ProbT: A Temporal Probabilistic Protocol to Mitigate the Broadcast Storm Problem in VANETs

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***Abstract*—VANETs are self-organized networks in which their constituent nodes are vehicles. They can be classified as a subcategory of MANETs. Due to their special characteristics, they demand protocols designed specifically for their scenario of action. Different types of applications can be created for VANETs such as security protocols, traffic management, systems maintenance, comfort for drivers and passengers, and others. In general, applications developed for VANETs make use of broadcast information. However, there are many issues to be considered. One of the central problems is the broadcast storm. In this paper we propose a temporal probabilistic protocol, named ProbT, to mitigate the broadcast storm problem. The ProbT performance was measured and compared to the protocols Blind Flooding, Weighted p-Persistence, AutoCast and Irresponsible Forwarding. Based on the results, the ProbT shows a good performance when compared to the mentioned protocols.**

I. Introduction

With the development of wireless ad hoc communication and vehicle technologies, there is a new model for traffic information systems. Using such technologies, data can be sent and received without fixed structures that are common in systems based in infrastructure. VANETs can be used as an alternative for data dissemination [1].

When the aim is to disseminate data in VANETs, one of the problems is the broadcast storm. In a scenario where this problem occurs, there is a high level of contention and packet collision [2]. The broadcast information can be done by single or multiple hops. A strategy in the case of multiple hops is the use of probabilistic protocols.

This paper proposes a Probabilistic Temporal Protocol named ProbT, that uses as a basis for forwarding decision taking the number of neighbors in common between the source and target, the distance between the source and its last known neighbor and the distance between the source and target.

The following sections of this paper are organized as follows: Section 2 presents related work to this research. Section 3 introduces different broadcast schemes in VANETs. Section 4 describes the algorithm proposed in this article. Section 5 presents analysis and test results performed comparing the ProbT performance to related work. Finally, section 6 presents the conclusion and future work.

II. Related Work

One way of carrying out the data broadcast in VANETs is through the use of blind flooding. This strategy is inefficient because its use may result in the broadcast storm in the network [3]. Studies show that the solution to this problem is NP-Complete [4].

Figure 1 shows a classification for data broadcast protocols presented by [1]:

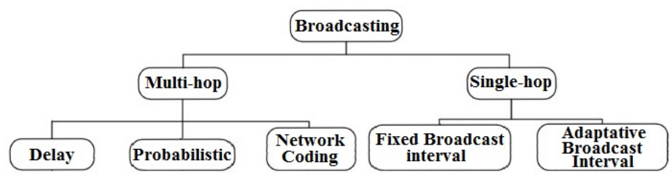

Fig. 1. A classification of broadcast protocols for VANETs (Edited) [1].

The data broadcast is divided into two categories: single-hop and multi-hop. The multi-hop category is subdivided into three parts: delay based model, network coding model and probabilistic protocols. In the delay based model, in general, different waiting times are assigned to the receiving nodes of a given packet prior to the data rebroadcast. In the network coding model, generally the data rebroadcast is sought from the junction of content of packet sent by different sources. In probabilistic protocols, some characteristic relevant to the network is analyzed and then translated into a mathematical formula, modeling of the probability of forwarding a given message.

In this classification [1], four probabilistic protocols used to broadcast information are presented: Weighted p-persistence; Optimized Adaptive Probabilistic Broadcast (OAPB), Auto-Cast and Irresponsible Forwarding (IF).

The Weighted P-Persistence assigns higher probability to nodes that are located farther away from the broadcaster given that GPS information is available and accessible from the packet header [2].

The Optimized Adaptive Probabilistic Broadcast Protocol (OAPB) [5] is a probability and restricted zone based broadcast scheme to handle the broadcast storm problem. Each vehicle node determines its own rebroadcast probability depending on its local information within two-hops. The local information is simply obtained from the periodical HELLO packets which are involved in the operation of Ad-hoc On Demand Distance Vector(AODV) routing protocol.

The AutoCast [6] protocol derives the forwarding probability from the number of neighbors of a node. To avoid broadcast storms, on average only two nodes of those receiving a new data unit rebroadcast it. An observation concerning this protocol in [1] is the fact that it does not indicate the procedure to be used in cases in which the number of neighbors is less than 5, producing not acceptable values for probability.

The Irresponsible Forwarding [7] takes into account the distance between transmitter and receiver and the statistical distribution of vehicles in the following way: once received the packet, the receiving node evaluates the probability of another vehicle farther from the transmitter with a better forwarding probability. If such vehicle is available - according to the distance and vehicle density - the node "Irresponsibly" chooses not to forward the packet (hence the name of the Irresponsible Forwarding protocol). Otherwise, it forwards the data according to the probability defined by this protocol.

In this work, will be simulated the Blind Flooding, Weighted p-persistence, AutoCast, Irresponsible Forwarding and ProbT.

III. PROBT

The ProbT is a hybrid protocol that takes into consideration the characteristics presented by probabilistic and delay-based protocols as basis for forwarding decision.

The forwarding decision is characterized by two phases. The first phase makes use of two characteristics as the basis for forwarding decision:

The first characteristic is related to the number of neighbors in common between the source and receiver nodes.

Figure 2 represents the number of common neighbors between two nodes A and B, taking into account the transmission range.

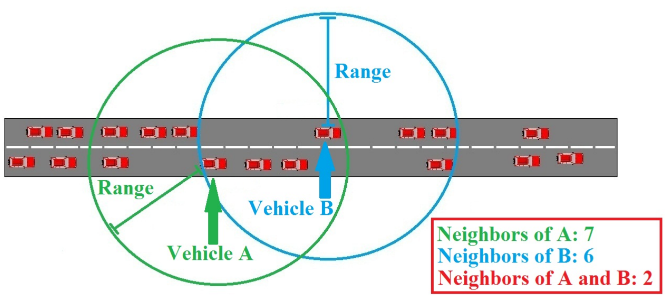

Fig. 2. Number of neighbors in common.

The number of neighbors in common with another node is predicted using as a basis a neighbor table maintained by the vehicle and a mechanism for predicting position. Each node sends a beacon packet (position, speed and acceleration) in broadcasting. All the nodes receiving it build a table of neighbohrs. When a node (e.g. A) receives a data packet issued by another node (e.g. B) to be rebroadcast it has to predict all the common neighbors between them (nodes A and B). In order to do this, the node A should iterate over the entries in its neighbor table to predict the position of all nodes and consequently all the common neighbors with node B, as depicted in the Figure 3.

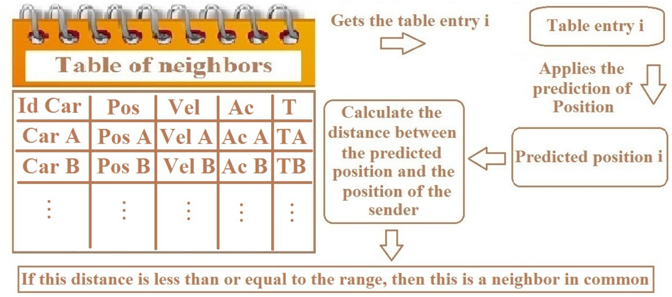

Fig. 3. Calculation of the number of neighbors in common.

The ProbT takes into account a second characteristic that uses as a basis for decision forwarding the positioning of the receiving node within the transmission range of the source node. Each sender includes in the data packet the position of its farthest node. That permits all the receiving nodes to calculate the distance between them and the source as shown in Figure 4.

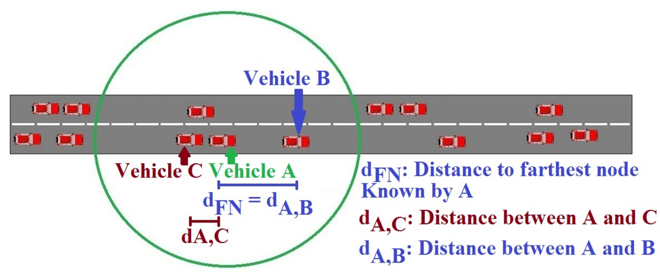

Fig. 4. Distance to the last neighbor

The decision forwarding using ProbT protocol can be described by the Formula 1:

$$p = \alpha * p1 + (1 - \alpha) * v * p2 \tag{1}$$

Where:
α = Priority factor belonging to the interval [0.0, 1.0] in $\mathbb{R}$;
v = 1 if the receiver node is at a distance that belongs to the interval [0.9 * Transmission Range, Transmission Range], or 0, otherwise;
$p1$ = The probability associated to the number of neighbors;
$p2$ = The probability associated with the receiver node position.

The probability associated to the number of neighbors is defined by the formula 2:

$$p1 = \frac{qNeigh - q}{qNeigh} \tag{2}$$

Where:
qNeigh = Number of neighbors that the receiving node has;
q = Number of neighbors in common with source and target node.

The most distant nodes from the sending node tend to have lower numbers of neighbors in common with the source when compared to the closest nodes. The greater the number of neighbors in common with the source, the worst node it is considered and vice versa. Thus, the formula for forwarding makes the receiving nodes with smaller numbers of neighbors in common with the source have the highest values of probability of forwarding and vice versa.

The probability associated with the receiver node position is modeled using the formula 3:

$$p2 = (1 - \frac{|dLastNeigh - dToSource|}{max(dLastNeigh, dToSource)}) \quad (3)$$

Where:
dLastNeigh = Distance to the last neighbor informed by the source;
dToSource = Distance between the source and receiver node.

When the node receives the data packet, it calculates its distance to the sending node. The closer the last neighbor known by the source node is the receiver, it is considered the best forwarder and vice versa. Figure 4 shows such distances. Assuming that the car C received a packet from A, dLastNeigh is the value of dA, B and dToSouce is the value of dA, C.

The priority factor α is used to assign percentages of values for the criteria analyzed. The variable v is used to apply a sectorization in the nodes transmission range (R). A node that is at a distance less than 0.9 * R, will have zero value as the probability associated with its positioning between the source and the last known neighbor. This is done because, in spite of the nodes located within this range have lower values of forwarding probability, many of them may still decide to send such packet, which is not desired. Thus, this reduces the number of rebroadcasts in the network.

In the second phase, the ProbT algorithm differs the time that a node will forward a given messages, as shown in Figure 5. This is done, since many nodes may receive a data packet, many of them may try to forward it at the same time and produce the previously mentioned problems such as contention and packet collision.

The node generates a random number x in the range 0.0 to 1.0 using a uniform distribution. If this number is less than the probability value calculated according to formula 1, it is assumed that the node has volunteered to send this packet. In this case, many nodes may volunteer and then try to send the packet at the same time. To avoid this problem, the ProbT protocol makes the nodes wait a time interval before sending the packet, according to formula 4. The nodes with the higher probabilities wait a shorter time interval to forward a message. Also, if another node has already volunteered and sent this packet received, such forwarding is no longer required . Thus, at the end of the waiting period, the receiving node checks if any node has sent this packet, if yes, it discards the packet, If not, it forwards that.

$$Wait\ Time\ 1 = (1 - p) * DT1 \quad (4)$$

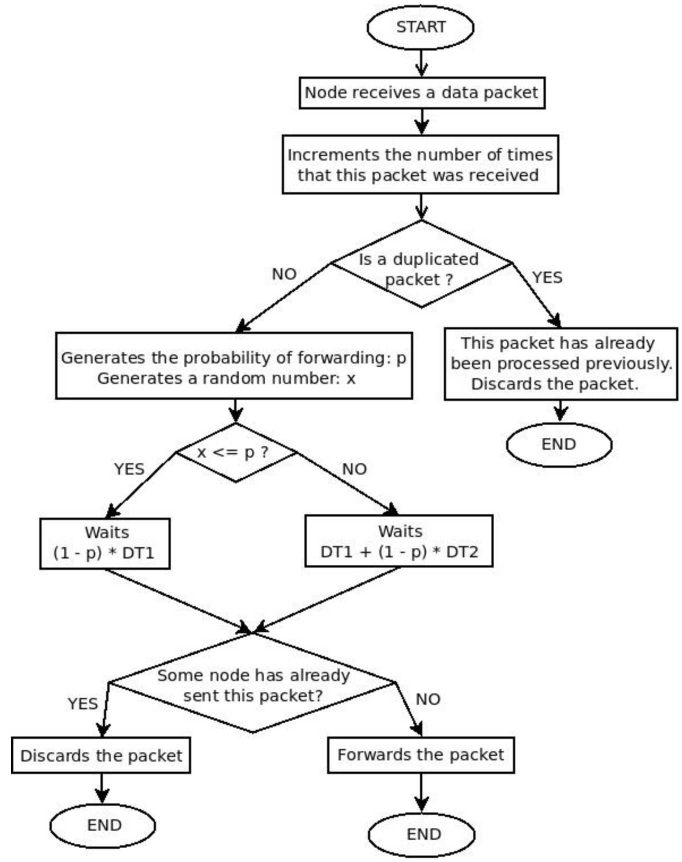

Fig. 5. Receiving Diagram and packets forwarding.

Where:
DT1 = Time Interval 1.

If the receiving node does not volunteer, it means, the random number x is greater than the probability value, the receiver must wait for some other node to volunteer and forward the packet if any other has not done it until the end of Wait Time 2. Nodes that are not volunteers, when realizing that no other node sent the packet, try to forward the packet simultaneously. To avoid this problem, ProbT adjust their waiting time according to the probability value. This time interval is given by equation 5:

$$Wait\ Time\ 2 = DT1 + (1 - p) * DT2 \quad (5)$$

Where:
DT2 = Time Interval 2.

To define the values of waiting time, we consider the drivers' brake reaction time according to [8], which varied from 0.4 second to 2.7 seconds with a mean value of 1.0 second.

IV. Analysis and Results

For the tests, we use the scenario with two lanes in a given direction. The vehicles in the simulation move through this lane with the same speed and direction. In [9], three types of traffic schemes for VANETs protocols are presented: sparse, dense and regular traffic. The regime of vehicular traffic simulated were: regular traffic (20, 30) and dense traffic (60, 90 and 120) cars / km by road. Once the number of cars and its density are determined, the cars are positioned on the lane following an intervehicular spacing exponentially distributed. Such scenario is created using the traffic simulator SUMO to generate the file that describes the mobility of vehicles.

All vehicles are moving from left to right. The vehicle that is on left edge will be the data message source so that the intermediate nodes must forward the messages according to the mentioned model.

For the simulations, the settings displayed in Table I were used:

TABLE I. *Configuration of the scenarios*

Parameter	Value
Number of iterations	33
Number of vehicles	500
Velocity	60 km/h
Packet Delivery Rate	1 packet/seg
Propagation Model	Nakagami
Parameter α of the *ProbT*	0.3
Traffic	20, 30, 90, 60 e 120 vehicles/km
Transport	UDP
MAC/PHY	802.11p
Transmission Range	1 km
Simulation Time	300 seconds
Confidence Interval	95 %

The Protocols Blind Flooding, Weighted P-persistence, Autocast and Irresponsible Forwarding are simulated in the NS-3 and compared with ProbT. The following metrics are analyzed: packet delivery rate, packet loss rate, link load and redundancy rate, defined in [1].

$$Packet\ Delivery\ Rate = \frac{Number\ of\ vehicles\ receiving\ packets}{Total\ of\ vehicles}$$

$$Packet\ Loss\ Rate = \frac{Number\ of\ lost\ packets}{Total\ of\ packets\ sent}$$

$$Link\ Load = \frac{number\ of\ received\ packets}{Observation\ period}$$

$$Redundance\ Rate = \frac{Number\ of\ duplicate\ packets}{Number\ of\ source\ packets}$$

Figures 6 and 7 show the results obtained with the delivery rate. For both scenarios, DT1 = DT2 = 0.5 s and DT1 = DT2 = 0.05 s, the ProbT showed the highest delivery rates. Obtaining such forwarding rate indicates that the spatial distribution of the volunteers, ie, their position is sufficient to deliver the packets to a large number of nodes in the network. If the selected nodes were not well positioned, a lot of nodes would not receive the packets, which is not true. This indicates that the forwarding probability is an efficient model on which the nodes should send the message, because there is a high delivery rate for it.

The delivery rate was bigger when the network was denser. This happened because there was a greater number of potential volunteer nodes, ie, a greater number of nodes to decide on the routing. Another factor responsible for the high delivery rate was the use of the waiting time before the forwardings. This strategy prevented the occurrence of broadcast storms.

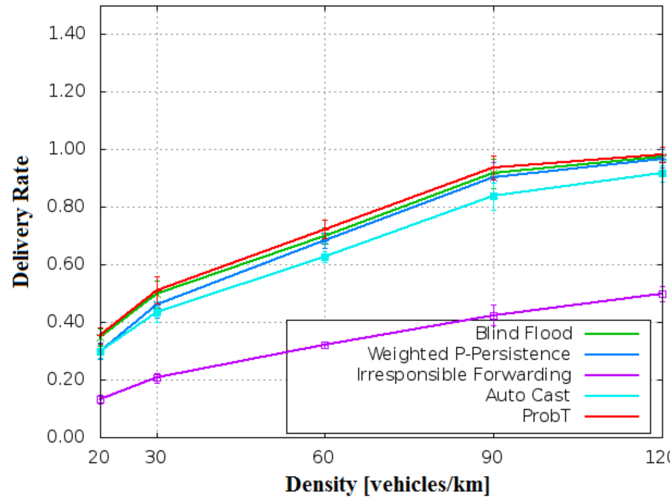

Fig. 6. Delivery rate of packets with DT1 = DT2 = 0.5 s.

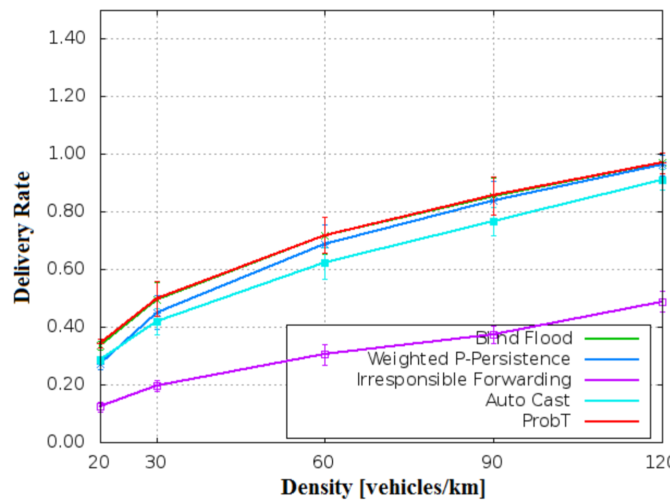

Fig. 7. Delivery rate of packets with DT1 = DT2 = 0.05 s.

Figures 8 and 9 show the results obtained with the packet loss. For both scenarios, DT1 = DT2 = 0.5 s and DT1 = DT2 = 0.05 s, the ProbT presented the lowest loss rates. The minimization of the loss rate occurred due to the junction of the mechanisms of probabilistic protocols to the delay-based protocols.

Another reason to the minimization of the loss rate was the waiting time from the nodes which were not volunteers for forwarding, to check if any node has really performed it. This strategy increased the number of reception of data packets.

The low rate of packet loss reflects the efficiency of the combination of these mechanisms. This indicates that the waiting mechanisms, when applications may use them, are efficient to produce low rates of packet loss.

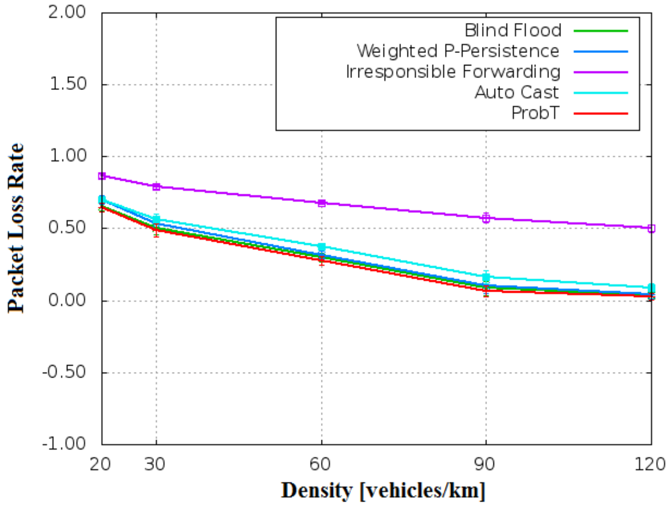

Fig. 8. Packet loss rate with DT1 = DT2 = 0.5 s.

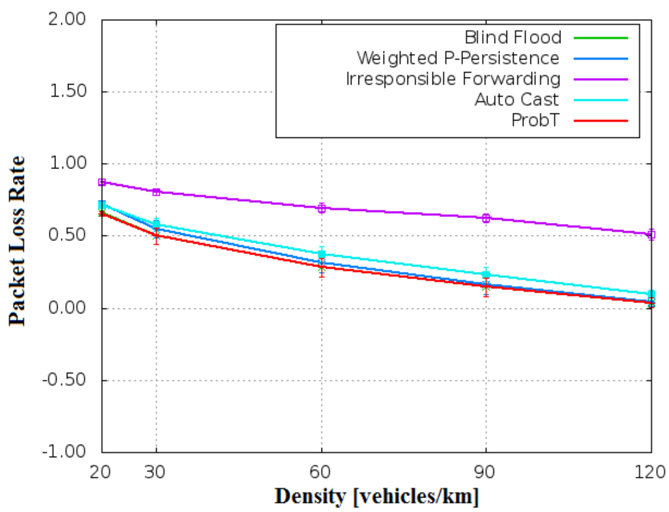

Fig. 9. Packet loss rate with DT1 = DT2 = 0.05 s.

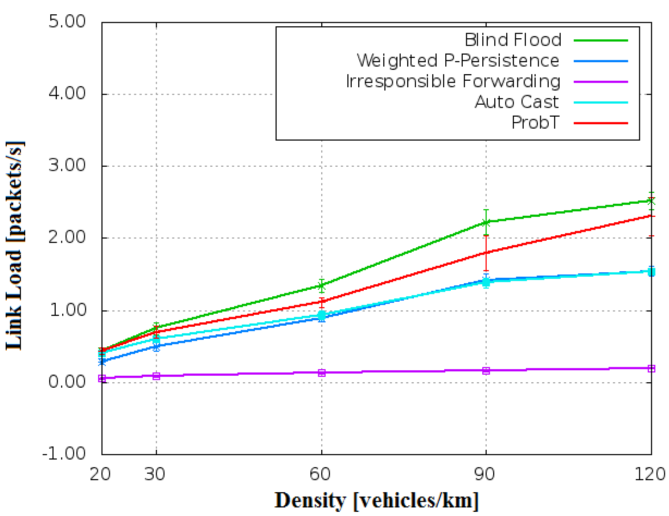

Fig. 10. Link load with DT1 = DT2 = 0.5 s.

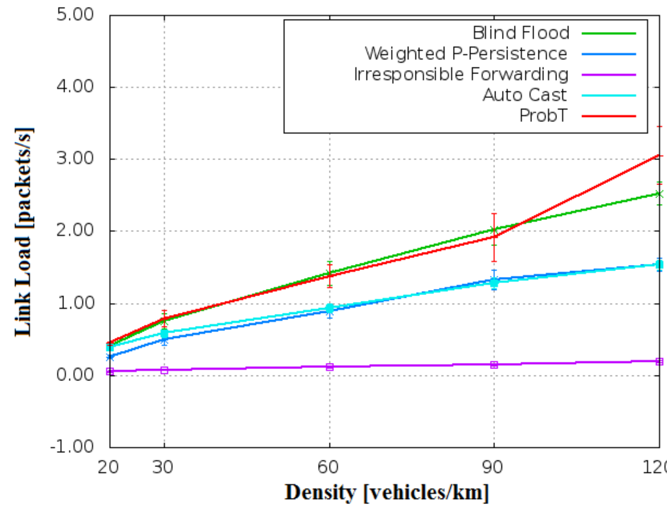

Fig. 11. Link load with DT1 = DT2 = 0.05 s.

Figures 10 and 11 show the results obtained with the link load. This metric must be examined in parallel with the metrics delivery rate and loss rate. The reason is that the link load protocols with a high rate of delivery cannot be compared to a protocol with a low delivery rate. Protocols with higher delivery rates tend to have larger link loads and vice versa.

Among the simulated protocols, the protocol that approximates the rate of delivery of ProbT is the Blind Flooding. With lower delivery rates there are the Weighted P-persistence and Auto Cast. With a very low rate of delivery there is the Irresponsible Forwarding. Thus, the protocols that can be compared concerning the link load, more fairly, are the Blind Flooding and ProbT. If Weighted P-persistence and Auto Cast are included in the load link comparison, it is not fair due to lower delivery rate that they have in relation to ProbT.

It is observed that, as the vehicle density increases, ProbT has higher link loads. This is due to the fact that with a greater number of nodes, the greater the number of nodes to take the forwarding decision. Thus, it tends to increase the amount of forwarding. This fact also explains the greater link load in other protocols for higher densities of vehicles. It is also observed, as expected, that the higher the waiting time for forwarding, the lower the link load. When the nodes volunteer, they wait intervals to check if any node has already sent the message. If a node has already sent it, the packet can be discarded. If the nodes tend to wait some more time, they should send fewer packets and vice versa. Thus, it is justified the higher link load for ProbT in a scenario with DT1 = DT2 = 0.05 s when compared to the scenario with DT1 = DT2 = 0.5 s.

Figures 12 and 13 show the results obtained with the redundancy rate. Similarly to the load link, it must be analyzed in parallel with the both metrics delivery rate and loss rate, since the redundancy rate of a protocol with a high delivery cannot be compared to a protocol with a low one. Protocols with lower delivery rates tend to have lower rates of redundancy and vice versa. Then, considering the delivery rate, the comparison of rates of duplication is fairer between ProbT and Blind Flooding.

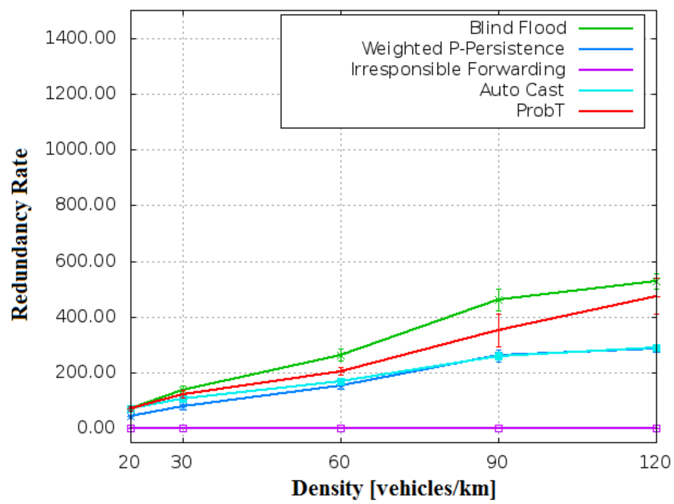

Fig. 12. Redundance rate with DT1 = DT2 = 0.5 s.

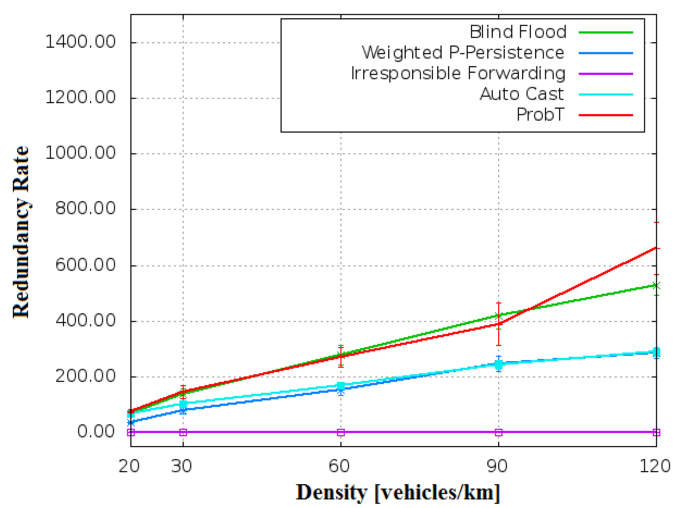

Fig. 13. Redundance rate with DT1 = DT2 = 0.05 s.

The ProbT showed the greatest packet redundancy rates in higher densities of vehicles, since the higher the densities of vehicles, the more the nodes that take the decision on forwarding packets, ie, the greater the number of possible duplication of packets.

As expected, the longer the waiting time for routing, the lower the number of packet duplicates. Once a node sends a packet, its neighborhood receives it, and takes the forwarding decision. The volunteer nodes will wait time intervals. The higher the waiting time, the lower the number of packet duplicates, since the vehicles give a greater time for its neighbors to perform the forwarding.

In general, the ProbT shows better performance for higher values of DT1 and DT2. The ProbT had good values regarding the metrics delivery rate and loss rate and the increase in these values highlighted that characteristic. To reduce the link load the values of the waiting time should be increased. Thus, non-emergency VANETs applications can make use of this broadcast protocol for high delivery rates and low rates of packet loss. Depending on the delay limit that application can handle, it is possible to manage the metrics link load and redundancy rate.

V. CONCLUSION AND FUTURE WORK

Based on the results, this protocol can be classified as a great option when it is aimed to have a high delivery rate and a low packet loss rate. It is also a reasonable option concerning the metrics link load and duplicate packets. Thus ProbT presents itself as a new option for broadcast packet protocols using a new model for the problem.

As future work may be indicated:

- Changing the layer on which the waiting intervals occur: In ProbT, the intervals of waiting time occur at the application layer from the calculation of the forwarding probability. It is possible to study how to put this waiting period, only at the data link layer;
- Implementation of this protocol in a Manhattan scenario: ProbT was applied only in the Highway scenario. It is possible to study the changes needed to its use in both scenarios.

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