Proceedings of the 2007 IEEE International Conference on Networking, Sensing and Control, London, UK, 15-17 April 2007 **TuesA02**

Study on QoS Support in 802.11e-based Multi-hop Vehicular Wireless Ad Hoc Networks

Zeyun Niu, Wenbing Yao, Qiang Ni, and Yonghua Song
Electronic and Computer Engineering, School of Engineering and Design
Brunel University, London, UK UB8 3PH

Abstract- **Multimedia communications over vehicular ad hoc networks (VANET) will play an important role in the future Intelligent Transport System (ITS). QoS support for VANET therefore becomes an essential problem. In this paper, we first study the QoS performance in multi-hop VANET by using the standard IEEE 802.11e EDCA MAC and our proposed triple-constraint QoS routing protocol, Delay-Reliability-Hop (DeReHQ). In particular, we evaluate the DeReHQ protocol together with EDCA in highway and urban areas. Simulation results show that end-to-end delay performance can sometimes be achieved when both 802.11e EDCA and DeReHQ extended AODV are used. However, further studies on cross-layer optimization for QoS support in multi-hop environment are required.**

I. INTRODUCTION

In recent years, it has been widely accepted in academic society and industry that cooperation between intelligent vehicles and road transport systems can significantly improve traffic safety, road efficiency and reduce environmental impact. In light of this, since 2002, the European Commission has funded a number of projects under eSafety initiative, e.g. SafeSpot, COOPERS, CVIS, SeVeCOM, COM2REACT, for halving the number of road fatalities by 2010 [11]. Efficient vehicles-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication technologies are key to such cooperative systems.

Within a cooperative intelligent road transport system, by using V2V communications, 1) Low level of sensor-type data, such as road condition and weather condition, can be shared with vehicles nearby, and then taken as inputs to various sensor fusion algorithms executed on-board the vehicles or in an infrastructure unit; 2) At application level, the complete situation around the vehicle can be described as a local dynamic map shared by all vehicles in the surrounding. Two vehicles can share their position in respect to each other and negotiate for lane changes; dynamic hot spots information can also be shared among the vehicles.

Wireless vehicular ad hoc network (VANET) is the key technology to realize the V2V communications. It refers to an ad hoc network among vehicles that are equipped with wireless communication capabilities. It enables wireless communications in vehicular environments. As a subclass of general mobile ad hoc network (MANET), VANET shares some common features as general MANET. For instances, no infrastructure architecture exists to provide any administration or centralization management; mobile nodes have to accomplish self-configuration and self-organization for dynamic transmission enquiries; communication over long distance that exceeds node individual radio range must apply to multi-hop transmissions. However, the following several *key* characteristics distinguish VANETs from general MANETs: The network topology of VANET is highly dynamic but somehow predictable due to the limitations from the roads and traffic; link breakages can often happen due to the vehicular movement and the unpredictable drivers' behavior; VANET nodes can be equipped by more than one wireless technology, such as satellite navigation systems and 802.11 communication unit; power consumption is not a problem for onboard communication equipment.

There is no doubt that multimedia application over VANET will play an important role in the future ITS. Different types of traffic information could be delivered (by pull or push service) to drivers through V2V communications. For instance, the road situation caught by cameras on the front vehicles can be passed on in video streams to the vehicles behind, so that the view of drivers at the back can be extended outside their visible distance. Another possible scenario could be that, drivers in a group of vehicles (e.g. a team of construction work vehicle, rescue vehicles, police vehicles) would like to share their conversations and view of traffic with each other. In this case, multimedia streams (video, audio streams) will have to be transmitted from one vehicle to another. No matter what type of data (video, audio, data or short message) is transmitted, it is important to have a certain level of quality of service (QoS) control in VANET so as to ensure the requested information are delivered to the drivers on time and with satisfying quality. But, to support QoS in VANET is also a very challenging topic.

QoS support in MANET has already been discussed in the past few years. However, to the best of our knowledge, less attention has been paid to end-to-end QoS support in multi-hop VANET environments. Actually, it is a systematic work - under a given QoS framework, QoS control and support need to be implemented at several sub-layers, which involve the following research issues: 1) QoS framework, an overall system architecture to support QoS; 2) QoS routing algorithm, that focus on routing layer issues such as how to deal with route computation and maintenance that satisfy both routing and QoS constraints; 3) QoS signaling for reserve and release network resources; 4) QoS MAC algorithm, media access mechanism support QoS control.

The main objective of this paper is to study the QoS support for multimedia communications in VANET. Three types of traffic, video, audio and data are considered. We firstly study the performance of IEEE 802.11e MAC layer in VANET - 802.11e is a recently published WLAN standard for QoS support at MAC layer. Secondly, we introduce a triple-constraint QoS routing algorithm, DeReHQ, and implement it over 802.11e in VANET. Thirdly, we perform the evaluation of DeReHQ over 802.11e, and analyze the simulation results.

The rest of this paper are organized as follows. Section II will review the related work in both MAC layer and network layer for VANET. In section III we will give an overview of the IEEE 802.11e EDCA MAC. Section IV will present a novel triple QoS routing algorithm called DeReHQ, and in section V and VI we will evaluate in NS2 the performance of the DeReHQ extended AODV protocol with 802.11e MAC, and in Section VII we concludes the paper and discuss the future work.

II. CHALLENING ISSUES AND RELATED WORK

MAC layer issues for VANET

In MANET, most existing work in MAC protocol design focus on distributed architecture or ad-hoc mode rather than centralized admission control mechanism. This is also true in a vehicular environment, as in most case, transmission delay caused by necessary negotiation messages can be huge if centralized architecture is applied due to the high speed of individual terminals and multiple requirements of communication traffic flows. IEEE 802.11 provides a distributed channel access method that can be applied for VANET. 802.11b-based WLAN is an option for VANET, and its performance evaluations can be found in [3]. The relationship between network performance and topology metrics such as node average speed and link distance was studied in this paper. In some vehicular scenarios, link quality in terms of signal-noise-ratio greatly relies on the link distance. Throughput decreased as the communication distance increased but it may obtain high performance in a freeway situation where node speeds are high but their relative speeds are steady. However, no QoS-aware mechanism has been testified and evaluated in their work.

To enhance 802.11 MAC in VANET, vehicle traffic flow information has been considered combined into media access mechanism. In [4], it implemented a CSMA/CA based media sensing scheme in which vehicle density was considered into the decision of media sensing distance and frame transmission distance. Time slot or code assignment is reserved but varied for every vehicle according to traffic density situation. Transmission observations are made by taking into account of the length of transmission cycle and frame size. Sensing vehicular environment before any transmission and media access decision is a key idea. Using directional instead of Omni-directional antenna is one approach [6]. Based on Time Division Multiple Access (TDMA), [5] figures out a space-based media access scheme in which assignments of time slots is obey to the location where a vehicle is on the roadway. Network performances of these works have been enhanced especially in terms of transmission throughput and delay.

Nevertheless, QoS MAC mechanisms have not been developed very well for VANET. The new IEEE 802.11e standard [9] has provided a QoS MAC scheme as an enhancement of 802.11. By classifying traffic types, 802.11e gives multiple priority value for each type of traffic flow. Voice or audio traffic that need low latency can be guaranteed to get smaller media access corresponding interval than the other traffics. However, how to cooperate 802.11e with VANET that has highly dynamic topology and multi-hop transmission required environment is still an open topic. In Section III, we will introduce 802.11e MAC protocol.

Routing layer issues for VANET

Some routing protocols have already been discussed and standardized for MANET. In MANET, two different routing mechanisms can be classified: topology-based routing and location-based routing. Topology-based routing protocols can be further divided into proactive, reactive and hybrid approaches based on their different routing strategies [2]. It usually contains routing discovery and routing maintenance by using the existing link state information. Topology-based routing is more suitable for the static or low dynamic ad hoc network as the link state information can be distributed smoothly. Location-based routing mechanisms not only use the link information, also additional information such as the node physical position obtaining by GPS or other positioning services. It is more suitable for the vehicle environment in which the frequently changing positioning information is crucial for routing protocol.

In VANET, some single-hop broadcasting routing algorithms have been discussed for intelligent message broadcasting from road side or traffic central unit. Some impressive performance has been achieved in this part of work single-hop communication is not quite enough for a vehicular communication network. Eventually, V2V communication should realize any two vehicle connection through multiple dynamic links that can find connection automatically besides listening to the central broadcasting messages. Some mature routing protocol for MANET can be applied in the situation as VANET. But, they can barely achieve satisfying results due to highly dynamic topology of VANET that can cause huge overhead and low throughput. However, few enhanced multi-hop routing protocols have been provided yet.

In a distributed topology as VANET, there is no centralized controller to do the scalability management. Nodes in such environment have limited link information to support route discovery as they may only know currently neighbor nodes and the intermediate node has no response for the traffic it relays. Link breakage can unacceptably happen corresponding to the nodes movement and topology change. Shortest-path routing algorithm that only concerns the route with minimum number of hops is no longer suitable for VANET. In this paper, we introduce a novel metric, link reliability, to reflect the link quality between two vehicles. We propose a delay-reliability-hopping triple constraint QoS routing algorithm, DeReHQ, that select routes subject to multiple routing/QoS constraints. Details of DeReHQ are presented in Section IV.

III. IEEE 802.11e MAC layer

IEEE 802.11e [9] has been released as a standard in Dec 2005, which provides QoS enhancements for PHY/MAC layers in WLAN. By modifying original distributed coordination function (DCF) and point coordination function (PCF) in IEEE 802.11, 802.11e improves media access mechanism for both contention-based and contention-free MAC schemes. For instance, different from best-effort support, 802.11e allows delay-sensitive application e.g. VoIP, access media before other delay-insensitive applications. In this way, the quality of VoIP services can be better supported.

The new features of IEEE 802.11e MAC can be summarized as follows.

- A new MAC layer function, namely the hybrid coordination function (HCF) is defined, which now combines the contention-based channel access scheme, enhanced distributed channel access (EDCA), and the enhanced polling-based scheme, HCF-controlled channel access (HCCA) into a single MAC function. In this way, the 802.11e based AP and stations can cooperate and the AP control the QoS performance of its service area in a more flexible manner than a legacy AP.
- In HCF, a new concept called transmission opportunity (TXOP) is defined for both EDCA and HCCA, which refers to a time duration during which a mobile terminal is allowed to transmit a burst of data frames.

In this paper, we only consider the EDCA function and its performance in VANET as no centralized AP or relevant functional nodes are available in VANET.

IEEE 802.11e EDCA

In EDCA, 802.11e defines 8 different traffic classes with different priorities (TCs) to accommodate different QoS requirements from higher layer applications. EDCA is designed to provide prioritized QoS by enhancing the contention-based DCF. Before entering the MAC layer, each data packet received from the higher layer is assigned a specific user priority value. How to tag a priority value for each packet is an implementation issue [12]. At the MAC layer, EDCA introduces four different priority queues, called access categories (ACs). Each data packet from the higher layer along with a specific user priority value (one out of the eight) should be mapped into a corresponding AC according to a table defined in [9].

At the MAC layer, with each AC, channel access contention scheme behaves the same as original DCF. However, the contention parameters of different ACs are assigned according to their priority levels, e.g. their contention window sizes (CW_{min} [AC], CW_{max} [AC]), inter-frame sizes (AIFS [AC]), and TXOP limitation ($TXOP_{limit}$[AC]) are specified based on the classes – AC accordingly. The main idea is to assign different priority levels to the traffic of applications with different delay requirements. This is achieved by setting different CW_{min} [AC], CW_{max} [AC], AIFS [AC] and $TXOP_{limit}$ [AC]. Different types of applications, such as video traffic, voice traffic, best-effort traffic and background traffic are given different priority value, and therefore, can be directed into relative ACs. It has been studied in [12] that 802.11e can provide certain QoS support in a single hop WLAN. However, the QoS support in a multi-hop VANET using 802.11e EDCA is still missing in the literature.

Limitations of 802.11e MAC in VANET

As abovementioned, in EDCA, service differentiation and thus the delay requirement of time-bounded traffic class can be supported by setting up a multiple channel access parameters such as increasing priority value and reducing backoff parameters for high-priority traffic. However, 802.11e doesn't take into account of link quality, terminal mobility issues and the impact of multi-hop, which are normal in a VANET. Table 1 lists the average end-to-end delay of CBR traffic in a VANET which comprises 10 mobile nodes and each node has AODV routing protocol running on top of EDCA MAC protocol. In a vehicular communication environment, the network topology could be highly dynamic. 802.11e in this case has to deal with frequent link breakages and handle messages retransmission and also multi-hop. If the table-driven routing protocol is applied, how to ensure the accessibility of a mobile node to the next mobile node along the discovered route is an extremely challenging task. As shown in Table 1, the service differentiation can't always be achieved due to multiple complex reasons, e.g. in this testing, the video delays are even higher than the delays of best-effort data traffic in VANET. Proper QoS support in a multi-hop VANET needs to consider jointly both the MAC layer QoS support and the routing layer QoS in a cross-layer design.

	Random Way point Model (Stable)	Freeway Model (highway)	Manhattan Model (Urban area)
Audio	798.6	485.6.	1164.4
Data	859.1	912.4	2210.6
Video	1113.2	926.4	3116.3

Table 1. Average delay of multimedia traffic flows in [ms]

IV. DeReHQ ALGORITHM

In this Section, we present a triple-constraint QoS routing algorithm, DeReHQ, as a QoS routing algorithm to address the challenging requirements of high reliability and short transmission time-delay of routing in VANETs. As a QoS routing algorithm, DeReHQ improves the route discovery and route computation of for traditional ad hoc routing protocols, such as AODV to support QoS. In this paper, we further investigate the QoS support of DeReHQ when 802.11e EDCA MAC layer is considered.

Three QoS metrics have been considered in DeReHQ: link reliability, end-to-end delay and hop account. Link reliability should have higher priority than link delay as it is more critical for the route quality in vehicular environments. The basic idea is that reliable routes that have longer expected lifetime and less hop numbers should be chosen instead of the shortest paths which may probably break soon and introduce high maintenance overhead. By taking this approach, we aim to significantly reduce the routing overhead, and improve the traffic throughput of the whole VANET.

Applying classical vehicular traffic theory, we use traffic density λ in [veh/km], relative speed Δv in [km/h] to describe link lifetime t_{ll}. The connection distance is usually the largest one among all the node pairs. We assume that each hop has the connection distance equal to the maximum communication radio range, D_r. As the value of relative velocity is assumed as normal distributed: $\Delta v \sim N(\mu_{\Delta v}, \sigma_{\Delta v}{}^2)$, and vehicles are assumed to have Poisson distributed arrivals. We obtain the probability distribution function (pdf) for link lifetime as:

$$p_t(t) = \frac{4 \cdot D_r}{\sigma_{\Delta v} \cdot \sqrt{2\pi}} \cdot \frac{1}{t^2} \cdot e^{-\frac{\left(\frac{2 \cdot D_r}{t} - \mu_{\Delta v}\right)^2}{2 \cdot \sigma_{\Delta v}{}^2}}$$

We introduce a link reliability model as given below:

$$\rho_{sd}(T_{sd}, \lambda) = \begin{cases} \dfrac{\delta \cdot \lambda}{\lambda_c} \displaystyle\int_{t_0}^{t_0+T_{sd}} T_{sd}\, p(t)\,dt, \text{ iff } \delta \cdot \lambda < \lambda_c \\ \displaystyle\int_{t_0}^{t_0+T_{sd}} T_{sd}\, p(t)\,dt, \text{ otherwise} \end{cases}$$

where t_0 is the connection start time, T_{sd} is the link active time during which the two mobile nodes are within the direct radio connection range, $p(t)$ is the empirical probabilities in terms of the link life time t we give above, and ρ_{sd} is the link reliability, i.e. the probability that the connection between s and d will last duration T_{sd}, which can be calculated from the range between the two active nodes L_{RA}, and the relative moving speed of the two vehicles V_{RA} using

$$T_{sd} = \frac{L_{RA}}{V_{RS}} = \frac{\sqrt{(y_1 - y_2)^2 + (x_1 - x_2)^2}}{\vec{v}_1 - \vec{v}_2}.$$

We simplify the ultimately NP-complete route searching problem into a problem of finding the path that has the best link reliability and the smallest hop number while the link delay is under a desired time-delay bound Δ_d.

Since link reliability has higher priority than link delay and path hops, we first search the route $P_{\max-relia}$ with the maximum link reliability among all the available routes, and set the found maximum link reliability value as the initial link reliability bound Δ_r and hop constraint Δ_h:

$$P_{\max-relia} = \arg\max_{P_i \in P(s,d)} R(P_i)$$

$$\Delta_r = \max_{P_i \in P(s,d)} R(P_i)$$

$$\Delta_h = \frac{n \cdot L_{sd}}{D_r} \cdot \frac{\lambda_c}{\lambda}$$

where L_{sd} is the distance of the source node and destination nodes, n is the number of lanes.

Meanwhile, we identify the routes whose link-delay satisfy the desired delay bound Δ_d ,and the broadcasting hops that the route message should set it as time to live metric by Δ_h. And put them into a route set

$$S_{dh} = S_{delay} \cap S_{hops}$$

where

$$S_{delay} = \{P_k, k = 1,2,\cdots,K\} \subset P(s,d), where \quad D(P_k) < \Delta_d$$
$$S_{hops} = \{P_k, k = 1,2,\cdots,K\} \subset P(s,d), where \quad H(P_k) < \Delta_h$$

If $P_{\max-relia} \in S_{dh}$, i.e., $P_{\max-relia}$ satisfies both the delay bound (Δ_d) and the hop constraint (Δ_h), we will take it as the final search result of the DeReHQ algorithm, and end the route searching.

If $P_{\max-relia} \notin S_{dh}$, we will reduce the link reliability requirement to $\Delta_r^{'} = \varepsilon \Delta_r$ and see if we can find any route within the route set S_{dh} that satisfy this requirement. Here ε is a constant for controlling the search speed ($0 \le \varepsilon \le 1$). If not, we will keep on lowering the link reliability bound $\Delta_r^{'}$ by multiplying the factor ε to the current bound value, until there is no available route in route set S_{dh}. Then the solution pool is found by changing back $\Delta_r^{'}$ without the last multiplying ε.

If there is only one route in the solution pool, the final search result is set to be this one. If not, there is more than one satisfactory routes found in last step, we will choose the route with the minimum hops as the final solution. By doing so, the final result of the algorithm will be the most acceptable path that has an acceptable time-delay and the best link reliability and possibly minimum hop number.

V. PERFORMANCE ANALYSIS

In this section, we study the QoS performance of a VANET by combing the 802.11e EDCA MAC layer and our DeReHQ extended AODV routing protocol together.

Simulation Environment

We use NS-2.28 to do network protocol simulation. Three types of mobility models, the random way point model, the freeway model and the Manhattan model are applied:

In the random waypoint model, a node randomly chooses a destination and starts moving towards it. The speed is chosen from a certain given range. When the node reaches the destination it waits for a certain amount of time and then moves to another randomly chosen destination with a new velocity.

In the freeway model, nodal velocities are dependent on its previous velocities with respect to time. Also, the node moves on fixed pathways (Lanes). In this paper, we utilizes the freeway model in simulation experiments to simulate the vehicular highway situations.

The Manhattan model consists of horizontal lanes and vertical lanes. Each pair consists of lanes with nodal movement in opposite directions. The nodes can turn right or left at the junctions where horizontal and vertical lanes intersect each other. In our simulation, the Manhattan model abstracts a vehicular scenario in urban areas.

Note that both freeway model and Manhattan model are map based models. On the map used by freeway model, there are 2 horizontal and 1 vertical roads that make 2 junctions. On the map for Manhattan model, 3 horizontal and vertical streets forming totally 12 lanes. Both maps cover an area of 1000 meter by 1000 meter.

Parameter settings for IEEE 802.11e EDCA are listed in Table 2. Three types of traffic flows have been defined: audio, video, and data flow. Simulation time is set to 1000s.

	Video	Audio	Data traffic
Transport Protocol	UDP	UDP	UDP
Routing Protocol	DeReHQ	DeReHQ	DeReHQ
AC	VI	VO	BE
CW_{min}	15	3	31
CW_{max}	255	7	1023
AIFSN	5	2	7
Packet Size	1280 bytes	106 bytes	1500 bytes
Packet Interval	10 ms	20 ms	12.5 ms
Sending Rate	1024 kb/s	64 kb/s	960kb/s
Priority Value	2	3	0

Table 2. Parameter setting for 802.11e EDCA

Simulation results are shown in Figure 1-5. We firstly evaluate the end-to-end delay performance in a VANET with 802.11e EDCA protocol running in each mobile node. Three types of traffic, audio, video and background data have been transmitted. Their priorities are set as low, medium and high respectively. We applied random waypoint model, freeway Model, and Manhattan model in the simulations. For random waypoint model, we turn off the node's random movement to represent a stable ad hoc topology, in order to compare networks performance with the other scenarios. For Freeway and Manhattan models, the average speed of the nodes is 5 m/s. Mean end-to-end delay is evaluated for each case in Figures 1, 2, and 3. The curves show the variation of end-to-end delay when the number of nodes increases.

The results in the above figures show that DeReHQ combined with EDCA can provide certain QoS support for different types of traffic flows in some VANET scenarios. Especially in a stable ad hoc scenario (figure 1), audio flow which has the highest priority value has lower delay than video and background traffics. The average delay increases as the number of nodes increases. The average delay when Manhattan Model is applied is higher than Freeway Model and static model are applied. This is mainly because the frequent topology changes cause many retransmission of messages for the link breakages and re-built. Meanwhile, in a highway scenario, the average delay is shorter than the one in the urban area. this is because, although nodes have higher moving speed, their relative mobility is more stable than the situation in an urban area.

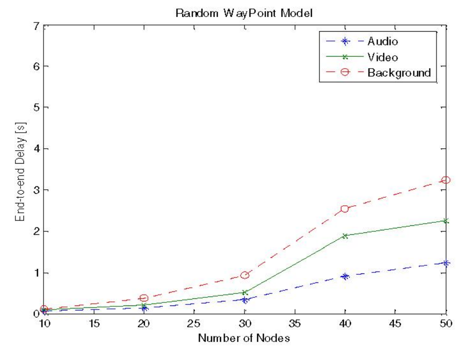

Figure 1, End-to-end delay vs. number of nodes in Random WayPoint Model

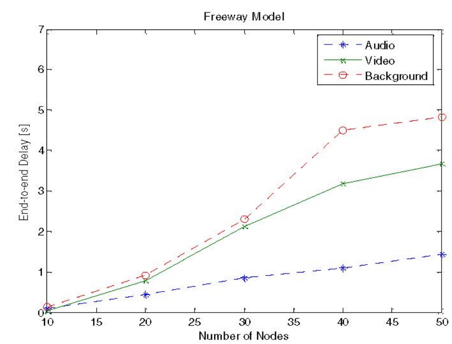

Figure 2, End-to-end delay vs. number of nodes in Freeway Model

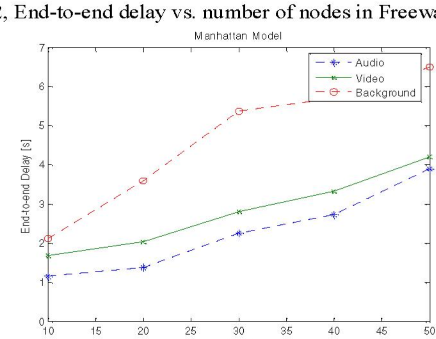

Figure 3. End-to-end delay vs. number of nodes in Manhattan Model

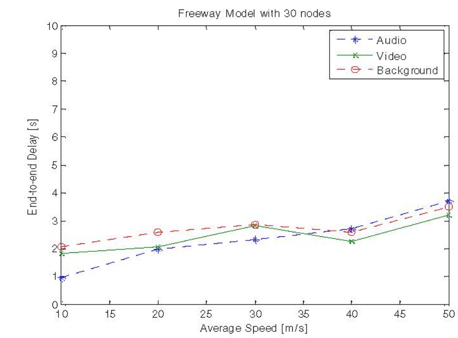

Figure 4. End-to-end delay vs. average speed in Freeway Model

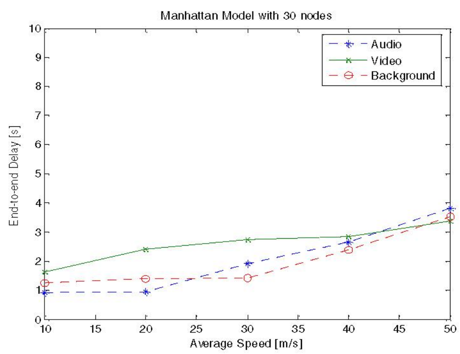

Figure 5. End-to-end delay vs. average speed in Manhattan Model

However, as shown in Figures 4 and 5, the service differentiation for different priorities of traffic are not achieved with the DeReHQ plus EDCA when the node average speed increases and thus changing the multi-hop scenarios. Average speed is set from 10 m/s to 50 m/s. Node number is set up as 30. Audio, video and background traffic are transmitted among the nodes. As the average speed increases, mean delay of each traffic flow goes up as well. While in the above two cases, service differentiation of the three types of traffic can not be clearly seen. They only have the common increasing trend for highly dynamic scenarios, but audio traffic, that has the highest priority, sometimes can not be satisfied. This strange behavior might come from, that the current classification of traffic categories are separately considered in the MAC layer and in the routing protocols. At the EDCA MAC layer, different channel access parameters are available for different priorities of traffic flows. However, the current DeReHQ routing algorithm doesn't consider service differentiation among different traffic flows and pass this information to the MAC layer. Thus the current simple combination doesn't guarantee the end-to-end QoS performance given that there is no cross-later interaction between MAC and routing protocols.

VI. CONCLUSION AND FUTURE WORK

We test the QoS performance of multimedia communication in VANETs by combining the 802.11e EDCA MAC and our DeReHQ routing protocols together. Service differentiation among audio, video, and background traffic can be achieved in some situations, but not always. Our future work is cross-layer design for multi-hop VANET to provide better end-to-end QoS performance for multimedia applications. Currently, DeReHQ doesn't consider service differentiation. Routing selection algorithm is based on a single-class link delay and reliability optimization. This is not enough to support multimedia traffics. Priority issues have to be sorted out in routing algorithm by taking into account the cross-layer interaction with the enhancement MAC scheme provided by 802.11e EDCA.

VII. REFERENCES

[1] FleetNET project information: http://fleetnet.paneris.net/project-info.html.

[2] E. M. Royer, C.-K. Toh, "A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks", *IEEE Personal Communications*, April 1999.

[3] J. Singh, "Wireless LAN Performance Under Varied Stress Conditions in Vehicular Traffic Scenarios," IEEE Vehicular Technology Conference, 2002.

[4] K. Dobashi, "Adaptive MAC Protocol for high-load Inter-Vehicle Communication," IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, 2005. (WiMob'2005), 22-24 Aug. 2005.

[5] J. Blum, "Adaptive Space Division Multiplexing: An Improved Link Layer Protocol for Inter-Vehicle Communications," Intelligent Transportation Systems, 2005. Proceedings of IEEE, 13-15 Sept. 2005.

[6] M. Sadashivaiah, "Performance evaluation of Directional MAC protocol for Inter-vehicle communication," The 61st IEEE *Vehicular Technology Conference* (VTC 2005-Spring), 30 May-1 June 2005.

[7] F. Bai, N. Sadagopan, A. Helmy, "A.IMPORTANT: a framework to systematically analyze the Impact of Mobility on Performance of Routing Protocols for Adhoc Networks". IEEE INFOCOM 2003. pp.825–835, vol.2, March 2003.

[8] Intelligent Transportation System : http://www.its.dot.gov/index.htm .

[9] IEEE Std. 802.11e-2005, IEEE Standard for Local and Metropolitan Area Networks, Part 11: Wireless LAN MAC and PHY specifications: MAC QoS Enhancements, Sept. 2005.

[10] Europe's IST FP6 eSafety Research Activities: 6FP RTD Project. Web: http://europa.eu.int/information_society/activities/esafety/research_activities/index_en.htm

[11] Car 2 Car Communication Consortium. Web: http://www.car-2-car.org/index.php?id=129

[12] Q. Ni. "Performance Analysis and Enhancements for IEEE 802.11e Wireless Networks". IEEE Network, Vol. 19, No. 4, July/August, 2005, pp. 21-27.