IEEE 802.11a physical layer main parameters.

B. MAC Layer

The MAC layer functions match to the IEEE 802.11e standard, enhanced distributed channel access (EDCA), which adds quality of service to IEEE 802.11 networks. Messages are categorized into four different ACs (AC0, AC1, AC2 and AC3), where AC0 has the lowest priority and AC3 has the highest priority [10].

When a particular message is selected, its contain parameters are sent to the transmitter. First the arbitrary inter frame space (AIFS), previously set for each AC. As each slot time is 16 μs, the AIFS time is equal to AIFS x 16 μs. Subsequently is calculated the contention window (CW) time. This is performed by a random value between 0 and CWmin. If there is any collision, the window time is recalculated by $2(CW + 1) - 1$, and a new attempt is done. The operation is repeated until the maximum window size (CWmax) is reached or the packet is sent successfully [4], [10].

The control and service channels contain parameters are shown in Tables II and III, respectively.

III. VANETS SIMULATION SUPPORT

VANETS performance evaluation is being studied by several researchers, [4], [5], [11], [12], and are very important for automotive industry. Although testbeds are still limited, due to the fact that IEEE 802.11p is not finished, computer simulations can be performed and its results used as a parameter for possible vehicular networks improvements. In this scenario we can highlight the use of NS-2.

NS-2 is a general purpose networks simulator developed by Berkley University [15] and is currently at version 2.34. VANETS support, however, was only developed in the last two versions (2.33 and 2.34).

Its implementation is done by applying the IEEE 802.11p physical and MAC layers features in the TCL simulation code, defined by two native modules: *WirelessPhyExt* and *MAC80211-Ext*.

Table IV shows the definitions of some vehicular networks key parameters in NS-2 TCL simulation code.

IV. EXPERIMENTS AND RESULTS

Using NS-2.34 VANETS's support, performance evaluation experiments were realized.

However, it was necessary to check whether this implementations was sufficient to obtain consistent results because, as described in Section III, the NS-2 IEEE 802.11p modules were recently developed, being found only in the two latest versions of the simulator.

So, foremost, an IEEE 802.11a and IEEE 802.1p comparison scenario was simulated, where data throughput and packets delay were verified. These experimental results, if consistent, would enable a more secure analysis in a scenario implemented only using IEEE 802.11p for VANETS simulations.

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TABLE IV
IEEE 802.11P PARAMETERS DEFINITIONS IN NS-2.34 TCL CODE

Phy/WirelessExt set Pt 5.0ϵ-2 *Phy/WirelessExt set freq 5.85ϵ+9* *Phy/WirelessExt set HeaderDuration 0.000040* *Phy/WirelessExt set BasicModulationScheme 0* *Phy/WirelessExt set PreambleCaptureSwitch 1* *Phy/WirelessExt set DataCaptureSwitchSwitch 0* *Phy/WirelessExt set SINRPreambleCapture 2.5118* *Phy/WirelessExt set SINRDataCapture 100.0* *Phy/WirelessExt set PHY-DBG 0* *Phy/WirelessExt set bandwith 70ϵ6*
MAC/80211Ext set CWmin 15 *MAC/80211Ext set CWmax 1023* *MAC/80211Ext set SlotTime 0.000016* *MAC/80211Ext set SIFS 0.000032* *MAC/80211Ext set ShortRetryLimit 7* *MAC/80211Ext set LongRetryLimit 4* *MAC/80211Ext set HeaderDuration 0.000040* *MAC/80211Ext set SymbolDuration 0.000008* *MAC/80211Ext set BasicModulationScheme 0* *MAC/80211Ext set use80211aFlag true* *MAC/80211Ext set RTSThreshold 2346* *MAC/80211Ext set MACDBG 0*

Then, a simple scenario containing two nodes (transmitter and receiver) was defined, with 100 m x 3000 m topology at a 10 seconds simulation. The nodes movement was done in opposite directions and in each simulation the speed of each node was increased by 20 km/h. Fig. 2 illustrates the proposed scenario.

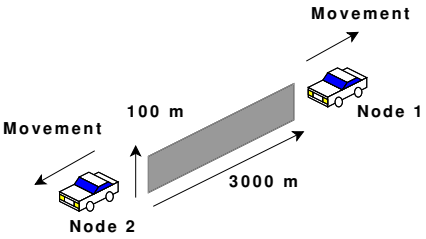

Figure 2. IEEE 802.11p and IEEE 802.11a comparison scenario.

Starting at an initial speed of 40 km/h and increased by 20 km/h until the final speed of 140 km/h, it was possible to obtain the packets delay and the transmitted data throughput. The results are shown in Fig. 3 and Fig. 4, respectively.

The graphs show clearly the best performance of IEEE 802.11p implementation compared to IEEE 802.11a.

Due to the increased power at the transmitter, [3], [8], [9], [10], and being exposed to the same propagation model (in this case the Nakagami model [13]), the IEEE 802.11p achieved considerably greater data throughput, especially at speeds below 80 km/h. Analyzing the delay, the NS-2 IEEE 802.11p implementation proved to be robust and promoted the low latency support required in the standard, [3], [8], [9], [10], resulting in average delays almost 3 times smaller than those ones obtained using IEEE 802.11a.

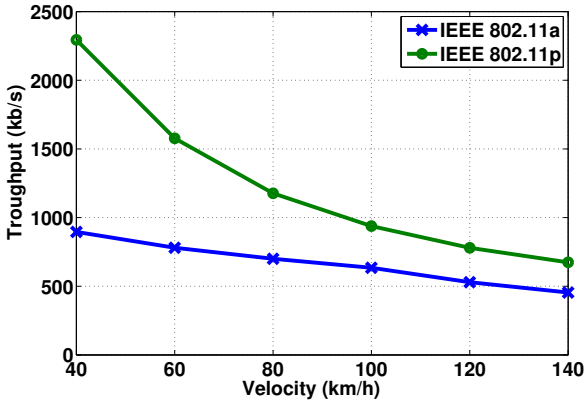

Figure 3. IEEE 802.11p and IEEE 802.11a data throughput comparison.

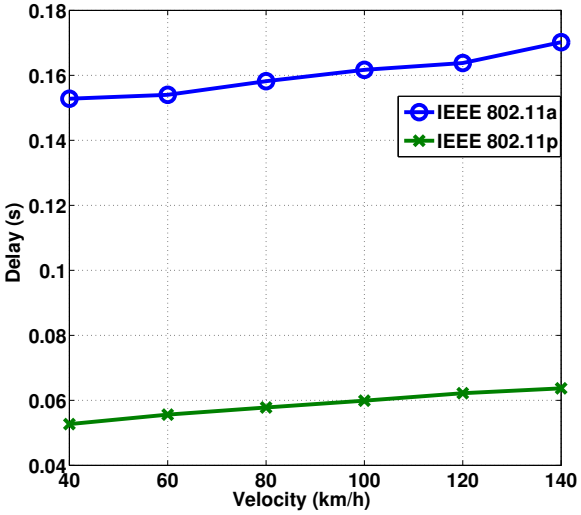

Figure 4. IEEE 802.11p and IEEE 802.11a packets delay comparison.

With these results, which showed the effectiveness of the NS-2.34 IEEE 802.11p implementation, a new series of experiments was performed. In these tests were analyzed vehicular networks performance at different scenarios using the same two metrics: throughput and delay.

The scenarios were defined according to three variables: number of nodes (10, 30 or 50 nodes), nodes average speed (70 km/h, 90 km/h and 110 km/h) and nodes average distance (10 m, 30 m or 50 m), totalizing 27 different scenarios.

The experiments were performed by TCP transmissions realized by two nodes located at the opposite sides of a road with 100 m x 3000 m topology, using AODV routing protocol, Nakagami propagation model (as this is the more accurate to characterize vehicular networks communications [13]), and the IEEE 802.11p physical and MAC layers implementations, in 10 seconds simulations. Table V shows the parameters definition in the TCL code used during the simulations, and Fig. 5 illustrates the scenarios general arrangement.

In the first experiment was observed if increasing the nodes

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TABLE V
TCL CODE PARAMETERS FOR VANETS PERFORMANCE EVALUATION IN NS-2.34.

```
set val(chan) Channel/WirelessChannel
set val(prop) Propagation/Nakagami
set val(netif) Phy/WirelessPhyExt
set val(mac) Mac/80211Ext
set val(rp) AODV
set val(x) 100
set val(y) 3000
set val(stop) 10.0
```

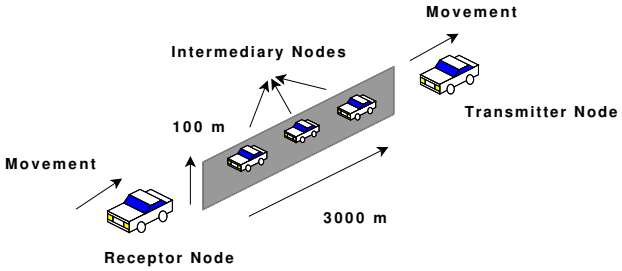

Figure 5. VANETS performance evaluation scenario

average speed (70 km/h, 90 km/h and 110 km/h), fixing the nodes average distance (10 m, 30 m and 50 m) could cause an impact on the data throughput. Fig. 6 illustrates the result, where n is the number of nodes and d is the average distance between them.

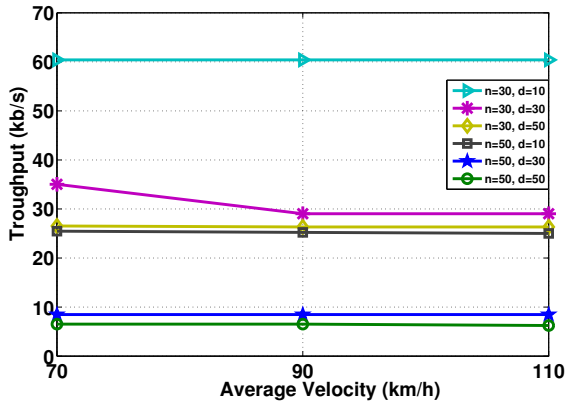

Figure 6. Data throughput changing nodes average velocity.

The results showed that the data throughput is almost invariant when the nodes average velocity remains relatively constant in IVC transmissions. However, the nodes distance influences the data throughput, being inversely proportional to the same. Thus one can imagine the standard is well-established for data transmissions on highways that allows this type of situation, as the German Autobhans for example [16], where cars can run at high speeds, forming blocks according to the adopted velocity.

For urban scenarios transmissions, where nodes average distance and average speed is constantly changing, although not simulated, the standard suggests the use of fixed infrastructure, applying RVC transmissions, in order to keep the data throughput stable in most of the cases [3].

The second experiment used the same procedure as the first, this time analyzing the packets delay. The result is illustrated in Fig. 7, where n is the number of nodes and d is the average distance between them.

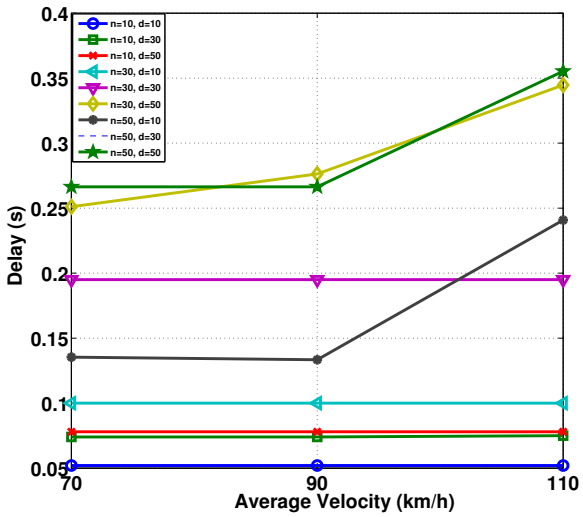

Figure 7. Packets delay changing nodes average velocity.

In this case, although some outliers, mainly for speeds above 90 km/h, the results showed that in most of the cases the delay was constant, confirming the first experiment results.

In the third experiment, the average speed of the nodes was fixed at 70 km/h; the impact on data throughput was verified by changing the number of nodes and the average distance between them. The result is illustrated in Fig. 8, where n is the number of nodes.

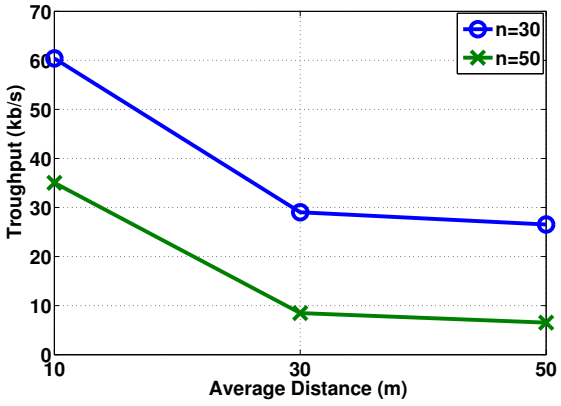

Figure 8. Data throughput for a fixed velocity of 70 km/h changing the number of nodes and the average distance between them.

The results show that for a constant velocity the data throughput impact is given by the network topology. In this

case the data throughput rate in a transmission of two nodes located in the opposite points of a road, with 30 intermediate routing nodes between them, can reach 5 percent of the value obtained in a two nodes direct transmission, as shown in the results of Fig. 3.

Finally, to prove that the network topology change has a greater impact on VANETS performance, was observed the packets delay of a simulation where the nodes average speed was fixed in 90 km/h and was changed the number of nodes and the average distance between them. Fig. 9 illustrates the result, where n is the number of nodes.

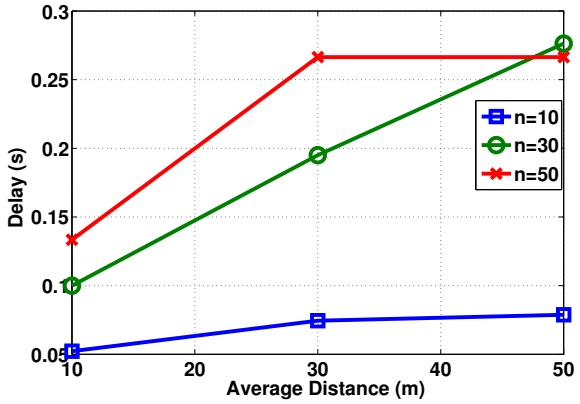

Figure 9. Packets delay for a fixed velocity of 90 km/h changing the number of nodes and the average distance between them.

The results show that the impact of changing the network topology is also noticeable in packets delay.

V. Conclusion

Due to big cities road systems growth, a lot of attention is directed to the development and performance of vehicular networks, not only by manufacturers and researchers, but also by governments and institutions responsible for maintenance of these roads.

While IEEE does not finish the IEEE 802.11p standard, which defines the VANETS physical layer and MAC layer characteristics, real testbeds are still limited.

Therefore, computational experiments become the most widely used tool for obtaining these performance parameters, and their results can be used for possible changes in the new standard specifications.

This paper described computer based simulations, using NS-2.34, whose goal was to obtain 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.

The results showed 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. That is, the standard provides good support for vehicles communications in scenarios such as highways, for example.

Furthermore, it was 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, being a possible limiting factor for the VANETS performance which adopts only IVC transmissions.

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