How to Disseminate Vehicular Data Efficiently in both Highway and Urban Environments?

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***Abstract*— Vehicular networks are a class of mobile networks in which vehicles are equipped with radio interfaces and are therefore able to communicate with an infrastructure (if existing) or other vehicles in an opportunistic way. Information dissemination enjoys wide applicability in these types of networks, ranging from traffic information and warnings, to parking availability, fuel prices, road conditions, and advertisements. Hence, we propose an efficient dissemination protocol: ROD (Road Oriented Dissemination) that consists in two modules: (i) Optimized Distance Defer Transfer module, and (ii) Store and Forward module. This protocol permits to increase the delivery ratio and optimize the bandwidth use by limiting the number of vehicles having to relay each packet. The protocol has been implemented and tested on the roads. In this paper we report its performance studies, performed by means of simulations, and we compare them to other dissemination protocols results. Performance study shows interesting results of ROD compared to existing solutions.**

Keywords-component; Vehicular networks; Cooperation; Dissemination; Multi-hop communication; Store and Forward

I. INTRODUCTION

Cooperative vehicular networks are considered as the best way to bring more comfort to the passengers and especially more safety to the human life. In 1998, there were more than 60 million accidents in the world. The financial cost of these crashes was more than 1,500 billion dollars. These statistics make governmental organizations allocating more and more interest and money to minimize the effects of this calamity. Besides, car manufacturers, automotive OEMs, networks operators, and service providers found a great interest in the domain. As a result, several projects and consortium have been launched. The most known are the Car2Car consortium [1], CVIS Project [2], CALM Project [3], ETSI ITS [14] and Pre-Drive [15], etc. All these projects have roughly three targets (i) harmonization of vehicle communication standards worldwide, (ii) development of realistic deployment strategies and (iii) development of more efficient applications.

The communication technologies used in cooperative vehicular networks will play a pivotal role in the efficiency and effectiveness of such applications and it is considered a primary concern in all these projects. The manner in which pertinent information is disseminated throughout the vehicular environment is also an important aspect of cooperative vehicular networks. However, dissemination is usually confronted with two major problems: (i) on one hand, in case of dense traffic, bandwidth proves to be insufficient and it is difficult to limit the packet losses, (ii) on the other hand, if the traffic density is low, temporary disconnection in vehicular network will be unavoidable.

Our aim is to introduce a new efficient approach for data dissemination in cooperative vehicular networks. This dissemination protocol has the capabilities to (i) avoid the waste of bandwidth by minimizing the amount of vehicles that have to rebroadcast packets, (ii) Use a store and forward module to help the limitation of the disconnection effects, and (iii) Adapt the solution to both highway and city environment. To achieve these requirements, we developed a dissemination protocol called *ROD* (Road Oriented Dissemination). ROD optimizes the bandwidth usage by using the same principle as DDT (Distance Defer Transfer Protocol) [6]. In DDT, only one vehicle is selected with each transmission to rebroadcast the message. To fulfill the second requirement, ROD adds a store and forward mechanism used in the case of no vehicle is able to disseminate packets further. The last characteristic of ROD is its accommodation with the vehicular environment and roads architecture. For that, ROD uses a specific algorithm to optimize the packets retransmission within intersections that makes it suitable for both highways and urban environments.

The rest of this paper is structured as follows. Section II showcases several data dissemination mechanisms in cooperative vehicular networks. In Section III, we introduce the functioning of ROD and Section IV shows and discusses the main performance evaluation results issued from simulation study. Finally, Section V concludes the paper.

II. BACKGROUND

Cooperative vehicular networks are characterized with new challenges as high mobility of nodes and varying roads densities. These properties make difficult the deployment of several cooperative applications. Knowing that a large number of vehicular applications are broadcasting by nature, it is fundamental to ensure the availability of a reliable dissemination service able to surpass all these challenges.

The simple flooding [7] is the most known dissemination protocol. It consists on retransmitting each message, when receiving it, to all neighbors. Each neighbor checks if it already received this message, in this case the message is dropped, otherwise, it is rebroadcast. Simple flooding causes the broadcast storm problem which produces an excessive bandwidth use and an increase in the end to end delay and packet loss ratio.

Several dissemination protocols were proposed in research works. They could be sorted into two classes: (i) protocols for infotainment services (e.g. advertisement applications) that have constraints related to the bandwidth, and (ii) protocols for emergency services (e.g. road safety services) that have end-to-end delay and delivery ratio constraints.

A. Dissemination of road safety information

Many dissemination protocols have been proposed to perform road safety services [8] [9] [10]. These protocols have to respect the delay and delivery ratio constraints even if all the available bandwidth is used.

In [8], the authors propose MHVB (Enhanced Multi-Hop Vehicular Broadcast) which could be used to deliver the emergency messages to all vehicles in a predefined zone. The principle of MHVB is to limit the retransmission of packets in the sender proximity. Each vehicle, which receives the packet and sends it once, continues to send it periodically until leaving the service area. The delays between successive emissions are modulated by some parameters (e.g. traffic density, vehicle-source distance, etc.). Unfortunately, with MHVB many vehicles transmit the same message periodically which increases the network charge.

In [16], the authors propose STEID (Spatio-Temporal Emergency Information Dissemination protocol). This dissemination protocol is based on a hybrid architecture. Each group of communicating vehicles is connected to external servers via cellular network. The different groups are formed based on periodic Hello messages containing the sender information (road identifier, position, direction, etc.). A head is elected for each group. This head is in charge of downloading data from external servers via cellular communication and disseminating it in its cluster using IEEE 802.11p communication. This system aims at resolving the disconnection problem due to the high velocity of vehicles. The major drawback of STEID is the head election process that requires periodic diffusion of Hello messages.

Another interesting work is Direction Propagation Protocol (DDP) [9]. In this work, authors propose to use a clustering algorithm to regroup vehicles into clusters. In each group two vehicles are elected as header and trailer and are in charge of propagating the message. So, DDP has three modules: a custody transfer protocol, an inter-group routing protocol, and an intra-group routing protocol. It uses also the store and forward mechanism to solve the disconnection problem due to network partition. Even if DDP seems to be an effective solution, the authors have not described all the functionalities of their protocol. They do not precise, for example, the method of the header and the trailer's election and do not detail the intra-group routing mechanism.

In [10], the author proposes ODAM for Optimized Dissemination of Alarm Messages. For example, when an accident occurs, the vehicle sends an alarm message and only vehicles circulating in the same portion and having to pass by the accident take into account the message. However, only one vehicle called "relay" will be in charge of disseminating it. This relay is selected in a distributed way; it must be the furthest neighbor away from the sender. Unfortunately, ODAM is not scalable since the periodically sent messages lead to an excessive use of the bandwidth.

B. Dissemination of infotainment information

The infotainment services interest mostly the network operators and service providers. The dissemination protocols used in such class of services have no strict constraints in terms of delay and delivery ratio. However, they have other constraints related to the bandwidth use. Among the proposed dissemination protocols, the one that has acted as a reference to the following works is Distance Defer Transfer (DDT) [6]. DDT principle consists in relaying messages only by receivers that are the farthest from the sender. To do that, each vehicle that receives a message waits for a backoff timer which is inversely proportional to the sender-receiver distance before retransmitting it. In this way, the farthest vehicle retransmits the message first. So, the other ones receive it one more time and can cancel the retransmission procedure. Thus, the DDT algorithm permits to optimize the bandwidth use. Unfortunately, with DDT each message is retransmitted no more than one time by each vehicle. So, this protocol is density dependant and seems to be unsuitable for low traffic densities. In the same paper [6], the authors propose another dissemination protocol called TRADE (TRAck DEtection). In this protocol, each vehicle knows periodically its neighbors positions. This information could be gotten thanks to periodically exchanged

Hello messages. Thus, the neighborhood's vehicles can be sorted in several groups and some of them are used to retransmit messages. Contrary to DDT, TRADE relies on an active method to choose vehicles in charge of retransmitting the information. Therefore, TRADE is not effective in case of dense networks. In fact, the periodic Hello messages induce an excessive use of the bandwidth.

In [11], Korkmaz and al. propose UMB (Urban Multi-hop Broadcast) which is an 802.11 based dissemination protocol for urban areas. UMB addresses essentially three problems (i) broadcast storm, (ii) hidden node, and (iii) reliability problems in multi-hop broadcast. UMB operates without exchanging location information among neighboring nodes. Each vehicle selects the furthest vehicle in the broadcast direction to assign the duty of forwarding and acknowledging the packet without knowing the positions of its neighbors. Repeaters are installed in the intersections to disseminate information in all directions. Even if the authors of UMB tried to find a solution to the hidden node issue, other problems like interferences and packet collision persist.

In [17], MDDV (Mobility-Centric Data Dissemination algorithm for Vehicular networks) is proposed. It is based on opportunistic forwarding, geographical forwarding, and trajectory based forwarding. This solution considers that vehicles do not know anything about neighbors' coordinates and focuses on vehicles mobility to detect the best opportunities to forward messages. The principle of MDDV is to associate a factor to each road segment. This factor reflects the segment length and the traffic density inside the segment. MDDV's computed factors are strongly warped when a high quota of vehicles is not equipped.

Most of these protocols do not consider the real conditions of road traffic. We saw, for example, that the majority of dissemination protocols designed for infotainment services fail to reach good delivery ratios in case of partionned network. We also noticed other problems like the excessive use of Hello messages to exchange topology information, the non consideration of roads topology, interferences and installation of repeaters in the intersections.

To resolve the above-mentioned problems we proposed a new efficient dissemination protocol for infotainment services: ROD (Road Oriented Dissemination). The proposed protocol is able to both optimize the bandwidth use and improve the delay and delivery ratio. In the following section, we bring a detailed description of ROD and present its added values.

III. ROD: Road Oriented Dissemination

Road Oriented Dissemination Protocol (ROD), the protocol proposed in this paper, aims to support an effective and optimized way to disseminate infotainment data in cooperative vehicular networks. It permits to deploy many infotainment applications such as advertisement delivery, announcements and sale information, etc. ROD enhances the bandwidth use, delay and delivery ratio.

A. ROD Assymptions

In our work, we consider both highway and urban environments. So, we suppose that velocity ranges from 30 km/h to 110 km/h. We consider also that each vehicle is equipped with a GPS device that enables positioning and time synchronization. In addition, each vehicle can identify its road and the neighboring ones through preloaded digital map which provides a street level map. The use of such tools is a valid hypothesis since the majority of navigation systems allow it. Vehicles can communicate using 802.11a/b/g/n/p as wireless technology.

A service provider sends, via an RSU (Road Side Unit), advertisement information. This information will be disseminated within a predefined area using ROD.

B. ROD Overview

The protocol scheme is organized into two modules (i) an Optimized Distance Defer Transfer (ODDT) module; and (ii) a Store and Forward (SNF) module. The ODDT mechanism is used to optimize data dissemination in road sections (between two intersections) and in intersections. If no retransmitting vehicle is found, the vehicle in charge of the message uses the Store and Forward module to keep data until finding a better retransmitter.

1) ODDT: Optimized Distance Defer Transfer Module

As shown in Section II, one of the lacks of many dissemination protocols is the use of a discovering module to identify neighboring nodes and to know their coordinates in order to choose the best relay vehicle in charge of data propagation. Our first challenge was to use the best relay to propagate data without having any prior idea about neighboring vehicles parameters (coordinates, velocity, direction, etc.). Therefore, we decided to adopt the same method as in DDT and we did not save any information about the neighboring vehicles. As in DDT, the GPS position of the vehicle is encoded in the header of the broadcast message. In addition, ROD encodes an extra-information as shown in Figure. 1, where GPS_pos represents the sender position, OI_pos represents the outgoing intersection position and II_pos represents the ingoing intersection position (e.g. in Figure. 2 the outgoing intersection of vehicle V is B and its ingoing intersection is A). ROD relies on timing to select, in a distributed way, the best re-transmitter vehicle.

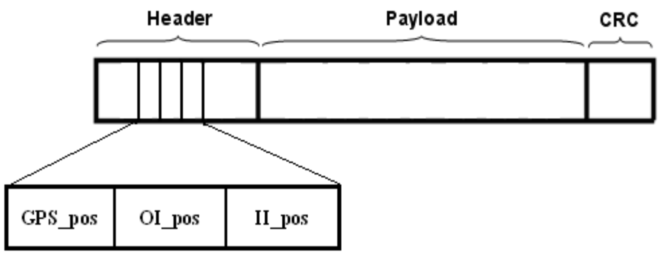

Figure 1. Header of the broadcast message

Throughout a road section, each message is propagated in each direction separately, in contrast to DDT that does not care of direction. Thus, when a message is received by a vehicle, it checks if it has the same couple of information “outgoing intersection” and “ingoing intersection” as the sender. Then, two cases are possible:

Case 1: Sender and Receiver have the same couple of information

The receiver compares its position to those of the sender and the outgoing intersection. If it is situated behind the sender it cancels the retransmission procedure. Otherwise, it computes a backoff time which is inversely proportional to the distance separating it to the sender and sets off a sending_timer S_t. If it receives the same packet before S_t expiration, the vehicle cancels the packet retransmission, otherwise it retransmits the packet.

Case 2: Sender and Receiver have not the same couple of information

The receiver checks the sender position. If the sender is not in the outgoing zone (see Figure. 2), it cancels the packet retransmission. Otherwise, it computes a backoff time which is inversely proportional to the distance separating it to the sender and sets off a sending_timer S_t. If it receives the same packet from another vehicle having the same couple (outgoing intersection, ingoing intersection) before S_t expiration, it cancels the packet retransmission, else it retransmits the packet. By this way, only the best situated vehicle in all intersection’s outgoing ways will relay the packet.

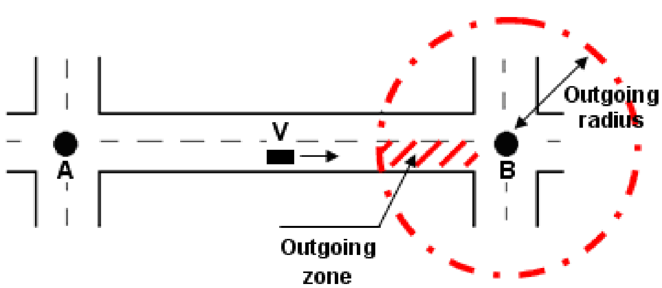

Figure 2. Outgoing zone

The diagram shown in Figure 3 illustrates the function of the ODDT.

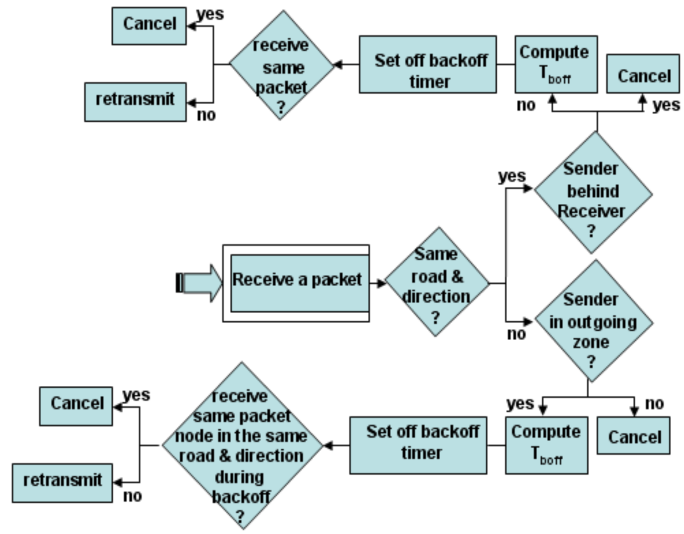

Figure 3. ODDT function

2) SNF: Store and Forward Module

The delivery ratio of DDT does not evolve even if it uses an interesting mechanism to optimize packet dissemination without overloading the network with topology discovering messages. An effective way to correct this deficiency is to add a store and forward module. So, instead of stopping the packet propagation when a vehicle does not found any better re-transmitter, the vehicle stores the packet and broadcasts it periodically with a time evolving period until finding a re-transmitter for the packet. After n SNF iterations, if a re-transmitter is found in the same road, the packet dissemination would be delegated to this node. This latter can execute any of the two modules depending on its neighborhood (it execute SNF if no other neighbor is found). As shown in Figure 4, vehicle V_2 receives the broadcast packet and tries to relay it but no re-transmitter could be found using the ODDT module, so V_2 stores the packet and rebroadcasts it periodically. Later, when V_2 overtakes V_3 it can send it the packet and stop re-transmitting it.

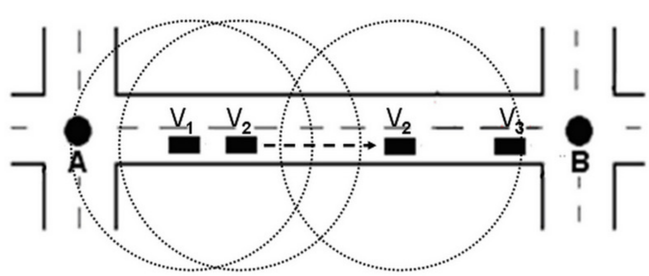

Figure 4. SNF function

IV. Simulations and Results

In this section, we evaluate the performances of ROD protocol via simulation. We used the Airplug software suite [13] that permits both road experiments and simulations under ns by using the same code. The simulations have then been done with Airplug-ns, an add-on to Network Simulator to reproduce real road conditions [4] [5]. The ROD performances are then compared to those of (i) basic DDT (Distance Defer Protocol) [6] described in Section 2, (ii) DDT with a Store and Forward mechanism, and (iii) MHVB (Enhanced Multi-Hop Vehicular Broadcast) [8], a road safety oriented protocol presented also in Section 2. In the following, we present the simulation environment and analyze the most relevant simulation results.

A. Simulation Setup

We used VehicleMobiGen [12], which is a Mobility Generator implemented in Orange Labs, to generate traffic. All the key parameters of the simulation are summarized in Table I.

TABLE I. Simulation Parameters

SIMULATION / MOBILITY SCENARIO	
Simulation time	150 s
Packet sending rate	3 packets/s
Road Width	15 m
Mobility Model	VehicleMobiGen
Number of vehicles	100 – 300
Velocity range	30 km/h – 110 km/h
Velocity in intersections	25 km/h
SNF period	10 s
Communication radio range	~250 m

B. Simulation Results

To evaluate the performances of our protocol, we focused on two performance metrics. (i) Saved rebroadcast ratio: the ratio between the number of packets saved in case of the simulated protocol and the number of packets disseminated with a simple flooding, and (ii) Packet delivery ratio: the fraction of vehicles that successfully receive the data.

1) Saved Rebroadcast Ratio

Figure 5 gives the saved rebroadcast ratio for all the four protocols. The difference between road safety dissemination protocols (e.g. MHVB) and infotainment dissemination protocols (e.g. DDT, ROD) could be seen clearly. In case of infotainment dissemination protocols, almost two thirds of the flooding packets are saved. The difference between ROD and DDT (ROD: 65.3 %, DDT: 71.8 %) is due to the store and forward module and the dissemination optimization in intersections. MHVB, as a road safety dissemination protocol, achieves a lower saved rebroadcast ratio than the others (~ 40%). In fact, MHVB is dedicated to safety applications which are sensitive to delay and delivery ratio, so packets are rebroadcast more frequently by more vehicles. These applications do not care with the excessive use of bandwidth.

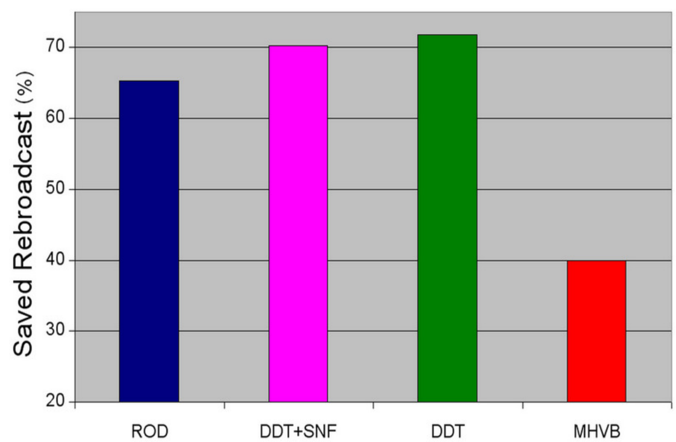

Figure 5. Saved Rebroadcast Ratio

2) Packet Delivery Ratio

We also evaluated the packet delivery ratio of ROD. We used a scenario with 200 vehicles. Figure 6 shows the delivery ratio changes of the four simulated protocols over time. The simulated vehicles have a mean velocity of 70 km/h. As expected, MHVB achieves the highest delivery ratio. Almost all vehicles receive the sent packet during the first 20s. In fact, the absence of a particular bandwidth constraint for this protocol allows it to procure this high delivery ratio within a limited time. On the other hand, DDT has a constant delivery ratio of 50%. This ratio depends on the initial distribution of the vehicles within roads and does not evolve over time since the dissemination stops at the first connectivity break. Adding store and forward module permits to improve DDT results since SNF gives the possibility to vehicles to store packets if no re-transmitters are found and send them later. This module permits to reach a delivery ratio of 85% in only 100 s. The dissemination optimization in intersections permits to improve the ROD results. After only 60s, we have a delivery ratio upper than 90%. This delay is accommodated to the sighted applications (infotainment services).

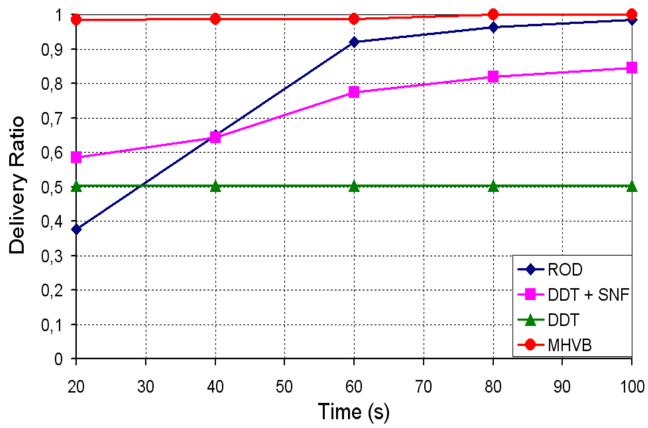

Figure 6. Delivery Ratio vs Time

Figure 7 shows the delivery ratios of the four simulated protocols after 60 seconds of simulation as a function of velocity. As usual, MHVB procures the best results whatever the mean speed. We can see that as much as velocity increases ROD outperforms DDT and DDT + SNF. For high speeds (e.g. 110 km/h), ROD is four times better than DDT in terms of delivery ratio. The delivery ratio is about 95% which means that almost all vehicles received the packet. The second interesting remark is that the curves of DDT and DDT + SNF are decreasing as speed increases. In fact, when speed increases in roads sections, we obtain a concentration of vehicles in the intersection since the speed in the intersections is fixed to 25 km/h. So with DDT and DDT + SNF, where there is no optimization of the packet dissemination in the intersections, the delivery ratio of the two protocols falls since they suffer from packet losses. On the other hand, ROD ensures the optimization of the dissemination in intersections which permits to minimize the data congestion effects in the intersections. As a result, it maintains a high delivery ratio (upper than 90%) even when the mean speed is 110 km/h.

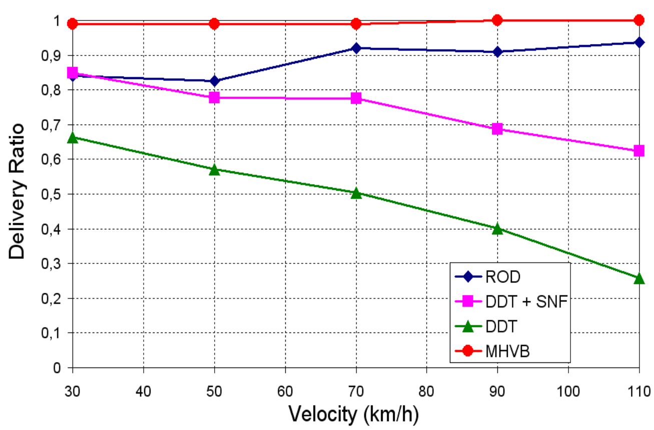

Figure 7. Delivery Ratio vs Velocity

Figure 8 shows the delivery ratios of the four protocols towards traffic density. Generally, delivery ratio increases with density. We remark in the figure that both ODDT and SNF modules improve the delivery ratio. In case of high densities, ROD permits to deliver packets to almost all vehicles in contrast to DDT and DDT+SNF.

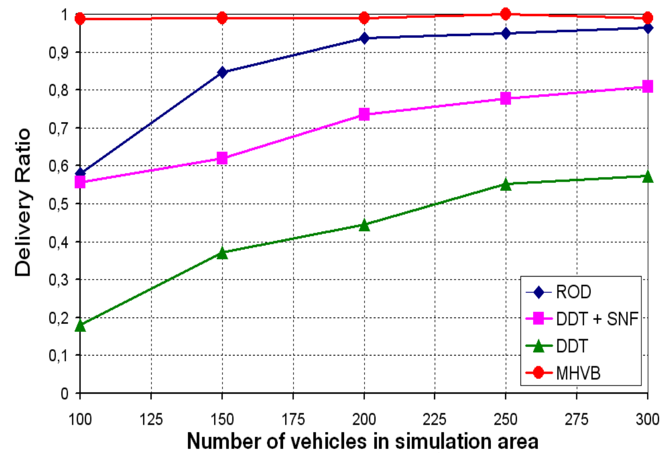

Figure 8. Delivery Ratio vs Density

V. CONCLUSION

Cooperative vehicular networks are particular networks characterized by (i) high speed of nodes, (iii) roads-constrained mobility, (iii) no power constraints, and (iv) variable communication conditions. Vehicular networks can be considered as the portal of many services, ranging from safety to traffic information and location based services (LBS). These services generally require efficient routing and dissemination protocols.

In this work we proposed an infotainment dissemination protocol called ROD which introduces an Optimized Distance Defer Transfer module to optimize data dissemination in both roads sections and intersections. ROD also implements a Store and Forward module allowing the storage of packets when no relay is found.

The performance evaluation via simulation study shows that ROD brings satisfactory results in term of resources use and excellent results in term of delivery ratio comparing to other existing solutions. As said in the abstract, ROD had been implemented and tested on roads [18] and shown good results in terms of delivery ratio and saved rebroadcast [19].

Actually, we are developing new services like info-traffic and parking's information services and we are defining a relevant mathematical model to determine the most appropriate values to choose for the SNF retransmission period. As in this paper there is not enough space to introduce this mathematical study and to describe the on-road tests and analyze their results, our whole solution will be described more in details later.

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