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LTE4V2X: LTE for a Centralized VANET Organization

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Abstract—Vehicular networks face a number of new challenges, particularly due to the extremely dynamic network topology and the large variable number of mobile nodes. To overcome these problems, an effective solution is to organize the network in a way which will facilitate the management tasks and permit to deploy a wide panoply of applications such as urban sensing applications. This paper presents LTE4V2X, a novel framework for a centralized vehicular network organization using LTE. It takes advantage of a centralized architecture around the eNodeB in order to optimize the clusters management and provide better performances. We studied its performances against a decentralized organization protocol for a well known urban sensing application, FCD application. We analyze the performances of LTE4V2X using NS-3 simulation environment and a realistic urban mobility model. We show that it permits performance improvement by lowering the overhead induced by control messages, reducing the FCD packet losses, as well as enhancing the goodput.

Index Terms—Vehicular networks, organization, self-organization, clustering, LTE, WAVE, 802.11p, centralization, Floating Car Data

I. INTRODUCTION

Considering our increased mobile society, we have witnessed in the recent years novel Information and Communication Technologies (ICT) solutions providing Internet connectivity on the move, notably in vehicles in which we spend an increasing daily time. This development has emerged new paradigm known as Vehicular ad hoc networks (VANETs). VANETs are attracting an extensive attention from both academia and industry. The most important feature of these networks is their ability to extend the horizon of drivers and on-board devices and, thus, to make the time spent in vehicle more enjoyable to both driver and passengers and improve road traffic safety and efficiency. However, vehicular networks have to deal with many constraints, like the high mobility of nodes and the natural fragmentation of the network (vehicles are often grouped as isolated clusters). Then, offering sufficient quality of service and limiting overhead in vehicular networks are major issues that are still an opened topic. A lot of works propose solutions to some of these issues [1] [2] [3]. Most of them are based on the creation, in a decentralized way, of dynamic clusters to self-organize a non-heterogenous 802.11p 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 this paper, we propose a novel framework for the organization of vehicular networks. This framework is centralized and uses the existing LTE network. We chose LTE for different reasons: (i) it is well suited to support the traffic induced by our protocol (a total of 20 kbps for 400 vehicles); (ii) LTE coverage is about 1 km² and is hence adapted to the vehicular network organization/management: about 400 vehicles to manage for a single eNodeB in an urban area; (iii) The usage of a centralized mechanism is intuitively better than the usage of decentralized mechanism, since the eNodeB has a global view of its coverage area which can improve the clusters' management; (iv) Most of the proposed VANET architectures (like CALM) proposes multiple interfaces in the vehicle, including 802.11p and LTE. This framework can have a lot of applications. Indeed, vehicles have become more sophisticated and are aware of not only their operational state but also of their surroundings, through sensors, radars or GPS receivers. Different kind of sensing devices are available on-board and also off-board to gather information about the driver's environment (speed, acceleration, temperature, road condition, electrical car battery level, tire swelling, etc.). Such collected information present an opportunity to service providers/municipalities in order to offer a set of new vehicle urban sensing applications that could be proposed to the drivers/passengers. Gathering such huge information is a challenging aspect that our centralized clustering protocol is able to solve efficiently.

Our framework, named LTE4V2X, uses both 802.11p and LTE to provide an efficient way to collect data periodically from vehicles and send them to a central server. We studied its performances against a decentralized clustering protocol for a well known urban sensing application, FCD application. Floating Car Data (FCD) are based on the collection of localization data, speed, direction of travel and time information from vehicles 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 rapidly generated. In contrast to traffic cameras, number plate recognition systems, and sensor loops embedded in the roadway, no additional hardware on the road network is necessary. The FCD version used in this architecture is Decentralized Floating Car Data (DFCD), which means that each vehicle generates its own data (it retrieves its position, velocity and heading) before transmitting it through the network.

LTE4V2X is inspired by CDC (Centralized Dynamic Clustering protocol) [4], a wireless sensor adaptive clustering protocol, which organizes the network into clusters. This protocol dynamically creates clusters, but it changes the cluster head each round in order to avoid premature energy outage of the cluster head. As our architecture uses vehicles instead of wireless sensors, the energy consumption aspects are not so restrictive. Then, this protocol was reinvented with the constraints related to vehicular networks (high mobility speed, unlimited electrical energy,...).

This document is structured in four parts. In section 2, a summary of background knowledge and related work are presented. After a presentation of the proposed architecture in Section 3, LTE4V2X protocol is detailed in Section 4. Section 5 presents and discusses the simulation results of our protocol for FCD case study. Section 6 concludes the paper and discusses some directions of future research.

II. RELATED WORK

Many works related to vehicular networks organization [5] [6] [3] [7] proposes self-organized architectures. Such architecture takes advantage of node properties to issue a global virtual structure enabling the network self-organization. In general, the architecture is sufficiently autonomous and dynamic to deal with any local change. Typically, in the case of vehicular networks, it often leads to a decentralized organization using clustering and virtual backbone. The idea of defining a virtual backbone structure is brought from the wired networks. The principle of this solution is to constitute a dorsal of best interconnected nodes. The only constraint is the judicious choice of backbone members (BM) to avoid the rapid loss of interconnection between BMs. The second self-organizing structure is clustering. It is the partition of the network in homogeneous zones named clusters. Each cluster has at least one cluster head and a set of members. Generally, the members of one cluster have some common characteristics as contiguous velocities or coordinates, etc. Cluster-based solutions represent a viable approach for vehicular sensing applications. The clustering structure is usually used as a support of backbone structure.

In [5], the authors take inspiration from the organization of the cellular network in adjacent cells to propose the division of the service area into a number of sub service areas (SSA). One base station (BS) is settled in each SSA. The SSA area is set larger than a service coverage area of one BS. Then, a self-organizing process is executed in each SSA to ensure the communication between the BS and Mobile Stations (MS) that are outside its coverage area. In this method, some MSs may be selected as relaying MS, so they support two radio communication channels, one for link establishment control and one for data transmission. In [6] the authors propose, within the context of VANET, DBA-MAC (Dynamic Backbone Assisted MAC), a proactive distributed scheme to form a virtual backbone in a dynamic way in order to send a broadcast alert message to a group of potential receivers in a risk zone. To create the backbone, a node elects itself

as a backbone member (BM) then it broadcasts a beacon message to spread the backbone creation process impulsion. After that, all the receivers enter in a distributed MAC access phase based on contention mechanism to elect the next backbone member. Since a reactive scheme for repairing the backbone would need break-detection capability and overhead, DBA-MAC proactively refreshes the backbone. In [8], the authors propose CSP (Cluster-based Self-organizing Protocol), a vehicular network proactive self-organizing architecture that is based on geographical clustering to ensure a permanent self-organization of the whole network. CSP adapts itself to vehicular network characteristics and permits to improve inter-vehicles or vehicle-to-infrastructure connectivity.

Using a decentralized organization is totally justified in these works since the authors assume that vehicles have a single 802.11p interface, and no cellular network interface. The vehicles organize themselves into clusters in order to provide a better connectivity with other nodes and infrastructures in an non-heterogeneous network.

However, nowadays we can easily assume that vehicles have multiple interfaces, which give 802.11p and cellular network (UMTS/LTE) connectivity. In a recent work [8] [9], the authors propose a clustering algorithm for an heterogenous network composed of a vehicular network and a cellular network. In their proposed architecture, cellular network is used to download data from vehicles, but also has indirect effect on cluster formation: the headings of the vehicles in relation to the eNodeB is taken in consideration in their cluster formation algorithm. As the previous works, the clustering process is decentralized: the vehicles manage the clusters around them autonomously. But it would be interesting to take advantage of the cellular network to help cluster formation. Indeed, it could have an overview of the VANET and could be used to organize it, in a centralized manner. The centralized approach allows the clusters manager (e.g. NodeB, eNodeB) to have a global view of the road traffic, and then create better clusters than a decentralized approach could do. Moreover, this global view also allows to easily see topology changes, like nodes arrivals in the network or departures from the network. Then, our proposed protocol uses this approach to create clusters, each of them containing a CH which will act as a gateway between the VANET and the LTE network.

III. LTE4V2X ARCHITECTURE

In this work, 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 (clusters can also be managed by a remote server, if it is not possible to implement that directly in the eNodeB). As indicated before, we will demonstrate our framework for a well known urban sensing application, FCD application. However, LTE4V2X is used to organize the network and permits to deploy a wide panoply of other applications.

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 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.

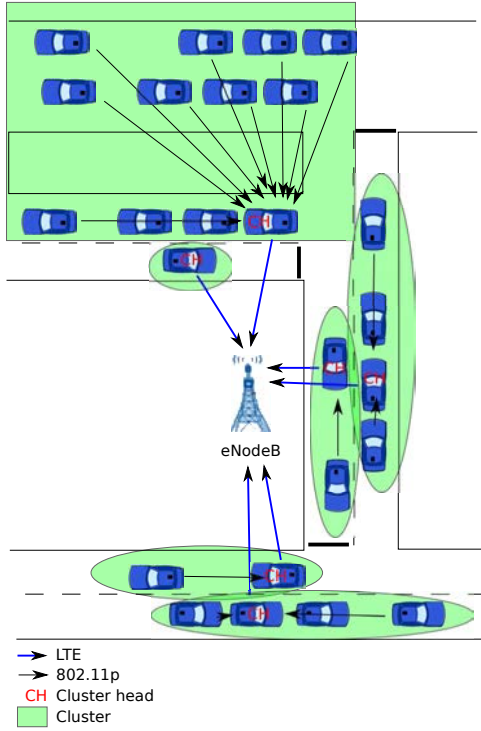


Figure 1. LTE4V2X architecture

IV. LTE4V2X PROTOCOL DESCRIPTION

In this section we describe different mechanisms involved in our LTE4V2X protocol.

After the initialization phase (see next Section), the system 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 VANET, 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.

First, the initialization phase, which is run only at the start of the system, is detailed. After that, we describe how the organization in clusters is maintained by the eNodeB, and

hence how the eNodeB manages the arrival and departure of the nodes (vehicles) within the clusters. Finally, we explain the data collection and aggregation phase where eNodeB collects FCD from the vehicular network.

A. Initialization Phase

During the initialization phase, the eNodeB receives FCD directly from all vehicles. This phase is executed only one time, when the network starts, and allows the eNodeB to know vehicles positions and then to create coherent clusters. At the beginning, the vehicular network is not organized and there is no clusters created. All the vehicles send an ID request using the frame shown in figure 3, until they receive an ID from the eNodeB. After that, the nodes send their FCD (position, speed and heading) to the eNodeB (see Figure 7), using the same mechanism as if they were entering the network (see section IV-B1). At the end of this phase, the eNodeB runs an algorithm to organize the vehicular network and form the clusters (see section IV-B3). After that, the eNodeB broadcasts this organization using a frame that defines the cluster heads and their associated cluster members. The payload of this frame is described in figure 4.

The ID request frame is used to add a new IPv6/ID association, to delete an existing association or to ask for the IPv6 address corresponding to a given ID.

B. Maintenance

In this Section, we detail how LTE4V2X maintains the clusters using the eNodeB: how the eNodeB manages the

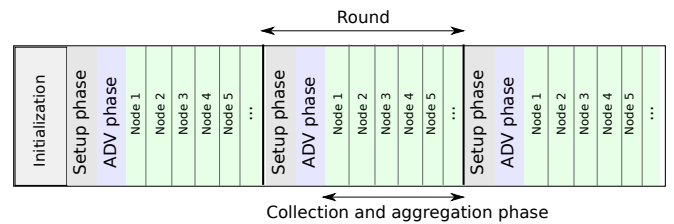


Figure 2. Round phases

Src	Type	Nbr
Node ID	0x02	Request type
2	1	2
		IPv6 Address
		16
		Node ID
		2

Figure 3. ID request frame

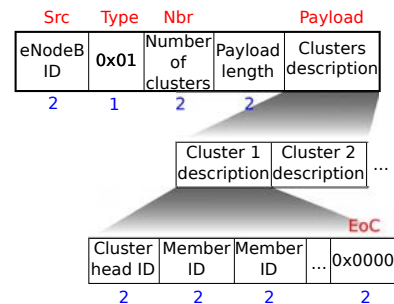


Figure 4. "Cluster topology" frame

arrival and departure of nodes, and what periodic checks and control messages are sent by the eNodeB.

1) *Arrival of New Nodes*: The arrival of a new node in a cluster is quite simple: First, the new node waits for the reception of an ADV frame in the VANET, a “Cluster update” frame from the eNodeB, or when a timeout counter expires. The reception of this frame allows the new node to know when the Collection and Aggregation phase will be initiated. During the next Collection and Aggregation phase, the new node sends an FCD frame directly to the eNodeB, like in the Initialization phase (with 0x0000 as Cluster ID). After that, the eNodeB will integrate the new node in the next “Cluster Update” frame.

2) *Leaving Nodes*: The behavior will obviously be different if the leaving node is a CH or if it is a simple member node.

When the leaving node is a member node, it is detected at most a round duration after its disconnection, because the eNodeB can easily notice when it did not received FCD from it. The leaving node will be removed from the clusters when the eNodeB does not receive FCD for a given number of consecutive seconds.

When the leaving node is a cluster head, the process is different. If the leaving CH node leaves before sending the aggregated FCD, all the cluster FCD will be lost for this round. The eNodeB will also notice this loss and fix the cluster for the next round.

3) *Periodic Operations*: A periodic check is executed by the eNodeB each round in the Setup phase.

The eNodeB tries to create clusters which have a lifetime as long as possible. 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). eNodeB creates clusters which contains the largest number of nodes circulating in the same direction (see Figure 1). This algorithm is executed periodically by the eNodeB during the Setup phase.

If the calculated clusters are different from the current ones, the eNodeB broadcasts a “Cluster Update” frame (see Figure 5). The “Cluster Update” frame contains commands for each cluster that needs an update. The commands can notify the addition of a node, the removal of a node, the ID a the new CH of a cluster, or the new ID of a cluster.

In the ADV phase, the clusters configuration is spread in the VANET: each CH broadcasts a short frame which contains the next CH ID of its cluster (see Figure 6) and the number of cluster members. Indeed, the CH can take the initiative of choosing an other node as CH. This frame also allows the cluster members to know that their CH is still alive.

4) *Collection and Aggregation Phase*: During this phase, each node sends its FCD (position, speed and heading) to its CH, in the attributed time slot (see Figure 7). The time slots correspond to the order used by eNodeB in the last update frame. If the node does not know the IPv6 address associated with its CH ID, it sends an ID request frame (see section IV-A))

Just before the end of this phase, each CH sends the aggregated data (which may be compressed) to the eNodeB (see

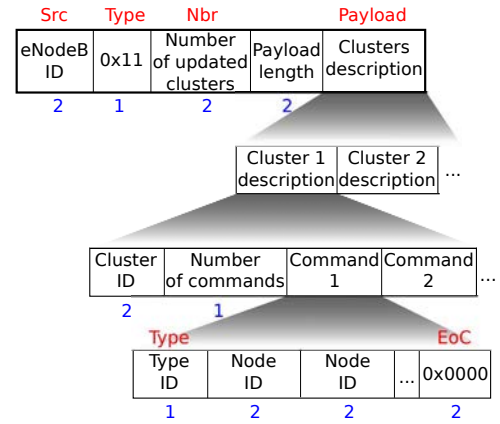


Figure 5. “Cluster update” frame

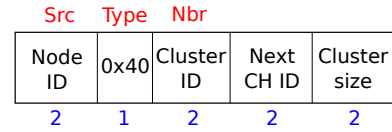


Figure 6. ADV frame

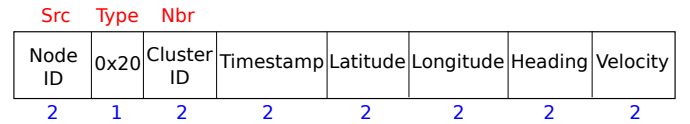


Figure 7. FCD frame

Figure 8). The size of this frame depends on the compression algorithm, the aggregation process, and obviously the number of nodes in the cluster. For example, with 30 nodes in the cluster and the compression algorithm used in tar-gzip format, the frame size reaches about 128 bytes.

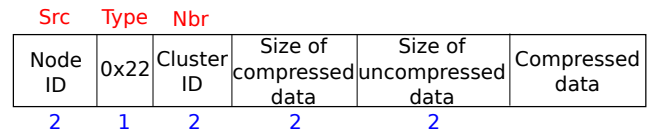


Figure 8. Aggregated FCD frame

V. SIMULATIONS

A. Simulation Assumptions

The simulations were made with network simulator NS-3.10 [10]. LTE4V2X was implemented upon the IP layer with FCD as an application.

We simulated an area of 1x1 km², which matches the coverage area of an eNodeB. We chose an urban topology, generated with VanetMobiSim [11]. The eNodeB is placed in the middle of the area. Vehicles are circulating with a mean speed of 20 km/h in residential areas, 30 km/h in downtown areas and 50 km/h in suburban areas. The choice of an urban topology was motivated by the fact that we first want to analyze the limits of our protocol in front of a high density of

vehicles. We plan to simulate, in a future work, an inter-urban topology (i.e. highways) in order to analyze the impact of high velocity in our protocol.

Table I
FCD APPLICATION PARAMETERS

Parameter	Value
Round duration	1 second
Initialization phase duration	10 seconds
Timeout for control messages reception	1.5 second

Table II
SIMULATION PARAMETERS

Parameter	Value
Physical network layers	802.11p, LTE
802.11p maximum range	300 m
Simulated area	1x1 km ²
Topology	urban/suburban
Maximum vehicles speed	20-50 km/h
Simulation time	120 seconds
Mobility model	IDM (by VanetMobiSim)

We compared our protocol against a decentralized clustering protocol (DCP). In DCP, the VANET is self-organized in a decentralized manner. Indeed, the vehicles compute the clusters each seconds, and send an ADV frame if they are cluster head. Then, all non-CH nodes send their FCD to their CH. The CH sends, after that, the aggregated data to the eNodeB. Simulations were run 10 times for each use case (i.e. vehicles number).

The performance metrics used to evaluate the simulation results are:

- Goodput: This application level metric reflects the useful bytes of information that transits on the network (for our application it reflects FCD bytes that are transmitted)
- Overhead: This reflects all non-useful bytes exchanged in the network, i.e. control messages (ID, ADV, "Cluster update" and "Cluster topology" frames)
- Packet loss: This is the percentage of packets that are sent by a given network interface but never received by the destination interface
- Cluster lifetime (or cluster stability): We evaluate cluster lifetime in measuring the average consecutive time a CH remains CH

B. Simulation Results and Analysis

Figure 9 presents the obtained packet losses for the two protocols. This Figure enlightens a huge packet loss for DCP. The decentralized approach creates less optimized clusters and vehicles are not aware of topology changes, and they can send packets to non-existent nodes or the cluster heads can miss the inclusion of a member in its cluster and then not send all the FCD it should send. Moreover, in LTE4V2X, all nodes are synchronized by the "Cluster update" frames

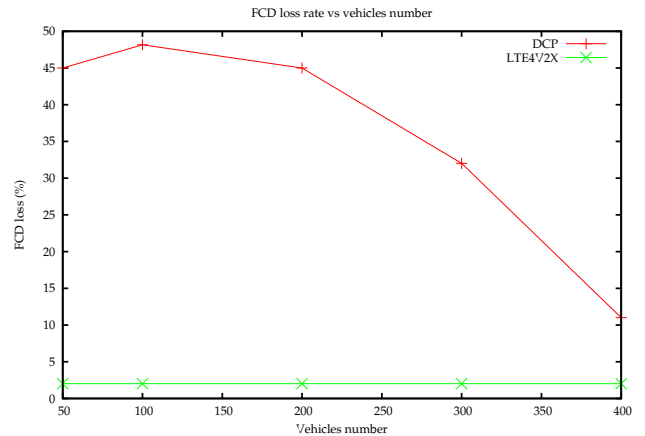


Figure 9. Packet loss vs vehicles number

received from the eNodeB, while in DCP the nodes have to synchronize themselves without a reliable fixed infrastructure. Then, this non-optimized synchronization in this dynamic vehicular environment leads to multiple packet losses. The packet loss rate observed in LTE4V2X does not depend on the vehicles number, because it is due to the non-ideal LTE and 802.11p channels, and not induced by the clustering mechanism.

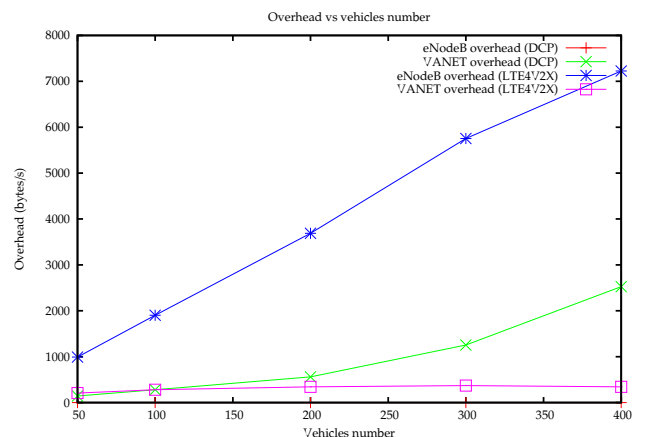


Figure 10. Overheads vs vehicles number

Figure 10 presents the obtained overhead for the two protocols: we show overheads on the LTE link and inside the VANET, for LTE4V2X and DCP protocols. The Figure shows that LTE4V2X creates a larger overhead at the eNodeB, but it can easily be handled by LTE. This overhead is induced by the fact that we have a low packet loss. Indeed, this implies that more vehicles are maintained correctly in the clustering process, and then more control messages have to be exchanged to maintain all those received FCD up-to-date.

Figure 11 presents the obtained goodput for the two protocols, on the LTE link and inside the VANET. The Figure shows clearly that LTE4V2X generates a very low 802.11p goodput, and a high LTE goodput. To understand this behavior,

we have first to come back to Figure 9: DCP has a high packet loss, and this induce a lower LTE goodput (few FCD arrive to the eNodeB). Second, the low VANET goodput of LTE4V2X comes from the fact that LTE4V2X creates smaller clusters than DCP, and then less FCD are exchanged inside the VANET. LTE4V2X creates smaller clusters because its global overview allows it to see that those big clusters are not optimized (e.g. it knows that some nodes are unreliable).

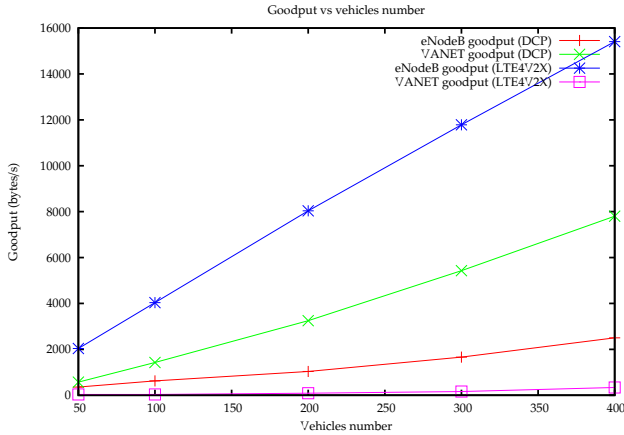


Figure 11. Goodputs vs vehicles number

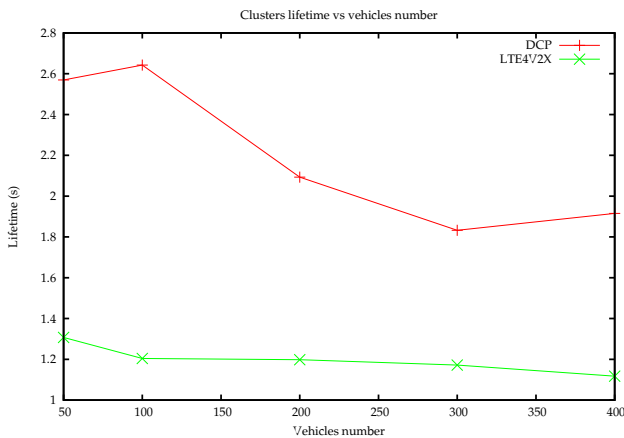


Figure 12. Clusters lifetime vs vehicles number

Finally, we can observe in Figure 12 that LTE4V2X has a lower average cluster lifetime than DCP (i.e. less clusters stability). In LTE4V2X, clusters are optimized whenever it is possible, and the eNodeB sees more potential optimizations because it has a global view of the network. This explains a

shorter lifetime of the clusters.

To conclude, our protocol benefits of a very low packet loss, while DCP loses half of its FCD sent to the eNodeB. The overhead generated by the eNodeB is not so large (7.1 kbps for 400 vehicles), and allows a better cluster management, while keeping the VANET bandwidth free for other applications, like online video streaming or other non-critical applications.

VI. CONCLUSION

This paper presented LTE4V2X, a novel framework which uses the eNodeBs of the LTE network as a cluster management infrastructure for the VANET. This new approach has been compared to a decentralized approach, and the results show that our protocol is better than DCP (even if clusters are less stable): it creates less overhead in the VANET, and loses only 2% of FCD. We are currently extending this work into the following directions. First, we want to perform other extensive simulation study to check the behavior of LTE4V2X in an inter-urban topology (highways) with very high speeds. Second, we want to simulate other decentralized clustering protocols or even decentralized approaches without clustering mechanisms, in order to have a wider comparison basis with LTE4V2X. Finally, we will work on extending our centralized approach to VANET applications other than data collection.

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