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Optimal broadcasting algorithm for VANET system

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Abstract. New and innovative approaches are expected to improve road safety and prevent road traffic incidents, based on the exchange of information between vehicles. Our aim is to respond to the need for rapid and reliable exchange of messages containing information on the state of vehicles. For this purpose, we propose an algorithm that prioritize the broadcasting of emergency messages and privilege long-distance communication so as to speed up the dissemination of warning messages without saturating the VANET.

Keywords: VANET, Broadcasting algorithms, braking signals.

1 Introduction

The main function of Vehicular Ad hoc NETWORK (VANET) is to prevent road traffic incidents, leveraging a rapid and reliable exchange of messages vehicles. However, the high dynamics of VANETs, sometimes coupled with a high density of vehicles in urban areas, imposes several restrictions on the use of standard networking solutions used under static or low movement situations. The use of RoadSide-Units (RSU) and fixed infrastructure improves the message delivery and reduce the bandwidth usage by diminishing the need of multi-hop retransmissions; upon the reception of an emergency message, the RSU-based infrastructure may partially endorse the function of (i) disseminating alerts and (ii) displaying warning messages on dedicated information boards. Due to limited budget, RDU are often too few to cover the whole road network. Thus, VANET appear as a cost-effective alternative to RSU. Recent trends in the automotive industry lies in equipping vehicles with a VANET-enabled safety system, named on-Board Units (OBUs). Given the rapid renewal of the vehicle fleet in developing countries, more efforts have been conducted to enhance the messages spread, considering their relative priorities. In this respect, some solutions re-

duce the probability of collisions during the message spread across the network, by adapting the signal strength [3, 4, 5, 6, 7] or leveraging directional antennas [1, 2]. Nonetheless, lowering the signal strength reduces the network connectivity/reachability [8, 9, 10, 11, and 12]. Directional antennas perform poorly if the antenna get misaligned during an accident. The proposed algorithms control the message transmission [13, 14, and 15] depending on the environmental conditions (presence of fading and multipath propagation caused by the re-reflection of signals from obstacles).

In this article, we propose a novel dissemination strategy that prioritizes time-sensitive messages that relate to an accident. We first evaluate the distance that a message should travel to alert nearby vehicles and avoid an accident (Section 3). Based on this distance, we prioritize warning messages. In addition, we propose a strategy that prevents the saturation of the transmission channel, by privileging long-distance communication to the detriment of many short distance transmissions (Section 4) so as to speed up the dissemination of broadcasted messages (Section 5).

2 RELATED WORKS

Like any network using competitive CSMA / CA access technology, VANET is extremely sensitive to the number of users and the volume of traffic that is carried. The IEEE 802.11p standard prioritizes some messages, using the so-called CCH channel. In this paper, we analyze the methods of prioritizing traffic on the main channel. There are two situations in which a node is unable to transmit a message. In the first case, the node, which attempts to access the transmission medium, detects that the channel is occupied. A temporization is then started, followed by a new access attempt. In the second case, several nodes simultaneously attempt to transfer data, which leads to a collision followed by a retry. In order to prevent such overload/collision, the following approaches have been proposed:

Broadcasting based on environmental information - The basic idea is to tune the transfer of messages, based on a knowledge on neighboring nodes. Information about neighboring nodes is added to the packet header and the packet is broadcasted over one or two hops, which leads to an excessive overload.

Broadcasting based on network clustering - This approach is widely used with MANET. Network clustering is the process of dividing the nodes into clusters. Clusters maintenance is done in two ways:

- Based on the control of periodically broadcasted messages over the network.
- By listening to data traffic. Algorithms based on this principle include On Demand Multicast Routing Protocol (ODMPR), Mobility-Centric Data Dissemination Algorithm for Vehicular Networks (MDDV), Dynamic Backbone-Assisted MAC (DBA-MAC) [10].

Sending based on information on traffic parameters – Protocols operate based on some information related to the neighboring nodes, their direction of travel and speed. Usually, the network congestion is limited by restricting the transmission to a small number of hops (typically one or two hops) and by merging the packets during their

relaying. The merging is done when the incoming packets e.g., follow the same direction of travel. Protocols include Optimized Adaptive Probabilistic Scattering (OAPB), Optimized Adaptive Probabilistic Scattering and Deterministic Scattering (OAPB/DB), Automatic Scattering, Distributed Vehicular Scattering (DV-CAST), Density Dependent Reliable Scattering in Vehicular Ad Hoc Networks (DECA) [10, 16, 17].

Broadcasting based on location information - Location-based broadcast methods rely on the information from satellite navigation systems such as GPS or GLONASS. The message source indicates in the message the geographical area wherein the message should be distributed. Upon the reception of a message, a node forwards the incoming message towards the desired area. Note that such approaches do not perform well in absence of positioning (tunnels). Location-aware protocols include Ad-Hoc Multi-Hop Broadcast (AMB), Distributed Robust Geocast (DRG), Edge Aware Epidemic Protocol (EAEP), Position Aware Reliable Broadcast Protocol (POCA), Smart Broadcast (SB), Urban Multi-Hop Broadcast (UMB) [14, 10, 16].

Distance-aware broadcasting - The decision on whether to retransmit the message is made based on the distance with the message source. The nodes, at the greatest distance, retransmit the incoming message quickly while others delay their retransmissions. As a result, a small number of retransmissions is needed to cover a large area. Such protocols include: direct retransmission (CTR), MobySpace, optimized alarm message broadcasting (ODAM), fast broadcast (FB), vehicle assisted data transmission (VADD) [10, 16].

Probabilistic diffusion – protocols rely on probabilistic functions to control the transmission delay; the same transmission probability is applied to all the traffic or is parametrized depending on the message content, the number of neighbors, the number of duplicates received so far etc... Such protocols include e.g. Position Based Adaptive Broadcasting (PAB), Receive Estimate Alarm Routing (REAR) [18, 19].

3 Techniques for improving the resilience of the VANET network

The network resilience depends of the quantity of message drops due to e.g. noise, interferences, reverberation or collisions. In particular, the probability that the message delivery fails, which is denoted p_{fail} , corresponds to the cumulated probability of failure during message delivery (p_{col}) and during access to the channel (p_{acc}). Thus, the probability of success of the transmission process, denoted P_{tr} verifies:

$$P_{tr} = (1 - p_{fail}) = (1 - (p_{col} + p_{acc})) \quad (1)$$

In turn, the probability of success of the transmission depends on the number of nodes N in communication range and the frequency of generated messages f_{br} . The following notation reflects the dependence:

$$P_{tr} \rightarrow \max_{Ua} |N, f_{br} \quad (2)$$

The probability of success may be increased by diminishing the volume of relayed traffic, by devising an efficient relaying algorithm or by decreasing the message coverage (a.k.a time to live). In addition, it is necessary to prioritize critical messages.

4 Calculation of the information distance

The main objective of our emergency system is to inform road users that are nearby, about accidents. To this end, it is necessary to infer the distance that the warning message should travel and to set accordingly a proper TTL for the warning/alert messages. Similarly, the frequency of dissemination of safety information messages needs to be parametrized. These parameters should be sufficient to enable a vehicle travelling at high speed to avoid an accident.

4.1 Limitation of information distance

It is assumed that the location of each node is determined by the coordinates given by the GPS system. Let consider an accident (see Figure 1) in which the vehicle V_1 collides with an obstacle and, stops abruptly, i.e., $v_1 = 0$. In order to avoid another accident, the second vehicle V_2 , which is travelling at a speed of v_2 , should have enough time to stop.

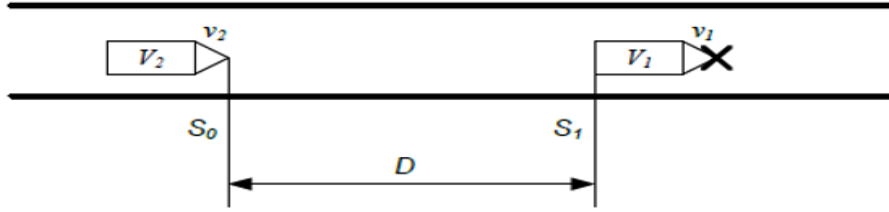


Fig. 1. Notification distance

Assuming that the driver of V_2 is successfully warned of the danger, the distance that the V_2 vehicle has time to travel, depends of (i) the driving speed v_2 , (ii) the driver reaction time t_r and (iii) the braking distance, which in turn depends on the acceleration/deceleration a_2 of the vehicle. Taking into account the above parameters, we may deduce the average time t_{stop} during which the driver must be warned and the distance, D_{stop} which the vehicle will travel from the moment of warning:

$$\overline{t_{stop}} = t_r + t_{br} \quad (3)$$

$$\overline{D_{stop}} = v_2 t_r + S_{br} \quad (4)$$

Where t_{br} is the braking time, S_{br} is the distance travelled by the car in t_{br} , t_r is the reaction time of the driver. To determine the values of t_{br} and S_{br} , we assume that the braking of the V2 vehicle occurs with a constant acceleration a_2 , then we use the following uniform deceleration equations:

$$S_{br} = S_0 + v_0 t_{br} - \frac{at_{br}^2}{2} \quad (5)$$

$$v = v_0 - at_{br} \quad (6)$$

Where v_0 is the speed of the V2 vehicle, at the time the warning report is received. Substituting these values in Equations (7) and (8), the braking time and the braking distance are:

$$t_{br} = \frac{v_0}{a} \quad (7)$$

$$S_{br} = v_0 t_{br} - \frac{at_{br}^2}{2} \quad (8)$$

Overall:

$$\overline{t_{stop}} = t_r + \frac{v_0}{a'} \quad (9)$$

$$\overline{D_{stop}} = v_2 t_r + v_0 t_{br} - \frac{at_{br}^2}{2} \quad (10)$$

Taking into account ISO 611:2003 standard [20], relating to the vehicle braking, the driver's reaction time varies from 0.4 to 1.6 seconds, depending on e.g. her/his psycho-physiological characteristics, her/his condition, her/his experience. Acceleration at uniform idle speed depends strongly on the quality of the braking system and the road surface [21]. Thus, still according to ISO611:2003(en) [20], on dry surfaces and drum brakes, it is 6 m /s². For a winter road, this value is reduced up to 6 times. Therefore, taking into account the worst-case scenario, we assume that $a = 1 \text{ m/s}^2$. Overall, we obtain $\overline{t_{stop}} = 22.2 \text{ s}$, $\overline{D_{stop}} = 282 \text{ m}$ for a vehicle moving at 80km/h. Since the V2 vehicle must stop well in advance, the minimum information distance must be $D_{inf}^{min} > \overline{D_{stop}}$.

5 Relays dimensioning and parameterization

5.1 Estimation of the number of relays

In order to ensure that the warning message travels the required distance, it should be considered that setting the TTL value too low will result in a premature packet drop, i.e. before they reach the required information distance.

$$Ttl > t_{inf}^{max} \geq t_{inf}^{min} \quad (11)$$

$$\text{with: } \overline{t_{stop}} = t_r + \frac{v_0}{a'} \quad (12)$$

- t_{inf}^{max} = The time of the arrival of the braking message at the node concerned.
- $t_{inf}^{min} = \overline{t_{stop}}$

So, to avoid saturating the channel, the TTL must be minimized as much as possible, while keeping it higher than t_{inf}^{max} .

Furthermore, to avoid broadcasting when the node is too far from the accident, the TTL must be as small as possible.

$$D_{inf}^{max} > D_{inf}^{min} = \overline{D_{stop}} \quad (13)$$

D_{inf}^{max} = Maximum distance to which the braking message must reach the driver.

We calculate the probability of receiving the message as a function of the distance, using the model introduced by Nakagami [28].

In order to assess the distance of distribution of broadcast messages, many factors are considered, e.g. vehicle density, location and ground conditions, which affect the occurrence of reflected signals. In [22, 27, 28], it is proposed to use the analysis apparatus obtained in [22] which, taking into account the above factors, allows the cumulative probability distribution function CDF (Cumulative Distribution Function) of the message transmission distance to be evaluated as follows:

$$F_R(a) = 1 - P(\gamma(a) > \psi) \quad (14)$$

Where R is the interaction distance; $P(\gamma(a) > \psi)$ is the probability that the Signal-to-NoiseRatio (SNR), is greater than the threshold value required for proper message reception.

By substituting the probability density function of the Nakagami [28] model in the expression (14), it is possible to calculate the CDF under different signal propagation conditions, depending on the location of the transmission. In this case, the mean value of the information distance can be obtained from (14) as:

$$E[R] = \int_0^{\infty} (1 - F_R(a)) da \quad (15)$$

5.2 Algorithm for delay level control

The proposed broadcasting algorithm corresponds to probabilistic and parametric methods. We propose to use the SINR (Signal-to-interference-plus-noise ratio) to control the propagation. The proposed algorithm determines a delay for transmitting the incoming messages; the delay value varies according to the SINR of the received message. When the message is delayed, the node is placed in a promiscuous mode

and listens to any emitted message. If a duplicate message is sniffed, the delayed message is deleted.

In addition, the algorithm limits the message lifetime. The working principle of the algorithm is detailed in Figure. 2.

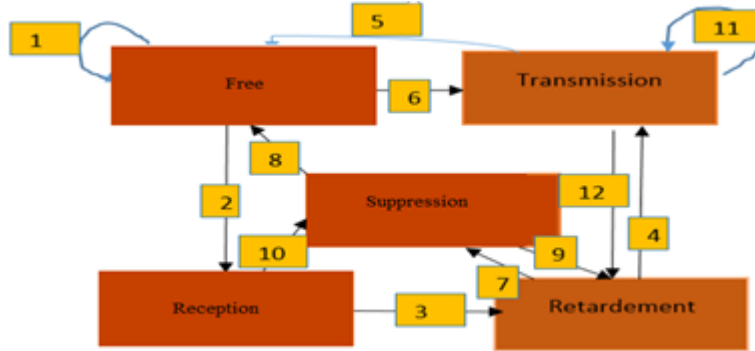


Fig.2. Diagram of node state transitions

Originally, the node is in the free state (1). The node leaves this state upon reception (2) or emission (6) of a message on the channel. If a new message arrives, the delay is defined based on the related SINR value, which is distributed according to the exponential law (3).

This setting of the delay interval gives priority to messages with lowest SINR levels, because the source of these messages is either far away or are located in the deepest fading zone. If no duplicate message is received during the delay interval, the current message is sent (4). Otherwise (i.e. if a duplicate message is received), then the original message is deleted. In the following cases of duplicate messages, they are all deleted immediately (10).

Once the deletion interval is elapsed, the message is removed from the delay buffer (7). If the delay buffer is empty, the node switches to the "free" state (8). Otherwise, the node expects the timer to expire to treat the next message (9). After all messages have been sent using the transmit queue (11), the node returns to the free state (5) or switches to the waiting state (12).

5.3 Choosing a delay

A critical feature of the proposed algorithm is the parametrization of the delay, which is based on the SINR value obtained from the physical layer. The delay is set so as maximize reliability rather than based on the distance as is the case in [22,23]. Thus, priority is not given to nodes that are far from the source but to nodes for which there is a degradation in the probability of successful delivery.:

$$Delay = \left(\frac{1}{1 + SINR} \right) * TTL + cte \quad (16)$$

$$SINR = \frac{Signal}{Interference + Noise} \quad (17)$$

6 Proposed algorithm

6.1 Lifetime limit and duplication control

Let analyze the proposed algorithm (Figure 2). A buffer is needed to store the incoming messages. If the incoming packet has been broadcasted, the packet is processed. Otherwise, the packet follows standard mechanism regulated by IEEE 802.11p.

During the period of low channel load, the buffer is mainly empty. If no data is available, the packet is immediately processed, i.e., the signal level of the incoming packet is used to determine the corresponding time delay value. A flag is used in the buffer structure to indicate if a duplicate message has been received. Then, the packet is placed in the buffer and the delay timer set is started. A detailed block diagram of this algorithm is shown in Figure 3.

The intended goal of this algorithm is to keep packets with a TTL below a threshold $TTL_{max} = t_{inf}^{max}$, while removing duplicate packets.

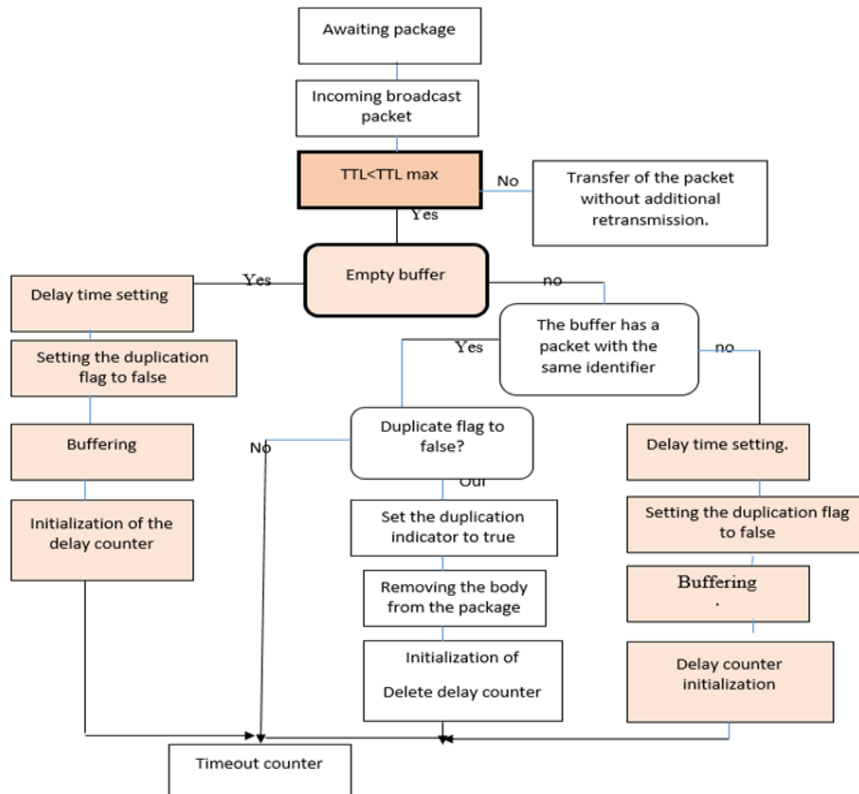


Fig. 3 Algorithm for duplication control and packet lifetime limitations

7 Experiments

In order to evaluate the performance associated with our solution, we have carried out a series of simulations.

7.1 Simulation Environment and parameters

Relying in the NS-2 simulation tool (v-2.35), we evaluate the effectiveness of our proposed method. Table 1 summarizes the simulation parameters. We consider the road network of the city of Béni Mellal, Marocco (Fig. 4), which is quite complex and contains many branched structures. Such an urban area is characterized by a high level of interferences and by some multipath propagations of the radio waves. Situation gets worse at road intersections due to the high density of vehicles and to crossing of vehicles that lead to an increase of the number of collisions and, consequently, a decrease in the probability of successful message delivery. Relying on the so-called SUMO simulator (Simulation of Urban MObility), we simulate the vehicle mobility, considering the road network of Béni Mellal.

Table 1. Simulation parameters

Parameters	Values
Number of Vehicles	200
Simulation Time	200 s
Data Rate	0.25
Packet Size	1000
Traffic Model	FTP
Routing Protocol	AODV
Number of Receivers	1, 2, 3, 4
Number of Senders	1
IEEE standard	802.11p

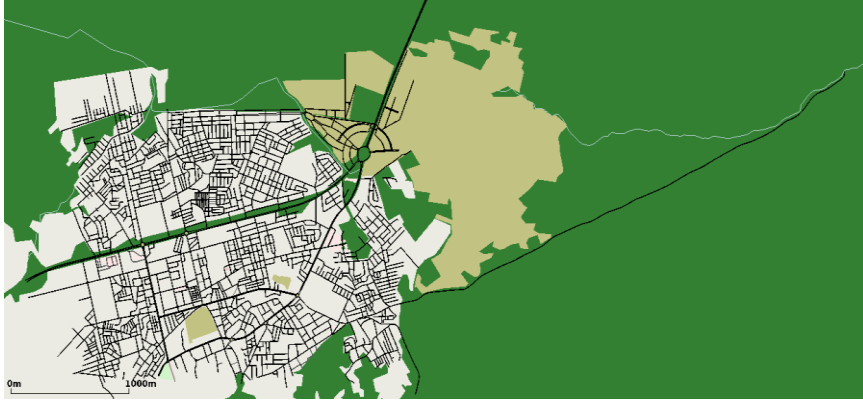


Fig. 4 Map of Béni Mellal city

7.2 Experimental results

In Figures 5 and 6, we plot the delay for several vehicles that are indexed by a number that reflects their distance to the source. One can see that with a basic/naïve solution, the delay is low when the node is far away. As visible in Figure 5, the delay at node 46 is very high compared to node 80. With our approach, the message dissemination is favored with the closest nodes, based on the SINR.

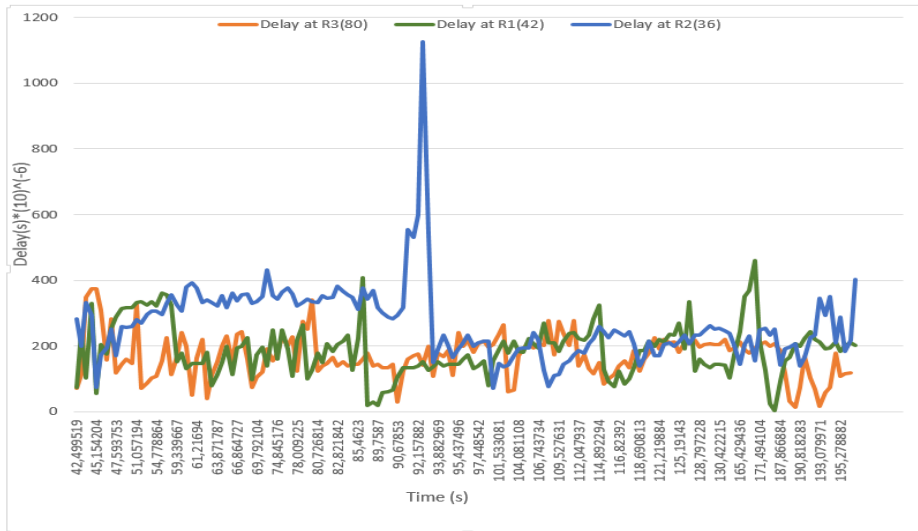


Fig. 5 Delay in normal case

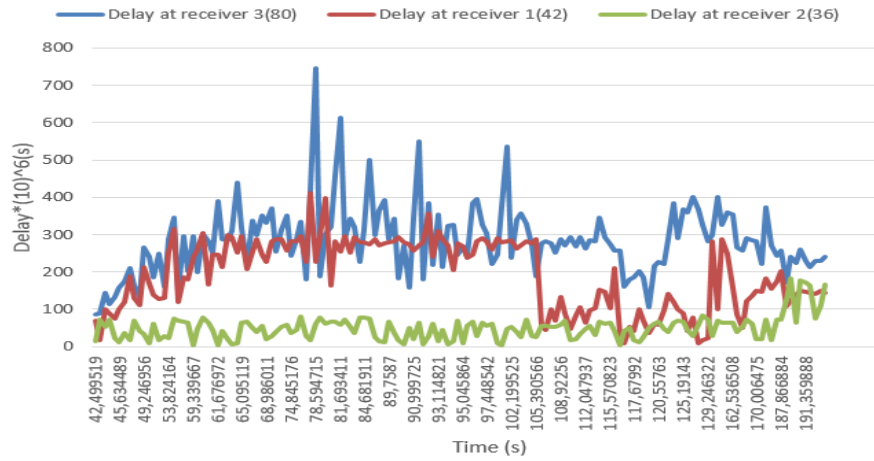


Fig. 6 Delay in improved case

Figures 7 and resp. 8 show the influence of the normal and resp. our improved protocol on the packet loss ratio. As expected, ratio of packet loss of our approach is considerably lower compared to the ordinary protocol.

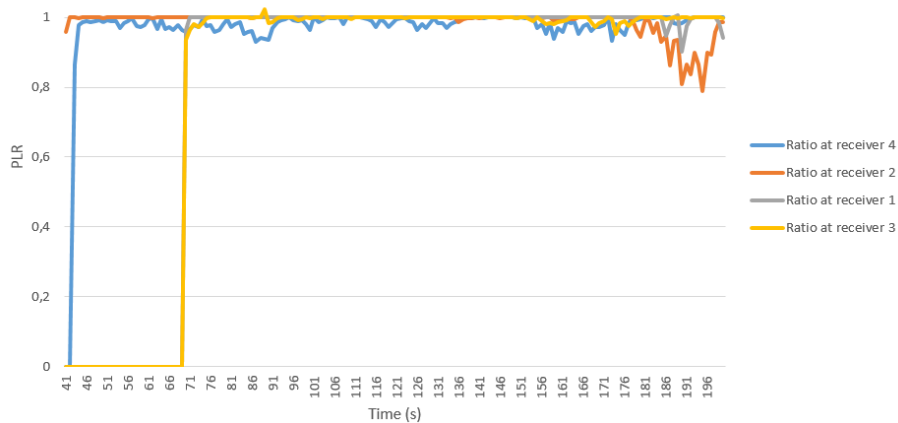


Fig. 7 Packet loss ratio in normal case

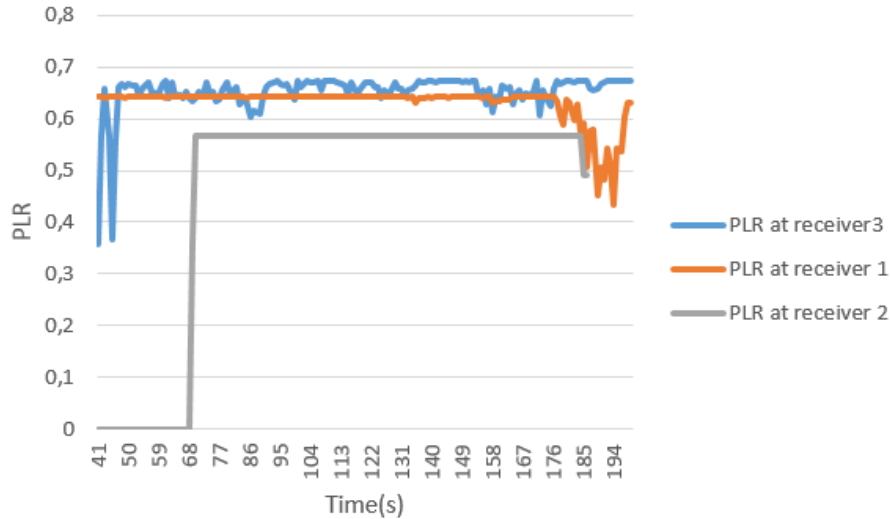


Fig. 8 Packet loss ratio in improved case

8 Conclusion

Excessive message transfer easily overload VANET: e.g. uncontrolled message broadcasting over several hops may lead to a message storm. With these regards, our aim is to limit the message dissemination to a small area and to keep to a minimum the amount of collisions, without leveraging a positioning system. In these regards, we have proposed to enhance the dissemination of warning messages over a VANET. The proposed design rationale is to give preference to long-distance communication. To do so, we forward rapidly the message characterized by the lowest SINR.

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