Hybrid Multi-Channel Multi-hop MAC in VANETs

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ABSTRACT

In this paper, we propose a Hybrid Multi-Channel Multi-hop Medium Access Control (HMM-MAC) meeting the safety and non-safety requirements in Vehicular Ad-hoc Networks when no infrastructure is present (V2V communication) with only a single transceiver at each vehicle. The simulation results showed that our scheme could achieve a higher delivery ratio of road safety messages and a high probability to select a free transmission channel in a certain region and during a certain time.

Categories and Subject Descriptors

C.2.1 **[COMPUTER-COMMUNICATION NETWORKS]:** Network Architecture and Design - *Network communications, Network topology, Store and forward networks, Wireless communication*.

General Terms

Algorithms, Performance, Design.

Keywords

Vehicular Ad Hoc Networks (VANETs), Multichannel MAC; Vehicle-to-Vehicle communication; Multi-hop communication; QoS; Packets Forwarding.

1. INTRODUCTION

Research on Vehicular Ad Hoc Networks (VANETs) was been spotlighted since 1999 when the U.S. Federal Communication Commission (FCC) allocated the 5.9 GHz channel for Dedicated Short Range Communications (DSRC) to be used exclusively for Vehicle-to-Vehicle (V2V) and Infrastructure-to-Vehicle (I2V) communications. One of the aspects highlighted by the research community is to meet the Quality of Service (QoS) requirements between the safety and the non-safety messages [1]. Indeed, road safety messages are highly time sensitive and should be prioritized compared to other kind of traffic. In order to meet this criterion, a service differentiation mechanism should be included into the MAC (Medium Access Control) layer protocol so as to achieve a timely dissemination of the emergency warning messages. However, even so the Infrastructure mode is more efficient and reliable than the V2V communication scheme, the installation of the base stations in the vehicular networks is not always convenient. Consequently, the communication scheme that allows the timely dissemination of the road warming information should be able to perform in both V2I and V2V multi-hop communications scheme.

The IEEE 802.11p working group has investigating a new PHY/MAC amendment of the 802.11 standard designed for VANETs: the Wireless Access in Vehicular Environments (WAVE). The requirements for this amendment are mostly coming from Vehicular Active Safety concepts where the applications' low latency and the robustness with fast topology changes were a critical aspect of the design. Nevertheless, the 802.11p working mostly failed to meet the QoS requirements defined by the vehicular community. To finally tackle these problems, new research efforts are now focusing on development of a Multi-channel MAC layer technology. With a multi-channel technology several transmissions can occur in parallel over distinct channels. This technique could significantly increase the throughput and potentially reduce the access delay to the medium, but also gives rise to a new distributed scheduling technique that enables the timely distribution of safety messages in a multi-hop communication scheme.

The objective of this paper is to propose a MAC scheme that uses a distributed channel allocation between the vehicles in order to provide a low collision probability and therefore decreasing the transmission time delay. In Section 3, we describe our method for increasing the safety-packets' receiving probability. Section 4 shows the performance results based on simulations. And finally section 5 concludes the paper and presents future directions.

2. RELATED WORKS

Different algorithms and protocols have been proposed for Multichannel MAC in MANETs. In [2], the authors classify and compare between the main multichannel MAC protocols in MANET. Based on their principles of operation, these algorithms can be classified in four groups: 1- Dedicated Control Channel [3, 4, 5], 2-Common Hopping Sequence [6, 7, 8], 3-Split Phase [9, 10], and 4-Parallel Rendezvous protocols [11, 12].

A hopping sequence technique is commonly used for all idle nodes in the second group, while it differs for each node in the fourth group. In both cases, the vehicle switches fast and frequently from one channel to another. If each commutation (switch) lasts about

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80 µs, there is a large period of time wasted. Communications between vehicles should be fast due to their high mobility, and also reliable especially for safety packets. This will not be maintained with high vehicle mobility and frequent channel switching. In conclusion, this technique (hopping sequence) is not efficient and very expensive for vehicle communications in term of wasted time and reliability.

In the first group, two transceivers (one for the data transmission channel and the other is dedicated for the control channel) are used at one host which is expensive in terms of equipments. The third group consists to split the time into 2 phases. The first phase is reserved for the channel negotiation on the default channel, while the second is reserved for data transfer on all channels. This technique can be convenient, but it requires an efficient channel selection mechanism and several adaptations to meet VANET requirements in term of QoS (differentiation between safety and non-safety packets) and mobility. We note that the RTS/CTS mechanism is used in all previous algorithms to establish a communication (control phase). However, an efficient mechanism for safety messages reception is required, and for data channel selection in an opportunistic manner. We can conclude that most of the presented Multichannel MAC algorithms in MANETs do not meet various requirements in VANETs and cannot be applied in V2V communications.

VANETs are a specific case of MANETs. They are distinguished by the hybrid network architectures, the node mobility characteristics, the no power constraint and the geographic position availability. In fact, the high mobility and rapid changing topology of vehicles prevent using most of the MANET MAC algorithms proposed in VANETs. Therefore, many researchers had the importance to develop new algorithms which are specific for VANETs and can meet their different requirements and special characteristics. To the best of our knowledge, few numbers of algorithms were recently proposed for Multichannel MAC in VANETS.

In [13], the authors propose A Multichannel VANET Providing Concurrent Safety and Commercial Services. This paper focuses on meeting the safety and non-safety requirements when an infrastructure is present. They assume that when no infrastructure is present, vehicles can only communicate safety data using one of the present ad-hoc protocols. However, and in a certain regions, it is important to position a mechanism that can maintain the both safety and non-safety data communications when infrastructure is not present (Multi-hop communication). In [14], an adaptive Multi-channel MAC Protocol for Dense VANET Using Directional Antennas is proposed. It relies on synchronization between two radio antennas at each vehicle. The others remained protocols exploit the Clustering concept. In [15], the proposed protocol consists of three core protocols: Cluster Configuration Protocol, Intra-cluster Coordination and Communication Protocol and Inter-cluster communication Protocol. This protocol requests two transceivers on each vehicle. Another Clustering-Based protocol with one transceiver at each node was proposed in [16]. This paper proposes a multi-channel MAC protocol based on cluster head for contention free. The cluster head manages the channel status table of the cluster and periodically broadcasts a CUL (Channel Usage List) in the control channel. Each station transmits an RCA (Request Channel Assignment) to the cluster head to get an allocation of data channel in the control channel [15]. In contrast to the protocol of [15], authors in [16] do not consider the interference between adjacent vehicles in two different clusters. A more efficient protocol, the Media Access Technique for Cluster-Based Vehicular Ad Hoc Networks, was published in [17]. It uses the clustering concept but now with only one single transceiver for each vehicle. It also considers the Intra-Cluster and Inter-Cluster communications. The first one uses a Scheduled-based approach, while the second uses a Contention-based approach. In addition, it maintains the Qos by exchanging safety and non- safety data within the cluster. Each cluster should contain one vehicle as Cluster Head, another as Cluster Forwarder and the remaining vehicles are the Cluster Members.

The idea to use clusters in vehicular environments can be embarrassing with the high mobility of vehicles. The Cluster Head makes the Base station role, but here this "base station" is in high mobility. Consequently, many difficulties can arise due to the high topology variation, starting with the cluster definition and ending with the cluster head (CH) selection. Over and above, the slot reservation made by the CH for the cluster members can cause a wasting time. In addition, the overhead will increase by transmitting packets for synchronization and slot allocation between the different types of members in the same cluster and between two clusters. In conclusion, using a central mechanism for data communication and channel reservation in Vehicular networks is so complex and could be not efficient in several general cases.

3. HYBRID MULTI-CHANNEL MEDIUM ACCES CONTROL

(For more details about this algorithm, the reader can refer to [18]).

The suggested algorithm is applied following two concepts. The first one contributes to use all the available channels in allocation between the vehicles in a manner providing a low data collision probability and therefore decreasing the transmission time delay. This is considered as a "Hybrid Multi-channel Allocation". Furthermore, if a safety message is generated by a neighboring vehicle in the safety channel while the transceiver is downloading a movie in a service channel, it will miss the message. Thus, increasing the safety-packet receiving probability during non-safety packet transmission is the objective of the second concept which is the "Periodic Transmission Chain".

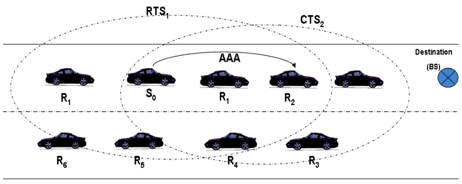

Figure 1: An example of communication establishment and forwarder selection

Our algorithm relies on the availability of the geographic position provided by a GPS receiver. It is assumed that all the data are forwarded to a destination with a defined position, for example the nearest base station to the sender. There are two types of channels: 1- The Control Channels (CCH) where the vehicles can exchange their signalling packets (RTS-CTS-AAA) and diffuse their Safety-Packets (Urgent-Packets) in case the vehicles are in Free State (idle). The RTS/CTS mechanism is used to establish a communication between two vehicles (Cf. Fig. 1). A third control packet, AAA (Acceptance And Allocation) packet, is used in order to inform all the neighbor vehicles about a settled communication and therefore a channel occupation for a period of time. 2- All the remaining channels are the Traffic Channel (TCH) where the data/ACK packets are exchanged. On these channels, vehicles can transmit their non-Safety Packets (Data Packets). Also, vehicles that are in Active Sate and receive Safety-packets can diffuse these packets using TCHs. Note that some neighbors that are being transmitting on other channels may not being hearing the control channel.

3.1 Periodic Transmission Chain

During data transmission, active vehicles are classified in 3 groups. The first one (the source) has all the data to transmit. It begins its transmission to the second group (the forwarder) when they are both listening to the same transmission channel. The forwarder, when it receives a data sequence, it periodically transmits it to another vehicle at the same time when the source listens to the control channel. This vehicle can be in the same group or from the third group (the temporarily destination). The time for these 3 groups is divided into 2 phases: transmission and listening.

The sender sends a sequence of its data in the first phase using the transmission channel and listens to the control channel in the second phase. The destination receives packets from the transmission channel during the first phase and listens to the control channel during the second phase. The second group receives data from the transmission channel during one phase and transmits its data in another transmission channel during the other phase (Cf. Fig. 2). The source switches periodically between the transmission channel and the control channel and that for three reasons. Firstly, the source can know if there are safety packets transmitted on the control channel by its neighbors. Secondly, if any neighbor sends any AAA beacon, the source can update its Allocation List (AL). The third reason is that the source, after listening to the control beacons between its neighbors, will be able to warn the latter to change their pre-selected transmission channel if it knows that this channel will be busy in this time period.

Note here that we can have many vehicles in the second group, and then the sequence of vehicles have this form: 1-2-2'-2''...-3. After receiving all the data packets, the temporarily destination (group3) becomes a source and restarts the same process of data forwarding to join the really destination or the Base Station. This is what we called "Periodic Transmission Chain". The aim of this 'Chain' is to save time when a sender switches to the control channel. In fact, another vehicle (forwarder) profits from this time to transmit its data.

3.2 Hybrid Multichannel Allocation

In this concept, it is required to avoid the rising broadcast storm problem [19] or packets collision probability between vehicles. To do that, no information gathering is done between vehicles if no data transmission is needed.

3.2.1.1 Channel Allocation

We can define many methods for a vehicle to select its transmission channel. The first method is by listening to the TCHs for a determined time (it must be larger than the transmission period in any cycle) and selecting a free channel for transmission. This method is expensive in terms of time. The second one (Opportunistic) is by choosing a TCH without having listened to the transmission channel. If the chosen channel is occupied, then the vehicle moves to another one (the vehicle can know if the channel is occupied by using the Packet Error Rate and the Acknowledgments transmitted by the receiver).

Our proposed method consists to select the channel in a hybrid manner without listening to the transmission channels (Deterministic + Opportunistic). In this method, the vehicles path is divided in several geographic consecutive numbered zones (Z_1 to Z_n). When a vehicle enters into a geographic zone, it begins calculating the stay time in this zone (Ts). In Free State, the vehicle listens to CCH and knows by the beacon packets (exchanged between the sender and the receiver(s)) the occupied channels in this zone and their occupation periods. This information will be stored in a list, called Allocation List (AL). If the vehicle wants to transmit, it tests Ts:

- If Ts > threshold (the vehicle has remained an important time in this zone), then it chooses a free transmission channel from its Allocation List (AL). This phase is 'deterministic' in the sense that the vehicle selects a non-occupied channel by only listening to the beacons of the CCH.

- If Ts < threshold, so it means that the vehicle arrived newly in this zone and did not have enough time to hear the CCH and construct its Allocation List. Therefore, it chooses the standard transmission channel for this zone for a defined period of time, using the Allocation Table (AT) (which will be described in the next section).

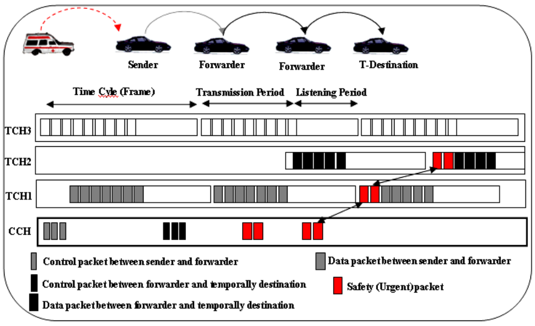

Figure 2: Data communication between different vehicle groups during the Periodic Transmission Chain

This phase is opportunistic because the vehicle picks a channel that is not certainly free, but it has an important probability to be free. In any case, if a chosen channel is occupied (can be known by receiver's acknowledgments), the vehicle chooses the next standard channel according to the distribution of the channels by zones and channels priority in each zone. After selecting a channel, the sender diffuses its RTS packet including the number of its future transmitting channel. The receiver, after receiving this packet, checks its Allocation list and responds to the sender by a CTS packet stating if the selected channel is occupied or not.

3.2.2 Allocation Table

Table 1: Example of Allocation table for vehicles moving in the same direction

Zone\AP	AP_1	AP_2	AP_3	AP_1	..
Z_1	C_1	C_2	C_3	C_1	..
Z_2	C_2	C_3	C_1	C_2	..
Z_3	C_3	C_1	C_2	C_3	..
Z_1	C_1	C_2	C_3	C_1	..
Z_2	C_2	C_3	C_1	C_2	..
Z_3	C_3	C_1	C_2	C_3	..
..	..	..	..	..	

Every route is divided in N-1 geographic area (Z_1 to Z_{N-1}). Each time zone has N-1 different Allocation Periods that repeat themselves repetitively (AP_1 to AP_{N-1}). If we have N=4 Channels (1 CCH, 3 TCH), the period is N-1=3. It is important to note that this Allocation Table (Table 1) is suitable for vehicles with the same direction. Vehicles with opposite directions use the same table but right-rotated for one step. According to this right-rotation, two vehicles, arriving to the same zone and during the same TP but in the opposite directions, can transmit their data without collision and using different channels.

3.2.2.1 Different Zones, Same time

For example (Cf. Fig. 3), in low traffic density and at time t=AP_1, the vehicle V_1 moves into the zone Z_n and communicates with V_2 over the Channel C1 by using the Allocation Table. If at the same time, a vehicle V_3 in the zone Z_{n+1} wants to communicate with V_4 without listening to V_1-V_2 communication on C_1, then according to the Allocation Table, it chooses the channel C_2 in priority. By this way, we will not have interference between V_2 and V_3.

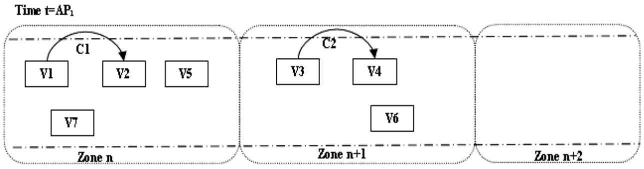

Figure 3: An example of Channel Allocation for two vehicles in different zones and at the same time

3.2.2.2 Same Zone, Different time

After a time delay (between AP_1 and AP_2), if at the same time when V_1 is still transmitting its data to V_2 over the channel C1, a vehicle V_0 enters into the zone Z_n and wants to transmit its data, then according to the AT, V_0 chooses the channel C_2 that has a high probability to be free, and so no collision will occur between V_0 and V_1, or even between V_0 and V_3 (Cf. Fig. 4).

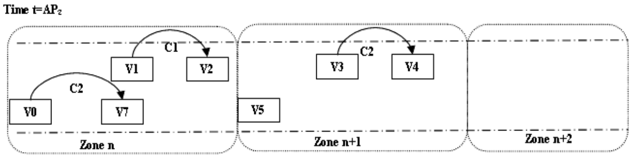

Figure 4: An example of Channel Allocation for two vehicles in different zones and at the same time

3.2.2.3 Different Zones, Different time

The same as in the previous section, but in this case V1 and V0 are in different Zones. Using the AL, while V1 using C1, V0 selects C3 and no collision occurs.

3.2.2.4 Same Zone, Same time

If we have two vehicles V_0 and V_1 wanting to send their data at the same time and in the same zone, the probability that the channel allocation can be managed by the RTS/CTS mechanism is very high. The vehicles in the same zone and at the same time listen to the communications on CCH between them, and then these vehicles share the transmission channels between them temporarily (seems as TDMA). As mentioned before, each vehicle communicates with the farthest vehicle. This fact minimizes the probability to have two vehicles communicating on the same channel and in the same zone.

For the channel selection, we performed simulations having three TCHs and one CCH. The simulation parameters are limited to the road traffic density in a certain zone and during a certain time. We took two scenarios having a normal and high road traffic density. The figures 6 and 7 show the performance of the algorithm in terms of collision probability at the beginning of data transmission for a normal and high road traffic density respectively. Note that the vehicle density in a zone is considered to be low at the beginning of the two scenarios.

4. PERFORMANCE EVALUATION

Our algorithm performance is evaluated using MATLAB. Two scenarios are taken for a highway model in order to study the motivation of the two parts in our algorithm.

It is evident that transmitting the data in many periods gives the sender more chance to listen to CCH and receive the urgent packets that are sent on this channel. In contrast, this decreases the channel capacity due to the frequent switches (between CCH and TCH) that cannot be done instantly. The figure 5 shows the probability to not receive urgent packets (sent on the CCH) in the same time where the vehicle transmits its data on a TCH. We can see that when the transmission period duration (X-axis) is short, the probability to receive urgent packets during data transmission is high. For the transmission delay, it is easy shown that it's the same in the case of permanent data transmission (without listening period). We have no time wasting due to the fact that we have several communications for the same data and in periodic manner.

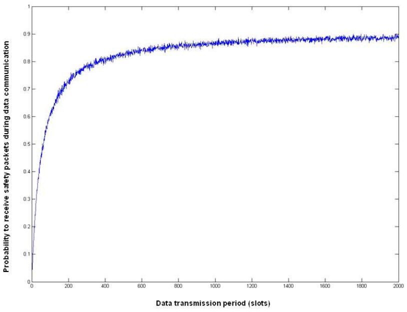

Figure 5 : Variation of the probability to have safety packets arriving at the same time of transmission period when the last increases.

The vehicles transmit data packets using exponential inter-arrival times. Compared to the single channel MAC, our algorithm decreases the collision probability between several data communications of many vehicles in the same zone. It is evident that the collision probability decreases when more channels are available. We can see that this collision probability remains low and stands to be constant with normal road traffic (Cf. Fig. 6). For a high traffic density, it is evident that the probability to select an occupied channel in a zone will increase since the number of vehicles increase. But, it is more probable that the neighbor vehicles benefit from their Allocation Lists and therefore the collision probability is expected to remain in a low range (Cf. Fig. 7).

5. CONCLUSION

In this paper, we focused on the Multichannel Mac mechanisms and their specifications in VANETs. We showed that most of the MANETs algorithms are not suitable to be used in vehicular networks. Different Multichannel algorithms proposed for VANET are also listed. Most of them do not meet the safety and non-safety requirements and the high topology variation. Our HMM-MAC algorithm defines two new concepts: ‘Hybrid Multi-channel Allocation’ and ‘Periodic Transmission Chain’. The first concept is an opportunistic method in the sense that it may choose a channel that is already used by other couple of nodes but it tries to exploit at the maximum the exchanged reservation signaling to minimize the conflict probability. It proposes also a kind of synchronization between the nodes on a route allowing some of them to transmit data when the others listen to the control channel. The second concept ensures a high probability for a vehicle to receive and retransmit the high priority traffic. Future Work will include a further improvement of our protocol by the use of a real network and traffic simulator, and within extensive traffic models and environment scenarios.

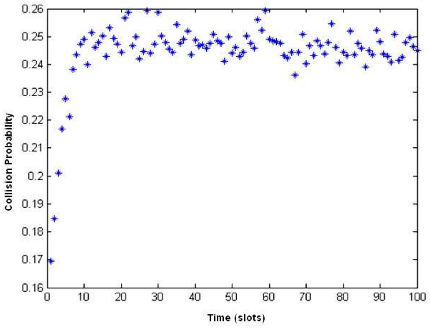

Figure 6: Probability to select an occupied channel in a zone during a time period of lightly load traffic

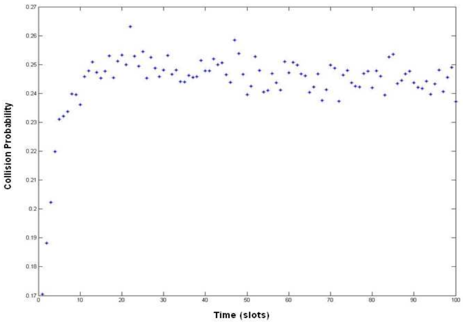

Figure 7: Probability to select an occupied channel in a zone during a time period for a highly loaded traffic

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