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Research on Dynamic Bandwidth Partition Algorithm for Control Channel of Vehicular Ad-Hoc Networks

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Abstract

In IEEE 802.11p protocol of Vehicular Ad-Hoc network (VANET), the multiple channels are divided into one control channel (CCH) and six service channels (SCHs). CCH is used for broadcasting safety messages related to road conditions, so that CCH access algorithm has great influence on efficiency of VANET. This paper proposes a contention-free bandwidth partition algorithm, which can dynamically partition the CCH interval and bandwidth assigned to on board units (OBUs) located in vehicles according to real-time VANET environments. Meanwhile, a frequency hopping communication scheme based on chaos scrambling is applied to our algorithm to improve the reliability of VANET. The performance of proposed algorithm are verified by theoretical analysis, the results show that it is able to enhance the transmission efficiency of safety packets in CCH with high reliability.

Keywords: *VANET, IEEE 802.11p protocol, control channel, channel access algorithm, bandwidth partition, chaos sequence, reliable communication*

1. Introduction

The number of vehicles is rising significantly, and the traffic related issues have dramatically increased, Vehicular Ad-Hoc network (VANET) is the primary solution to improve traffic management in future intelligent transportation system (ITS). VANET can provide vehicle to vehicle as well as vehicle to roadside unit (RSU) wireless communications, so it is an efficient way to improve the safety and comfort of urban transportation. The IEEE 802.11p working group has proposed a new physical layer (PHY)/medium access control (MAC) layer amendment for VANET in 2010. In IEEE 802.11p standard draft, 75MHz bandwidth of licensed spectrum at 5.9 GHz is allocated for vehicle to vehicle and RSU to vehicle communications, as shown in Figure 1. The overall bandwidth are divided into seven frequency channels, the bandwidth of each channel is 10MHz. The lower end of the band is a safety margin of 5MHz. The center channel (CH178) is control channel (CCH), which is used as a public channel for safety-relevant applications on the road. The other six channels are service channels (SCHs), CH172 and CH184 are reserved for special public uses, the rests are available for non-safety applications to improve the comfort of driving. [1-3].

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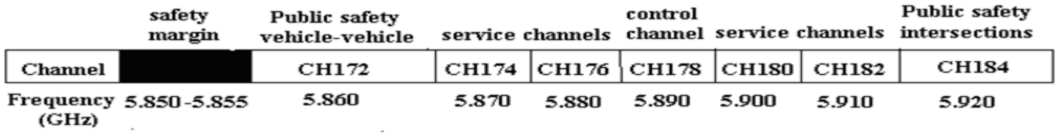


	safety margin	Public safety vehicle-vehicle	service channels		control channel	service channels		Public safety intersections
Channel		CH172	CH174	CH176	CH178	CH180	CH182	CH184
Frequency (GHz)	5.850-5.855	5.860	5.870	5.880	5.890	5.900	5.910	5.920

Figure 1. IEEE 802.11p Multiple Channels

To reduce the effects of Doppler spectrum spread and Inter Symbol Interference (ISI) caused by multi-path propagation, the IEEE 802.11p PHY employs 64-subcarrier Orthogonal Frequency Division Multiplexing (OFDM) technique, which can provide a data rate of 3M bps up to 27 Mbps with 300m-1000m communication distance. 52 sub-carriers are used for data transmission consisting of 48 data sub-carriers and 4 pilot sub-carriers. The pilot signals are used for tracing the frequency offset and phase noise. After being coded and interleaved, the data are modulated onto the sub-carriers. Obviously, because CCH is opened to public use, OBU's authentication is important to ensure information reliability in VANET [4, 5].

In MAC layer, channel access algorithm has great influence on efficiency of VANET. The study in [6] discussed the feasibility of using Carrier Sense Multiple Access /Collision Avoidance (CSMA/CA) mechanism for control channel competition, but differentiated services are not considered. There are different priorities for safety messages sent over the CCH, depending on how critical they are for vehicle safety. For this reason, Enhanced Distributor Channel Access (EDCA) algorithm is recommended to perform control channel competition, data traffic in CCH is classified into four EDCA access categories (ACs), the highest priority AC3 is given to safety-related urgent information, the AC2 is given to vehicles to advertise their presence to other vehicles, the AC1 is given to non-urgent messages, the lowest priority AC0 is given to SCH service request messages. However, safety packet traffic increases seriously with the number of OBUs in the VANET, so contention-based EDCA algorithm may result in more transmission delay of safety packets in high overload VANET [7, 8].

To operate channel access on the CCH and multiple SCHs efficiently, many researches focus on channel coordination between CCH and SCHs. In study of Coordinated Universal Time (UTC) scheme [9], the channel access time is divided into synchronization intervals with a fixed length of 100 ms, consisting of 50 ms CCH interval and 50 ms SCH interval. According to UTC scheme, all devices must monitor the CCH for safety and private service advertisements during CCH interval. During SCH interval, OBUs may optionally switch to SCHs to perform non-safety applications. However, the limited length of CCH is unable to provide sufficient bandwidth to transmit a large amount of safety packets in overload VANET, on the other hand, if the OBU density is sparse, the occasional transmission on the CCH will waste the bandwidth resource. The variable CCH interval (VCI) scheme [10] can dynamically adjust the length ratio between CCH and SCHs according to VANET conditions. Although VCI scheme is able to provide efficient channel utilization in both CCH and SCHs in a way, both contention-based channel competing and undifferentiated service in CSMA/CA mechanism will influence on transmission performance and quality of service (QOS), especially for safety-related urgent messages in CCH. The study in [11] proposed a vehicular MESH network (VMESH) MAC protocol, which applies a distributed beaconing and reservation–based channel access scheme to improve the channel utilization of SCHs. Although VMESH outperforms typical VANET channel access scheme in terms of network throughput, CCH still has low channel utilization.

The rest of this paper is organized as follows: In Section 2, we describe the proposed CCH access control algorithm in detail, which performs dynamical CCH interval adjustment and bandwidth partition. Besides, in order to improve communication reliability between OBUs in proposed algorithm, a frequency hopping scheme based on chaos scrambling technology is applied. In Section 3, the performance of our algorithm is analyzed by theoretic analysis in varying VANET environments. In Section 4, some useful conclusions and further research issues complete the paper.

2. Dynamic CCH Bandwidth Partition Algorithm

2.1. The Process of CCH Dynamic Bandwidth Partition Algorithm

The process of CCH access control scheme is shown in Figure 2, the method of synchronization interval partition between CCH and SCHs is shown in Figure 3.

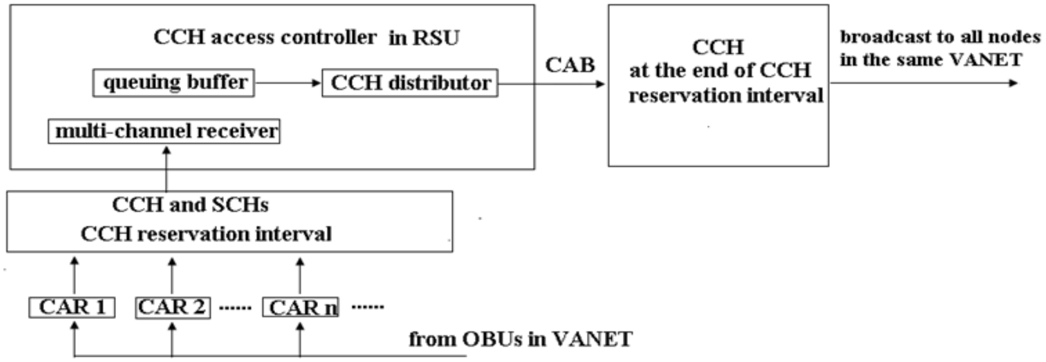


Figure 2. The Process of CCH Access Control Scheme

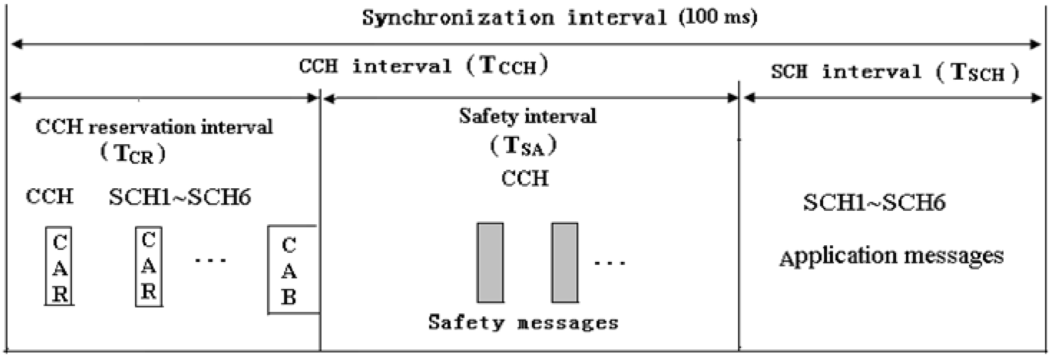


Figure 3. The Method of Synchronization Interval Partition between CCH and SCHs

The CCH dynamic bandwidth partition algorithm is executed by CCH distributor in R
The algorithm of CCH dynamic bandwidth partition is as follows:

//T_{CR}: the length of CCH reservation interval.

//T_{SA}: the length of safety interval.

//V: data rate of CCH and SCHs.

//L_{CR}: the length of CCH access request packet.

// N: the number of CCH access request in queuing buffer of RSU.

//*Num*: the number of permitted CCH access request.

// L_{SA}: the average length of safety packets.

//*request-type*: the priority of CCH access request. The value of highest priority is 3; the second priority is 2; the third priority is 1; the lowest priority is 0.

//λ_{Sk}: safety packet sending frequency of different CCH access priorities. (k=0,1, 2, 3)

pi: the CCH access probability of *request-type i* (i=0,1,2,3)

//*BW*: the bandwidth of sub-carrier channel assigned to OBUs for safety packets transmission.

//*CAB*: CCH assignment broadcast packet. It denotes the result of CCH assignment, including the information of appointed OBU-identity (OBU-ID) and assigned sub-carriers.

$$T_{CR} = [\alpha \cdot (\sum_{k=1}^{4} \lambda_{Sk}) \cdot 100ms \cdot L_{CR}]/(7V)\ (ms) \qquad (1)$$

```
$Num=0$; $k=N$;
do while ($k>0$)
{p= a random number between [1,k];
  rn= a random number between [0,1];
  i=request-type of CCH access request packet p in queue buffer
  if ( rn<= pi)
    { CCH access request p is retained in queuing buffer;
      Num=Num+1; }
  else CCH access request p is removed from queuing buffer;
  k=k-1;}
```

$$BW=(5895-5885-16*0.15625)/Num\ (MHz); \qquad (2)$$

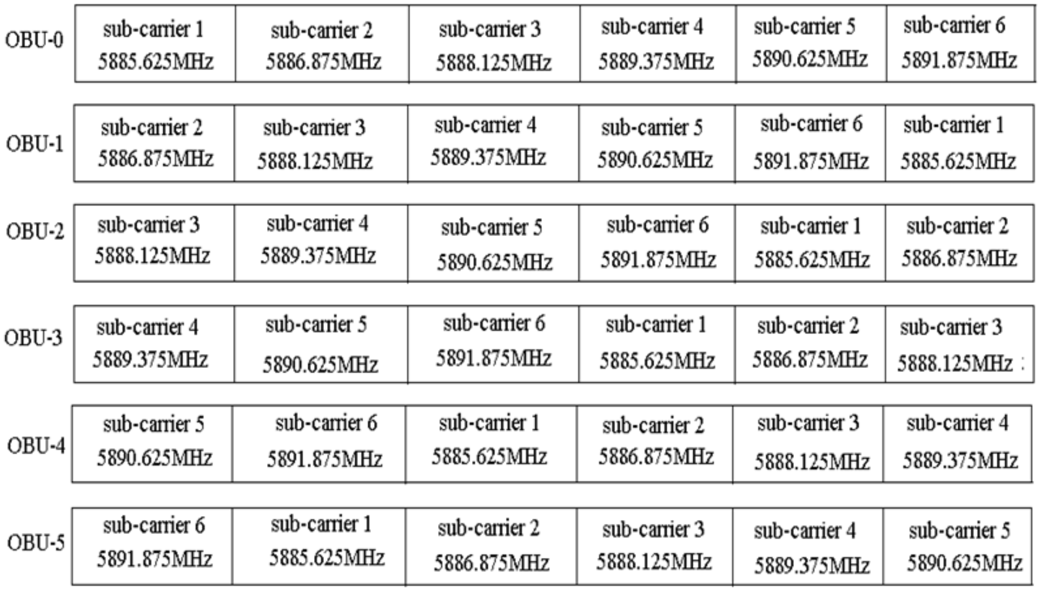
$$T_{SA} = (L_{SA} \cdot Num)/V\ (ms)\ \ (T_{CR} + T_{SA} < 100ms) \qquad (3)$$

Broadcasting *CAB* packet at the end of CCH reservation interval.
Transmitting safety packets during safety interval.

In our algorithm, CCH interval is further divided into CCH reservation interval and safety interval. A new synchronization interval begins from the CCH reservation interval, during which OBUs can transmit CCH access request (CAR) packet to CCH access controller set in RSU through CCH or SCHs. In order to ensure transmission time for both CCH reservation packets and safety packets, T_{CR} and T_{SA} are dynamically adjusted by formula (1) (3) according to current vehicular conditions. In formula (1), α is a predefined factor, considering the extra time of channel competition, the value of α should usually be more than 1.

CCH access controller is consists of CCH distributor, queuing buffer and multi-channel receiver, queuing buffer is intended for storing CCH access requests, CCH distributor is intended for CCH dynamic access control and bandwidth partition. During CCH reservation interval, OBUs which need transmit safety packet must send CAR packet through CCH or SCHs, CAR packet contains the information of OBU number and *request-type*, which denotes the CCH access priority. CCH access priority has four types, the higher the CCH access priority, the larger the probability to be assigned CCH successfully. When CAR is received by CCH access controller, it is recorded into queuing buffer. CCH distributor reads access request randomly from queuing buffer, and then, makes a decision to accept or reject this request according to access probability of different priorities. If the CCH access request is accepted, it is retained in queuing buffer. If the CCH access request is rejected, it is removed from queuing buffer. At last, the required bandwidth, orthogonal sub-carriers and the length of safety interval are calculated, and the CCH assignment broadcast packet (CAB) containing the information of assigned sub-carriers, frequency bandwidth and OBU-ID is transmitted to all OBUs at the end of CCH reservation interval. Permitted OBUs can transmit their safety packets in specified sub-carriers during safety interval by frequency-hopping communication system.

For example, suppose $V=3\ Mbps$, $L_{SA}=1000\ bytes$, $Num=6$. According to our algorithm, we have $BW=1.25MHz$; $T_{SA}= 16ms$. A frequency hopping communication scheme during safety interval are shown in Figure 4, the frequency hopping rate is 375hop/second.



OBU-0	sub-carrier 1 5885.625MHz	sub-carrier 2 5886.875MHz	sub-carrier 3 5888.125MHz	sub-carrier 4 5889.375MHz	sub-carrier 5 5890.625MHz	sub-carrier 6 5891.875MHz
OBU-1	sub-carrier 2 5886.875MHz	sub-carrier 3 5888.125MHz	sub-carrier 4 5889.375MHz	sub-carrier 5 5890.625MHz	sub-carrier 6 5891.875MHz	sub-carrier 1 5885.625MHz
OBU-2	sub-carrier 3 5888.125MHz	sub-carrier 4 5889.375MHz	sub-carrier 5 5890.625MHz	sub-carrier 6 5891.875MHz	sub-carrier 1 5885.625MHz	sub-carrier 2 5886.875MHz
OBU-3	sub-carrier 4 5889.375MHz	sub-carrier 5 5890.625MHz	sub-carrier 6 5891.875MHz	sub-carrier 1 5885.625MHz	sub-carrier 2 5886.875MHz	sub-carrier 3 5888.125MHz
OBU-4	sub-carrier 5 5890.625MHz	sub-carrier 6 5891.875MHz	sub-carrier 1 5885.625MHz	sub-carrier 2 5886.875MHz	sub-carrier 3 5888.125MHz	sub-carrier 4 5889.375MHz
OBU-5	sub-carrier 6 5891.875MHz	sub-carrier 1 5885.625MHz	sub-carrier 2 5886.875MHz	sub-carrier 3 5888.125MHz	sub-carrier 4 5889.375MHz	sub-carrier 5 5890.625MHz

Figure 4. Frequency Hopping Scheme in Assigned Sub-carriers during Safety Interval

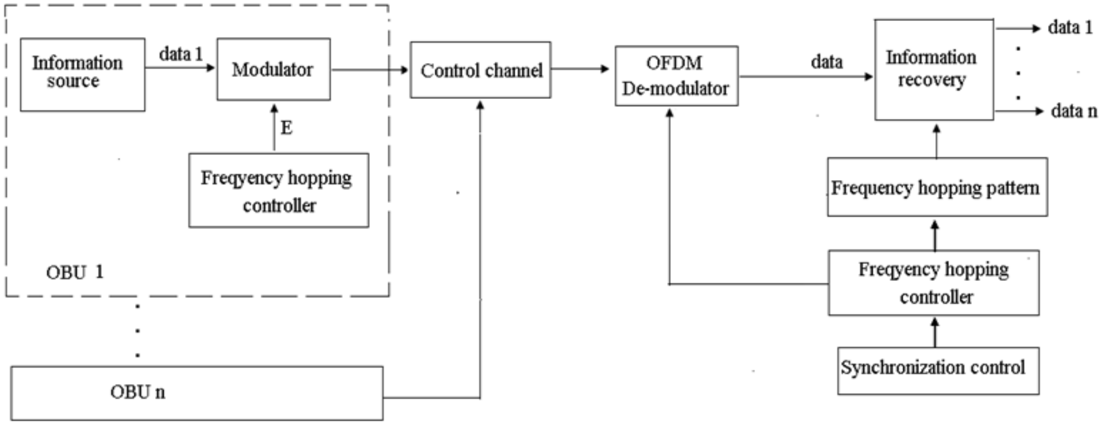
2.2. Sub-carriers Frequency Hopping Communication Scheme

2.2.1. Design of Sub-carrier Frequency Hopping System: High reliable communications can usually be achieved by the methods of encryption coding or scrambling technology [12]. We design a sub-carrier frequency hopping communication scheme, which can be used in our dynamic bandwidth partition algorithm to improve the communication reliability in VANET, the construct is as shown as Figure 5 (a). During the *i*th safety interval, data of each permitted OBU is modulated onto assigned sub-carriers, and then it is sent to multiplexed wireless control channel. Sub-carrier's hopping pattern is regulated by frequency hopping controller. At information receiving side, modulated signals are de-modulated from multiple orthogonal sub-carriers by OFDM de-modulator, and the data can be disassembled according to synchronal frequency hopping pattern. The constitution of frequency hopping controller is shown in Figure 5 (b), it is based on scrambling technology of Logistic chaos sequence. In Figure 5 (b), the length of left-shift register is n bit (n=Num). Logistic chaos sequence X_i is also transformed into n bit binary sequence by quantization and coding, which is the initial value of left-shift register. In each frequency hopping period, the data in left-shift register is processed by left-shift circuit. At last, sub-carrier numbers are determined by selective gate. The status of left-shift register is updated in each sub-carrier frequency hopping period. According to the theory of Logistic map [13, 14], we know that

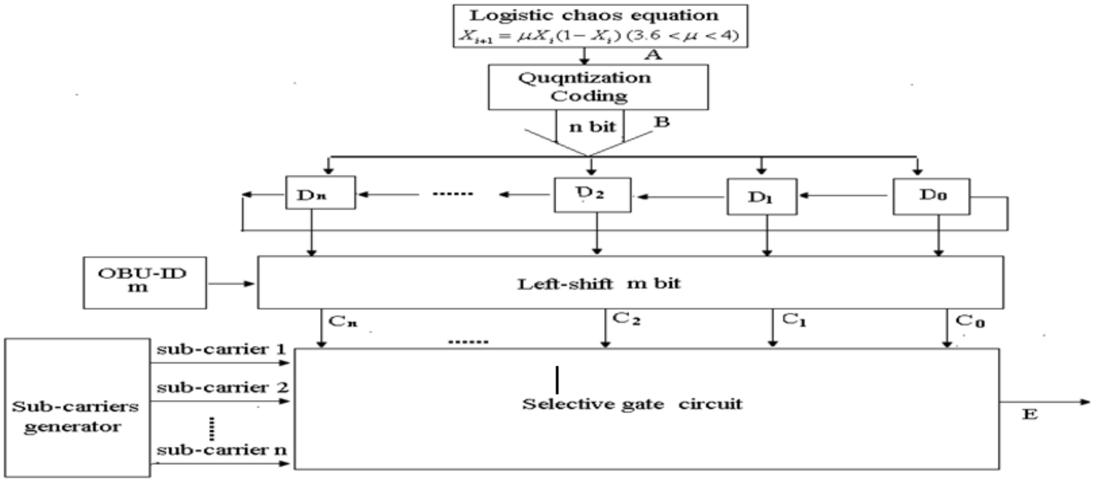
(1) X_i has two fixed points: $x_1 = 0$ and $x_2 = 1 - \frac{1}{\mu}$. If $0 \le \mu < 1$, x_1 is stable fixed point; if $1 \le \mu < 3$, x_2 is stable fixed point; if $\mu > 3$, X_i becomes chaotic gradually.

(2) Second iteration will add two fixed points $x_3 = 1 + \mu - \frac{\sqrt{(\mu + 1)(\mu - 3)}}{2\mu}$ and $x_4 = 1 + \mu + \frac{\sqrt{(\mu + 1)(\mu - 3)}}{2\mu}$. If $0 \le \mu < 1$, x_1 is stable fixed point; if $1 \le \mu < 3$, x_2 is stable fixed point; x_3 and x_4 are unstable fixed points, but when $3 \le \mu < 1 + \sqrt{6}$, they are stable fixed points of second iteration.

Hence, in order to ensure the chaos status of X_i, the value of μ must be between 3.6 and 4.



(a) Construct of VANET Sub-carriers Frequency Hopping System



(b) The Constitution of Frequency Hopping Controller

Figure 5. Sub-carriers Frequency Hopping System

In previous example in 2.1, let n=6, i=500, μ=3.9, the initial value of X_i is 0.6, we can obtained: X_i=0.6867, B=010000. The other analysis results of sub-carriers frequency hopping scheme are shown in Table 1 and Table 2. Although the frequency hopping pattern is different to Figure 4, it is also a feasible frequency hopping pattern.

Table 1. The State of Register in Each Sub-carriers Frequency Hopping Period (OBU-ID=2)

frequency hopping period	$D_5D_4D_3D_2D_1D_0$	$C_5C_4C_3C_2C_1C_0$	E
1	010000	000001	sub-carrier 1
2	100000	000010	sub-carrier 2
3	000001	000100	sub-carrier 3
4	000010	001000	sub-carrier 4
5	000100	010000	sub-carrier 5
6	001000	100000	sub-carrier 6

Table 2. Sub-carriers Frequency Hopping Pattern

$N_2N_1N_0$	Sub-carriers frequency pattern					
0	sub-carrier 5	sub-carrier 6	sub-carrier 1	sub-carrier 2	sub-carrier 3	sub-carrier 4
1	sub-carrier 6	sub-carrier 1	sub-carrier 2	sub-carrier 3	sub-carrier 4	sub-carrier 5
2	sub-carrier 1	sub-carrier 2	sub-carrier 3	sub-carrier 4	sub-carrier 5	sub-carrier 6
3	sub-carrier 2	sub-carrier 3	sub-carrier 4	sub-carrier 5	sub-carrier 6	sub-carrier 1
4	sub-carrier 3	sub-carrier 4	sub-carrier 5	sub-carrier 6	sub-carrier 1	sub-carrier 1
5	sub-carrier 4	sub-carrier 5	sub-carrier 6	sub-carrier 1	sub-carrier 2	sub-carrier 3

2.2.2. Synchronization Method of Logistic Chaos Sequence: In proposed VANET frequency hopping system above, because chaos sequence is very sensitive to initial value, the periodic orbits of two identical chaos systems may become uncorrelated. So it is difficult to keep chaos sequence synchronization between information sending side and receiving side. So far, there are many theories for synchronization control of chaotic sequence have been proposed [15, 16], we present a straightforward method [14], which can be used to achieve synchronization control between chaotic sequences X_i (in sending side) and Y_i (in receiving side) in VANET frequency hopping communication system. Let

$$\begin{aligned} X_{i+1} &= \mu_1 X_i(1-X_i) \quad (3.6<\mu_1<4) \\ Z_{i+1} &= \mu_2 Z_i(1-Z_i) \quad (3.6<\mu_2<4) \\ e_i &= \alpha X_i + \beta Z_i \\ e_{i+1} &= \mu e_i(1-e_i) \quad (1<\mu<3) \end{aligned} \tag{4}$$

From periodic orbit of Logistic sequence shown in Figure 6, we know that X_i and Z_i are all in chaotic status. Further more, we let

$$Z_{i+1} = \mu_2 Z_i(1-Z_i) + \xi_1(X_i - Z_i) + \xi_2[(\gamma+1)X_i - Z_i)]^2 + 2\xi_2\gamma X_i Z_i \tag{5}$$

We can get

$$\begin{aligned} &\alpha\mu = \alpha\mu_1 + \beta\xi_1 \\ &\alpha^2\mu = \alpha\mu_1 - \beta\xi_2(\gamma+1)^2 \\ &\mu = \mu_2 - \xi_1 \\ &\alpha\mu = \xi_2 \end{aligned} \tag{6}$$

And then, we have

$$\begin{aligned} &\xi_1 = \mu_2 - \mu \\ &\xi_2 = \frac{\mu_2(\mu_2 - \mu)}{\mu_2 - \mu_1} \\ &\alpha = \frac{\mu_2(\mu_2 - \mu)}{\mu(\mu_2 - \mu_1)} \\ &\beta = \frac{\mu_2(\mu - \mu_1)}{\mu(\mu_2 - \mu_1)} \end{aligned} \tag{7}$$

If formula (7) can be met, e_i converges to stable fixed point $e^* = 1 - 1/\mu$. X_i and Z_i have linear relationship as $Z_i = (e^* - \alpha X_i)/\beta$. And then, $Y_i = (e^* - \beta Z_i)/\alpha$, X_i and Y_i can keep synchronization commendably.

If let μ=2, μ_1=3.9, μ_2=3.7, according to formula (7), we have ζ_1=1.7, ζ_2=31.45, α=-15.725, β=15.575, γ=0.002841. Figure 7 shows the process of synchronization control between X_i and Z_i. It can be observed that e_i is unstable at the beginning time, during this time, X_i and Z_i are asynchronous. When time interval is more than 4, e_i converges to stable fixed point 0.5, From then on, Z_i keep synchronism with X_i.

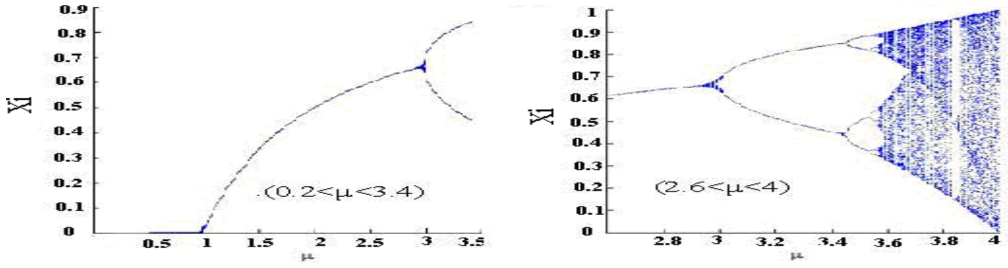
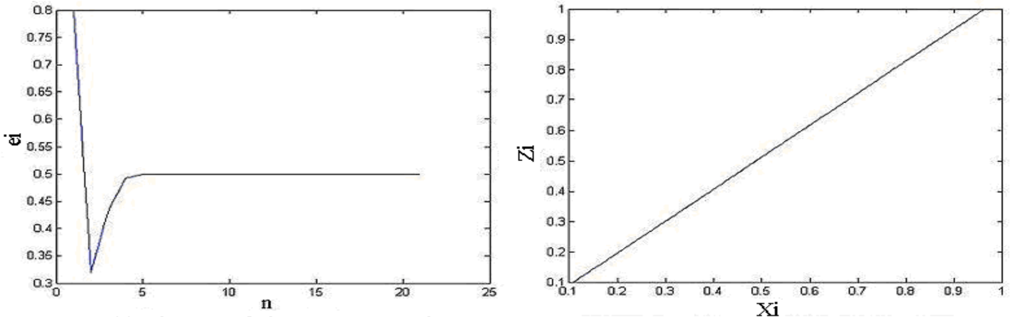


Figure 6. Periodic Orbit of Logistic Chaos Sequence



(a) Diagram of chaos sequence ei

(b) Synchronized relationship between Xi and Zi

Figure 7. Synchronization Control Process

3. Performance Analysis of Dynamic Bandwidth Partition Algorithm

In this section, we validate the performance of proposed dynamic bandwidth partition algorithm. According to formula (1), we have

$$N = \frac{7T_{CR} \cdot V}{L_{CR}} \tag{8}$$

The average number of permitted CCH access request is

$$E[Num] = N \times \sum_{i=1}^{4} \left(\frac{\lambda_{si}}{\sum_{k=1}^{4} \lambda_{sk}} \cdot p_i \right) \tag{9}$$

Hence, bandwidth assigned to ACi safety packets during safety interval is

$$S_i = \frac{N \cdot [\lambda_{si} / (\sum_{k=1}^{4} \lambda_{sk})] \cdot p_i \cdot L_{SA}}{T_{SA}} (M\ bit/s) \tag{10}$$

And total bandwidth of safety packets during safety interval is

$$S = \frac{Num \cdot L_{SA}}{T_{SA}} (M\ bit/s) \tag{11}$$

We validate the proposed dynamic bandwidth partition algorithm in different VANET conditions, the results are shown in Table 3, Table 4 and Table 5. It is assumed that V=6M bit/s, α=1.2, the four different priorities of safety packets have the same sending frequency, and the length of CCH reservation packets or safety packets is identical.

Table 3 shows the optimum length of CCH reservation interval and safety interval in terms of the safety packet sending frequency with different CCH access probability. Table 4 shows the optimum safety interval in terms of the safety packet length with different CCH access probability. It is clear that, CCH reservation interval increases with safety packet sending frequency, and safety interval increase with both the safety packet length and sending frequency significantly. In this case, the required time of transmitting CCH reservation packets or safety packets can be ensured commendably. Besides, if the CCH access probability increase, safety interval has to be increased for transmitting more safety packets during safety interval. Table 5 shows the bandwidth of safety packets during safety interval in terms of CCH access probability. It can be observed that, during safety interval, the 6M bit/s CCH bandwidth is assigned to different safety packets dynamically according to their CCH access probabilities. The assigned bandwidth of high priority safety packets is larger than low priority safety packets obviously. It means the QOS requirements of high priority safety packets can be met adequately.

Table 3. The Analysis Results of T_{CR} and T_{SA} in Terms of Safety Packet Sending Frequency

(Unit: ms, L_{CR}=600bytes, L_{SA}=2000bytes)

λ_{Si} (packets/second)	T_{CR} (ms)	$p_1=0.2,p_2=0.4,p_3=0.6,p_4=0.8$			$p_1=0.3,p_2=0.5,p_3=0.7,p_4=0.9$		
		T_{SA}	T_{CCH}	T_{SCH}	T_{SA}	T_{CCH})	T_{SCH}
20	1.0971	12.8	13.8971	86.1029	15.36	16.4571	83.5429
40	2.1943	25.6	27.7943	72.2057	30.72	32.9143	76.0857
60	3.2914	38.4	41.6914	58.3086	46.08	49.3714	50.6286
80	4.3886	51.2	55.5886	44.4114	61.44	65.8286	34.1714
100	5.4857	64.0	69.4857	30.5143	76.80	82.1857	17.7143
120	6.5829	76.8	83.3829	16.6171	92.16	98.7429	1.2571
140	7.6800	89.6	97.2800	2.7200	------	------	------

Table 4.The Analysis Results of T_{CR} and T_{SA} in Terms of Safety Packet Length

(Unit: ms, L_{CR}=600bytes, λ_{Si}=80 packets/second)

L_{SA} (bytes)	$p_1=0.2,p_2=0.4,p_3=0.6,p_4=0.8$			$p_1=0.3,p_2=0.5,p_3=0.7,p_4=0.9$		
	T_{SA} (ms)	T_{CCH} (ms)	T_{SCH} (ms)	T_{SA} (ms)	T_{CCH} (ms)	T_{SCH} (ms)
800	20.48	24.87	75.13	24.58	28.96	71.04
1100	28.16	32.55	67.45	33.79	38.18	61.82
1400	35.84	40.23	59.77	43.01	47.40	52.60
1700	43.52	47.91	52.09	52.22	56.61	43.39
2000	51.20	55.59	44.41	61.44	65.83	34.17
2300	58.88	63.27	36.73	70.66	75.04	24.96
2600	66.56	70.95	29.05	79.87	84.26	15.74
2900	74.24	78.63	21.37	89.09	93.48	6.52

Table 5. The Bandwidth Assignment Results with Different CCH Access Probability

(Unit: M bit/s)

CCH access probability	S_4	S_3	S_2	S_1	S
$p_1=0.2,p_2=0.3,p_3=0.4,p_4=0.5$	2.14	1.71	1.29	0.86	6
$p_1=0.3,p_2=0.4,p_3=0.5,p_4=0.6$	2.00	1.67	1.33	1.00	6
$p_1=0.2,p_2=0.4,p_3=0.6,p_4=0.8$	2.40	1.80	1.20	0.60	6
$p_1=0.3,p_2=0.5,p_3=0.7,p_4=0.9$	2.25	1.75	1.25	0.75	6

4. Conclusions

In this paper, we present a dynamic bandwidth partition algorithm for control channel of IEEE 802.11p VANET. The feature of our algorithm can be summarized in following three folds. First, CCH interval is divided into CCH reservation interval and safety interval. In order to ensure the throughput capacity of safety packets in CCH, the length of CCH reservation interval and safety interval can be adaptive adjustment according to current VANET conditions. Further, safety packets are differentiated to four priority types to meet varying QOS requirements of traffic safety messages. Meanwhile, a contention-free based CCH access control algorithm is presented, which performs dynamic CCH bandwidth partition according to traffic load and safety packets priorities. Finally, a frequency hopping system based on chaos scrambling technology is designed to improve communication reliability in VANET. Performance of our algorithm are analyzed by theoretical model, the results show that it is able to enhance the transmission efficiency of safety packets in CCH with high reliability. As further work, we will extend the research to complex VANET simulation model in Network Simulator 2 (NS 2), performance analysis of IEEE 802.11p physical layer, and efficient routing algorithm in multi-hop VANET environments.

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