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A Fuzzy Multi-metric QoS-balancing Gateway Selection Algorithm in a Clustered VANET to LTE Advanced Hybrid Cellular Network

Ghayet el mouna ZHIOUA†*, Nabil TABBANE*, Houda LABIOD† and Sami TABBANE*
† InfRes - Telecom ParisTech - France
* MEDIATRON - Higher School of Communication of Tunis (Sup'Com) - Tunisia
Email: {zhioua, houda.labiod}@telecom-paristech.fr, {nabil.tabbane, sami.tabbane}@supcom.rnu.tn

***Abstract*—Intelligent Transportation Systems (ITS) attract nowadays research community and the automotive industry, aiming to provide not only more safety in the transportation systems but also other high QoS based services and applications for their customers. In this work, we propose a cooperative traffic transmission algorithm in a joint VANET - LTE Advanced hybrid network architecture that elects a gateway to connect the source vehicle to the LTE Advanced infrastructure under the scope of Vehicle to Infrastructure (V2I) communications. The originality of the proposed Fuzzy QoS-balancing Gateway Selection (FQGwS) algorithm is the consideration of QoS traffic classes constraints for electing the gateway. Our algorithm is a multi-criteria and QoS based scheme optimized by performing the fuzzy logic for making the decision over the appropriate gateway. Criteria are related to the Cluster Head and gateway candidates Received Signal Strength, load and the vehicle to vehicle Link Connectivity Duration. Simulation results demonstrate that our algorithm presents better results than the deterministic scheme for gateway selection. Moreover, results show the efficiency of FQGwS algorithm as it adapts its gateway selection decision to cluster density and to relative velocity of source node.**

I. INTRODUCTION

IEEE 802.11-based Vehicular Ad hoc (VANET) networks have been widespread due to their relevant attractive features such as self-organization and the decentralized administration. Although VANET networks are considered to be a subset of MANETs networks, they have some advantages over these later. Typically VANET nodes do not have battery limitations and benefit from more processing power and storage space. The great potential of this technology has been acknowledged with the establishment of ambitious research programs on vehicular communication systems worldwide, such as European eSafety framework, numerous United States V2V and V2I projects, and the Japanese Smartway and Advanced Safety Vehicle programs. Moreover, vehicular communication and networking present an active field of standardization activities worldwide, such as ISO TC204, IEEE (802.11p and 1609.x) and SAE DSRC in the USA, ETSI TC ITS and CEN WG278 in Europe and ARIB T-75 in Japan. In addition to these standardization efforts, considerable evolution inside the vehicles themselves is observed. In fact, future vehicles are expected to be equipped with high efficiency computing systems and multiple wireless communication interfaces. According the ETSI 102 638 technical report, in 2017, 20% of the running vehicles will have communication capabilities and they estimate that by 2027 almost 100% of the vehicles will be equipped with On Board Units (OBUs). OBUs are devices that provide communications among neighboring vehicles, i.e Vehicle to Vehicle (V2V) or between vehicles and nearby fixed equipments (called also Road Side Units (RSU)), i.e. Vehicle to Infrastructure (V2I) communications [1]. Thus, Intelligent Transportation Systems (ITS) attract not only research community but also the automotive industry. Recently, they focus their efforts to grow vehicular communication and networking into maturity by moving it from research field into real implementation, aiming to provide not only more safety in the transportation systems but also other high quality of service (QoS) based services and applications for their customers.

Obviously, VANET networks have to overcome some issues and challenges related to their specific characteristics, such as the very dynamic network topology related to vehicles high velocity, to ensure acceptable Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications. Most of the solutions proposed to handle these issues are based on the creation of dynamic clusters to self-organize the vehicular network where the dynamic clustering formation can be either in a decentralized or centralized way. Clustering is to group the nodes into homogeneous sets named clusters. Each cluster has one Cluster Head (CH) elected from the cluster members' that controls flows and signaling inside the cluster specially for V2I communications. Typically, the members of one cluster have some common characteristics, e.g. near coordinates, velocities, same direction, etc.

An initial set of services for use by V2I systems on European highways has been defined within the European Commission project on COOPerative systEms for intelligent Road Safety (COOPERS)[2]. There are safety-critical services, such as accident warning, and roadwork information, and convenience services, such as journey time and road charging services. The focus of this paper is on defining an algorithm aiming to select the appropriate gateway for a given source vehicle under the scope of V2I communications and based on the QoS class of the traffic to be transmitted to the infrastructure. In this paper, we focus not only on safety-critical and convenience services delivered on highways via V2I architecture but also on other QoS classes delivering real time, streaming or best effort services. An efficient algorithm based on a QoS-balancing scheme will be proposed.

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In addition, the infrastructure in V2I communications can be supported by various wireless technology interface, i.e. IEEE 802.11p, 802.16m, LTE Advanced, etc. In this work, we consider an LTE Advanced interface for many reasons. In fact, according to [3], it is more advantageous to use a cellular infrastructure rather than WiFi based infrastructure, for V2I communications. On the other side, LTE Advanced standard is characterized by very relevant and advanced system features as compared to other systems that meets the requirements of IMT Advanced project for the 4^{th}G of cellular systems [4]. Moreover, LTE Advanced cellular network is a well designed system that offers high uplink (UL) and downlink (DL) data rates for high and low mobility environments [5]. In this paper, we propose a cooperative traffic transmission algorithm in a joint LTE Advanced-VANET hybrid network architecture where an elected gateway will connect a source vehicle to the LTE Advanced infrastructure. Some references that do not consider ad hoc nodes clustering, elect the gateway after information broadcast and gathering from all nodes leading to have a high amount of overhead in the network. In a clustered architecture, in spite of its role of initiating the communication and controlling the flow of signaling messages within the cluster, the cluster head could be also set as the gateway to the infrastructure for source vehicles of its cluster. Obviously, centralizing the connectivity to the infrastructure for nodes belonging to one cluster is beneficial. The key advantage is to decrease the cellular network resources consumption, by multiplexing distinct source nodes' flows by one gateway that handles to send them to the infrastructure. However, this scheme generates serious issues such as inducing CH overload, increasing end-to-end delay as compared to the direct link (i.e. send directly to the eNodeB) which is intolerable for delay sensitive services. Moreover, the cluster head might not be the optimal gateway to the infrastructure as almost all algorithms consider only VANET layer features for CH election and forget reflection about the infrastructure layer features such as base station load and received signal quality. Therefore, it is essential to propose a method that considers traffic priority and its QoS constraints and on the other side take aware of both VANET and infrastructure features.

The remainder of this paper is structured as follows. We first present, in Section II, an overview of VANET clustering algorithms. Then, in Section III, we present the most relevant related works of gateway selection algorithms in a clustered and non-clustered architecture. Sections V and VI describe our system model and the fuzzy logic modeling method. We address also gateway selection challenge by presenting our gateway selection algorithm based on fuzzy logic modeling. Finally, simulation results are presented and future works are highlighted in Sections VII and VIII.

II. VANET Clustering

As in a classical MANET network, VANET nodes have dynamic connectivity and self organizing features. However, with the increasing of the number of nodes, where each node handles its own decentralized routing and neighborhood connectivity maintenance tasks, serious scalability and hidden terminal problems may occur. The most common solution adopted for this problem is the clustering. Clustering in VANET aims at organizing vehicles into groups based on some specific common characteristics. Using that technique can lead to more nodes' coordination and fewer inter-nodes interference. The main challenge for a VANET clustering algorithm is to maintain cluster stability for the longest period otherwise the performance will be degraded due to the frequent re-clustering operations. Besides, clustering in VANETs requires selecting a Cluster Head (CH) to be responsible for coordinating the members of the cluster. This process is carried out by each node belonging to the cluster by broadcasting its information to all other neighboring nodes. Thus, after network information collection and based on a specific CH selection algorithm, see section III, these nodes select a CH to coordinate the communication among them. After decision over the CH is completed and cluster nodes informed, the CH will be able to communicate directly to all other cluster members and may act also as the relay node of communications to other cluster members and other nodes in different clusters.

Several clustering algorithms have been proposed in literature. In [6], the cluster formation is based on direction of vehicles, where vehicles moving in the same direction belongs to the same cluster. Authors in reference [7] propose a clustering algorithm for a heterogeneous network based on vehicular and UMTS cellular networks. The clustering is based on three criteria: direction of movement, UMTS received signal strength (RSS) and 802.11p wireless transmission range. Neighboring vehicles having the same direction of movement and an RSS higher than a specific threshold becomes belonging to the same cluster. The drawback of this approach is that one cluster could be composed of a high number of nodes which generates a huge amount of overhead for cluster maintenance. Algorithm proposed in [8] is a clustering protocol that does not use special control packets dedicated to perform clustering but it builds the cluster and maintains it based on data traffic forwarding. This algorithm is suitable for a dense network with high mobility because the cluster maintenance is dependent of the traffic. Moreover, it is not affected by the increase of control overhead caused by frequent changes of cluster members. However, this algorithm does not consider relative velocity metric which causes a decrease of the lifetime of the cluster. Clustering method proposed in [9] is build upon protocol of reference [8] and extends the lifetime of the network by balancing energy consumption among the network nodes. Reference [10] proposes MOBIC algorithm that uses a special mobility metric for cluster formation phase where each mobile node sends two consecutive messages to each of its neighbors to compute their relative speeds. Then, each mobile node broadcasts this information to its neighbors. The drawback of this method is the need for extra explicit message exchanges among mobile nodes for maintaining the cluster structure. Thus, with frequent network topology changes resulting to frequent clustering update, cluster maintenance overhead would increase drastically, consuming high portion of the bandwidth. In [11], authors propose a hierarchical clustering technique where cluster members are grouped into subsets of slaves nodes and cluster relay

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nodes and a Cluster head that is in the top of the hierarchy. This algorithm generates a huge amount of overhead due the clustering hierarchy maintenance. In [12], authors propose a density based clustering algorithm that takes into account the effects of multi path fading. The cluster formation is based on the weight metric which takes into consideration the link quality and the traffic conditions. A position based clustering technique is proposed in [13] where the cluster structure is determined by the geographic position of the nodes. The stability of the system is improved by electing the vehicles having a longer trip as cluster heads. Despite it seems that this solution gives stable clusters, performances simulations and evaluation do not consider sparse and jammed traffic conditions which are very frequent in VANET environment. A similar approach is defined in [14]; where clusters are formed based on vehicles position in the road. However, proposed algorithm is very limited as it does not address the cluster maintenance and CH election challenge. Another position based clustering algorithm that performs hierarchical and geographical data collection and dissemination is proposed in [15]. The cluster formation in this algorithm is based on the division of the road into segments. Its performances are affected by the mandatory availability of an infrastructure. Moreover, it generates high overheads for V2V and V2I communications.

III. Related works

In this paper, we address the gateway selection challenge in a clustered VANET architecture. The gateway will relay traffics of a source vehicle to the infrastructure under the scope of V2I communications. In a clustered VANET architecture, the CH is the default gateway to the infrastructure for all source nodes belonging to its cluster. However, in a non-clustered architecture, the gateway is elected after information broadcast and gathering from all mobile nodes in the network. In this section, we present some algorithms that have been proposed for gateway, respectively CH selection in a non-clustered, respectively clustered mobile ad hoc architecture.

For a non-clustered ad hoc networks, in reference [16], authors proposed an algorithm for gateway selection based on choosing the mobile node with shortest hops from source node. One single metric that combines physical hops and, virtual hops relative to congestion and contention levels, is used. This algorithm has got one limitation which is the use of the NAV timer to compute virtual hops for contention measurements which is not an easy parameter to evaluate concretely. In [17], authors discuss the issues associated with the selection of mobile gateways in an integrated MANET-UMTS heterogeneous network. They use simple additive weighting techniques to select an adequate gateway based on residual energy, UMTS signal strength and mobility speed of the gateway candidates. In [18], metrics used to select the gateway for interconnecting the MANET with the infrastructured network are remaining energy, mobility, and number of hops based on a simple additive weighting method. Node with the highest weight will be selected as a gateway. These three metrics are not enough to select the optimal gateway as the link from the gateway to the infrastructure is not considered.

In clustered networks, clustering algorithms are used in VANETs to ensure stability and increase link lifetime between vehicles belonging to the same cluster. There are basic clustering and CH election techniques that were proposed in literature such as highest degree [19] and lowest Id [20] algorithms which are not effectively efficient as they may generate frequent re-clustering. In [6], as cluster formation is based on direction of vehicles, the first vehicle moving in that direction will be elected as CH. Using this method, vehicles with high relative speed will generate frequent CH reselection which causes additional overhead in the cluster. In [21] authors propose to elect one CH in each segment of a road based on geographical information collection which are provided by the infrastructure. This algorithm fails to address cluster stability and cluster maintenance. In reference [22], the cluster head is elected based an additive metric of three criteria: network connectivity level (based on the maximum number of vehicles that are directly connected to considered vehicle and on the vehicles on the same traffic flow) and average distance and velocity levels. Authors considers urban scenarios characterized by several lanes and intersection architecture, e.g. going straight through or turning left or right. Gathering information over the roads' topology and flows intersections requires accurate positioning systems which is not always achieved. Moreover, the high dynamicity of the vehicular nodes and the random drivers' reactivity causes limits to this approach. In reference [10], authors elects the cluster head based on relative velocity. The relative velocity is computed using a ratio of received signal strength of two successive HELLO messages. The CH is then the node with the lowest relative velocity variance. This is an interesting approach for electing the CH, however, there is more accurate schemes for computing relative velocity than the HELLO messages based approach. In [11], after handling hierarchical clustering technique, authors propose to elect the CH as the slave node that received three synchronous messages. This method does not consider vehicles' movement dynamicity and causes huge amount of overhead to the messages exchange for the hierarchical cluster maintenance. In [7], the cluster head is designed as the vehicular node that is in the middle of the cluster, at equal distance from the border nodes. A source vehicle will then select one of the elected CH as gateway to the infrastructure.

To the best of our knowledge, there is no proposed algorithm for gateway selection to infrastructure in a clustered VANET architecture that considers traffic class priority. In this paper, we propose a cooperative traffic transmission algorithm in a joint VANET - LTE Advanced hybrid network architecture that elects a gateway to connect the VANET source vehicle to the LTE Advanced infrastructure under the scope of V2I communications. LTE Advanced standard might be widely adapted by numerous operators as the next generation of their cellular networks. We propose then a multi-criteria and QoS related attributes approach used to make a decision of the appropriate gateway for source vehicle to the LTE Advanced infrastructure. The originality of our algorithm is the consideration of QoS traffic classes constraints for electing the gateway. The next section presents the adopted system model.

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IV. System Modeling

The system model is based on a hybrid network architecture that consists of two systems: an LTE Advanced infrastructure and a VANET network. The architecture comprises IEEE 802.11p based VANET vehicles and LTE Advanced eNodeBs interconnected through X2 interface and connected via S1 interface to core network, i.e. Evolved Packet Core (EPC), see Fig.1. We assume that all vehicles are equipped with OBUs that contain an IEEE 802.11p interface. Each vehicle uses its VANET interface to communicate with its neighboring vehicles based on IEEE 802.11p standard. IEEE 802.11p inter-vehicle communications are possible even if vehicles are inside eNodeB coverage. The OBU could also contain an LTE interface to communicate directly with the infrastructure. Simultaneous two interfaces communications do not cause harmful interferences as they lie on distinct non-overlapping channels in two different spectrum regions.

We made the assumption that the VANET network is already clustered and the cluster head (CH) is elected. Clustering and cluster head selection techniques are out of the scope of this paper. The goal of this work is to make the decision of a source vehicle upon the gateway to select to connect to the LTE Advanced infrastructure. The gateway could be the cluster head of its cluster, another Gateway candidate (GWC) vehicle or there may be also no gateway between the source and the infrastructure where the source vehicle will be directly attached to the eNodeB, depending on traffic classes. Obviously, sending the traffic of each source vehicle directly to the infrastructure without defining a gateway is in theory the ideal scheme. However, nowadays cellular networks still suffer from the lack of resources in spite of numerous proposed solutions for the optimization of radio resources allocation. Thus, decreasing cellular network resources consumption, by aggregating distinct source nodes' flows to one default gateway, i.e. the CH, that handles to send them to the infrastructure seems to be an advantageous solution for a clustered VANET architecture. However, despite it overcomes radio resources lack dilemma, this scheme generates serious issues like inducing CH overload and increasing end-to-end delay, which is intolerable for delay sensitive, real time and alerts services, etc. Therefore, the key challenge we address in this work is how to select for a source vehicle the appropriate V2I gateway while considering at the same level the QoS traffic class, the CH features and the cellular network load. The next section presents our proposed algorithm which is optimized by the integration of the fuzzy logic.

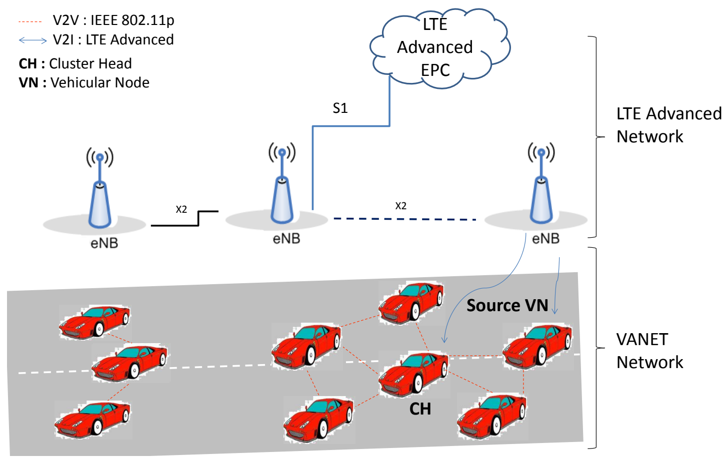

Figure 1. System Model

V. Fuzzy QoS-balancing Gateway Selection Decision

An efficient gateway selection algorithm have to take aware of the QoS features of traffic to be transmitted to the infrastructure. We designed a QoS-balancing gateway selection algorithm (QGwS) in a VANET - LTE Advanced hybrid network where the decision over the gateway depends on the traffic to be transmitted to the infrastructure [23]. It is an adaptive multi-criteria multi-attribute gateway selection decision algorithm. In this work, we optimize gateway decision of QGwS algorithm by performing the fuzzy logic because of the inherent strength of fuzzy logic in solving problems exhibiting imprecision and the fact that many of the terms used for describing radio signals are fuzzy in nature [24]. The proposed algorithm is named Fuzzy QoS based Gateway Selection (FQGwS) algorithm. Fuzzy logic can be viewed as a theory for dealing with uncertainty about a complex system, and as an approximation theory. The fuzzy logic has two objectives: first, it develops computational methods that can perform reasoning and problem solving tasks that require human intelligence, and second it explores an effective trade-off between precision and the cost in developing an approximate model of a complex system [24]. Fuzzy inference system is a computing framework based on the concepts of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning. It is known as the process that draws conclusions from a set of facts using a collection of rules. In this work, we use Mamdani fuzzy inference system [25]. The Mamdani fuzzy system is composed of following modules: the fuzzifier, the fuzzy rules base, the fuzzy inference engine and the defuzzifier. We propose to implement FQGwS algorithm in the vehicles having OBUs. The next section lists the input parameters of FQGwS algorithm.

A. Input parameters

FQGwS algorithm input parameters are divided into two categories: attributes and criteria.

1) Attributes: In this paper, we consider only one attribute which is the type of traffic to be transmitted by a source vehicle to the infrastructure. we define three classes of traffic: Class 1, Class 2 and Class 3. As the source vehicle is a VANET node, generated traffic types are governed by IEEE 802.11p standard. On the other side, the infrastructure is an LTE Advanced cellular network. Thus, to achieve systems' compatibility, a mapping between IEEE 802.11p access categories and LTE Advanced priority classes, using the QoS Class Indentifier (QCI) [26] is done. The mapping is performed based of QoS constraints (packets average delay budget and packets loss) of VANET and LTE Advanced standards. Traffic mapping is pre-

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QoS Classes	Class 1 (Voice)	Class 2 (Streaming)	Class 3 (Data)
IEEE 802.11p Standard Designation	Voice AC	Video AC	BE and BK ACs
LTE-Adv QCI	1-3-5-7 Conversational, Signaling	2 Streaming, Interactive	4-6-8-9 Background
Average Delay Budget	<100ms < 50 ms real-time gaming	< 150 ms	< 300 ms

Table I
TRAFFIC MAPPING

sented in Table I. We define only three QoS category classes because for first deployments, a majority of 4G operators will likely start with three basic service classes containing voice, and best effort data classes. In the future, dedicated bearers offering premium services such as high-quality conversational video can be introduced into the network. Moreover, for sake of simplicity, in this paper, we will call Class 1 traffic as Voice traffic, Class 2 as Streaming and Class 3 as Data traffic.

In addition to the delivery of information and entertainment, i.e. infotainment, services, the role of typical V2I communications includes the provisioning of safety related, real-time and alerts services, such as speed limit information, traffic jam, safe distance and accident warnings, etc [2]. All these services aim to prevent accidents by directly providing information to vehicles' drivers. Moreover, ITS protocols are designed for the 5.850- to 5.925-GHz band, divided into one central control channel (CCH) and six service channels (SCHs) where CCH is dedicated to the transmission of traffic safety messages, whereas SCHs are dedicated to the transfer of various application data. IEEE 802.11p standard allows the use of the four traffic classes for SCH and CCH channels with a MAC layer based on IEEE 802.11e enhanced distributed channel access (EDCA) [27]. We propose to classify traffic safety applications as real-time systems. However, communicating real-time messages require a predictable system that is able to deliver the message before the deadline. Therefore, inside the class 1 traffics, safety and alerts services have priority over other conversational voice or live streaming services. Our work considers traffic priority class for choosing the adequate gateway to the infrastructure under V2I context.

2) Criteria: Criteria are input parameters that are either measured or received by the source vehicle from neighboring vehicles:

- ***Source Vehicle to LTE Advanced Infrastructure Link Connectivity Strength (Source2I LCS):*** As source mobile vehicle could detect one or several eNodeBs with various loads, source vehicle build a diversity set containing detected BSs. We define the LCS_{S2I} criterion, computed using formula (1), which is a simple additive metric (SAM) of two important metrics: the Received Signal Strength (RSS) and the Load (L) in order to select the best base station from this diversity set. It is based on a SAM to minimize the computational efforts that causes delays and resources consumption. In fact, using only the RSS to select the best BS is not sufficient. The load is also an important criterion for base station selection in nowadays cellular networks, as important as RSS. It describes the resources occupation ratio of the eNodeB.

LCS_{X2I} between X and the Infrastructure is computed using (1), where $X \in \{Source,\ CH,\ GwC\}$.

$$LCS_{X2I} = \max_{i\in[1,n]} \left\{ \frac{RSS_i}{Thr_{RSS}} + \frac{Thr_{Load}}{L_i} \right\} \quad (1)$$

where n is the number of eNodeBs in the diversity set, RSS_i is the Received Signal Strength of $eNodeB_i$, L_i is the load of $eNodeB_i$ and Thr_{RSS} (= 41.76 dBm) and Thr_{Load} are thresholds of respectively RSS and Load criterion.

Therefore, source vehicle selects the best eNodeB from the diversity set, with the highest LCS_{S2I} computed using (1), to ensure the best compromise between the RSS and the Load. Without the loss of generality, for source vehicles that are not equipped with an LTE interface, LCS_{S2I} criteria will be considered as very low.

- ***CH to LTE Advanced Infrastructure Link Connectivity Strength (CH2I LCS):*** is the LCS between the cluster head and the selected eNodeB. In fact, the CH selects the eNodeB with the highest LCS_{CH2I} computed using (1), where $X = CH$.
- ***Load of the CH:*** it is the occupation ratio of the buffering queue of the cluster head.
- ***Source Vehicle to CH Link Connectivity Duration (Source2CH LCD):*** The LCD_{S2CH} between the source vehicle and the CH is computed using (2).

LCD criterion reflects well the stability of the link and its lifetime between two vehicles. In fact, considering only relative velocity is not sufficient to characterize link stability between two mobile nodes as vehicles positions, moving directions and VANET transmission range impact also on the connectivity duration of the V2V link. LCD_{ij} between vehicle i and vehicle j is computed using (2), inspired from [28]:

$$LCD_{ij} = \frac{\sqrt{(\alpha^2+\gamma^2)R^2 - (\alpha\delta - \beta\gamma)^2} - (\alpha\beta + \gamma\delta)}{\alpha^2+\gamma^2} \quad (2)$$

where, $\alpha = v_i cos\theta_i - v_j cos\theta_j$, $\beta = x_i - x_j$, $\gamma = v_i sin\theta_i - v_j sin\theta_j$, $\delta = y_i - y_j$. (x_i, y_i), respectively (x_j, y_j), is the Cartesian coordinates of two neighboring vehicles i and j and that have an inclination of θ_i, respectively θ_j($0<\theta_i$, $\theta_j<2\Pi$) with respect to the x-axis and moving at v_i, respectively v_j, speed. R is IEEE 802.11p wireless transmission range. For LCD_{S2CH}, we suppose that the CH and the source vehicle are adjacent, otherwise $LCD_{S2CH} = \min\{LCD_{ij}\}$, $1 \leq i, j \leq n$, where n is the number of hops between the source and the CH.

- ***Gateway candidate to LTE Advanced Infrastructure Link Connectivity Strength (GwC2I LCS):*** There could be another gateway candidate (GwC) for the source

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vehicle with better LCS, load and LCD as compared to the CH. Therefore, each Ordinary Vehicle (OV) that experience high RSS (>RSS_{th}), low buffering queue load (<L_{th}) and high LCD (>LCD_{th}) becomes a potential GwC (pGwC), see paragraphs 2 and 3 of section V-B2 for more details. The latter will elect and then keep a track of the best GwC, and uses it as an input for FQGwS algorithm for making final gateway decision.
For GwC2I LCS criterion, the gateway candidate selects the eNodeB with the highest LCS_{GwC2I} computed using (1).

- ***Load of the Gateway candidate:*** It is the occupation ratio of the buffering queue of the gateway candidate.
- ***Source Vehicle to gateway candidate Link Connectivity Duration (Source2GwC LCD):*** It is the LCD between the source vehicle and the gateway candidate. LCD_{S2GwC} is computed based on (2).

B. Proposed algorithm

In this subsection, we present our proposed algorithm for gateway selection, under the scope of V2I communications. FQGwS algorithm is a decentralized scheme performed by a source vehicle that have to connect to the LTE Advanced infrastructure. It is a QoS-balancing scheme as gateway selection is based on the traffic class to transmit to the infrastructure. FQGwS is performed in three phases: Data collection phase, Decision phase and Maintenance phase.

1) Data Collection phase : Criteria are provided using network measurements handled either by the source vehicle and/or participant vehicles (e.g. CH, OVs). Afterward, gateway decision is performed. The first step is the data collection phase, where dual interface source vehicle triggers measurements on its LTE Advanced and IEEE 802.11p network cards. On the LTE Advanced interface, source vehicle measures the RSS of neighboring base stations and checks their loads. It builds then, the diversity set which contains all BSs it senses and sorts them based on the LCS metric computed using (1). Afterward, source vehicle selects the eNodeB with the highest $Source2I\ LCS$ to ensure a compromise between RSS and Load. On the IEEE 802.11p interface, as we focus on a VANET clustered architecture, source vehicle is already aware of the CH features, position and velocity. Thus, it deduces $Source2CH\ LCD$. For remaining criteria, source vehicle requests the CH about $CH2I\ LCS$ and load and sends it to the source vehicle.

QoS Classes		Class 1	Class 2	Class 3
CH	RSS_{th}	-90dBm	-90dBm	-90dBm
	L_{th}	70%	65%	75%
	LCD_{th}	50 s	80 s	80 s
pGwC	RSS_{th}	-120dBm	-120dBm	-120dBm
	L_{th}	90%	85%	95%
	LCD_{th}	30 s	60 s	60 s

Table II
FQGWS ALGORITHM PARAMETERS

2) Decision phase : The second phase is the decision phase where the gateway to the infrastructure have to be elected. The figure 2 illustrates the diagram of FQGwS proposed algorithm that will make the decision upon the adequate gateway to select to attach the source vehicle to the infrastructure. In this phase, if $Source2I\ LCS$ criterion is acceptable and the traffic type is Voice, the source vehicle will be attached directly to the best BS without defining a gateway to the infrastructure. This decision is taken because Class 1 traffics are very delay sensitive traffics and not resources' greedy. Source vehicle will check CH criteria for Class 1 traffic only if $Source2I\ LCS$ criterion is not acceptable. However, with the remaining traffic classes, in spite of $Source2I\ LCS$ criterion, the source vehicle will always check the CH features.

1) **Cluster Head criteria check:**
With Class 2 and Class 3 traffics, source vehicle verifies the metrics of the default gateway, i.e. the CH. In fact, if the CH metrics values, i.e. $CH2I\ LCS$, CH load and $Source2CH\ LCD$, are acceptable, the decision over the gateway is immediately taken, without the solicitation of other gateway candidates. The gateway to the infrastructure is then the CH. In fact, the CH has got acceptable features when the membership function of each of the three criteria is equal to one, i.e. LCS_{CH2I}> LCS_{th}, CH load <L_{th} and LCD_{S2CH}>LCD_{th} relative to the CH threshold features of Table II.
2) **Gateway Candidates solicitation** :
If the levels of the three criteria of the CH are not acceptable (as compared to the specified threshold of TableII), source vehicle broadcasts a GATEWAY SOLICITATION REQuest message through the cluster to take track of potential OVs that may become gateway candidates. In fact, each OV with acceptable criteria respond with a GATEWAY SOLICITATION RESponse, containing its metrics features ($GwC2I\ LCS$, load, velocity and position (used to compute LCD by source vehicle)). They become potential GwCs (pGwCs). In other terms, pGwCs are OVs with high LCS_{GwC2I} (>LCS_{th}) and low load (<L_{th}) relative to pGwC threshold features of TableII. Afterward, source vehicle collects information over all pGwCs and to use it to take the decision over the gateway candidate to select as a gateway to the infrastructure based on an additive metric weights computing.
Note here that GATEWAY SOLICITATION REQuest and GATEWAY SOLICITATION RESponse messages are a 6-bytes packets containing the node LCS (1 byte), load (1 byte), velocity (1 byte) and position (3 bytes). If it is a request message, LCS, load, velocity and position fields contains 0. If it is a response message, these fields contains the computed value of each criterion.
3) **Gateway Candidate Selection** :
Based on criteria collection of all pGwCs, source vehicle computes and affects a weight to each pGwC. Weights computing are performed using (3), which is a SAM of the three criteria. Criteria are divided into two categories: positive and negative. A positive criterion is a criterion

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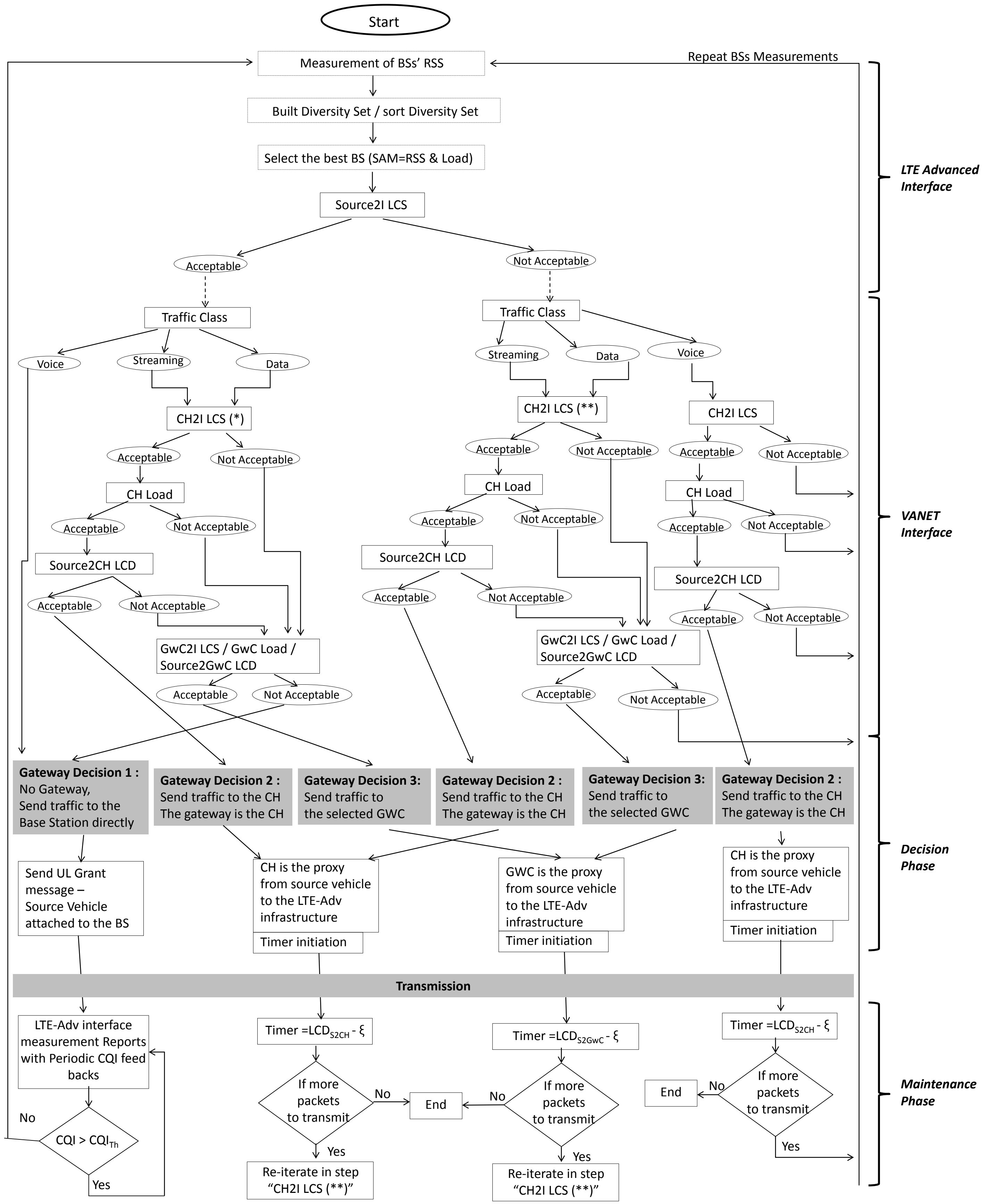

Figure 2. FQGwS algorithm

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that is considered better while increasing, such as LCS and LCD. However, a negative criterion is a criterion that goes worse as it increases, like the load. Therefore, the weight W_i of the potential gateway candidate i ($pGWC_i$) can be formulated like in (3).

$$W_i = \sum_j \frac{M_{ij}}{M_{jth}} + \sum_k \frac{M_{jth}}{M_{ik}} \tag{3}$$

where, M_{ij} is the positive criterion and M_{ik} is the negative criterion. LCD_{th} and L_{th} are defined in TableII. LCS_{th} is -2.17 for the three traffic classes.

The source vehicle keeps track of the best pGwC with the highest weight, named the Gateway candidate (GwC). $GwC2I\ LCS$, load and $Source2GwC\ LCD$ of the GwC are then used to compute the gateway decision as input of FQGwS algorithm.

This algorithm is the baseline for making the decision over the gateway. As it can be deduced, a source vehicle checks in priority the CH state ($CH2I\ LCS$, load and $Source2CH\ LCD$). If the latter ensures efficient proxy capabilities, it will be selected as the gateway and source vehicle won't send the GATEWAY SOLICITATION REQuest message. Otherwise, source vehicle will solicitate other pGwCs. Thanks to this step, gateway efficient decision is taken without leading to useless extra overhead due to GATEWAY SOLICITATION REQuest and GATEWAY SOLICITATION RESponse messages.

3) Maintenance phase: After making the decision over the gateway, source vehicle initiates its Timer and starts transmitting. If there is no gateway between source vehicle and the infrastructure, the link maintenance phase is handled by periodic Channel Quality Indicator (CQI) reports. However, if a gateway is elected, the transmitting period will last $LCD_{S2CH} - \varepsilon$ or $LCD_{S2GwC} - \varepsilon$ depending on the selected gateway, afterward, if there is more packets to be transmitted, source vehicle will re-iterate the process in the CH check phase to re-elect the appropriate gateway for the remaining packets.

C. Fuzzification

In the fuzzy logic, the fuzzifier transforms the inputs values into degrees of match with linguistic values. The fuzzifier maps a crisp point, $\underline{x} = [x_1, x_2, x_3, ..., x_n]^\top \in U$, into a fuzzy set $A = (x_1, \mu_A(x_1)), (x_2, \mu_A(x_2)), ..., (x_n, \mu_A(x_n))$ in U where $\mu_A : U \longrightarrow [0, 1]$ is the membership function of the fuzzy set A and $\mu_A(x_i)$ is the membership degree of x_i in A.

In our system model, input parameters ($Source2I\ LCS$, $CH2I\ LCS$, CH load, $Source2CH\ LCD$, $GwC2I\ LCS$, GwC load and $Source2GwC\ LCD$) collected by the source vehicle are fuzzified using the predefined input membership functions shown in the figures 3 (a, b, c, d, e, f). The fuzzification transforms the input value to names and degrees of membership in the functions. Each curve presents the possible memberships degrees for each values set of that criterion. For example for one input parameter computed or received by source vehicle, using the membership function figure, we can determinate the coordinate of this value into the curve and therefore identifying each couple of membership-function and

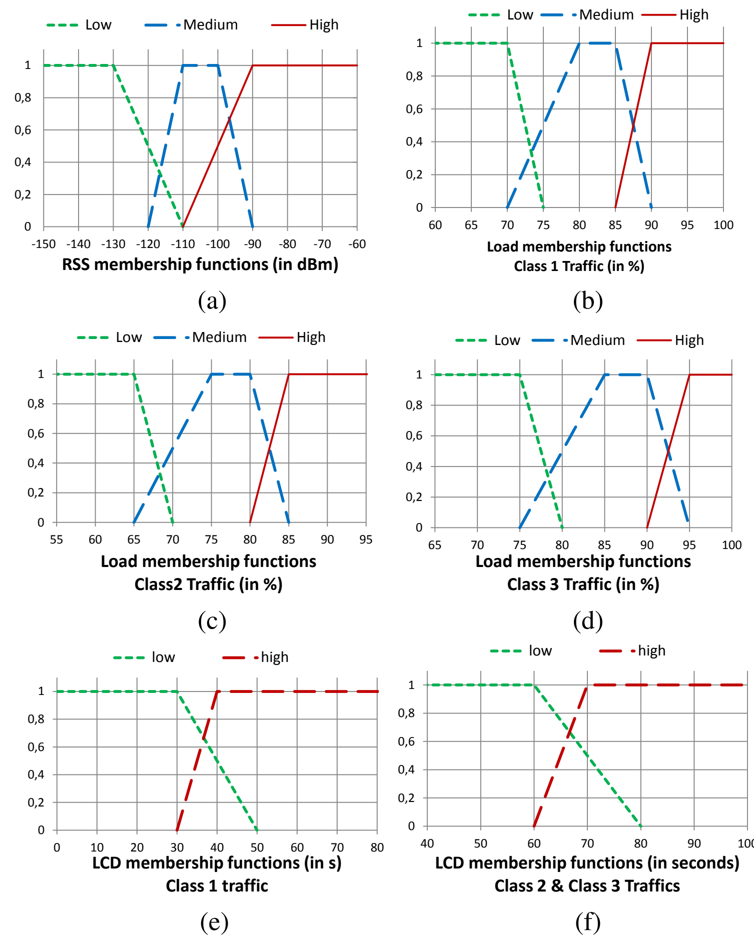

Figure 3. Membership functions

membership-degree. These results will be used then to decide of the vehicle gateway to the infrastructure based on rules base. Note here that the membership function of $X2I\ LCS$, where $X \in \{Source, CH, GwC\}$, is not presented as the RSS and the Load membership functions are more significant and illustrative. However, while performing FQGwS algorithm, the LCS membership function is used. It is concluded from both RSS and loads membership functions and by using (1).

The fuzzification step is performed directly after measuring the values of each proposed criteria. It will generate one or several membership degrees from each value for one or several membership functions which will be applied into the next step of rules evaluation. Values range of each curve is fixed based on the standard scenario when the degree is equal to 1, and based on extrapolation between the best and worst scenarios in the fuzzy part when the degree is different from 1.

D. Rules evaluation

After the fuzzification step of the input values, fuzzified generated values are used to evaluate the rules to obtain the Fuzzy Gateway Decision. The fuzzy rule base contains a number of fuzzy IF-THEN rules. If a fuzzy system has n inputs and a single output, its fuzzy rule R_j is of the general form:

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FQGwD Output	CH GW	Send to the BS	Repeat Measurements
Membership function	$FGwD$ <0.125	0.125< $FGwD$ <0.625	$FGwD$ >0.625

Table III
DEFUZZIFICATION TABLE OF CLASS 1 TRAFFIC

FGwD Output	Send to the BS	CH GW	GwC	Repeat Measurements
Membership function	$FGwD$ <0.125	0.125< $FGwD$ <0.55	0.55< $FGwD$ <0.625	$FGwD$ >0.625

Table IV
DEFUZZIFICATION TABLE OF CLASS 2 / 3 TRAFFICS

IF $x_1\ is\ A_{1j},\ x_2\ is\ A_{2j},\ ...\ x_n\ is\ A_{nj}$ THEN $y\ is\ B_j$, where A_{1j} and Bj are fuzzy sets in $U_i \subset R$ and $V \subset R$, respectively. The variables $\underline{x} = [x_1, x_2, x_3, ..., x_n]^\top \in U_1 \times U_2 \times U_3 ... \times U_n$ and $y \in V$ are called the input and the output linguistic variables, respectively.

The fuzzy inference engine performs the inference operations on the fuzzy rules. Fuzzy logic principles are used to combine fuzzy IF-THEN rules in the rule base, and fuzzy sets in $U = U_1 \times U_2 \times U_3 ... \times U_n$ are mapped into fuzzy sets in V. Let $A \in U$ be the input to the fuzzy inference engine, and let the fuzzy rule be represented as the fuzzy implication

$R = R_{1j} \times R_{2j} \times R_{3j} ... \times R_{nj} \longrightarrow G_j = C$ in $U \times V$.
Then, each fuzzy IF-THEN rule determines a fuzzy set $D = B_j \in V$ using the composition:

$\mu_D(u, w) = \underset{\underline{x}}{sup} \in U\,[\mu_{R \longrightarrow C}(\underline{x}, y) \triangle \mu_A(\underline{x})]$

In our system model, for Class 1 traffic, there are four input parameters. The three input parameters ($Source2I\ LCS$, $CH2I\ LCS$ and CH load) are each composed of three fuzzy sets (High, Low and Medium) and the $Source2CH\ LCD$ input parameter is composed of only two fuzzy sets (High and Low). Therefore the maximum possible number of rules used to build the rule base is

$N_r = 3^3 \text{x } 2^1 = 54$ rules

For Class 2 and Class 3 traffics, there are seven input parameters. The five input parameters ($Source2I\ LCS$, $CH2I\ LCS$, CH load, $GwC2I\ LCS$, GwC load) are each composed of three fuzzy sets (High, Low and Medium) and the $Source2CH\ LCD$ and $Source2GwC\ LCD$ input parameters are composed of only two fuzzy sets (High and Low). Therefore the maximum possible number of rules used to build the rule base is

$N_r = 3^5 \text{x } 2^2 = 972$ rules

Rules table is build on IF-THEN basis. It contains at most N_r rules defining the FQGwS decision of input parameters belonging to diverse membership-functions after fuzzification step. N_r seems to be a high number of rules. However, while building rules data base, several rules can be combined in only one rule. For example, if the $Source2I\ LCS$, $CH2I\ LCS$, $GwC2I\ LCS$ are all Low (in the fuzzy set), it becomes useless to check CH load, GwC load, $Source2CH\ LCD$ and $Source2GwC\ LCD$ as neither the CH nor the GwC could be a gateway for the source vehicle. Thus analytically there is 3^2x 2^2=36 rules having the same output but concretely these rules could be combined in only one rule which is «Repeat measurements».

We note here that the gateway that could be elected for a Class 2 traffic might not be the same if the source vehicle has to transmit a Class 1 or Class 3 traffic (c.f. TableII) as QoS requirements are not the same for the three traffic classes. Therefore, our algorithm takes advantages of the elasticity of some traffic classes to make an efficient gateway decision and to balance the QoS classes over the cluster.

E. Defuzzification

The last step is defuzzification which is used to determine the value of the Fuzzy Gateway Decision ($FGwD$). In our system model, we consider the Centroid defuzzification technique. This method is also known as center of gravity or center of defuzzification area. This technique was developed by Sugeno in 1985. This is the most commonly used technique and is very accurate. The centroid defuzzification technique is computed using this formula:

$$FGwD = \frac{\int \mu_i(x)\ x\ dx}{\int \mu_i(x)\, dx} \tag{4}$$

where $FGwD$ is the defuzzified output, it is the membership degree of output, $\mu_i(x)$ is the aggregated membership function and x is the output variable. The only disadvantage of this method is that it is computationally difficult for complex membership functions. However, in our system membership functions have a simple trapezoid shape. Table III and table IV illustrate membership degrees of output $FGwD$ used to make the final decision over the gateway. Membership functions of the $FGwD$ output are built after collection of experimental simulation result of several scenarios where the decision over the gateway is trivial. Depending on the value of $FGwD$ and according to the table III and table IV, the gateway is selected. In the next section, the FQGwS decision is illustrated by a realistic example and compared to deterministic gateway selection algorithm.

VI. PERFORMANCES EVALUATION

In this section, we present simulation results to confirm the validity of our proposed approach. Simulations are performed in our testbed. Through these simulations, we compare our FQGwS algorithm with the deterministic gateway selection scheme in a clustered VANET architecture. The testbed contains a Matlab module where FQGwS algorithm attributes, criteria and rules are implemented. Membership functions

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VANET Interface	
Parameters	***Values***
Physical/Mac protocols	IEEE 802.11p
Transmission range	R = 250m
Preamble Length	144 bits
PLCP Header Length	48 bits
Beacon Interval	100ms
CW Min / Max	15 / 1023
802.11p Data Rate	11 Mb/s
Interface Queue Type	DropTail/PriQueue
Interface Queue Length	50 packets
Number of vehicles N_v	15 - 40
Traffic Simulator	VanetMobiSim
Mobility Scenarios	IDM_IM / IDM_LC
Data Rate (Mb/s): Class 1 / 2 / 3	0.064/ 0.2/ 0.3
Packet Size (bytes): Class 1 / 2 / 3	160 / 1300 / 1000
N_S	20
ε	1s

LTE Advanced Interface	
Parameters	***Values***
Physical Layer protocols	LTE Advanced
Carrier frequency	2 GHz
eNobeB Trans Power	15 W
Queue/LTEQueue qos	True
Source / GwC / CH - eNodeB link	Data Rate : 10Mb LTEQueue/ULAirQueue LTEQueue/ULAirQueue
eNodeB - Serving GW link	Data Rate : 1000Mb LTEQueue/ULS1Queue LTEQueue/ULS1Queue
Radio Propagation Model	$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L}$
N_{BS}	3
System Loss (L)	1 dB
Tran/Rec Antenna High (h_t / h_r)	1.5 m / 20 m
Tran/Rec Antenna Gain (G_t / G_r)	1 dB / 1 dB
α (Confidence Interval)	0.5

Table V
SIMULATION PARAMETERS SETTINGS

of LCS, $Load$, LCD and the output $FGwD$ for the CH, GwC and $Source\,Vehicle$ for each traffic class are defined in this module. Rules base based on membership functions fuzzy sets is also built and integrated into the module for the 3 traffic classes. Network performances simulation are performed using the Network Simulator NS2.33 [29]. We implement in our testbed an IEEE 802.11p package in order to enable VANET communications among high-speed vehicles and an LTE module to enable 4G communications [30]. Vehicles mobility is generated using VanetMobiSim [31]. Table V lists parameters of VANET and LTE modules. Specifically, a source vehicle first collects the input parameters of the FQGwS algorithm using NS2.33 module. Then, these input parameters are integrated into the Matlab fuzzy module to perform decision over the gateway by considering the class of the traffic to be transmitted to the infrastructure. The fuzzy module generates then the output of the FQGwS. FQGwS gateway decision is afterward plugged into the simulator and compared to the default deterministic scheme.

A. Simulation Scenario

In the simulation scenario, we consider a section of a straight multiple-lane highway. Vehicles are equipped with a Global Positioning System (GPS) receiver. Thus, we assume that each vehicle knows its own position and velocity. The vehicles are organized into clusters where a CH is elected at the top of each cluster. A cluster is composed of N_v vehicles. Clustering and CH election schemes are out of the scope of this paper. Hence, we consider two clustering and CH election algorithms [6], [7] recently proposed in literature for VANET networks. In reference [6], authors propose the C-DRIVE algorithm for cluster formation that is based on direction of vehicles, where vehicles moving in the same direction belongs to the same cluster. The first vehicle moving in each direction will be elected as CH. This algorithm considers intersection scenarios, while in our work we focus on the generalization of the C-DRIVE to use it as a comparison base for CH election algorithms. In reference [7], the CH is the vehicle in the middle of the cluster at equal distance, in terms of number of hops, from vehicles in the border of the cluster, called here Middle algorithm. On the other hand, the infrastructure is composed of N_{BS} eNodeBs positioned in the border of the highway where vehicles are attached to the eNodeB offering highest LCS_{S2I}, see Table V.

In the traffic simulation scenario, a source node that belongs to the cluster uses the FQGwS or the deterministic scheme for gateway selection. In the deterministic scheme, i.e. C-DRIVE or Middle without FQGwS, the selected gateway is always the CH. With FQGwS algorithm, source vehicle takes the decision over the gateway using our fuzzy module and after data collection. C-DRIVE and Middle without FQGwS algorithms are compared to C-DRIVE and Middle with FQGwS schemes in order to evaluate the performances of our FQGwS scheme in terms of delay, throughput, Packet Loss (PL), overhead and LCD and RSS improvement. Simulation scenarios have been repeated N_S times by varying source vehicle velocity. We plot simulation results using confidence interval (CI) with a certitude of 95% (see α (confidence interval) in Table V).

B. Impact of Cluster Density

In this section, we evaluate the performances of our algorithm while increasing the cluster density. We compare two deterministic schemes, noted in the legends C-DRIVE w/o FQGwS and Middle w/o FQGwS, where the gateway to the

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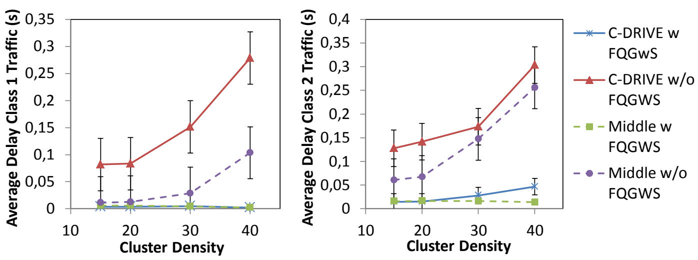

Figure 4. Average Delay Vs Cluster Density for Class 1 & Class 2 traffics

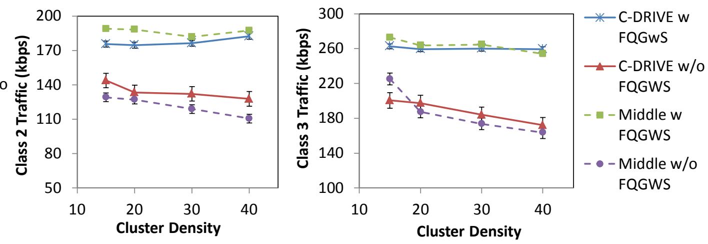

Figure 6. Average Throughput Vs Cluster Density for Class 2 & Class 3 traffics

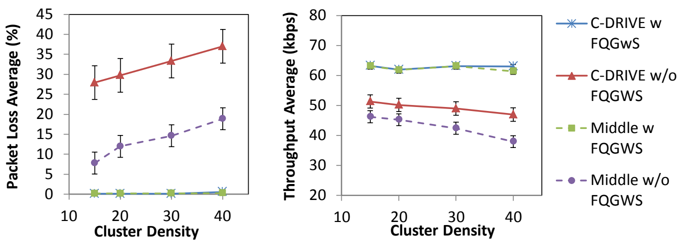

Figure 5. Packet Loss and Throughput Averages Vs Cluster Density for Class 1 traffic

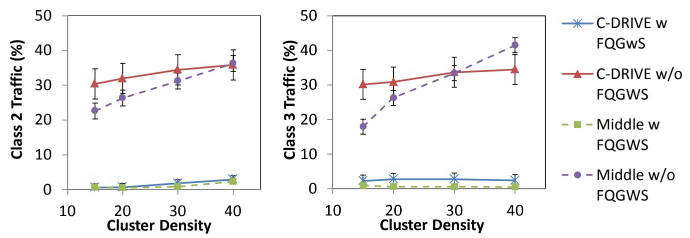

Figure 7. Packet Loss Average Vs Cluster Density for Class 2 & Class 3 traffics

infrastructure is always the CH.

In figure 4, we plot the average delay of Class 1 and Class 2 traffics while increasing the cluster density. The computed delay is the average of the delay of the all received packets. The figure shows clearly that with FQGwS scheme lower delays (<0.5ms) are generated as compared to deterministic approaches, i.e. C-DRIVE w/o FQGwS and Middle w/o FQGwS for both Classes which exceeds the delay constraints, see Table I. This is due to the fact that the selected gateway has better features of VANET and LTE Advanced interfaces than the CH. In fact, FQGwS algorithm is decision efficient as it takes into consideration at the same level the LTE Advanced and VANET features. Thus, if the LTE Advanced link properties, i.e. BS load and source vehicle RSS, are acceptable, it is more suitable to have no intermediate gateways and relays for Class 1 traffic type as, for delay sensitive traffics such as alerts, voice or real time gaming, the lower the delay is the better the QoS perceived by the users is. Without FQGwS algorithm, for Class 1 and Class 2 traffics, as the number of vehicle increases, the delay increases because the CH will handle and manage more vehicles. However, with FQGwS, the delay is almost invariant as the algorithm takes aware of the load of the either the CH and the gateway candidates for gateway selection.

In figure 5, we first plot the average packet loss for Class 1 traffic while increasing the cluster density. With FQGwS packets drop is lower than 0.05%, in opposite to algorithms without FQGwS which increases the PL average as the number of vehicles belonging to the cluster increases. Without FQGwS scheme, buffering queues of the CH becomes rapidly overloaded while the number of handled nodes increases causing considerable packets losses. However, with FQGwS, one of the main criteria for gateway selection is the buffering queues load of the either the CH and/or the gateway candidate leading to an adequate gateway selection. Moreover, curves show clearly that C-DRIVE algorithm without FQGwS scheme presents high amount of packet loss as the CH is positioned in front of the cluster members causing an increase in the number of hops to attend the gateway to the infrastructure. In figure 5, we plot also the throughput average of Class 1 traffic while increasing the number of vehicles in the cluster. The throughput remain constant for C-DRIVE and Middle w FQGwS near to 64kb/s. However, w/o FQGwS algorithm, the data rate decreases while increasing the cluster density. The throughput decreases reaches the half of initial data rate for Middle algorithm in a cluster density of 40 vehicles.

In figure 6, we plot the throughput average of Class 2 and Class 3 traffics while increasing the cluster density. Class 2 throughput constraint is 0.2Mb/s and Class 3 constraint is 0.3Mb/s. According to the figure, C-DRIVE and Middle w FQGwS algorithms reach the throughput constraints as LCS, LCD and load are baseline criteria of our algorithm. However, w/o FQGwS algorithm the throughput decreases considerably while cluster density increases.

In figure 7, we plot the packet loss average of Class 2 and Class 3 traffics while increasing the number of vehicles in the cluster. Without FQGwS algorithm, as the number of vehicle increases, the PL increases because the CH will handle and manage more vehicles. However, with FQGwS, the PL is almost invariant as the algorithm takes aware of the load of the either the CH and the gateway candidates for gateway selection.

We plot in figure 8, the percentage of control packets overhead in the network from the total number of packets send by the source vehicle against the number vehicles in the cluster. Though, this is generally the trend, Middle and C-DRIVE for Class 1 traffics show less control packets overhead as compared to the other traffic Classes (Class 2 and 3) due to the fact that only the CH is solicited for to be a

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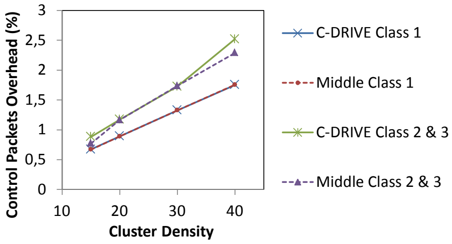

Figure 8. Overhead Vs Cluster Density

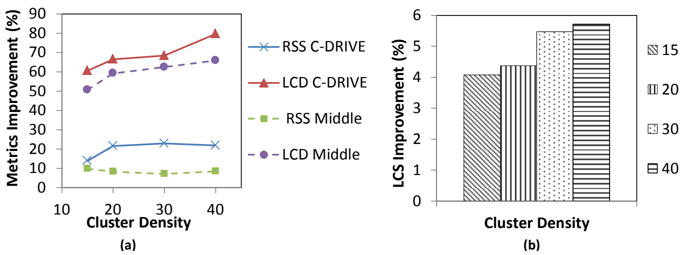

Figure 9. (a) Metrics Improvement Vs Cluster Density - (b) FQGwS Vs Flat Architecture

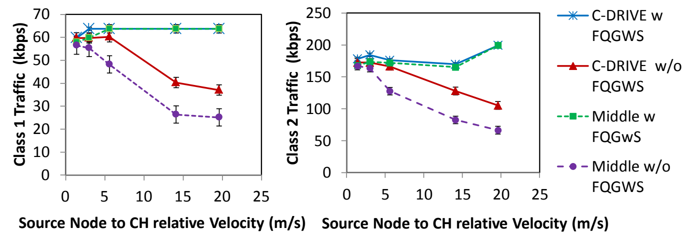

Figure 10. Throughput Average Vs Relative Velocity for Class 1 & Class 2 traffics

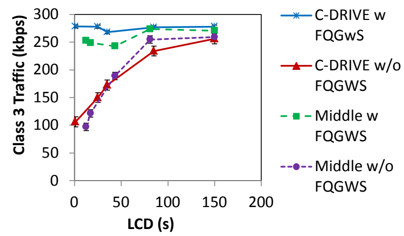

Figure 11. Throughput Average Vs LCD for Class 3 Traffic

potential gateway for Class 1 traffics, no other pGwCs are considered. Indeed, Class 1 traffics exhibit around 1.5% of overhead packets as compared to the 2.5% for Class 2 and Class 3 traffics.

In figure 9-(a), we plot the metrics improvement while comparing our algorithm to the C-DRIVE and Middle schemes. Two metrics are considered in this paper: RSS and LCD. LCD metric is the link connectivity duration between the source node and the selected gateway (either the CH or the GwC). According to the figure, there is an improvement of more than 10% in terms of RSS for Middle algorithm and about 20% for C-DRIVE. It is important to choose a gateway that has high RSS as it will interface the VANET layer with the LTE Advanced layer. An improvement of about 80% for Middle scheme and 90% for C-DRIVE scheme of the LCD metric is performed with FQGwS thanks to the fact that our algorithm selects the gateway with a low relative velocity and high LCD.

We compare our proposed FQGwS algorithm with the flat architecture where the VANET network is not clustered. In a flat architecture, the source vehicle sends directly to the eNodeB. In figure 9-(b), we plot the improvement of the LCS criterion when using the FQGwS algorithm as compared to the flat architecture. An improvement of more than 5% is noticed, it increases while the cluster density increases because the set of pGwCs becomes bigger, increasing the chance to find a better GwC. Note that with our FQGwS algorithm the direct link is considered as the first choice to check for sending the traffic to the infrastructure. If the latter presents acceptable criteria, traffic will be sent directly to the infrastructure for class 1 traffic without CH solicitation. In fact, the advantage of using a clustered architecture is to propose an alternative way for V2I communications in the situation where the direct link from the source vehicle to the infrastructure is not possible or presents a bad LCS.

C. Impact of Nodes' Velocity

In this section, we evaluate the impact of CH to source vehicle relative velocity and LCD upon the performances of the algorithm.

Figure 10 illustrates the throughput average of Class 1 and Class 2 traffics while the relative velocity between source vehicle and the CH increases. As it can be noticed from the figure, throughput average is much higher with FQGwS algorithm than the one without FQGwS algorithm as LCD criterion, which considers relative velocity is one of the input criteria of our algorithm. Moreover, the throughput remains invariant while increasing the relative velocity. It is decreased by almost the half while not using FQGwS algorithm for both clustering schemes.

We plot, in figure 11, the throughput average versus LCD for Class 3 traffics. The figure shows better results of FQGwS algorithm as compared to deterministic approach. This is due to the fact that the selected gateway has better features than the CH leading to better simulation results. In fact, as the LCD between the source node and the gateway decreases, the relative velocity increases, therefore, the V2V link become

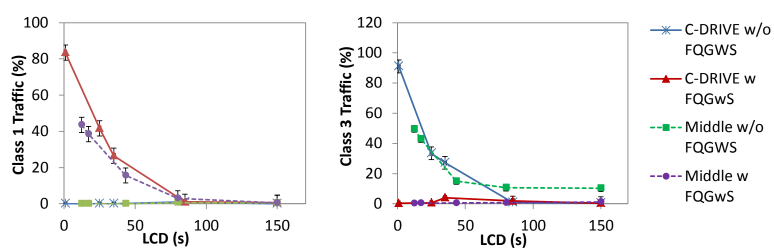

Figure 12. Packet Loss Average Vs LCD for Class 1 & Class 3 Traffics

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Scenario Specifications	
Parameters	***Values***
RSS / Load Source Node	-98.57 dBm / 81 %
Source Node Velocity	25.2 ms
RSS / Load eNodeB CH	-100.56 dBm / 80 %
CH Velocity	19.6 ms
CH Load	85 %
LCD CH	85.57 s
GwC LCS	-1.33
Load GwC	77.4 %
LCD GwC	77.08 s

Table VI
SCENARIO SPECIFICATIONS

	Class 1	Class 2	Class 3
w FQGwS	Direct link	($FGwD$= 0.6) <-> GWC	($FGwD$ = 0.48) <-> CH
w/o FQGwS	CH	CH	CH

Table VII
FQGWS GATEWAY DECISION

		C-Drive		Middle	
		w FQGwS	w/o FQGwS	w FQGwS	w/o FQGwS
Class 1	CH	30	100	40	100
	GwC	0	0	0	0
	eNB	70	0	60	0
Class 2	CH	25	100	25	100
	GwC	45	0	60	0
	eNB	30	0	15	0
Class 3	CH	20	100	40	100
	GwC	50	0	60	0
	eNB	30	0	0	0

Table VIII
QOS-BALANCING GATEWAY SELECTION PERCENTAGE

unstable. However, with our algorithm, thanks to the LCD criterion, source vehicle to gateway link stability is achieved.

Figure 12 illustrates the PL average versus LCD for Class 1 and Class 3 traffics. The figure shows better results of FQGwS algorithm as compared to deterministic approach. This is due to the fact that the selected gateway has better features than the CH leading to better simulation results. In fact, as the LCD between the source node and the gateway decreases, the relative velocity increases, therefore, the V2V link become unstable. However, with our algorithm, source vehicle to gateway link stability is achieved.

D. QoS-balancing for Gateway selection

In this section, we point out the QoS-balancing feature of FQGwS algorithm while deciding over the gateway to select for a source vehicle depending on the Class of the traffic to be transmitted to the infrastructure, under the scope of V2I communications. To this end, we consider an example of scenario in which, we present and compare the gateway decision of both the FQGwS and the deterministic algorithms.

Table VI presents the input criteria of the scenario. According to table VII, depending on the class of the traffic to be transmitted to the infrastructure, the gateway decision is different. If it is a Class 2 traffic, it is better to use the GwC than the CH as a gateway. If it is a Class 3 traffic, it is better to use the CH as a gateway to the infrastructure. This is due to the fact that LCS and load membership functions for Class 2 and Class 3 do not present same limits of the fuzzy set. This feature leads to have, in this scenario, the CH is a good gateway for a Class 3 traffic and not for a Class 2 Traffic. Therefore, QoS-balancing feature of FQGwS algorithm is achieved.

Table VIII presents percentage of each gateway selection decision. These percentage are computed using information gathering and statistics over previous figures.

According to Table VIII, for Class 1 traffics, more than half of traffics are send directly to the infrastructure without defining a gateway for the source vehicles. However for Class 2 traffics, only 25% of the traffic is handled by the CH. The GwC has got the highest percentage to be selected as gateway to the infrastructure. For Class 3 traffics, more than 50% of the traffics are handled by the GwC.

VII. CONCLUSIONS

This paper presented an original algorithm based on a fuzzy logic for gateway selection from a VANET network to the LTE Advanced infrastructure. This new approach has been compared to the standard deterministic approache that uses the CH as a default gateway. Two clustering and CH selection algorithms have been studied and simulation results show that our protocol performs better results in terms of delay and packet loss than the deterministic approach for both algorithms. Moreover, simulations show that an efficient CH election algorithm is important to ensure good performances as with C-DRIVE higher packet loss averages have been observed than with middle algorithm. In our future works, we will focus on studying the performances of FQGwS algorithm and investigating its adaptability while performing cluster head handovers in a clustered architecture and optimizing the gateway solicitation phase where selected gateway candidate might be identical for several source nodes belonging to the same cluster specially in case of small clusters.

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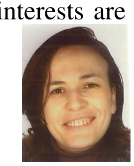
Ghayet el mouna ZHIOUA obtained her PhD degree jointly from Sup'Com (the Higher School of Communication of Tunis- TUNISIA) and Telecom Paris-Tech (Paris-FRANCE). She received her Master's degree in Telecommunication from Sup'Com. She had publications in refereed International Conferences, such as IEEE WCNC, IEEE WiMob, ACM MSWiM. Her research interests are: 3GPP LTE, 4G Heterogeneous Wireless Networks, Vehicular Communications, IEEE 802.11p, IEEE 802.11s standard and wireless mesh communications.

Nabil TABBANE is currently an Associate Professor in the Computer Networks Department at Higher School of Communications, Tunis: SUP'COM. He received his PhD degree in SUP'COM and in the University of Versailles Saint-Quentin-en-Yvelines (France) in joint guardianship. His PhD research was on stochastic models for forecasting the quality of service in multi-media ad hoc networks. His research interests are in ad hoc and sensor networks.



Houda LABIOD received a PhD degree in Computer Science from the University of Versailles Saint-Quentin-en-Yvelines (France) in 1998. From 1999 to 2000, she worked as an assistant researcher at Eurecom Institute in Sophia-Antipolis (France) in the Mobile Communications Unit. Since September 2000, she is an associate professor at Telecom ParisTech in the INFRES (Computer Science and Network) department. She is an author of a book titled "De Wi-Fi à Bluetooth" (Hermès Editions, 2004). Her main research interests include optimization of mobile and wireless networking and mobile ad hoc networks (unicast routing, multicast routing, security, QoS routing).

Sami TABBANE is currently a Professor in the Computer Networks Department at Sup'Com. He is a specialist of mobile communication systems. He has graduated from Ecole des Mines de Paris in 1998 and got a PhD of Telecom ParisTech in 1991. He started his carreer at France Télécom in 1992-94 and was recruted by Sup'Com in 1994. He has achieved many missions for ITU in the domain of mobile networks planning, management and training as well as spectrum management in regulatory agencies. He is the co-author of "Réseaux GSM" (Hermes, 1995) and "Ingénierie des Services de Télécommunications" (Hermes-Lavoisier, 2005). He is the author of "Réseaux Mobiles" (Hermes, 1997), "Handbook of Mobile Networks" (Artech House, 2000), "Ingénierie des Réseaux Cellulaires" (Hermes-Lavoisier, 2002).