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Design Guidelines for a Network Architecture Integrating VANET with 3G & Beyond Networks

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***Abstract*— Vehicle Ad Hoc Networks (VANETs), based on IEEE 802.11p, and 3G & beyond networks are characterized by their high data transmission rates and wide range communication, respectively. This paper presents an architecture that integrates between the two, making advantage of the features of each. Design guidelines pertaining to vehicle clustering and gateway management are defined. The former aims for enhancing the link stability within the VANET, whereas the latter sustains inter-connectivity of the VANET with the backhaul 3G & beyond network. Simulations are carried out using NS2 to evaluate the performance of the integrated network architecture and encouraging results are obtained in terms of high data packet delivery ratio, reduced control packet overhead, and reduced packet drop rate.**

I. Introduction

Along with recent and ongoing advances in the area of wireless communications, a wide plethora of wireless technologies is emerging, defining different types of networks. The IEEE 802.11-based Wireless Local Area Networks and the 3G Cellular Networks are two notable ones. The enhanced version of IEEE 802.11 networks, which is IEEE 802.11p, forms the standard 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 transmission rate, ranging from 6 $Mbps$ to 27 $Mbps$ and a short-range radio communication of approximately 300 meters. On the other hand, Universal Mobile Telecommunication Systems (UMTS), as a 3G & beyond cellular network technology, operates with a frequency range of around 2 GHz. The UMTS dedicated channel offers a peak downlink data rate of 2 Mbps and a peak uplink data rate of $384\ Kbps$, whereas the UMTS High Speed Data Packet Access (HSDPA) radio service offers peak downlink data rates of $7.2\ Mbps$ and uplink rates of 2 $Mbps$. UMTS offers a wide range of communication of around 8 to 10 km per Base Station (BST).

As an attempt to couple the high data rates of IEEE 802.11p and the wide communication range of 3G networks, this paper envisions an integration of IEEE 802.11-based Vehicular Ad hoc Networks (VANETs) with UMTS. The need for such integrated architecture stems from the numerous optimality challenges associated with the inter-connectivity of VANETs with static roadside infrastructure gateway units (i.e., using Dedicated Short Range Communication (DSRC)). These challenges are mainly attributable to the dynamic, infrastructure-less topology and the multi-hop nature of communication of VANETs. An efficient integration of IEEE 802.11p and UMTS network interfaces on vehicles would contribute to better data access services to vehicles and would significantly reduce the issue of dead spots in UMTS.

For the support of reliable and stable inter-vehicular communication and internet connectivity to VANETs, two important concerns need to be exhaustively addressed. They are namely vehicle clustering and gateway management. In this paper, gateways refer to vehicles that link VANET with the 3G/UMTS network. The present paper addresses these concerns in the envisioned VANET-UMTS integrated architecture and delineates the methodology of dynamic clustering and adaptive gateway management.

The remainder of this paper is organized in the following fashion. In Section II, we survey some clustering and gateway management schemes. Section III introduces the envisioned architecture, followed by a description of the adopted clustering operation and the adaptive mobile gateway management scheme. The performance of the architecture and the introduced mechanisms is evaluated in Section IV. The paper concludes in Section V.

II. Related Work

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 by using the characteristics of vehicular movements. This paper considers vehicles to be stationary or mobile, but the gateways to be purely stationary. The authors use two metrics, namely Link Expiration Time (LET) between adjacent vehicles and Route Expiration Time (RET) between vehicles and gateways. Communication with gateways is pro-active and gateway handover is also addressed. Whilst LET and RET shall be used in our paper as well, as a metric for gateway selection, discussed in Section IV, communication with the gateways is not purely pro-active. A clustering approach with a risk-aware collaborative vehicular collision avoidance system is devised in [2]. In this work, vehicles are clustered based on their velocities, their direction of 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. Though risk-aware collision-avoidance is beyond the scope of our paper, our clustering

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mechanism is also metric-based, as discussed in Section IV. A stable routing protocol to support ITS services is proposed in [4]. This paper addresses the issue of path disruptions caused by vehicles' mobility. 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. It uses the vehicles' characteristics to predict a link-breakage event prior to its occurrence. Within the same clusters, communications among the vehicles are carried out over stable paths with acceptable LET values. In our paper, direction of movement is used in clustering to select the minimum number of optimal gateways per direction.

Regarding gateway selection, a wide library of research work has been conducted in the recent literature. In [7], an adaptive gateway management mechanism for multi-hop B3G networks is proposed. In this research work, the authors use multi-attribute decision making theory and simple additive weighting (SAW) techniques 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. Though our paper also deals with gateway handover, battery is not a constraint in vehicles. Moreover, VANET cannot exhibit random movement of vehicles like MANET. In [8], 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 Gateway Advertisement (GWADV) zone within which the gateways periodically propagate advertisement messages. It is equal to the number of hops, corresponding to the TTL value, adaptively selected by the gateway. As this reduces both delay and overhead, it has been adopted in our mechanism too, pertaining to a VANET scenario. In [9], the author 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. The paper aims at improving the usage efficiency of network resource by considering the threshold for the distance metric between mobile terminals, in addition to signal strength.

III. PROPOSED VANET-3G INTEGRATED NETWORK ARCHITECTURE

A. Architecture Description

Fig. 1 portrays the envisioned architecture, considering a scenario of two different tracks over a particular road (e.g., highway), with a track for each direction. The key components of the architecture are IEEE 802.11p-based VANET vehicles, a UMTS Node B and the main components of the UMTS core network. Communication over the VANET network is multi-hop and on a peer-to-peer basis. VANET is linked to UMTS via selected VANET mobile gateways using the Universal Terrestrial Radio Access Network (UTRAN) interface.

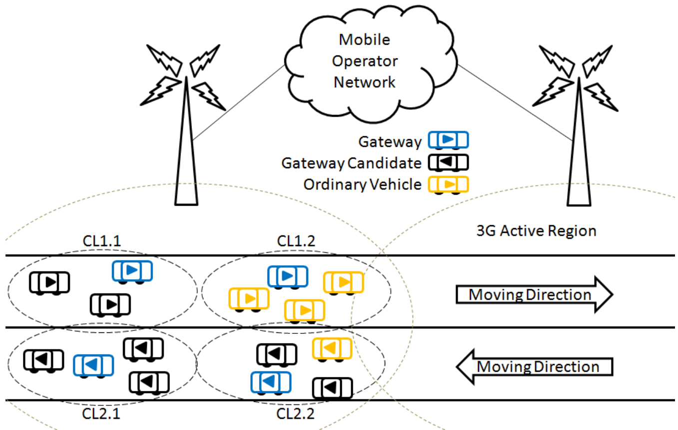

Fig. 1. An example scenario of the envisioned VANET - UMTS integrated network architecture.

The main purpose of our paper is to select only a minimum number of vehicles to communicate with the UMTS network as gateways.

Referring to the architecture shown in Fig. 1, the VANET region under the coverage of UMTS BST, where the UMTS Received Signal Strength (RSS) is intense, is termed as the 3G active region. The vehicles, equipped with both the IEEE 802.11p and UMTS interfaces, lying within or moving into the 3G active region, are called Gateway Candidates (GWCs). The rest of the vehicles, that do not lie in the 3G Active Region, are not equipped with the UMTS interface, or do not have their UTRAN interfaces enabled are called Ordinary Vehicles (OVs). Among the gateway candidates, a minimum number of Cluster Heads (CHs) per direction are elected as optimal gateways (GWs) using different metrics. The number of gateways is required to be minimum, so as to avoid bottle-neck at the UMTS BST and save UTRAN resources. Gateway candidates are grouped into clusters using dynamic clustering mechanism, and only the selected gateways will have their 3G UTRAN interfaces activated. However, the IEEE 802.11p interface is enabled and activated on all the VANET vehicles.

B. Dynamic Clustering Operation

For the sake of effective relaying of messages and enhanced stability of inter-vehicular links, we cluster vehicles using three metrics, namely the direction of vehicles' movement, UMTS Received Signal Strength, and the IEEE 802.11p Wire-less Transmission Range. The per-moving direction clustering is initially carried out relative to the moving direction of vehicles in the Cartesian space and then relative to the position of the UMTS BST. In each cluster formed in the first step, vehicles are then grouped into two sub-clusters: vehicles moving towards the BST (CL1.1 and CL2.1 in Fig. 1) and vehicles moving away from the BST (CL1.2 and CL2.2 in Fig. 1).

For further refinement of the clustering operation, we use the UMTS Received Signal Strength (RSS). Indeed, vehicles, in each sub-cluster formed in the first step, that are equipped with both the UTRAN and IEEE 802.11p network interfaces and lying within or moving into the 3G active region, would receive intense UMTS signal intensity (i.e., greater than a specific Signal Strength threshold SS_{Th}), and hence, will together form a single gateway candidate sub-cluster. These vehicles are called gateway candidates (GWCs), as shown in Fig. 1, and their UTRAN interface is enabled. The rest of the vehicles behave as Ordinary Vehicles (OVs).

The pen-ultimate stage in clustering is based on the IEEE 802.11p wireless transmission range of gateway candidate vehicles: 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 GWC is determined as follows:

$$R = T_r \cdot (1 - \upsilon) \tag{1}$$

where, T_r denotes the maximum IEEE 802.11p transmission range and υ reflects the wireless channel fading conditions in the current location.

After the clustering operation, the final stage is to elect a Cluster Head (CH) for each cluster. A CH is in charge of initiating communication and controlling the flow of signaling messages among GWCs within the cluster. The border edge GWCs in each cluster are to be identified. A GWC having no neighbour before it, is the leading edge GWC and the GWC with no neighbour behind it, is the tail edge GWC. To determine the CH, the leading edge GWC broadcasts its position in the opposite direction of its movement and the tail edge GWC broadcasts its position in the same direction of its movement. Each GWC, receiving both these messages, shall compute its relative distance from these two edge GWCs. The GWC, whose relative distances to both edge GWCs are almost equal, is closest to the centre of the cluster and deems itself to be the Cluster Head. Computation of TTL_c is then followed by CH. It is set to the maximum number of hops from the CH to the tail or to the leading edge GWCs. The TTL_c value is used to restrict the flow of signaling messages pertaining to a particular cluster within the same cluster.

C. Adaptive Mobile Gateway Management

The Adaptive Mobile Gateway Management mechanism consists of three mechanisms, namely "multi-metric mobile gateway selection", "gateway handover" and "gateway discovery/advertisement" mechanisms. The gateway selection mechanism is used to select the minimum number of adequate gateways to optimally communicate with the backhaul UMTS network. It is based on the Simple Additive Weighting (SAW) technique using metrics such as the mobility speed of the CH, its UMTS RSS, and the stability of its link with the source vehicles (i.e., LET and RET metrics [1]).

In this paper, the first vehicular source broadcasts a Gateway Solicitation (GWSOL) message within the VANET, using the TTL value (TTL_s) as discussed below. In the gateway selection mechanism, 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; whereas if the movement is away from the BST, the criterion is negative (i.e., less optimality with increase in value). Given the fact that a hybrid gateway discovery mechanism is employed, every GWC belonging to a cluster tends to know information about its CH, using TTL_c. Hence, it is sufficient for the GWSOL to reach a GWC of any cluster to get information about its CH, instead of reaching the CH.

As shown above, the source elects the CH with the maximum weight as its Gateway (GW). 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, 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 GW for communicating with the UMTS BST. Otherwise, the source selects another new GW from the remaining CHs of the other clusters, by applying the same "multi-metric mobile gateway selection" approach. Additionally, a CH can directly receive the GWSOL message, if it forms a sub-cluster of itself, with no neighbor.

Gateway handover is performed to elect a new gateway and handover the responsibilities of the serving gateway to it, when the serving gateway starts losing its optimality. A loss of optimality is accounted when either the value of the UMTS RSS of the serving gateway or its RET with any one of the vehicular sources goes below the respective threshold values. Handover, thus, aims to sustain the inter-connectivity of the integrated network to pursue the data transaction. In this case, the serving gateway broadcasts METRIC_REQUEST packet within the VANET. Some of the CHs/GWCs which receive this packet respond, transmitting the metric values of their respective CHs. Of course, there is no common GWC between any two clusters. However, a GWC/CH of another cluster can receive the metric information through OVs as intermediate vehicles, especially in case they traverse through the clusters. As a result of dynamic clustering, GW, which was the CH when it got elected, may not be the CH at another instance, as it may become a part of a new cluster. If its optimality, with respect to its sources, is affected, then the CH of the cluster in which the GW is present, may also respond to the METRIC_REQUEST broadcast by the GW. The serving gateway elects one or more CHs with the maximum weights with respect to each of its vehicular sources. The vehicular sources are informed of the new gateway(s) by hybrid gateway discovery mechanism, as discussed below and the vehicles communicate to the backhaul UMTS network using the newly-elected GWs from then on.

In this paper, we employ a hybrid gateway discovery mechanism: we integrate the periodic pro-active Gateway Advertisement (GWADV) and the on-demand reactive Gateway Solicitation (GWSOL). The gateway broadcasts its GWADV message within the cluster using TTL_c and every GWC within this cluster gets information about the GW. In case the CH is not the Gateway, it then broadcasts Cluster Advertisement (CA). As stated above, the sources need to communicate to at least one GWC within a reachable cluster to seek information

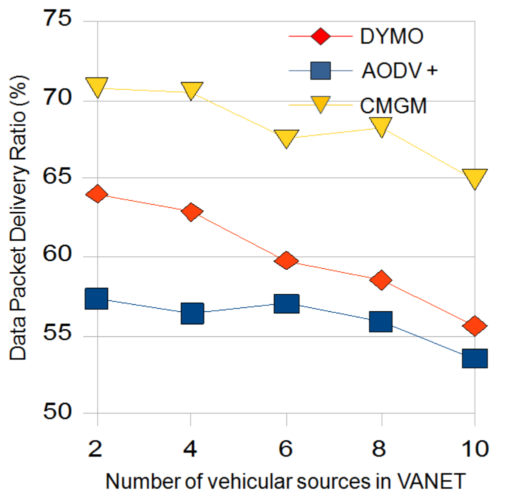

Fig. 2. Performance of the three protocols in terms of data packet delivery for different numbers of vehicular sources in VANET.

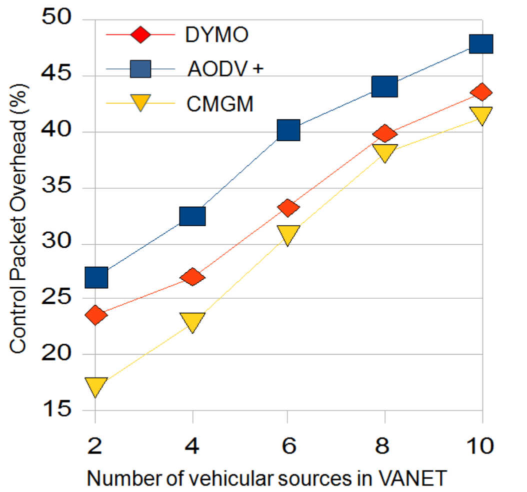

Fig. 3. Performance of the three protocols in terms of control overhead for different number of vehicular sources in VANET.

about the CH/GW. Furthermore, once it seeks information about the GW, it should broadcast the information among the OVs in the VANET so that each OV gets information about the GW. Consequently, the TTL value of the source (TTL_s) should be the maximum of these hop distance values (i.e., maximum of hop distances between source and at least one GWC, and between source and the first OV (OV_1) in the VANET). It should be also noted that the nearest GWC will be at one-hop distance from the last OV (OV_n). Therefore, TTL_s is computed as:

$$TTL_s = MAX(\frac{d_{(s,OV_1)}}{R_s}, \frac{d_{(s,OV_n)}}{R_s} + 1) \qquad (2)$$

where, OV_1 and OV_n denote the leading edge ordinary vehicle and the tail one, respectively. $d_{(s,m)}$ denotes the distance between a source vehicle s and a destination vehicle m. R_s is the wireless transmission range of the source vehicle s.

IV. PERFORMANCE EVALUATION

The proposed Clustering-based Multi-metric adaptive mobile Gateway Management mechanism (CMGM) is implemented in the Network Simulator NS2.33 [10], using WAVE [11] and NS-Miracle [12]. The performance of the integrated network is evaluated in terms of Data Packet Delivery Ratio (DPDR), Control Packet Overhead (CPO) and packet drop fraction parameters. We used the AODV routing protocol incorporating our proposed CMGM mechanism, and evaluated its performance against AODV+ [14]] and DYMO [15]. For simulation purposes, the threshold values of the metrics for Gateway Migration are set to 25% of the initial values of the metrics possessed by the vehicles, when they were elected as GWs.

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 of the underlying protocol, DPDR generally tends to decrease along with increase in the number of sources. The curves show a negative trend: as the number of sources increases, the packet drops also subsequently increase, especially when the gateway is on the verge of losing its optimality. By handover, another gateway assumes responsibility to proceed with the transactions. This explains the good performance of CMGM. Fig. 3 shows increase in CPO against the number of sources generating data. Though this is generally the trend, CMGM over AODV shows less CPO compared to the other protocols due to the fact that only minimum number of adequate gateways are elected for carrying on the transaction. Indeed, CMGM exhibits 12.07% and 23.39% decrease in CPO compared to AODV+ and DYMO, respectively.

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 (Positive Criterion) and when it is moving away from it (Negative Criterion). 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, and 22.75% and 10.65% improvement in DPDR over DYMO.

In the graph shown in Fig. 5, performance of CPO is evaluated against the IEEE 802.11p wireless transmission range of vehicles. 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. 5. Short IEEE 802.11p transmission ranges result also in frequent gateway handoffs and consequently loss of in-flight packets during the handover process.

Fig. 6 emphasizes the importance of having an optimal number of clusters. The packet drop fraction increases with the increase in the number of clusters. This is because the generation of control packets increases during the selection of gateways among CHs. This may result in congestion within the network resulting in wasteful consumption of available bandwidth, as a result of which error messages

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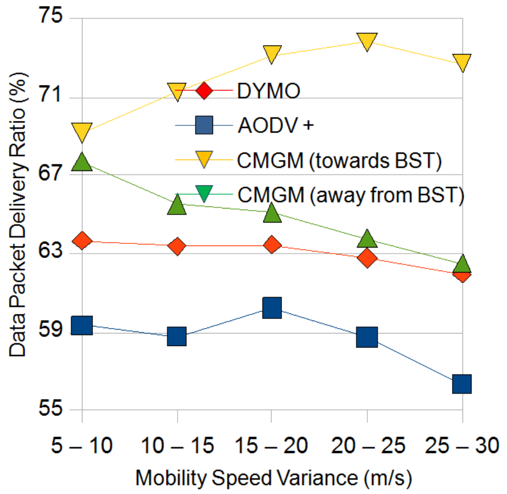

Fig. 4. Performance of the three protocols in terms of data packet delivery for different mobility speed variances.

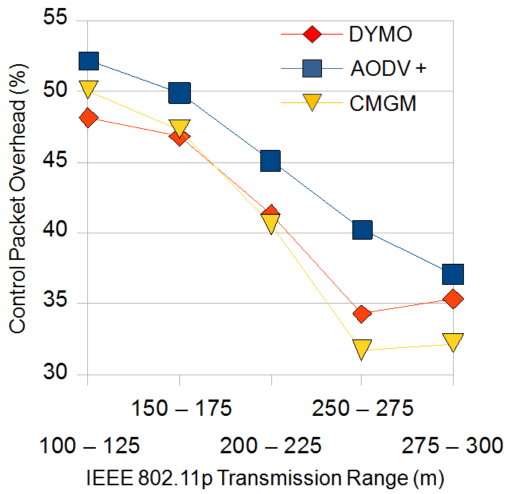

Fig. 5. CPO for different average IEEE 802.11p wireless transmission ranges.

are flooded within the network. AODV in CMGM shows an improvement of 8.75% over AODV+ and 16.4% over DYMO in integrated VANET-Internet network, as gateway handover increases DPDR and hence, reduces the packet drop fraction.

V. CONCLUSION

In this paper, we introduced a network architecture that integrates VANET with UMTS. To enable such an integrated architecture, vehicles are clustered according to different metrics. A minimum number of adequate vehicles is selected to serve as a liaison between VANET and UMTS. Gateway management and selection is also performed in a dynamic manner using different metrics.

The performance of the overall architecture was evaluated using computer simulations and interesting results were obtained. As future research direction, we would like to investigate how QoS requirements can be reflected in the clustering of vehicles and the selection of vehicle gateways.

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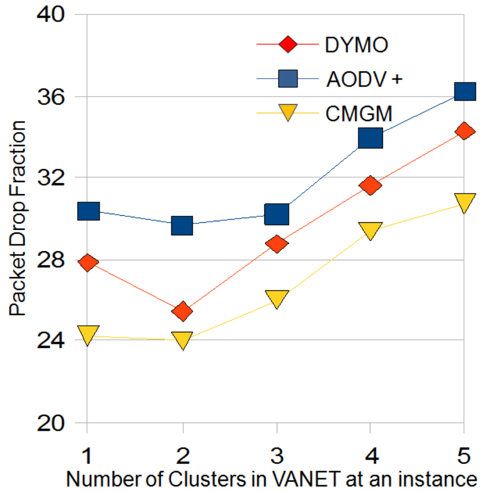

Fig. 6. Packet drop fraction for different numbers of clusters.

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