A Novel MAC Protocol for VANET Based on Improved Generalized Prime Sequence

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Abstract. Protocol sequences are used for multiple access in the collision channel without feedback. In order to increase inter-cluster packet delivery radio in cluster-based VANETs, a MAC protocol based on Improved Generalized Prime Sequence (IGPS) is proposed in this paper. Extra transmitting time slots are inserted in Generalized Prime Sequence (GPS) of cluster heads while the corresponding positions in GPS of cluster members are inserted with extra receiving time slots. Compared to the MAC protocol based on GPS, the proposed MAC protocol guarantees the inter-cluster data transmission when the conflict occurred between inner-cluster and inter-cluster communication. Numerical results illustrate that the performance of IGPS-based scheme is superior to GPS-based one in terms of packet delivery ratio and throughput in the inter-cluster communication.

Ⅰ. Introduction

As one of the important component of Intelligent Transportation Systems (ITS), Vehicular Ad-hoc Networks (VANETs) have drawn the worldwide attention. In VANETs, each vehicle is equipped with an on-board unit (OBU), which is used to communicate with other vehicles and roadside units (RSU). Besides, RSU are distributed along the road, which are connected to the Internet. Thus, communications in VANET includes both vehicle-to-vehicle communications (V2V) and vehicle-to-roadside communications (V2R) in [1]. The U.S. Federal Communications Commission (FCC) has approved 75MHz in the 5.9 GHz frequency band licensed for Dedicated Short Range Communications (DSRC) for inter-vehicular communications.

Like all the other wireless networks, a MAC protocol should play a crucial role in scheduling application packet transmissions fairly and efficiently in VANETs. Due to the lack of a centralized control and the high mobility of vehicles in VANETs, maintaining time synchronization among nodes is a difficult task. It is also infeasible to elect one of the vehicles as a central access point using a leader election algorithm when vehicles may join or leave the system at a fast rate. Other than centralized control, carrier-sense multiple access (CSMA) and ALOHA is traditional contention-based and fully-distributed protocols for channel access. The CSMA protocol is not easy to implement and may not be suitable for quick dissemination of data in VANETs, because it requires a backoff algorithm.

Slotted ALOHA is a simple channel-access protocol without centralized scheduler. In slotted ALOHA, each node sends a packet in a time slot whit some fixed probability. Random numbers are required in the implementation. In practice, deterministic finite-state generators are used rather than truly random numbers. Protocol sequences are the deterministic binary sequences which used for multiple access in the collision channel without feedback in [2,3,4]. The zeros and ones in a protocol sequence are read out periodically, and a packet is sent if and only if it is one. In [5], the

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generalized prime sequences (GPS) is proposed for broadcasting safety messages. GPS guarantee that each node can send one packet at least in a sequence period. GPS does well than ALOHA-type random access scheme in the delay performance and packet delivery radio.

In VANETs, suitable clustering methods can construct a stable network topology and reduce the overhead of re-clustering. Clustering is also an effective method to limit channel contention, increase network capacity by spatial reuse of network resource and effectively control the net topology according to some researches of clustering-based MAC protocols in [6,7,8,9]. In this paper, we propose a MAC protocol based on Improved Generalized Prime Sequence (IGPS) for inter-cluster communication on VANETs.

In the rest of this paper, we first give a system model of VANETs and introduce the performance and construction of GPS in Section 2. Then we present our novel MAC protocol based on IGPS for VANET in Section 3, followed by simulation and performance analysis in Section 4. Conclusions are given in Section 5.

Ⅱ. System Model and Generalized Prime Sequences

We assume that the system is slot-synchronous and limited by interference. And it is also the half-duplex transmission. Each time frame is divided into several time slots. At any time slot, there is a collision if two or more users transmit packets, then the collided packet cannot be recovered. Packet can be received without any error if only one user transmits packet at a time slot. All lost packet are due to packet collisions and successfully received packets are error-free.

Clustering is an effective way to solve the scalability of VANETs. According to relative position, movement directions and speeds of the nodes, we use SOM neural network algorithm to cluster nodes together. Number of each cluster's nodes is less than M which is a maximum prime number to construct IGPS with good performance. If N is defined as the number of nodes in cluster which is less than M, the parameter of IGPS is decided with N. Otherwise, IGPS is constructed with M. Consider a cluster consisting of cluster head and cluster members, each of them is within the transmission range of each other. A node is elected to be the cluster head. And only cluster head can transmit the inter-cluster packets. The other nodes called cluster members. Cluster member only can handle the inner-cluster packet. In each cluster, cluster head selects a channel for the inner-cluster communication; moreover, every cluster member transmits packets on the same channel. Cluster head assign protocol sequences to each node. Each node reads out the zeros and ones of the assigned protocol sequence periodically, and transmits a packet in a time slot if and only if the sequence value is equal to one.

Then we will introduce the constructions method of protocol sequences.

Let L be the period of a set of protocol sequences. The *hamming weight* of a protocol sequence a(t) is the number of ones in period.

$$w_a = \sum_{t=0}^{L-1} a(t). \tag{1}$$

The *hamming cross-correlation* between two sequences a(t) and b(t) is the number of overlapping ones between a(t) and the sequence obtained by cyclically shifting b(t) by some delay offset τ.

$$H_{ab}(\tau) = \sum_{t=0}^{L-1} a(t) b^{(\tau)}(t). \tag{2}$$

The *characteristic set* of sequence a(t) is the set of time indices. That is, it is the location where element is equal to 1 in a(t).We define $rem(x, p)$ to be the remainder of x divided by p, which is an integer between 0 and p-1. Let p be a prime number and q is an integer greater than or equal to p. We construct p protocol sequences which *hamming weight* is p as follows:

For $g = 0, 1, 2,\dots, p$-1, then the *characteristic set* of sequence s_g(t) is

$$I_g = \{rem(gl, p) + lq, l = 0,1,2,\dots, p-1\}. \tag{3}$$

The sequence associated with I_g is called the *generalized prime sequence* (GPS) by g. Then the sequence is a deterministic and periodic sequence with period $L=pq$. The sequence can be divided into p *pieces* and the length of *pieces* is q. According to *characteristic set*, we can construct the sequence s_g(t) according to I_g.

For example, let $p = 5$ and $q = 7$, the five *characteristic sets* are

$I_0 = \{0, 7, 14, 21, 28\}$, $I_1 = \{0, 8, 16, 24, 32\}$,

$I_2 = \{0, 9, 18, 22, 31\}$, $I_3 = \{0, 10, 15, 25, 30\}$,

$I_4 = \{0, 11, 17, 23, 29\}$.

And according to the corresponding *characteristic sets* $\{I_g\}$, GPS are

$s_0(t)$: 1000000 1000000 1000000 1000000 1000000

$s_1(t)$: 1000000 0100000 0010000 0001000 0000100

$s_2(t)$: 1000000 0010000 0000100 0100000 0001000

$s_3(t)$: 1000000 0001000 0100000 0000100 0010000

$s_4(t)$: 1000000 0000100 0001000 0010000 0100000

User g starts transmitting at *the relative delay offset* τ_g, and transmits a packet at time slot $t+\tau_g$ if $s_g(t+\tau_g) = 1$, but listens to incoming packet if $s_g(t+\tau_g) = 0$. The *individual delay* of user g is defined as the waiting time until packet can be received without collision. The *group delay* of user g is the waiting time until all users have transmitted one packet successful at lease. We can define the group delay as the maximum of the individual delays.

Ⅲ. Improved Generalized Prime Sequence

Because the assignment of protocol sequences is controlled independently by each cluster head, we can’t guarantee that the sequences between cluster heads are different to each other. So it is difficult to avoid collisions among the inter-cluster communication. Then we propose the novel MAC protocol based on IGPS for inter-cluster communication.

We assume that the number of cluster nodes less than M which is a prime number. M is a suitable number for constructing GPS. Each cluster uses the same set of protocol sequences but the sequences of cluster heads assigned are different. Then in the sequence of cluster head, we will insert “1” behind each original element “1”, and in the same positions of sequences of cluster members insert “0”. In other words, extra transmitting time slots are inserted in GPS of cluster heads while the corresponding positions in GPS of cluster members are inserted with extra receiving time slots. The new protocol sequences constructed in this way is called *improved generalized prime sequence*.

Let $p = 5$ and $q = 7$, we assume the protocol sequences of cluster head is $s_0(t)$ in cluster1. IGPS of cluster1 are

$s_0(t)$: 11000000 11000000 11000000 11000000 11000000

$s_1(t)$: 10000000 00100000 00010000 00001000 00000100

$s_2(t)$: 10000000 00010000 00000100 00100000 00001000

$s_3(t)$: 10000000 00001000 00100000 00000100 00010000

$s_4(t)$: 10000000 00000100 00001000 00010000 00100000

Then if $u_3(t)$ is the protocol sequence of cluster head in cluster2, IGPS of cluster2 are

$u_0(t)$: 10000000 10000000 10000000 10000000 10000000

$u_1(t)$: 10000000 01000000 00010000 00010000 00000100

$u_2(t)$: 10000000 00100000 00000100 01000000 00001000

$u_3(t)$: 11000000 00011000 01100000 00001100 00110000

$u_4(t)$: 10000000 00000100 00001000 00100000 01000000

Due to each cluster uses the same set of protocol sequences, we stipulate that sequence can not be used if other clusters head have used. Then we assume that cluster1 and cluster2 use the same parameters to construct protocol sequences. For the convenience, we mark nodes with s_i(t) in cluster1 and u_i(t) in cluster2 in Figure. 1. Cluster head in each cluster is assigned different sequence such as s_0(t) and u_3(t), clusters member use sequences except sequence has used. So u_0(t) in cluster2 and s_3(t) in cluster1 can't be used If s_0 has transmitted inter-cluster packet to u_3 at t = 8, s_0 will repeat this process at $t = 9$ due to the inserted consecutive transmission time slots. Unfortunately, u_1 will also transmit the inner-cluster packet at $t = 9$ due to $u_1(9) = 1$. Thus, a collision occurred because there are two packets transmitted at the same time slot in cluster 2. At next time slot, it is time for u_1 to transmits packets in cluster2 because of $u_1(9)$ equal to 1.Then there is a collision occurred because two users transmit packet to u_3. Those packets are not received by u_3.

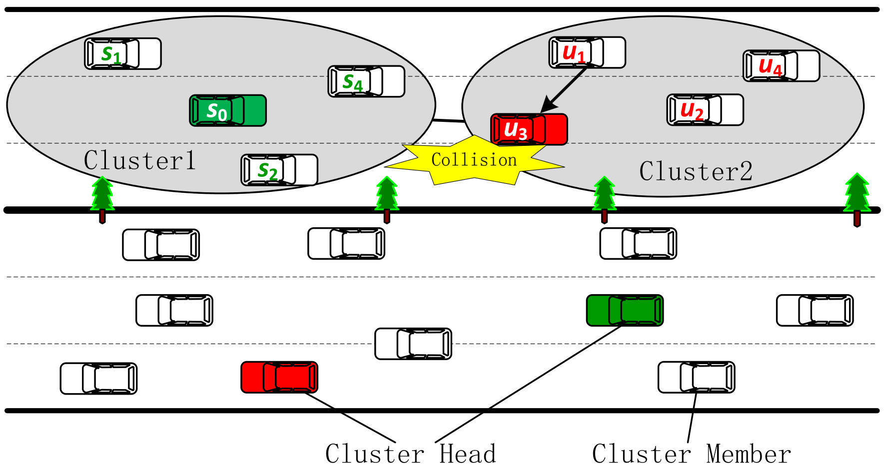

Fig. 1 A dual three-lane road scenario

Cluster head's *hamming weight* of IGPS is $2p$, and cluster members' *hamming weight* are p. And IGPS is a deterministic and periodic sequence with period $L = p(q+1)$. It can be divided into p *pieces* and the length of *pieces* is $q+1$. The sequence of cluster head assigned by IGPS has two consecutive time slots per *piece* to send packets. This method increase inter-cluster packet delivery radio and average throughput.

Ⅳ. Simulation and Performance Analysis

We present our simulation and analysis to show the performance results of the proposed IGPS-based MAC protocol in this section. In simulation scenario, users are divided into two clusters that the number of cluster nodes is fixed; then two clusters use the same set of sequences based on GPS or IGPS to transmit packet. Each of nodes is within the transmission range of each other in the same cluster. Only cluster head can transmit packet between two clusters. The main parameters are listed in Table 1 as follow.

Table 1. Simulation parameters

PARAMETER	VALUE
Maximum vehicle speed	28m/s
Working frequency	5.9GHz
Transmit radio	6Mbps
Receiving threshold	300m
transmit antenna gain G_t	1
receive antenna gain G_r	1
system loss L	1
Received power threshold	5.09314×10^{-11}W
packet size	30 bytes
time slot	42μs

The contrast of the success transmission times in a period of cluster head based on GPS and IGPS is showed in Figure. 2. We consider that the number of users and the relative delay offset are the same in two cases. Then we can see that when the number of users is fixed, success transmission times in a period based on IGPS is more than GPS. Because IGPS assigns cluster head with two consecutive time slots to transmit inter-cluster packets, the opportunity of transmit packets of cluster head is more than GPS. When users start transmitting after *the relative delay offset*, times of transmission without collision is also more than GPS.

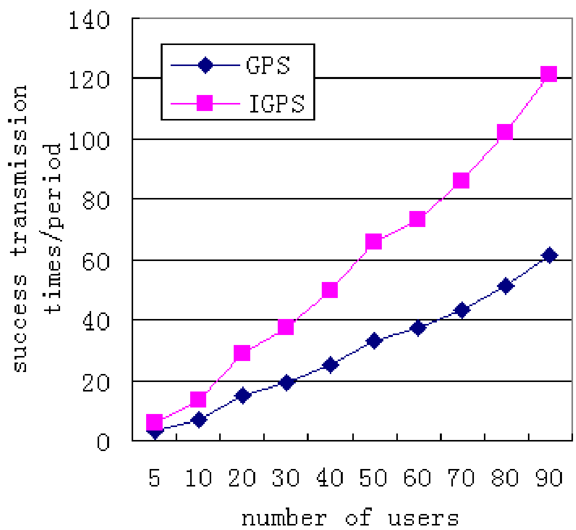

Fig. 2 Success transmission times

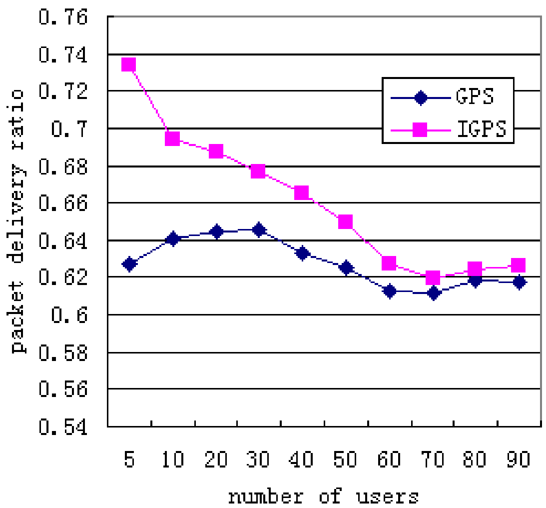

Fig. 3 Packet delivery ratio

When cluster head wants to communicate with another cluster head, we analyze the packet delivery ratio between two clusters in system. Fig. 3 shows the packet delivery ratio performance of cluster head. We can observe that the superiority of IGPS is distinct when the number of users in system is small. The reason is that cluster head has more opportunities to transmit inter-cluster packet in a period. As the number of nodes increases, the difference of two curves becomes indistinguishable because the proportion of the success transmission times per period will decrease and become close to each other (1/p for IGPS and 1/(2p-1) for GPS). However, the dominated advantage of IGPS is shorter average time interval of inter-cluster success communication compared to GPS as shown in Figure. 4.

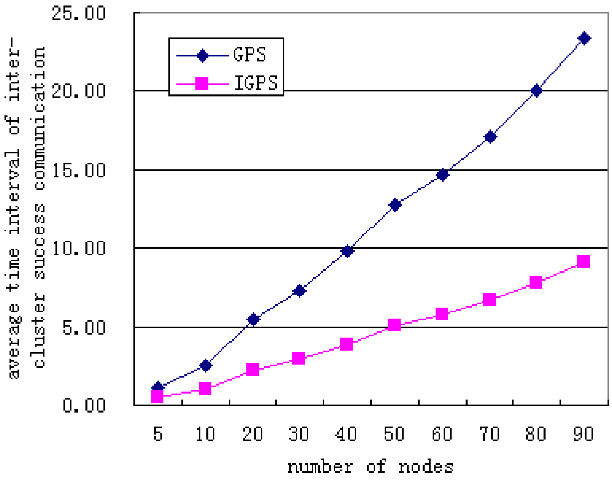

Fig. 4 Average time interval of inter-cluster success communication

As the increase of total nodes, the superiority of IGPS becomes more significant than GPS in terms of average time interval of inter-cluster success communication. For a given node number, the aforementioned average time interval of IGPS is smaller than GPS. The transmission times of cluster head based on IGPS per *pieces* is two, and it is adjacent so that the transmission time interval is zero in *piece*. However, each pieces of GPS only has one transmission times, it led to cluster head should wait the next *piece* when transmits unsuccessfully. As the increase of nodes, the length of *pieces* is also increase. So the average time interval of successful transmission based on GPS is greater than IGPS.

It should be noted that it has a great influence on the whole system's performance if inserting many transmitting time slots for cluster head in GPS such as throughput, packet delivery ratio.

Ⅴ.Conclusions

Vehicular ad hoc networking is a promising MANET for Intelligent Transportation Systems. In this paper we protocol a novel MAC protocol for VANETs for inter-cluster communication based on Improved Generalized Prime Sequence (IGPS). IGPS is designed to increase the inter-cluster success communication radio. The proposed schemes can provide the deterministic binary sequences IGPS which used for multiple access in the collision channel without feedback. Simulation results show that IGPS increases the success transmission times per period and decrease average time interval of inter-cluster success communication. Therefore, IGPS is more suitable than GPS in cluster-based VANETs.

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