Exploiting the Inherent Connectivity of Urban Mobile Backbones Using the P-DSDV Routing Protocol

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***Abstract*—Vehicular ad hoc networks (VANETs) are mobile networks where the communication is established among vehicles (V2V) and/or roadside units (V2I). In these networks, the main challenges of the communication are related to problems of connectivity, and the consequent worsening of the routing protocol's performance by the starting of a new route discovery procedure. Many studies claim that the use of fixed infrastructure with classic routing protocols may provide connectivity and allow the use of VANETs. However, high deployment and maintenance costs in these networks make them unpractical most of the times. In many big cities, public transport buses travel through exclusive lanes with relatively regular schedules. This fact can be used to establish a cheap and reliable wireless communication infrastructure (called MOB-NET). This paper proposes the P-DSDV, a proactive routing protocol which prioritizes the buses of MOB-NET. The P-DSDV considers a route selection metric which takes into account the characteristics of the mobile nodes. Simulation results indicate the benefits of the pair P-DSDV/MOB-NET in networks with low connectivity (density ≤ 60 vehicles/km^2). The average gains obtained were 85% in packet delivery rate and 60% in throughput.**

***Index Terms*—computer simulation, network topology, quality of service, routing protocols, vehicular ad hoc networks.**

I. Introduction

Automobiles are the most used means of transportation by millions of people all around the world. Vehicular ad hoc networks (VANETs) are mobile networks where the communication is established among vehicles and/or roadside units [1]. VANETs are expected to enhance the intelligent transportation system (ITS) and support a gamut of applications ranging from low overhead delay tolerant entertainment applications to safety critical applications such as collision avoidance and traffic management [2].

Many different services have been proposed in the literature using vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. V2V networks are self-organized and self-managed mobile networks with a decentralized control. They are characterized by being built anywhere, because they do not depend on the existence of a fixed infrastructure [3], and allow communications over sequences of vehicles in a multihop fashion [4].

VANETs present a difficult environment for protocol and application design due to their potentially very large scale, the high degree of dynamism they tend to exhibit, and the communication clearly limited by the orientation of the highways or the urban roads [1], [5]. In these networks, the main challenges of the communication are related to problems of connectivity (due to frequent path disruptions caused by vehicles' mobility), and the consequent worsening of the routing protocol's performance by the starting of a new route discovery procedure.

Classical routing protocols for V2V networks are normally classified into two categories: proactive (table driven) and reactive (on demand). The proactive protocols keep information about the network topology continuously updated in their routing tables, independent of the use of stored routes (e.g. DSDV [6]).The reactive protocols do not keep information about routing updated, they discover routes only when an origin node needs to transmit data packets to a destination node (e.g. AODV [7]). Many studies show that the use of fixed infrastructure (normally created by access points or base stations) with classical protocols may provide connectivity and enable the use of VANETs [8-10]. However, high deployment and maintenance costs in these networks makes them unpractical most of the times [11].

In urban environments there are basically private vehicles, heavy transport vehicles, and public transport vehicles (buses). Among these, buses show a different traffic behavior in relation to the other vehicles. In particular, in the public transport system of Curitiba city - Brazil, the buses belonging to the express lines travel through exclusive lanes, according to a relatively regular schedule, in a quasi-linear path practically without obstacles. These lanes are two-way lanes, which allow overtaking maneuvers, and usually connect the main districts to downtown [12]. These characteristics suggest that a system that makes use of these buses to create a communication infrastructure will perform better when compared to a system that does not distinguish between vehicles. These characteristics gave rise to MOB-NET a mobile ad hoc network formed by buses from the public urban transport system [13-14]. MOB-NET has the capacity of providing infrastructure and rising the network connectivity. However, it can be better explored by routing protocols, which must recognize and use the MOB-NET nodes as frequently as possible. This way, this paper proposes the *Priority Destination-Sequenced Distance Vector Routing Protocol* (P-DSDV), a new routing protocol which exploit the

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inherent connectivity of MOB-NET, minimizing the lack of connectivity effects and improving the network performance.

P-DSDV has the ability to build routes considering a cost-benefit decision among two different data, specifically, the number of hops to the destination and the number of buses belonging to the route. In this proactive protocol, the packets travel through routes which have a balance between these two metrics, presenting a better performance this way. Besides, this new protocol contributes significantly for the technology integration among routing protocols and MOB-NET (other protocols tested with MOB-NET are reactive: P-AODV [14] and P-AOMDV [15].

The rest of this paper is organized as follows. Section II gives an overview of related work. Section III describes the new proposed routing protocol. In Section IV, numerical results are discussed, based on simulations carried out with the software NS-2 (2.35). Finally, conclusions and future work are drawn in Section 5.

II. Related Work

To make this paper as self-contained as possible, we now present a succinct survey of works that have addressed connectivity problems in VANETs.

The aim of the work presented in [16] was to understand the causes that make VANETs unconnected. In order to achieve this, it was necessary to analyze the behavior of the vehicles traffic on intersections and two-lane streets. These analyses may help in the project of more efficient routing protocols. The study results indicate that the VANET topological behavior may oscillate between high density (extremely connected network) and low density (unconnected network). The connection problems appear when the density of vehicles is under 60 vehicles/km^2. It was also observed that the VANETs urban networks have a high number of redundant routes, making it more appropriate to use the multipath protocols in these networks. These protocols may also balance the workload among vehicles and prevent network congestions. The mentioned work considered only statistical and numerical results. No simulation results using multi or single path protocols were presented.

The work done in [17] considered a statistical traffic model with data collected in the I-80 Highway, California - USA, and aimed to study parameters for unconnected VANETs, such as network recovery time and the distance between vehicles. The study showed that, depending on the vehicle dispersion, the network recovery may take from some seconds to several minutes. These results can tell whether the present routing protocols work or new ones should be projected, considering that the traditional routing protocols do not tolerate long times for network recovery.

In [18], the authors point out that the greatest challenge for VANETs is the development of routing protocols which consider the frequent disconnections caused by the high mobility of vehicles. Because of that, they proposed a routing protocol that has information about the position, direction and speed of vehicles and a map of the streets as well. In hand of this information, it is possible to foresee a link interruption before it happens. Simulation results show that the protocol can decrease the routing overload and increase the packet delivery rate. However, all the vehicles belonging to the network should have a GPS equipment previously installed, which would make the network dependent on a fixed infrastructure.

The authors in [19] have adapted the AOMDV protocol so that it would be more efficient when applied to VANETs. In addition to preserving the known advantages of AOMDV, such as the time reduction of the route discovery process, some modifications in the way routes are selected were introduced. New metrics were used, such as number of hops to destination and MAC layer retransmissions in order to select the best route. Based on the new routing metric, a cross-layer AOMDV with retransmission counts metric (R-AOMDV) routing protocol is designed to make use of advantages of multi-path routing protocol. This work presented positive results, but it was evaluated only in networks that were pre-configured to guarantee connectivity among vehicles.

In [20], the authors proposed the Traffic Light Aware Routing Protocol (ETAR) for VANETs. This protocol finds the most stable route for exchanging data packets based on traffic lights and vehicles traffic density. With hello packets, it determines the density and connectivity of the vehicles. To deliver data packets to their destinations three steps are used, they are: Path Selection, Greedy Forwarding and Carry and Forward method. Simulation results show that ETAR outperforms AODV and GyTAR protocols in terms of packet delivery rate and End-to End delay.

Quershi et al. [21] proposed the Road Perception Based Geographical Routing Protocol (RPGR) fo VANETs. It considers mid-range node, distance and direction as metrics to select the next hop node in the network. To overcome the disconnection problem it uses a Carry and Forward mechanism. Simulation results show that RPGR outperforms GeoSVR, SDR and GMGR protocols in terms of path lengths.

Based on theorems, the authors in [22], proposed the Minimum Delay Routing Algorithm (MDRA) for selecting the path with the lowest expected delay. Simulation results demonstrate that the proposed MDRA can achieve the delay performance close to the flooding-based Epidemic routing while only a single copy of the message is maintained in the network. However, it is assumed that vehicles are equipped with preloaded digital map applications, which provide the street-level map and near real-time traffic statistics including vehicle density and speed of different road segments.

We note that our proposal does not rely on carry and forward mechanisms, fixed infrastructures, traffic lights, GPS equipment or street maps, being a totally ad-hoc solution.

III. Exploiting the Inherent Connectivity of MOB-NET: The P-DSDV Protocol

The *Priority Destination-Sequenced Distance Vector Routing Protocol* (P-DSDV) is a modification of the DSDV protocol. It was developed to act together with the MOB-NET at the moment when the nodes are discovering the routes, acquiring the capability of building routes by making a cost-benefit decision considering two different data, specifically, the number of hops to destination and the number of buses in the route. In this protocol, the messages are sent by routes that are balanced between those two metrics, presenting a better performance (connectivity and reliability). The modification was made mainly in the route maintenance/updating procedure of the DSDV protocol.

The DSDV is a kind of distance-vector protocol [6], in which sequence numbers are added to it. In the DSDV, the network nodes keep a route table with all the available destinations, the number of hops to reach the destination and the sequence number associated. The sequence number is used to distinguish old routes from new ones, avoiding the formation of loops. The maintenance of route tables is made through the periodical sending of updating messages, informing if there were any changes in the routing tables. When the nodes receive the messages from its neighbors, they compare the sequence number from their own tables. If this number is higher (or, more recent), the updating is made regardless of other parameters. If the numbers are equal, the route with the best metric is used (or, the minimum number of hops to the destination) [6].

Received messages with equal sequence numbers are usual, once all nodes make the distribution of updating messages by broadcast. As it can be perceived in the example in Fig. 1, node D performs the periodical sending of an updating message containing information about its route table. Node H receives the message sent by D firstly through node D, performing after the updating of its routing table, once it has a smaller sequence number stored. Next, D receives the message sent by D through node D; however, in this case the route has not been updated, due to the fact that the updating message has the same sequence number from the previously stored route.

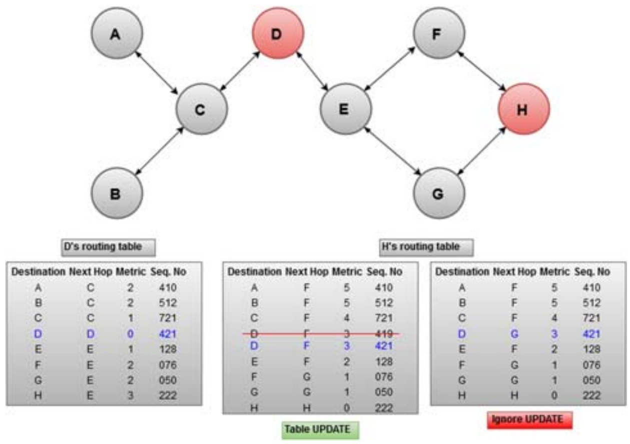

Figure 1. Receiving of an updating message with the same sequence number.

A. *The P-DSDV Route Maintenance Procedure*

The P-DSDV route maintenance procedure is similar to that in DSDV. The flowchart depicted in Fig. 2 describes the complete procedure. The nodes send updating messages periodically to neighbors containing information about their routes tables (destination address, number of hops, sequence number, etc). The P-DSDV route table has a new field named count_bus whose function is to store the quantity of buses, pertaining to the MOB-NET, that each route possesses. The structure of the DSDV and the P-DSDV routing tables are illustrated in Table I.

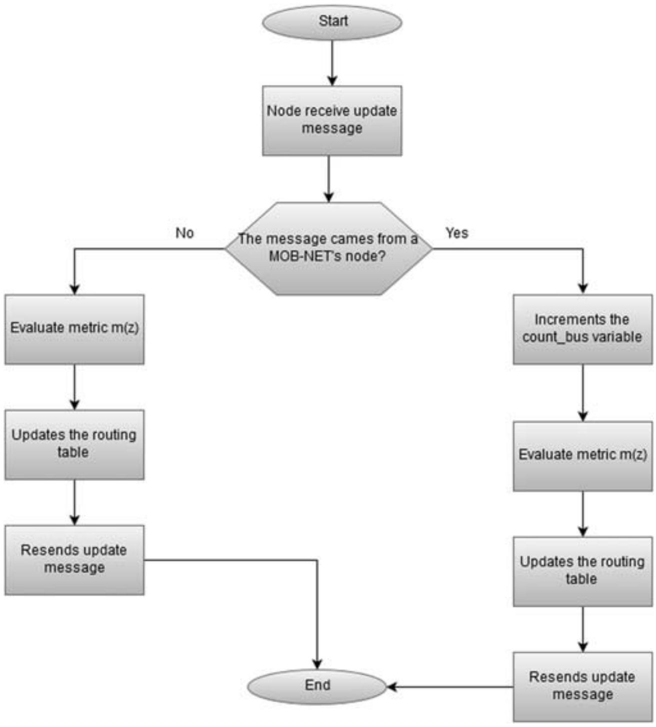

Figure 2. The P-DSDV route maintenance procedure.

This way, when the updating messages start being sent through the network, they will also contain the *count_bus* variable, which will be incremented in one unit every time the receptor node verifies that the updating messages is coming from a bus pertaining to MOB-NET. The *count_bus* variable increment method occurs as the following: when a node receives a neighbor's routing table, it verifies if the neighbor is a MOB-NET bus, it updates the *count_bus* variable (increment in one unit if needed), records the information in its routing table and resends the table with updated information to its neighbors. It is assumed that all the nodes on the network are able to identify the buses pertaining to the MOB-NET through a unique identifier (ID).

TABLE I. THE P-DSDV ROUTE MAINTENANCE PROCEDURE.

DSDV	**P-DSDV**
Destination	Destination
Next	Next
Metric (number of hops)	Metric (number of hops)
Sequence number	Sequence number
	Count_bus

Conventionally, at the moment the nodes receive the routes updating message, they compare the sequence numbers (those which they have in their tables with those that are coming with the updating messages), and if those numbers are equal, the route with the best metric (minimum number of hops to the destination) is used. Instead, a network operator may be interested in maximizing connectivity. In that case, it is appropriate to choose routes so as to maximize the number of reliable nodes (buses). Selecting a route that is optimal in connectivity may result in a large number of hops. Thus one wants to meet two (possibly contradictory) objectives: maximizing the network connectivity while simultaneously minimizing the number of hops. In our case, when the sequence numbers are equal, the P-DSDV protocol will select a route which presents the lowest value for Eq. (1):

$$m_r(z) = n_{hops} + z.(n_{hops} - n_b), \qquad (1)$$

where n_{hops} is the number of hops of a given route, n_b is the number of nodes pertaining to MOB-NET, and z is a (non-negative) control variable. Note that (n_{hops} - n_b) is the number of common nodes (ordinary vehicles that do not belong to MOB-NET). The variable z is associated to a penalty applied to the routes which have a larger number of common nodes. Thus, in function of the value of z, the protocol can use, possibly, shorter and less reliable routes (with a lower number of nodes pertaining to MOB-NET) or longer and more reliable routes (with more nodes pertaining to MOB-NET).

B. Analysis of the $m_r(z)$ Metric

As it can be observed in Fig. 3, the $m_r(z)$ metric intends to properly discriminate routes in all possible routing scenarios, specifically:
1. There will be only common nodes on the routes;
2. There will be only MOB-NET nodes on the routes;
3. There will be common nodes and MOB-NET nodes on all routes (mixed routes);
4. There will be routes only with MOB-NET nodes and mixed routes;
5. There will be routes only with MOB-NET nodes and routes only with common nodes.

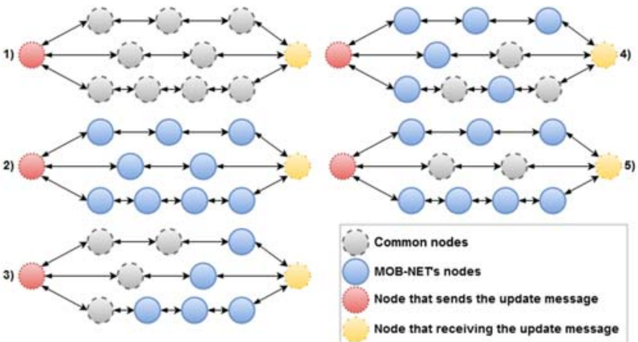

Figure 3. Existing routing scenarios.

Fig. 4 illustrates an example of the routing updating process executed by the P-DSDV protocol. In this example, the node E (after receiving several copies of an updating message with equal sequence number) must be able to select the most appropriate route.

As it can be observed in Fig. 4, initially node A sends an updating message, which arrives to node E through node D (Fig. 4(A)). After that, node E receives a new message, but through node G (Fig. 4(B)). When it receives this new message, node E evaluates the $m_r(z)$ metric (in this example with z = 1.5) to both routes and compare the results. As the route through node G presents the lowest result value, it is selected (the old route is excluded from the table, the new route is added and an updating route message is immediately sent to the neighbor nodes). Lastly, node E receives the updating message through node J (Fig. 4 (C)), and it evaluates the $m_r(z)$ metric one more time for the existing route on the table and the new route. In this case, the new route is the one which presents the best metric (the lowest value for Equation 1). Thus, the route used so that node E finds node A is through node J (E → J → I → H → A).

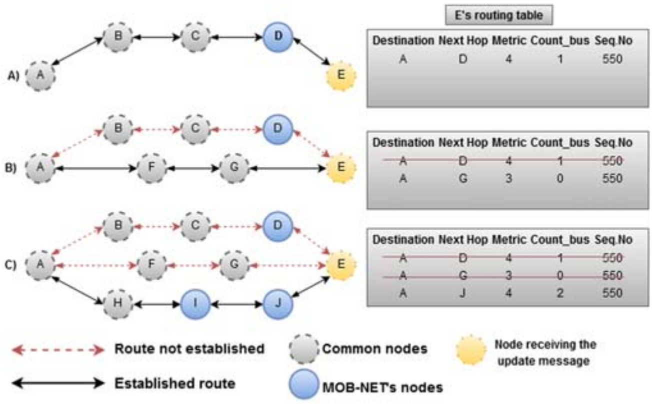

Figure 4. Example of the application of the route updating process executed by the P-DSDV protocol.

Table II presents the values of Equation (1) for the three routes described in Fig. 4 (through node D, G and J). As it can be noticed, the route where $m_r(z)$ assumes the lowest value is the route through node J.

TABLE II. EXAMPLE OF THE APPLICATION OF EQUATION 1

Route	n_{hops}	n_b	z	$m_r(z)$
From node D	4	1	1.5	8.5
From node G	3	0	1.5	7.5
From node J	4	2	1.5	7

IV. EVALUATION OF THE P-DSDV USING A NETWORK SIMULATOR

We considered a simulation that aims to reflect the real behavior of the express buses in the urban transport system of Curitiba - Brazil. For that, a representative area with two kilometers of extension (Marechal Floriano Peixoto Avenue) was selected. The main avenue and neighboring streets, from a rectangular area of 2000m x 500m, were reproduced using the VanetMobiSim software. In each simulation the same density of buses (7 buses/km) was considered, as observed in the real scenario and for each one of those buses it was attributed an exclusive lane in which they can move. Furthermore, the maximum and mean speed, the number of traffic lights and their stopping time were captured from the real data. A number of common vehicles in the neighboring streets use MOB-NET to exchange information. Fig. 5 shows a (not accurate) representation for the simulation scenario.

In NS-2 [23], each node represents one vehicle in the mobility simulations, traveling based on the vehicle movement history in the trace file obtained using VanetMobiSim [24]. The performance evaluation was made through comparisons considering the following situations:

- Without the MOB-NET and with the original DSDV (Without MOB-NET);
- With the MOB-NET and with the original DSDV

(With MOB-NET);

- With the MOB-NET and with the P-DSDV (P-DSDV/MOB-NET);

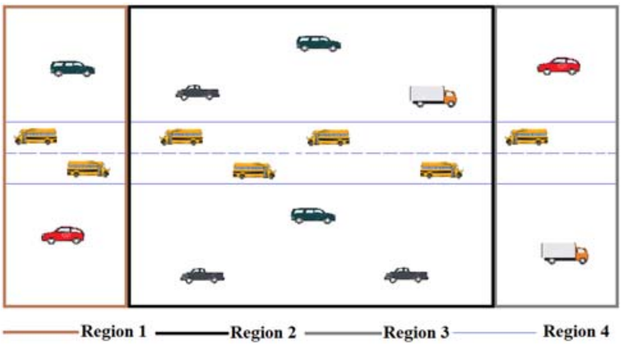

Figure 5. Pictorial representation for the simulation scenario. Express buses travel on the main exclusive lane. Common vehicles in the vicinity use MOB-NET to exchange information.

A. Simulation Scenarios

The network simulations intend to examine the proposal in three scenarios. In all scenarios the rectangular area (Fig. 5) is divided into four regions: 1, 2, 3 and 4 (each region is identified by a different color). There are five common vehicles distributed in region 1 and five vehicles in region 3. The vehicles in region 1 randomly communicate with vehicles in region 3, causing messages to pass through regions 2 and 4. Regions 1, 2 and 3 are common areas of a city, and region 4 represents the express lanes of MOB-NET. The traffic pattern consists of connections with constant bit rate (CBR) considering the UDP protocol. The radio propagation model is the twoRay ground, while the MAC/PHY layer follows the IEEE 802.11p standard [25].

In scenario 1, the target is to investigate the behavior of the network, considering the variation on the number of common vehicles. Thus, the network has 15, 25, 35, 45 or 55 vehicles distributed throughout regions 1, 2 and 3 (additional vehicles to the five ones which already exist in regions 1 and 3). This way, the density of vehicles ranges from 30 to 90 vehicles/km^2 .In this scenario, the common vehicles transmit their radio-frequency signals in a 300m radius and the MOB-NET buses in a radius of 500m (here, a longer range has been considered, because there are no obstacles among the buses). The transmission rate is equal to 4 messages per second. In scenario 2, the scope is to investigate the behavior of the network while varying the transmission range of the MOB-NET buses, so the common vehicles transmit the radio-frequency signals in a radius of 300m and the MOB-NET buses in a radius of 100m, 300m and 500m.

The transmission rate is equal to 4 messages per second. For scenario 2, there is a fixed number of 35 vehicles distributed throughout the regions 1, 2, and 3. In scenario 3, the objective is to investigate the behavior of the network while varying the transmission rate (4, 8, 16, 32 or 64 msg/s). For scenario 3, there is a fixed number of 35 vehicles distributed throughout regions 1, 2, and 3 and the common vehicles transmit their radio-frequency signals in a radius of 300m while the MOB-NET buses transmit it in a radius of 500m.

The simulations run by 600 seconds considering the same traffic pattern, but with different mobility scenarios. Finally, we repeated each simulation 35 times and took their average as simulation results. We computed 95% confidence interval for each performance data and a confidence interval bar is plotted for each data point of the average curves. The configured simulation parameters are shown on Table III.

TABLE III. SETTING OF THE SIMULATION PARAMETERS.

Parameters	Settings
Simulator	NS-2
Routing protocols	DSDV, P-DSDV
Simulation area	2000 m X 500 m
Number of common vehicles	15, 25, 35, 45, 55
MOB-NET density	7 buses/km
Mobility Model	VanetMobiSim
Transmission range of common vehicles	300m
Transmission range of MOB-NET buses	100, 300, 500 m
Maximum speed of common vehicles	40 km/h
Maximum speed of MOB-NET buses	54 km/h
Traffic pattern	UDP/CBR with 4, 8, 16, 32, 64 msg/s
Simultaneous connections	5
Simulation time	600 s
Radio propagation model	*twoRay ground*
MAC/PHY layer	IEEE 802.11p
Buffer size (MAC)	50 packets
Bandwidth	2 Mbps

B. Metrics

The P-DSDV/MOB-NET was evaluated based on the following metrics:

- *Packet Delivery Rate (PDR):* It represents the ratio of all successfully received data packets at the destination to the total number of data packets generated by the application layer at the source vehicles, for each origin and destination.
- *Throughput (THR):* It is the ratio between the quantity of transferred data between two nodes by the time interval in which they remain connected, for each origin and destination.
- *Protocol's Routing Overhead (PRO):* It is the ratio between the number of transmitted routing packets by the quantity of received data packets, for each origin and destination. In packets sent through multihops, each hop counts as one transmission.

C. Simulation Results

Figs. 6 and 7 present the results obtained for packet delivery rate and throughput versus the number of vehicles on the network (scenario 1). Comparing the cases in which the MOB-NET was used with the cases in which it is not, it is possible to notice that the packet delivery rate and the throughput present superior results most of the times when the MOB-NET is used (with 15, 25, and 35 vehicles); a fact which demonstrates the importance of the MOB-NET on networks with low connectivity (density $\leq$ 60 vehicles/km^2). It is worth noting that the case Without MOB-NET corresponds to no reliable infrastructure anyway (opposite to the case With MOB-NET) and, in both cases, the original DSDV considers always shortest paths.

The results are significantly better where the P-DSDV/MOB-NET is used, highlighting the increasing the PDR and the THR, regardless of the number of common vehicles. This fact stems from the MOB-NET reliability that provides conditions for the P-DSDV to prioritize routes with better performance. Moreover, in some cases, the P-DSDV/MOB-NET with z = 0.5 presents slightly better results related to z = 1.5, which means that short routes with MOB-NET buses tend to be more efficient (larger values of z were tested not presenting additional performance improvements).

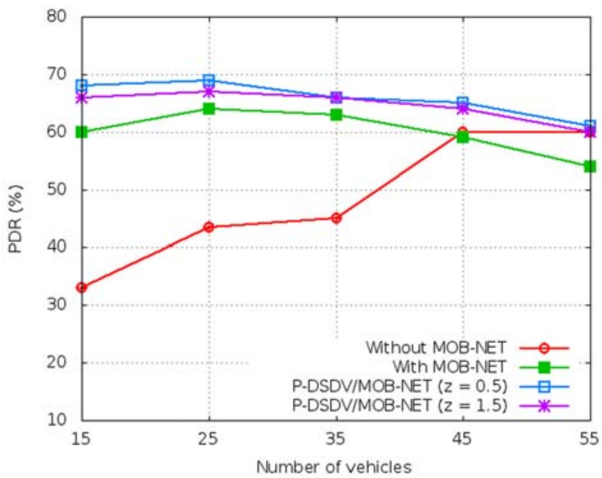

Figure 6. Scenario 1 - Packet delivery rate.

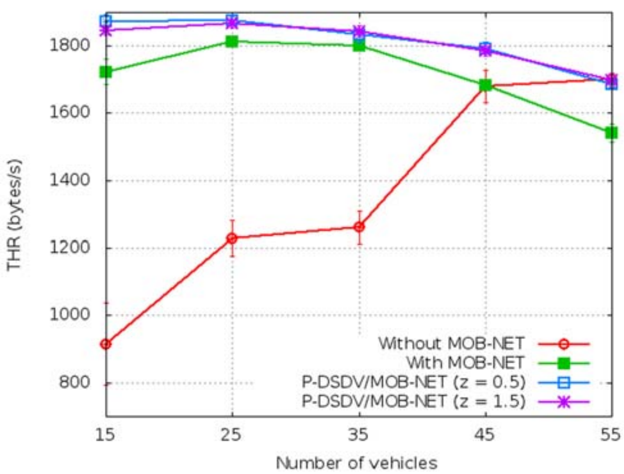

Figure 7. Scenario 1 - Throughput.

It is observed in Fig. 8 that the overhead of the routing protocol rises with the number of vehicles for all the cases. When the MOB-NET is present, besides the existence of more vehicles, the propagation of routing tables occurs on larger areas in the network, increasing the overhead, even with more data packets delivered. When the P-DSDV/MOB-NET is present, the overhead becomes even larger, because every time a route is modified by passing through the MOB-NET, an updating message is immediately sent on the network.

Figs. 9 and 10 present the results obtained for packet delivery rate and throughput versus the transmission range of the MOB-NET buses (scenario 2). As the objective is to verify the behavior of the network with the variation of the transmission range, there were not simulations without the MOB-NET. It is possible to notice that the packet delivery rate and the throughput increase with the increase of the transmission range of buses in the MOB-NET. This result is expected, because larger the connectivity in the MOB-NET, better the use of the P-DSDV in selecting the routes. However, when the P-DSDV/MOB-NET was used, the results were even better (the packet delivery rate and the throughput increase when compared to the other cases).

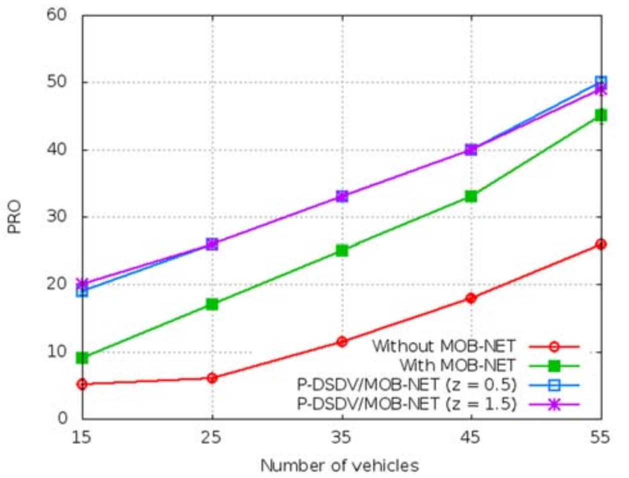

Figure 8. Scenario 1 - Protocol's routing overhead.

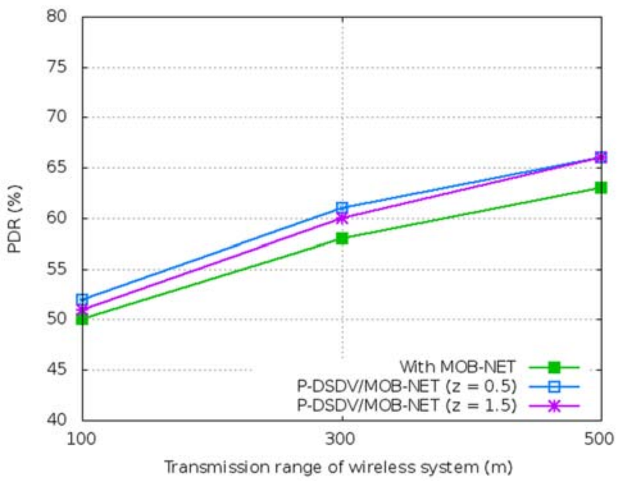

Figure 9. Scenario 2 - Packet delivery rate.

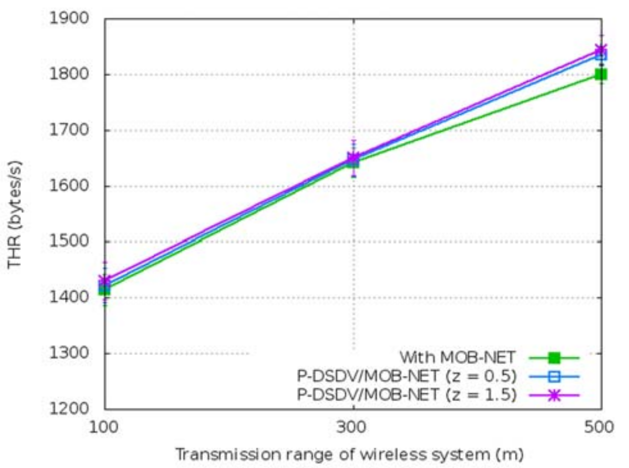

Figure 10. Scenario 2 – Throughput.

It is observed in Fig. 11 that the protocol's routing overhead decreases with the increase of the transmission range, because the larger the connectivity, less is the need of updating the routing tables. However, as expected, when the

MOB-NET or the P-DSDV/MOB-NET are in the network, the overhead is larger. Figs. 12 and 13 present the results obtained for packet delivery rate and throughput versus the source transmission rate (scenario 3). In this scenario, only the following situations are compared: with the MOB-NET and the P-DSDV/MOB-NET with z = 0.5 (previous results have already shown the behavior of the network without the MOB-NET and the parameter z). With the increase of the transmission rate it is possible to notice that the packet delivery rate decreases (Fig. 12) and the throughput increases (Fig. 13). However, the P-DSDV/MOB-NET has obtained better results regardless of the transmission rate. This behavior is observed because when prioritizing reliable routes the P-DSDV is able to sustain the performance, even with an extra overhead in the network. The packet delivery rate decreases because the discards caused by the congestion and buffer overflow rise sharply.

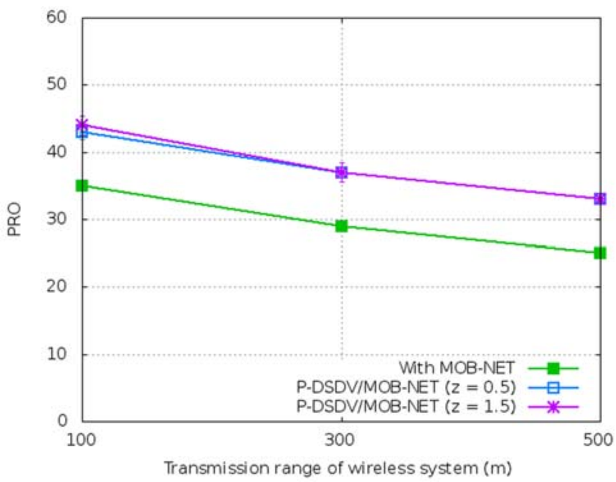

Figure 11. Scenario 2 - Protocol's routing overhead.

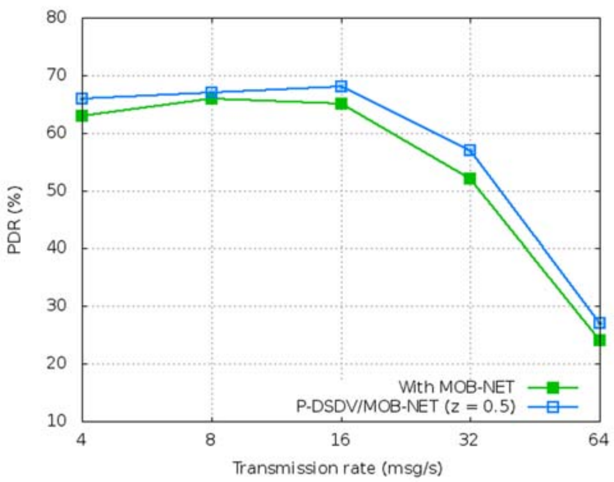

Figure 12. Scenario 3 - Packet delivery rate.

As observed in Fig. 14 the routing overhead diminishes with the increase of the transmission rate, and the extra overhead generated by the P-DSDV tends to become nonexistent after 16 messages/s. Such behavior can be explained since the rising number of data messages sent implies directly on the rise of received data messages, but it does not necessarily imply a rise of routing messages.

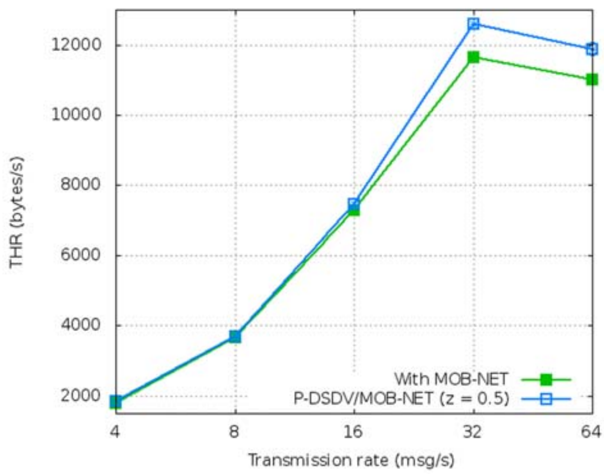

Figure 13. Scenario 3 - Throughput.

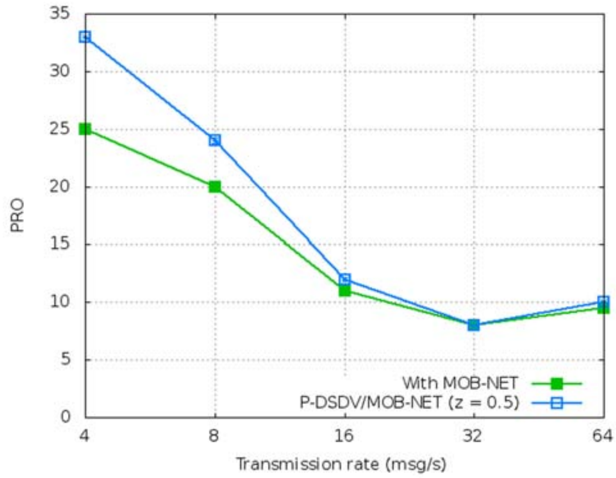

Figure 14. Scenario 3 - Protocol's routing overhead.

V. CONCLUSION

This paper has presented the P-DSDV, a new proactive routing protocol that, together with the MOB-NET, is able to minimize the effects of the lack of connectivity and improve the network performance. The P-DSDV is a routing protocol capable of exploiting the connectivity provided by the MOB-NET, in order to increase the network performance. With the P-DSDV, the packets travel mainly by reliable and connected routes. In order to do that, it is proposed a routing metric $m_r(z)$ which takes into consideration the number of hops and the number of buses in the MOB-NET.

An extensive group of simulations involving the modifying of many parameters, as the number of ordinary vehicles, the wireless transmission range and the source transmission rate, has shown the superior performance of the P-DSDV/MOB-NET proposal. Specifically in networks with low connectivity (density $\leq$ 60 vehicles/km^2), by using MOB-NET, average gains of 75% in packet delivery rate and 50% in throughput, were obtained. The use of P-DSDV yielded an additional gain of 10% in both metrics, but with a corresponding increase in routing overhead.

Future works include the development and the analysis of a more extensive group of simulations focusing on deeply verifying the effect of parameter z on the performance of the proposed protocol and the study of approaches that may reduce the routing overhead.

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