Delay-Based Strategy for Safety Message Dissemination in Vehicular Ad Hoc Networks: Slotted or Continuous?

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***Abstract*—The diversity of applications' types in Vehicular Ad hoc NETworks (VANETs) has spawned a large variety of messages that need to be efficiently disseminated between connected vehicles. The most critical messages are those dedicated for safety applications such as road hazardous warning, signal violation warning, etc. The dissemination of this sort of messages is considered as a challenging task in mobile networks where the topology changes dynamically. Indeed, transmitted messages should achieve a high data reachability within a limited transmission delay and an acceptable overhead in a Vehicle to Vehicle (V2V) communication mode. In this work, we focus on a special type of data dissemination protocols based on the delay strategy. The purpose of this paper is to compare two basic distinguished techniques, namely the slotted technique and the continuous technique, and study in depth their impact on the data dissemination performance. A proper selection of the convenient technique according to the application's requirements is consequently deduced. For a faithful and rigorous study, simulations are performed by means of ns-3 simulator under a realistic VANET environment in terms of map layout, mobility pattern and radio model. Simulation results show that contrary to the theoretical reflection, slotted technique is approved as the most appropriate one for safety message dissemination. This technique achieves the same packet data ratio and redundancy ratio, compared to the continuous one, while reducing the data transmission delay.**

Keywords*—Vehicular Ad hoc Networks, Broadcast storm, Slotted delay-based technique, Continuous delay-based technique, Data Dissemination, Vehicles to Vehicle Communication.

I. Introduction

Vehicular Ad-hoc Networks (VANETs) are emerging as new prominent technologies that have a great impact on the new concept known as Internet of Vehicles (IoV) and improve the efficiency and the safety of intelligent transportation systems (ITSs). Composed of mobile vehicles connected via wireless links, VANETs may support a wide variety of applications ranging from safety and traffic management to generalized infotainment and entertainment applications [1].

In order to ensure all these applications a wide variety of messages need to be efficiently disseminated between vehicles. Considering the wireless environment of VANET, where nodes are in a high mobility and the topology changes dynamically, these messages are typically disseminated through a broadcast technique. However, this technique suffers from the so called "Broadcast Storm" problem [2] in a dense network. The medium occupancy is increased due to an excessive amount of redundant messages which results in serious contention and collisions.

In this context, several dissemination protocols have been proposed to overcome this problem. Their main purpose is to reduce the number of excessive transmissions by reducing the number of forwarding nodes. These protocols may be classified into different categories and according to different criteria. Based on the forwarders selection metric, we mainly distinguish the delay-based protocols, probability-based protocols, and deterministic protocols.

In the current paper, we focus on the well known category of protocols based on the time delay strategy. Two main techniques are distinguished within this category, denoted slotted technique and continuous technique. To the best of our knowledge, no prior work has evaluated and compared these two techniques within the vehicular environment. Therefore, we aim in this work to thoroughly investigate their design, compare their performance efficiency, and conclude their convenience to the data dissemination in VANET. In particular, we attempt to study the impact of each technique on the performance of a "Redundancy-based Protocol (RBP)" [3], that combines a delay-based strategy with a probability-based strategy, and then deduce the most appropriate technique. To this end, three versions of the RBP protocol are proposed. In each version we alter the delay strategy by the studied technique and combine it with the probability-based strategy. The originality of such protocol relies on the design of the probability of broadcast. Indeed, RBP implicitly takes into account the surrounding vehicles density, in a beaconless manner where no message exchange among neighbors is needed. Thanks to a particular defined metric, called "Redundancy Ratio", each vehicle is able to locally determine its possibility of broadcast with regard to the network state. However, this latter strategy remains inefficient if no transmission scheduling is planned. Therefore, an accurate delay-based technique selection should be performed.

The remainder of this paper is organized as follows. In Section II, we report previous works from each delay-based technique. Section III is dedicated to thoroughly describe the principle of each technique and theoretically compare their transmission delay. In section IV, we present the simulation environment and we discuss the performance evaluation. At the end, concluding remarks and future works are presented in Section V.

II. Related Works

Various solutions have been proposed in the literature to overcome the Broadcast Storm problem. Among these solutions we mainly point out the protocols' category which is based on the time delay strategy. The basic idea behind this strategy is to reduce the number of relaying nodes by scheduling their upcoming transmissions. Therefore, as opposed to the blind flooding strategy, each receiver must wait a period of time before reforwarding. Different waiting times are assigned to each node. This timer is canceled by a vehicle upon the reception of the same message. As a result, only few vehicles perform their transmissions after the timer expiration. The main concern of such category lies in how to define the appropriate waiting time, i.e., according to which criteria and based on which technique. Through some presented reviews [4][5], we may distinguish two time assignment techniques, namely the slotted technique and the continuous technique.

Most of researchers build their broadcast protocol on slotted delay based technique [6]–[11]. In [6], the authors propose the basic slotted technique, denoted Slotted 1-persistence protocol (S1PD). According to this technique the sender transmission range R is divided into N_{st} segments. All vehicles belonging to the same segment are assigned to the same waiting time. The criteria considered in the defined timer, presented in Eq. 1, is the distance D_{ij} between the transmitter i and the receiver j. The longer the distance, the shorter the waiting period. Thus, distant vehicles have more chance to relay message further in the network than near ones. Notice that the waiting time within a segment is a multiple of δ, which is a period of time larger than one hop delay including medium access delay and propagation delay.

$$W_t = \left\lfloor N_{st} * (1 - \frac{min(D_{ij}, R)}{R}) \right\rfloor * \delta \tag{1}$$

Based on this protocol, authors in [7] propose a sophisticated slotted waiting timer leading to an "Optimized S1PD" (OS1PD) protocol. Adding to the distance separating the transmitter and the receiver, the timer design takes into account the receiver moving direction toward the message dissemination direction. Therefore, vehicles moving in the same direction as that of the message dissemination have more priority to reforward their messages, unlike vehicles moving in the opposite direction. Thus, they are assigned to lower segment number, i.e., shorter timer. Moreover, they have tackled the synchronization problem between vehicles within the same segment by adding a micro delay μ to the waiting time W_t, which is defined as follows:

$$W_t = \begin{cases} \lfloor N_{st} * (1 - P_{D_{ij}}) \rfloor * \delta + \mu & if \quad V_{dir} = M_{dir} \\ \lfloor N_{st} * (2 - P_{D_{ij}}) \rfloor * \delta + \mu & if \quad V_{dir} \neq M_{dir} \end{cases} \tag{2}$$

where $P_{D_{ij}}$ is the ratio between D_{ij} and R, as defined in Eq. 3. V_{dir} and M_{dir} represent the vehicle direction and the high direction priority of the message dissemination, respectively.

$$P_{D_{ij}} = \frac{min(D_{ij}, R)}{R} \tag{3}$$

In [8], the authors enhanced the aforementioned timer design and proposed a new broadcast scheme called "Distributed Optimized Time" (DOT) slot. The contribution of this work, is that it takes into account the surrounding vehicles' density to determine the number of vehicles assigned to a single segment. Thus, the number of segments is no longer a predefined parameter but a function of the vehicles' density in vicinity. More the vehicles' density is high more the segments' number, within the transmission range, is high. Simulation results, have confirmed that DOT outperforms S1PD and OS1PD under different networks' density. However, in order to ensure this feature, a periodic safety beacon exchange between 1-hop neighbors is required. This obviously leads to a messaging overhead and probably collisions problems in dense network. Still on the basis of the delay slotted technique, authors in [3], [10] and [11] succeed to propose efficient data dissemination protocols, that takes into account the vehicles' density parameter by applying beacon-free design.

From another side, only few works have adopted the continuous strategy. As opposed to the slotted strategy, the waiting time is continuously assigned to each receiver. In [12], the authors propose a delay-based data dissemination protocol that applies the basic design of the continuous technique. In such technique, the waiting time W_t for each node is linearly inversely proportional to the distance D_{ij} separating the sending node i and the receiver j. This waiting time is represented by the following equation:

$$W_t = -a * D_{ij} + c \tag{4}$$

where a and c are constant parameters.

In [13], the authors propose a continuous delay-based technique, called "Inter-Vehicle Geocast" (IVG) where a non linear waiting time is defined, as presented in Eq.5:

$$W_t = T_{max} * \frac{R^\beta - D_{ij}^\beta}{R^\beta} \tag{5}$$

T_{max} denotes the maximum delay that a node should wait. β is a critical parameter that has a great impact on the waiting time curve and then on the timer values' distribution, i.e., W_t more or less close. In attempt to generate a uniform waiting time between [0, T_{max}], authors suggest to settle β = 2.

On the basis of this work, authors in [14] introduce a probabilistic rebroadcast scheme, called "probabilistic Inter-Vehicle Geocast" (p-IVG) that depends on the surrounding vehicles' density. In this work, authors are convinced that the continuous technique presents better performance than the slotted one. They argue this choice by the fact that, the node transmission in the slotted technique is restricted to be initiated at certain defined times (time-slot) which leads to channel contention. Whereas, by applying continuous strategy nodes are able to perform their transmissions in different times. Even this fact is true, many researchers are entirely convinced that the slotted delay technique is an efficient way to achieve high data broadcast performance. Overall, we find that if the efficiency of each scheme is proven, none can conclude which

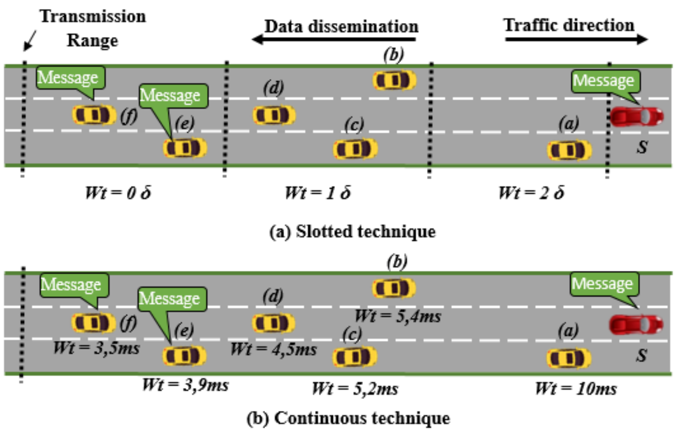


Fig. 1. Example of delay-based techniques

technique is in reality better than the other. For this reason, we definitely believe that a comparative study between the slotted and the continuous techniques should be conducted in order to reveal the strength and the weakness of each one. As a result, we become able to rigorously choose the appropriate technique for safety message dissemination.

III. Delay based-protocol techniques : Principles and characteristics

In this section, we aim to describe in detail the principle of each technique and depict their distinctive features. In order to make it simple we propose the following example, illustrated in Fig. 1. Let's consider S a source node that has detected a dangerous condition and thus started sending a warning message. We assume that the transmission range is configured to reach 300 m. Upon the reception of the warning message, each node holds the message for a period of time, called Waiting Time Wt, before rebroadcasting it. The calculation of such timer depends on the deployed technique.

A. Slotted technique

According to the slotted strategy, the transmission range of the sender is divided into a fixed number of segments. In our example, presented in Fig. 1.a, we assume that the number of segments is 3, i.e., one segment per 100 m. All vehicles within the same segment are assigned to the same waiting time which is multiple of δ. Generally, the distance separating the transmitter and the receiver position is the typical parameter taken into account for the timer computation. More the distance is higher, more the waiting time is shorter. Therefore, vehicle (e) and (f) immediately send the message, whereas vehicles (b), (c) and (d) wait for 1δ and (a) for 2δ, knowing that the δ value is more than twice 1-hop delay. Thereby, nodes belonging to different segments have enough time to receive the message sent from the last segment before their waiting time expires. Once vehicles (a), (b), (c) and (d) receive the same message, they cancel their transmissions. In this way, the number of transmitters is efficiently reduced. Notice that, in this example the transmissions of nodes (e) and (f) do not collide due to the backoff mechanism. Nevertheless, if we consider a dense network, the number of vehicles within the same segment is then increased which results in high collisions between nodes that attempt to simultaneously send their messages. Based on the delay slotted principle description we can deduce the following characteristics:

- two vehicles belonging to different segments have enough time to receive message from each other even when they are close (e.g., nodes (d) and (e)),
- the slotted technique guarantees a certain amount of message redundancy to overcome the lost messages due to the VANET environment (e.g., nodes (e) and (f)),
- given a dense network, high collisions are expected between vehicles within the same segment.

B. Continuous technique

Based on such technique, the waiting time is continuously assigned to each receiving vehicle according to its distance from the sending vehicle. Generally, the farthest node is assigned to the shortest timer to enhance the data propagation farther in the message direction. By this way, each vehicle is assigned to a different waiting time. Based on the same example, illustrated in Fig. 1.b, we notice that node (f) is theoretically selected as a relaying node, which may significantly reduce the number of forwarders, since it is assigned to the shortest waiting time. However, in reality, this period of time seems insufficient for the message to reach the application layer of neighboring nodes before their timer expiration. This means that for a protocol implemented at the application layer, the difference of waiting times between two close vehicles must be sufficiently great to allow the message reaching the application layer, which is always in progress, before being transmitted to lower layers and cancel its transmission. As a result, both of nodes (e) and (f) are forwarding nodes. At first glance, the continuous technique seems to be the best solution to efficiently reduce the number of forwarders; each vehicles has a different timer from the others. Therefore, it is considered as the appropriate technique to resolve collisions' problems between neighbors vehicles and mitigate the broadcast storm. Nevertheless, a deep investigation in the transmission phases shows that a minimum Time delay T_{min}, discussed below, should be respected between two adjacent nodes to effectively overcome the problem of collisions in dense network. This additional delay will induce an increase of the end-to-end delay. Based on this description we can conclude the following:

- the number of forwarders is significantly reduced,
- the forwarding transmission is not restricted to a certain period of times,
- introducing enough waiting delay may induce to an extra end-to-end delay.

C. Delay assignment investigation

The purpose of this section is to further explain the continuous technique weakness in terms of delay transmission. Thus, for a proper investigation, we illustrate in Fig. 2 the schedule of the different times delay that could be encountered in a typical wireless transmission, performed between two nodes $n1$ and $n2$ using CSMA/CA protocol. Based on this analysis, we become able to precisely determine the period of time that

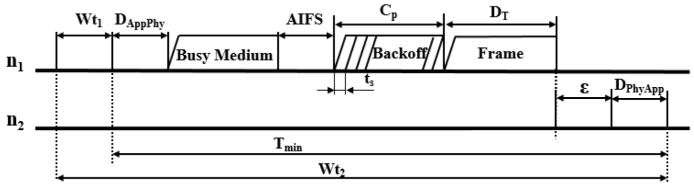


Fig. 2. Typical 1-hop time delay

could influence the waiting time design. As it is shown from the graph, T_{min} can be defined by the following:

$$T_{min} = D_T + \epsilon + D_{AppPhy} + D_{PhyApp} + \theta + AIFS + C_p \quad (6)$$

where D_T is the transmission delay for a packet size, set to 500 bytes at 6 Mbit/s ($D_T = 666\ \mu s$). "ϵ" is the propagation delay upon 100 m ($\epsilon = 0.33\ \mu s$). D_{AppPhy} and D_{PhyApp} are the times delay for the packet reception between the physical layer (wireless card) and the application layer. We assume that they are negligible, as well as the θ which represents the time delay while the medium is busy. As we are considering safety applications, the considered packets have the highest priority and should then wait for an "Arbitration inter-frame spacing" $AIFS = 2 \cdot t_s + SIFS$ where the time slot $t_s = 13\ \mu s$ and the Short Interframe Space $SIFS = 32\ \mu s$ according to the IEEE 802.11p standard [15]. Thereafter, the transmission shall wait for a contention period C_p, randomly selected according to the backoff mechanism within the range [0, CW], where CW is the contention window size ($CW = 15$ in case of broadcast technique). Therefore, for a proper reception of the message from n_1 before the re-forwarding process, the node n_2 shall wait for a total delay $Wt_2 = Wt_1 + T_{min}$. By taking into account T_{min} in Eq. 4, we can notice the impact of such delay on the curve slope. For example, for two close vehicles located 10 m of distance from each other, T_{min} is estimated to 860 μs in the worst case where $C_p = 15$. Hence, a steep slope is induced for a transmission range of 500 m. This leads to increase the end-to-end transmission delay, up to 28 ms over a distance of 500 m, as compared to the slotted technique.

IV. Performance Evaluation

Based on the principle design of each delay-based technique, we are conducted to theoretically compare the performance of the slotted technique with the continuous technique, depict significant features and therefore be aware of the best technique. However, in order to confirm this investigation, simulation experiments are required. We propose, in this section, to thoroughly evaluate and compare the performance of both slotted and continuous techniques under realistic vehicular environment. In particular, we propose to evaluate their impact on the performance of a recent dissemination protocol, called "Redundancy Based Protocol" (RBP). The originality of this protocol is that it enhances the delay scheme performance by applying an efficient probability strategy. Based on redundancy ratio (r) parameter, which is integrated in the broadcast probability (P) defined in Eq. 7, each vehicle is able to determine its ability of broadcast, after the timer expiration, in relation with the surrounding vehicles' density.

$$P = \frac{2}{r} * P_{prev} = \frac{2}{r_{current}} * \frac{2}{r_{prev}} \quad (7)$$

Three RBP versions implemented in this work are:

- RBP-S1PD: the slotted version of the protocol that combines the RBP with the typical slotted protocol (S1PD) proposed in [6].
- RBP-LCD: the linear continuous version of the protocol that combines the RBP with a Linear Continuous Dissemination protocol (LCD) proposed in [12].
- RBP-NLCD: the non-linear continuous version of the protocol that combines the RBP with a Non-Linear Continuous Dissemination protocol (NLCD) [13].

A. Simulation Platform and Parameters

(a) Google Map (b) TIGER Line Map

Fig. 3. "Afton Oaks" Area.

Simulation experiments were performed while assuming the real city map of Afton Oaks in Houston, United States, to carry out a realistic VANET scenario. The topology related to the map shown in Fig. 3, is generated by MOVE using TIGER (Topologically Integrated GEographic Encoding and Referencing) database [16]. The simulated road, in the considered city map, is composed of a set of segments. Each segment is a multi-lane road where the overtaking behavior between vehicles is allowed. The number of lanes and maximum velocity may vary (from 2 up to 6 lanes and from 15 m/s up to 90 m/s, respectively) from one segment to another. Given the traffic lights absence, each segment of the simulated road is characterized by a priority percentage.

The performance evaluation of the selected delay-based technique is carried out through extensive simulations, using NS3.19 [17] simulator, where a full implementation of VANET protocol stack is integrated. For a realistic mobility pattern within the considered map, we generated the traffic using the micro-traffic simulator, called "SUMO - Simulation of Urban Mobility" [18]. We set the bit rate to 6 $Mbit/s$ in the MAC layer. The transmission power is tuned to roughly achieve 500 meters of transmission range while assuming m-Nakagami propagation model. For the delay based techniques, we set δ to 4 ms. We fix the total number of slots N_{st} to 5 (one slot per 100 m). We set the constant a to 0.004 ms and the constant b to 20 ms. We fix T_{max} to 16 ms and β to 2. It should be noticed that, for a proper comparison, all these waiting time parameters are adjusted in a way to guarantee the same data reachability for all the studied versions. For the application scenario, we configure the 5 first vehicles to periodically generate a new message with 500 bytes of size at a frequency of 1Hz. In order to evaluate the RBP versions scalability, we vary the number of the simulated vehicles until 90 vehicles with a maximum

speed defined by the selected road.
For the protocols evaluation we consider the following metrics:

- *Packet Delivery Ratio (PDR):* the average number of original packets successfully received by a vehicle, compared to the total number of generated messages.
- *Redundancy Ratio (R):* the average amount of received messages per one original message.
- *Forwarding Ratio (FR):* the proportion of vehicles in the network that are involved in the rebroadcast of a new packet.
- *End-to-End Delay (E2EDelay):* the average difference between the packet generation time by the source vehicle and the reception time of this packet by the last reached vehicle.

B. Simulation Analysis

As we can notice from Fig. 4(a), the RBP-S1PD and RBP-LCD protocols outperform RBP-NLCD in terms of redundancy ratio. In order to achieve the same amount of packet reachability, Fig. 4(c), as it is achieved by RBP-S1PD and RBP-LCD, the non-linear continuous delay-based technique exhibits more redundant packets and therefore more network resources consumption. This fact, may be explained through Fig. 4(b), where more vehicles are involved in the re-forwarding process of RBP-NLCD protocol, compared to RBP-S1PD and RBP-LCD protocols, especially for low dense networks. On the whole, we can say that the NLCD technique is less reliable than the slotted and the linear continuous techniques. Therefore it is not the best solution to reduce unnecessary transmissions and to overcome the broadcast storm. Moreover, it is clearly noticed, through Fig. 4(d) that the RBP-NLCD protocol induces more end-to-end delay, as compared to the slotted and the linear continuous versions. This result remains the most important one, since it reflects the efficiency of a certain protocol toward safety message dissemination in VANET.

The focus on comparing the slotted and the linear continuous RBP versions leads us to deduce that the slotted technique outperforms the continuous one, since it is able to achieve the same packet delivery ratio in a short transmission delay. Based on Fig. 4(d), the continuous technique presents more end-to-end delay for all amounts of vehicles that operate in the system, compared to slotted one. This delay may reach up to $15\ ms$, which could be critical mostly for message dissemination in dangerous situations, such as hard braking, road accident, hazardous road condition. This result highlights the fact that in continuous design, forwarding-nodes need to wait enough time in order to give the chance to the nearest vehicles to cancel their transmissions, once they receive the same message from their neighbors. Elsewhere, all adjacent vehicles will send the same message at close time which may result in increasing resources' consumption and maybe collisions at a serious redundancy ratio. Overall, the slotted scheme is suitable either for safety applications or for further kinds of applications by saving the network capacity consumption.

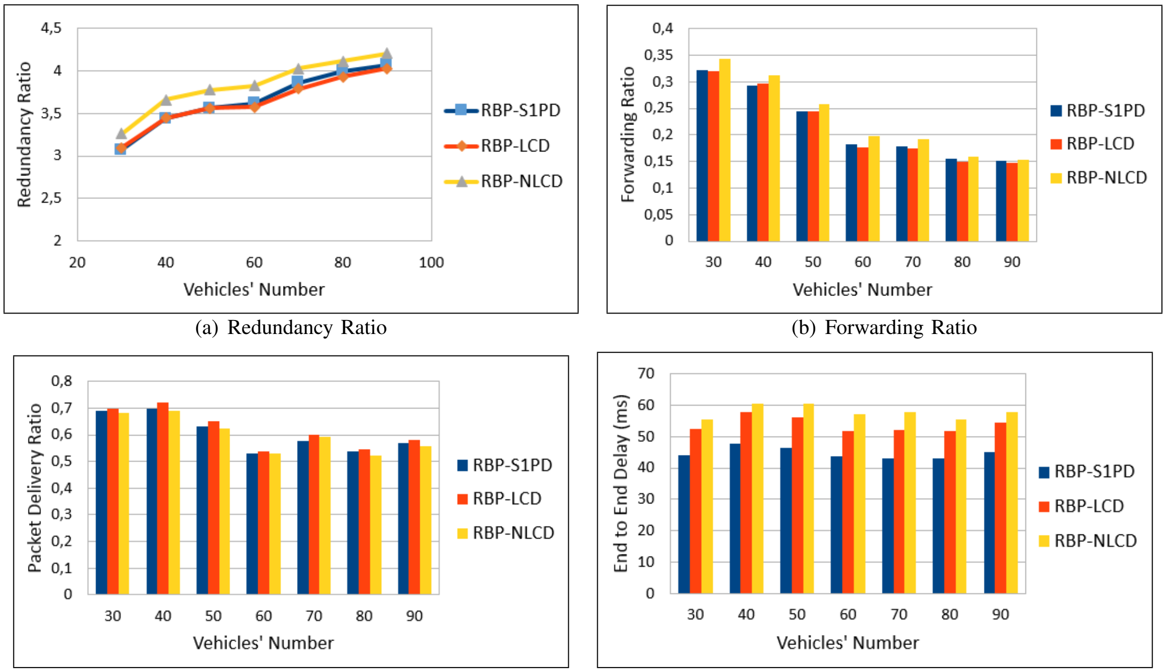
With regard to the simulation environment, it should be noticed that the scenario characteristics has a great impact on the protocol performance evaluation. In prior work presented in [3], RBP protocol has achieved an outstanding performance for safety message dissemination in a simple highway scenario. In short, it has shown i) a high efficiency in terms of data reachability, transmission delay and network resources consumption and ii) a high robustness toward the network scalability. However, under a realistic map as it is presented in this work, RBP reveals its design weakness against the variable speed and direction of the simulated vehicles and therefore against the intermittent connectivity. The reason for which we can explain the data reachability performance of RBP, that does not exceed 70% for all protocol versions, as illustrated in Fig. 4(c). Thus, we can confirm that more the simulation environment is realistic more the data dissemination performance analysis are exhaustive and robust.

Theoretically speaking, we can affirm that the continuous version is more efficient than the slotted technique to alleviate the broadcast storm problem effect. In fact, the number of transmissions is effectively reduced and fewer nodes are chosen as relaying nodes. Whereas in the slotted technique, all vehicles belonging to the furthest segment are chosen as forwarders. Although this prominent property, and as opposed to what was expected, we notice that the continuous technique suffers from a high end-to-end delay in order to achieve the same packet delivery ratio reached by the slotted strategy, as it is depicted in Fig. 4(d) and Fig. 4(c). This observed delay amounts to a steep slope, required in the waiting time calculation. If the waiting times of nearby nodes are not enough spaced, serious collisions' problems may occur, especially in dense network. In fact, as nearby vehicles have not enough time to receive messages from each other to cancel their redundant transmissions, they consequently decide to retransmit their messages almost at the same time. From the other side, under the same condition, the slotted strategy is able to mitigate this problem by assigning enough time space between two close vehicles belonging to different segments. Whereas, vehicles belonging to the same segment are managed through a probability-based strategy, offered by RBP protocol.

Moreover, this delay spanned by the continuous technique, may be a way to overcome the network reliability under a realistic radio model, where the messages are likely to be lost. Therefore, having enough time-space between forwarding nodes leads to decrease collisions and then ensure a certain amount of redundancy which would be able to fill lost messages. However, in the slotted technique, this amount of redundancy is guaranteed through one segment without the need of extra waiting delay.

V. Concluding Remarks

In this work, we propose a comparative study between two delay-based techniques (slotted and continuous techniques). Our focus is to reveal the strength and the weakness of each technique and then to conclude which technique is the most appropriate for safety message dissemination. In particular, our investigation is performed upon an original dissemination protocol denoted "Redundancy based protocol (RBP)". The particularity of such protocol, is that it improves the delay-based technique by combining it with a probabilistic design in order to further overcome the collisions problems.
Simulation results of RBP slotted version outperforms the RBP continuous version under realistic VANET environment. It was shown that compared to the slotted strategy, the continuous



(a) Redundancy Ratio

(b) Forwarding Ratio

(c) PDR

(d) E2E Delay

Fig. 4. Simulation results under various vehicles' number.

strategy reduces the number of forwarders and ensures an acceptable amount of data reachability. But, these benefits are achieved at the cost of the end-to-end dissemination delay throughout the network. Then, the continuous delay-based technique is not convenient for safety applications, where the transmission delay is a crucial metric for the warning messages dissemination.
As a future work, and on the basis of the slotted version, we will try to enhance the RBP performance in a sparse network where the connectivity between vehicles is not constantly guaranteed.

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