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# LTE4V2X - Collection, dissemination and multi-hop forwarding

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***Abstract*—In a recent work [1], we proposed LTE4V2X, a novel framework for a centralized vehicular network organization based on 4G LTE network. We demonstrated the efficiency of our framework for an FCD (Floating Car Data) application. Such applications are based on data collected from vehicles (localization, speed, direction, etc.) in order to feed a traffic management server. In the continuity of this work, this new paper presents two extensions of LTE4V2X. The first one is the multi-hop extension, which uses multi-hop communications to deal with areas where there is no LTE coverage (e.g. tunnels). The second extension deals with the adaptation of LTE4V2X framework for a dissemination application that aims to disseminate a specific message in a given geographical area. We analyze the performances of LTE4V2X using NS-3 simulation environment and a realistic highway mobility model. The results show that the multi-hop extension leads to an improvement of LTE4V2X performances, for applications based on both data collection and data dissemination.**

***Index Terms*—Vehicular networks, organization, self-organization, clustering, LTE, 802.11p, FCD, high mobility, multi-hop, data dissemination, data collection.**

## I. INTRODUCTION

Emerging vehicular networks are rapidly becoming a reality. Nowadays, several organizations are supporting standardization activities that will enable a variety of applications such as safety, traffic efficiency, and infotainment. However, these networks are challenging as they have some specific characteristics, such as high vehicles' velocity and the dynamic network topology, that need to be taken into account when designing a solution. Some works propose solutions to handle some of these issues [2] [3] [4]. Most of them are based on the creation, in a decentralized way, of dynamic clusters to self-organize the vehicular network. With a highly dynamic environment such as vehicular networks, a decentralized clustering is not appropriate since it creates a large amount of overhead within the network.

In a recent work [1], we proposed LTE4V2X, a novel framework for the organization of vehicular networks using the existing LTE network. LTE4V2X uses a centralized clustering mechanism: eNodeBs organize vehicles into clusters, and broadcasts the clusters topology to the vehicles. Performances evaluations were carried out with a well known urban sensing application, the FCD application. FCD applications are based on data collection from vehicles (location, speed, direction, and time) in order to feed a traffic management server. Based on these data, traffic congestion can be identified, travel times can be calculated, and traffic reports can be quickly generated. The FCD version used in this architecture is DFCD (Decentralized Floating Car Data), which means that each vehicle generates its own data (it retrieves its position, velocity and heading) before transmitting it through the network.

In the continuity to this work, we present in this paper two extensions of LTE4V2X framework. The first one is the multi-hop extension, which uses a multi-hop communication to deal with areas where there is no LTE coverage (e.g. tunnels). The second extension deals with the use of LTE4V2X for a dissemination application that aims to disseminate a specific message in a given geographical area.

This document is structured as follows. In Section 2, a summary of background knowledge is presented. After a brief presentation of LTE4V2X framework with the multi-hop extension in Section 3, we present the extension of LTE4V2X framework for a dissemination application in Section 4. Simulation results and analysis are discussed in Section 5. Section 6 concludes the paper and discusses some directions of our future research.

## II. BACKGROUND

A network self-organizing architecture simplifies the network management task and permits the deployment of a lot of services. It should take advantage of node properties to issue a global virtual structure enabling the network self-organization, and it should be sufficiently autonomous and dynamic to deal with any local change. There are two main types of self-organization: (i) decentralized organization, in which the ad hoc network is autonomous and does not use any external infrastructure to organize itself, and (ii) centralized organization, in which the organization of the ad hoc network is delegated to a third-party fixed infrastructure (e.g. eNodeB). Typically, in the case of vehicular networks, existing works often used a decentralized organization. However, vehicular networks often co-exist with a fixed infrastructure (e.g. Road-side unit, Base station, eNodeB). This is the reason why we investigated, via the LTE4V2X framework in [1], a centralized self-organization mechanism, using the LTE network as the fixed infrastructure in charge of the network organization task.

However, as centralized organization relies mainly on a fixed infrastructure, a broken connexion with the fixed infrastructure leads to a complete loss of the organization in the concerned area (i.e. vehicles in a tunnel are invisible to the eNodeB). This results in the loss of a large amount of data by any application that runs on the vehicles: data collection application (uplink) cannot send their data on the network, and data dissemination application (downlink) does not receive the disseminated data. To deal with this issue, we created a hybrid organization mechanism, which acts either as a centralized organization mechanism (presented in [1]), or as a decentralized self-organization mechanism when we face an area not covered by the fixed infrastructure.

For the related work dealing with the main areas of this paper (self-organization, data collection, and data dissemination in vehicular networks), we encourage the reader to refer to our recent works [1] and [5].

## III. LTE4V2X FRAMEWORK

In this section we briefly present the basic LTE4V2X architecture and the multi-hop extension of LTE4V2X framework when an FCD application is considered. The basic architecture is used when the area is covered by LTE, and the multi-hop extension is used in the areas where there is no LTE coverage (tunnels, etc.).

### A. Basic Architecture and Protocol Description

As stated before, our framework LTE4V2X investigated a centralized organization mechanism, using the LTE network as the fixed infrastructure in charge of the the network organization task. We consider that all vehicles have both LTE and 802.11p interfaces. The organization of the vehicular network is constituted of clusters that are managed by the eNodeBs. We demonstrated the efficiency of our framework for a well known urban sensing application, FCD (Floating car data) application. This later is based on data collection (localization, speed, direction, etc.) from vehicles.

The size of a cluster is at most the range of 802.11p, so that each node can reach the other nodes of the cluster (the CH more particularly). Each vehicle sends FCD data periodically and each eNodeB manages the vehicles that are under its coverage area. In each cluster, a cluster head (CH) is elected (see Figure 1). The CH has the responsibility to send application data of itself and its cluster members to the eNodeB via LTE. Cluster members only send their application data via 802.11p to their CH.

All nodes (i.e. vehicles) can be elected as CH. CHs aggregate data of cluster members before sending it to the eNodeB. This will lower LTE goodput by avoiding to send useless data (e.g. when the heading and velocity of a vehicle is unchanged, CH can avoid to send data of this node to the eNodeB). The CH can also use a compression algorithm on the aggregated data to save more bandwidth.

The systems runs an "**Initialization phase**" when it starts. Then, it runs in a cyclic manner (see Figure 2): each round contains three phases and is repeated indefinitely. The three round phases are: (i) **Setup phase**, in which the eNodeB creates and updates clusters (ii) **ADV (Advertisement) phase**, in which CHs send a notification frame in the vehicular ad hoc network, and (iii) **Collection and aggregation phase**, in which cluster members send their FCD to CHs, and CHs send aggregated FCD to the eNodeB. Note that nodes use TDMA in each cluster to send their FCD (position, velocity and heading) to the CH.

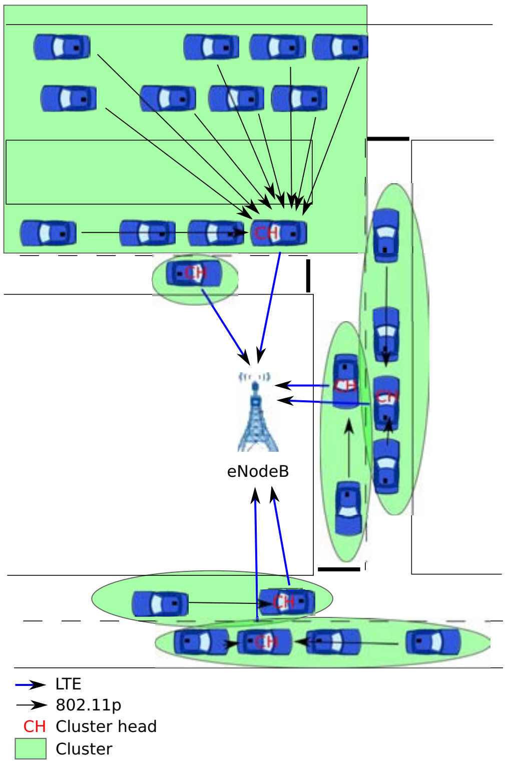

Figure 1. LTE4V2X architecture

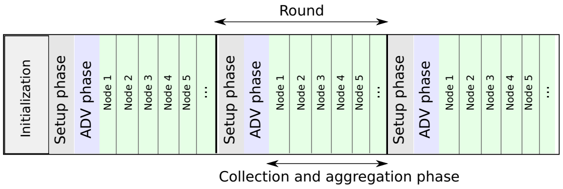

Figure 2. Round phases

For more details about these different phases, please refer to [1].

### B. Multi-Hop Extension

When a vehicle enters a tunnel (or any area with no LTE coverage), it automatically switches to the decentralized mode, where there is no need to contact directly the fixed infrastructure. This mode is based on CGP (Clustered Gathering Protocol) [6]. CGP uses a fixed clustered topology to organize the network: the road is divided into fixed-length segments and each segment corresponds to a cluster. Segments have a length of 150 meters, in order to ensure that a CH can reach the CH of an adjacent cluster using a single-hop communication. Such mode will enhance the performances of data collection and data dissemination based applications especially in the areas where there is no LTE coverage. For data collection based applications like FCD, CGP uses a periodic round scheme with three round phases described hereafter: CH election, data aggregation and data collection.

CH election mechanism chooses the node that is ahead in the cluster, in order to reduce the delay between data reception by the CH and its retransmission to the adjacent cluster. To achieve this goal, CH_ANNOUNCE messages and a back-off time were introduced. CH_ANNOUNCE messages are short packets broadcasted by all nodes during the CH election phase. Vehicles send the CH_ANNOUNCE packet at a time corresponding to the start of the CH election phase, plus the calculated back-off time for the current round. The back-off time is calculated so that vehicles with a high velocity and that are close to leave the cluster have a low back-off time (see Equation 1). When a node receives the CH_ANNOUNCE of another node in its cluster, it discards the sending of its own CH_ANNOUNCE packet (because the node that sent the CH_ANNOUNCE has a lower back-off, and thus will be a better forwarder for the cluster). Then, the vehicle elected as a CH is the one that was the first to send its CH_ANNOUNCE packet. This CH election phase is also used by the nodes to detect the nearby CHs (i.e. CHs of adjacent clusters), which is very useful for the last phase of the round.

$$t_b(i) = \frac{seg\_length \cdot exp\left(-\frac{velocity}{max\_velocity}\right)}{2 \cdot seg\_length - distance(seg\_end, position(i))} \tag{1}$$

During the aggregation phase, each vehicle that is not a CH sends its FCD to the CH of its cluster. It uses its back-off time (calculated in the CH election phase) to avoid simultaneous sending by all members of the cluster. CH aggregates and compresses the received FCD.

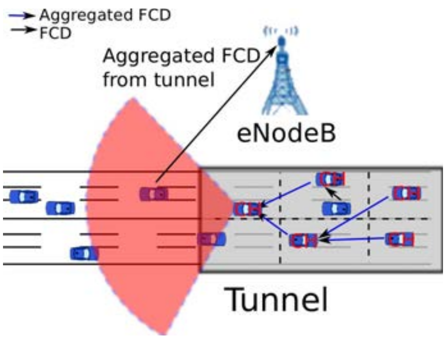

Figure 3. Multi-hop data collection

During the collection phase, CHs in the tunnel try to send their aggregated FCD to the eNodeB via a multi-hop communication (see Figure 3). They use the nearby CHs detected during the CH election phase to have an overview of their local topology, and hence choose the best CH to forward their data. Each packet containing the aggregated FCD is forwarded within the tunnel in a hop-by-hop fashion from CH to CH, until it reaches one of its bound. The version of the protocol used in simulations assumes that non-covered areas are known by the vehicles (we can realistically suppose that tunnels for example are registered in a database and signaled by the eNodeB to the vehicles). With this information, nodes can better choose the forwarding CH for their messages (e.g. in a tunnel, if a node know that it has not yet reached the middle of the tunnel, it will send its message backward). However, we can also imagine a version in which the shape of this area is not known, and where nodes send their messages in multiple direction to be sure at least one of them reaches a bound of the area.

When packets reach the bound of the tunnel, there is a final step before the eNodeB can grab those collected FCD. Indeed, there is a need to inter-connect the centralized LTE4V2X and this CGP-based multi-hop extension, so that eNodeB receives FCD packets and takes them into account.

We consider that when a vehicle is close to the tunnel boundaries, it broadcasts its aggregated FCD. This will allows nearby vehicles that are covered by the fixed infrastructure to receive the FCD that were aggregated in the tunnel, and to forward it to the fixed infrastructure immediately, without waiting for a particular phase or slot in the round.

## IV. LTE4V2X FOR DATA DISSEMINATION

We described in the previous section how we can use the self-organization architecture of LTE4V2X for a data collection based application (FCD). In the following, we will see how we can adapt such architecture to a data dissemination based application. In fact, disseminating data in a determined geographical area is one of the crucial use cases in vehicular networks (hazard warning, traffic information, etc.). This LTE4V2X adaptation works as follows:

In its basic configuration, i.e. when all vehicles are connected to the eNodeB and can receive data from it, LTE4V2X uses the LTE broadcast capability. The eNodeB broadcasts the notification message to all vehicles, along with a header containing the area concerned by the notification (see Figure 5). Hence, all nodes circulating in the concerned area receive the message and take it into account when they notice that they are in the area described by the header of the notification packet. eNodeB rebroadcasts the message periodically, in order to ensure that nodes arriving in the area are alerted.

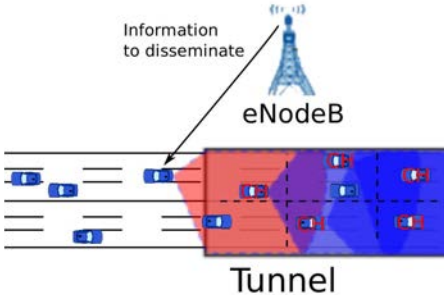

Figure 4. Multi-hop for data dissemination

If a part of the eNodeB coverage area does not receive the LTE signal (e.g. in a tunnel), and if this ”blind” part of the coverage area is concerned by the notification, all vehicles that are close to it broadcast the notification in the vehicular network using the CGP-based architecture presented in the previous section (see Figure 4). The message is hence forwarded within the tunnel in a hop-by-hop fashion from CH to CH, until it reaches the notification area boundaries.

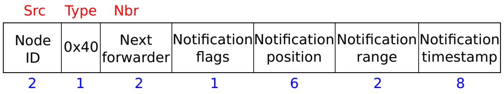

Figure 5. Notification packet

## V. SIMULATIONS

### A. *Simulation Assumptions*

This section presents the parameters and metrics used in our simulations. We used the topology represented in Figure 6: two parallel highways (2x3 lanes) cross the area. The eNodeB is placed in the middle. We added a tunnel with a length of 4kms, represented with gray color, corresponding to an area not covered by the eNodeB. The area concerned by the disseminated notification is colored in red in the figure.

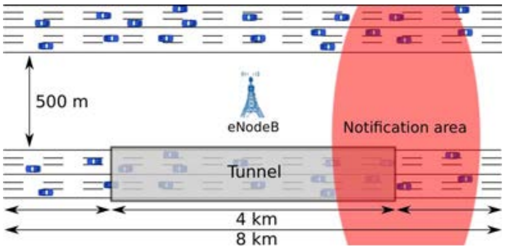

Figure 6. Simulation area

We implemented our protocol using `NS-3.10` (Network Simulator) [7], and generated vehicles mobility using `VanetMobiSim` [8].

We compared LTE4V2X with multi-hop extension against: (i) LTE4V2X without multi-hop extension and (ii) DCP (Decentralized Clustering Protocol). DCP has the same purposes as LTE4V2X, but creates its clusters in a decentralized way: eNodeB does not send any "Cluster Update" frame, and vehicles manage the clusters themselves, in analyzing local data they receive. As LTE4V2X, CHs send ADV (Advertisement) frames in the VANET, aggregate FCD and send aggregated FCD to the eNodeB. The performance metrics used to evaluate the simulation results were:

- **Efficiency**: This is a metric we introduced to reflect the ability for the protocol to optimize the LTE bandwidth and to have reliable inter-vehicle communications. It is given by the formula:

  $$E = 1 - \frac{1}{a} \tag{2}$$

  where

  $$\begin{aligned} a = & \sqrt{\text{Number of vehicles per cluster} - 1} \\ & \cdot (1 - \text{FCD loss rate})^2 + 1 \end{aligned}$$

  $\Rightarrow 0 \leq E < 1$

  Indeed, when a cluster contains a lot of vehicles, it aggregates many FCD in a single frame, and thus compress and aggregates more efficiently, resulting in an optimization of the LTE bandwidth. Moreover, a high FCD loss rate implies non-reliable inter-vehicles communication (mainly due to non-efficient clustering mechanism)
- **Packet loss**: This is the percentage of FCD that are sent by the vehicles but never received by the eNodeB

Simulation parameters are summarized in Table I. These parameters were chosen to be as most realistic as possible. We chose the IDM mobility model, with lane changing feature. In [9], we presented simulations results for a urban topology.

| **Parameter** | **Value** |
|---|---|
| Simulation area | 8km$^2$ |
| Simulation time | 120s |
| 802.11p maximum range | 300m |
| Iteration number for each simulation case | 10 |
| Vehicles number | 100 to 300, step 50 |
| Vehicles velocity | 90 to 145 km/h, step 18 |
| Round duration | 1 second |
| Notification rebroadcasting period | 0.6 seconds |

Table I
SIMULATION PARAMETERS

In order to analyze the performance metrics evolution with different vehicles' densities, we gave a random initial velocity value, between 100 and 145 km/h.

In order to analyze the performance metrics evolution with different vehicles' velocities, we fixed the vehicles number to 300. The vehicles move with the same speed ranging from 90 to 145 km/h, using the "constant speed motion" model of `VanetMobiSim`. This does not reflect real vehicles movement, but it ensures to actually see the impact of vehicles' velocity.

### B. *Simulation Results and Analysis*

This section presents and analyzes LTE4V2X performances within two kinds of applications: data collection based application (FCD) and data dissemination based applications.

*1) Data Collection:* Figure 7 shows the efficiency of the three protocols (LTE4V2X without multi-hop extension, LTE4V2X with multi-hop extension, and DCP) with different densities. As expected, LTE4V2X with multi-hop extension shows a better efficiency than DCP and LTE4V2X without this extension. In fact LTE4V2X is more efficient than DCP since it combines an optimization of the LTE bandwidth and a clustering mechanism that allows a low FCD loss in the VANET. The multi-hop extension further improves the efficiency, since data is collected in not-covered areas too. We also observe that efficiency increases with the vehicles number since the LTE bandwidth is more optimized when we aggregate a lot of FCD in a single frame. This is what happens with high vehicles densities.

Figure 8 shows the FCD packet loss for the three protocols with different densities. It is interesting to point out that LTE4V2X multi-hop packet loss increases with the vehicles' number until 150 vehicles, then decreases with the vehicles' number. This can be explained by the fact that before having enough vehicles on the highway, there are not enough vehicles in the tunnel to forward the packets. As vehicles are not fairly equally distributed, more vehicles we have, more vehicles percentage are in the tunnel. When vehicle's density reaches a given amount (≃150), the vehicle's distribution flatten itself: we always have the same proportion of vehicles under the tunnel, but the number of potential forwarders increases with the vehicle's density, hence increases the FCD delivery ratio. Packet loss for LTE4V2X without multi-hop remains the same (≃28%). This can be explained by the fact that the packet loss is only induced by the wireless channel and the presence of the tunnel (which covers 25% of the roads).

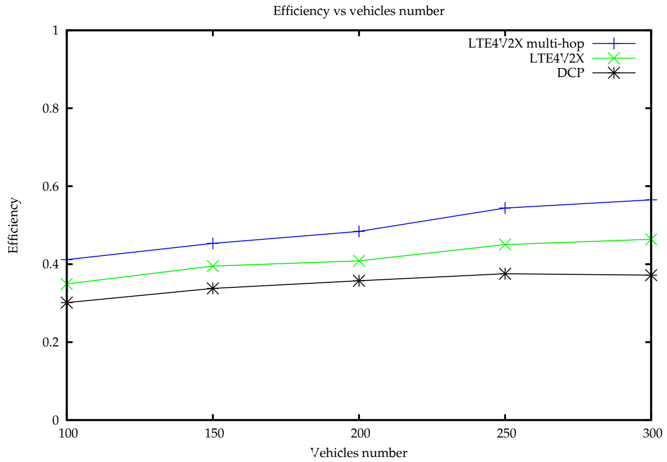

Figure 7. Efficiency vs Vehicles' density

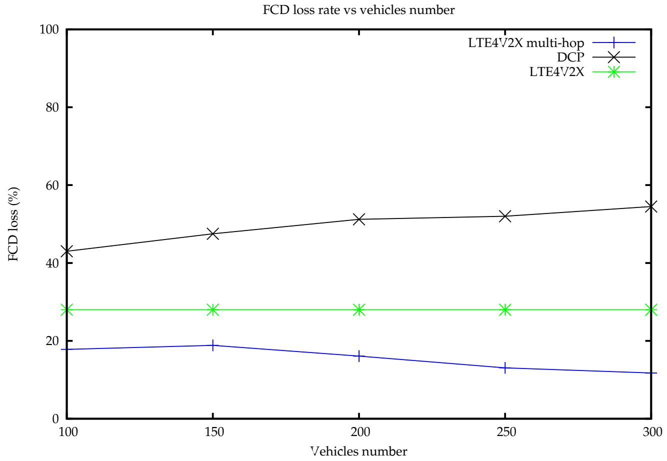

Figure 8. FCD packet loss vs Vehicles' density

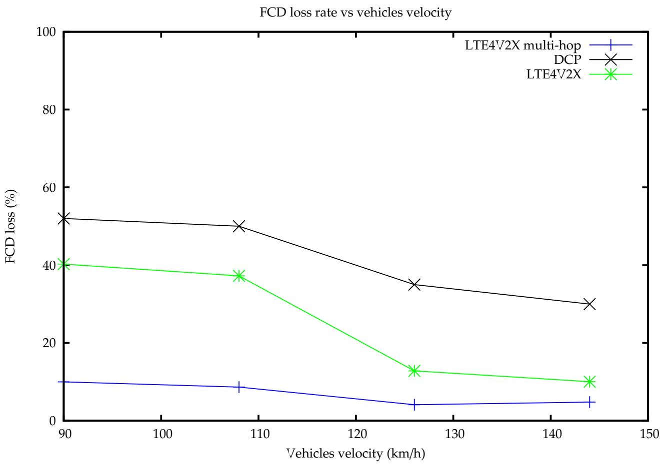

Figure 9. FCD packet loss vs Vehicles' velocity

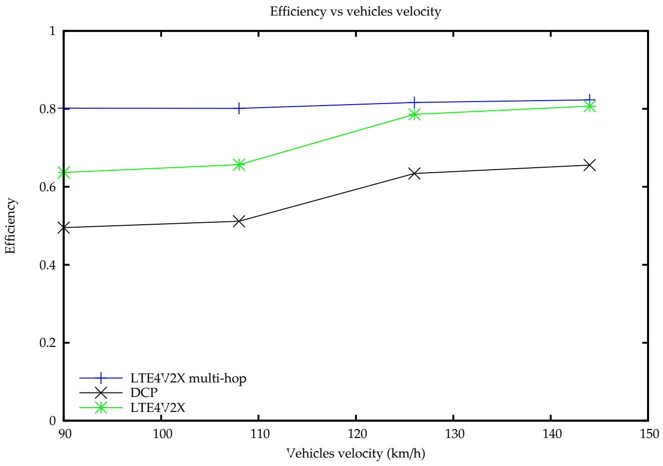

Figure 10. Efficiency vs Vehicles' velocity

Figure 9 shows the FCD packet loss for the three protocols with different velocities. We clearly see that LTE4V2X with multi-hop extension has the lowest packet loss. The variation we can see for the three protocols are a consequence of the fact that a high velocity makes the vehicles cross the tunnel quicker, and hence induces a lower packet loss, resulting in a decrease of the packet loss. Tunnel has more influence on basic LTE4V2X and DCP, because they have no mechanisms to deal with the coverage issue under it.

Figure 10 shows the efficiency of the three protocols with different velocities. We observe, not surprisingly, that multi-hop LTE4V2X is better than basic LTE4V2X, which is in turn better than DCP. The reasons are the same as for Figure 7. We also see that efficiency increases when we change the vehicles' velocity. An interesting fact is the connection we observe between Figure 9 and this figure: the packet loss we observed directly impacts on the efficiency. If we look at Equation 2, we conclude that it reflects an almost constant number of vehicles per cluster. This is due to the fact that all vehicles circulate in small groups, with the same velocity. Then, increasing the velocity does not change the relative velocity between vehicles, and clusters remain unchanged.

*2) Data Dissemination:* Figure 11 shows the delivery ratio of the disseminated message among vehicles that are under the notification area represented in Figure 6. The simulation was generated for 150 vehicles on the highway. We compared the basic broadcast of LTE (named LTE in the figure) to LTE4V2X with multi-hop extension. At the beginning, the notification is delivered successfully to all vehicles, for both LTE and LTE4V2X protocols. This means that all vehicles under the notification area are outside the tunnel. At t=49 and t=80 for examples, we see that the delivery ratio decreases for LTE, which means that some vehicles entered the notification area and have not yet received the message since they are in the tunnel. The eNodeB should wait for the vehicles to leave the tunnel. We do not observe this decrease for multi-hop LTE4V2X, because it was very short: the notification message is always delivered in less than 900 ms with LTE4V2X.

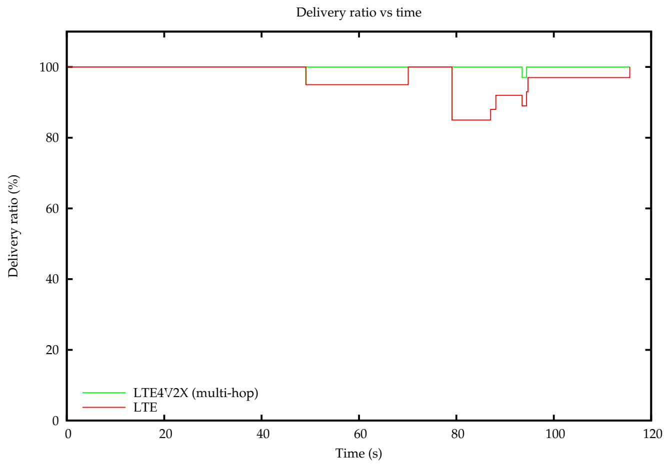

Figure 11. Delivery ratio vs Simulation time

## VI. CONCLUSION

This paper presents two extensions for LTE4V2X, the framework for a centralized vehicular network organization based on 4G LTE network: (i) multi-hop extension in order to deal with areas where there is no LTE coverage, and (ii) LTE4V2X framework extension for dissemination applications. Performance evaluation shows that LTE4V2X has better performances than DCP and basic LTE (with no multi-hop extension) in terms of packet loss and efficiency.

Our future directions are to deeply study LTE handover and cell boundaries mechanisms for LTE4V2X. A small study has been done in [1], but only for data collection with the FCD application. Moreover, we plan to develop LTE4V2X security mechanisms, in order to make it deployable in real networks.

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