Research on Access Control Mechanism of Multiple Channels in Vehicular Ad-Hoc Network

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Abstract. In IEEE802.11p protocol, multiple channels are assigned to Vehicular Ad-hoc network (VANET), the licensed spectrum of 5.850GHz-5.925GHz is divided into one control channel (CCH) and six service channels (SCHs). So that the mechanism of channel access control has great influence on communication efficiency of VANETs. We propose a channel access control mechanism, which integrates channel reservation algorithm with contention-based Distributed Coordination Function (DCF) and contention-free Time Division Multiplexing Access (TDMA) to coordinate channels’ access between CCH and SCHs. The analysis results show that the proposed mechanism not only can dynamically adapt network load conditions, but gives consideration to communication efficiency both in CCH and SCHs, high throughput can be obtained even in heavy load VANETs.

1. Introduction

Vehicular Ad-Hoc network (VANET) is a new application field of Ad-Hoc networks which attracts extensive attention in Intelligent Transportation System (ITS). VANET can provide On Board Unit (OBU) to OBU as well as OBU to Roadside Unit (RSU) wireless communications, so that OBUs can exchange messages not only with other OBUs in the same VANET, but also transportation management center in real time. As the important component of ITS, VANET is a feasible approach to improve the efficiency of ITS [1].

As the part of Wireless Access in Vehicular Environments (WAVE) protocol stack, IEEE802.11p is a standard of Medium Access Control (MAC) layer and physical layer. In MAC layer, licensed spectrum of 5.850GHz-5.925GHz is divided into seven wireless channels, including one control channel (CCH) for transmitting traffic related messages and six service channels (SCHs) for transmitting various application messages. In physical layer, 64 sub-carriers Frequency Division Multiplexing (OFDM) technique is employed to provide data transmission rate of 3M bit/s up to 27 Mbit/s. Because IEEE802.11p VANET applies multiple channels to transmit large amount of messages in ITS, the channel access control mechanism has great influence on communication efficiency of VANETs [2-4].

We propose a channel access control mechanism for IEEE802.11p VANET, in which channels’ access time is segmented into three periods to transmit different packets, including channel reservation period, control packet period and service packet period. In order to maintain higher channel utilization, the duration time of control packet period and service packet period can be dynamically adjusted according to the load conditions in CCH and SCHs. Furthermore, our scheme integrates channel reservation algorithm with contention-based Distributed Coordination Function (DCF) and contention-
free Time Division Multiplexing Access (TDMA) to coordinate channels’ access between CCH and SCHs.

2. Access Control Mechanism of Multiple Channels in VANET

The method of channel coordination between CCH and SCHs is shown in figure 1. Channels’ access time is divided into different synchronizing cycles, each synchronizing cycle contains three time periods: channel reservation period for reserving channels through SCHs, control packet period for transmitting control packets through CCH, service packet period for transmitting service packets through SCHs. The duration time of control packet period $T_{CP}$ and service packet period $T_{SP}$ can be dynamically adjusted by

$$T_{CP} = \frac{N_{RC} \cdot L_{CP}}{V}$$  \hspace{1cm} (1) $$
$$T_{SP} = \frac{N_{RS} \cdot L_{SP}}{6V}$$  \hspace{1cm} (2)

In above formulas, $V$ is data transmission rate, $N_{RC}$ is the number of OBUs successfully reserving CCH during channel reservation period, $N_{RS}$ is the number of OBUs successfully reserving SCHs during channel reservation period, $L_{CP}$ is average length of control packets, $L_{SP}$ is average length of service packets.

![Figure 1](image-url)

Figure 1. The method of channel coordination between CCH and SCHs

The process of channel reservation algorithm is described in algorithm 1.

|Algorithm1: channel reservation algorithm executed by RSU during channel reservation period. |
|---|
//CCRP: request packet of control channel reservation  
//SCRP: request packet of service channel reservation  
//CCAR: one-dimensional array for storing control channel allocation result  
//SCAR: two-dimensional array for storing service channel allocation result  

When channel reservation period begins:  
$N_{RC}=0; N_{RS}=0;  
T_{CR}$=time length of channel reservation period;  
$T_{CR}$ timer starts;  
do while $T_{CR}\not=0$  
{ OBUs send CCRP or SCRP to RSU through six SCHs;  
if receiving CCRP: $N_{RC}=N_{RC}+1;  
if receiving SCRP: $N_{RS}=N_{RS}+1; }
calculating \( T_{CP} \) according to formula (1);
calculating \( T_{SP} \) according to formula (2);
calculating CCAR and SCAR;
broadcasting CCAR and SCAR to all OBUs at the end of channel reservation period through CCH;

During control packet period:
permitted OBUs sending control packets at the assigned time-slots through CCH;

During service packet period:
permitted OBUs sending service packets at the assigned time-slots through SChs.

In our mechanism, different channel allocation methods are used in three periods. To satisfy high randomness of channel access request packets, contention-based DCF is used in channel reservation period. In order to maintain high channel utilization in heavy load VANETs, contention-free TDMA is provided during subsequent control packet period and service packet period.

During channel reservation period, OBUs want to transmit packets must send control channel request packet (CCRP) or service channel request packet (SCRP) to RSU through six SChs. When receiving channel access request packet, RSU assigns sub-channels (that is TDMA time-slots) to required OBUs according to the load conditions in CCh or SChs. At the end of channel reservation period, RSU broadcasts CCAR packet and SCAR packet to all VANET members through CCh, which contain channels’ allocation results and time lengths of packet periods. During subsequent control packet period and service packet period, permitted OBUs may transmit packets through assigned TDMA time-slots.

For example, suppose \( N_{RC}=8, N_{SC}=35 \), a feasible allocation scheme of CCh and SChs is

\[
CCAR = [3, 6, 1, 7, 4, 2, 8, 5]
\]

\[
SCAR = \begin{bmatrix}
1, 28, 19, 11, 6, 34 \\
35, 7, 18, 29, 16, 13 \\
9, 30, 2, 24, 31, 10 \\
\cdot, 12, 20, 8, 3, 33 \\
15, 4, 21, 14, 17, 26 \\
23, 32, 27, 22, 25, 5
\end{bmatrix}
\]

The elements in above arrays denote number of permitted OBUs. At last, the time-slots assigned to OBUs during control packet period are as shown as figure 2 (a), the time-slots assigned to OBUs during service packet period are as shown as figure 2 (b).

(a) The time-slots assigned to OBUs during control packet period

(b) The time-slots assigned to OBUs during service packet period

**Figure 2.** The time-slots allocation results
3. Performance Analysis of Channel Access Control Mechanism

3.1. Performance Analysis Method
Considering that the length of channel reservation packet is much smaller than control packets or service packets, basic access mechanism of DCF is applied during channel reservation period, meanwhile, CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) algorithm is performed to reduce collision probability in wireless channels [5]. The values of CSMA/CA parameters are as shown in table 1, which refers to IEEE802.11b protocol of WLAN [6].

| Parameter            | Value       | Parameter            | Value       |
|----------------------|-------------|----------------------|-------------|
| PHY header           | 192μs       | ACK length           | 112 bit     |
| MAC header           | 272 bit     | \( CW_{\text{min}} \) | 8           |
| SIFS                 | 28μs        | Maximum of back off stage \( (m) \) | 5           |
| DIFS                 | 128μs       | Propagation Delay \( (\delta) \) | 1μs         |
| CSMA/CA slot time \( (\sigma) \) | 20μs       | Data Rate \( (V) \) | 6M bit/s    |

During channel reservation period, the normalized channel utilization rate can be calculated by [7, 8]

\[
U = \frac{P_s P_r (L_{\text{RP}} / V)}{(1 - P_r) \sigma + P_s P_r T_s + P_r (1 - P_s) T_c}
\]  

(3)

In formula (3), we have

\[
\tau = \frac{2}{1 + CW_{\text{min}} + pCW_{\text{min}} \sum_{j=0}^{n-1} (2p)^j}
\]

(4)

\[
p = 1 - (1 - \tau)^{n-1}
\]

\[
P_s = \frac{n\tau(1 - \tau)^{n-1}}{1 - (1 - \tau)^{n}}
\]

\[
P_r = 1 - (1 - \tau)^{n}
\]

\[
T_s = \text{PHY header} + \text{SIFS} + \text{DIFS} + 2\delta + (\text{ACK length} + \text{MAC header} + L_{\text{RP}}) / V
\]

\[
T_c = \text{PHY header} + \text{DIFS} + \delta + (\text{MAC header} + L_{\text{RP}}) / V
\]

(5)

In above formulas, \( n \) is the number of VANET nodes, \( p \) is collision probability in CSMA/CA slot time, and \( \tau \) is probability of OBU sending channel reservation packet, \( T_s \) is average packet transmission time, \( T_c \) is average channel collision time, \( P_r \) is probability of OBU transmitting packets, \( P_s \) is probability of OBU successfully sending packets.

Furthermore, let \( P_{\text{CR}} \) be average rate of OBU sending CCRP, \( P_{\text{SR}} \) be average rate of OBU sending SCRP, \( L_{\text{RP}} \) be the length of CCRP and SCRP, \( S_{\text{CP}} \) be throughput of control packet period, \( S_{\text{Sp}} \) be throughput of service packet period, we have
\[ \beta = \frac{P_{CR}}{P_{CR} + P_{SR}} \]

\[ N_{RC} = \frac{6U \cdot T_{CR} \cdot V}{L_{RP}} \cdot \beta \]

\[ N_{RS} = \frac{6U \cdot T_{CR} \cdot V}{L_{RP}} \cdot (1 - \beta) \]

\[ S_{CP} = N_{RC} \cdot L_{CP} \text{ (bit)} \]

\[ S_{SP} = N_{RS} \cdot L_{SP} \text{ (bit)} \]

### 3.2. Analysis Results and Discussion

We calculate performance indicators in vary VANET conditions to verify our channel access mechanism. Figure 3 shows throughputs in control packet period and service packet period under different packet length and the number of OBUs. It is clear that our scheme can obtain high throughput in CCH and SChs even in heavy load status, but the throughput decrease with increasing of the number of OBUs.

Table 2 shows duration time of packet periods in different packet length and the number of OBUs, it can be observed that:

1. The duration time of packet periods increases with packet length, so that transmission time of packets can be guarantee adequately.

2. The duration time of packet periods decreases with increasing of the number of OBUs. It because that the increase of channels’ collision probability leads to less BOUs can successfully reserve channels, so that duration time of control packet period and service packet period decreases to ensure channel utilization in CCH an SChs.

3. The number of OBUs in VANET must be restricted to avoid overlong synchronizing cycles and too low throughput.

| Table 2. The duration time of packet periods (\(L_{RP}=200\)bytes, \(T_{CR}=20\)ms) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| \( \beta=1/4 \) | \( \beta=1/3 \) |
| \( n \) | \( L_{CP} \) | \( L_{SP} \) | \( T_{CP} \) | \( T_{SP} \) | \( n \) | \( L_{CP} \) | \( L_{SP} \) | \( T_{CP} \) | \( T_{SP} \) |
| 10 | 1000 | 1500 | 40.8 | 30.6 | 10 | 1000 | 1500 | 54.4 | 27.2 |
| 1500 | 2000 | 61.2 | 40.8 | 1500 | 2000 | 81.6 | 36.3 |
| 2000 | 2500 | 81.6 | 51.0 | 2000 | 2500 | 108.8 | 45.3 |
| 2500 | 3000 | 102.0 | 61.2 | 2500 | 3000 | 136.0 | 54.4 |
| 20 | 1000 | 1500 | 36.4 | 27.3 | 20 | 1000 | 1500 | 48.6 | 24.3 |
| 1500 | 2000 | 54.7 | 36.4 | 1500 | 2000 | 72.9 | 32.4 |
| 2000 | 2500 | 72.9 | 45.6 | 2000 | 2500 | 97.2 | 40.5 |
| 2500 | 3000 | 91.1 | 54.7 | 2500 | 3000 | 121.5 | 48.6 |
4. Conclusions
In order to maintain high coordination between CCH and SCHs in VANET, we propose a channel access control mechanism, in which channels’ access time is segmented into channel reservation period, control packet transmission period and service packet transmission period, packet transmission periods can be dynamically adjustment according to the load status in channels. Besides, we integrate channel reservation algorithm with DCF and TDMA to improve channel utilizations. The analysis results show that the proposed mechanism can obtain high throughput even in heavy load VANETs.

In our further research, we will focus on simulation model of VANET under urban traffic environments, design of security communication system in VANET physical layer and VANET node’s location prediction algorithm.

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Figure 3. The throughput of packet periods with different number of OBUs
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