Investigating Various Interval Assignments in IEEE 1609.4 Multichannel MAC Protocol

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Abstract

In this paper, first, we briefly present two kinds of interval assignments that used in IEEE 1609.4 multichannel MAC protocol. Then, we propose a new kind of interval assignment and investigate the performance of three different approaches in term of throughput, delay and packet delivery ratio. The main purpose of this work is to investigate how the different interval assignments affect the performance of the protocol and the investigations were performed based on the operation of the IEEE 1609.4 multichannel MAC protocol.

1. Introduction

Recently many research works have focused on developing multichannel MAC protocols since multichannel operation can enhance throughput, reliability and spectrum efficiency of wireless networks. The protocol IEEE 802.11p is being standardized for wireless access in vehicular environments (WAVE). IEEE 1609.4 is the multichannel extension of IEEE 802.11p and is considered as a default multichannel MAC protocol for vehicular ad hoc network VANETs [2]. In IEEE 1609.4 standard, the total spectrum bandwidth is divided into seven channels: one control channel (CCH) and six service channels (SCHs), with each having a bandwidth of 10 MHz [1]. The CCH is specified for use for safety-related applications and control messages. The multiple SCHs are used for both safety- and non-safety-related applications [3].

The basic MAC operation of IEEE 1609.4 (called WAVE MAC) can be seen in Fig.1 (a). The channel access time is divided into synchronization (SYN) intervals, and the length of each interval is fixed as 100 ms. The SYN interval is further divided into two fixed intervals called the control channel (CCH) interval and the service channel (SCH) interval. The duration of CCH and SCH intervals are fixed as 50 ms. Every node in the network switches to the CCH during the CCH interval for broadcasting and monitoring important safety messages. Moreover, the control packets can be exchanged for channel negotiation between nodes during this interval via the CCH. Non-safety-related messages are transmitted among nodes via SCHs during the SCH interval.

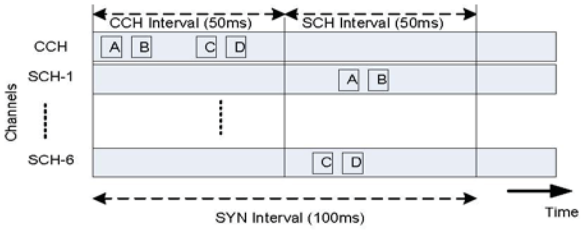
Based on this main operation, some works proposed to dynamically adjust the CCH and SCH intervals in order to improve the performance of the protocol [4]. In this paper, we propose another way of interval assignment and investigate the performance of three different approaches.

2. Various Interval Assignments

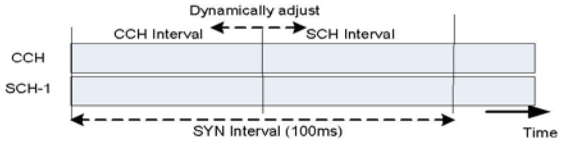
In this section, we present three different interval assignments for the IEEE 1609.4 multichannel MAC protocol and we briefly discuss about pros and cons of each approach.

2.1 IEEE 1609.4 WAVE MAC

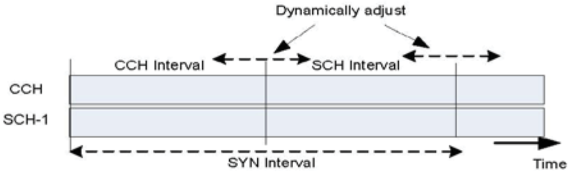
As shown in the Fig.1 (a), all the intervals, SYN, SCH and CCH intervals, are fixed in WAVE MAC. According to the basic principle, during the CCH interval, all nodes switch to CCH and transmit and receive the safety messages or perform network coordination for data communication. Thus, all SCHs remain idle during the CCH interval.



(a) IEEE 1609.4 WAVE MAC : All the intervals are fixed



(b) VCI MAC : The CCH and SCH intervals are dynamically adjusted, but the SYN interval is fixed



(b) Proposed dynamic interval assignment : All the intervals, not only CCH and SCH but also SYN interval, are dynamically adjusted

Figure.1. Various interval assignments in IEEE 1609.4 multichannel MAC protocol.

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2.2 VCI MAC

The authors of [4] proposed a multi-channel MAC protocol, called VCI MAC, to dynamically adjust the CCH and SCH intervals as shown in Fig.1 (b). In this approach, the CCH interval is further divided into a safety interval, which is used for safety message transmission, and a WSA interval, used for network coordination. The VCI MAC adjusts the CCH and SCH intervals in order to improve the saturation throughput of SCHs, while the SYN interval is unchanged. The CCH interval is optimized according to the number of users in the network. If the users in the network are sparse, the CCH interval is reduced to the minimum interval but remains long enough for safety message transmissions and network coordination. Intuitively, when the number of users in the network increases, the CCH interval needs to be increased. When the CCH interval consumes half of the SYN interval, the interval assignment of the VCI MAC will be the same as in the original standard, IEEE 1609.4, but the VCI MAC will cause more transmission overheads because of network coordination.

2.3 Dynamic Interval Assignments

Here, we propose an alternative way of interval assignment. The main goal is dynamically adjust not only CCH and SCH intervals but also the SYN interval. Intervals are adjusted according to the number of users in the network and packet arrival rates. If the users in the network are sparse, the intervals can be reduced to minimum that long enough for safety message transmissions, network coordination and data communication. Obviously, when the number of users increases, the intervals need to be enlarged. However, the problem is, when we enlarge the SCH interval, it will cause undesirable delay for safety related messages since these messages are transmitted only within the CCH interval. For example, if a safety related message arrives to a node during the SCH interval, the node needs to wait until the next CCH interval for transmitting it. Moreover, the safety messages are delay sensitive. Therefore, when the number of users increases, we enlarge the intervals as long as the delay requirement for safety messages is satisfied.

When a node has to transmit a safety message or to perform network coordination, it will transmit the packet with probability τ. There are n users in the network and if more than one node transmits at the same time, a collision will be caused with probability p and we have,

$$p = (1 - (1 - \tau)^{n-1}). \qquad (1)$$

Note that $0 < p < 1$ and $0 < \tau < 1$. The variables τ and p can be solved by the numerical method as in [5]. In every time slot, the packet will be successfully transmitted with probability p_{sus}, packet collision will occur with probability p_{col}, or the channel will be idle or busy with probabilities p_{idle} and p_{busy}. Then, by adapting the results of [4], we have

$$p_{idle} = (1 - \tau)^n$$
$$p_{busy} = 1 - p_{idle} = 1 - (1 - \tau)^n$$
$$p_{sus} = n\tau(1 - \tau)^{n-1}$$
$$p_{col} = 1 - (1 - \tau)^n - n\tau(1 - \tau)^{n-1} \qquad (2)$$

Let T_{sr}, T_{ack} and T_{safety} denote the time taken for transmission of a service request message, an acknowledgement (ACK) and a safety message, respectively. T_{idle}, T_{col} and T_{sus} represent the duration of the channel idle period, the duration of packets collision and the duration of a successful safety message transmission. We have

$$T_{idle} = aSlotTime$$
$$T_{sus} = T_{safety} + AIFS$$
$$T_{col} = T_{sr} + DIFS \qquad (3)$$

Network coordination refers as a node sends service request packet to a destination node and the destination reply an ACK. Note that, the destination node could be an access point or a road side unit or a neighbor node. Therefore, successful negotiation represents two-way handshaking between a pair of nodes. The time duration for the successful coordination (negotiation) can be

$$T_{sus}^{N} = DIFS + T_{sr} + SIFS + T_{ack} \qquad (4)$$

If successful network coordination has accomplished on the CCH during the CCH interval, the service data communication can be performed on selected SCH during the next SCH interval. The time duration for service data communication is

$$T_{data} = \frac{Data_L}{R} + DIFS + T_{ack} + SIFS \qquad (5)$$

$Data_L$ represents the total packet length of service data and R denotes the data rate.

Suppose that X is the time interval from channel access contention to the time when a safety message is successfully transmitted or negotiation is carried out successfully. Then we obtain the mean of time interval X as

$$E[X]^1 = \frac{T_{idle}}{p_{sus}} + \frac{p_{col}T_{col}}{p_{sus}} + T_{sus} \qquad (6)$$

Let λ_1 is the overall safety packet arrival and λ_2 is the service data arrival of each user and, we assume that both follow the Poisson distribution. Then, the average duration of the CCH interval can be estimated as

$$T_{cch} = \lambda_1 E[X] + \lambda_2 n\left(\frac{T_{idle}}{p_{sus}}\right) + p_{col}\frac{T_{col}}{p_{sus}} + T_{sus}^{N} \qquad (7)$$

The SCH interval should be long enough to accomplish the number of data communications, which is equal to the number of negotiations made on the CCH during the CCH interval. Thus, the SCH interval should be

$$T_{sch} = \left\lceil\frac{N_{sus}}{m}\right\rceil \left(\frac{T_{idle}}{p_{sus}} + p_{col}\frac{T_{col}}{p_{sus}} + T_{data}\right) \qquad (8)$$

where m is the number of SCHs and N_{sus} is the average number of successful negotiations. Then, the duration of an SYN interval becomes

$$T_{syn} = T_{cch} + T_{sch} \qquad (9)$$

As mentioned above, safety messages should be transmitted only on the CCH during the CCH interval. If a node receives a safety packet during the SCH interval, it has to wait until the beginning of the CCH interval to attempt transmission. We have assumed that the safety packets arrive at rate λ_1. If the safety packet arrives during the CCH interval, the node will try to transmit it immediately and the delay will be just *E[X]*. The probability of a safety packet arriving during the CCH interval is $P(cch) = 1 - e^{-\lambda_1 T_{cch}}$. Similarly, the safety packet arrives during the SCH interval with probability $P(sch) = 1 - e^{-\lambda_1 T_{sch}}$. The average delay of a safety packet becomes

$$E[Delay] = P(cch)E[X] + P(sch)\left(\frac{1}{2}T_{sch} + E[X]\right). \qquad (10)$$

Then, the suitable intervals can be calculated by using algorithm1.

1. Detailed proof for E[X] can be seen in [4].

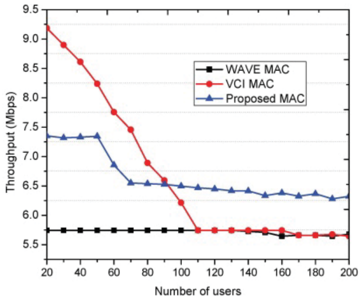

Fig.2 Throughputs comparisons

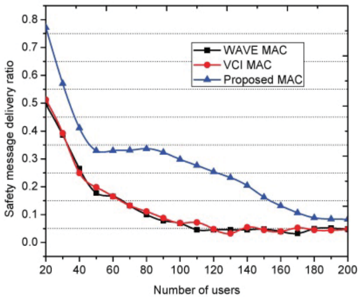

Fig.3. Safety packet delivery ratio

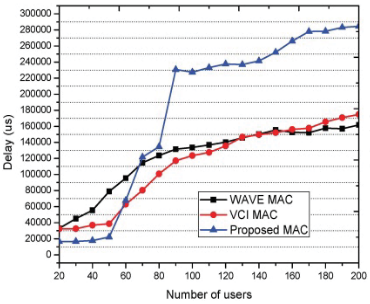

Fig.4 Delay for non-safety messages

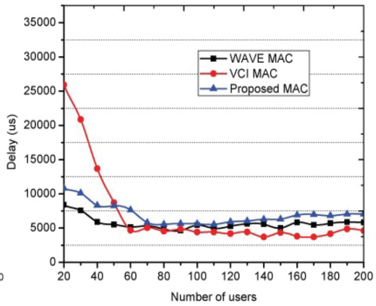

Fig.5 Delay for safety messages

Algorithm 1. Intervals Calculation

```
While i ≤ n or E[Delay] ≤ Delay Threshold
Do
    Find $T_{cch}, T_{sch}$ and $T_{syn}$ by using (7)(8)(9)
    Find E[Delay] by using (10)
    i++
End While
```

3. Performance Comparisons

We evaluate the performance of three different approaches by running simulation in the same network scenario. The simulation parameters are described in Table.1. Other simulation parameters are similar as that of [5]. First, the overall service throughput of three different approaches can be seen in Fig 2. When the number of users in the network is spare, VCI MAC outperforms other approaches. This is because, VCI MAC uses major portion of SYN interval as SCH interval. When the number of users increases, the interval assignments of VCI and WAVE MAC become similar. Therefore, the throughputs of these two approaches are also similar. In general, the proposed method provides higher service throughput no matter what the number of user in the network is. This is because; it adjusts the SCH intervals according to the number of users in the network.

When the number of users in the network is high, there is a higher chance of packet collisions and the value of E[X] increases since nodes need to spend more time in channel contention. Obviously, using larger intervals can provide higher packet delivery ratio. That is the reason why proposed method provides higher delivery ratio than two other approaches as shown in Fig.3.

On the other hand, large intervals can cause longer delay. The average delay for a service (non-safety) packet can be investigated from Fig.4. Here, we define delay as the time from the packet arrival up to the time when the packet is successfully transmitted. Thus, if the packet arrives during the current SCH interval, the node has to wait until the next CCH interval to carry out negotiation, and it performs data communication in the next SCH interval. Therefore, the use of larger intervals will cause higher delays for service packets. That is why the proposed MAC protocol has higher delay than the other two protocols in the dense networks.

Fig.5 represents the average delay for a safety packet. When the number of users in the network is small, VCI MAC assigns a major portion of the SYN interval as SCH interval. Thus, the average delay for safety packet in VCI MAC is significantly higher in a sparse network compared to the other two approaches. As shown in the figure, the overall delay of the proposed MAC method is slightly higher than those of the other two approaches because it uses longer intervals. The overall performance in terms of the average delay of safety message is similar in dense networks and it is not affected by the number of users. This is because, in our simulation, we assign higher priority to transmit the safety messages and use constant packet arrival rate $\lambda_1 = 20$ par SYN interval.

Table 1. Simulation parameters

Parameter	Values
Data rate	10 Mbps
Safety Packet Length	512 bytes
Service packet length	2048 bytes
Request/ACK	20 bytes
Delay Threshold	100 ms

4. Conclusion

We have presented performance of three different interval assignments in the IEEE 1609.4 multichannel MAC protocol. The efficiency of the protocols is dependent on the network environment. According to the simulation results, the proposed method is more suitable for dense networks, but it suffers the synchronization problem. The VCI MAC outperforms in sparse network and the standard WAVE MAC guarantees the stable network performance in various node populations.

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