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An Improved Routing Protocol Based on Gauss-Markov Model In Ad Hoc Networks Utilizing Prediction of Link Quality

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Abstract: Ample research has been conducted in routing protocols for Mobile Ad Hoc Networks while traditional protocols cannot satisfy the demand of highly-dynamic environment. Though nodes in highly-dynamic environment often have supersonic velocity, they mainly perform their task with the same mission and their velocity and direction are basically approximate. Hence, the feature makes it possible to forecast links' quality. In this paper, Gauss-Markov mobility model (GM) was introduced in order to reduce the influence of random movement on simulation performance; meanwhile we have improved the routing protocol based on DSR by utilizing the idea of link's lifetime. Although the improved protocol may increase the number of hops in data transmission, it makes the network more stable. Compared to the original DSR protocol based 'minimum hops', simulation results operated in Qualnet present us the superior performances of the improved protocol, especially in Packet Delivery Ratio, Received Throughput, Average End-to-end Delay and Average Jitter.

Key Words: Ad Hoc, highly-dynamic, Gauss-Markov Model, lifetime

1 Introduction

Tactical Internet based on Ad Hoc Network technology plays a vital role in battlefield communication systems. At present, the flight speed of advanced cruise missiles, air defense missiles, fighter jets, unmanned reconnaissance aircraft and other high-speed flight bodies can reach Mach 3-4. In the future, flying bodies which employ the next-generation supersonic combustion ramjet will be able to fly at a speed of Mach 6-10. Due to high-speed and high dynamic resistance which gives rise to frequent changes in network topology, flying bodies form the highly dynamic network.

Network nodes complete the appropriate path selection through routing protocols, thus providing basis and support for end-to-end data transmission. Therefore the performance of routing protocols will affect the quality of data transmission in a great extent. Although international research of mobile Ad Hoc Network technology has been conducted for many years, the speed of mobile Ad Hoc Network relay nodes involved in most cases is slower. In general, the speed is 5-50 m/s, and it has an order of magnitude difference with supersonic flying bodies, which cannot satisfy the demand of high-speed mobile ad hoc networks. As a consequence, the task we confront is to design a suitable routing protocol for highly-dynamic environment, and to ensure better data delivery and real-time communication.

In highly-dynamic environment, because of high speed and limited wireless communication range, the life time of link between nodes is short. However, in modern warfare, combat aircraft mainly perform their task in flying formation with the same mission, whose velocity magnitude and direction are basically approximate and trend to reveal a series of specific variation rules, as shown in Fig.1. Hence, the feature makes it possible for the forecast of link quality.

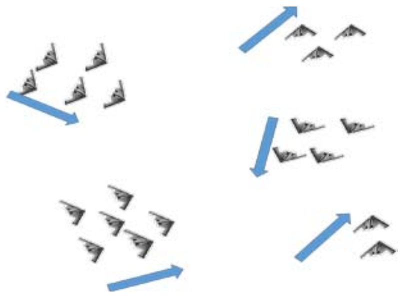

Fig. 1: Combat formations in highly-dynamic environment

Quite a few approaches have been proposed to predict the link quality. A link existence probability model was put forward [1] for the network whose channels changed slowly. Literature [2] presented a method to predict the link stability through the signal strength, but it did not take into account node's memory of movement. A routing protocol based on the geographical location was provided in which nodes moved at the speed of 25 m/s in [3] and the typical high-speed is 20 to 50 m/s in the current multitudinous location-based routing protocols. Literature [4] provided the network performance of DSR, OLSR and AODV routing protocols under the speed of 2000m/s (equivalent to 6 Mach) through simulation. Nevertheless, these methods were all simulated in random mobility model at low speed. When nodes move completely randomly, we cannot foresee the next position with huge difference from node movement of actual network.

Therefore, Gauss-Markov mobility model (GM) is introduced in order to reduce the influence of random movement on simulation performance, while the algorithm of life time based on DSR routing protocol is utilized for link quality prediction. A number of simulation results show that the algorithm based on life time of link has obviously

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improved the effect of packet delivery ratio, transmission delay, delay jitter, etc. We assume that every node knows its velocity and location.

The rest of this paper is organized as follows. The next section presents the GM model and section 3 describes our algorithm based on DSR routing protocol by utilizing link's lifetime. Section 4 shows the superiority of the scheme by simulation results, and Section 5 concludes this paper.

2 Gauss-Markov Mobility Model

The research and optimizing of most network protocols depend on a large number of simulations. In the simulation, we need to imitate the movement of nodes, thus the concept of mobility model was proposed. The performance of the same algorithm may vary tremendously in different network mobility models. As a result, in order to achieve the best network performance, a specific mobility model must be established for the particular application scenario.

Gauss-Markov Mobility Model was primitively applied to terminal's rapid positioning in mobile network. In this model, the movement rate of mobile nodes is regarded as a Gauss-Markov process of temporal relation. Originally, each mobile node is assigned to the initial speed and direction, and each node updates its current speed and direction after a fixed time interval. The model is divided into discrete time intervals and the velocity vector updates at the beginning of each interval.

The speed of nodes in GM is described as follows:

$$\begin{cases} x_n = \alpha x_{n-1} + (1-\alpha)\overline{x} + \sqrt{(1-\alpha^2)}x_{x_{n-1}} \\ y_n = \alpha y_{n-1} + (1-\alpha)\overline{y} + \sqrt{(1-\alpha^2)}y_{y_{n-1}} \\ z_n = \alpha z_{n-1} + (1-\alpha)\overline{z} + \sqrt{(1-\alpha^2)}z_{z_{n-1}} \end{cases} \quad (1)$$

$\overline{x}$, $\overline{y}$, $\overline{z}$ represent the average speed of nodes in the three coordinate axes and $x_{x_{n-1}}$, $y_{y_{n-1}}$, $z_{z_{n-1}}$ denote random variables who obey Gauss distribution. Besides, $0 \le a \le 1$ is a random variable, and the randomness of nodes can be controlled through changing the value of a.

GM model provides a more authentic model for mobile nodes. As nodes' speed at any moment is a function whose parameters are nodes' past speed and a Gaussian random variable, the movement of nodes is smooth thus avoiding mutations of speed or direction. As long as the memory parameter $a \ne 1$, the node will not move in a straight line and will not stop in the entire process of simulation. Previous to this work, the simulator built-in mobility models included constant velocity, random-walk, random-direction, random-waypoint, etc [5]. Later in this paper we will show that these features have a remarkable impact on routing performance.

Fig.2 is a schematic diagram of node movement when the value of a is respectively assigned to 0.0, 0.25, 0.85 and 1.0. As shown, the smaller the parameter a is, the stronger the randomness and mutation of node movement is. On the contrary, the stronger the memory of node movement is, the smoother the motion trajectory is. Results show that the GM model is consistent with the node movement in veritable highly-dynamic environment and it possesses favorable predictability, so GM model could be applied to the simulation of this paper.

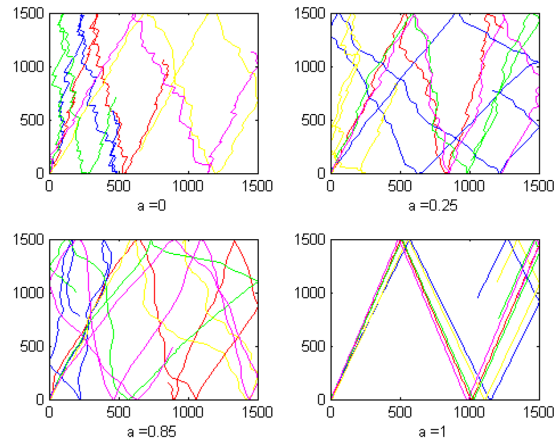

Fig. 2: Gauss-Markov model with a = 0, 0.25, 0.85, and 1

3 Improved Routing Algorithm

DSR protocol (Dynamic Source Routing) employs source routing and the header of each packet contains the entire routing information in order that intermediate nodes do not need to maintain all the current routing information. Moreover, it is feasible to avert the periodic routing broadcast and detection for neighboring nodes owing to the feature of on-demand routing. DSR protocol consists of two processes: route discovery and route maintenance. Firstly, flooding routing is adopted by the process of route discovery. In order to reduce the overhead of route discover, each node includes a buffer to store routing information learned and used recently. Secondly, route maintenance process is the mechanism for the source node to detect whether the network topology has changed. If the topology changes and source routing is interrupted, the source node will receive an error message. It will try to use the routing information in the cache, if it fails to restart the route discovery process. Then the source node will try to search the routing information in its cache, if it fails and then it will restart the route discovery process.

The DSR protocol has the following advantages: (1) The source routing is capable of avoiding loops and supports both unidirectional and bidirectional paths. (2) It can obtain a plurality of available paths by means of simultaneous searching, so as to response to changes in network topology as rapidly as possible. (3) The routing buffer technology can reduce the cost of routing discovery further. (4) It only maintains routes when it comes to communication; meanwhile it reduces the cost of routing maintenance.

Nevertheless, the DSR protocol selects routing path according to the principle of 'minimum hops'. Due to nodes' high-speed movement in highly-dynamic environment, network topology changes drastically and disconnections between communication links may occur frequently, which lead to the loss of data packets and increase of packet loss rate. As a result, it requires frequent establishment of route link, increasing the overhead of network routing and deteriorating the performance of network routing.

Since there are always differences in direction and velocity between flying bodies, the displacement will change constantly. In addition, because of the attenuation of electromagnetic wave, communication between two nodes is affected by distance. When the distance between two flying bodies has reached the maximum communication distance, the communication link between two flying bodies will be disconnected; therefore there is finite lifetime in a communication link between mobile communicating nodes. In low-speed mobile environment, link failures will not happen in general within the effective time. But in the high-speed mobile environment, the link's lifetime is extremely small so that the link is prone to become invalid, resulting in the loss of data packets being forwarded. And a large number of routing maintenance packages caused by link failures add much cost to the process of routing maintenance.

In addition, the routing discovery restarted will bring a lot of redundant load to network and the performance of current network will decrease sharply. The uppermost reason why the criterion of 'minimum hops' cannot be applied to highly-dynamic environment is that it cannot handle the issue of frequent link failure caused by link lifetime.

As shown in Fig.3, $d_{\max}$ represents the maximal communication range between node A and node B. When B moves beyond the scope of A's communication range, this link will become ineffective and then we can calculate the link's lifetime.

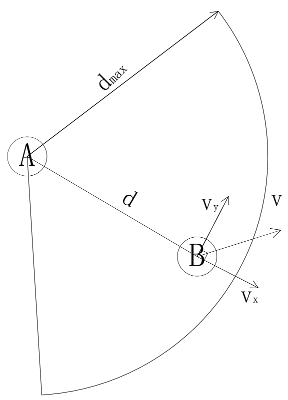

Fig. 3: The lifetime between nodes

As shown in Fig.4, d is the current distance between nodes A and B, α and β represent the velocity direction of nodes A and B. What's more, $(x_1, y_1), (x_2, y_2)$ are coordinates of two nodes' current position, v_{ab} and γ represent the magnitude and direction of two nodes' relative velocity and θ denotes the direction of two nodes' relative displacement [6]. Thus, the effective communication lifetime (as shown in Equation(2)) between two mobile nodes can be calculated according to the method in Figure 4.

$$LT = \frac{\sqrt{d_{\max}{}^2 - d^2 \sin^2(\gamma-\theta)} - d\cos(\gamma-\theta)}{v_{AB}} \quad (2)$$

A route consists of several links in general. For instance, the path's-1-2-d' consisting of node s, 1, 2, d is composed of link s-1, 1-2 and 2-d. According to the above method in Fig.4, we can calculate each link's lifetime $LT(N_s, N_1)$, $LT(N_1, N_2)$, $LT(N_2, N_d)$. If any link of the path breaks, the path will also be invalid, therefore the lifetime of the entire path is determined by the shortest lifetime of all links, as shown in (3).

$$LT(N_s, N_d) = \min[LT(N_s, N_1), LT(N_1, N_2), LT(N_2, N_d)] \quad (3)$$

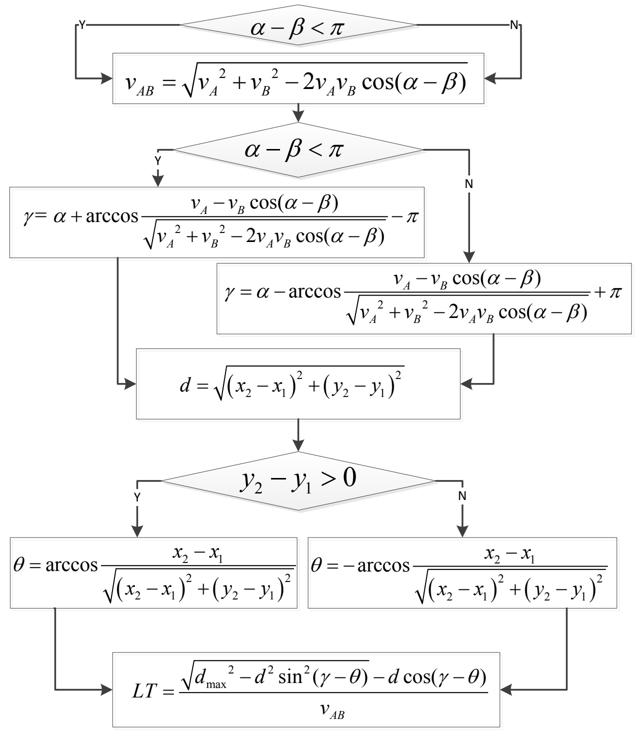

Fig. 4: The approach to compute lifetime between nodes

What's more, we have to discuss the impact of GM models and ordinary memoryless models for simulation. As is described, mobility models built-in the traditional simulation tools are unrealistic and unnatural. It is impossible to anticipate the position and velocity of next moment in highly-dynamic environment so that our proposed methods and improved protocols become meaningless. In the GM model the predictability of speed and position ensure the feasibility of our improved protocol.

Table 1: Comparison between Memoryless and GM model

	Memoryless Model	GM
Packet Delivery Ratio	12.10%	62.85%
Average End-to-end Delay(sec)	0.422308841	0.016373330
Average Jitter(sec)	0.068961944	0.005188396

As can be seen from Table 1, the deterioration of Packet Delivery Ratio and Average End-to-end Delay of the memoryless model is extremely serious in highly-dynamic environment, thus there is no reference and any significance in such research. Therefore, any new algorithms or improved protocols must be operated in the model with practical significance and only in this way there will be possibility for further study.

4 Simulation and Results

We study the performance of our improved protocol in Qualnet which is widely employed by networking simulation research. Our simulations were performed with

10 nodes in a square sized 30 km*30 km. The antenna type was Directional-Antenna and the node transmission range was 1500m. Every simulation ran for 300s and in this way we can ensure that the modified algorithm had been steady before performance metric calculations. This parameter will be described later in this section. In the simulation, we mainly change the average velocity of mobile nodes from 1 Ma to 5 Ma. Each group of simulation was performed 300 times using different Data Sets, and finally we computed average results of each simulation group.

Table 2 concludes the mainly parameters for simulation of the improved protocol. Our GM model will take both the memory parameter and random Gauss variables into consideration and they can be tuned as nodes mobility type changes. In this simulation the value of memory parameter a in GM model is 0.85 and the range of random Gauss variable is [-50, 50]. In the simulation 10 nodes were divided into a group.

Table 2: Simulation Parameters

Number of Nodes	10
Packets	UDP
Traffic Type	CBR
Packet Size	512 byte
Node Transmission Range	1500 m
Simulation Time	300 s
Nodes Speed Range	1M,2M,3M, 4M,5M
Antenna Type	Directional Antenna
Network Size	30 km*30 km

4.1 Clustering Performance Metrics

The following three metrics are used to evaluate the improved routing protocol's overall performance:

- Packet Delivery Ratio
  The ratio of the number of received packets and the number of transmitted packets.
- Received Throughput
  In wireless networks or cellular systems, the system spectral efficiency in bit/s/Hz/area unit, bit/s/Hz/site or bit/s/Hz/cell, is the maximum system throughput (aggregate throughput) divided by the analog bandwidth and some measure of the system coverage area.
- Average End-to-end Delay
  This metric indicates average time that it takes to transmit data packets successfully.
- Average Jitter
  This metric takes the difference of end-to-end delay between two continuous packets in data stream into consideration.

4.2 Performance Analysis

From Fig.5, Fig.6, Fig.7 and Fig.8 we can see that performances of improved protocol obviously exceed that of original DSR protocol. Fig.5 and Fig.6 present us the fact that the Packet Delivery Ratio and Received Throughput in all groups were increased due to the more stable link chosen by the network. Simulation results show that selecting the link with the longest lifetime makes the network steadier than with the principle of 'minimum hops' in terms of data transmission especially in highly-dynamic environment. In this case, networks will not produce a large number of RRER messages transferring the information of links' breakage and topology changes, certainly avoiding sending large amounts of RREQ messages constantly to explore new link information. As a result, the network load is bound to be reduced and the Packet Delivery Ratio and Received Throughput will inevitably rise. Similarly, the performances of the Average End-to-end Delay and Average Jitter have been improved as shown in Fig.7 and Fig.8. Ultimately, the improved protocol utilizing link's lifetime contributes to forecast the link's quality in highly-dynamic environment and makes the entire network more stable.

In addition, intuitively we can see that in Fig.5, Fig.6, Fig.7 and Fig.8, as the velocity rises, the Average End-to-end Delay and Average Jitter are inevitably on the decline, but the Packet Delivery Ratio and Received Throughput have increased. The reason is that the range of random variables is [-50, 50] in the five groups' simulation and as the velocity becomes higher, it impacts more slimly on the topology changes in supersonic environment, which drives the topology of overall network more stable.

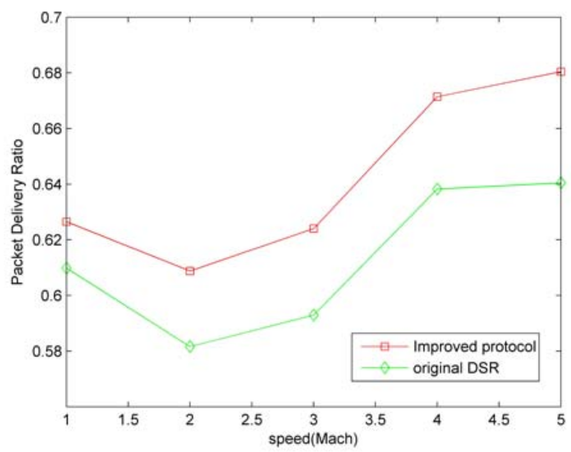

Fig. 5: Packet Delivery Ratio

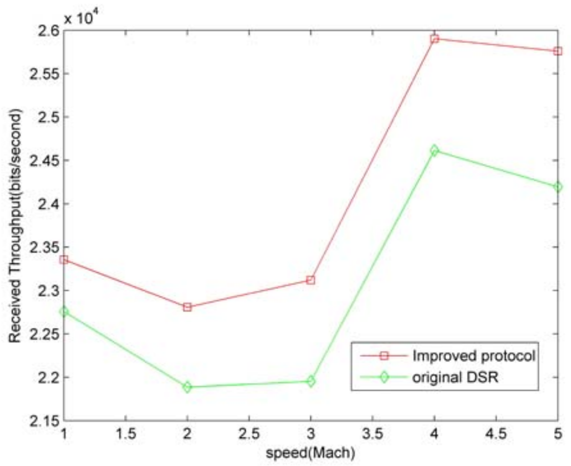

Fig. 6: Received Throughput

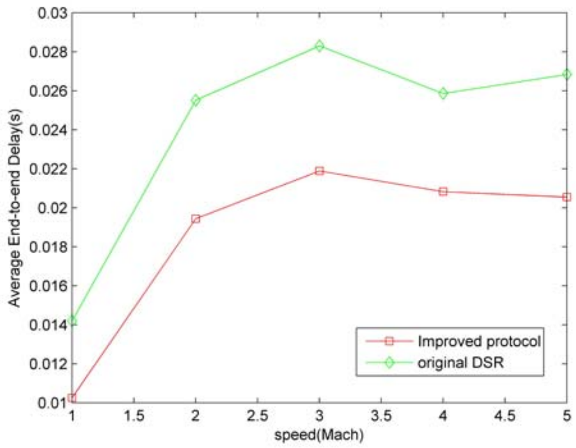

Fig. 7: Average End-to-end Delay

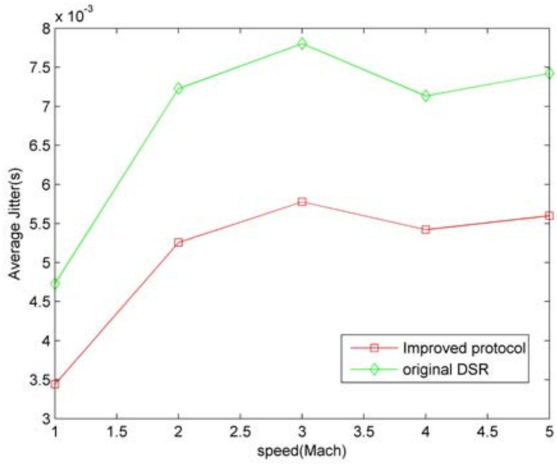

Fig. 8: Average Jitter

5 Conclusion

We improved the DSR routing protocol as being motivated by the latest research results in Ad Hoc Networks, making it suitable for highly-dynamic combat environment based on GM model. Our algorithm takes the entire communicating link's maximum lifetime into consideration instead of employing 'minimum hops' in routing election. Although the improved protocol may increase hops of data transmission, it makes the network transmission more stable. Compared to original DSR based 'minimum hops', ample simulation results operated in Qualnet present us the superior performance of the improved protocol, especially in Packet Delivery Ratio, Received Throughput, Average End-to-end Delay and Average Jitter.

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