Dynamic Clustering-based Adaptive Mobile Gateway Management in integrated VANET – 3G Heterogeneous Wireless Networks

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Abstract – **Coupling the high data rates of IEEE 802.11p-based VANETs and the wide coverage area of 3GPP networks (e.g., UMTS), this paper envisions a VANET-UMTS integrated network architecture. In this architecture, vehicles are dynamically clustered according to different related metrics. From these clusters, a minimum number of vehicles, equipped with IEEE 802.11p and UTRAN interfaces, are selected as vehicular gateways to link VANET to UMTS. Issues pertaining to gateway selection, gateway advertisement and discovery, service migration between gateways (i.e., when serving gateways lose their optimality) are all addressed and an adaptive mobile gateway management mechanism is proposed. Simulations are carried out using NS2 to evaluate the performance of the envisioned architecture incorporating the proposed mechanisms, and encouraging results are obtained in terms of high data packet delivery ratios and throughput, reduced control packet overhead, minimized delay and packet drop rates.**

***Index Terms* – VANET, 3G, system integration, clustering, and adaptive mobile gateway management.**

I. INTRODUCTION

In today's wireless networking domain, diverse wireless technologies are utilized for sharing data and providing data services. Among the available technologies, the leading examples are the widely-deployed 3G cellular networks and IEEE 802.11-based Vehicular Ad hoc Networks (VANETs). 3G cellular networks, such as Universal Mobile Telecommunication Systems (UMTS), are pre-dominantly used for wide-area wireless data and voice services via access to a Base Station Transceiver (BST), also referred to as UMTS Node B. On the other hand, VANETs are used for short-range, high-speed communication among nearby vehicles, and between vehicles and roadside infrastructure units [1]. Vehicle-to-Vehicle (V2V) communication supports services such as car collision avoidance and road safety by exchanging warning messages across vehicles [5].

Internetworking over VANETs has been gaining a great deal of momentum over the past few years. Its increasing importance has been recognized by major car manufacturers, governmental organizations and the academic community. The Federal Communications Commission has allocated spectrum for Inter-Vehicle Communications (IVC) and similar applications (e.g., wireless access in vehicle environment) [6]. Governments and prominent industrial corporations, such as Toyota, BMW, and Daimler–Chrysler, have launched important projects for IVC communications. Advanced Driver Assistance Systems (ADASE2) [7], Crash Avoidance Metrics Partnership (CAMP) [8], Chauffeur in EU [9], CarTALK2000 [10], FleetNet [11], California Partners for Advanced Transit and Highways (California PATH) [12], and DEMO 2000 by Japan Automobile Research Institute (JSK) are few notable projects, which are a major step towards the realization of intelligent transport services.

In this paper, a heterogeneous integration of VANET and 3G networks using mobile gateways (i.e., vehicles) is introduced. The envisioned architecture shall enable mobile data access for vehicles, anytime and anywhere. In particular, the integration of IEEE 802.11-based multi-hop VANETs with 3G shall contribute to the evolution of Beyond 3G (B3G) wireless communication systems. As an integral part of the architecture, UMTS enables mobile data access to vehicles, offering a wide range of communication of around 8 to 10 km per BST. The UMTS takes a phased approach towards an all-IP network by extending 2G GSM/GPRS networks with international roaming capabilities and using Wide-band Code Division Multiple Access (WCDMA) technology. The set of enhancements to the UMTS, introduced in the 3GPP Release 8, defines the Long Term Evolution (LTE), which is the last step towards the 4G communication systems.

On the other hand, the enhanced version of IEEE 802.11 networks, which is IEEE 802.11p, forms the standards for Wireless Access for Vehicular Environments (WAVE). It operates at a frequency of 5.9 GHz, divided into 7 channels, each operating at a frequency of 10 MHz. It provides a high data rate, ranging from 6 Mbps to 27 Mbps and a short-range radio communication of approximately 300 meters. By integrating VANET with UMTS, high data rate can be coupled with wide-range of communication. In the envisioned VANET/3G network, if one vehicle is connected to the UMTS network using its 3G UTRAN interface, it can serve as a relay node (i.e., mobile gateway) for other vehicles in its vicinity to access the UMTS network, by receiving data from them (using its IEEE 802.11p interface) and relaying the data to the UMTS network. With such an integration, dead spots in UMTS can be minimized to a significant extent [14]. Additionally, the overall frequency of handoff occurrences at base stations and the associated cost can be dramatically decreased. This is without mentioning the savings in the scarce resources of the access network. The need for connecting vehicles to the 3G backbone network, via mobile gateways instead of static gateway access points, is elaborated in the forthcoming subsection.

A. Purpose of Mobile Gateways in VANET – UMTS integrated network

In the existing literature, the gateways are regarded as static roadside infrastructure. These units are deployed at fixed distances from one another, depending on their transmission range, which renders the overall system deployment costly. Furthermore, the dynamic and multi-hop nature of VANET communication impacts the stability of links to these gateways. Additionally, as these gateways are fixed, the routing and discovery mechanisms are mainly pro-active. Though pro-active routing mechanisms reduce delay, they increase the signaling overhead and require frequent changes in the pre-defined routing tables of vehicles.

To cope with these shortcomings, this paper introduces a VANET-3G integrated network architecture and defines the concept of mobile gateways. A mobile gateway refers to the dual-interfaced vehicle that relays data from other vehicle sources to the UMTS backhaul network. It is enabled with dual interfaces of IEEE 802.11p and the UMTS UTRAN networks. The main challenge is to integrate these two network interfaces on a hybrid gateway node, as they lie in two different spectrum regions. The next challenge is to select a minimum number of optimal gateways using relevant metrics. There could be several nodes in the VANET which possess the essential criteria and required metric information, and hence, the qualification to serve as gateways. The focus of this paper is on defining a mechanism that selects a minimum number of optimal VANET gateways, at an instance and per moving direction, so as to avoid the bottleneck at the UTRAN radio access interface of the UMTS network.

The next challenge in gateway management arises when the current serving gateway loses its optimality. At this instance, a gateway handover mechanism, with minimum overhead, is required for migration of the responsibilities of the existing gateway to a newly-elected optimal gateway. This should be done to support service continuity and the inter-connectivity of the integrated network. Efficient gateway discovery mechanisms are also required. With this regard, as pro-active gateway discovery reduces delay and reactive discovery reduces signaling overhead, this paper envisages a hybrid gateway discovery mechanism for VANET, combining the pros of both the pro-active and reactive concepts. This requires adequate configuration of different parameters such as gateway advertisement zone (i.e., in terms of TTL value or number of hops from gateway) and the advertisement interval (i.e., the periodicity for which the GWADV messages should be broadcast within the advertisement zone). In this paper, we address all the above-mentioned issues by devising an adequate adaptive gateway management mechanism.

B. Purpose of Clustering in VANETs

In the envisioned integrated VANET-3G network, vehicles are distinguished as either Ordinary Vehicles (OVs) or mobile gateway vehicles. Based on their geographical locations, directions of movement, and other metrics, vehicles are grouped into different clusters. Clustering enhances effective broadcasting and relaying of messages, such as Gateway Advertisement (GWADV), and reduces the overhead associated with signaling, as links among vehicles within the same cluster tend to be more stable. The main challenge in clustering lies in the dynamic topology changes in VANET and hence, an efficient clustering should be based on adequate metrics and should take into account the frequent topology changes.

This paper aims for clustering gateway candidates (i.e., to be described later) according to key relevant metrics and selecting out of each cluster, a cluster head that serves as the gateway to interface VANET with the 3G environment. In the existing literature, clustering within VANETs was performed based upon metrics such as vehicle velocity, inter-vehicular distance, and the direction of movement. Concerning the velocity, the variance in the speed of vehicles at different instances is not consistent. This variance in velocity results in drastic changes in the inter-vehicular distance because of the unpredictable behavior of drivers. As a result, different clusters of vehicles may frequently form, subsequently resulting in significant signaling overhead, service instability, and so forth. Instead of vehicular velocity, this paper envisions using the UMTS received signal strength metric of the vehicles for dynamic clustering mechanism, due to its relatively better consistency along a pre-defined direction. This shall subsequently elaborate upon the impact of the backbone 3G network on gateways. In addition to the UMTS signal strength, the direction of movement of vehicles and their inter-vehicular distance metrics are also considered for the purpose of dynamic clustering of vehicles.

The remainder of the paper is structured as follows. Section II presents an overview of the state of the art. The VANET-3G integrated network architecture is described in Section III. Section IV delineates the methodology of clustering and introduces our proposed dynamic clustering mechanism. Section V presents our adaptive mobile gateway management mechanisms. The performance of the proposed mechanisms is evaluated in Section VI. The paper concludes in Section VII with a summary recapping the main advantages and achievements of the integrated 3G/VANET architecture. Future research directions are finally presented.

II. REVIEW OF EXISTING LITERATURE

In the area of vehicular communications, there has been a plethora of research work. In [1], the authors proposed a new protocol, which selects a route with the longest lifetime to connect VANET nodes to the wired network. This research work considers vehicles to be stationary or mobile, but the gateways to be purely stationary. The protocol uses the characteristics of vehicle movements to predict the future behavior of vehicles. The work uses two metrics, namely Link Expiration Time (LET) and Route Expiration Time (RET). LET and RET reflect the stability of the link between two adjacent vehicles and the life-time of the route between the vehicles and the gateways, respectively. By defining these metrics, the authors established pro-active communication between the vehicles and the fixed gateways by measuring the stability of the links and updating the progress towards the destination. The authors also addressed gateway handover and compared the performance of their proposed protocol against that of Greedy-Perimeter Stateless Routing (GPSR) and an extended version of Ad-Hoc On-Demand Distance Vector Routing (AODV+). In the present research work, RET is used to assess the stability of links between source vehicles and candidate gateways. It is then used for gateway selection, but not in a completely proactive way.

Another routing protocol that considers link stability is defined in [2], as an improvement to the fish-eye state routing protocol [3]. In this routing protocol, metric-related information, such as hop-length or path stability, are collected with the help of routing updates disseminated to retain stability. In this Neighborhood Fish-eye State Routing (NFSR) protocol, a node is considered to be a neighbor if a path with minimum reliability to this node exists. Our paper also uses the concept of neighborhood for clustering and TTL computation. However, in our paper, neighborhood determination is not based on link reliability, but rather on IEEE 802.11p wireless transmission range of vehicles. We, subsequently, elaborate upon the importance of the neighborhood-hop distance to make an accurate estimation of the TTL value, as will be explained in Section IV-D. A protocol for Optimized Dissemination of Alarm Messages (ODAM) in VANET is proposed in [4], overcoming the limitations of classical broadcasting and multicasting in VANET. In this work, the author achieves scalability and reliability via an efficient dissemination of alarm messages to only special nodes, called relays in risk zones. A metric, dubbed “defer-time”, is defined as the time for which the re-broadcasting is delayed by a vehicle, receiving a control packet or an advertisement message. Relaying is performed by the vehicle with the minimum value of the defer-time. The defer-time is computed either randomly or from the inter-vehicular distance, which is inversely proportional to the defer-time. Here, the author increases the delay by defining the defer-time, at the cost of reducing the re-broadcasting overhead.

Another clustering approach is devised in [5], where a cluster-based risk-aware collaborative vehicular collision avoidance system is introduced. In this work, vehicles are clustered based on their velocities, the direction of their movement, and inter-vehicle distances. Additionally, a risk-aware Media Access Control (MAC) protocol is designed to increase the responsiveness of the system by associating an emergency level with each vehicle in its corresponding cluster. In our current paper, as in [5], we carry out clustering of vehicles based on the direction of their movement and their IEEE 802.11p wireless transmission range for inter-vehicular distance estimation. However, due to the inconsistency and unpredictable nature of mobility speed (unlike the work in [5]), we do not base our clustering on vehicles’ velocities. Instead, we additionally consider the UMTS signal strength, as will be detailed later. Another stable routing protocol to support ITS services is proposed in [6]. This work addresses the issue of path disruptions caused by vehicles’ mobility. The main concept behind the work consists in using vehicles’ characteristics to predict a link-breakage event prior to its occurrence. Vehicles are grouped according to their movement directions to ensure that vehicles of the same group establish stable single and/or multi-hop paths while moving together. Within the same clusters, communications among the vehicles are carried out over stable paths with acceptable LET values.

Regarding gateway selection, a wide library of research work has been conducted in the recent literature. In [13], an adaptive gateway management mechanism for multi-hop B3G networks is proposed. In this research work, the authors discuss the issues associated with the selection of mobile gateways in an integrated MANET-UMTS heterogeneous network. They use multi-attribute decision making theory and simple additive weighting (SAW) techniques [15] to select an adequate gateway based on residual energy, UMTS signal strength and mobility speed of the gateway candidates. In case the current serving gateway loses its optimality, the authors proposed a multi-metric gateway migration approach for handing over the responsibilities of the serving gateway to a newly-elected one. A comparison has been carried out between the existing heterogeneous wireless network architectures and theirs to infer that their proposed adaptive gateway management-based multi-hop B3G architecture makes significant improvement in terms of sustaining the inter-connectivity and improving the throughput of the integrated network. Whilst our envisioned gateway selection mechanism is also based on different metrics (without considering the vehicle’s residual energy, as battery is not a constraint for vehicles), we refine further the gateway selection mechanism by restricting its application to only gateway candidates of predetermined clusters.

In [16], an adaptive distributed gateway discovery mechanism for hybrid wireless networks is introduced. The proposed gateway discovery method is hybrid; combining both reactive and pro-active approaches. It defines a limited zone based on the number of hops from gateways whereby the gateways periodically propagate advertisement messages. This hop distance corresponds to the TTL value, adaptively selected by the gateway. The gateway discovery mechanism used in our paper is also hybrid. However, our paper confines pro-active gateway advertisement broadcast within individual sub-clusters of a zone and not to the whole zone. In the present research work, the *TTL* value varies for every sub-cluster, based on the cluster size. For BST handover support, an interesting mechanism based on signal strength and distance for interoperability in mobile cellular networks is presented in [19]. In this research work, *Singh* proposes an initiation algorithm for intersystem (i.e., 2G GSM and 3G UMTS) handover, based on a combination of the geographical location of mobile terminals and absolute signal strength thresholds. Compared to the existing literature that considers only signal strength as a threshold, this research work aims at improving the network resource usage efficiency by also considering the threshold for the distance metric between mobile terminals.

III. Proposed VANET-3G Integrated Network Architecture

The topology of our envisioned integration of VANET and 3G is depicted in Fig. 1. The scenario considers two different tracks over a particular road (e.g., highway), with a track for each direction. The architecture comprises IEEE 802.11p-based VANET vehicles, a UMTS Node B and the main components of the UMTS core network. Vehicles are assumed to be equipped with GPS devices, experiencing different UMTS signal strength intensities at different regions of each track. Communication over the VANET network is multi-hop and the nodes of the VANET communicate with each other on a peer-to-peer basis. The main components of the UMTS network are Radio Network Controller (RNC), Base Station Transceiver (BST), Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) [20]. The VANET mobile gateway accesses the UMTS network via Node B BST using the Universal Terrestrial Radio Access Network (UTRAN) interface. The UMTS network is connected to the external IP networks through GGSN. The GGSN is responsible for converting circuit-switched data, if any, from the external networks, into packet-switched data. SGSN is responsible for routing data packets to the correct RNC from GGSN and vice-versa. The main purpose of our paper is to allow only a minimum number of vehicular gateways to communicate with the UMTS network. Indeed, if all vehicles of a large VANET directly communicate with the UMTS Node B, they may cause a bottleneck at the BST. On the other hand, UTRAN may also allocate individual channels to all vehicles, even if they would stay within the BST coverage region for a short period of time. Moreover, the large size of a VANET poses significant signal overhead to the BST, at times of roaming and handover (i.e., as vehicles moving along the same road are more likely to perform handoff at nearly same time). This results in additional consumption of the UTRAN access network resources which may affect the overall performance of UMTS.

The main objective of the architecture is to primarily determine the gateway vehicles in the VANET. Referring to the architecture shown in Fig. 1, there are two VANET regions under the coverage of BST1 and BST2, where the UMTS signal strength is intense. They are termed as 3G active regions. The active regions can overlap or not, depending on the ITS system management. The vehicles lying within or moving to the 3G active region are called Gateway Candidates (GWCs). These vehicles are equipped with the IEEE 802.11p and UMTS interfaces. Among these gateway candidates, a minimum number of optimal gateways (GWs) per track are selected using different metrics, as will be detailed in Section V. Gateway candidates are grouped into clusters using dynamic clustering mechanism, and only the gateways have their 3G UTRAN interfaces activated. However, the IEEE 802.11p interface is enabled and activated on all the VANET vehicles.

IV. Dynamic Clustering in VANETs

As stated earlier, clustering contributes to effective broadcasting and relaying of messages, and increases the stability of inter-vehicular links within the VANET. In this paper, clustering is performed following three steps, based on the direction of vehicles' movement (θ), UMTS Received Signal Strength (*RSS*), and inter-vehicular distance (*IVD*), respectively.

It is to be noted that clusters are formed with the gateway candidates only. Ordinary vehicles, as shown in Fig. 1, can only traverse through these clusters. This is only to show that there is no physical separation between vehicles.

A. Clustering based on Direction of Movement

As mentioned in Section III, a minimum number of mobile gateways need to be selected per track, corresponding to each direction. As a first step towards this, clustering is performed on the basis of direction of movement in two stages. Initially, it is carried out relative to their moving directions and then relative to the position of the UMTS Node B. As a result, the vehicles are grouped into a number of different clusters. (e.g., CL 11, CL 12, CL 21 and CL 22 in one direction and CL 13, CL 14 and CL 23 in the other direction in Fig. 1). For example, in Fig. 1, Cluster CL 11 comprises vehicles that are moving towards the UMTS Node B, BTS1, whereas Cluster CL 12 consists of vehicles moving away from BST1. Next, the directional-antenna-based MAC protocols can be utilized to accurately group vehicles on the basis of the direction of their movements in the Cartesian space. In such MAC protocols, the transmission surface of vehicles is split into M transmission angles ($D_1, D_2, \ldots D_M$) of equal degrees (360/M). By assigning each transmission angle to a unique vehicle group, *M* directional groups are formulated. In a Cartesian space, each group is characterized by a vector $S_N = (Cos\ \theta_N, Sin\ \theta_N)$, where θ_N denotes the angle of inclination. A vehicle uses its GPS device to determine its angle of inclination θ_N and then determines its vector co-ordinates (S_N) in the Cartesian space.

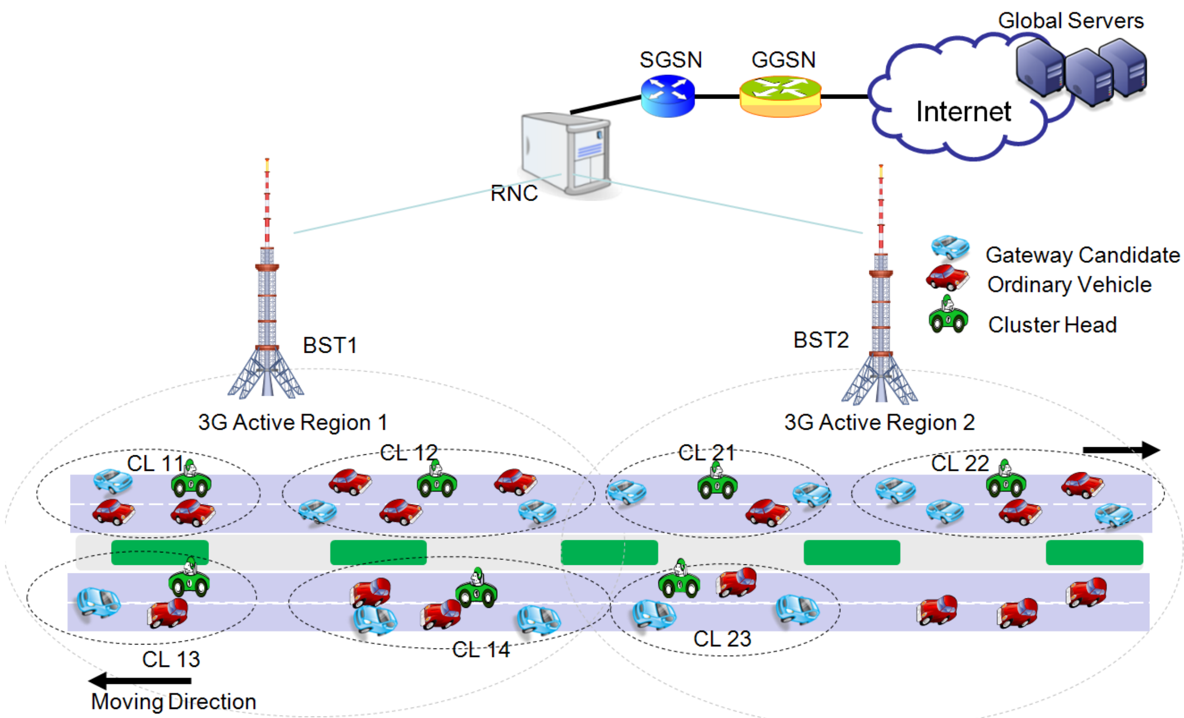

Fig. 1: Envisioned VANET – 3G integrated network architecture.

B. Clustering based on UMTS Signal Strength

To refine the clustering operation further, the UMTS Received Signal Strength (RSS) is used. The rationale behind using the UMTS signal strength (instead of, for instance, vehicle velocity) consists in its better consistency, as shown in the equations below. Additionally, the mobility speed of vehicles, moving along a particular direction, is implicitly reflected in the UMTS signal strength. Irrespective of the variation in the mobility speed of the vehicles, the signal strength keeps increasing if the vehicles move towards the base station, and vice versa. However, the faster a vehicle moves towards the base station, the faster will be the increase in its received UMTS signal strength. Similarly, the faster the vehicle moves away from the base station, the faster will be its decline in the RSS. This is characterized by the rate constant 'a' and the variation in the velocities, in the equations below.

In case a vehicle is moving towards the BST, the UMTS signal strength of the vehicle at a time instant t can be expressed as follows:

$$RSS_t = RSS_{t-1} + (1 - e^{-|v_t - v_{t-1}|/a}) \qquad (1)$$

Similarly, in case a vehicle is moving away from the base station, the UMTS RSS of the vehicle at an instance t is given by:

$$RSS_t = RSS_{t-1} - (1 - e^{-|v_t - v_{t-1}|/a}) \qquad (2)$$

where,

- RSS_t and RSS_{t-1} denote the received UMTS signal strength values at time instances t and (t-1), respectively,
- v_t and v_{t-1} denote the values of the mobility speed of the vehicles at time t and (t-1) such that $0 \leq v_{t-1}$, $v_t \leq v_{MAX}$, where v_{MAX} is the maximum speed of the vehicle,
- $|v_t - v_{t-1}|$ represents the magnitude of the difference in the mobility speed of the vehicle at t and (t-1),
- $(1 - e^{-|v_t - v_{t-1}|/a})$ is the function denoting the variation in the UMTS signal strength by the corresponding variation in the mobility speed of vehicles, and
- a is a constant that defines the rate of variation of the UMTS signal strength for a unit increase or decrease in the mobility speed, in a particular movement direction, relative to the position of the UMTS BST. The lower is a, the faster the function rises.

In general, the UMTS RSS of a vehicle, relative to its initial signal strength value RSS_0 and the position of the UMTS BST, is given by:

$$RSS = RSS_0 \pm \int_{v=0}^{v=v_{max}} (1 - e^{-v/a})dv \qquad - (3)$$

Using the UMTS signal strength, vehicles in each sub-cluster, formed at the first step, equipped with the UTRAN and IEEE 802.11p network interfaces, and lying within or moving towards the 3G active region would receive intense UMTS signal intensity (greater than a specific Signal Strength threshold SS_{Th}), and will together form a single gateway candidate sub-cluster. These vehicles are called the gateway candidates and their UTRAN interface is enabled. The other vehicles form the ordinary vehicle (OV) sub-cluster.

C. Clustering based on IEEE 802.11p wireless transmission range

Having clustered vehicles based on their directions of movement and the UMTS signal strength, the next step is to cluster them using their IEEE 802.11p wireless transmission range: a pair of gateway candidates, whose inter-vehicular distance is less than or equal to their IEEE 802.11p transmission range, form a new sub-cluster or join an existing one (i.e., if one of the gateway candidates is already a member of a cluster). The transmission range of a gateway candidate vehicle is determined as follows:

$$R = T_r \ . (1 - \epsilon) \qquad (4)$$

where, T_r denotes the maximum IEEE 802.11p transmission range and ϵ reflects the wireless channel fading conditions in the current location. For instance, ϵ can be set to small values in environments with no major obstacles (e.g., highway) and take high values in urban areas with tall buildings [5]. A mapping function between the geographical locations and the values of ϵ can be provided by the used positioning system (e.g., GPS, Galileo), while taking into account, the weather conditions.

D. Defining the cluster head and the TTL value of a Cluster

After the clustering operation, the next step is to determine the TTL (Time to Live) value for each cluster. TTL is used for an effective broadcasting and relaying of control messages within the cluster. For each cluster, a Cluster Head (CH), which initiates communication and controls the flow of signaling messages within each cluster, needs to be elected. It is required that information on CH can be communicated to each GWC within its corresponding cluster. This paper proposes a distributed approach for electing the CH and determining the TTL value. Here, the gateway candidate, closest to the centre of the cluster, is elected as the CH, as it would be at an equivalent hop distance from the farthest-hop border gateway candidates at the cluster edges. The TTL value of the cluster is then defined as the maximum hop-length between the selected cluster head, i.e. the vehicle closest to the centre of the cluster, and the border gateway candidates at the two cluster edges. In the distributed approach, the cluster size and the geographical locations of the gateway candidates in the cluster are not readily available. Each gateway candidate in the cluster knows the location information of only its one-hop neighbours. Cluster size is determined by identifying the edge gateway candidates. Indeed, if a gateway candidate in the cluster has no one-hop neighbour ahead of it (i.e., with respect to the moving direction), it deems itself as the leading edge gateway candidate in the cluster. Similarly, the GWC which has no one-hop neighbour behind it represents the tail edge gateway candidate. To determine the CH, the leading edge GWC broadcasts its position in the opposite direction and the tail edge GWC broadcasts its position in the same direction of the movement. The vehicle receiving the two messages and which is at the middle from both edge GWCs, declares itself as the CH. The TTL of the cluster can be easily calculated by the CH. It is equal to the maximum number of hops to the tail or to the leading edge GWCs.

V. ADAPTIVE MOBILE GATEWAY MANAGEMENT IN VANET-3G INTEGRATED NETWORK

Having performed the clustering of the vehicles in the considered VANET, we now focus upon the selection of a minimum number of adequate gateways that will serve, for the vehicles of the cluster, as a point of attachment to the UMTS network. We, therefore, envision an Adaptive Mobile Gateway Management mechanism (AMGMM), consisting of three major mechanisms: “multi-metric mobile gateway selection”, “handover support”, and “gateway discovery and advertisement”. The gateway selection mechanism is initiated to select a minimum number of optimal gateways when VANET sources desire to communicate with the UMTS network. The handover mechanism is employed for migrating the current responsibilities of the serving gateway to one or more new gateways, when the serving gateway loses its optimality. The gateway discovery and advertisement mechanism is launched to inform the VANET nodes about a newly-selected gateway.

A. Multi-metric Mobile Gateway Selection Mechanism

The pseudo-code of the proposed Multi-metric Mobile Gateway Selection Algorithm (MMGSA) is shown in Algorithm 1 and it is employed upon the available *CHs* of the *GWC* sub-cluster. The algorithm is based on the Simple Additive Weighting (SAW) technique. The considered metrics of the *CH* are the mobility speed, the UMTS RSS, and the link stability. The link stability is defined by the *LET* and *RET* metrics between the source and the *CH*. At a certain time instance, let (x_i, y_i, z_i) and (x_j, y_j, z_j) denote the Cartesian coordinates of two adjacent vehicles *i* and *j*, moving at speeds v_i and v_j, along two roads inclined at θ_i and θ_j ($0 \leq \theta_i$, $\theta_j < 2\pi$) with respect to the x-axis, respectively. Let *R* denote the maximum wireless transmission range of the IEEE 802.11p interface of the two vehicles. LET_{ij} can be then computed as in Equation (5).

$$LET_{ij} = \frac{-(ab+cd) + \sqrt{(a^2+c^2)R^2 - (ad-bc)^2}}{a^2+c^2} \quad \ldots (5)$$

where,

$a = v_i \cos \theta_i - v_j \cos \theta_j$,

$b = x_i - x_j$,

$c = v_i \sin \theta_i - v_j \sin \theta_j$,

$d = y_i - y_j$

Intuitively the larger the value of the *LET*, the higher is the stability of the link. Let a route between a source and the gateway consist of (n – 1) links between n vehicles. *RET* of the route can then be expressed as follows:

$$RET_{n-1} = \min\{LET_{i,i+1}\},\ i = 1,\ldots,n-1 \quad \ldots (6)$$

The scaling, weighting of priority factors and normalization of the metric values follow the method described in [15] to obtain the scaled metric value Y_i and weight (W_{CH}) of any CH_i. In Algorithm 1, the UMTS RSS and RET are metrics with positive criterion (i.e., more optimality with increase in value). As far as the mobility speed metric is concerned, if the direction of movement is towards the BST, the criterion is positive (unlike in [15]); whereas if the movement is away from the BST, the criterion is negative (i.e., less optimality with increase in value). However, in this paper, the first vehicular source broadcasts a Gateway Solicitation (*GWSOL*) message broadcast within the VANET, using the TTL value as discussed in Section V-C. Given the fact that a hybrid gateway discovery mechanism is employed, every GWC belonging to a cluster knows information about its CH. Hence, it is sufficient for the GWSOL to reach a GWC of any cluster to get information about its CH, instead of reaching directly the CH. The metric information of each CH lies with the GWCs of the cluster, and when the GWSOL message reaches any GWC, this information is notified to the source. An optimal gateway is then selected by the source vehicle using the MMGSA mechanism. The source vehicle then notifies the vehicles of the newly selected gateway. By the time, the next set of vehicular sources emerge, at least one gateway would have been elected as a result of the GWSOL initiated by the first source.

Begin Algorithm 1

1. A source broadcasts *GWSOL* message within the *VANET*
2. When receiving GWSOL by a vehicle

   If (*VEHICLE_TYPE = CH or GWC*) **Then**

   2.1. Transmit metric information of *CH* containing the three metrics Xi (i=1..3): *RET* with source, *UMTS RSS* and *MOBILITY_SPEED*

   2.2. Discard duplicate *GWSOL* messages from the same source (if any).

   Else

   2.3. Forward *GWSOL* to all vehicles in the next hop in the same direction and so on, till *GWSOL* reaches at least one of the *GWCs* in each sub-cluster, reachable from the source.

   End If
3. When receiving a reply,

   3.1. The source calculates the scaled metric Y_i. **For** each metric X_i of the *CH*, where $1 \le i \le 3$ **do**:

   If (X_i*[CRITERION]* is *POSITIVE)* **Then**

$$Y_i = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

   Else If (X_i*[CRITERION]* is *NEGATIVE)* **Then**

$$Y_i = \frac{X_{max} - X_i}{X_{max} - X_{min}}$$

   End If

   End For

   3.2. The source calculates the weight of each *CH* by:

$$W_{CH} = \sum_{i=1}^{3} (X_i[PRIORITY\_FACTOR] * Y_i)$$

4. The source determines the *CH* with the maximum Weight and selects it as the *GATEWAY*
5. The source broadcasts information about the *GATEWAY* within the *VANET*
6. The GATEWAY activates its *3G UTRAN* interface in order to communicate with the *UMTS BST*
7. **For** every new *ACTIVE_SOURCE* **do**

   7.1. **If** (($UMTS\_RSS \ge SS_{Th}$) and (*RET* with New $ACTIVE\_SOURCE \ge RET_{Th}$))**Then**

   7.1.1. New *ACTIVE_SOURCE* continues with the same *GATEWAY*

   Else

   7.1.2. Repeat Steps 1 to 5 for selecting a new *GATEWAY*

   End If

   End For

End Algorithm 1

Algorithm 1: Multi-metric mobile gateway selection algorithm.

Each metric of the CH has its own threshold value. After a time instance Δt, if another vehicle becomes an active source for communicating with the UMTS BST. At that instance, that source checks if the UMTS RSS of the serving gateway and its *RET* with the gateway are greater than the respective threshold values. If yes, the active source uses the same gateway for communicating with the UMTS BST. Otherwise, the source selects another new gateway from the remaining CHs of the other clusters, by applying the MMGSA. Thus, MMGSA aims at selecting only a minimum number of optimal gateways, saving the UTRAN access network resources, especially during handoff, by letting only a minimum number of gateways, at an instance, to communicate with the UMTS BST.

It should be noted that, according to the above discussed multi-metric gateway selection algorithm, the RET value is the maximum for a source with its nearest CH. This is because if there exists any sub-cluster beyond the reachable sub-clusters from the vehicular source, the RET between the source and the CH of that sub-cluster will be null as there will be no common neighbor GWC between any two sub-clusters.

B. Multi-metric Adaptive Mobile Gateway Handover Mechanism

The pseudo-code of the gateway handover mechanism is shown in Algorithm 2. The main concept behind the gateway handover approach is as follows. If the UMTS RSS of the gateway goes below the signal strength threshold and/or if the RET of the gateway with the source vehicle goes below its predetermined threshold, migration from the serving gateway to one or more gateways, selected by MMGSA, should take place for that vehicle. It should be stated that the mobility speed metric is not considered in the gateway handover decision due to the extremely inconsistent and dynamic variation in the velocity of vehicles, which makes it difficult to use a threshold value for speed. The serving gateway forms a list of Gateway-Elects by selecting one or more CHs having the maximum weight with respect to each of its sources. All new incoming transactions are forwarded to the new Gateway-Elects. The serving gateway GW informs the current active vehicular sources in VANET about the Gateway-Elects using a hybrid gateway discovery and advertisement mechanism, as will be detailed in Section V-C.

Begin Algorithm 2

For the current serving gateway GW with respect to its sources,

1. **If** ($SS[GW] < SS_{Th}$) Or ($RET[GW] < RET_{Th}$)
   Then
   1.1. Broadcast *METRIC_REQUEST* solicitations for new gateways
   1.2. Receive *METRIC_REQUEST* from some *CHs*
   1.3. Determine Gateway-Elects as the list of *CHs* with the maximum weight using *MMGSA*, with respect to each of its *ACTIVE_SOURCE*
   1.4. Forward new incoming transactions to Gateway-Elects
   1.5. Use *Hybrid Gateway Discovery and Advertisement* mechanism to inform vehicles about the Gateway-Elects
   End If
2. Gateway-Elects become serving gateways and send acknowledgement to the old gateway GW
   End Algorithm 2

Algorithm 2: Multi-metric Adaptive Mobile Gateway Handover Algorithm.

During the gateway selection, the gateway may correspond with one of the CHs. However, at a different instance, the same gateway may not serve as a cluster head, due to the dynamic clustering mechanism, stated above. It may also instantaneously lose all its neighbors which it had while being elected. It subsequently forms or joins a new cluster, while still maintaining its role as gateway in case its optimality is not affected, and gets new neighbors during the communication course. There is also no guarantee that it will be the CH of the new cluster. Prior to losing its optimality, a serving gateway selects Gateway-Elects (one or more), with respect to each of its active sources. It should be noted that a serving gateway may select more than one Gateway-Elects as the RET metric may differ for each of its active vehicular sources with each of the available CHs.

C. Gateway Discovery/Advertisement

The traditional gateway discovery mechanisms are pro-active or reactive in nature. In this paper, we adopt a hybrid one where we combine the advantages of both these approaches. In our work, the dynamic clustering influences the hybrid gateway discovery mechanism and is different from the one described in [16]. Indeed, upon its election, a newly elected gateway broadcasts periodic Gateway Advertisement (GWADV) messages within its sub-cluster using the TTL value (as discussed in Section IV-D), which determines the gateway advertisement zone, that is the boundary of the cluster. Accordingly, the gateway candidates of that cluster get informed about the newly elected gateway. If the CH is not the gateway, then instead of GWADV, the CH sends periodic Cluster Advertisement (CA) within the cluster. When a vehicle desires to access the UMTS network via the gateway, it sends on-demand Gateway Solicitation (GWSOL) messages, to which the first receiving GWC (or CH) in the corresponding cluster responds indicating the metric information of its CH. The TTL value for the source to broadcast GWSOL messages within the VANET is computed as TTL_s in a distributed approach, as follows:

$$TTL_s = Max\left(\frac{d_{(s,OV_1)}}{R_s}, \left(\frac{d_{(s,OV_n)}}{R_s} + 1\right) \right) \quad \text{... (7)}$$

where, OV_1 denotes the leading edge ordinary vehicle, OV_n is the tail edge ordinary vehicle in the VANET, $d_{(s,OV_1)}$ is the distance between the source and the leading edge OV_1 and $d_{(s,OV_n)}$ is the distance between the source and the tail edge OV_n. R_s is the wireless transmission range of the source *S*. TTL_s defines the maximum hop length between the source and the leading edge OV, and between the source and any GWCs belonging to a sub-cluster. This is derived accordingly so that *GWSOL* messages would reach all gateway candidates in a particular sub-cluster. The advantage is twofold: first, it stops other gateway candidates from responding to the request of the source vehicle and thus prevents flooding the VANET network with duplicate signaling messages; second, all VANET vehicles will be notified of the serving gateway using this TTL_s.

So, if any new source vehicle desires to connect to the UMTS network after a predefined time interval, it would directly connect to the gateway in question.

Vehicle OV_n would have at least one of the gateway candidate vehicles as its one-hop neighbor in front of it. Consequently, $d_{(s\ ,\ OV_n\ )}/R_s$ expresses the approximate hop distance between the source and the last OV. Adding one to this value covers the leading edge gateway candidate in the gateway candidate cluster. This GWC would already have information about its CH from the Cluster Advertisement (CA*)* (or GWADV in case CH is a Gateway) and it replies to *S* without having the GWSOL message reach the CH. Also, once the source *S* comes to know about the gateway, it should broadcast this to the entire set of OVs within the VANET, so that any new source which comes after a time interval of Δt, would have information about the gateway. For this reason, the TTL value should correspond to the hop-distance between source S and the leading edge vehicle (OV_1), hence the usage of ($d_{(s\ ,\ OV_1\ )}/R_s$). TTL_s is ultimately calculated as the maximum of the two hop-distance values of the vehicular source with the leading and tail edge OVs.

VI. PERFORMANCE EVALUATION

The proposed Clustering-based Multi-metric adaptive mobile Gateway Management mechanism (CMGM) is implemented in the Network Simulator NS2.33. The performance of IEEE 802.11p for vehicular networks using NS2 is discussed in [17]. In this work, the Wireless Access for Vehicular Environments (WAVE) standards for IEEE 802.11p protocol are defined. The WAVE protocol provides enhancements to the physical and MAC layers of the existing 802.11 standards, which are required to support ITS. This paper gives insights on some measurements of the WAVE protocol using NS2. The conducted measurements pertain to the aggregate throughput, average delay and packet losses. Integration of IEEE 802.11p and UMTS-UTRAN network interfaces, resulting in a B3G network, is implemented using Multi-interface Cross Layer Extension for NS2 (NS-MIRACLE) [23]. It is a set of libraries which enhance the functionalities offered by NS2 for handling cross-layer messages and enabling co-existence of multiple modules within each layer of the protocol stack. For creating a mobile terminal with dual interfaces, the IEEE 802.11 and the UMTS libraries of NS-Miracle were used. The scenario consists of a VANET connected to the UMTS network via the UTRAN interface. Tables 1 and 2 list the simulation parameters of the VANET and UMTS networks, respectively.

The performance of the integrated network is evaluated in terms of Data Packet Delivery Ratio (DPDR), Control Packet Overhead (CPO), throughput, Packet Drop Fraction and delay parameters, defined as follows:

- Data Packet Delivery Ratio (DPDR) is defined as the ratio of the total number of successfully-transmitted data packets to the total number of data packets sent from the source to the destination.
- Control Packet Overhead (CPO) measures the ratio of the total number of control packets to the total number of packets generated within the integrated network.
- Throughput is the average rate of successfully transmitted data packets over the IEEE 802.11p/3G communication channels' capacity.
- Packet Drop Fraction is the ratio of the number of unsuccessfully transmitted packets (i.e., as a result of packet drops) to the total number of packets sent from the VANET sources.

Table 1: NS2 Simulation Parameters for VANET.

Parameters	*Values*
Area	8000 x 1000 (m^2)
Channel	Channel/WirelessChannel
Propagation model	Propagation/Nakagami
Network Interface	Phy/WirelessPhyExt (for IEEE 802.11p)
MAC Interface	Mac/802_11Ext (for IEEE 802.11p)
Peak Wireless Transmission Range	300 m (acc. to WAVE standards)
Interface Queue Type	Queue/DropTail/PriQueue
Interface Queue length	20 bits
Antenna Type	Antenna/OmniAntenna
Routing Protocol	AODV
Total number of VANET vehicles	50
Peak Mobility speed	30 ms^{-1}
Mobility Model	Manhattan Mobility Model
UMTS RSS Threshold	-94 dBm
Transport-Layer Protocol	TCP/Newreno
Application	FTP
Packet Size	1 KB

Table 2: NS2 Simulation Parameters for UMTS.

Parameters	*Values*
Uplink Frequency	1.925 GHz
Downlink Frequency	2.115 GHz
Peak UTRAN Uplink Channel Bit Rate	384 Kbps
Peak UTRAN Downlink Channel Bit Rate	2 Mbps
Wireless Transmission Range of UMTS Node B	7 km
Node B Interface Queue Length	20
UMTS Node B – RNC Data Rate	622 Mbps (TTI: 1 ms)
RNC – SGSN Data Rate	622 Mbps (TTI: 1 ms)
SGSN – GGSN Data Rate	622 Mbps (TTI: 10 ms)
GGSN – external IP network data rate	10 Mbps (TTI: 15 ms)
Routing Protocol	3G Pro-active routing

- The delay metric, used in our evaluation, refers to the total time elapsed since the broadcasting of *GWSOL* by a source till the establishment of a path between the source and a selected gateway.

Whilst our proposed CMGM mechanisms can be implemented on top of any VANET routing protocol, we consider the usage of the reactive Ad-hoc On-demand Distance Vector (AODV) [24] as it copes efficiently with the high dynamicity nature of VANETs. As comparison terms, we use MGSA using AODV+ [25] and Dynamic MANET On-demand (DYMO) routing protocol, which has been also tested in integrated VANET-Internet scenarios [26].

AODV+ enables the usage of AODV as an ad hoc routing protocol for simulation of wired-cum-wireless scenarios, especially for internet connectivity to an ad hoc network. DYMO is a new reactive routing protocol, tested in a VANET environment, providing enhanced features such as covering possible MANET-Internet gateway scenarios. The major difference between DYMO and AODV is that DYMO stores information for each intermediate hop, whereas AODV stores information about only the source and destination nodes.

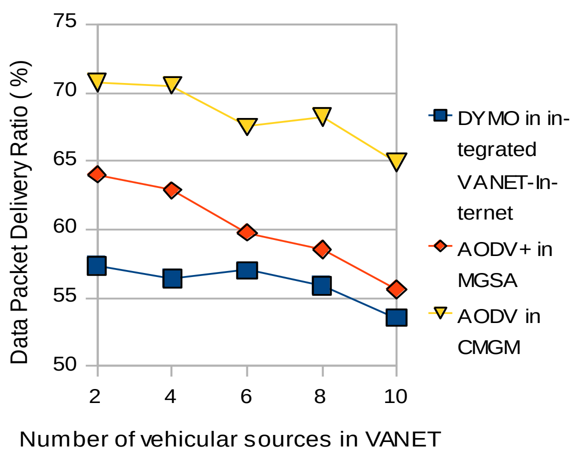

Fig. 2: Performance of the three protocols in terms of data packet delivery for different numbers of vehicular sources in VANET

.

In Algorithm 2, migration from a serving gateway to a newly elected one takes place if the serving gateway gets its optimality downgraded by a specific ratio. Without any purpose in mind, we set this ratio to 25% in the simulations. Additionally, the priority factors for the three metrics, used in Algorithm 2 of MMGSA, are assigned equal values (i.e., X_i = 0.33 for i =1, 2, 3).

The graph, shown in Fig. 2, demonstrates the good performance of the proposed CMGM in terms of higher DPDR, compared to the other two protocols, and that is for different numbers of vehicular sources in the VANET. The graph indicates that regardless the underlying protocol, DPDR generally tends to decrease along with increase in the number of sources. A possible explanation to this phenomenon consists in either congestion at the serving gateway and/or increase in the number of control packets generated for both clustering and handover support operations when the number of sources increases. Regarding the latter, Fig. 3 confirms that as it shows a sudden increase in CPO along with increase in the number of sources, and that is for the three considered protocols. However, it should be noted that our proposed CMGM outperforms the other two protocols as it ensures reduced CPO. Indeed, CMGM exhibits 12.07% and 23.39% decrease in CPO compared to “AODV+ in MGSA” and “DYMO in VANET-Internet”, respectively.

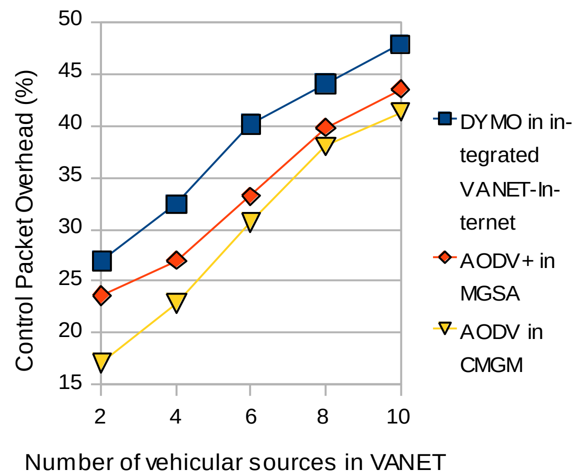

Fig. 3: Performance of the three protocols in terms of control overhead for different number of vehicular sources in VANET.

One of the main differences between MGSA and our proposed CMGM mechanisms consists in the fact that mobility is considered as a highly important metric in CMGM whilst it is overlooked in MGSA. In Fig. 4, we plot DPDR achieved by the three protocols for different mobility speed variances of VANET vehicles. Concerning our proposed CMGM, we consider both the case when the selected gateway is moving towards the base station and when it is moving away from it. In the figure, depending on the movement direction of the gateway with respect to BST, our proposed CMGM mechanism shows 18.79% and 2.96% improvement in terms of DPDR over “AODV+ in MGSA”, and 22.75% and 10.65% improvement in DPDR over “DYMO in integrated VANET-Internet”.

The performance of the three protocols in terms of CPO considering different mobility speeds is illustrated in Fig. 5. In case the serving gateway moves towards BST, it keeps receiving good UMTS RSS, maintaining its optimality, and therefore minimizing the number of control messages that could be, otherwise, associated with gateway reselection and handover. This is also applicable to CHs. As a result, the trend in CPO is negative when the gateway moves towards the BST and positive when it moves away from the BST. On average and depending on the movement towards or from BST, the proposed CMGM yields 16.71% to 22.24% improvement in reducing CPO compared with “AODV+ in MGSA”, and .24.97% to 29.45% improvement compared to DYMO in VANET-Internet integrated network.

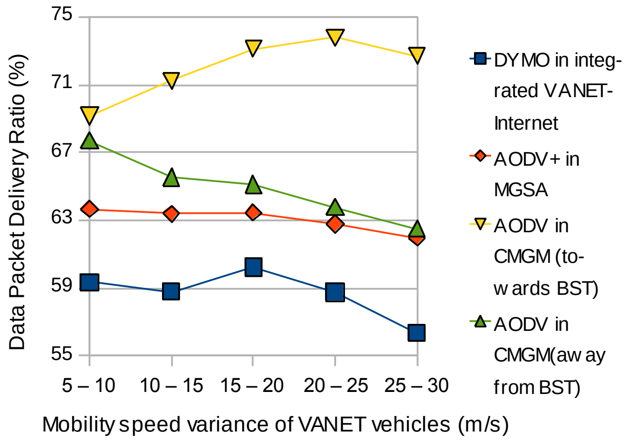

Fig. 4: Performance of the three protocols in terms of data packet delivery for different mobility speed variances.

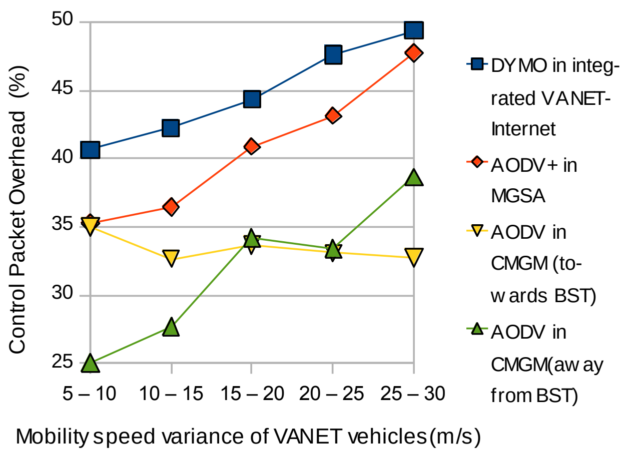

Fig. 5: Performance of the three protocols in terms of CPO for different mobility speed variances.

The graphs of Figs. 6 and 7 show the performance of the three simulated protocols, in terms of DPDR and CPO respectively, for different values of the IEEE 802.11p wireless transmission ranges. In the graphs, IEEE 802.11p transmission ranges of less than 225m may correspond to urban scenarios whereas transmission ranges exceeding 250m may correspond to highway scenarios. Intuitively, with short transmission ranges, many clusters of small sizes may be formed. This leads to high CPOs as indicated in Fig. 7. Short IEEE 802.11p transmission ranges results also in frequent gateway handoffs and consequently loss of in-flight packets during the migration process. This is manifested in the form of low DPDRs, as illustrated in Fig. 6.

In Fig. 8, the achieved average individual throughput at the UMTS BST is plotted for different numbers of clusters. In case there are many VANET clusters, CMGM would be able to select optimal CHs as gateways and to support service continuity. Indeed, as shown in Fig. 8, when there are more than three clusters available, AODV in CMGM shows an improvement of 13.22% and 5.09% in throughput over AODV+ in MGSA and DYMO in integrated VANET-Internet scenario, respectively. However, in case there are few clusters with not enough available gateways (i.e., less than the required optimal number), the selected gateways will be overloaded with data packets; some of which will be discarded, ultimately impacting the throughput. Hence, the first set of readings in the figure does not show a big difference in the throughput achieved by the three protocols.

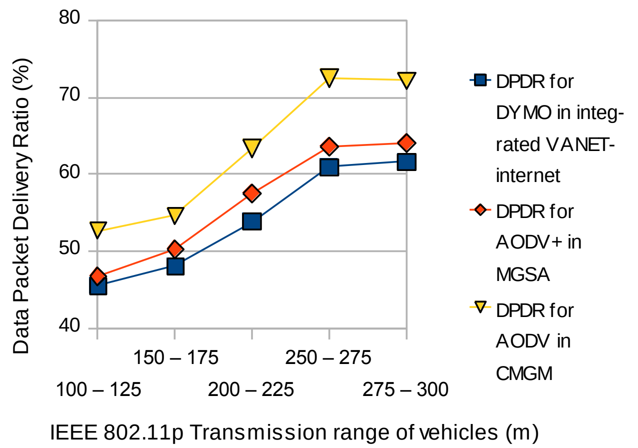

Fig. 6: DPDR for different average IEEE 802.11p wireless transmission ranges.

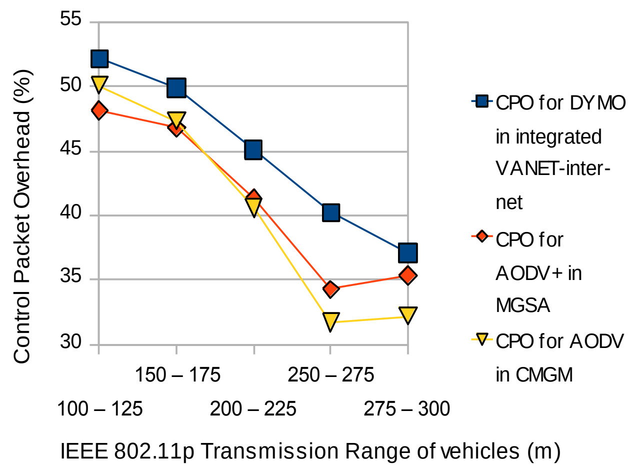

Fig. 7: CPO for different average IEEE 802.11p wireless transmission ranges.

Fig. 9 also emphasizes the importance on having an optimal value of the number of clusters. As stated above, with the increase in number of clusters, the generation of control packets increases during selection of gateways from the CHs. This may result in congestion within the network resulting in unwanted consumption of available bandwidth, as a result of which error messages are flooded within the network. Hence, the trend of Packet Drop Fraction is generally positive. AODV in CMGM shows an improvement of 8.75% over AODV+ in MGSA and 16.4% over DYMO in integrated VANET-Internet network, as handover results in the election of an optimal gateway for handling the transaction, when the serving gateway loses its optimality, thereby reducing the Packet Drop Fraction.

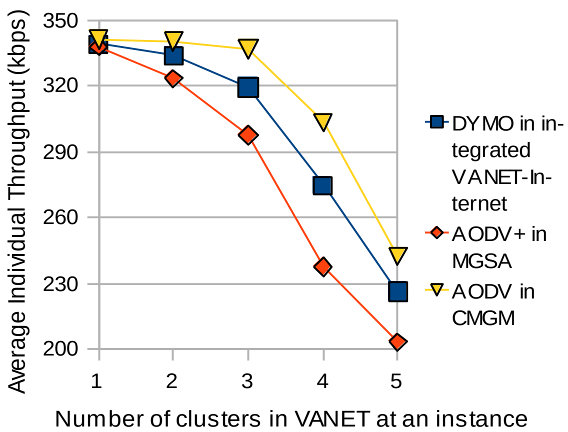

Fig 8: Achieved throughput for different numbers of clusters.

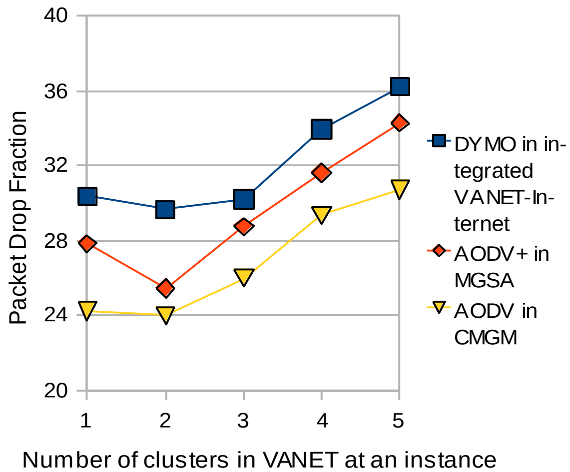

Fig. 9: Packet drop fraction for different numbers of clusters.

In Fig. 10, the time elapsed since the broadcasting a *GWSOL* message (by a particular source) till the establishment of a path between the source and an adequate gateway is plotted for varying numbers of VANET clusters. The difference between CMGM and MGSA, as stated earlier, is that CMGM selects a minimum number of CHs as gateways. A new gateway is elected for handover support, provided that the optimality of the serving gateway downgrades by a certain ratio. On the other hand, in MGSA, each vehicular source selects its own gateway without checking the threshold values of the metrics. This may result in the selection of multiple gateways, more than the optimal number of gateways. As there are more gateways in MGSA, the experienced delay becomes longer. Hence, on average, our proposed CMGM mechanism exhibits 9.17% less delay in establishment of a path towards the gateways than AODV+ in MGSA.

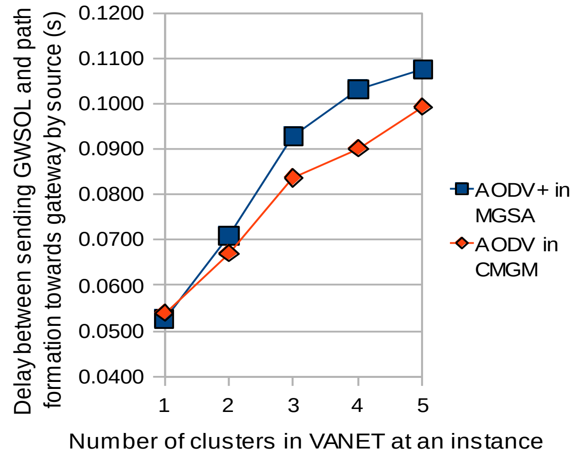

Fig. 10: Delay since the transmission of GWSOL till the establishment of a path towards the gateway, for varying numbers of clusters.

VII. Concluding Remarks and Future Research Directions

In this paper, we introduced a novel architecture that integrates 3G/UMTS networks with VANET networks. In this architecture, a minimum number of gateways, per time instance, is selected to connect ordinary vehicles with the UMTS network. Route stability, mobility features, and signal strength of vehicles are all taken into consideration when clustering vehicles and selecting vehicle gateways. Gateway discovery and migration scenarios are also considered and adequate solutions are presented.

The envisioned 3G/VANET integrated network with minimum number of gateways is expected to prevent frequent handoffs at UMTS base stations and the associated signaling overhead; an event more likely to occur when all vehicles connect directly to the UMTS network. By using this integrated VANET-3G network and having minimum number of optimal gateways at an instance, even vehicles without 3G interface can access the UMTS network. On other hand, by allowing more than one gateway to operate at an instance, bottlenecks and congestion across the path towards a single gateway can be eliminated.

The performance of the overall architecture was evaluated using computer simulations and encouraging results were obtained. As future research directions, we plan to augment an optimal inter-vehicular collision avoidance technique to the dynamic clustering mechanism. This is to ensure that the vehicles perform safety communication with each other, by defining a critical 'inter-vehicular distance' to be maintained between any two vehicles. Moreover, certain vehicles such as ambulance, fire service vans, police patrols need to be given a high priority in our envisioned network architecture, as their requirements are crucial during emergency situations. Hence, enabling QoS for differentiating the services according to vehicular priorities and providing group communications, alongside vehicular collision avoidance, will also be experimented as our future research in the sense of deploying our research in an effective real-time application.

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