An Enhanced MAC protocol to prioritize channel assignment for safety message broadcast in VANET

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Abstract. Spectrum shortage in Vehicular Communications has become an area of concern due to the diverse nature of applications served. Though the allocated 5.9GHz Dedicated Short Range Communication (DSRC) spectrum for vehicular communication is inefficiently utilized, the problem of congestion creates an impression that there is always a scarcity in the spectrum. The criticality of the issue becomes high when a safety message is unable to access the channel or is dropped due to congestion. This paper proposes an approach to prioritize channel access to safety messages through dynamic spectrum sharing. In case, when a safety message finds all the DSRC sub-channels occupied, then any one of the ongoing non-safety messages is switched over to the adjacent 5.8GHz ISM/UNII-3 band allowing the former to access the DSRC band. The proposed approach shows an increased QoS and reduced channel access delay for safety messages compared to the previous works.

Keywords: Channel Delay, DSRC, Safety message, Spectrum Sharing, VANET.

1 Introduction

Vehicular communication has gained considerable attention from both the automobile industry as well as the research community. Vehicular ad hoc network (VANET) is a sub-class of Mobile Ad Hoc Network (MANET), in which the participating nodes are vehicles. In VANET, two types of communications are possible namely, Vehicle-to-Vehicle (V2V) or Vehicle-to-Infrastructure (V2I).

Considering the scope and requirements of such a network, the United States Federal Communications Commission (FCC) allocated 75 MHz of spectrum in the

5.9 GHz band dedicatedly for Vehicular Communications [1]. The spectrum consists of 7 sub-channels, each of 10 MHz with a total 5 MHz guard band (shown in Fig.1). Each sub-channel is used for a specific purpose.

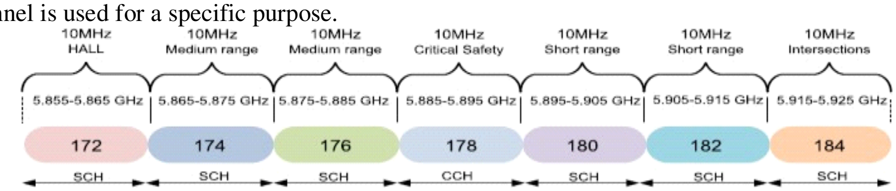

Fig. 1. 7 Channel Split-up of DSRC band

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VANET serves many applications which fall into either of three major categories- Commercial, Convenience, and Safety [2]. Among these, safety applications carry life-critical information, such as Accident Notification, Collision Warning, Emergency alert, Road condition Notification, etc., These messages have to be propagated and delivered with the minimum delay possible. Else the information becomes no good and it might even lead to loss of lives.

One of the main challenges in this communication is spectrum scarcity [3]. There is always an impression of channel unavailability all through the available spectrum is utilized poorly. Thus no effective communication occurs the majority of the time. Also, a vehicular network is inherently made up of nodes that are highly mobile, leading to frequent link disconnections. These characteristics, along with limited spectrum resources pose a great challenge in designing a highly reliable vehicular network. Hence, the task of prioritizing safety message transmission becomes inevitable. Especially in the case of a dense vehicular scenario like an urban environment, channel access to safety messages must be given higher priority.

Cognitive Radio (CR) is an upcoming option that can counteract the spectrum shortage problem for public safety communication [4]. CR is a technology in which a transceiver monitors the RF environment intelligently and detects the used communication channels and which are not, and instantly moves into vacant channels while avoiding occupied ones. This optimizes the use of the available radio-frequency (RF) spectrum while minimizing interference to other users.

The proposed work focuses on improving the spectrum utilization and eliminating the channel unavailability issue to safety messages when none of the DSRC sub-channels are present for safety communication. This is achieved by exploiting the adjacency of the unlicensed ISM/UNII-3 band to the DSRC band. When safety message dissemination has to occur and all the 7 DSRC sub-channels are being used by non-safety messages, any one of them is switched over to occupy the ISM band allowing the former to access the DSRC band. In this way, a higher priority is given to safety messages to access the DSRC spectrum.

The rest of the paper is organized as follows: Section II deals with the previous work done in the related context, Section III briefs about the characteristics of the system and assumptions. Section IV explains the proposed methodology and algorithm in detail, Section V discusses and analyses the simulation setup and experimental results obtained. Finally, the work is concluded.

2 Related Work

The majority of the existing papers have proposed possible enhancement of the WAVE-related 1609.4 multi-channel scheme. The MAC protocols developed for dynamic channel accessing can be broadly classified into six categories [5]: Multichannel coordination based MAC protocols, Clustering-based MAC protocols, TDMA based MAC protocols, ADHOC-MAC based protocols, Space Division Multiple Access (SDMA) based MAC protocols, Space Division Multiple Access (SDMA) based MAC protocols.

"A novel distributed asynchronous multichannel MAC scheme for large-scale vehicular ad hoc networks" [6] is a Multichannel coordination-based MAC protocol. In this paper, the authors have proposed safety message transmission with low latency and maximum throughput. The major limitation of this paper was the constant maintenance of the required QoS.

The next category of MAC for VANETs is Clustering-based MAC protocols which groups nodes by parameters like distance, thereby providing scalability. The concept of clustering in VANETS provided mobility handling, fair channel access to all vehicles that reduce co-channel and adjacent channel interferences.

The authors of "Cluster-based multi-channel communications protocols in-vehicle ad hoc networks", [7] proposed a MAC to provide a reliable network for real-time safety data and to increase the throughput for non-real-time traffic (e.g., e-maps download, movie downloads, etc.).However, the tradeoff between latency and throughput is significantly high causing a major limitation.

The next category of MAC for VANETs is TDMA based MAC protocols, where multiple nodes are allowed to transmit on the same channel which is time-sliced. One such TDMA-based MAC protocol is "Congestion-controlled- coordinator-based MAC for safety-critical message transmission in VANETs" [8]. In this protocol, several virtual segments contribute to a network. A local coordinator node provides time frames for transmission for all nodes. This protocol fails in the presence of a hidden terminal problem when a mobile node is selected as a coordinator due to its mobility and it works best only when an RSU is a coordinator.

ADHOC-MAC based is the next category mainly developed to avoid channel congestion in VANET. This protocol is effective in reducing collisions, encountering hidden and exposed terminal problems, but fails to prioritizethe safety message. This leads to a high end-to-end delivery time and decreased throughput.

The next class of MAC protocols is Cognitive radio-based MAC protocols. “A cognitive MAC for VANET based on the WAVE systems” that use DSRC spectrum effectively in highly dynamic vehicular conditions is discussed in the paper [9]. The approach fails to provide a high priority channel access to real safety messages leading to high safety packet drops during channel congestion.

3 System Characteristics And Assumptions

The characteristics of high mobility and dynamic topological changes are the characteristics that distinguish a VANET from a MANET.

The proposed approach assumes the following.

- Each participating vehicle is mounted with a transponder radio interface called an On-Board Unit(OBU) as shown in Fig. 2
- The OBU is comprised of a dual antenna system capable of switching between DSRC and ISM/U-NII-3 bands.
- All vehicles are equipped with GPS that provides time synchronization between vehicles, based on Coordinated Universal Time (UTC).

Fig. 2. On-Board Unit mounted in vehicles

4 Proposed Model

In the proposed model, all the vehicles are set to have a constant communication range. Each vehicle can communicate with the vehicles that are present within the range. All vehicles broadcast the beacon messages at regular intervals. This allows all vehicles to find and construct the 1- hop neighbor list. The beacon carries the updated message about the vehicle positional information.

The contributions of the proposed work are,

- Clustering of vehicles based on relative mobility of vehicles.

- Allowing a safety message to access all DSRC channels.
- A cognitive algorithm providing dynamic switching of the messages between DSRC band and U-NII-3/ISM band prioritizing safety message broadcast.

- *Frames used*

Multiple types of messages have to be transmitted and received for cluster formation and band switching. The formats of such frames used are given in Fig 3

ID of vehicle	Velocity of vehicle	Position of vehicle

(a)

Selected channel	Access category	Physical address of the transmitter

(b)

Selected channel for Hand-off on ISM band	Access category	Physical address of the transmitter

(c)

Fig. 3. Frames Used (a) Beacon Frame (b) Request to Transmit Frame (c)Request to Hand-off Frame

- *Clustering*

The protocol also employs a clustering-based message dissemination mechanism. Vehicles within communicating range are clustered in a dynamic manner using the information from the beacon messages. The two parameters for clustering are i) Speed ii) Heading direction. The vehicles moving in the same range of speed and the same direction fall under one cluster. The Centroid position for a cluster is calculated using Eqn(1)

$$(x_c, y_c) = \left(\frac{\sum_i x_i}{i}, \frac{\sum_i y_i}{i}\right) \quad (1)$$

Then the variance between a vehicle's current position and the calculated centroid value is found for all nodes. The node which is nearest to the centroid is unanimously elected as the CH by all the Cluster Members (CM) as shown in Fig 4. This is done to ensure cluster stability. Any communication within a cluster is through the intra-cluster link.

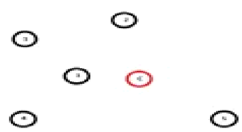

Fig. 4. Cluster Head Election

- *Construction of Status table*

The main role of CH is channel allocation to CMs and maintenance of the Channel Allocation Status Table (CAST) as shown in Table I.

TABLE I. CHANNEL AVAILABILITY STATUS TABLE (CAST)

Channel Number	**Channel status 0-Idle 1-Busy**	**Message type 0-Low 1-High**
172	1	0
174	0	-
176	1	1
..	..	..
..	..	..
n	0	-

- **Channel Number**: It is the corresponding number assigned to the sub-channel frequency in both DSRC or ISM bands. The 7 sub-channels of the DSRC band have numbers 172,174,..184.
- **Channel status**: This field holds the status of the sub-channels, i.e either idle(0) or busy(1).
- **Message type**: This field holds information about the priority of the message being sent in a channel. If the channel status is 1(busy channel) then 0 in message type indicates the non-safety message and 1 indicates the safety message is being sent in that channel. If the channel status field holds 0(idle channel), then the message type field holds no value.

Once this is done, the data or payload messages originated from any of the CMs are directed through CHs except when the destination node lies within the same cluster. As per conventional IEEE 802.11, a node senses the channel before the actual transmission. A CH updates the CAST by merging the received information from CMs. A vehicle moving in a cluster is aware of spectrum availability before transmission through CAST. This helps a CH decide in advance the channel to be used for the message transmission.

- *Channel Switching*

Now assume that a message is generated at any node in a cluster. The node communicates with CH through an intra- cluster communication link. The CH checks CAST for all transmissions on all channels. If the specified channel is free, the message is broadcasted; else if it is occupied with a transmission then the message type of this ongoing transmission is checked. If the generated message type carries higher priority (safety message) then it will defer the ongoing transmission and allocate it to the incoming transmission. The transmitter of the deferred message (non-safety message) sends a Request-to-Handoff on the ISM/U- NII-3 band. If the generated message type carries equal or lower priority, then it does not defer the ongoing transmission but waits for random back-off time and reattempt. The transmitter sends data on the corresponding service channel. The overall algorithm for channel allocation is given in Table II.

TABLE II. CHANNEL ALLOCATION ALGORITHM

TABLE IV. NETWORK PARAMETERS

PARAMETER	**RANGE**
Channel type	Wireless channel
Antenna model	Omni antenna
Routing protocol	AODV
Interface queue type	DSRC
Network interface type	Wireless PhyExt
MAC type	802.11Ext
Agent	Agent/DSRC App

- *Performance metrics*

The performance of the protocol is evaluated in terms of throughput, Packet Delivery Ratio (PDR), Packet Loss Ratio (PLR), switching delay for safety messages. The formulae for the performance metrics are calculated by the following equations 2, 3, and 4.

$$PDR = \frac{\text{No. of packets successfully received}}{\text{No. of packets transmitted}} \quad (2)$$

5 Performance Evaluation

The proposed approach is simulated with the help of three software tools.

- OpenStreetMaps - A real-time roadway and the geographic scenario was generated using this software.
- Simulation of Urban MObility - Real-time traffic was simulated for the scenario extracted.

6 Simulation Results

This section reports the results obtained from OpenStreetMaps, SUMO, and NS-2 simulations. Fig 5 shows the roadway scenario extracted from OpenStreetMap. The roadway is 15km with 6 lanes. The routing information extracted from this file is fed to SUMO and traffic is generated (shown in Fig 5 and Fig 6) for 25, 50,

iii)Network Simulator 2 - The proposed protocol is
implemented in Ns-2 and the simulation parameters are shown in Table III and Table IV.

TABLE III. SIMULATION PARAMETERS

PARAMETER	RANGE
Radio Propagation	Two Ray Ground
Radio Range	300 meters
Simulation Time	100 seconds
No. of nodes	25,50,75,100
No. of lanes	6
Node speed range	10-100 kmph
Simulation area	10000 m × 10000 m

75,100 vehicles. The vehicle movements are configured for the speed range of 10-100 kmph for clustering.

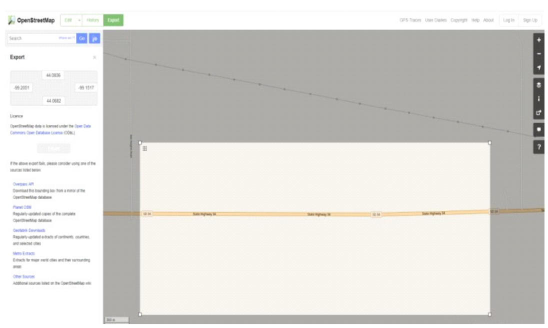

Fig. 5. Extraction of 6 lanes, 15km roadway from OpenStreetMap

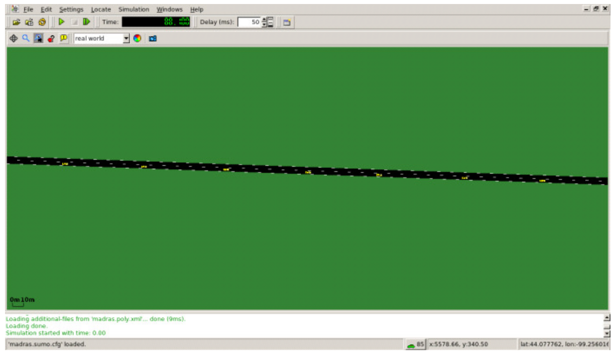

Fig. 6. Traffic Creation using SUMO

Fig 7 shows a single cluster when an emergency vehicle (red node) approaches.

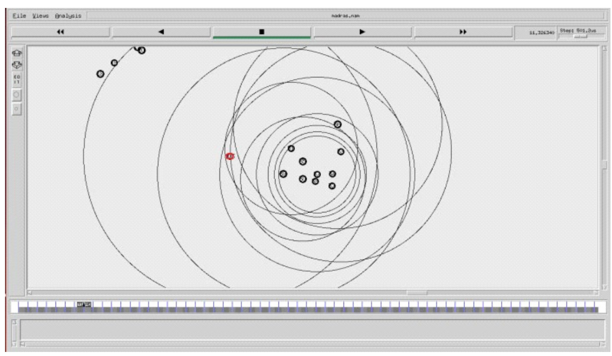

Fig. 7. NAM window showing an Emergency Vehicle approaches

Fig 8 and Fig 9 show the plots of PDR and Packet Loss Ratio for the varying number of nodes. The proposed method shows better performance since an emergency vehicle is open to access at any DSRC sub-channel, unlike standard IEEE 802.11p. It can be seen that PDR tends to decrease and loss increases, as packet collisions increase with the increasing number of vehicles.

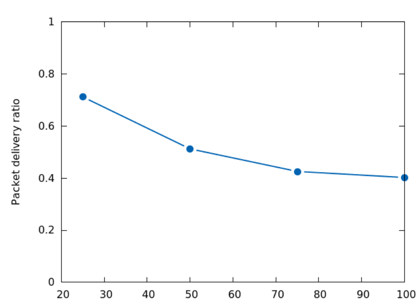

Fig. 8. No. of nodes Vs. PDR

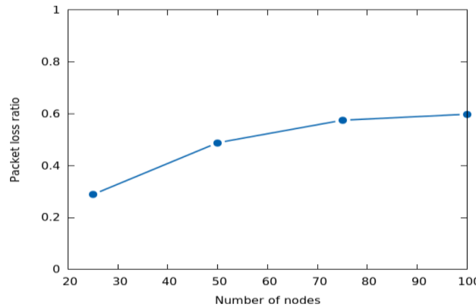

Fig. 9. No. of nodes Vs. Packet Loss

Fig 10 shows the plot between the Numbers of handoffs Vs the number of nodes. Channel congestion is expected to increase with increasing traffic, thereby channel availability decreases. This justifies the incrementing number of handoffs as vehicular density increases.

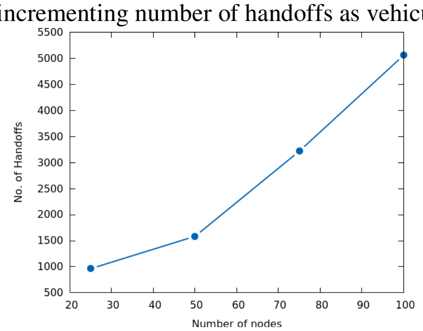

Fig. 10. No. of nodes Vs. No. of Handoffs

Switching delay calculated as per [4] is plotted in Fig 11. As there are more nodes, the switching delay increases due to the limited message handling capability of Cluster Head.

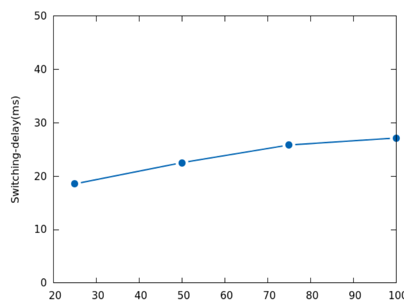

Fig. 11. No. of nodes Vs. Switching Delay

Conclusion

In this paper, an approach is proposed and simulated to prove the advantages of the clustering-based dissemination of event-driven messages in VANET. The improvement in spectrum utilization is seen with the use of dynamic spectrum sharing for V2V communication. The adjacency of the 5.8GHz ISM band is exploited. It can be seen that the work provides good QoS for increased vehicular density in terms of delivery ratio, loss ratio, and delay compared to the IEEE 802.11p standard for vehicular communication. In the future, the proposed work can be extended to provide queuing and scheduling of both safety and non-safety messages to increase the packet delivery ratio and reduced end-to-end delay.

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