A Novel Adaptive Hello Mechanism Based Geographic Routing Protocol for FANETs

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Abstract. In geographic routing protocols for flying Ad hoc networks (FANETs), unmanned aerial vehicles need to maintain real-time positions of their one-hop neighbor nodes to make effective routing decisions. Periodic broadcasting of Hello packets that involve real-time geographic position coordinates of nodes itself is a popular method to maintain neighbor information table. However, the traditional periodic Hello mechanism ignores node mobility, network connectivity and traffic type, thus causes temporary communication blindness (TCB). To address this problem, an adaptive Hello mechanism (AHM) for geographic routing is proposed in this paper. The Hello period of working nodes is calculated according to the real-time relative characteristic values between the node and its upstream node, and the Hello period of idle nodes adopts a fixed value according to the movement characteristics relative to all neighbor nodes. Moreover, the AHM is integrated into the widely-used greedy perimeter stateless routing (GPSR) protocol, and is compared with the original GPSR in simulation. The results show that AHM significantly mitigates the TCB problem and gains a high packet successful transmission rate without producing more routing overhead.

Keywords: Flying Ad hoc network · Geographic routing · Adaptive Hello mechanism · Temporary communication blindness · Successful transmission rate

1 Introduction

Recently, Unmanned Aerial Vehicles (UAVs) with the characteristic of low cost, strong robustness, various applications etc., have become a high-tech with rapid growth, and attracted much attention in both military and civil fields. Especially, the multi-UAV system, which has the advantages of good scalability, high invulnerability and high efficiency, etc., can play an important role in multiple military operations, such as battlefield reconnaissance, border patrolling, communication relay, precision strike, etc. A flexible, dynamic, distributed, and robust communication network for multi-UAV is the basis and premise for task coordination between UAVs. Flying Ad hoc Network (FANET) is the core technology for constructing UAV communication networks [1, 2]. Not relying on prebuilt communication infrastructures, it can transmit multiple kinds of information between UAVs, such as control instruction, situational awareness, and

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reconnaissance intelligence, etc., through aeronautical wireless channel, thus forming a multi-hop, self-organized, temporary and distributed network. Several key technologies, such as dynamic topology control and routing protocol, etc., are used in FANET to achieve the interconnection of multiple UAVs [3]. It can not only extend the communication coverage, provide high-reliability and high-robustness communication links, but also improve the efficiency of task execution for UAVs.

FANET is a special form of mobile Ad hoc network (MANET), and routing protocol is responsible for discovering one or more paths and delivering packets from source to destination through a multi-hop path [4]. Till now, a large number of routing protocols have been used in FANETs, such as, DSDV, OLSR, DSR, AODV, TORA, and so on [5, 6]. Among these routing protocols, geographic routing protocols have received much attention due to their substantial advantages as compared to topology based routing protocols [7–10]. Geographic routing protocols have been shown to be efficient with accurate position information in static topology networks. However, in situations where nodes are mobile, the local topology rarely remains static. Hence, it is necessary that each node periodically broadcasts its up-dated location information to all of its neighbors. These position update packets are usually referred to as Hello information. In most geographic routing protocols, Hello packets are broadcast periodically for maintaining a neighbor table at each node. Periodic Hello mechanism has several drawbacks: (1) In the mobile scenarios, fixed period Hello mechanism will bring out temporary communication blindness (TCB) problem and will cause massive data packets loss; (2) Reception and processing of Hello packets consumes energy which is wasteful in idle nodes; (3) Hello packets may collide with data packets.

The periodic Hello mechanism for MANETs stems from the Hello protocol in OSPF version 2 and is adopted by most geographic routing protocols. Chakeres et al. in [11] studied Hello protocol in 802.11 ad-hoc networks and suggested that the lifetime for which a neighbor entry should be 2 times the Hello interval for optimal throughput in mobile scenarios. Han et al. in [12] proposed an adaptive Hello scheme to save energy by suppressing unnecessary Hello information. Mahmud et al. in [13] also proposed an energy efficient Hello scheme based on some mission-related information to save energy for FANET routing protocols. Hernandez-Cons et al. in [14] proposed an adaptive Hello mechanism based on the link change rate. Park et al. in [15] proposed a Hello mechanism where the Hello interval is determined by node speed and transmission range.

In this paper, we propose a novel adaptive Hello mechanism (AHM) for geographic routing protocols to mitigate the drawbacks of the periodic Hello mechanism in FANETs. In the AHM, the Hello period of working nodes is calculated according to the real-time relative characteristic values between the node and its upstream node, and the Hello period of idle nodes adopts a fixed value according to the movement characteristics relative to all neighbor nodes. Furthermore, we integrate the AHM into the widely-used greedy perimeter stateless routing protocol (GPSR) [16] to verify its performance.

The rest of paper is organized as follows. In Sect. 2, we briefly describe the TCB problem. A detailed description of the AHM is provided in Sect. 3. The performance of AHM protocol is verified and analyzed through simulation in Sect. 4. Finally, Sect. 5 concludes the paper.

2 Description of TCB

In geographic routing protocols, when a source node needs to send a packet to a destination, it searches its neighbor table for a node that is closest to the destination. However, the selected node is often close to its communication boundary. The communication link between them may easily break down due to the movement of nodes, and the link stability is poor. Meanwhile, the upstream node does not recognize the situation timely that the link is broken. Thus, packets transmitted on the link will be lost. This phenomenon is defined as the TCB problem, and it is caused by high node dynamics, long Hello period and short node transmission range.

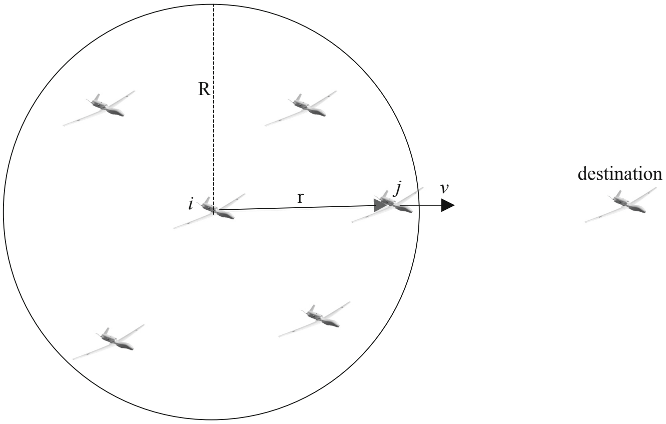


Fig. 1. The TCB problem.

The TCB is shown in Fig. 1. Hello period is assumed to set as 4s in geographic routing protocol. The upstream node *i* selects node *j* as the next hop node from its neighbor table at time 0 s, for it is the closest to the destination in its neighbor nodes. However, due to the movement of node *i* and node *j*, node *j* may move out from the transmission range of node *i* at time 2 s. If node *i* forwards a packet to node *j* after time 2 s, node *j* cannot receive the packet. And it is not recognized by node *i* at the time of forwarding the packet. In the periodic Hello mechanism, the lifetime of neighbor nodes in neighbor table is often set to be 2 times of the Hello period. Thus, node *j* will be removed from the neighbor table of node *i* at time 8s. During this period, TCB will lead to packet loss and affect the performance of the geographic routing protocol seriously.

3 Adaptive Hello Mechanism

3.1 Network Model

In this paper, FANET is modeled as a graph $G(V, E)$, where V is the set of nodes and E is the set of full-duplex, directed communication links. E is changing over time when nodes move. Each node has at least one transmitter and one receiver, and is represented by a unique identifier. Let $N(i)$ denote the set of neighbor nodes of node i. In addition, among the numerous characteristic variables, we assume that the characteristics of FANET are determined by the following factors: location, velocity, direction and transmission range of each UAV. Thus, a set of characteristic variables about any node i is denoted as a_i^t,

$$a_i^t = \left(\left(x_i^t, y_i^t\right), v_i^t, \theta_i^t, R_i\right) \tag{1}$$

Where $\left(x_i^t, y_i^t\right)$, v_i^t, and θ_i^t represents location, velocity and direction of node i at time t respectively, and R_i represents the transmission range of node i.

Node j is a neighbor node of node i, and a_{ij}^t is used to represent characteristic value of node j relative to node i. Hence, a_{ij}^t is the function of relative location, relative velocity and transmission range of node j and node i, namely,

$$a_{ij}^t = \left(\left(x_{ij}^t, y_{ij}^t\right), v_{ij}^t, \theta_{ij}^t, R_i, R_j\right) \tag{2}$$

Where $\left(x_{ij}^t, y_{ij}^t\right) = \left(x_j^t, y_j^t\right) - \left(x_i^t, y_i^t\right)$ represents the relative location vector between node j and node i at time t. v_{ij}^t and θ_{ij}^t represents the relative velocity and the relative direction between node j and node i at time t, respectively.

In this paper, we make the following assumptions:

(1) The transmission range of all nodes is equal. For any $i, j \in \forall\ (V)$, $R_i = R_j = R$;
(2) Each node i knows its position $\left(x_i^t, y_i^t\right)$, which can be acquired through GPS device or other types of positioning service;
(3) Each node in FANET makes random motion with a velocity valued randomly at $[0, v_{\max}]$, and a direction valued randomly at $[0, 2\pi]$, and the velocity and direction are independent of each other. That is

$$v \sim U[0, v_{\max}], p(v) = \frac{1}{v_{\max}}, v \in [0, v_{\max}] \tag{3}$$

$$\theta \sim U[0, 2\pi], p(\theta) = \frac{1}{2\pi}, \theta \in [0, 2\pi] \tag{4}$$

$$p(v, \theta) = p(v)p(\theta) \tag{5}$$

(4) Δt is defined as the Hello period of the Hello mechanism. We assume that in Eq. (3) to Eq. (5), v and θ are constant values in the short time interval Δt.

3.2 Theoretical Derivation of Adaptive Hello Period

According to the above assumptions, node j is a neighbor node of node i and makes movement relative to node i. The departure probability P is defined as the probability that node j moves out of the transmission range of node i after Δt. Intuitively, P is a monotonous increasing function of Δt. One Hello period Δt is corresponding to a certain probability $1-P$ within which node j will stay in the transmission range of node i. So we can select a certain value of P and correspondingly calculate the value of Δt. If the value of P is smaller, the value of Δt is smaller correspondingly, and the TCB problem will be mitigated. If P is 0, the TCB problem will be eliminated. We select a certain value of P (defined as the threshold P_0 of departure probability) and calculate the variable Hello period Δt as follows.

As shown in Fig. 2, it is easy to know that the characteristic value of node j relative to node i at time t_0 is $a_{ij}^{t_0}$, namely

$$a_{ij}^{t_0} = \left(\left(x_{ij}^{t_0}, y_{ij}^{t_0}\right), v_{ij}^{t_0}, \theta_{ij}^{t_0}, R\right) \tag{6}$$

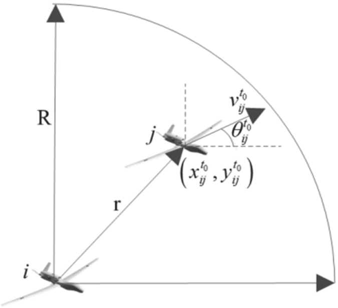


Fig. 2. Characteristic value $a_{ij}^{t_0}$ of node j relative to node i at time t_0.

The position of node j after Δt can be expressed as $\left(x_{ij}^{t_0} + v_{ij}^{t_0}\Delta t\cos\theta_{ij}^{t_0}, y_{ij}^{t_0} + v_{ij}^{t_0}\Delta t\sin\theta_{ij}^{t_0}\right)$.

So the condition that node j moves out from the transmission range of node i can be expressed as

$$\left(x_{ij}^{t_0} + v_{ij}^{t_0}\Delta t\cos\theta_{ij}^{t_0}\right)^2 + \left(y_{ij}^{t_0} + v_{ij}^{t_0}\Delta t\sin\theta_{ij}^{t_0}\right)^2 \geq R^2 \tag{7}$$

It can be derived from Eq. (7) that

$$\Delta t \geq \frac{-\gamma_{ij}^{t_0} + \sqrt{R^2 - \left(r_{ij}^{t_0}\right)^2 + \left(\gamma_{ij}^{t_0}\right)^2}}{v_{ij}^{t_0}} \tag{8}$$

Where

$$\gamma_{ij}^{t_0} = x_{ij}^{t_0}\cos\theta_{ij}^{t_0} + y_{ij}^{t_0}\sin\theta_{ij}^{t_0} \tag{9}$$

$$\left(r_{ij}^{t_0}\right)^2 = \left(x_{ij}^{t_0}\right)^2 + \left(y_{ij}^{t_0}\right)^2 \tag{10}$$

Where $r_{ij}^{t_0}$ represents the distance between node j and node i at time t_0.

From Eq. (8) to (10), Δt is a function of $\left(x_{ij}^{t_0}, y_{ij}^{t_0}\right)$, $v_{ij}^{t_0}$, and $\theta_{ij}^{t_0}$. Given the relative position $\left(x_{ij}^{t_0}, y_{ij}^{t_0}\right)$ of the two nodes and the distributed density of $v_{ij}^{t_0}$ and $\theta_{ij}^{t_0}$, and with the derivation of the distributed density $p(\Delta t)$ of Δt, the threshold P_0 can be set. Therefore, it has

$$p(\Delta t) = \int_0^{\Delta t} p(t)dt = P_0 \tag{11}$$

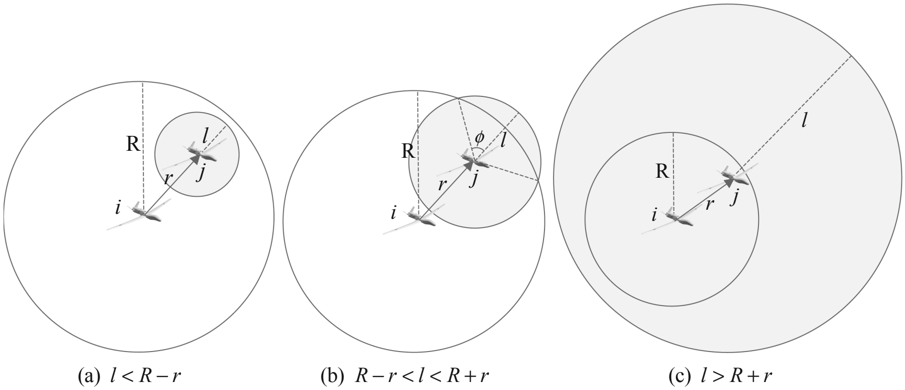
The value of Hello period Δt can be obtained according to Eq. (11). However, it is very difficult to derive the value of Δt by this method, and the following method can be used to replace the above one.

The departure probability $p(\Delta t)$ that node j moves out of the transmission range of node i after Δt can be expressed as

$$p(\Delta t) = \iint\limits_{\Omega} p(v, \theta)dvd\theta = \iint\limits_{\Omega} p(v)p(\theta)dvd\theta \tag{12}$$

Where Ω represents the area where node j will appear outside the transmission range of node i.

The area where node j will appear after time Δt is a circle with radius $l = v_{\max}^{ij} \cdot \Delta t$, in which $v_{\max}^{ij}$ represents the maximal relative velocity between node j and node i. According to the relationship between l, R and r, there are three circumstances, as shown in Fig. 3.



(a) $l < R - r$ (b) $R - r < l < R + r$ (c) $l > R + r$

Fig. 3. Possible locations of node j after Δt.

(1) As shown in Fig. 3(a), if $l < R - r$, it can be obtained that $p(\Delta t) = 0$.

(2) As shown in Fig. 3(b), if $R - r < l < R + r$, the relative velocity v should satisfies that

$$0 \le \frac{R - r}{\Delta t} \le v \le \frac{R + r}{\Delta t} \le v_{\max}^{ij} \tag{13}$$

Here, we define $v_{-} = \max\left(0, \frac{R-r}{\Delta t}\right)$ and $v_{+} = \min\left(v_{\max}^{ij}, \frac{R+r}{\Delta t}\right)$. Therefore,

$$p(\Delta t) \ = \ \int_{v_{-}}^{v_{+}} p(v) \int_{-\phi(v)}^{\phi(v)} p(\theta) d\theta dv \qquad (14)$$

Where $\phi(v)$ means the maximal direction which node j can move out of the transmission range of node i, and it can be expressed as

$$\phi(v) \ = \ \pi\text{-}\arccos\left(\frac{(v\Delta t)^2 + r^2 - R^2}{2rv\Delta t}\right) \qquad (15)$$

(3) As shown in Fig. 3(c), if $l > R + r$, when v is valued at $\left[\frac{R+r}{\Delta t}, v_{\max}^{ij}\right]$, node j can move out of the transmission range of node i with any direction, and it has

$$p(\Delta t) \ = \ \int_{\frac{R+r}{\Delta t}}^{v_{\max}^{ij}} p(v) \int_{0}^{2\pi} p(\theta) d\theta dv \qquad (16)$$

Based on the above analysis, the Hello period Δt can be calculated from Eq. (11). Figure 4 shows the numerical results of departure probability P as a function of time Δt. In Fig. 4, the relative velocity v_{ij} is uniformly distributed on [300, 340] m/s, the transmission radius R is 200 *km*, and the distance r between two nodes is 180 km and 150 km, respectively. It can be seen that P increases with the increase of Δt, and when the distance between two nodes is longer, the faster P rises with the increase of Δt. When P_0 is 0, Δt will be less than $\frac{R-r}{v_{\max}}$. This means that the departure probability P that a node j moves out of the transmission range of node i is 0. In this case, the TCB problem will not occur and packets will not be lost.

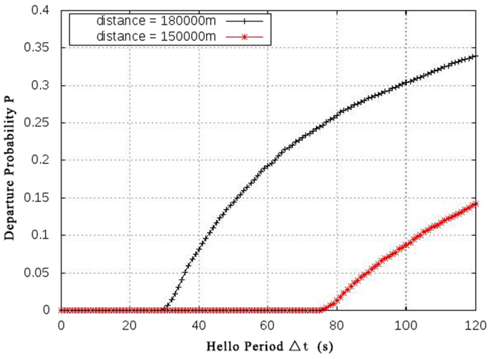


Fig. 4. Departure probability P as a function of time Δt.

In FANETs, if node i have $K = num(N(i))$ neighbor nodes, the Hello period of node i relative to all nodes in $N(i)$ can be derived as Δt_n $(n = 1, 2, 3, \cdots, K)$ using the above method.

3.3 Description of Adaptive Hello Mechanism

The overall flow of the proposed AHM in this paper is shown in Fig. 5. It is mainly composed of three modules: node state differentiation, calculation of Hello period for working nodes, and calculation of Hello period for idle nodes.

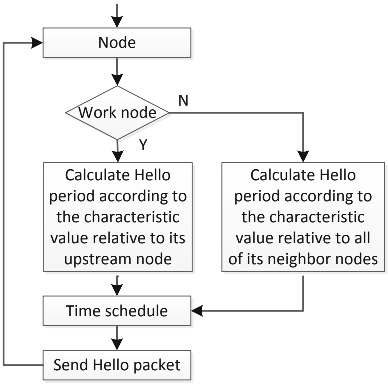


Fig. 5. Flow of AHM.

The first module differentiates node state. When a small percent of nodes in a large FANET are involved in packet forwarding, channel resource spent by all of its neighbor nodes in maintaining their positions is a huge waste. To address this problem, we divide all nodes into working nodes and idle nodes. Working nodes are packet forwarding nodes, which are participating in packet transmission. The other nodes are idle nodes, which are not participating in packet transmission. However, with the change of tasks or network topology, the state of nodes may change at any time.

The second module is calculation of Hello period for working node. For working nodes, they should send Hello packets timely to its upstream node to provide accurate position for routing decision. Therefore, the Hello period of working nodes should be calculated according to the relative characteristic values between the node and its upstream node using the method described in Part B of Sect. 3. And the Hello period is updated timely according to the changes of their relative motion.

The third module is calculation of Hello period for idle nodes. For an idle node, it should get the characteristic values relative to all of its neighbor nodes firstly, and then calculate the Hello period respectively. Finally, its Hello period Δt is obtained by $\Delta t = \frac{1}{K}\sum_{n=1}^{K}\Delta t_n$. In order to simplify the calculation and save energy, the idle node can adopt a fixed Hello period, which can be set longer than that in GPSR protocol.

4 Simulations

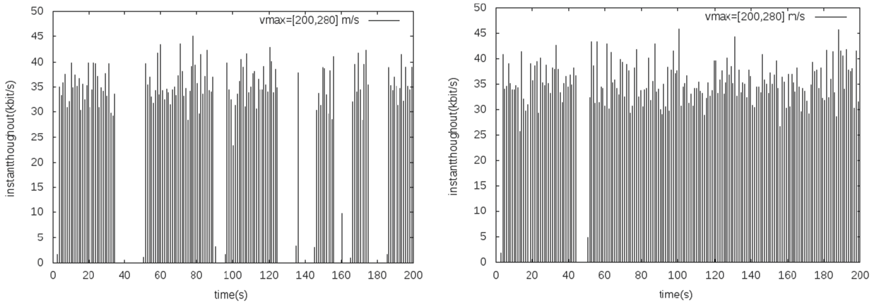
In this paper, we have incorporated the AHM to the traditional GPSR protocol, which is labeled as AGGR. In this section, the effectiveness of AHM will be verified by the comparison of simulations for AGGR and GPSR protocol which adopted the Hello scheme of fixed period (10s). The simulations are conducted in NS-2. The main simulation parameters are set as in Table 1.

Table 1. Simulation parameters.

Parameter	Value	Parameter	Value
Number of nodes	50	Simulation scenario	$500 \times 500 \times 20$ km^3
Transmission range of nodes	200 km	Simulation time	3600 s
Packet type	CBR 512 bits	Packet rate	10 packets/s
Channel bandwidth	2 Mbit/s	Node velocity	[200,280], [280,360], [360,440], [440,520], [520,600], [600,680] m/s

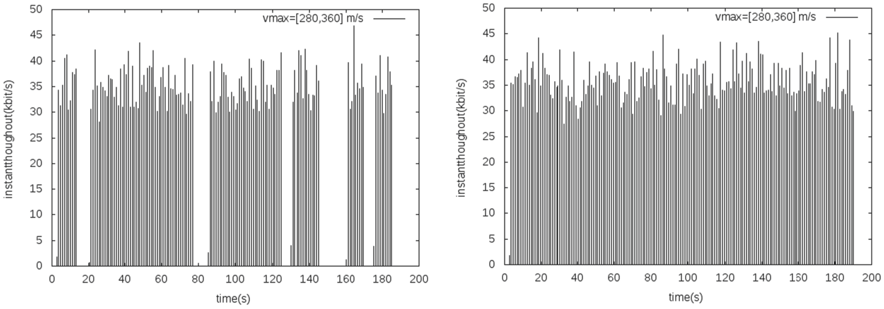
Instant throughput of GPSR and AGGR protocol under different node velocity is shown in Fig. 6. As can be seen, GPSR protocol using the periodic Hello mechanism causes the TCB problem. With the increase of node velocity, the network dynamics increases, and the packet loss caused by TCB becomes more serious. However, the AGGR protocol using the AHM reduces TCB effectively, and gets a high instant throughput.

Delivery success ratio, control overhead, average throughput and transmission delay of GPSR and AGGR protocol are shown from Fig. 7, 8, 9 and Fig. 10, respectively. As can be seen from Fig. 7, the packet successful transmission rate decreases with the increase of node velocity in the GPSR protocol using periodic Hello mechanism, but it is less affected by the motion of nodes in the AGGR protocol. It indicates that the AGGR protocol has good adaptability to dynamic network topology and can be applied to highly-dynamic FANETs. As shown in Fig. 8, in the GPSR protocol, due to the increase of node velocity, the total number of packets successful transmitted is reduced, while the number of Hello packets is basically unchanged, resulting in an increase of the control overhead. In the AGGR protocol, the Hello period decreases adaptively with the increase of velocity of relative motion between nodes, and the number of Hello packets increases, resulting in an increase of control overhead. But it is still lower than that in GPSR. Figure 9 shows that after adopting the AHM, the neighbor node table is accurately constructed and maintained, which can reflect the changes of local topology, improve the sensitivity to link breakages, and reduce packet loss. Figure 10 shows that due to the accurate construction of neighbor table, the optimal node can be chosen for the next hop, and the transmission delay is also reduced.



(a) Instant throughput of GPSR with v_{max}=[200, 280]m/s.

(b) Instant throughput of AGGR with v_{max}=[200, 280]m/s.



(c) Instant throughput of GPSR with v_{max}=[280, 360]m/s.

(d) Instant throughput of AGGR with v_{max}=[280, 360]m/s.

Fig. 6. Instant throughput of GPSR and AGGR with different velocities.

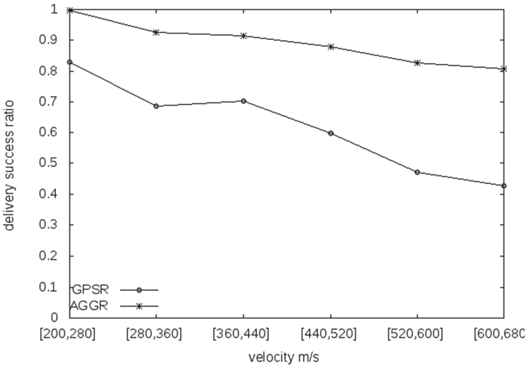


Fig. 7. Delivery success ratio of GPSR and AGGR.

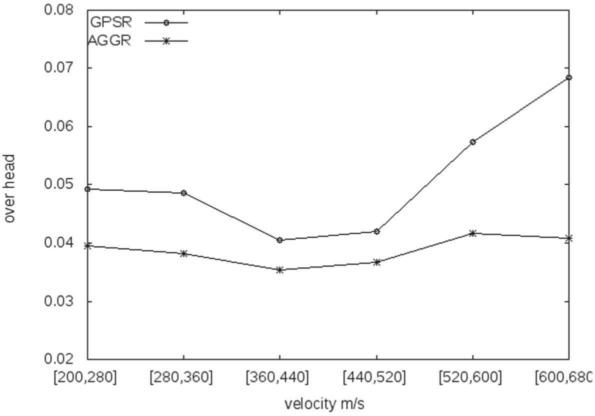


Fig. 8. Control overhead of GPSR and AGGR.

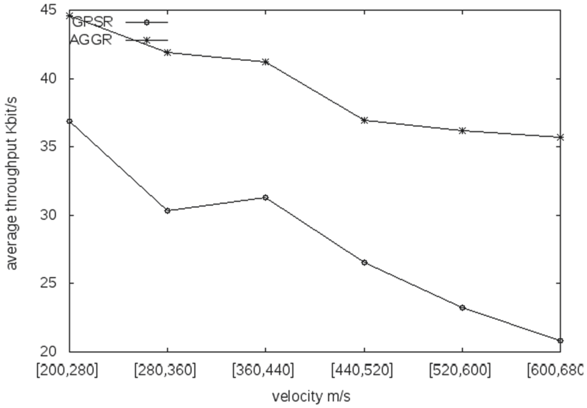


Fig. 9. Average throughput of GPSR and AGGR.

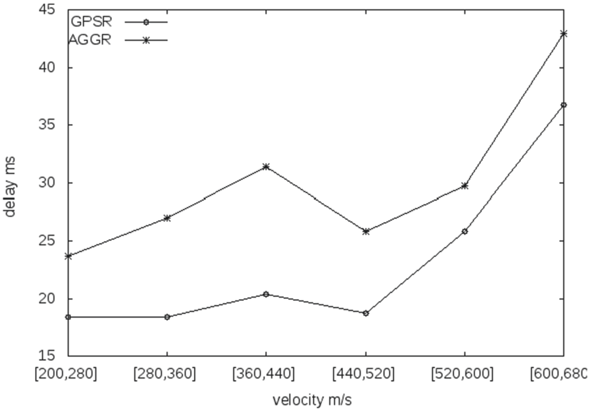


Fig. 10. Transmission delay of GPSR and AGGR.

5 Conclusions

In this paper, in order to address the TCB problem in geographic routing protocols, a novel AHM is proposed for FANETs. The AHM divides all nodes into working nodes and idle nodes, and nodes in different states adopt different methods for the Hello period. It can eliminate the drawbacks of the periodic Hello scheme and gain a high packet successful transmission rate without causing more routing overhead. Simulation results show that it improves the accuracy and real-time performance of the neighbor table, provides a reliable basis for geographic routing protocols, and is scalable and applicable to FANETs.

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