More insights into communication issues in the Internet of Vehicles

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***Abstract*—The incorporation of information and communication technologies within vehicles has truly revolutionized the way we travel today. Connected vehicles represent the building blocks of the emerging Internet of Vehicles (IoV). They are spurring an array of applications in the area of road safety, traffic efficiency and driver's assistance. Connected vehicles refer to vehicles that can support Vehicle-to-X (V2X) connectivity. The critical challenge is to design good mobility and propagation models. In this paper, we intend to study the relevance of a realistic mobility model and a realistic propagation model. First, we analyze the most common routing protocols performance for MANET, namely OLSR, AODV and DSR thanks to a network simulator. Next, we study the influence of both models on a simple safety service. The major result is highlighting the impact of realistic modeling on the simulation.**

***Index Terms*—IoV, connected vehicles, radio propagation, mobility modeling, routing protocols, performance analysis.**

I. Introduction

The rapid development of information and communication technologies (ICT), equipping cars with wireless communication capabilities is driving the evolution of conventional Vehicle Ad-hoc Networks into the Internet of Vehicles (IoV). This network presents unique features like high and predictable mobility, high node density, frequent disconnections in network, etc. Connected vehicles are mainly designed to support applications in order to increase the capacity of Intelligent Transportation Systems (ITS) and provide drivers with better road safety. They are also used in traffic optimization like flow congestion control, emergencies and accidents and commercial applications like file sharing files, Internet access and parking free places reporting.

Connected vehicles present two communication types [1]: Vehicle-to-Infrastructure (V2I) communications, in which vehicles are connected to fixed stations located on the roadsides for information exchange or Internet access; Vehicle-to-Vehicle (V2V) communications, where vehicles exchange information without relying on any fixed entity.

One of the major issues in connected vehicles is to maintain established routing paths before the end of data transmission due to the high mobility. Indeed, the network topology is constantly changing and the wireless communication links are inherently unstable. Unfortunately, ad-hoc routing protocols must adapt continuously to these constraints. Their performances are directly related to the characteristics of the underlying environment. Thus, it is important to evaluate different routing protocols using propagation and mobility models that reflect, as closely as possible, the real behavior of vehicular traffic and environment.

Realistic models of mobility and propagation were proposed in a previous research framework [17], [18], now we aim to achieve a new system validation in two levels. In the first level, we analyze the performances of three popular routing protocols in MANET, namely AODV (Ad-hoc On-Demand Distance Vector) [2], OLSR (Optimized Link State Routing) [3] and DSR (Dynamic Source Routing) [4] in the context of vehicular network. We examine the behavior of each protocol at different vehicular densities and data traffic rates. The radio propagation model considers obstacles effect on radio signals. The mobility model implements a real city traffic which based on information describing, the degree of interest of areas for moving vehicles, terrain characteristics and urban infrastructures. This information is taken into account in vehicles movement and radio signal propagation modeling. In the second level, we study the influence of realistic modeling on simulation results by considering a safety service: the dissemination of information in case of accident. This is because vehicular communications aim to insure safe driving by improving the traffic flow and therefore significantly reducing the car accidents.

Such evaluations can help us determining the characteristics of radio links in vehicular networks and then to identify the routing protocols that are suitable for vehicle communications and those that cause performance degradation. To do this, we analyze the behavior of each protocol by considering a real world environment and traffic. We also study the impact of obstacles on radio signal propagation. The issued results reflect a real-world environment, a real mobility traffic and obstacles effect.

The remainder of this paper is organized as follows: In section II, we provide some related work in the performance evaluation field of routing protocols in vehicular network while in section III, we briefly depict the mobility model and the propagation model studied in our previous works. Simulation environment and results are presented in section IV. In section V, we illustrate a case study of a road safety application. Finally, section VI concludes the paper.

II. Related work

Because of the dynamic topology formed by vehicular communication design and the high mobility of vehicles, finding and maintaining routes is a very challenging task. In essence, it is important to consider a simulation environment with a realistic mobility and propagation models. Existing mobility models try to closely represent the movement vehicules and the radio propagation is strongly influenced by the type of environment where the communication occurs. In vehicular communications, the most important objects that influence the propagation are obstacles such as buildings, vehicles and vegetation.

Many studies in litterature have highlighted the use of radio propagation and mobility models in VANET. During this section, we present topology based routing protocols employed in IoV implementations and studied in the next section [5]. These routing protocols use link's information within the network to perform packet forwarding. They are further divided into Proactive (table-driven), Reactive (on-demand) and hybrid (between proactive and reactive) [6].

Several studies have been published comparing the performance of routing protocols using different mobility models or performance metrics. The authors of [7] compared AODV, DSDV, DSR and TORA on highway scenarios. The results showed that TORA is not feasible for vehicular network and that AODV is the protocol with the best performance, followed by FSR and DSR which present good results only at low vehicular densities. In [8] the same authors evaluated the performance of the four protocols in city traffic scenarios. They confirmed the previous results and they showed that TORA or DSR are completely unsuitable for vehicular network and that AODV outperforms FSR.

Authors in [9] compared a position-based routing protocol (LORA) with both topology based protocols AODV and DSR. Their conclusions are that, although AODV and DSR perform almost equally well under vehicular mobility, the location-based routing schema provides excellent performance. In [10], the authors considered three geographic routing techniques and presented the problems that may be encountered in each technique. They found that by using greedy heuristics, the protocol chooses the farthest neighbor as a next hop, which usually has low receiving probability. They also found that a bad choice of a next relay in trajectory based routing can cause data message to get stuck or move away from the final destination.

Another evaluation of AODV and OLSR in realistic urban traffic environment is done in [11]. In order to model the realistic vehicular motion patterns, Vehicular Mobility Model (VMM) is used. The proposed model is able to closely reflect spatial and temporal correlations amongst cars, and between cars and urban obstacles. The results showed that OLSR is able to outperform AODV in any condition and for almost all studied metrics. Furthermore, AODV delivers more data packets than OLSR after a certain nodes density and data traffic rate. A similar results has been reached by authors of [12]. They studied the topology based routing protocols by varying the velocity of vehicles and then comparing their performances with respect to throughput, packet delivery ratio and normalized routing load during communication.

In [13], the authors compared the topology based routing protocols in vehicular network on the basis performance metric in two standards of two mac protocols (IEEE802.11 and IEEE802.11p). Another comparison between AODV and OLSR performed through the ORBIT indoor testbed was presented in [14]. Authors use MAC level filtering to block the connection between two neighbors. Evjola et all. presented in [15] a performance comparison of AODV, DSDV, and OLSR for their usage in the safety applications. Authors in [16] used random and Open Street real map topologies and then analyze the performance of AODV, DSDV and DSR with different mobility models. The results showed that the reactive protocols outperform the proactive ones. Furthermore, AODV presents the best performance in the random as well as the real map with different mobility models characteristics.

To complement communication and routing protocols for vehicular communications, studies were conducted on performance evaluations of mobility models in urban traffic or highway traffic conditions [7], [11], [16] and on comparing different MAC protocols. Generally, all of these studies concluded that in topology-based routing protocols, reactive routing protocols perform better than proactive routing protocols. However, their mobility models were quite limited and some of them cannot be applied to simulation of vehicular networks (such as the Random Way-point mobility model). Hence, the mobility model limited the scope of the presented results. Furthermore, these studies model the transmission range by a perfect circle around each transmitter, which is absolutely wrong especially in urban environments. Finally, they did not consider the propagation model simultaneously with the mobility model under realistic urban traffic configurations in performance evaluations. Accordingly, we analyze in this work the performances of AODV, DSR and OLSR considering a realistic mobility model and obstacles in signal propagation model.

III. Background

Both mobility and radio propagation models can significantly affect simulation results. For good results, it is important that the simulated model is as close to reality as possible. In fact, for our performance comparison study, we consider a simulation environment representing a real-city map with its terrain characteristics and urban infrastructures. We shortly address both propagation and mobility models in the rest of this section. We present the validation and the simulation of both mobility and propagation models under realistic conditions.

A. Mobility model: V-MBMM

The mobility model V-MBMM (Vehicular Mask-based Mobility Model) [17], simulates vehicles movements in an urban environment. The considered graph in V-MBMM is extracted from a real map. In fact, edges correspond to road segments and vertices to the connections between these segments. The roads are bidirectional and the intersections are regulated by means of traffic lights. Two coefficients that take into account roads congestion and vehicle previous movements are defined in the model; they are applied to the Markov chain in order to make the displacements more realistic.

Fig. 1: Mobility of vehicles

In V-MBMM vehicles displacement are determined based on survey data and information on terrain characteristic and urban infrastructure describing the zones attractivity. Hence, the area is divided into square cells, each characterized by the types of structure located in the cell, cell altitude and cell attraction power for vehicles. Information varies continuously during the day and is added to the road topology by assigning dynamic attraction powers to all roads.

V-MBMM is tested under an application written in C++ which represents the city of Belfort in the northeastern France. Figure 1 shows an example of the mobility of vehicles on the subarea of the map of Belfort downtown. Several data are used to reproduce the real environment including GIS shapfiles representing the map of the city, survey data and socio-economical information.

The originality of this proposed model is that, as in real life, the path taken by a vehicle to reach some destination is not necessarily the shortest path. It is also capable of modeling detailed vehicular movements in different traffic conditions.

B. *Propagation model: V-PROPAG*

The proposed model, named V-PROPAG [18], determines the received signal power according to the type and the density of obstacles encountered by the radio waves. In fact, this model takes into account the terrain characteristics and defines three terrain categories according to the type and density of obstacles (building, forest, mountain, etc) present in the environment. Then, the received signal power is determined according to the category of terrain located between the transmitting and receiving antennas. The city map is divided into equally-sized cells, each characterized by information representing its ability to attract vehicles, its altitude and type of structure located in the cell. Figure 2 presents the signal propagation of each antenna determined by V-PROPAG, each color corresponding to vehicle coverage area.

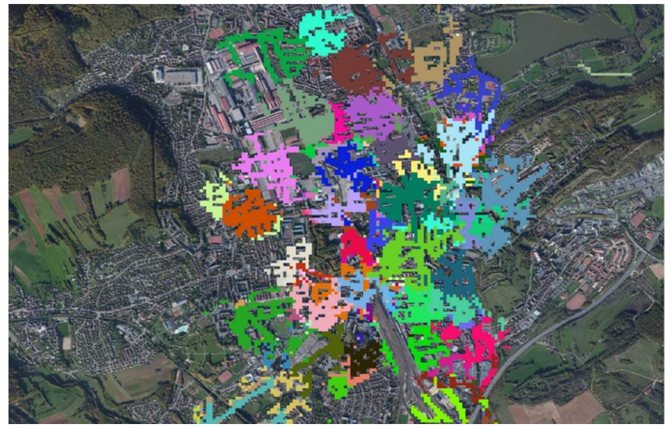

Fig. 2: Coverage area of vehicles

The mobility and the propagation models have been integrated to the application of figure 1 by considering only those cells that are roads. In other words, the mobility is restricted to road cells and the path loss is only computed for those cells but it takes into account all obstacles between transmitters and receivers even outside the roads.

We calibrated the model parameters to meet the physical layer specifications of the standard dedicated to inter-vehicular communication, 802.11p. We studied the radio connectivity for a vehicular network in realistic city environment and evaluate the impact of obstacles on information dissemination in vehicular network.

IV. Simulations and results

Now, our effort is twofold: validate the proposed models and show their influence on a safety service simulation which will be discussed in the next section. Hereafter, we start with the validation stage. To do this, we studied the performance of the most popular routing protocols AODV, DSR and OLSR in the context of V-MBMM and V-PROPAG models presented in [17] and [18]. We considered a real-world environment that is Belfort downtown. The area is divided into equally-sized cells of $25m \times 25m$. Each cell is characterized by specific information describing its attraction weight for vehicles, its altitude and the terrain characteristics. The mobility and the propagation have been integrated to our platform (C++ application): the mobility is determined by simulation of a geographic zone of $2500m \times 2500m$ for a time period between twelve and twelve fifteen pm and a density of 100, 150 and 200 vehicles. The mobility is restricted to road cells. Traces describing vehicles displacements in Belfort are generated from our application and used as movement scenario files in NS2. The path loss is calculated only for road cells; obstacles between transmitters and receivers, even outside the roads, are taken into account.

In order to show the advantages and the drawbacks of the mechanisms used by the routing protocols, we conducted several series of tests. We have considered three types of network where we varied the density of nodes: sparse network with 100 vehicles, moderate network with 150 vehicles and dense network with 200 vehicles. We also varied the number of data traffic sources from 5% to 20%. The transmitted data is of CBR type. Four metrics were estimated: the routing overload, the delivery ratio, the hop number and the average end-to-end delay.

A. Simulation Parameters

The simulations were realized considering a real-world area of $2500m \times 2500m$ and two propagation models. The first one, TRG (TwoRayGround), assumes an unobstructed flat space and represents the transmission range of each node by a circle of $200m$ radius. The second one, V-PROPAG model, takes into account the obstacles effect on radio signals. The duration of each scenario is $300s$. All presented results are an average of five runs. The parameters are summarized in Table I.

TABLE I: Simulation parameters

Parameter	Value
Simulations duration	300s
Area size	$2500m \times 2500m$
Number of vehicles	100, 150 and 200
Number of CBR sources	5%, 10%, 15% and 20% of nodes.
Inter packet arrival time	0.5s
Packets size	512 bytes
OLSR HELLO interval	2s
OLSR TC interval	5s
Transmission range	$200m$

B. Routing Overload

The first analyzed metric represents the number of control packets transmitted over the network. The packet retransmission is included in the calculus. Figures 3(a), 3(b) and 3(c) represent the number of control packets transmitted and forwarded in the network. The number of control packets generated with DSR in the case of TRG being very high with regard to others, the values represented on the graphs are obtained from the initial values divided by 5 ($\frac{DSR-TRG}{5}$).

The control traffic in OLSR being independent from the data traffic, the number of transmitted packets is almost constant for every density. The control traffic increases as the node density raises. Consequently, the higher is the node density, the higher is the number of HELLO and TC (topology control) packets and the better is the network connectivity, thus enabling more retransmission of TC packets. This is also the reason why the control traffic in OLSR is higher in TRG compared to V-PROPAG, TRG connectivity being well above.

The control traffic ratio registered with AODV and DSR based on V-PROPAG model increases with the data sources number regardless the node density. This is due to the Route REQuest (RREQ) packets broadcasted just before sending data packets. RREQ packets are generated proportionally to the number of nodes. At the same time, the traffic raises since the data sources increase; enhancing the network connectivity

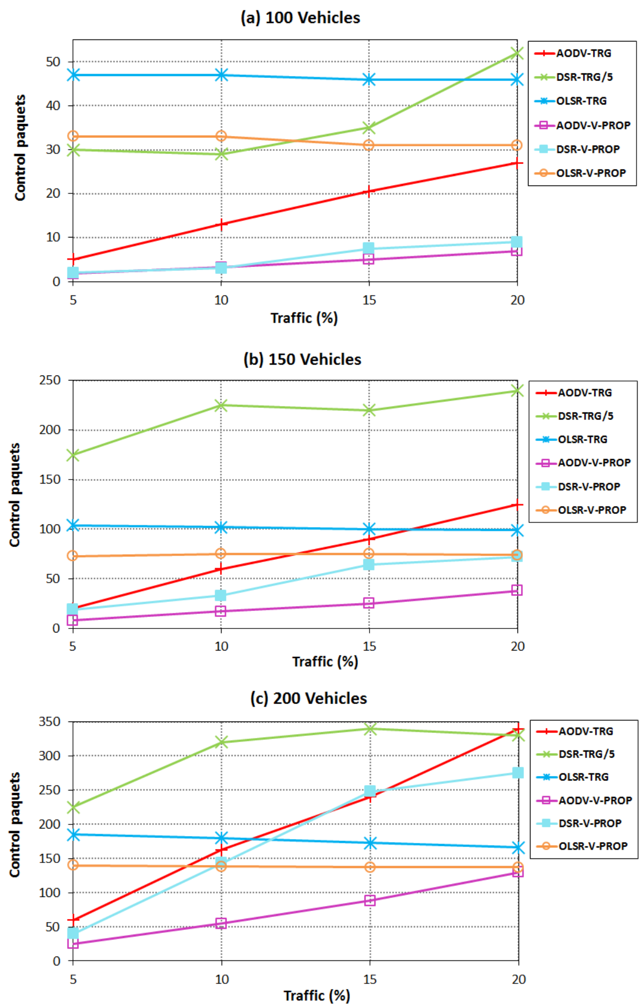

Fig. 3: Routing Overloads vs. Percentage of CBR traffic sources

allows more retransmission of RREQ packets. With an over-estimated connectivity, the mean number of control packets increases significantly with TRG compared to V-PROPAG notably in DSR: the control traffic is 12 times higher with DSR and 3 times higher with AODV.

With V-PROPAG and sparse network, AODV and DSR generate almost the same number of control packets, which is lower than that of the OLSR. In reactive protocols, control packets are generated on-demand only and given that the sources number is small and given that the connectivity in the network is low, few RREQ packets are generated and transmitted. With a moderate network, control traffic with OLSR is generated periodically even if there is no data to be sent by the nodes. In this case, the number of control packets generated with OLSR is higher than with AODV and DSR. As far DSR prioritizes the control traffic, thus the number of generated packets grows more quickly with the increase of the sources data compared with AODV. DSR and OLSR present the same number of control packets with 20% of source nodes.

With a dense network, AODV registers the lowest values and DSR generates much more packets than OLSR as soon as the sources percentage exceeds 10%.

With TRG, AODV generates less packets when the network connectivity is low and the data sources number is small. From 17% of sources in case of moderate network and 12% in case of dense network, the control traffic becomes more important than in OLSR due to multiple generations and retransmissions of RREQ packets. The control traffic in DSR is clearly higher whatever the data traffic ratio because of the priority assigned to the control packets.

C. Delivery ratio

The second analyzed metric represents the data packets ratio received by the destination nodes, which is the rate between the data packets received by the destination nodes and the data packets sent by the source nodes. Figures 4(a), 4(b) and 4(c) show the packets delivery rates obtained with all three protocols. For a density of 100 vehicles, the packets delivery ratios of every protocol are clearly higher with TRG compared to V-PROPAG. By ignoring the effect of the obstacles on the signals propagation, TRG assumes a better network connectivity, which offers more probability to establish multi-hop communications. AODV presents the best results because it discovers more routes followed by DSR then OLSR. With V-PROPAG, since the network connectivity is lower, the routes discovery failures are more frequent. As DSR is more tolerant in the problem of routes discovery, it registers better results than AODV. By buffering data packets for which the route discovery failed, DSR offers more chance to those packets to be transmitted; on the contrary, AODV deletes all the pending data packets immediately.

With TRG, the packets delivery ratio in DSR begins to decline from a density of 150 vehicles because of the important volume of the generated control traffic. This causes the network overhead, prevents the routes discovery and penalizes the data transmission. The best rates are obtained with AODV then by OLSR. By considering all the parameters, which affect the quality of the signals, V-PROPAG presents very different results. Vehicular communications are prone to volatile network connectivity and network partitioning, such phenomena lead to routes break and routes discovery failures are frequent. By generating more control packets, by keeping more than one route in the routing table of every node and by keeping the data in case of route discovery failure, DSR offers better results than AODV and OLSR. Obtained ratios for DSR with V-PROPAG and densities of 150 and 200 vehicles, were even higher to those registered with TRG.

D. Hop number

The third metric we analyzed represents the number of relay nodes through which the packets transit before reaching their final destination. The figures 5(a), 5(b) and 5(c) show the average nodes number crossed by the data packets and received by the destination nodes. Whatever is the nodes density, the routes used with OLSR have the lowest hops number that

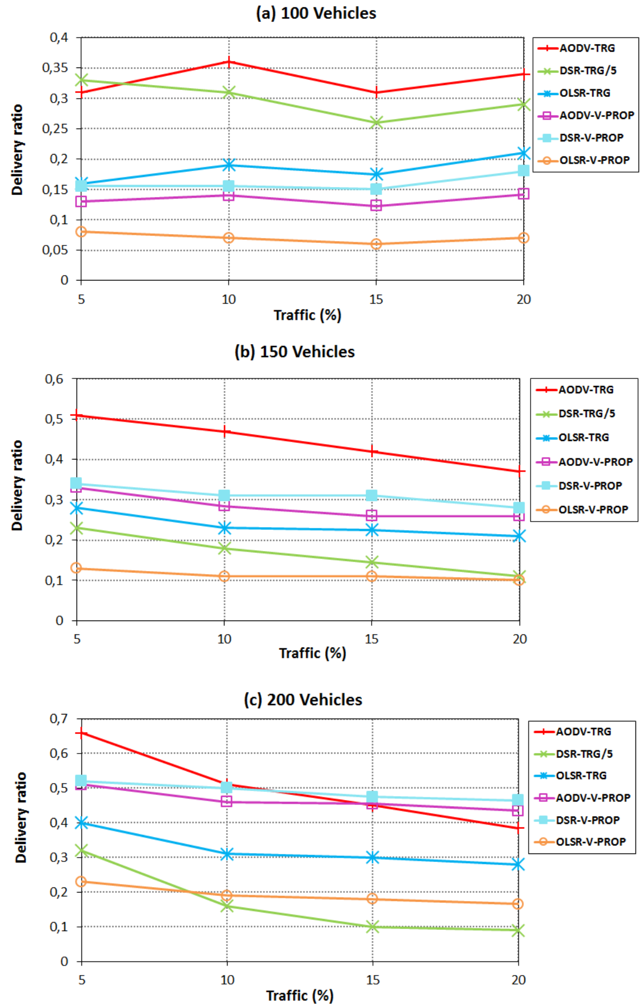

Fig. 4: Delivery ratio vs. Percentage of CBR traffic sources

does not exceed 3. Nodes using OLSR discover practically all the two-hop routes from the HELLO messages and all the routes having more than two hops from the TC messages. The sending frequency of the HELLO packets being higher than the one for TC packets, the two-hop routes have more probability to be valid during the data packets delivery. The hop number is lower with V-PROPAG because of the low connectivity of the network.

For all nodes densities, the hop number for AODV and DSR, obtained with V-PROPAG, is almost the same. With TRG, the hop number for DSR becomes lower than the one for AODV whenever the source nodes percentage exceeds 10 or the number of vehicles is important. The significant control traffic load in DSR prevents the discovery of multi-hop routes. Indeed, the hop number decreases with the increase of the density, 150 and 200 vehicles, even though the network connectivity is better. It is AODV who allows the nodes to better discover multi-hop routes. The mean length of the routes is about 6 for a population of 150 vehicles. However, the hop number for AODV decreases with the increase of the number

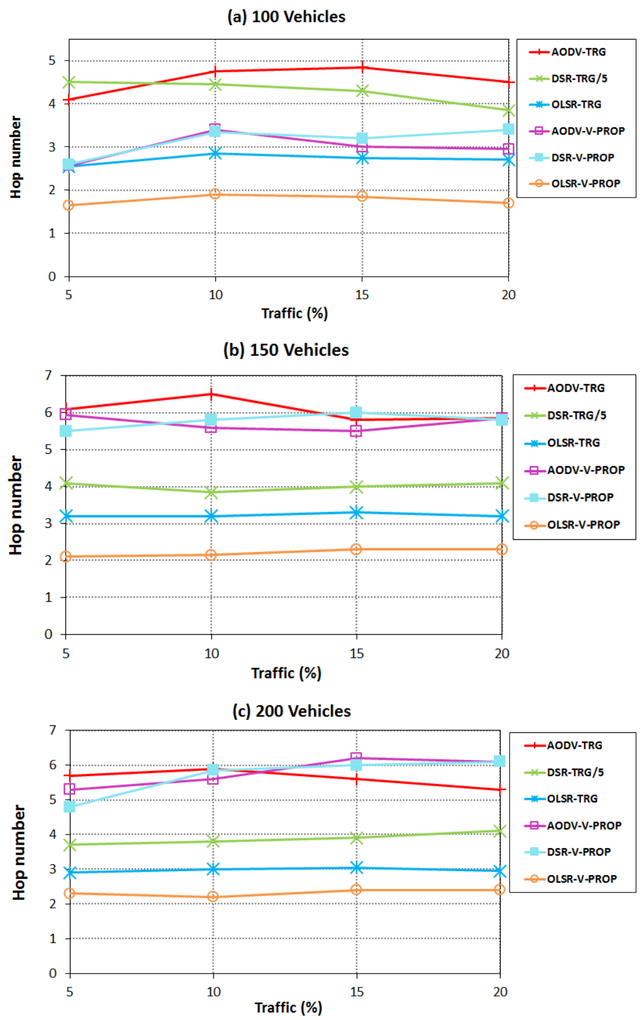

Fig. 5: Hop number vs. Percentage of CBR traffic sources

of source nodes, from 10% for both densities, 150 and 200 vehicles. As for DSR, this is due to the overload in control traffic that prevents the multi-hop routes discovery.

When using V-PROPAG with both densities of 150 and 200 vehicles, the average hop number in AODV and DSR is 6. Despite the low connectivity compared with TRG, both protocols take advantage of the low overload of the control traffic, which releases the channel and allows the discovery of multi-hop routes.

E. Average end-to-end delay

The fourth metric we analyzed represents the average difference of time between the data packet emission by the source node and its receiving by the destination node. Figures 6(a), 6(b) and 6(c) show that the registered delays for OLSR, with both TRG and V-PROPAG, are very low and do not exceed 0,1s. This is due to the OLSR specific functionality. Firstly, as a proactive protocol, OLSR does not initiate any route discovery when sending data packets. Data is transmitted directly if a route exists, otherwise the data is deleted. Secondly, data packets will pass through a lower intermediate nodes number compared with AODV and DSR as shown previously.

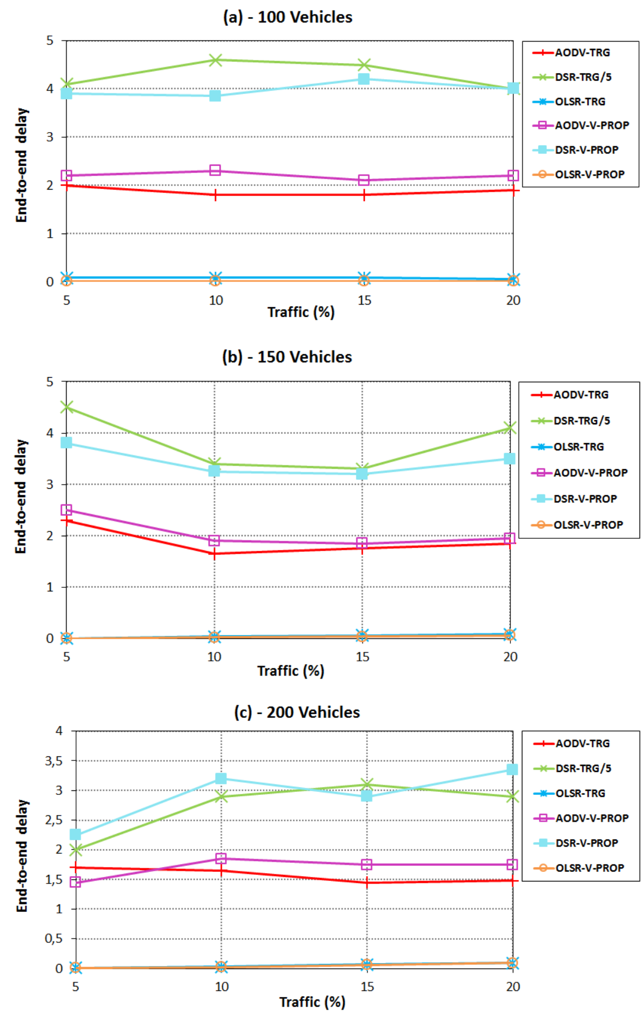

Fig. 6: Average delay vs. Percentage of CBR traffic sources

The transmission delays obtained with each of the protocols AODV and DSR is almost the same for both propagation models TRG and V-PROPAG. The registered values are higher in DSR compared with AODV due to the additional delay when data packets are queued in case of routes discovery failure.

With this metrics analysis, we can come to the following conclusions. The performance of the proactive routing protocols depends essentially on the network connectivity and on the topological modification frequency. Since the network connectivity is unstable, the link duration of the neighboring nodes is low. Since the network topology is always changing, the information from TC packets obsolete very quickly. However, if the control packets overload is increased, the network performance is degraded and the network communications are disrupted. Subsequently, using proactive protocols is not recommended for vehicular communications where the network is very dynamic.

Among the mechanisms used by the reactive routing protocols, the most important one is the routes discovery. The results showed that the routes discovery mechanism and the response of the protocol facing a routes discovery failure are the dominant factors of the reactive protocols performances. In case of a sparse network, the network performances decline. This is due to the lack of links between nodes that prevents multi-hop routes. A store-carry-forward technique could be used. However, this depends totally on the applications type: is the transmitted data tolerant to delay?

In case of moderate to dense networks, the performances are better due to better network connectivity. For instance, DSR offers the best packets delivery ratios. As for AODV, the packets delivery ratios are close to those of DSR, but the end-to-end delays and the control traffic are lowest. Since AODV generates less control traffic packets, the protocol is quickly able to determine routes and then forwards more data.

V. Road safety application: alert message broadcast

As a first step to show the influence of modeling on the simulation results, we considered a simple service which is a road safety application to realize additional tests. An example of popular safety service is the dissemination of information in case of accident. A vehicle, which is involved in an accident, broadcasts a warning message to all vehicles which move towards the accident site. Alert message allows the drivers which are close to the accident site to slow down. A simple protocol is implemented using NS2. This protocol executes, besides usual commands which allow to configure the position and the movement of nodes, a command which asks a node to broadcast at a given time an 'ACCIDENT' message. The traffic type is consistent with a CBR data packets broadcast by the node involved in the accident, with a frequency of two packets per second. Then, data packet is propagated step by step in the node neighborhood. Although, this mechanism is not effective, our main goal is to show the interest of modeling realistic propagation of the radio signal. To simulate an accident, we configured the V-MBMM so as to force a vehicle, which is involved in the accident, to stop during the simulation. The vehicle stop into traffic influences the mobility of all the nearby vehicles. Four metrics are measured:

- Delivery ratio, which is the nodes number that receive the information successfully. This is the ratio between simulated nodes number and the nodes number receiving the information.
- Hop number, which is the average nodes number that relay the data packet before it is received by the destination node. Only the first copy of data packet received by each node is considered in the calculation.
- Delivery delay which is the average of the differences between the reception time of the first copy of the packet by every destination node and its sending time by the node involved in the accident.
- Mean distance, which is the average distance from the accident site at which nodes received the first copy of the data packet.

The tests are realized with both models V-PROPAG and TRG by varying nodes number between 40 and 100. The simulation duration is set to 300s, the area of simulation is about 2km squared, all the other parameters are in the same conditions as described previously in Table I. Figure 7 shows the metrics values registered with both TRG and V-PROPAG. The graphs show that TRG being more optimistic on the radio coverage with obstacles, it leads to better results compared with V-PROPAG whatever is the nodes density. With 40 nodes, in spite of low density, almost 60% of vehicles receive the message alert as shown in Figure 7(a). This rate grows with the density increase to reach 90% when the vehicles number is 100. With V-PROPAG the rates are almost divided by two. Because of obstacles, only 38% of vehicles are alerted when the density is 40 nodes and 45% with a density of 100 nodes. The same observation can be made for the other metrics. Figure 7(b) shows that with TRG the average routes length through which packets transit when the density is 100 vehicles, is 7,8 against only 4 with V-PROPAG. The reason being that TRG underestimate the network partitioning problem by supposing a proper connectivity. Figure 7(d) shows that for TRG packets arrive at an average distance of 800m from the accident site against 450m for V-PROPAG. Finally, Figure 7(c) shows that the alert messages arrive earlier at the drivers with TRG because it is more likely to find faster the route towards every node. On all the results, we observe that TRG overestimates from 30% to 50% the service performance.

VI. Conclusion

Our study focused on the influence of a realistic modeling on the performance of vehicular communications. The analysis was realized with a network simulator that exploits the traces provided by a realistic mobility model, V-MBMM, which takes into account the spatio-temporal characteristics of the environment and a realistic propagation model, V-PROPAG, which considers the surrounding obstacles. The study was conducted in a real-world environment and relied on two propagation models, one optimistic, TRG, that assumes an unobstructed flat environment and another one, V-PROPAG, that takes into account the impact of obstacles on radio waves. The major result of this analysis is highlighting the impact of the radio propagation models on the results of the simulation. Indeed, the obtained results differ from one model to another and the performances can completely be reversed. This is the case of DSR that, with TRG, presents the lowest delivery ratios while with V-PROPAG, which is a more realistic model, registers the best ratios. Relying on simplistic propagation models results in misleading conclusions since they overestimate the received signal strength resulting in an overestimated connectivity graph. This observation is also confirmed with performances study of a safety service.

In the design of topology-based routing protocols, the network is supposed to be sufficiently interconnected to allow

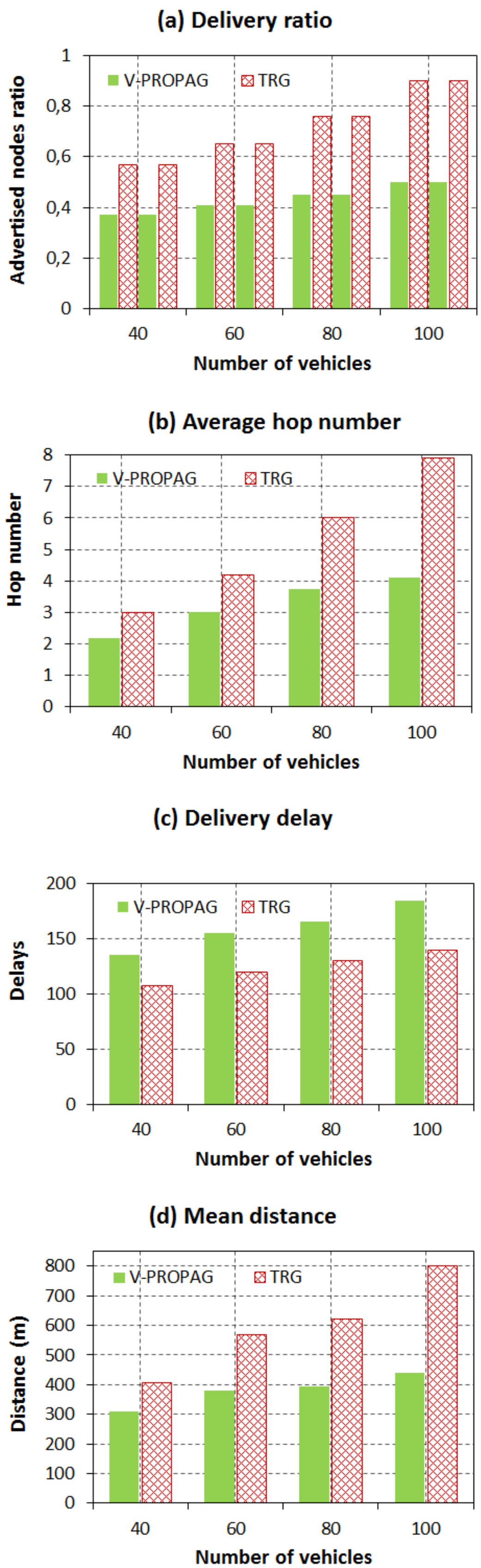

Fig. 7: Safety service performance

end-to-end communications between any pair of nodes. Protocols do not take into account one of the major problems of the vehicular communications which is the network partitioning. The use of a mechanism similar to store-carry-forward and the consideration of some additional information about the link state as well as their variation could lead to better performances. In further work, more in depth analysis must be realized based on different traffic scenarios.

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