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The Topology Stability of Vehicular Ad Hoc Network

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Abstract: The goal of this paper is to look for relatively stable area in the Vehicular Ad hoc Network (VANET), thereby helping for developing more stable routing protocols. We built a theoretical model to analysis the stability of the VANET topology, and provided the simulation experiment to verify the correctness of the theoretical analysis. Results show that the vehicle traveling in the same direction is easier to maintain the stability of the topology of a VANET, and the valid time of the path will decrease with the increase of the intersection angle in the direction of the vehicle movement, the vehicle movement velocity and the time. In addition, the simulation results also show that the bigger the initial distance among the vehicles is, the less stable the network topology is. The discovery of this phenomenon is important to develop zoned routing protocols.

Introduction

As a typical application of Mobile Ad hoc Network (MANET), Vehicular Ad hoc Network attracts attentions from many researchers [1,2,3,4]. It has wide application prospect in traffic control, traffic safety, driving assistance, business services and other aspects. In Vehicular Ad hoc Network, with nodes moving at high speed, the motion trail is limited on the road. Besides, the network topology changes quickly. As a result, more attention shall be paid to traffic condition of the road ahead during the vehicle travel[5]. Therefore, looking for reliable and stable transmission path in Vehicular Ad hoc Network to convey traffic condition of the road ahead to the vehicles behind is what Vehicular Ad hoc Network study focuses on. One of the key factors that result in the decline of network performance and limit of Internet scale expansion is the quick movement of nodes[6,7]. Hence reducing the number of path interruption resulted from the highly mobile to the largest extent will be of great importance to improve the performance of network, and choosing stable data forwarding path is one of effective ways to reduce the influence of nodes mobile. There are two ways of confirming stable paths: Nodes location method and nodes received signal strength method[8,9]. The former, attaching GPS Orientation information to the data grouping, is used to predict the period of validity of the link to the adjacent node and choose the most stable path. The latter predicts the stability of the link according to signal strength received by nodes. Forwarding path is allowed to be built only when the received signal strength is bigger than threshold value. This method needs the support of Cross layer function. During actual design, sometimes, it is difficult to get received signal strength information from basic protocol[10]. Given that GPS devices installed on modern vehicle are relatively widespread and nodes in the Vehicular Ad hoc Network are hardly affected by electric energy and memory capacity, the stable path selection method based on the nodes location has wider and brighter development prospect[11]. This paper builds analytical mode based on Nodes location method. Theoretical analysis and simulation results show that the vehicles traveling in the same direction are easier to maintain the stability of the topology of the network in a VANET, and the valid time of the path will decrease with the increase of the intersection angle in the direction of the vehicle movement, the vehicle movement velocity and the time.

Theoretical Analysis

Nodes location method, attaching GPS Orientation information to the data grouping, is used to predict the period of validity of the link to the adjacent nodes and choose the most stable path. As it can decide the routing according to the data package destination nodes location information without maintaining routing table information, it has high expandability and validity. In the Vehicular Ad hoc network environment, the nodes location reflects the connectivity among them. Thus location information-based routing is very applicable to Vehicular Ad hoc Network, and is expected to be a key factor to promote the development of Vehicular Ad hoc Network. In order to obtain the nodes location information, each node is requested to be allocated with devices such as GPS, which can provide not only information for limited route, but also network timing and Global step for nodes with GPS.

Provided that the location of vehicles can be obtained by vehicle-mounted GPS device, the neighboring vehicles will send signal mark periodically to communicate. Set that signal coverage area of vehicles is a circle with the radius of r, and vehicle B is within the range of signal coverage area of vehicle A. Set that the running speed of vehicle A is v_1, and that of vehicle B is v_2. Initial position of vehicle A is represented in (x_0 , y_0), and vehicle B is (x_0' , y_0'). Included angle between running direction of vehicle A and X axis is θ_1, and included angle between running direction of vehicle B and X axis is θ_2; after time t, the location of vehicle A is represented in (x_1 , y_1), and vehicle B is represented in(x_2 , y_2). See figure 1.

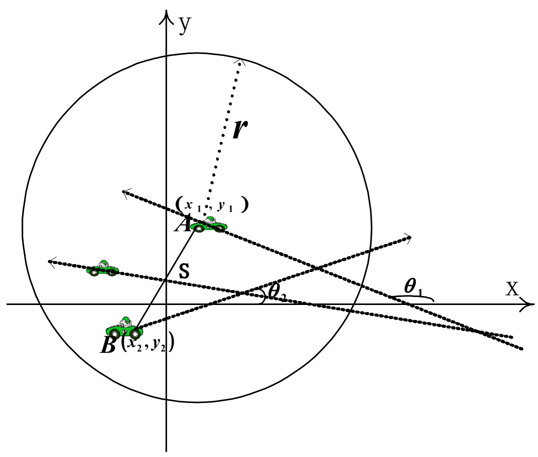

Fig1 Vehicle travelling location

Intuitively, if the included angle between vehicle A and vehicle B is 0°. After time t, the distance d between them is $|v_1 - v_2|t$, if the included angle between vehicle A and vehicle B is 180°, and after time t, the distance d between them is $(v_1 + v_2)t$.

In the actual transportation system, the included angle of the running direction among the vehicles can not always remain 0° or 180°, According to the above assumptions, the following mathematical model can be built to describe the distance between vehicle A and vehicle B after time t.

Set the running distance of vehicle A in time t is d_1, and that of vehicle B is d_2. After time t, the distance between vehicle A and vehicle B is S, so:

$$d_1 = v_1 t \, , d_2 = v_2 t \tag{1}$$

$$x_1 = x_0 + d_1 \cos\theta_1(t) \, , y_1 = y_0 + d_1 \sin\theta_1(t) \tag{2}$$

$$x_2 = x_0^{'} + d_2 \cos\theta_2(t)\,,\; y_2 = y_0^{'} + d_2 \sin\theta_2(t) \tag{3}$$

$$S_0 = \sqrt{(x_0 - x_0^{'})^2 + (y_0 - y_0^{'})^2} \tag{4}$$

$$\begin{aligned} m &= 2t[(x_0 - x_0^{'})(v_1\cos\theta_1 - v_2\cos\theta_2) + (y_0 - y_0^{'})(v_1\sin\theta_1 - v_2\sin\theta_2)] \\ &= 2[(x_0 - x_0^{'})(x_1 - x_2) + (y_0 - y_0^{'})(y_1 - y_2)] - 2s_0^2 \end{aligned} \tag{5}$$

$$n = t^2[v_1^2 + v_2^2 - 2v_1 v_2 \cos(\theta_1 - \theta_2)] \tag{6}$$

$$s = \sqrt{s_0^2 + m + n} \tag{7}$$

According to the formula (7), the change of **s** is directly related to the change of **m** and **n.** Suppose when $|\theta_1 - \theta_2| < \frac{\pi}{2}$, $n_1 = t^2[v_1^2 + v_2^2 - 2v_1v_2\cos(\theta_1 - \theta_2)]$ .when $\frac{\pi}{2} < |\theta_1 - \theta_2| < \pi$, $n_2 = t^2[v_1^2 + v_2^2 - 2v_1v_2\cos(\theta_1 - \theta_2)]$. Clearly the following conclusions can be obtained: ① $n_2 > n_1 > 0$,② n_1 and n_2 increase as $|\theta_1 - \theta_2|$ increases,③ n_1 and n_2 increase as time **t** increase, ④ n_2 increases as v_1 and v_2 increase.

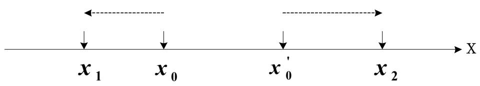

Fig 2 Situation 1 of reverse driving

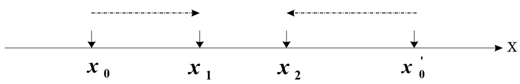

Fig3 Situation 2 of reverse driving

The initial position of Vehicle A is (x_0 , y_0) and that of Vehicle B is ($x_0^{'}$, $y_0^{'}$). So $(x_0 - x_0^{'})$ and $(y_0 - y_0^{'})$ are constants. As a result of the restriction of road width, the value of $y_1 - y_2$ changes little in time **t.** When inspecting the value of **m,** we should pay attention to the changes of $(x_0 - x_0^{'})(x_1 - x_2)$ as time changes. If Vehicle A and Vehicle B travel in the same direction, set $s^{'} = (x_0 - x_0^{'})(x_1 - x_2)$. If Vehicle A and Vehicle B travel in the reverse direction, set $s^{''} = (x_0 - x_0^{'})(x_1 - x_2)$. When $x_0 < x_0^{'}$, and $s^{'} > 0$, driving in the reverse direction. It can be divided into three situations to discuss the relationship between $s^{'}$ and $s^{''}$: the first situation is as seen in figure 2, where $s^{''} > s^{'}$; the second situation is as seen in figure 3, where $s^{''} < s^{'}$; the third situation is as seen in figure 4,where $s^{''} < s^{'}$.

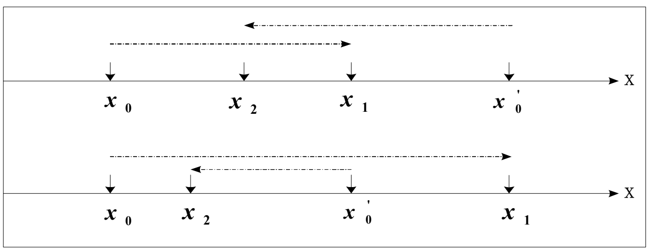

Fig4 Situation 3 of reverse driving

Similarly, when $x_0 > x_0^{'}$, we can analyze the relationship between $s^{'}$ and $s^{''}$. Suppose no matter when the Vehicle A and Vehicle B travel in the same direction or reverse direction, they shall be subject to uniform distribution. Set p'$_1$={t| $s^{''} > s^{'}$ },p'$_2$={t| $s^{''} < s^{'}$ }. Based on the above analysis, we can get $p'_1=p'_2$. Suppose $\bar{s}_1$ is the distance between vehicle A and vehicle B after homonymous driving of time t, and $\bar{s}_2$ is the distance between vehicle A and B after reverse driving of time t. $p_1=\{t|\bar{s}_1 < \bar{s}_2\}$,$p_2=\{t|\bar{s}_1 > \bar{s}_2\}$. Based on the above analysis, we can get $p_1 > p_2$.

Simulation

From formula （7）,we can get $\frac{ds}{dt}=(\frac{dm}{dt}+\frac{dn}{dt})/2s$. When the vehicle speed changes in [40km/h, 60km/h], G1 is used to represent that the included angle between the driving directions of vehicle A and vehicle B changes in the range of [5°, 10°], G2 represents the included angle changes in the range of [15°, 20°] , G3 represents the included angle changes in the range of [30°, 35°] and G4 represents the included angle changes in the range of [130°, 160°]. When the vehicle speed changes in the range of [80km/h, 100km/h], F1 is used to represent that the included angle of the driving directions of vehicle A and vehicle B changes in the range of [5°, 10°], F2 represents the included angle changes in the range of [15°, 20°], F3 represents the included angle changes in the range of [20°, 25°] and F4 represents the included angle changes in the rangeof [130°, 160°]. When the vehicle speed changes in the range of [120km/h, 140km/h], H1 is used to represent that the included angle of the driving directions of vehicle A and vehicle B changes in the range of [5°, 10°], H2 represents the included angle changes in the range of [15°, 20°], H3 represents the included angle changes in the range of [20°, 25°] and H4 represents the included angle changes in the range of [130°, 160°]. Simulation results are as shown in the figures 5 to 13.

The simulation results show that, as the included angle of driving directions of vehicle A and vehicle B increases, the rate of change of the distance between them will be greater. It shows that the network topology of the vehicles driving in the same direction is easier to maintain stable. When the included angle of driving direction of vehicle A and vehicle B changes in the range of 130°-160°, the distance between vehicle A and B will change sharply from the beginning and is difficult to keep stable. It shows that the driving direction of vehicles has great effects on the topology stability in Vehicular Ad hoc Network. The figures 11-13 show when the vehicle speed reaches above 120km/h, H1 will have obvious fluctuations, and the topology stability in Vehicular Ad hoc Network will decrease as the driving speed increases. The simulation results also show that, with time increasing, the topology stability in Vehicular Ad hoc Network will become worse and worse, and it decreases as time increases. Through the simulation, an interesting phenomenon can be found that initial distance of vehicles also has certain effects on the topology stability in Vehicular Ad hoc Network. The further the initial distance is, the less stable the network topology is. It can contribute to construct more precise partition and is of great importance in developing a kind of quick and reliable routing protocol suitable to Vehicular Ad hoc Network.

Conclusion and future work

Theoretical analysis and simulation results show that the vehicles driving in the same direction are easier to maintain the stability of the network topology. When the vehicles keep driving in the same direction, the stability of the network topology will decrease as time and speed increases. The impact of the driving speed on the stability of network topology is smaller than that of driving direction. Initial distance of vehicles also makes impact on the stability of network topology. The bigger the initial distance, the less stable the network topology is. The discovery of this phenomenon is important to improve Multicast Protocol of “Space temporary” raised by Chen[12]. The protocol can support some interesting applications, such as emergencies, online games and video advertising. In the future, something can be done to improve the protocol according to the research results in this paper.

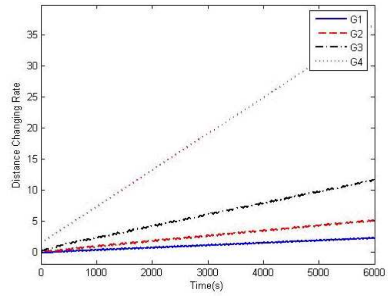

Fig5 Distance 100m, velocity 40-60km/ h

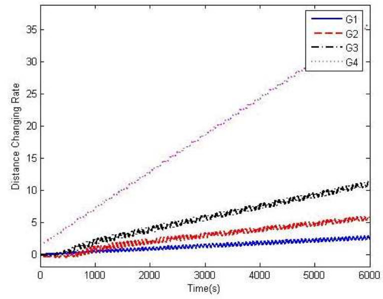

Fig6 Distance 500m, velocity 40-60km/h

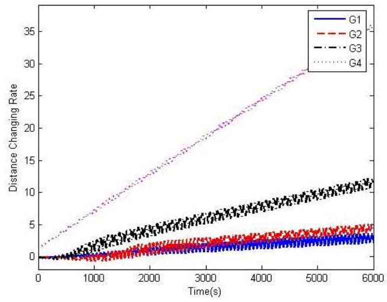

Fig7 Distance 1000m, velocity 40-60km/h

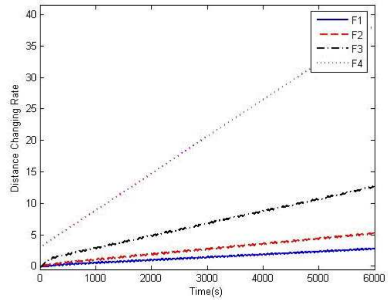

Fig8 Distance 100m, velocity 80-100km/h

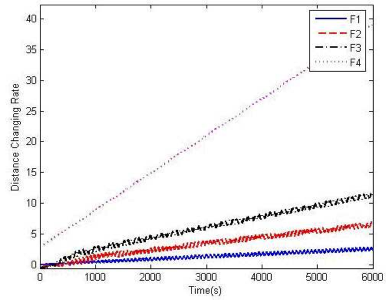

Fig9 Distance 500m, velocity 80-100km/h

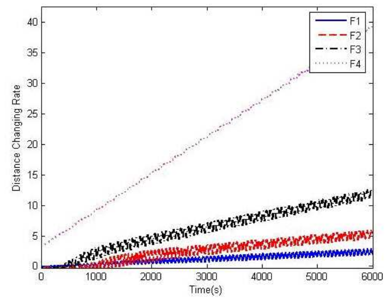

Fig10 Distance 1000m, velocity 80-100km/h

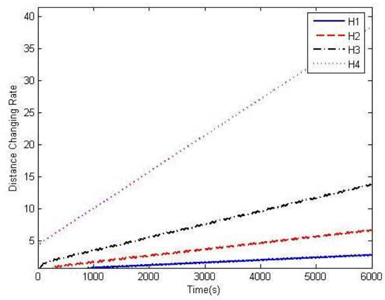

Fig11 Distance 100m, velocity 120-140km/h

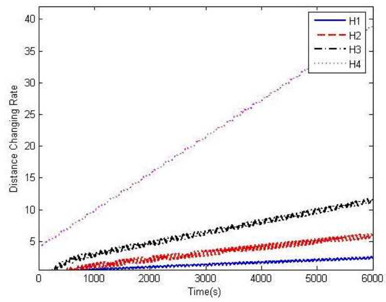

Fig12 Distance 500m, velocity 120-140km/h

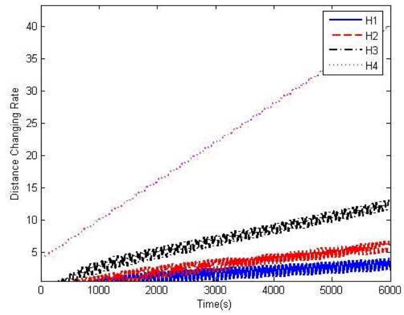

Fig13 Distance 1000m, velocity 120-140km/h

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