VANETs 내 효율적이고 적응 가능한 하이브리드 멀티 채널 멀티 홉 MAC 프로토콜
(An Efficient and Adaptable Hybrid Multi-channel Multi-hop MAC Protocol in VANETs)

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요 약 차량과 관련된 애드혹 네트워크(VANETs)는 교통사고를 줄이고 안전을 향상시키는 등 운송 효율을 개선하기 위해 설계되었으며. 또한 VANETs는 차량 간의 또는 차량과 인프라 간의 정보를 전송하고 교환하기 위해 만들어졌다. VANETs의 경우, 효율적인 브로드캐스트 서비스를 제공하는 데 쓰이는 MAC 프로토콜은 차량과 공급자 간의 두 차 정보를 효율적으로 공유하기 위해 설계되었다. 최근 하이브리드 MAC 프로토콜은 QoS를 향상시키고 공평하게 분배하기 위해 TDMA 및 CSMA 기반 메커니즘을 단일 메커니즘으로 결합하였 다. 본 논문에서는 우리는 EAHMAC 프로토콜이라 불리는 효율적이고 적응 가능한 하이브리드 멀티 채널 멀티 홉 MAC 프로토콜을 제안한다. EAHMAC 프로토콜은 차량이 두 개의 환경의 정보를 기반으로 유연하게 방식으로 타임 슬롯을 점유하고 브로드 캐스트 패킷 역시 점유할 수 있게 한다. 시뮬레이션 결과는 우리의 제안이 기존 프로토콜보다 액세스 충돌 비율, 패킷 전달 비율 및 서비스 제공 방식에서 우수한 결과를 보여주었다.

키워드: VANET, MAC, QoS, hybrid multi-channel

Abstract  Vehicular Ad-hoc NETworks (VANETs) are designed to improve transportation efficiency such as to increase safety and reduce traffic accidents. In addition, VANET is created to connect and exchange information between vehicles or between vehicle and infrastructure. For VANET, Medium Access Control (MAC) protocols, which provide an efficient broadcast service, are designed to efficiently and fairly share the wireless medium between vehicles and providers. Recently, the hybrid MAC protocol was designed to combine TDMA- and CSMA-based mechanisms into a single mechanism to improve the Quality of Service (QoS) and decrease the collision rate. In this paper, we propose an Efficient and Adaptable Hybrid Multi-channel Multi-hop MAC protocol in VANETs, called the EAHMAC protocol, which allows vehicles to not only occupy time slots but also to broadcast packets in a flexible way based on the two-hop neighbor’s information. The simulation results show that our proposal outperforms the existing protocols in terms of access collision rate, packet delivery ratio, and throughput on the service channel.

Keywords: VANET, MAC, QoS, hybrid multi-channel
1. Introduction

Vehicular ad-hoc network (VANET) is designed for the moving vehicle to create the mobile network. To improve the transportation, VANETs can provide three main applications: safety-related applications, traffic management, and user-oriented services, as shown in Table 1 [1,2]. First, safety-related applications, such as the pre-crash sensing, blind spot warning, emergency electronic brake light, and cooperative information broadcast require that each vehicle periodically broadcasts information about its position, speed, heading, acceleration, and so on, to all vehicles within its one-hop neighborhood. Second, traffic management applications form part of a greater intelligent transportation system (ITS) and include toll collection, intersection management, cooperative adaptive cruise control and detour or delay warning. Third, user-oriented services provide information, advertisements, and entertainment for users during their journey. They have two basic applications: Internet connectivity and peer-to-peer applications [1]. However, safety services require fast and guaranteed access and a short transmission delay, while user-oriented services need a broad bandwidth at the same time.

Medium access control (MAC) plays a role to satisfy these requirements. Various MAC protocols are proposed to improve the performances of applications such as throughput, packet delay, packet loss ratio, based on either Time Division Multiple Access (TDMA) or Carrier Sensing multiple access (CSMA). CSMA-based MAC protocols allow a vehicle to randomly access the channel when they need to broadcast without predetermination. However, CSMA-based MAC protocols cannot guarantee the Quality of Service (QoS). On the other hand, TDMA-based MAC protocols need a predetermined channel access schedule to access the channel without any collisions. Especially, hybrid MAC protocols, which are designed by combining TDMA and CSMA access channel method into the single architecture, can improve the QoS and reduce the packet collision. Hybrid MAC protocols consist of two periods: the TDMA-based period called reservation period (RP), and the CSMA-based period called contention period (CP), as shown in Fig. 1. Each vehicle must occupy a one-time slot in RP to broadcast its packet even though it does not have data to transmit.

In hybrid MAC protocols, one issue is known as access collisions which are defined that when more than two vehicles attempt to access the same time slots. In HER–MAC [4], new vehicles attempt to broadcast HELLO packets in CP. If all its one-hop neighbors confirm its ID and the reserved time slot, a new vehicle successfully occupies a time slot. However, the packet loss ratio of HELLO packet increases when the vehicle density is high. On the other hand, in DMMAC [5] and HTC–MAC [6] protocols, new vehicles randomly choose the available time slots or virtual time slots [5] to broadcast HELLO packets. Nevertheless, if there is no available time slot, the author did not study in HTC–MAC. In DMMAC, there are waste time slots since virtual time slots are included in the length of time slots in CP even though there is no new vehicle entering the topology.

<table>
<thead>
<tr>
<th>Applications</th>
<th>Packet size / Bandwidth</th>
<th>Latency (ms)</th>
<th>Network Data Type</th>
<th>Application Range (m)</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection Collision Warning/Avoidance</td>
<td>100 bytes</td>
<td>100</td>
<td>Event</td>
<td>300</td>
<td>Safety of life</td>
</tr>
<tr>
<td>Cooperation Collision Warning</td>
<td>100 bytes/10 Kbps</td>
<td>100</td>
<td>Periodic</td>
<td>50-300</td>
<td>Safety of life</td>
</tr>
<tr>
<td>Work Zone Warning</td>
<td>100 bytes/1 Kbps</td>
<td>1000</td>
<td>Periodic</td>
<td>300</td>
<td>Safety</td>
</tr>
<tr>
<td>Transit Vehicle Signal Priority</td>
<td>100 bytes</td>
<td>1000</td>
<td>Event</td>
<td>300-1000</td>
<td>Safety</td>
</tr>
<tr>
<td>Toll Collections</td>
<td>100 bytes</td>
<td>50</td>
<td>Event</td>
<td>15</td>
<td>Non-Safety</td>
</tr>
<tr>
<td>Service Announcements</td>
<td>100 bytes/2 Kbps</td>
<td>500</td>
<td>Periodic</td>
<td>0-90</td>
<td>Non-Safety</td>
</tr>
<tr>
<td>Movie Download</td>
<td>&gt; 20Mbps</td>
<td>NA</td>
<td>NA</td>
<td>0-90</td>
<td>Non-Safety</td>
</tr>
</tbody>
</table>
During the contention period, the senders broadcast the Wireless Access in Vehicle Environments (WAVE) Service Announcement (WSA) packets and piggyback with service information and SCHs to be used. For efficient WSA packets transmission, DMMAC allows vehicles can exchange WSA/ACKnowledge-ment (ACK)/RESPonse (RES) packets before the end of the length of the RP. In DMMAC, the sender and receiver based on their one-hop information decide the time to exchange packets. Moreover, DMMAC cannot provide the parallel transmission between vehicles in three-hop neighbors.

In this paper, we propose an adaptable time slot acquisition scheme and flexible broadcast WSA packet mechanism for hybrid MAC protocol in VANETs, called EAHMAC protocol. Our proposal based on multi-hop neighbor information allows vehicles to occupy time slots or broadcast WSA packets faster than the existing MAC protocols.

The rest of this paper is organized as follows. In Section 2, we present the adaptable time slot acquisition scheme. Section 3 presents flexible broadcast WSA packet mechanism. Section 4 provides the simulation results and Section 5 concludes the paper.

2. Adaptable time slot acquisition

In hybrid MAC protocol, each vehicle has to tune to control channel interval (CCHI) to collect one-hop neighbor’s information. Especially, each node must acquire exactly one time slot in RP. Once a node acquires a time slot, it keeps accessing the same slot in all subsequent. Each vehicle broadcasts a HELLO packet during its reserved time slot. A HELLO packet is created into seven fields according to EFAB [7] protocol: (i) Identifier (ID), (ii) a reserved time slot, (iii) Length of map of one-hop neighbors (OH), (iv) OHNM: The bitmap of time slots used by one-hop neighbor, (v) THNM: The bitmap of time slots used by two-hop neighbors, (vi) Suggestion Field (SF), and (vii) high priority safety application, as shown in Fig. 4.

When a new vehicle, x, is entering to network, it must listen to one duration of RP to collect x’s one-hop neighbor’s information. If there are available time slots, vehicle x will randomly choose one available time slot and broadcast its HELLO packet, as shown in Fig. 2. Otherwise, if there is no available time slot, vehicle x will attempt to broadcast HELLO packet during CP, as shown in Fig. 3. After all one-hop neighbors confirm its ID and reserved time slot, it successfully occupies a time slot in RP. Our proposal can be shown in Fig. 5.

For instance, we consider the scenario shown in Fig. 4. A vehicle, x, is entering the network. After one duration of SI, vehicle x collects its one-hop neighbor’s information, vehicle c, node c’ one-hop neighbors information, \(X_c = \{d, e\}\), and length of the reservation period. Based on this information, we classify into two cases: case 1) there are available time slots, and case 2) there is no available time slot. In case 1, node x will choose one available time slot, #4 and broadcast its packet including its ID and #4 into SF filed during time slot #4. Otherwise, node x will broadcast HELLO packet including its ID and #4 into SF field. If node c confirms x’ ID and #4 into SF
field in c’ HELLO packet, node x successfully occupied time slot #4. Note that, in case 2, in HELLO packet, node c will increase the length of reservation period and broadcast this information to c’ one-hop neighbors, as shown in Fig. 4.

3. Flexible WSA packet transmission

One issue is known that a pair of sender and receiver have to wait until the end of the length of reservation period and then, they will exchange WSA/ACK/RES packets. It makes the system waste throughput. In this section, we propose a new WSA packet transmission scheme to improve the throughput on SCHs.

**Rule 1:** For a node x, it receives all packets including their OHMs transmitted by its OH. The length of THNM (LTHN), \( \bar{L} \), is given

\[
\bar{L} = \max_{x} \left( \frac{L}{j} \right), \quad \forall j \in N_x
\]

**Rule 2:** Among one-hop neighbors set, the sender
The length of two-hop neighbors is computed following Rule 1. For instance, in Fig. 6, the length of THNM for each node is computed as 

\[ L^{(WSA)} = \max \left( \sum_{a, b, c, d, e, f, g, h} L^{(2)} \right) \]

(3: 3; 5: 5; 5: 4; 3). If nodes \( d \) and \( e \) want to exchange WSA/ACK/RES packets, they have to wait for \#5 time slots of RP. If nodes \( a \) and \( b \) have data to transmit, since \( L = 3 \) for \( a \) and \( L = 3 \) for \( b \), they will transmit packets after \#3 time slots of RP according to Rule 10. Especially, our scheme allows transmitting parallel packets. If nodes \( g \) and \( h \) want to transmit data, because of \( L = 4 \) for \( g \) and \( L = 3 \) for \( h \), according to Rule 2,
node $g$ transmits WSA packet to $h$ after #4 time slots of RP, as shown in Fig. 7.

During the contention period, service providers broadcast WSA packets and piggyback with service information and the identities of SCHs to be used. Nodes that the service can optionally respond to the WSA packet with an acknowledgment (ACK) and the sender will broadcast Respond packet (RES) to eliminate the exposed terminal problem. Furthermore, a service user can send a request for service (RFS) packet to make an agreement with a service provider. After the end of the CCH interval, nodes tune to certain SCHs to transmit service packets. As shown in Fig. 8, the operation of flexible WSA packet transmission as follows.

1) The cluster head will broadcast the length of contention period, OPL. All members store this value to reduce the length of CCH.

2) At the end of the time slot in reservation period or the time slot following condition Rule 2, service providers broadcast WSA packets and piggyback with service information and the identities of SCHs to be used.

3) After the end of the OPL, nodes tune to certain SCHs to transmit service packets.

4. Performance Evaluation

To validate our model, we use NS-2 and SUMO. The values of the parameter are summarized in Table 2 to obtain the numerical result for the analytical model.

First, in Fig. 9, the packet delivery ratio (PDR) of WSA packets in our proposal is higher than HER-
MAC and DMMAC. New vehicles can occupy the time slots in a flexible way and hence, the collision of packets in contention period is decreased in our proposal. The PDR between our proposal and DMMAC is approximate since the DMMAC has the virtual time slots for new vehicles. But, the length of reservation period is greater than our proposal. In HER-MAC, the collision is high because there are many types of packets transmitted during the contention period.

Second, in Fig. 10, the access collision in our proposal is lower than HER-MAC and DMMAC. Our proposal not only reduces the length of reservation period but also supports a flexible way of occupying time slots.

The flexible WSA transmission scheme is used to improve the throughput on SCHs. We compare between our proposal, DMMAC, and HER-MAC in terms of throughput on SCHs. We set up the packet arrival rate is 5 Packet in each SI (PSI) and 50 PSI, as shown in Fig. 11. In low packet arrival rate, 5PSI, when the number of nodes increases, the throughput decreases because of increasing collisions between data traffic. In HER MAC, in contention, there are three types of packets transmitted as HELLO packet, SWITCH packet, and WSA/ACK/RES packets. Hence, the collision is high. In DMMAC, there are virtual slots for avoiding potential collisions caused by synchronous. In addition, during the contention period, nodes exchange WSA/ACK/RES packets and hence, the throughput on SCHs in DMMAC is higher than HER-MAC. On the other hand, our proposal not only reduces the length of RP faster than DMMAC and HER-MAC but also provide our adaptive WSA transmission scheme. The throughput employing our proposals is higher than both DMMAC and HER-MAC, as shown in Fig. 11. In high vehicle density, the throughput employing our proposals is higher than DMMAC because the adaptive WSA transmission scheme allows nodes can parallel transmit WSA packets. As high packet arrival rate, the collision is high. When the number of nodes increases, the length of RP is also increased. There are many WSA packets transmitted during the contention period. Consequently, throughput on SCHs is very low. However, throughput employing our proposal is higher than both DMMAC and HER-MAC, as shown in Fig. 11.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data rate</td>
<td>12 Mbps</td>
<td>ACK</td>
<td>14 bytes</td>
</tr>
<tr>
<td>WSA</td>
<td>100 bytes</td>
<td>RES</td>
<td>14 bytes</td>
</tr>
<tr>
<td>Slot time σ</td>
<td>13 μs</td>
<td>SIFS</td>
<td>32 μs</td>
</tr>
<tr>
<td>Propagation time δ</td>
<td>1 μs</td>
<td>DIFS</td>
<td>58 μs</td>
</tr>
<tr>
<td>λs</td>
<td>25 pkt/s</td>
<td>Wo</td>
<td>16</td>
</tr>
</tbody>
</table>

Fig. 9 Packet delivery ratio

Fig. 10 The rate of access collision

Fig. 11 Throughput on SCHs versus number of nodes
In another case, we fix the number of nodes is 50 nodes and vary the number of packet arrival rate, as shown in Fig. 12. During the contention period, there are 3 types of packets transmitted as HELLO, SWITCH, WSA/ACK/RES packets in HER-MAC. The throughput employing HERMAC is lowest than DMMAC and our proposal and it is zero when packet arrival rate is greater than 20 PSI. In lower packet arrival rate, DMMAC and our proposal are approximately from 0 to 25 PSI. From 25 PSI to 45 PSI, our proposal outperforms DMMAC because it is applied the optimal contention period and the adaptive WSA transmission scheme. In large packet arrival rate, 50PSI, because there are many collisions between WSA packets, DMMAC and our proposal are approximate, as shown in Fig. 12.

5. Conclusion

In this paper, we propose a novel scheme for time slot acquisition in hybrid MAC protocol and a flexible WSA transmission mechanism. This scheme not only allows that a new vehicle randomly chooses an available time slot but also broadcasts HELLO packet when there is no available time slot. In addition, the sender and receiver can exchange the WSA/ACK/RES packets in a flexible way based on the two-hop neighbor’s information. Our proposal allows parallel WSA packets transmission to improve the throughput on SCHs. The simulation results show that our proposal outperforms HER-MAC and DMMAC in terms of packet delivery ratio, the access collision rate, and throughput on SCHs.

References


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