# Multichannel Cognitive Medium Access Control Protocol for Vehicular Ad-hoc Networks

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***Abstract*—Intelligent transportation system (ITS) has enjoyed a tremendous growth in the last decade and the advancement in communication technologies has played a major role behind the success of ITS. Due to the nature of communication in vehicular environments, wireless access is considered as an integral part of any ITS system. The IEEE 1609.4 has evolved as a standard for wireless access for vehicular environment (WAVE), which describes multichannel access operations over the 5.9GHz dedicated short range communications (DSRC) spectrum. Communication channels in the 1609.4 are grouped into service and control channels. Control channels (CCHs) are used for transmitting safety and management messages (e.g., traffic congestion data, data for emergency services) whereas service channels (SCHs) are used by the nodes for transmitting service data (e.g., text, voice, video). In the existing channel access mechanism, nodes are not allowed to use service channels (i.e., remain idle) during control channel interval and vice verse. This causes half of the service channel intervals to remain idle, which makes the WAVE system heavily underutilized and inefficient. In this paper, we propose a medium access control (MAC) protocol for WAVE system to improve the channel utilization (CU) and reliability of safety messages. The proposed protocol has been developed based on the concept of cognitive radio and it outperforms the existing channel access mechanism by a significant margin in terms of channel utilization, jitter and robust delivery of safety data. Simulation results confirm that the proposed cognitive MAC protocol increases the CU up to 70% compared to the IEEE 1609.4 standard, and improves reliability for the safety related data transmission.**

***Index Terms*—Vehicular ad-hoc network, safety data, channel access, channel utilization, cognitive radio.**

## I. INTRODUCTION

VEHICULAR ad-hoc network (VANET) is a network of moving vehicles where participating vehicles or infrastructures create a network that facilitates vehicle to vehicle and infrastructure communications. Due to the nature of communication, VANET offers some extreme challenges, and some of these challenges include: dropping out of connections as the moving vehicle moves out of the coverage range, joining of new nodes moving at high speeds, dynamic change in topology and connectivity, time variability of signal strength, throughput and time delay. The main application of the VANET in ITS lies in the exchange of safety messages between nodes and an example scenario is shown in Fig 1. If there is a collision between car 1 and car 2, VANET allows every node in the network to be informed about the crash site and road condition, which helps to reduce traffic congestion and chance of fatality. VANET therefore can play a vital role as a part of ITS to improve road safety. .

For developing vehicular infrastructure, the US Federal Communications Commissions (FCC) has allocated 75 MHz DSRC spectrum in the 5.9 GHz band. In Europe, a similar band has recently been allocated for similar applications. As shown in Fig. 2, the total band is divided into 7 separate channels with one CCH and six SCHs, each with a 10MHz bandwidth [1]. The CCH is mainly used for transmitting management and safety traffic while all data transmission is carried out on SCHs.

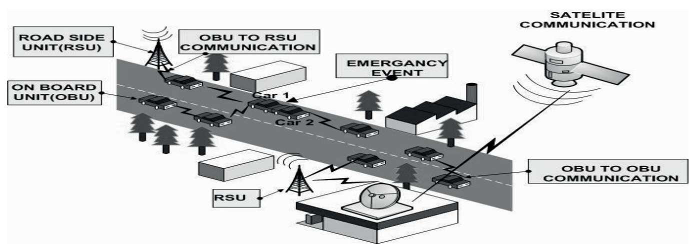


Figure 1. Vehicular ad-hoc network.

The IEEE 1609.4 draft standard for VANET [2] defines the sync interval which constitutes of control channel interval (CCH interval) and service channel interval (SCH interval) as shown in Fig 2. The IEEE 1609.4 standard defines the time division scheme for WAVE radios to alternatively switch between CCH and SCH during a sync interval to support different applications concurrently [3]. Start of a sync interval is synchronized with the coordinated Universal Time (UTC) second and multiples of 100 ms thereafter. A sync interval with a default length of 100ms is equally divided into 50 ms CCH and 50 ms SCH interval [4]. According to the WAVE, a Wave Basic Service Set (WBSS) consists of one provider (the node that has services to offer, also known as WBBS initiator) and one or more WBSS users. As described in the IEEE 1609.4, in VANET has to switch to CCH every 50ms to listen to safety messages and for network management processes (e.g., channel contention and negotiation and WBBS formation). Therefore, SCH is not utilized during the CCH interval which is 50% of every sync interval. This causes under utilization of available resources, which ultimately results in more waiting time, more jitter and increased frame error rates for the transmission of safety messages.In this paper, we propose a resource management technique based on the concept of cognitive radio that addresses the above mentioned challenge.

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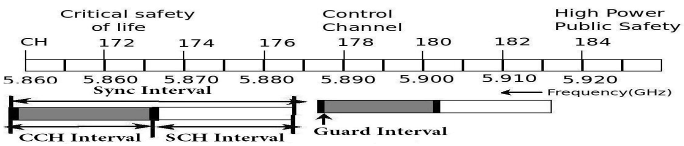


Figure 2. Spectrum allocation in WAVE and sync interval.

## II. Previous Works

Several MAC protocols have been proposed based on the IEEE 1609.4 standard to improve the performance and reliability. The IEEE 1609.4 standard has been studied by Qi *et al.* [3] where the authors showed that in IEEE 1609.4 standard the channel is heavily underutilized. The extended SCH interval has been proposed in [5], which increases the saturation throughput of the SCH, but does not improve the reliability of the system for safety applications in-terms of end to end (E2E) delay, throughput and jitter. Cognitive MAC protocol proposed by Seung *et al.* [6], improves system throughput at the cost of detereorating performance for safety data delivery. The above mentioned MAC protocols for VANET focus on improving the overall system performance for IP services only. None of them showed any improvement for a safety related application, which is the most crucial application for VANET. In this paper, we propose a novel mechanism that is based on IEEE 1609.4 and guarantees the reliability of the system performance for safety traffic with a better CU.

## III. Multichannel operation in IEEE 1609.4

As mention earlier, CCH and SCH intervals are 50 ms each which together forms one sync interval (i.e., 10 sync intervals per second). This is motivated by a desire to map a sync interval to the generally assumed 10Hz vehicle safety messaging rate [3]. There is a guard interval of 4ms at the start of each CCH and SCH interval as shown in Fig 2, which takes care of radio switching and timing inaccuracies among different nodes. During a CCH interval, a provider intending to transmit data, broadcasts the wave service advertisement (WSA) frame. A WSA frame consists of the identification number of WBSS, the SCH that it intends to switch to, and the MAC address of the user. A user who wants to join WBSS, acknowledges to the provider by the WSAR (WSA Response) frame. Once the WSA/WSAR handshake is finished, the provider and users select the agreed SCH for data transmission during the next SCH interval.

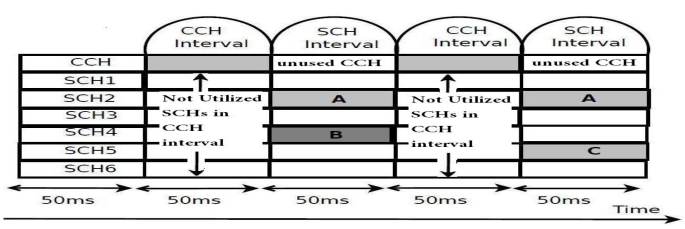


Figure 3. WBBS formation.

There can be multiple providers trying to compete for any of the six SCHs' access. To avoid collision between WSA frames on CCH during the CCH interval, random back-off scheme is being used. Moreover, when any provider listens to the successful WSA/WSAR handshake within the same CCH interval and also intends to broadcast WSA frames, adjusts it's SCH in order to avoid collision and if the successful WSA/WSAR handshake is conducted, the provider chooses different SCH during the SCH interval. If the provider fails to conduct WSA/WSAR handshake within the CCH interval then it has to wait until the next sync interval and then the provider will make another WSA announcement with larger contention window size. After the above mentioned contention and negotiation process, the nodes switch to their corresponding SCHs in the SCH interval for data transmission. In addition, large amount of data requires several sync intervals to complete the transmission.

The explained mechanism fails to meet the requirements of the VANET and posses a challenge that is explained below. In order to transmit the data in more then one sync interval, the provider has to go through the WSA/WSAR handshaking process in every CCH interval until the transmission is finished. Fig 3 shows how three WBSS A, B and C are initiated by their corresponding provider and are established to conduct the data transmission. All the nodes have to tune into CCH during CCH interval for resource management and contention and then they tune into corresponding SCH during the SCH interval for data transmission. We can observe that the standard mechanism causes three major problems as shown in Fig 3: i) CCHs during a SCH interval remain idle, ii) SCHs remain underutilized for 50% of each sync interval, iii) large data can not be continuously transmitted as every node has to terminate their transmission during the next CCH interval. As shown in Fig 3 WBSS A has to terminate data transmission during the next CCH interval to contend for the channel to be used in the SCH interval.

The IEEE 1609.4 standard currently uses the Enhanced Distributed Channel Access (EDCA) parameters defined in the IEEE 802.11 standard, which does not implement absolute priority (e.g., safety message first no matter what the network status is), rather applies service differentiation only within the different priority messages [7]. The EDCA mechanism is not suited for VANET because a low priority traffic may still win the channel before than higher priority traffic and may collide with a higher priority traffic because of the minute difference in AIFSN values for different priorities, which makes the system unreliable.

## IV. Proposed Multichannel Cognitive MAC (MCM) Protocol

The main purpose of the proposed multichannel cognitive MAC (MCM) protocol is to improve CU and transmission reliability for safety related data. To achieve the goal, cognitive radio concept has been adopted in the MCM protocol. According to the concept of the cognitive radio, primary providers (PPs) are mapped as nodes with safety related data (e.g., emergency vehicles such as police cars, ambulance, fire trucks) and secondary providers (SPs) and secondary users (SUs) are mapped as commercial and general automobiles, where as

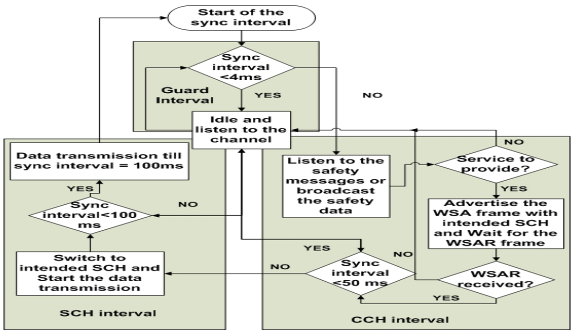


Figure 4. System flow diagram for the IEEE 1609.4.

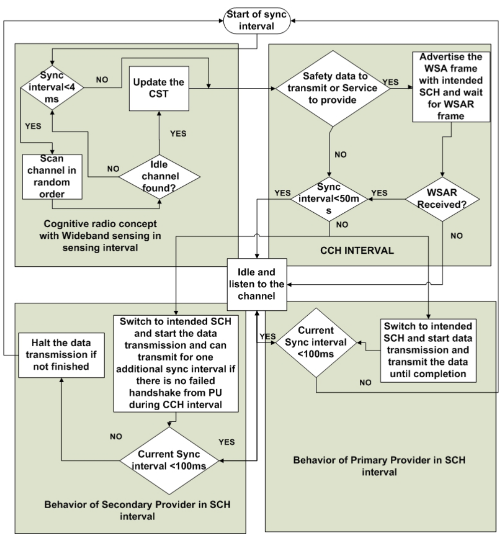


Figure 5. System flow diagram for the proposed MCM protocol.

primary users(PUs) can be any node in the system. The MCM protocol with a modified EDCA ensures that PPs have higher probability to win channel access and are given opportunities to transmit their data until finished. On the other hand, the SPs can only use the channel to transmit when there is a spectrum hole in the system. The system flow diagram for the IEEE 1609.4 and the proposed MCM protocol is presented in Fig 4 and Fig 5, respectively.

### *A. Multichannel operation in the MCM protocol using cognitive radio*

In the MCM protocol, all the nodes are required to perform wide-band spectrum sensing [8] to utilize the cognitive radio

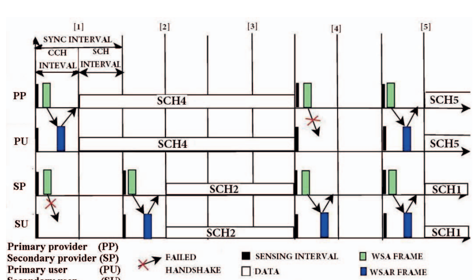


Figure 6. The operation of the proposed MCM protocol.

concept which is presented in the flow chart as summarized in Fig 5. Each node senses the spectrum across all six SCHs using its radio trans-receivers and update the spectrum condition at the beginning of each CCH interval. Once all the nodes go through the sensing phase, they establish their own Channel Status Tables (CST) which have the information about all six SCHs. The CST indicates whether the channel is available during the desired intervals. As mentioned above, each provider needs to go through a channel contention and negotiation process during the CCH interval. A provider advertises its WSA frame during CCH interval for channel access and negotiation process. The SCH that the provider targets to switch to, is decided based on its own CST. Once all interested users acknowledge the WSA frame with a WSAR frame, the handshake process is finished and the provider is ready to send it's data in the next SCH interval.

In the proposed MCM protocol, the PPs are given the opportunity to transmit their data for more then one sync interval without going back to the CCH during the next CCH interval. PPs do not need to go through the channel contention and negotiation process again during its data transmission. Once they finish their data transmission, they go back to normal sync interval and channel switching process. T The behavior is explained in Fig 6 where PPs go through the channel contention process and complete the handshake during the CCH interval and transmit data during the next four sync intervals. In the MCM protocol, SPs always have lower priority for channel access and they follow the same process as the PPs for data transmission. In case where the SPs have larger data to transmit , they are allowed to transmit for one additional sync interval as long as handshakings from the PPs in the CCH interval are successful. The behavior is explained in Fig 6. All the nodes other than PPs are ready to listen to the CCH during the next CCH interval, so the failed handshake from PP is clearly visible. Assuming there is no failed handshake in the fifth sync interval, all the SPs can extend their data transmission for an additional sync interval. If there is a failed handshake from one of the PPs during the CCH interval, SP only transmits its data in the upcoming SCH interval and then goes back to the CCH during the next CCH interval and starts all over again. This allows PPs to have a upper hand and win channel as they need. The ability of nodes to transmit data for more than one sync interval (through the use of cognitive radio) without the need to go back through the whole process of channel contention and negotiation again, certainly improves the CU, which is a key innovation in the proposed MCM protocol.

Table I
DEFAULT VALUE OF EDCA PARAMETERS IN WAVE AND PROPOSED VALUE OF AIFSN$_{new}$

| $AC\ [i]$ | $CWmin$ | $CWmax$ | $AIFSN_{default}$ | $AIFSN_{proposed}$ |
|---|---|---|---|---|
| 0 | 15 | 1023 | 9 | 19 |
| 1 | 7 | 15 | 6 | 12 |
| 2 | 3 | 7 | 3 | 9 |
| 3 | 3 | 7 | 2 | 2 |

### B. Prioritized channel access mechanism in the MCM protocol

For channel contention resolution between PPs and SPs in the MCM protocol, we use the EDCA mechanism with strict priorities (i.e., SPs must not get channel access ahead of PPs and their frames do not collide). The EDCA mechanism defines different Access Categories (ACs) in all nodes with their specific Arbitrary Inter Frame Space(AIFS) and Contention Window (CW) sizes. In EDCA, for a given access category, the minimum time period that a node needs to sense the wireless medium in order to determine if it is idle, is larger than the AIFS plus the largest possible back-off interval of all ACs corresponding to higher-priority frames[9]. According to the concept mentioned above, the waiting time period in the worst case to transmit the highest priority frame belonging to class $i$ is AIFS[$i$] plus the largest possible back-off interval. For lower priority frames belonging to class $i$-1, the waiting time period to transmit in a best case is AIFS[$i$-1] assuming the random back-off interval is zero. In order to establish the strict priority, the waiting time interval for higher priority frames must be less than the lower priority frames. If we use the default parameters of standard EDCA, the condition mentioned is not satisfied.

According to the proposed mechanism, $AC[3]$ frames (i.e., safety data) have strict priorities over $AC[2]$ frames. While the rest of the categories (i.e., category 1-0) are not for safety related messages, they can still have priorities, but we do not need to establish the strict priorities (i.e., wide variation in AIFS and CW) among them. Table I shows the EDCA parameters used in WAVE and table I shows the $AIFS_{proposed}$ used to establish the strict priorities and so that $AIFS[2]$= $AIFS[3]$+$CW_{min}$, $AIFS[1]$= $AIFS[2]$+$CW_{min}$, and $AIFS[0]$= $AIFS[1]$+$CW_{min}$.

Table II
SIMULATION PARAMETERS

| Simulator | NS-2.34 and Cognitive Radio Cognitive Network Simulator [10] |
|---|---|
| Simulated area | 2000*400 meter$^2$ |
| Number of nodes | 0 to 200 |
| Vehicle speed | Random speed from 20km/h to 80km/h |
| Each simulation time | 500 seconds |
| Data rate | 3 Mbps |
| Traffic | Poisson traffic with arrival rate y=2, 8, 20 frames/sec |
| Frame size | Exponentially distributed with the mean value equals to 300 kbits |
| Wide-band sensing interval | 4ms at the start of CCH interval |
| Highest-priority traffic load | 0% to 100% |

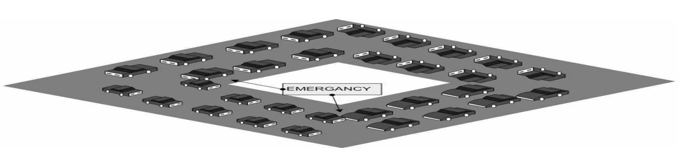


Figure 7. Simulation highway scenario.

## V. PERFORMANCE EVALUATION

Performance evaluation of the proposed MCM protocol was carried out through simulation and results were analyzed against the IEEE 1609.4 standard. We adopted the parameters defined in the IEEE 1609.4 standard [2], which are shown in table II. The topology used in the simulation is shown in Fig 7. The simulation was conducted in two phases: i) in the first phase, we evaluated the system performance in-terms of CU, number of waiting time slots (WTSs) and control overhead (CH) at different traffic arrival rates (i.e. Y=2, 8, 20 frames/sec) to show how the MCM protocol performs against the standard 1609.4 standard, and ii) in the second phase, we monitored the reliability of safety messages in terms of frame error rate (FER), E2E delay and jitter as the safety data load was increased.

First Phase: As shown in Fig 8a, the MCM protocol consistently achieves higher CU at various traffic arrival rates. The MCM protocol achieves up to 70% CU whereas the IEEE 1609.4 standard achieves a maximum of 40% CU as the load is increased. This is because the MCM protocol efficiently uses SCHs during the CCH interval for data transmission while, in the IEEE 1609.4, CU is very poor as the number of nodes increases, because of increasing frame collisions. Fig 8b shows the waiting time period (i.e., 1 WTS = 1 SCH interval = 50 ms) at three different frame arrival rates as a function of number of providers. It is observed from the Fig 8b that the MCM protocol provides much lower waiting time than in the IEEE 1609.4. A provider in the MCM protocol on average, has to wait 5 intervals less than the providers in the IEEE 1609.4 in case of Y=2 frames/sec and 50 providers in total, which clearly offers an advantage for safety related application in ITS. Fig 8c shows the amount of CH with respect to the number of providers at different frame arrival rates. The CH is calculated as an average number of handshaking from a provider within the sync interval. When the number of provider is high, every node has to go through the contention and access control process and as a result, the number of WSA/WSAR handshakes increases. As the number of provider increases, the MCM protocol shows large number of CH as compared to IEEE 1609.4 in case of Y=2, 8 frames/sec. However, at high arrival rate (e.g., Y=20 frame/sec), both the MCM and the IEEE 1609.4 show degraded performance in terms of CH. This is because, providers have to frequently rebroadcast their handshake frames because the system has very high traffic which causes large number of collisions. The MCM protocol still maintains lower CH because the WSA/WSAR handshake is not needed for the extended intervals of data transmission.

Table III
SUMMARY OF PERFORMANCE EVALUATION

| Parameters | IEEE std 1609.4 | MCM protocol |
|---|---|---|
| Maximum CU | 40% | 70% |
| Maximum waiting time | 1.25s | 1s |
| Maximum FER | 25% | 0.6% |
| Maximum jitter | 0.22ms | 0.04ms |

Second Phase: In this phase, we evaluated the FER, E2E delay and jitter for the system as we changed the safety traffic load from 0% to 100% with respect to the total traffic load of the system. The FER is the ratio of frames that are never successfully received because to the total number of frames transmitted . Fig 9a shows the FER in the MCM and

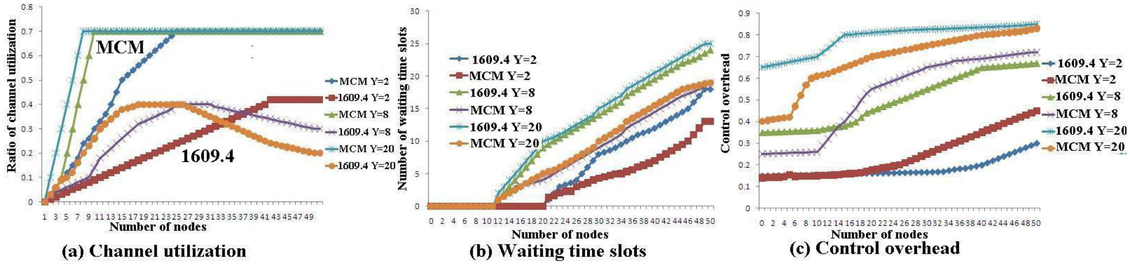


Figure 8. Results for first phase of simulation.

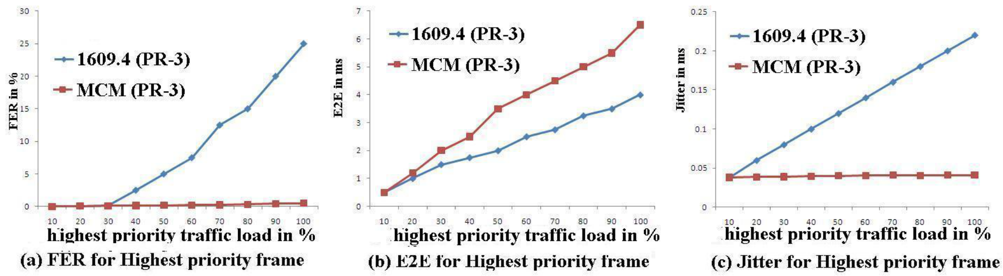


Figure 9. Results for second phase of simulation.

IEEE 1609.4 protocol. It is evident that the FER remains very low ( 0.6% max) in the MCM protocol whereas the FER reaches to 25% in the 1609.4 standard when the load of safety traffic reaches close to 100%, which proves that the proposed strict priority scheme improves the system reliability for safety applications. Fig 9b shows the one hop E2E delay for the highest priority frames for both protocols. It is observed that E2E delay in case of the MCM protocol increases as the highest-priority traffic load increases and reaches to a maximum of 7ms whereas in case of the IEEE 1609.4, the E2E delay reaches a maximum of 4ms. The E2E delay in case of the MCM protocol is higher because of the handshaking process needed to decide the targeting SCH, which increases the time for successful transmission. It can be noted that although the maximum delay is 7ms in the MCM protocol, it is still less than the recommended 10ms delay for VANET [11]. Fig 9c shows the jitter for the highest-priority traffic load (i.e., safety data for VANET) . It shows that the jitter experienced by the highest-priority frames increases with increasing percentage of traffic load and reaches to 0.22ms in case of the IEEE 1609.4 and a maximum jitter of 0.04ms in the MCM protocol. This also proves the advantage of the proposed protocol in terms of reliability experienced by the highest-priority frames. Table III shows the comparison between the IEEE 1609.4 and proposed the MCM protocol for different evaluated parameters in the simulation scenario

## VI. Conclusion

In this paper, we proposed a new MAC protocol for VANET that increases channel utilization and improves transmission reliability for safety messages. We adopted the cognitive radio concept and utilized a modified EDCA mechanism for developing the MAC protocol for VANET. The proposed MCM protocol increases channel utilization for both primary and secondary users, due to extended transmission time periods. The better CU and strict priorities improves the reliability for safety applications in terms of FER and Jitter. Our extensive simulation results show the effectiveness of our protocol that significantly reduces jitter and frame error rates for highest-priority frames.

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