Efficient Data Dissemination in Cooperative Vehicular Networks

Journal:	*Wireless Communications and Mobile Computing*
Manuscript ID:	Draft
Wiley - Manuscript type:	Research Article
Date Submitted by the Author:	n/a
Complete List of Authors:	CHERIF, Mohamed; Orange Labs, Lannion SENOUCI, Sidi-Mohammed; France Telecom R&D, CORE/M2I Ducourthial, Bertrand; Université de Technologie de Compiègne
Keywords:	Vehicular networks, Data dissemination, Multi-hop communication, Store and Forward, Performance evaluation

Efficient Data Dissemination in Cooperative Vehicular Networks

Abstract- Vehicular Networks are drawing the attention of both research community and automotive industry since they provide Intelligent Transportation Systems (ITS) as well as drivers and passengers' assistant services. However, the industrialization of such networks faces a number of challenges, in particular the high cost of the infrastructure to deploy. To overcome this problem, an effective solution is to rely on cooperative vehicle-to-vehicle (V2V) communication to minimize the deployed infrastructure. Since, a large number of Cooperative V2V applications are broadcasting by nature, we proposed an efficient dissemination protocol: ROD (Road Oriented Dissemination). ROD consists in two modules: (i) Optimized Distance Defer Transfer module, and (ii) Store and Forward module. We compare our protocol to other dissemination protocols and analyze its performances by simulations, on-road tests and analytically. Performance study shows interesting results of ROD compared to the other existing solutions. ROD is able to provide a low end-to-end delay, a high delivery ratios and a minimum bandwidth usage since only a limited number of vehicles are involved in the broadcast scheme.

Keywords- Vehicular networks, Data dissemination, Multi-hop communication, Store and Forward, Performance evaluation.

1. Introduction

Today, cooperative vehicular networks are considered as the perfect way to bring more comfort to the passengers and more safety to the human life. In 1998, there were more than 60 million accidents in the world. Almost 38 million people were injured and

1,170,694 people were killed [20]. The financial cost of these crashes was more than 1,500 billion dollars. All these horrible statistics make governmental organizations allocating more and more interest and money to minimize the effects of this calamity. So, in 1999, the Federal Communications Commission allocated in the USA 75 MHz of spectrum in the 5.9 GHz band for Intelligent Transportation Systems (ITS). Besides, in 2008, the European Telecommunications Standards Institute (ETSI) allocated 30 MHz of spectrum in the same band. In Japan, since 2001, the ARIB STD-T75 has permitted the use of the 5.8 GHz frequency band and envisages the attribution of another 70 MHz frequency band in 2012 for ITS applications. Car manufacturers, automotive OEMs, networks operators, and service providers found a great interest in the domain since they attract people by providing many comfort and safety applications. As a result, several projects, consortium and standardization groups have been launched. The most known are the Car2Car consortium [1], SafeSpot Project [2], CALM Project [3], CVIS Project [4], GeoNet Project [5], ETSI-ITS [26] and Pre-Drive [27], etc. All these projects have roughly three targets (i) harmonization of vehicle communication standards worldwide, (ii) development of realistic deployment strategies and business models, 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 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. To limit as far as possible these two effects, one solution is to self-organize the vehicular network [19], [6] by using geographic clusters and delegating the data dissemination in each cluster to one node, called "head node" and elected dynamically. However, this requires huge logistic effort which limits its interest especially in case of local dissemination applications.

Our aim is to propose a new efficient approach for data dissemination in cooperative vehicular networks. This approach has to permit to (i) avoid the waste of bandwidth by optimizing the amount of vehicles that have to rebroadcast the packets especially in the intersections, (ii) use a store and forward module to help the limitation of the disconnection effects, and (iii) Adapt to both highway and city environments. 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) [7]. So, with ROD only one vehicle is selected with each transmission to rebroadcast the message in each direction. To fulfill the second requirement, ROD adds a store and forward mechanism used in 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 make it suitable also for city environment.

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. Section IV justifies the choice of the main key parameters of our protocol. Section V shows the on-road-test performances of ROD and

Section VI shows and discusses the main performance evaluation results issued from simulation study. Finally, the conclusion of this study and planned future work are discussed in Section VII.

2. Related Work

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

The simple flooding [22] 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 delay and delivery ratio constraints, and do not really care about the bandwidth since it will be used only for short times. In the following some protocols of these two classes are presented.

2.1. Dissemination of road safety information

Many dissemination protocols have been proposed to perform road safety services

[10] [11] [12] [13]. These protocols have to care about the delay and delivery ratio constraints even if all the available bandwidth is used.

In [10], the authors proposed 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, that 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 [11], the authors proposed STEID (Spatio-Temporal Emergency Information Dissemination protocol) 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 (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 called Direction Propagation Protocol (DDP) [12]. In this work, the 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. DDP has 3 modules: a custody transfer protocol, an intergroup 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 election method of the header and the trailer and do not detail the intra-group routing mechanism.

In [13], the author proposes ODAM, a protocol designed 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 it into account. However, only one vehicle called "relay" is 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 periodic messages sent by some vehicles lead to an excessive use of the bandwidth.

2.2. Dissemination of infotainment information

The infotainment services (such as delivering announcing advertisements about sale promotions, getting information on the available parking places, and carpooling possibilities, etc.) interest mostly the network operators and service providers. The dissemination protocols used in such class of services have no constraints in terms of delay and delivery ratio (a good delay or delivery ratio is appreciated but not mandatory). However, they have constraints related to the bandwidth use. Among the proposed dissemination protocols, the one that has acted as reference to the following works is Distance Defer Transfer (DDT) protocol [7]. DDT principle consists in relaying messages only by receiver that is 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 [7], 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, 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, TDADE is not effective in case of dense networks. In fact, the periodic Hello messages induce an excessive use of the bandwidth.

Paper [8] proposes UMB (Urban Multi-hop Broadcast) which is an IEEE 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 [9], a Mobility-Centric Data Dissemination algorithm for Vehicular networks (MDDV) 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 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 vehicular traffic. We saw for example that the majority of dissemination protocols designed for infotainment services fail to reach good delivery ratios in case of topology with many broken links. 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. The proposed protocol is able to both optimize the use of bandwidth and improve the delay and delivery ratio. In the following section, we bring a detailed description of our protocol and present its added values compared to other existing dissemination protocols.

3. 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 and announcements about sale information, etc. ROD enhances the bandwidth use, end to end delay and delivery ratios.

3.1. ROD Assumptions

In our work, we consider both urban and highway 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 IEEE 802.11a/b/g/n/p as wireless technology.

Initially, an infotainment application's information is sent by a RSU (Road Side Unit) or via 3G communication. It will be disseminated within a predefined area using a V2V communication.

3.2. 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. The two modules are described in details in this sub-section.

3.2.1. ODDT: Optimized Distance Defer Transfer Module

One of the lacks of many dissemination protocols seen in Section II is the use of a discovering module to identify neighboring nodes and know their coordinates in order to choose the best vehicle for data propagation. If we rely on such module, we have to fix the sending period parameter. If a small period is chosen, many resources risk to be wasted when sending the periodical discovering messages, especially in case of dense roads. Otherwise, if a high period is chosen, neighboring information would not be valorous all the more we have a very dynamic environment.

The 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, the same method as in DDT is adopted and no information about the neighboring vehicles has to be saved. 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: the outgoing intersection position and the ingoing intersection position. In Figure 1 the outgoing intersection of vehicle V is B and its ingoing intersection is A. In addition, each outgoing intersection is associated to an outgoing zone and an outgoing radius as shown in Figure 1. The outgoing radius depends on both the road section length and the velocity limitation. ROD relies on timing to select, in a distributed way, the best re-transmitter vehicle.

Throughout a road section, each message is propagated in each direction separately, in contrast to DDT that does not care for 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. We have two cases:

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 packet retransmission; otherwise it computes a backoff time which is inversely proportional to the distance separating it from 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 1), it cancels the packet retransmission; otherwise it computes a backoff time which is inversely proportional to the distance separating it from 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 each intersection's outgoing way will relay the packet.

Figure 2 illustrates the function of the ODDT module and introduces the 6 possible output states.

As shown in Figure 3.a, vehicles V_1 and V_2 receive broadcast packet from vehicle V. When extracting the sender information and running the ODDT algorithm, V_1 cancels the packet retransmission (output state n° 2) whereas V_2 retransmits the packet (output state n° 1). The packet sent by V_2 is intercepted by V, V_1, V_3 and V_4. So, the four vehicle run the ODDT algorithm. V and V_1 cancel the packet retransmission (output state n° 3), V_3 also cancels the packet retransmission (output state n° 4), whereas V_4 retransmits the packet. The packet disseminated by V_4 (situated in the outgoing zone) is intercepted by V_2, V_3, V_5, V_6, V_7, V_8, V_9, V_{10}, V_{11} and V_{12}, all these vehicles run the ODDT algorithm. As a result, V_2 cancels the packet retransmission (output state n° 3), vehicles V_5, V_6, V_8, V_{10} and V_{12} also cancel the packet retransmission (output state n° 6) whereas vehicles V_3, V_7, V_9 and V_{11} retransmit the packet.

This module is useful especially in case of urban environment characterized by the high density in the intersections that are usually equipped with traffic lights.

3.2.2. SNF: Store and Forward Module

The delivery ratio of DDT does not evolve even if it uses an interesting mechanism to optimize the 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 that has to retransmit the packet did not found any better retransmitter, the vehicle stores the packet and broadcasts it periodically with a time evolving period until finding a retransmitter for the packet. After n SNF iterations, if a retransmitter 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.

As shown in Figure 3.b, vehicle V_2 receives the broadcast packet and tries to relay it but no retransmitter 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 the retransmission process.

The choice of the retransmission period is a very important issue since a great period may lead to great dissemination delays and a small period can involve a loss of resources. The choice of this parameter will be discussed in Section IV.

4. Fine-Tuning ROD Parameters

The ROD performances could vary depending on the chosen protocol parameters especially the SNF period. In this section, we first define a mathematic model to represent the connection between two vehicles. Then, based on this model we determine the most appropriate values to choose for the SNF retransmission period. The two steps are detailed in the following.

4.1. Mathematical Model

According to many works [14], [15] the inter-vehicle distance in vehicular networks could be modeled with exponential distribution. Thus, the inter-vehicle distance distribution could be expressed as:

$$P(x) = \lambda . e^{(-\lambda . x)} \quad (1)$$

where λ represents the traffic density (vehicles/m).

Let's note R the communication range and V_{moy} the mean vehicles' velocity. According to [16], the probability to have a multi-hop connection between two x-distant vehicles is:

$$P_c(x) = \begin{cases} 1 & if\, 0 \le x \le R \\ \sum_{i=0}^{\left\lfloor \frac{x}{R} \right\rfloor} L(i,x) - e^{-\lambda R} . \sum_{i=0}^{\left\lfloor \frac{x}{R} \right\rfloor - 1} M(i,x) & if \quad x \ge R \end{cases} \quad (2)$$

Where $\left\lfloor \frac{x}{R} \right\rfloor$ is the largest integer smaller than or equal to $\frac{x}{R}$ and

$$L(i,x) = \frac{(-\lambda . e^{-\lambda R}(x - iR))^i}{i!} \quad (3)$$

$$M(i,x) = \frac{(-\lambda . e^{-\lambda R}(x - (i+1)R))^i}{i!} \quad (4)$$

In the rest of this section, ζ will represent the retransmission period of the SNF module (store and forward module). Our final target is the search of the optimal retransmission period ζ_{opt}. First we are going to compute the probability to have a multi-hop connection between two x-distant vehicles after n SNF iterations. For this purpose a

2-state probabilistic graph is used. The initial state is:

$$P(x) = [P_c(x),(1-P_c(x))] \quad (5)$$

where $P_c(x)$ is the probability to have, initially, a multi-hop connection between two x-distant vehicles and $(1-P_c(x))$ is the probability to have no connection between them.

Let's p_1 and p_2 be, respectively, the probability to establish connection between two non connected x-distant vehicles via SNF module and the one to loose the connection between two connected vehicles. Then, a 2-sate transition matrix can be obtained.

$$M_T = \begin{bmatrix} 1-p_1 & p_1 \\ p_2 & 1-p_2 \end{bmatrix} \quad (6)$$

So, we can determine the probability to have a first connection between two x-distant vehicles only after n SNF iterations:

$$P(x) = (1-P_c).(1-p_1)^{(n-1)}.p_1 \quad (7)$$

In practice, equation 7 could not be used till defining a method to compute p_1.

Since, the variation of vehicles positions is random, it is impossible to find a mathematic approach that models perfectly the probability p_1. But, in our case only the vehicles circulating in the same direction are able to relay the packets of each other. The relative displacement of these vehicles (same direction) is less random than the relative displacement of all vehicles. Based on some observations and measurements we proposed a mathematical model that approaches the probability p_1 but only in a low time range (less than one minute).

$$p_1 = (2/\pi).arctg\left(100.\lambda.\left|\sin\left(\frac{\xi.V_{moy}}{100}\right)\right|\right) \quad (8)$$

The p_1 value depends on three parameters which are λ (vehicle.m^{-1}), ζ (s) and V_{moy} (m.s^{-1}).

4.2. *Optimal retransmission period*

We are interested in calculating the optimal retransmission period of the SNF module. This corresponds to the case of low traffic (R ~ 1/λ, a mean value of one vehicle per radio range) where connectivity between distant nodes is not usually possible.

Using the formula 7 and injecting the values obtained with the two formulas 2 and 8, we can find the probability to have a multi-hop connection between two x-distant vehicles only after n SNF iterations. Hence, we obtained $P(x)$ as a function of ζ. Using this result, we plotted in Figure 4 the optimal values of ζ for different n values (λ = 1/R, V_{moy} = 50km/h). For example, we notice that the optimal SNF retransmission period providing the highest connection probability after 1 period is ~ 10s. This value will be referenced in the simulation study section later.

5. Experimental Characterization of ROD

In this section, we look into some on-road tests results of our protocol.

5.1. *Equipment description and Software tools*

To setup our experiments, we used a platform of seven vehicles numbered from 1 to 7. Each vehicle is equipped with a mini Dell laptop running Linux operating system (Redhat) and equipped with an Atheros PCMCIA IEEE 802.11b/g Orinoco card with external antenna (Blink Technology Omnidirectional Antennas), and Holux GPSlim236 Bluetooth based. We used a modified version of Multi-band Atheros Driver for WiFi, also known as MADWIFI [21] which gives the ability to monitor the entire transmitted and received packets that reach the network card.

To test our dissemination protocol, we used Airplug software suite [18], which permits both road experiments and simulations under NS using the same code for ROD. We implemented an announcement advertisement service that use ROD to disseminate information about fuel prices in the different gas stations, info traffic, restaurants, hotels, etc. Besides, we endowed the platform with a Tcl/Tk attractive interface as shown in Figure 5. In the following we give some on-road testbed results. We notice that a video demonstrating this work is also available in our website [23]. In the implemented service, a hotspot “Orange” diffuse announcements periodically and ROD is used to disseminate this information via V2V communication.

5.2. Results and Analysis

First, the required time to deliver packets to all the seven vehicles is analyzed. The mean inter-distance between vehicles is about 50m and the radio range is about 300m. Figure 6.a shows that 130 ms are sufficient to deliver packets to all the vehicles. When receiving the information, the farthest vehicle was nearly 1000m far from the Orange hotspot. It could be noticed that 3 hops were used to reach this vehicle. The packet broadcast by the hotspot is received by both first and second vehicle within almost 17 ms. Then the second vehicle takes nearly 100 ms to deliver packet to vehicles 3, 4, 5 and 6. So we can conclude that the distance between vehicle 2 and the hotspot is relatively small, so vehicle 2 takes much time (backoff) to retransmit packets. Finally, the vehicle 6 re-broadcasts the packet and vehicle 7 receives it. Vehicle 7 receives the packet within 130 ms (after 3 hops) which could be considered a good delay for infotainment applications.

In addition, the protocol reliability in terms of saved resources was checked in case of different traffic densities. The saved rebroadcast (the percentage of saved packets comparing with simple flooding) was computed for two inter-distance mean values (50m and 200m). Figure 6.b shows that for an inter-distance mean value of 200m, ROD permits to save nearly 37 % of the simple flooding traffic. When the inter-distance between the vehicles was reduced, the obtained results were become better. In fact 63 % of the traffic generated in case of simple flooding could be saved. This improvement is simply due to the fact that more vehicles receive a sent packet and hence few vehicles have to retransmit it.

6. Simulation Study

In this section, we evaluate the performances of ROD protocol via simulation. The simulations have been performed using Airplug-ns, an add-on to Network Simulator to reproduce real road conditions [25]. The ROD performances are then compared to those of (i) basic DDT described in Section 2, (iii) DDT with a Store and Forward mechanism, and (iv) MHVB [10] a road safety oriented protocol presented also in Section 2. In the following, we introduce briefly the mobility model used to realize these simulations, we present the simulation environment and the main simulation parameters and we analyze the main simulation results.

6.1. Mobility model

Mobility model, used to generate the traffic, has a great impact on vehicular network protocols and the accuracy of the obtained simulation results. In this work we developed our own realistic traffic generator called VehicleMobiGen (VMG) [24]. VanetMobiGen permits to fix different speed ranges in road sections and intersections. It defines a realistic circulation model. Thus, vehicles are initially uniformly distributed over the different roads and then move on the simulation area respecting both the fixed velocity range and the acceleration / deceleration parameters.

6.2. Simulation setup

The simulation area covers 2000 × 2000 m², 9 two-way roads and 9 intersections. For the displacement behavior, each vehicle changes continuously its speed respecting the velocity range and the acceleration/deceleration parameters. Further to the analytical study results, we choose a 10s SNF retransmission period. All the key parameters of the simulation are summarized in Table I.

6.3. Simulation results

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

6.3.1. Saved Rebroadcast Ratio

Figure 7.a 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) can be seen clearly. In case of infotainment dissemination protocols, almost two thirds of the flooding packets are saved. The difference between ROD and DDT (65.3 % for ROD and 71.8 % for DDT) 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 bandwidth use.

6.3.2. Packet Delivery Ratio

The packet delivery ratio of ROD was also evaluated. A scenario with 200 vehicles was used. Figure 7.b 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 a store and forward module permits to improve DDT results since SNF gives the possibility to vehicles to store packets if no retransmitters 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 60 s, we have a delivery ratio upper than 90%. This delay is accommodated to the sighted applications (Infotainment).

Figure 7.c 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. Now, if the three infotainment dissemination protocols are compared, the first remark would be 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. As a result, it maintains a high delivery ratio (upper than 90%) even when the mean speed is 110 km/h.

Figure 7.d shows the delivery ratios of the four protocols as a function of traffic density. Generally, delivery ratio increases with density. It could be noticed 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.

7. Conclusion

Cooperative vehicular networks are particular wireless networks based on Vehicle-to-Vehicle and Vehicle-to-Infrastructure communications. They are characterized by (i) high speed of nodes (iii) roads-constrained mobility (iii) no power constraints (iv) variable communication conditions. Vehicular networks can be considered as the portal of many services, ranging from security and 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 the data dissemination in both road sections and intersections. ROD also implements a store and forward module allowing the storage of packets when no relay is found. We gave the possibility to optimize the choice of the store and forward retransmission period via an analytical probabilistic study.

The performance evaluation via on-road tests (A video that illustrates these tests could be found in [26]) and simulation study shows that ROD brings satisfactory results in term of resources use and excellent results in terms of delivery ratio and end-to-end delay comparing to other existing solutions.

Actually, we are developing new services like info-traffic and parking availabilities. These services, also based on ROD protocol, will be demonstrated in the same platform but with more vehicles.

References

[1] *C2C-CC (Car2Car Communication Consortium).* Available: http://www.car-to-car.org

[2] *SafeSpot Integrated Project.* Available: http://www.safespot-eu.org/

[3] *CALM Project (Continuous Air interface for Long and Medium distance).* Available: http://www.isotc204wg16.org/concept

[4] *CVIS Project (Cooperative Vehicle-Infrastructure Systems).* Available: http://www.cvisproject.org

[5] *GeoNet Project.* Available: http://www.geonet-project.eu/

[6] M.O. Cherif, S.M. Senouci and B. Ducourthial, "CSP: Cluster-based Self-organizing Protocol for Vehicular Networks", *in Proceedings of the 2nd IEEE-GIIS Conference,* Hammamet, Tunisia, June 2009.

[7] M.T. Sun, W. Feng, T. Lai, K. Yamada, H. Okada and K. Fujimura, "GPS-based message broadcast for adaptive inter-vehicle communications", *in Proceedings of the IEEE Vehicular Technology Conference (VTC 2000),* vol. 1: 2685-2692, Boston, USA, September 2000.

[8] G. Korkmaz, E. Ekici, F. Ozguner and U. Ozguner, "Urban Multi-Hop Broadcast Protocol for Inter-Vehicle Communication Systems", *in Proceedings of the 1st ACM Workshop on Vehicular Ad hoc Networks (VANET 2004),* pp: 76-85, Philadelphia, USA, October 2004.

[9] H. Wu, R. Fujimoto, R. Guensler and M. Hunter, "MDDV: A Mobility-Centric Data Dissemination Algorithm for Vehicular Networks", *in Proceedings of the 1st ACM Workshop on Vehicular Ad hoc Networks (VANET 2004),* pp: 47-56, Philadelphia, USA, October 2004.

[10] M. Mariyasagayam, T. Osafune and M. Lenardi, "Enhanced Multi-Hop Vehicular Broadcast (MHVB) for Active Safety Applications", *in Proceedings of the 7th International Conference on ITS Telecommunications (ITST 2007)*, pp: 1-6, Sophia-Antipolis, France, June 2007.

[11] J. Nzouonta, C. Borcea, "STEID: A Protocol for Emergency Information Dissemination in Vehicular Networks", *Report, Department of Computer Science, New Jersey Institute of Technology*, 2006.

[12] T.D.C. Little and A. Agarwal, "An Information Propagation Scheme for VANETs", *in Proceedings of the 8th IEEE Conference on Intelligent Transportation Systems (ITSC 2005)*, pp: 155-160, Vienna, Austria, September 2005.

[13] A. Benslimane, "Optimized Dissemination of Alarm Messages in Vehicular Ad-Hoc Networks (VANET)*", in Proceedings of the 7th High Speed Networks and Multimedia Communications Conference (HSNMC 2004)*, pp: 655-666, Toulouse, France, July 2004.

[14] H. Inose and T. Hamada, *Road Traffic Management*. Tokyo, Japan: Sangyo-Tosho, 1972.p.23 (in Japanese).

[15] A. Kesting, M. Treiber, M. Schonhof, C. Thiemann and D. Helbing, "Analytic and Simulated Statistics and Applications of Inter-Vehicle Communication", *Presentation at the 1st open workshop on Simulation of the Car2Car Communication Consortium and the COMeSafety project*, March 2007.

[16] O. Dousse, P. Thiran and M. Hasler, "Connectivity in Ad-hoc and Hybrid Networks", *in Proceedings of IEEE INFOCOM 2002*, pp: 1079-1088, New York, USA, June 2002.

[17] http://www.hds.utc.fr/~ducourth/airplug/doku.php?id=en:dwl:ns:welcome

[18] B. Ducourthial, S. Khalfallah, "A Platform for Road Expriments", *in Proceedings of the 69th IEEE Vehicular Technology Conference (VTC2009-Spring)*, Barcelona, Spain, April 2009.

[19] L. Wischhof, A. Ebner and H. Rohling, "Information Dissemination in Self-organizing Intervehicle Networks", *IEEE Transactions on Intelligent Transportation Systems*, 6(1): 90-101, 2005

[20] Safe Car Guide. Available: http://www.safecarguide.com/exp/statistics/statistics.htm

[21] Multi-band Atheros Driver for WIFI (MADWIFI). Available: http://madwifi.org

[22] N. Karthikeyan, V. Palanisamy, K. Duraiswamy, "Performance Comparison of Broadcasting methods in Mobile Ad Hoc Network", *International Journal of Future Generation Communication and Networking* , Vol.2, N.2, June 2009.

[23] ROD Proof of concept. Available: http://www.senouci.net/download/video_rod.wmv

[24] Introduction of VehicleMobiGen (VMG). Available: http://www.senouci.net/VehicleMobiGen.pdf

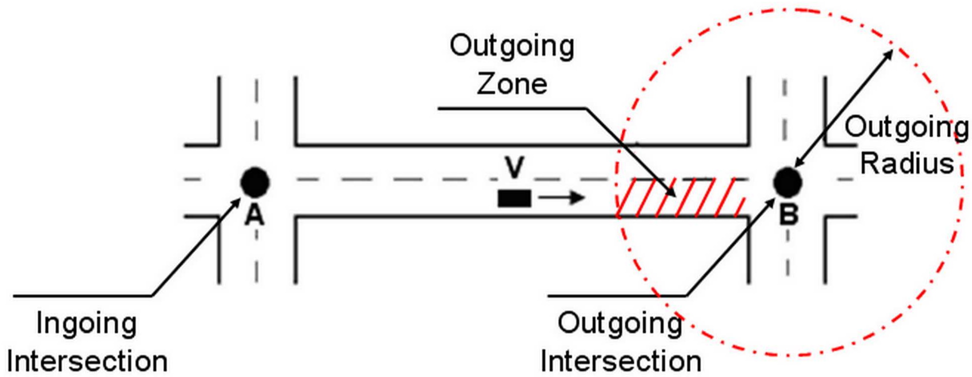
[25] S. Khalfallah an B. Ducourthial "Bridging the Gap between Simulation and Experimentation in Vehicular Networks", *Submitted to VTC-fall 2010*

[26] *ETSI- ITS*. Available: http://www.etsi.org/WebSite/technologies/IntelligentTransportSystems.aspx

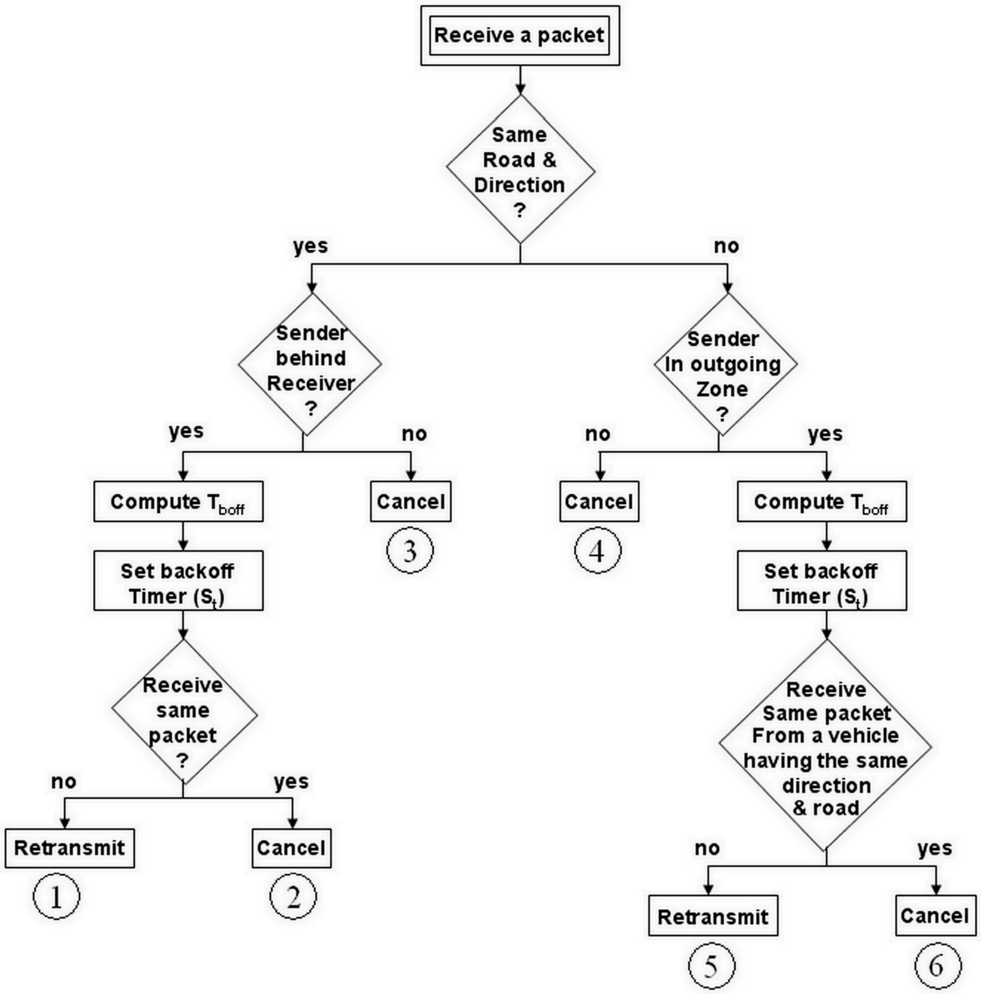
[27] *Pre-Drive C2X Project*. Available: http://www.pre-drive-c2x.eu

TABLE I. SIMULATION PARAMETERS

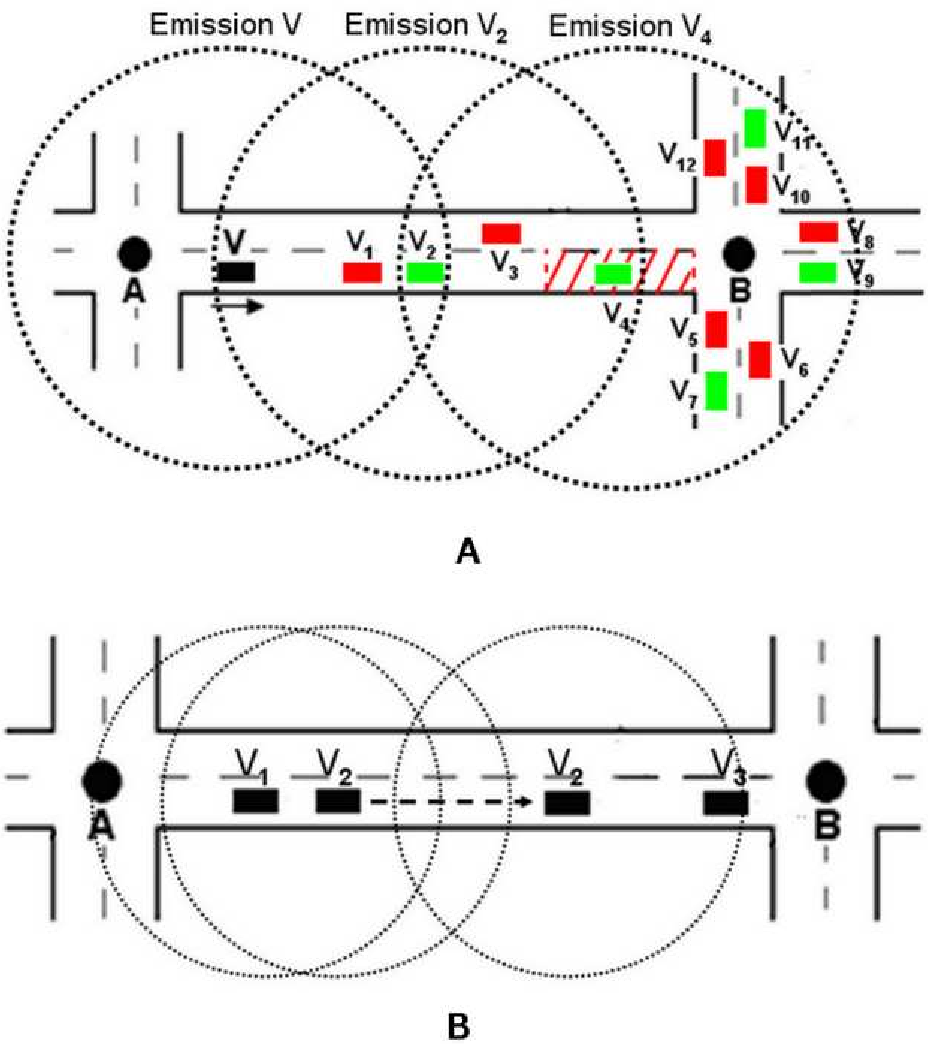
SIMULATION / MOBILITY SCENARIO			
Simulation time	150 s	*Packet emission time*	15 s
Packet sending rate	3 packets/s	*Road Width*	15 m
Mobility model	VMG	*Number of vehicles*	100 – 300
Velocity range	30 – 110 Km/h	*Velocity in intersections*	25 Km/h
SNF period	10 s	*Communication range*	~ 250 m



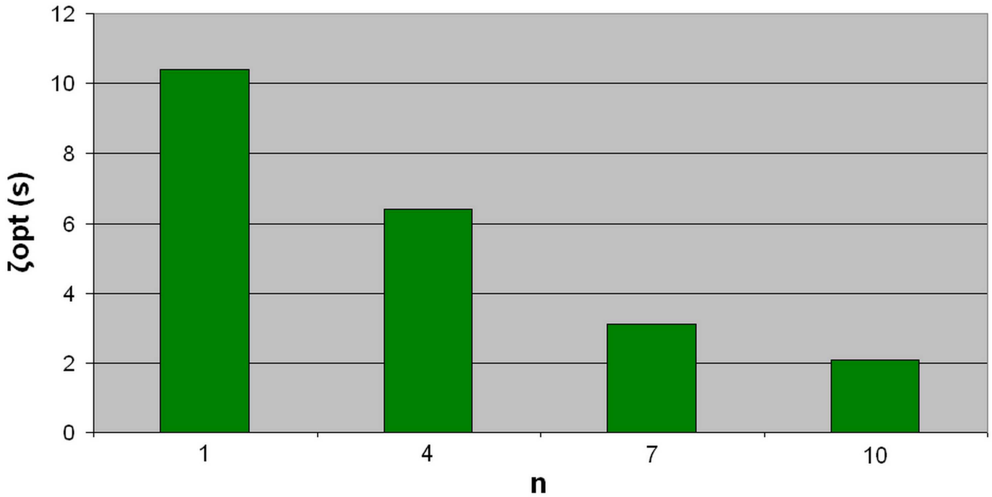
Ingoing and outgoing intersections.
169x66mm (600 x 600 DPI)



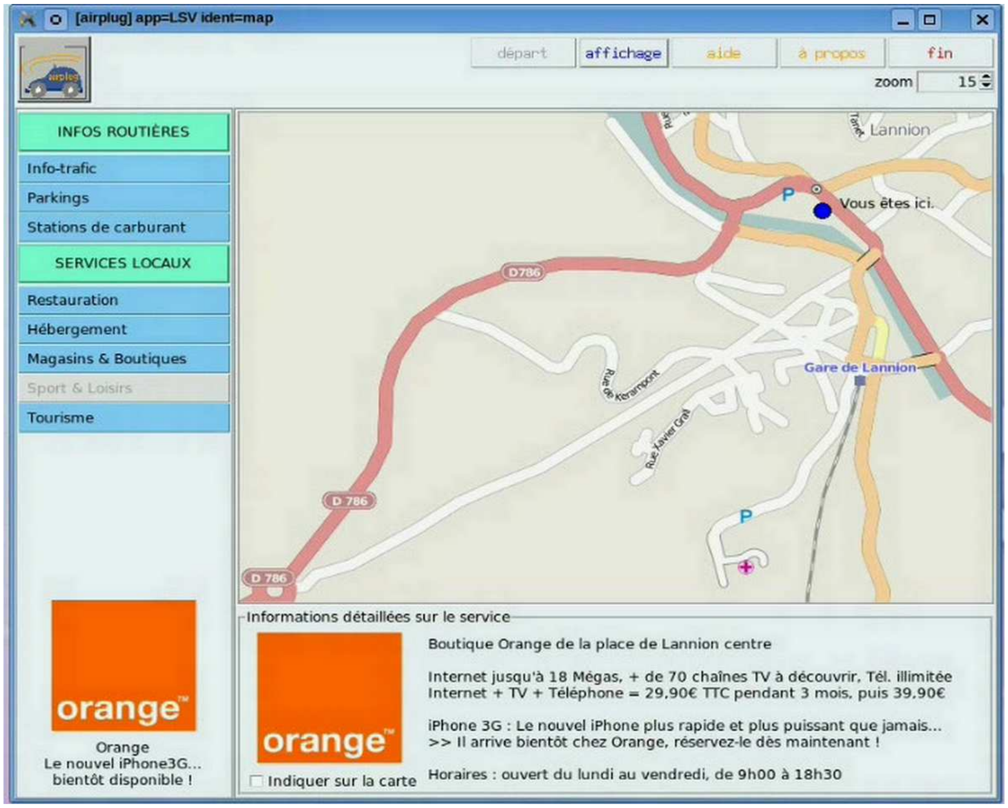
ODDT function.
118x119mm (600 x 600 DPI)



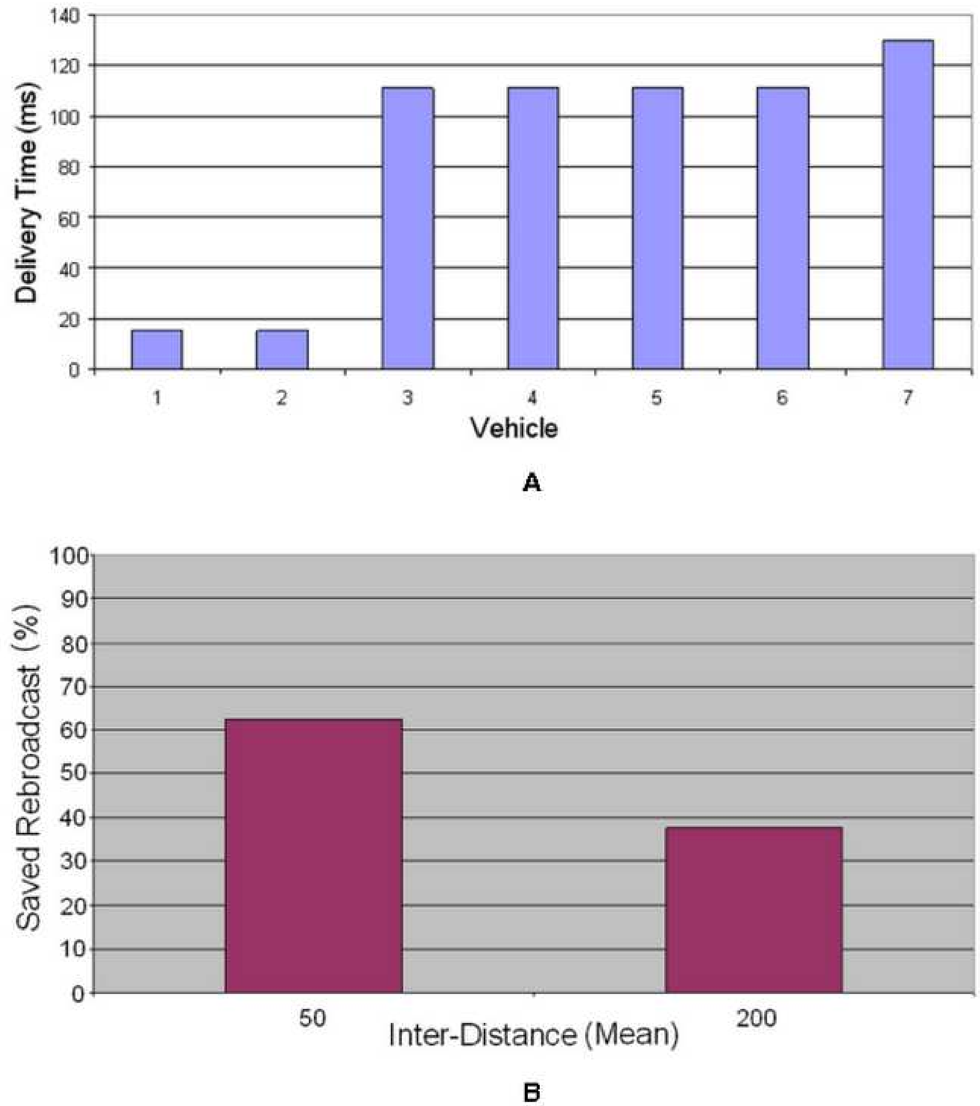
(a) Optimized Distance Defer Transfer module. (b) Store and Forward module.
177x192mm (96 x 96 DPI)



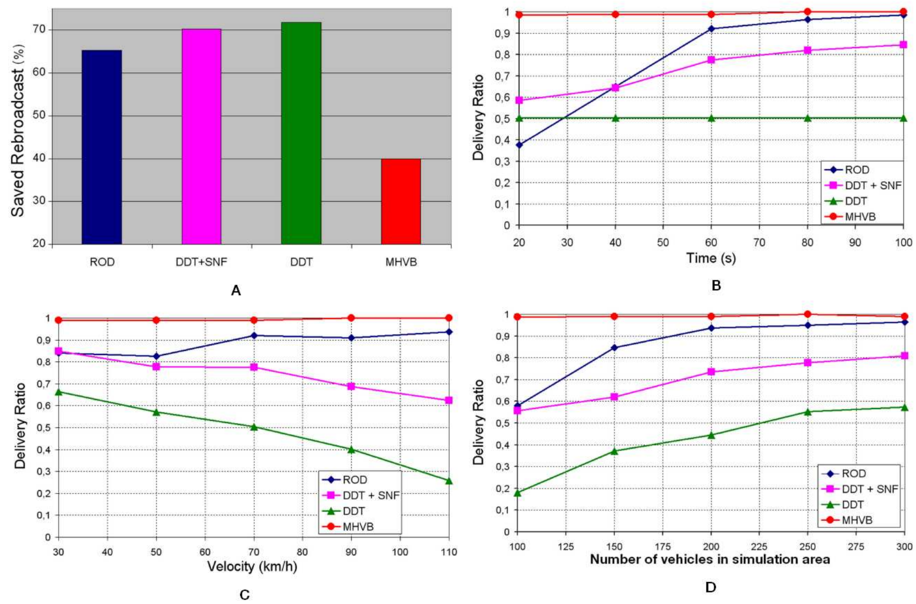
ζopt vs. SNF iterations (n).
127x64mm (600 x 600 DPI)



Platform interface
101x81mm (300 x 300 DPI)



(a) Delivery time for all vehicles (inter-distance value of 50 m). (b) Saved rebroadcast vs Inter-distance mean value.
92x104mm (180 x 180 DPI)



(a) Saved rebroadcast ratio. (b) Delivery ratio vs Time. (c) Delivery ratio vs Velocity. (d) Delivery ratio vs Network density.
243x152mm (150 x 150 DPI)