An Efficient QoS MAC for IEEE 802.11p Over Cognitive Multichannel Vehicular Networks†

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***Abstract*—One of the most challenging issues facing vehicular networks lies in the design of an efficient MAC protocol adaptable to different traffic scenarios (urban and suburban environments). While each environment has its own characteristics leading to different challenges, the merit of this paper lies in developing a MAC protocol suitable for both. In this work, we propose an efficient Multichannel QoS Cognitive MAC solely dedicated for Vehicular Environments (MQOG). MQOG incorporates efficient channel negotiation on the dedicated control channel whereas data is transmitted on other channel without contention. Since vehicular environments are widely known to suffer from interference and multipath, MQOG assesses the quality of channel prior to transmission employing a dynamic channel allocation and negotiation algorithm to achieve significant increase in channel reliability and throughput. The channel assignment problem was solved in an integrated manner while taking into account the QoS of different frames(Safety and NonSafety. The uniqueness of this protocol lies in making use of the ISM Band and UNII-3 in case all available channels in DSRC were considered unreliable. The proposed protocol was implemented in OMNET++ 4.1 and extensive experiments demonstrated that the proposed MAC ensures the reception of safety messages much faster, more efficient and reliable than other existing VANet MAC Protocols.**

I. INTRODUCTION

By the end of 2010, World Health Organization (WHO) estimated that nearly 3,500 people die on the world's roads every day and millions of people are injured or disabled every year. Since worldwide traffic accidents are considered one of major cause of death for humans, in 2003, the Federal Communications Commissions (FCC) in the United States mainly responsible for spectrum allocation allocated 75 MHz in the 5.9 GHz DSRC Band for vehicular communications. One major VANet challenge on the MAC layer is the frequent network topology changes and connections/disconnections because of random vehicular mobility. This mobility imposes a high multipath environment with dynamic delay spread due to multiple reflections, scattering and refraction. Moreover congested environments such as downtown suffer from high levels of noise and interference. Therefore there is a need to assess the channel dynamically before initiating transmission. On the other hand, there exists an imposed latency requirement for QoS services. Data transmitted over VANets can be classified as Safety or NonSafety with different considerations. Safety messages must be sent within a certain upper threshold known as delay bound otherwise they reach their target late. In this work, the proposed protocol MQOG considers all those challenges as it is capable of prioritizing traffic to ensure QoS, mitigating interference in high multipath vehicular environments and maximizing system throughput by introducing a unique multichannel cognitive operation.

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II. RELATED WORK

The different MAC protocols for Vehicular Ad Hoc Networks were widely investigated in the literature. Since the nature of vehicular communication imposes a distributed architecture where there is not any centralized controller managing transmissions, multichannel solutions were shown to be more suitable than single channel protocols [2-9]. This is due to the fact that multichannel solutions ensure intelligent control and coordination between vehicles on a particular channel. In general, Multichannel MAC protocols for VANets can be classified under 2 categories: Single and Multiradio Solutions.

A. Single Radio Solution

IEEE ratified 802.11p in 2010 as WAVE Amendment[7] defining the PHY and MAC layer for VANets operating in 5.9 GHz Band. IEEE 802.11p divided DSRC into seven 10 MHz channels, composed of one control channel (CCH) which is assigned for broadcast and control messaging and six service channels (SCHs) for ongoing data transactions. IEEE1609.4[8] defines the multichannel operation of 802.11p where all devices participating should monitor the CCH where high priority control and safety messages are transmitted.

In [6], authors propose VMESH, an extension to IEEE 802.11p with Multichannel operation. VMESH uses a contention-based access method for control channel and a contention-free (TDMA) access method for service channels in parallel with 802.11p multichannel operation.

B. Multiradio Solution

In [4] Su and Zhang propose a clustering-based multichannel MAC that uses contention-free and contention-based MAC protocols. Cars can be grouped together in a cluster and by using an election protocol, a cluster head is elected while others are considered cluster members. Authors define the use of TDMA for cluster members while cluster heads use 802.11p CSMA/CA to contend on a different frequency.

In [9], the authors define Distributed Channel Access (DCA)

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for MANets (mobile ad hoc networks) based on dynamic channel assignment. DCA utilizes two transceivers; one always operates on a dedicated control channel while the other can be switched to any data channels in an on-demand manner.

Since our work proposes a new Multichannel MAC, we conclude the related work section by outlining the differences between our work and others. First, contrary to many QoS MAC protocols, our proposed protocol grants priority of sending safety messages and in case of having contention on the medium, the protocol makes use of the ISM or UNII-3 band by requesting to handoff a nonsafe data channel to an unlicensed free band. Secondly, our proposed protocol considers interference on a channel (Adjacent and Co-Channel Interference) as this might be a major obstacle in VANet environments. Finally, our proposed protocol uses two transceivers; a transceiver dedicated for control and intelligence while other for data transmission which demonstrates improvement in throughput.

III. Proposed Multichannel QoS Cognitive MAC for VANets (MQOG)

MQOG uses multichannel operation with a unique dedicated control channel and multiple service channels for data transfer. The Dynamic Channel Allocation Protocol (Section III.B) ensures that each transmitter searches for the best available channel by assessing the noise and interference level on the DSRC, ISM, and UNII-3 bands. As shown in Fig.1, directly before the DSRC band there exist the ISM and UNII-3 bands. Those bands are both unlicensed and free to use by any user except that the user must abide by the Channel Transmit Power (CTP) and Bandwidth Requirements set by the local regulatory entity in his country. In general, the 5.8 GHz ISM and UNII-3 are both used for outdoor communications with transmit power suitable for vehicular communications. In our proposed protocol, we use them only for sending nonsafe data bursts in case all DSRC channels are occupied. Moreover, non safe data will handoff to an ISM or UNII-3 band in case a safety message has to be sent and the channel assessment did not find any suitable channel on the DSRC band. In our proposed protocol, we separate the control from the actual data transmission. The underlying communication and intelligence lies on the control channel to dedicate a service channel for data transfer. All vehicles track the communication between neighboring vehicles using the Channel Neighbor State Table (CNST) (refer to section III.C). This table shows the transmissions of neighboring vehicles in the range and hence a car while monitoring the control channel has enough intelligence to be aware of all transmissions occurring next to it.

A. System Radio Architecture

Vehicles are equipped with two transceivers working simultaneously. The first transceiver is connected to an omnidirectional antenna configured on channel 178 and serves as a dedicated control channel. Vehicles in the same range listen and transmit control data on this channel and any

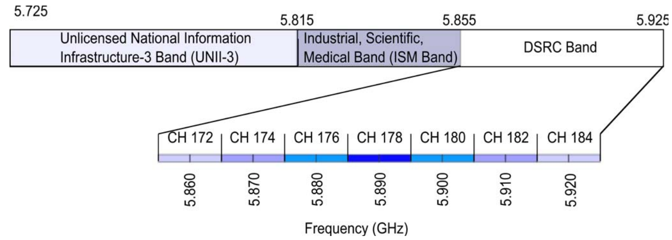


Fig. 1. ISM and UNII-3 Band directly before DSRC Band

change in the vehicle network topology is directly sent to inform neighboring vehicles to update their CNST. Vehicle's contention for this channel is based on CSMA/CA as defined by IEEE802.11p standard. However unlike the IEEE standard, only control frames are sent on this channel ensuring short messaging (50B) and short medium reservation. Beacons (Vehicle ID, Speed, and Position) and control frames for frequency selection (Adjusted RTS and CTS) are only sent on the dedicated control channel. The second transceiver is a cognitive radio capable of hopping and adjusting between different frequencies ranging from the ISM and UNII-3 band up to DSRC band (5.725 GHz - 5. 925 GHz). The cognitive radio is solely used for transmitting and receiving data.

As shown in Fig.2, the vehicle can operate in three different modes. In the idle mode, the control channel exchanges control info and updates the CNST Table while the cognitive radio senses unlicensed and licensed bands for channels for reliable transmission. In the pre-transmission mode, the channel negogiation occurs on the control channel while the dynamic channel allocation algorithm runs on the cognitive radio. Finally, during the transmission mode, the cognitive radio sends the data on the selected channel while the control channel keeps on exchanging control frames and updating the CNST Table.

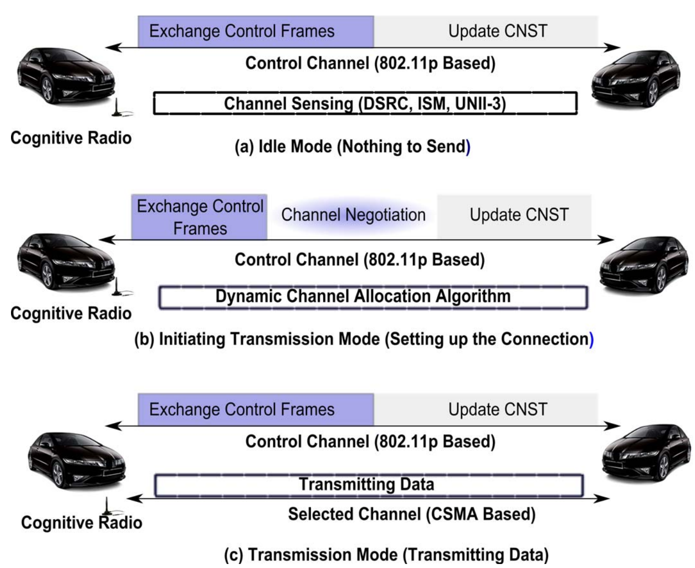


Fig. 2. Proposed Protocol

B. Dynamic Channel Allocation Algorithm

The Dynamic Channel Allocation Algorithm selects the best available channel with low interference and noise levels. The flowchart is shown in Fig.3 and it works as follows:

If the Cognitive Radio Assessment reveals an available DSRC channel with optimum conditions then it is directly selected for the incoming transmission. However, if all available DSRC channels are being used by neighboring vehicles then an assessment for the level of noise and interference on each channel is made. If at least one channel is above the threshold then this channel is selected and checked by comparing it with the CNST. This channel is then reserved by the vehicle for the upcoming transmission.

If all channels suffer from high interference and noise levels then the QoS of the message to be sent is investigated. If the message to be sent is safety then CNST is checked to assess if all occupied channels belong to safety transmissions. If this is the case, then the vehicle has to wait for the end of the first transmission. If neighboring vehicles are transmitting non safe data then the vehicle sends a request to handoff and safety transmission would replace nonsafe transmission on the DSRC channel while nonsafe transmission are handed off to an ISM or UNII-3 Channel. If the frames to be sent are non safe messages then transmission can occur on the ISM or UNII-3 since it is not a critical message. Unlicensed Channels are checked for the interference and noise levels and once a channel with good conditions is assessed, it is then directly selected for transmission. Before initiating transmission, adjusting Transmit Power (TP) is necessary to ensure the abidance to RF regulations of the local regulatory entity. If all ISM/UNII-3 bands were suffering from high interference levels then after checking CNST the vehicle reserves the channel the first to be vacant.

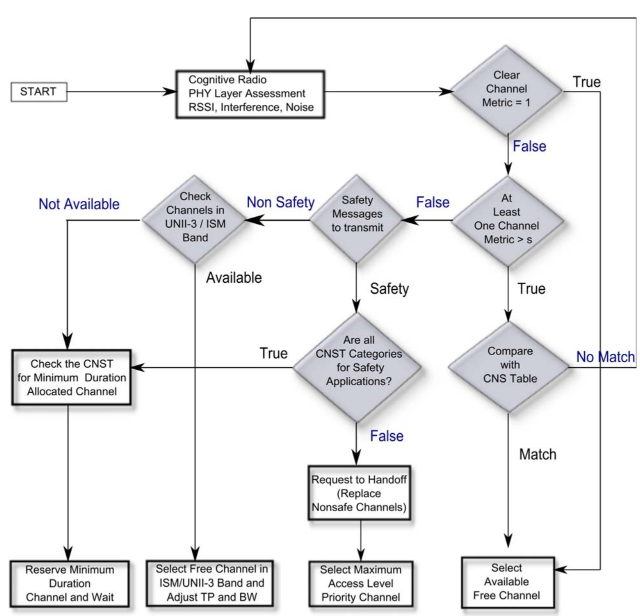


Fig. 3. Dynamic Channel Allocation Protocol Flowchart

C. Control Frames, Channel Neighbor State Table (CNST) and QoS Access Categories

MQOG requires the use of special control frames to help in the negotiation process between vehicles and to ensure the collision -free transfer of information. Those are the only frames sent on the dedicated control channel and characterized by being short messages (50B). They are responsible for establishing the communication link between the transmitter and receiver for the actual data transmission on the service channel.

- **Beacon Management**: Periodically sent by each vehicle to the neighboring vehicles within the range and it conveys the Vehicle ID, Velocity and Position.
- **Adjusted-RTS**: This frame replaces the known RTS frame by adding channel selection parameters which shows the assessed channels for transmission.
- **Adjusted-CTS**: Analogous to the known CTS packet with the difference of adding an agreed upon channel between transmitter and receiver.
- **Request-to-Handoff**: This frame is triggered once a frame with high priority is required to be sent while all other channels are occupied by lower priority transmissions. The request to handoff selects the channel occupied with lowest priority and sends a request to the transmitting vehicle to handoff to another ISM or UNII-3.
- **Handoff-to-ISM or UNII-3**: Sent from the transmitter in an ongoing communication to the receiver on the control channel. This informs the receiver to switch to the following ISM or UNII-3 band as the channel being used would be granted to a more prior transmission.

For the Channel Neighbor State Table (CNST), it stores the ongoing neighboring communications between neighboring vehicles in each vehicle's database. Neighboring vehicles continuously update their channel transmission by sending control frames on the dedicated control channel. CNST stores for every ongoing transmission the frequency channel being used, Access Category priority level, the duration of the ongoing transmission and a Reserved Field which shows the Vehicle ID reserving the channel either for handoff or for an incoming transmission. For handoff purposes, the reserved field is triggered when the Request-to-Handoff control frame is sent reserving the channel for a more prior communication ensuring a First Come First Serve (FCFS) basis.

In our proposed protocol we define 6 access categories rising from the different Vehicular QoS needs. The Access Categories are shown in Table 1 ranging from highest to lowest priority and are divided into 3 main categories: safety, nonsafety realtime, and nonsafety non realtime.

IV. Performance Evaluation

To evaluate the proposed protocols, the implementation and simulation was done using OMNET++ version 4.1. INETMANET framework was added as part of the simulation as it comprises many known networking layer protocols for

TABLE I
QoS Different Category Levels

Access Categories	Priority	Examples
Safety(Broadcast/Multicast)	1	Warning Messages (Accident, Icy Road, Oil Stain, Sudden Breaking)
Safety (Unicast)	2	Lane Change or Wrong Way Warning
NonSafety Real Time (Broadcast/Multicast)	3	Video/Voice Conference
NonSafety Real Time (Unicast)	4	Voice Conversation
NonSafety Non Real Time (Broadcast/Multicast)	5	Downloading EMaps from RSU
NonSafety Non Real Time (Unicast)	6	Web Surfing/Sending Emails

TABLE II
General Simulation Parameters

Simulation Parameters	Values
Download Map Area	4km x 3km (Downtown Ottawa)
Radio Propagation	Nakagami
Radio Range	250m
MAC bitrate	12 Mbps
Radio Transmit Power	20 dBm (100 mW)
Vehicular Speed	Vary from 40km/h - 120km/hr
Carrier Frequency	5.8125 - 5.925 GHz (Dynamic)
Radio Sensitivity	-85 dBm
Data Frame Size	1000 Bytes
Control Frame Size	50 Bytes
Simulation Time	15 minutes

MANets (Mobile Adhoc Network). Regarding the traffic simulation and mobility, we used SUMO as it performs simulations of vehicle movements in real world maps adhering to multiple lanes, speed limits and traffic lights. TraCI (Traffic Control Interface) opens a TCP Connection between both SUMO and OMNET++ to couple both applications. For the purpose of this simulation, we used a map from downtown Ottawa. The map data region was downloaded from OpenStreetMap Project[10] and it included all roads attributes such as speed limits, lanes count, stop signs, road type and traffic direction. Random routes and mobility patterns for vehicles were also generated using different scenarios with different number of vehicles departing randomly.

A. General Simulation Parameters

All vehicles have same general simulation parameters shown in Table 2. The number of vehicles increases in the simulation starting from 30 vehicles/area (Suburban) to 200 vehicles/area (Urban). Quality metrics are recorded for a one hop communication link as we are increasing the number of vehicles.

B. Simulation Scenario

We consider a communication scenario where there exists a safety broadcast and unicast transmissions. For the Safety Broadcast, we assume an accident occurred and a vehicle is broadcasting safety packets to neighboring vehicles. The traffic rate is set to 1 frame/s with a Broadcast Interval of 500ms. Simultaneously, we consider Unicast Transmissions with 30% of the vehicles in the region transmitting various QoS unicast packets to the other 30%. The traffic rate is set at 1 frame/s.

C. Evaluation Metrics and Results

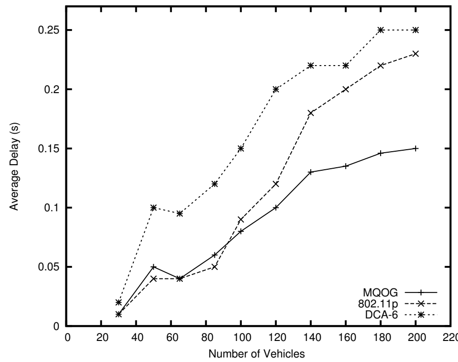
In order to quantitatively evaluate our proposed protocol, we assess different metrics for the scenario and we compare our protocol with the IEEE 802.11p [7,8] and DCA[9].

1) Delay: We evaluate the delay in ms for the reception of safety messages in the broadcast scenario. In general, signals received with high power have better transmission rate leading to a lower delay. As can be seen in Fig.4.a, the delay for all implemented protocols starts low and increases with an increasing number of vehicles. For 802.11p, we can see that at the beginning it was performing well however when the number of vehicles increases, the interference increases degrading the performance. The proposed protocol MQOG outperforms 802.11p when the number of vehicles is above 96. As the protocol is sensing the channel and testing its transmission conditions, it is ensuring a lower delay with a higher reliability of transmission.

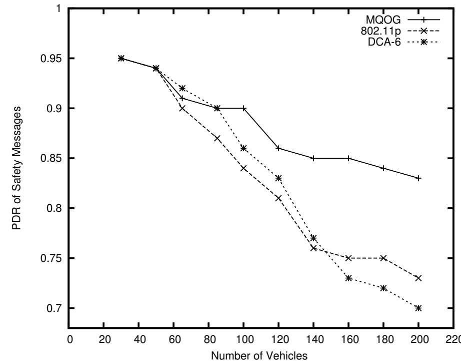
2) Packet Delivery Ratio (PDR) for Safety Messages: PDR shows the ratio of number of safety messages received to the number delivered. As can be seen in Fig.4.b, 802.11p and DCA start by having a high PDR when the number of vehicles is around 80. However as the number of vehicles increases the PDR degrades gradually. The proposed protocol MQOG outperforms 802.11p and DCA since it is ensuring the reliable transmission of safety messages by channel assessing prior to transmission. Moreover, MQOG requests a data channel to handoff to an ISM or UNII-3 channel in case there was an unreliable DSRC Channel.

3) Throughput: The throughput reflects the system's performance. As shown in Fig.4.c, the throughput of MQOG starts as being slightly less than the 802.11p and DCA in a suburban environment where the traffic generation is relatively low compared to urban environment. However as we are increasing the number of vehicles in the same area, MQOG outperforms others since it is accounting for the level of interference and compensating for them by switching to other frequencies with less interference. This switch would decrease the retransmission of corrupted packets leading to an increased throughput.

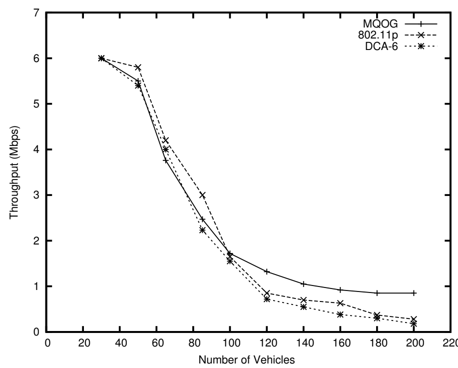
4) L2 Retransmission Rate: L2 Retransmission Rate is a direct consequence of multipath, interference and packet collisions. Fig.4.d shows that the percentage of L2 retransmissions dropped significantly when MQOG was used instead of 802.11p or DCA. This is due to the fact that the proposed protocol takes into consideration the interference and noise



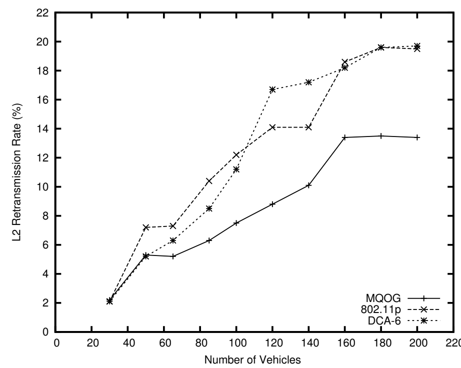
(a) Average Transmission Delay



(b) Packet Delivery Ratio



(c) Throughput × Number of Vehicles



(d) L2 Retransmission Rate

Fig. 4. Simulation Results

level on a channel prior to transmission whereas 802.11p and DCA transmit without assessing the channel quality.

Although with low number of vehicles, MQOG does not provide significant advantage compared to others however its contribution lies in granting safety messages priority in transmission. Nevertheless, MQOG drastically improves throughput in congested environments by using a unique multichannel operation as it assesses channel conditions before transmission.

V. Conclusion

In this work, we proposed a new Multichannel QoS Cognitive MAC (MQOG) tailored for vehicular communications. Channel sensing is done prior to transmission and messages are always sent on the best available channel to mitigate high interference and multipath problems. Moreover, this protocol ensures QoS by granting safety messages higher priority of accessing the medium over data messages. To evaluate the performance of MQOG, implementation was done in OMNet++ 4.1 and our results showed an improvement in throughput and packet delivery ratio. Simulation results demonstrated that unlike 802.11p contention based protocols or DCA channel negotiation style protocols, MQOG can offer better vehicle safety through smaller latency and less L2 retransmission rates.

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