A CCH CYCLE ADAPTIVE ALGORITHM FOR IEEE 802.11P MAC PROTOCOL IN SAFETY APPLICATIONS

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Abstract: The IEEE 802.11p standard, especially the 802.11p MAC protocol, has attracted much attention as part of the WAVE protocol in VANETs. Safety applications are very challenging for the design of MAC protocols due to their low latency and high reliability requirements. The CCH interval is also a key parameter for the 802.11p MAC protocol since it can affect the performance of delivering safety messages significantly. In this paper, a simulation based evaluation is proposed firstly to evaluate the performance of the 802.11p MAC protocol with various vehicle densities and CCH interval settings. Based on the simulation results, a CCH cycle adaptive algorithm for the 802.11p is then proposed. In this, the CCH interval is adjusted according to the vehicle density. The simulation results show that the proposed algorithm outperforms the IEEE 802.11p MAC protocol in terms of channel utilization and reliability in safety applications.

Key words: Vehicular ad-hoc Networks, IEEE 802.11p; MAC; safety, delay; collision; reliability, throughput.

1. INTRODUCTION

Vehicular ad-hoc Networks (VANETs) have attracted much attention owing to many present day societies' transportation problems such as traffic congestion, traffic accidents, lack of mobility and accessibility etc. VANETs present a challenging environment for protocol and application design due to their low latency and high data rate requirements in a high mobility environment. The IEEE 1609 working group has defined the first version of the protocol stack IEEE 802.11p/1609.x protocol families [1], also known as WAVE (Wireless Access in a Vehicular Environment). The WAVE protocols are designed for the 5.850-5.925 GHz band, the Dedicated Short Range Communications (DSRC) spectrum band in the United States (US), known as the intelligent transportation systems radio service (ITS-RS). This 75 MHz band is divided into one central control channel (CCH) and six service channels (SCH) as depicted in Fig. 1. The IEEE 802.11p standard [2] defines the physical (PHY) and medium access control (MAC) layers based on earlier standards for Wireless LANs (Local Area Networks). The IEEE 802.11p uses the enhanced distributed channel access (EDCA) MAC sub-layer protocol designed based on the IEEE 802.11e with some modifications, while the physical layer is OFDM (Orthogonal Frequency Division Modulation) as used in IEEE 802.11a.

According to the IEEE 1609.4 coordination scheme [4], as illustrated in Fig. 2, the channel time is divided into synchronization intervals with a fixed length of 100*ms*, consisting of 50*ms* (including 4*ms* guard interval) alternating CCH and SCH intervals. All vehicles stay in the control channel during the CCH period and switch to one of the six service channels during the SCH interval.

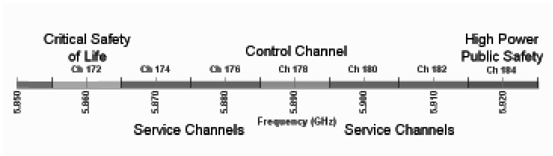

Figure 1: The set of channels defined in the WAVE trial standard [3]

However, as stated in [5], this is a significant concern if BSMs (Basic Safety Messages) are constrained to be sent on the CCH during the 50*ms* CCH interval, since there could be hundreds of devices in a given area and the collision rate could be very high. A special safety Channel

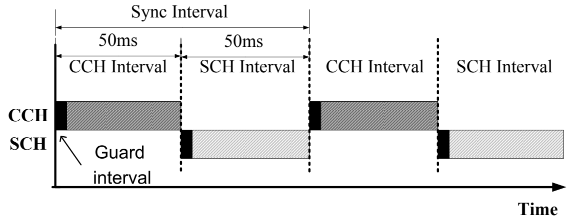

Figure 2: Channel interval

172 for safety communication is also proposed in [6] and [5]. On the other hand, the 50*ms* CCH interval could be too long and therefore wasted in a low vehicle density environment. Certain concepts for adapting the intervals of CCH and SCH are proposed in [7] [8] and [9]. In those works, the CCH interval is reduced in order to improve the SCH service, but the authors do not consider extending the CCH interval for a high vehicle density environment in order to reduce the collision probability. In our previous work [10], the performances of the IEEE 802.11p MAC protocol in safety applications with various CCH intervals are evaluated based on INET-2.0.0 [11]. However, due to the limitation of INET-2.0.0, the CCH/SCH switching is not considered in [10]. The main purpose of this paper is consequently to propose a CCH adaptive algorithm for the 802.11p MAC protocol in terms of the safety applications in VANETs, in which the CCH interval is adapted according to the vehicle density environment. In order to obtain a more accurate CCH adaptation threshold, the IEEE 802.11p MAC is revaluated based on Veins [12] in terms of reliability and delay.

The rest of this paper is organised as follows. In Section II, the related work is discussed. The IEEE 802.11p MAC is revaluated and the CCH interval adjustment threshold is obtained in Section III. In Section IV, the proposed CCH adaptive algorithm for the 802.11p MAC is presented and evaluated. Finally, the conclusions and possibilities for future studies are provided in Section V.

2. RELATED WORK

The effects of time allocations on CCH and SCH in IEEE 802.11p are analysed in [7] and [8]. In [7], the effect is analysed while the CCH/SCH duty cycle is changing. The results obtained indicate that the performances on CCH and SCH alter significantly following the changing of the CCH/SCH duty cycle. Three various CCH intervals (9, 27 and 45*ms*) are considered, and the tradeoff between the numbers of users on CCH and SCH are described. However, the effect is not analysed when the interval of CCH is greater than 45*ms*. In [8], an algorithm is proposed to improve the channel access scheme by adapting the intervals of CCH and SCH. However, the proposed algorithm cuts off CCH in order to extend SCH; hence it only improves the service channel utilisation without considering that of the control channel.

In [9] a variable CCH interval (VCI) multichannel MAC Scheme is proposed. The VCI MAC scheme adopts a new coordination mechanism to provide contention-free SCHs by a channel reservation on CCH. However, the CCH interval reserved for safety message delivery is not calculated well. Firstly, in the VCI MAC scheme, only the safety message transmission time is counted in the CCH interval calculation. The backoff time should also be counted; hence the time duration needed by the safety message delivery will be much longer than the result obtained in [9]. Secondly, the safety message frequency is considered as 2 per second which is too low to meet the safety application requirement. In addition, in the analytical model only the saturation scenario is considered, which is not suited to the realistic network environment.

It can be observed from the above discussions that no work has been conducted on considering both the increasing and decreasing of the CCH interval according to the vehicle density. In our previous work [10], the performances of the IEEE 802.11p MAC protocol in safety applications with various CCH intervals were evaluated. The 802.11p MAC protocol was evaluated in terms of collision, reliability, delay and throughput with the model of INET-2.0.0 [11]. However, the CCH/SCH switching is not supported by INET-2.0.0. The 4*ms* guard interval is also not considered in the INET simulation model. As a result, the simulation results obtained from [10] may not be very accurate for some scenarios. Hence, in this work, the IEEE 802.11p MAC protocol is revaluated in order to determine a more accurate CCH interval adjustment threshold.

3. PERFORMANCE EVALUATION

In this section, the performance of the IEEE 802.11p MAC protocol in safety applications is evaluated. Its performance with various CCH intervals is focused on.

3.1 Evaluation Configurations

To build an accurate and realistic simulation model, the latest released Veins 2.0-rc2 [12] is used, which is based on MiXiM 2.2 [13] working on OMNeT++ [14] platform and features the new models of IEEE 802.11p and IEEE 1609.4 DSRC/WAVE protocols. In Veins 2.0-rc2, the HCF (Hybrid coordination function) backoff process [2] , WSM (Wave Short Message) application [15] and CCH/SCH switching function are all properly considered. Compared with our previous work in [10], the Veins model is more accurate and realistic for the performance of the 802.11p.

In the simulations conducted, as shown in Fig. 3, a bi-directional highway segment of length 2000*m* is considered. A number of vehicles varying from 10 to 100 are deployed on the highway randomly. The speed of vehicles ranges from 60 to 120*Km/h*. Each vehicle will return once it reaches the border of the field in order to make sure that every vehicle remains in this highway segment. In this scenario, assume a vehicle (the red vehicle) is stopped right at the middle of this segment due to an accident. The accident vehicle broadcasts one emergency message every 100*ms* in AC3. Each of the other vehicles sends one status safety message every 100*ms* in AC0. The safety messages are generated randomly during $[0, T_{CCH}]$ for each vehicle, where T_{CCH} denotes the CCH interval. The T_{CCH} is set as $[20, 30, 40, 50, 60, 70, 80, 90, 100]$ respectively in order to evaluate the performance of 802.11p MAC at various CCH intervals. As defined in [16], the message size for the BSM part I is 39*bytes* and for Part II, the VehicleSafetyExtension frame of the BSM, which is less than 100*bytes*. Hence, the emergency and status safety message sizes are set as 139 *bytes* (100+39) and 39 *bytes* respectively. The communication range R is set as 1000*m* since the expected

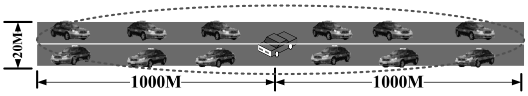

Figure 3: Simulation network

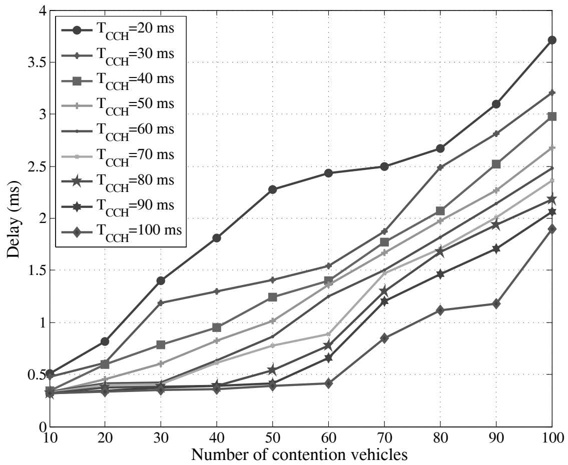

Figure 4: Delay of status message

radio range for a highway is up to 1000m [17]. The value of parameters used in the simulation is depicted in Table 1.

3.2 Evaluation Results

Fig. 4 depicts the average status safety message delivery delay for various contention vehicles and CCH intervals. It can be observed that the delay increases according to the increase in number of contention vehicles and a decrease of the CCH interval. The delivery delay T_{Delay} is the time duration from when the safety message is generated till the time that the message is received by a vehicle. The T_{Delay} is determined as

$$T_{Delay} = \frac{S_{Status} + S_{MAC}}{R_{Data}} + T_{Queue} + T_{Backoff} + \delta, \qquad (1)$$

where δ is the propagation delay, and T_{Queue} and $T_{Backoff}$ denote the Queue time and Backoff time respectively. It can be observed that the T_{Delay} is mostly determined by T_{Queue} and $T_{Backoff}$ since the other parameters such as S_{Status}, S_{MAC} and R_{Data}, are constant. δ is also a approximate constant in this short range communication scenario. The increase in numbers of contention vehicles as well as the decrease in the CCH intervals will cause more contention together with a longer Queue and Backoff time. As a result, a lengthier delay is caused.

Fig. 5 illustrates the average emergency safety message delivery delay for various contention vehicles and CCH interval. It can be observed that the delay does not change much according to the contention vehicles and CCH intervals. Since only one emergency safety message is broadcast every CCH intervals in AC3, neither the contention vehicles nor the CCH interval affect the delay significantly. The delay is quite short and stable since the

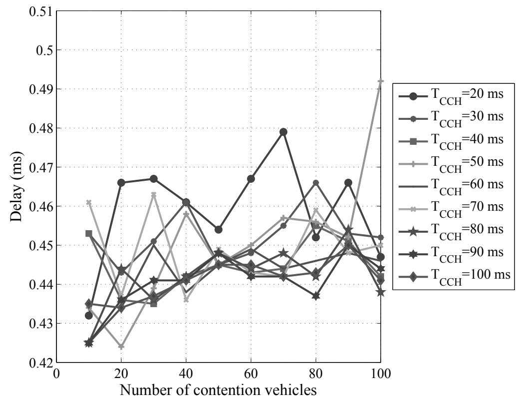

Figure 5: Delay of emergency message

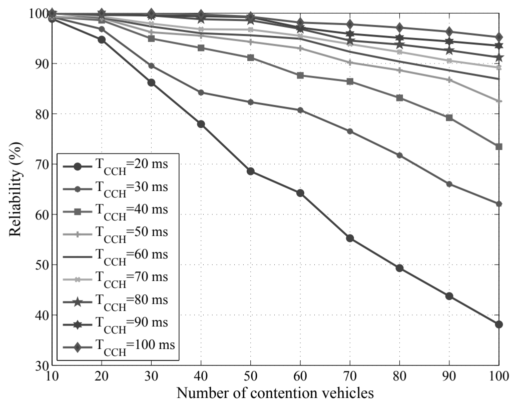

Figure 6: Reliability of status message

emergency safety message, which is transmitted in AC3, always has the highest priority to access a channel.

Fig. 6 portrays the average status of the delivery reliability of safety messages for various contention vehicles and CCH intervals. It can be observed that the reliability decreases according to an increase in numbers of contention vehicles and a decrease in CCH intervals. The reliability is strongly related to the collision probability. Since each vehicle sends one status safety message every CCH interval, the increase in contention vehicles means that more vehicles will contend for the idle slots. As a result, more collisions will be caused. The decrease of CCH intervals will also cause more collisions since the total idle slots are decreased. As a result, the probability that more vehicles will contest an idle slot at the same time increases. More collisions will cause worse reliability. According to the requirements for safety applications in VANETs [18] [19], the delay should be less than 100ms. However the reliability requirement is not defined precisely. In this work, considering a specific reliability requirement, the network capacity represented by the number of vehicles that can be accommodated in a network can be derived from Fig. 4 and Fig. 6. The results obtained are listed in Table 2. It is

Table 1: Parameter settings.

Parameter	Value
Status safety message access Class AC	AC0
Emergency safety message access Class AC	AC3
aSlotTime	13 μs
Size of emergency safety message $S_{Emergency}$	140bytes
Size of status safety message S_{Status}	39 bytes
Size of MAC header S_{MAC}	32 bytes
Data rate R_{data}	6 Mbps
Communication range R	1000 m
Maximum backoff time k	5
Message sending frequency	10/s
Simulation time	10 s
Maximum transmission power	760 mw
Sensitivity	-82dBm
Mobility model	LinearMobility
Propagation model	SimplePathlossModel

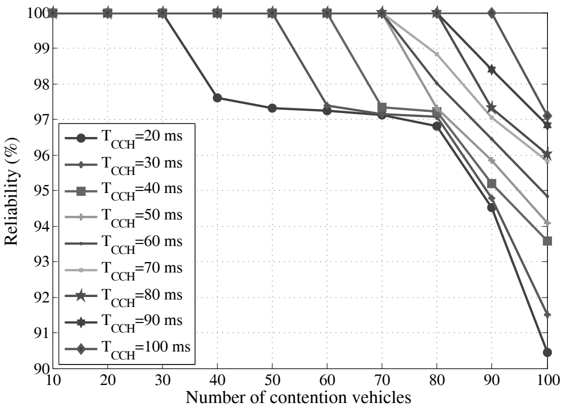

Figure 7: Reliability of emergency message

evident that the reliability is much more critical than the delay. Hence, the reliability constitutes the bottleneck for the IEEE802.11p MAC protocol in meeting the safety application requirements in VANETs. Compared with our previous work in [10], it can be observed that the network capacity achieved in this work is mostly less than the results obtained in [10] because in the Veins simulation model, the CCH/SCH switching is considered and hence, the 4*ms* guard interval is included in the T_{CCH}. As defined in [2], no message should be transmitted during the guard interval. However, in our previous work, the guard interval is not considered. As a result, the network capacity obtained in this work is less than our previous result in [10].

Fig. 7 indicates the average delivery reliability of emergency safety messages for various contention vehicles and CCH intervals. It can be observed that the reliability decreases according to any increase in contention vehicles and decrease in CCH intervals. As discussed before, the reliability is closely related to the collision probability. Although there is only one emergency transmitted for every CCH interval, the probability of collision with the status safety message will increase according to an increase in contention vehicles and a decrease in CCH interval. As a result, more collisions cause worse reliability. However, the emergency safety messages delivery reliability is always 100% for the scenarios presented in Table. 2.

In conclusion, in VANETs safety applications, the CCH interval can be adjusted according to the number of contention vehicles in order to improve the channel utilisation ratio. In the mean time, the safety application requirement should be satisfied since the safety application is very critical in VANETs.

4. CCH ADAPTIVE ALGORITHM

In the former section, it is concluded that the channel utilisation ratio can be improved via adjusting the CCH interval with guaranteed, certain reliability. In this section, a CCH adaptive algorithm is proposed, in which the CCH interval is adjusted according to the number of contention vehicles.

4.1 Proposed Algorithm

As shown in Fig. 8, the basic concept of the proposed algorithm in this work is to adjust the CCH interval parameter according to the average number of contention vehicles in a highway segment. The number of contention vehicles is recorded by each RSU and collected at

Table 2: Accommodated number of vehicles

$T_{CCH}(ms)$	20	30	40	50	60	70	80	90	100
Number of vehicles ($P_{Reliability} \geq 99\%$)	5	10	15	20	25	30	35	40	50
Number of vehicles ($P_{Reliability} \geq 95\%$)	20	25	30	40	50	60	70	80	100

Table 3: Accommodated number of vehicles [11]

$T_{CCH}(ms)$	20	30	40	50	60	70	80	90	100
Number of vehicles ($P_{Reliability} \geq 99\%$)	10	20	20	30	30	40	40	40	50
Number of vehicles ($P_{Reliability} \geq 95\%$)	25	35	45	55	60	70	80	90	125

Algorithm 1 Contention vehicle recording algorithm

switch to CCH interval
$N_i \leftarrow the\ number\ of\ contention\ vehicles\ 0$
if received a safety message successfully **then**
  $N_i = N_i + 1$
else if failed to receive a message due to collision **then**
  $N_i = N_i + 2$
end if
switch to SCH interval
send N_i to upper layer

the control centre. According to Table 2, the CCH interval parameters are calculated and then distributed to every RSU periodically. In this work, the CCH interval parameters are updated every $100ms$. The proposed algorithm contains three steps: Contention vehicle recording, CCH interval calculating and CCH interval resetting.

Contention vehicle recording: In this algorithm, the CCH interval is set according to the number of contention vehicles in a VANET. Hence, the contention vehicle number N_i needs to be recorded by each RSU, where N_i denotes the number of contention vehicles recorded by RSU_i during one CCH interval. In this scheme, each RSU records the number of vehicles according to the safety messages received for each cycle. The detail of the contention vehicle recording algorithm is shown in Algorithm. 1. In order to simplify the algorithm, the collision is assumed to occur only between two vehicles. As a result, the number of contention vehicles is recorded as 2 for a collision. The N_i will be finally sent to the control centre in order to calculate the proper CCH interval parameter according to the average number of contention vehicles in a highway segment.

CCH interval calculating:

In this algorithm, as shown in Fig. 8, the control centre is responsible for calculating the CCH interval according to the number of contention vehicles. As discussed in the former section, the N_i recorded by RSU_i for each CCH interval is collected in the control centre periodically. Suppose that a highway segment contains j RSUs; the average number of contention vehicles N_{Ave} can then be determined as

$$N_{Ave} = \frac{1}{j} \times \sum_{i=1}^{j} N_i. \qquad (2)$$

The CCH interval parameter T_{CCH} can then be determined according to N_{Ave} and Table. 2. Suppose the reliability requirement is 95%; the details of the CCH interval calculating algorithm are shown in Algorithm. 2

Algorithm 2 CCH interval calculating algorithm

$N \leftarrow 0$
$N_{Ave} \leftarrow 0$
$j \leftarrow the\ number\ of\ RSUs$
for $i = 1; i \leq j; i++$ **do**
  receive N_i from RSU_i
  $N = N + N_i$
end for
$N_{Ave} = \frac{N}{j}$
if $N_{Ave} \leq 20$ **then**
  $T_{CCH} = 20$
else if $20 < N_{Ave} \leq 25$ **then**
  $T_{CCH} = 30$
else if $25 < N_{Ave} \leq 30$ **then**
  $T_{CCH} = 40$
else if $30 < N_{Ave} \leq 40$ **then**
  $T_{CCH} = 50$
else if $40 < N_{Ave} \leq 50$ **then**
  $T_{CCH} = 60$
else if $50 < N_{Ave} \leq 60$ **then**
  $T_{CCH} = 70$
else if $60 < N_{Ave} \leq 70$ **then**
  $T_{CCH} = 80$
else if $70 < N_{Ave} \leq 80$ **then**
  $T_{CCH} = 90$
else if $N_{Ave} > 80$ **then**
  $T_{CCH} = 100$
end if
broadcast T_{CCH} to all RSUs

CCH interval resetting:

As stated in [15], in WAVE, each vehicle is expected to

Algorithm 3 CCH interval resetting algorithm

start timer $t \leftarrow T_{CCH}$
receive a WSA
$T_{CCH} \leftarrow$ *CCH interval parameter in WSA*
if t=0 **then**
  switch to SCH
end if

join a WBSS (WAVE Basic Service Set), which is a unique identifier for each communication zone. Vehicles must associate with only one WBSS at a time. To establish a WBSS, a RSU periodically broadcasts the WAVE Service Advertisement (WSA) on the CCH. WSA contains the necessary information for the users to join the WBSS, such as the WBSS identifier, the availability of a service, the selected SCH, synchronisation timing information etc. In the meantime, all the vehicles have to listen to the CCH during the CCH intervals. In our proposed CCH adaptive algorithm, the WSA is extended to contain a CCH interval parameter T_{CCH}. The T_{CCH} is calculated by the control centre and distributed to every RSU every $100ms$. Each vehicle will reset its CCH interval according to the T_{CCH} contained in WSA. However, the new CCH interval parameter will be activated during the next cycle since the vehicle is already on a CCH channel. The detail of the CCH interval resetting algorithm is depicted in Algorithm. 3.

4.2 Validation and Discussions

The proposed CCH adaptive algorithm is evaluated utilising the same simulation configuration as discussed in Section 3.1. The CCH adaptive algorithm is evaluated for two reliability requirement settings respectively. As discussed in Section 3.2, for emergency messages, the delay is quite short and stable. In addition, the reliability is always 100% for the scenario in Table. 2. Hence, only the status messages are discussed in this section.

Fig. 9 illustrates the CCH interval settings for various contention vehicles. In the IEEE 802.11p, the CCH interval is a constant with $50ms$. In the proposed CCH adaptive algorithm, the CCH interval is adjusted according to the number of contention vehicles in a network. According to Table. 2, the CCH adjusting thresholds are different for different reliability requirements. It can be observed that the CCH interval for the adaptive algorithm

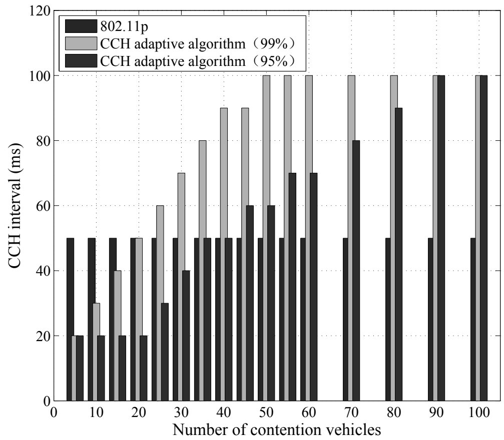

Figure 9: CCH interval

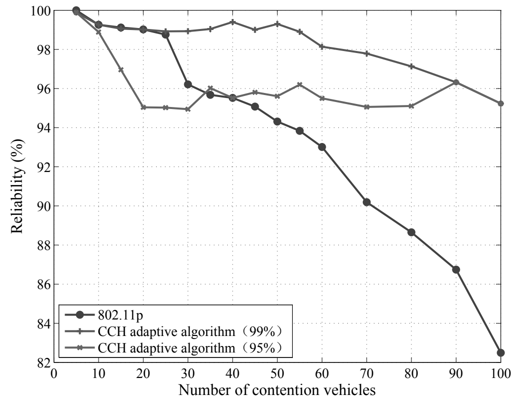

Figure 10: Reliability of status message

increases according to the number of contention vehicles in order to meet the reliability requirement. In the scenario where the network density is low, a shorter CCH interval ($< 50ms$) is sufficient for the status safety messages to meet a certain reliability requirement. As a result, a longer SCH interval ($> 50ms$) is obtained to offer a better service to the customer. The SCH interval can be extended up to 60%. On the other hand, in the scenario where the network density is high, the network needs a longer ($> 50ms$) CCH interval to deliver the status safety messages in order to meet the reliability requirement.

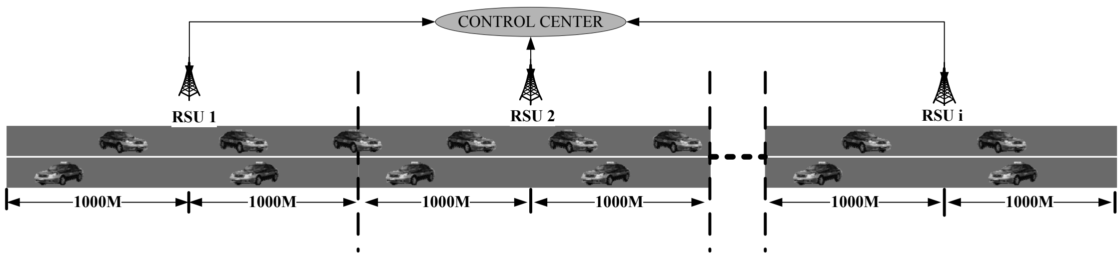

Figure 8: CCH interval adaptive example

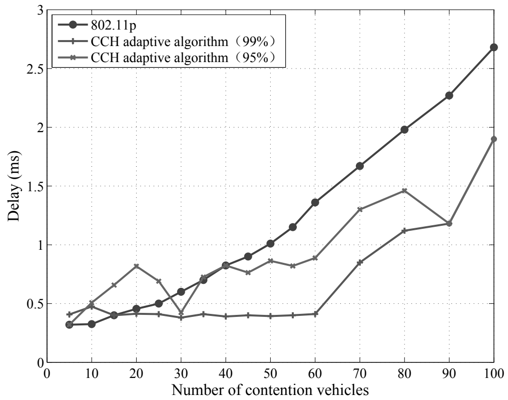

Figure 11: Delay

Fig. 10depicts the average delivery reliability status of safety messages for various contention vehicles. It can be observed that the CCH adaptive algorithm outperforms the 802.11p in terms of reliability when the number of contention vehicles is greater than a specific threshold. The threshold is $N_{Threshold} = 15$ and $N_{Threshold} = 30$ for the two reliability requirements ($\geq$ 99% and $\geq$ 95%) respectively. On the other hand, the 802.11p outperforms the CCH adaptive algorithm in terms of reliability when the number of contention vehicles is less than the threshold $N_{Threshold}$. It can be noted that the threshold $N_{Threshold}$ is just the point that the T_{CCH} is switching to be $50ms$ according to Table. 2. However, the reliability of the CCH adaptive algorithm is always better than the reliability requirement when the number of contention vehicles does not exceed the maximum network capacity N_{Max}, which is $N_{Max} = 55$ and $N_{Max} = 100$ for the two reliability requirements ($\geq$ 99% and $\geq$ 95%) respectively.

In Fig. 11 the average status safety message delivery delay for various contention vehicles is illustrated. It can be observed that the delay shows a similar distribution to that of the reliability. The CCH adaptive algorithm records a slightly longer delay than the 802.11p when the number of contention vehicles is less than the threshold $N_{Threshold} = 15$ and $N_{Threshold} = 30$ for the two reliability requirements ($\geq$ 99% and $\geq$ 95%) respectively. On the other hand, the CCH adaptive algorithm has a slightly shorter delay than the 802.11p when the number of contention vehicles is greater than the threshold $N_{Threshold}$. It can also be observed that all the delays are much shorter than the latency requirement ($< 100ms$) .

In conclusion, the CCH adaptive algorithm can improve the channel utilisation ratio for a low traffic scenario (up to 60%) and increase its reliability for a heavy traffic scenario via adjusting the CCH interval. In the meantime, the average delivery delay is much shorter than the latency requirement in the scenarios considered.

5. CONCLUSIONS

In this study, a CCH adaptive algorithm for the IEEE 802.11p MAC protocol is proposed, in which the CCH interval is adjusted according to the average number of contention vehicles in a VANET. In comparison with the existing works in [7] [8] [9], the safety application's reliability, rather than that of the SCH service, is considered and guaranteed a higher priority. In order to establish a more accurate and realistic CCH adjustment threshold, the 802.11p MAC protocol is evaluated based on the latest released Veins 2.0-rc2 model. The network capacity with a certain reliability requirement is derived, which is taken as the CCH adjustment threshold in the CCH adaptive algorithm. The simulation results demonstrate that the CCH adaptive algorithm can improve the channel utilisation ratio (up to 60%) for a low traffic scenario and increase the reliability for a heavy traffic scenario via adjusting the CCH interval.

Some of the future studies will include: (1) proposing a analytical model to evaluate the performance of the IEEE 802.11p MAC protocol with different CCH/SCH interval settings; and (2) evaluating the network capacity of IEEE 802.11p standard for SCH interval.

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