A Study of the Relationship between Mobility Model of Ad Hoc Network and Its Connectivity

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***Abstract*— With the development of ad hoc network technology, its mobility models have recently emerged as a premier research topic. Several mobility models of ad hoc network were introduced in this paper, and a formula to calculate the connectivity of mobile ad hoc network was proposed. Three of those mobility models were simulated in NS2.The relationship function among the number of nodes, the range of nodes and the connectivity of ad hoc network were gained by curve-fitting using Boltzmann Function for the first time, which provides a judgment criterion for ad hoc networking.**

***Index Terms*—ad hoc network; mobility model; network connectivity**

I. Introduction

Ad hoc network technology [1, 17] originated from military field of U.S.A. in the seventies of the 20th century and has been a topic of research in recent years. It was a wireless multi-hop network formed by a group of nodes in self-organizing way without any basis of established infrastructure. With the development of wireless communication and mobile terminal technology, mobile ad hoc networks had been envisioned in some civilian applications, especially in some crisis fields, such as rescue operation, battlefield and etc.

Connectivity of ad hoc networks had got more attention during the past years, because the connectivity is one of the fundamental and important properties in ad hoc network. But most of the research was based on the static situation where the nodes do not move in the ad hoc network. For example, in [2] connectivity based on the node density and the transmission range is evaluated in the static scenario. Another problem that was tackled is the critical transmission range, which is the minimum transmission range of each node for the network to be connected [3, 4].The main methods used for investigation of ad hoc network connectivity are based on the graph theory[16,18] and the probability theory. For instance, in graph theory, RGG (random geometric graph) is a random undirected graph drawn on a bounded region. In terms of RGG theory some conclusions can be made on the transmission range in a dense ad hoc network [5]. The percolation theory [6] can be used to investigate ad hoc network connectivity. Probabilistic approach can be also used for the investigation of sparse ad hoc networks. The probabilistic approach can determine the critical transmission range which generates communication graphs that are connected with high probability [4].

Unfortunately, above research are only suitable for the investigation of static ad hoc network. The mobility of nodes makes the ad hoc network more complicated, because many applications of ad hoc networks require the network is connected when the nodes move. It has been confirmed that the mobility model of the nodes has a great impact on the performance of the ad hoc network [7, 8].

To incorporate the dynamics of a network topology into the analysis of the connectivity problem, we resort to the statistics and probabilistic methods to define the connectivity of the mobile ad hoc network in this paper.

In section 2, we introduced some representative mobility models that had been proposed in some papers; a new calculation formula based on statistics and probabilistic methods to the connectivity of mobile ad hoc network is given in section 3; in section 4, we simulate three mobility models [9] in ns2, and give the relative function among the number of nodes, the range of nodes and the network connectivity using the curve fitter respectively. The last section is the conclusion. Our contribution in this paper is that we give the computational formula among the number of nodes, the range of nodes and the network connectivity of the mobile ad hoc network firstly.

II. Mobility Models of Ad Hoc Network

A. Random Waypoint Mobility Model

Random Waypoint mobility model [10, 11] is used in many papers. It is a simple and straightforward stochastic model that describes the movements of mobile nodes in a given area as follows: firstly, a node randomly chooses a destination point in the given area $\mathbb{Z}$, the destination points are independent and distributed at complete random on $\mathbb{Z}$. Secondly, the node randomly chooses a speed from $[V_{min}, V_{max}]$. The speed is ultimately distributed at random in $[V_{min}, V_{max}]$. Then the node moves at the

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speed on a straight line to the destination point. Once arriving at the destination point, the node randomly chooses a pause time T_p from $[0, T_{p,\max}]$. After waiting T_p time, the node will chose a new destination point and speed, move at a constant speed to the new destination point, and so on. The track of nodes in Random waypoint model is showed in Figure1.

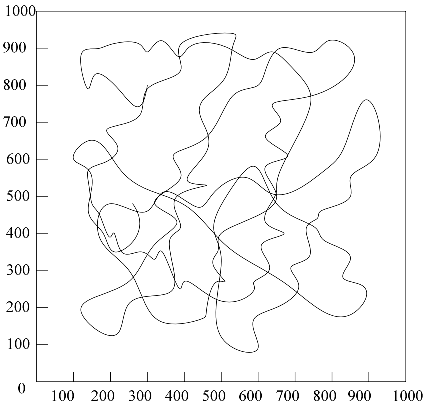

Figure1. Track of node in Random Waypoint model

B. Random Direction Model

Random Direction Model [12] is created to overcome non-uniform density produced by Random Waypoint Model. In this mobility model, nodes choose randomly a direction angle from $(0^o, 360^o]$ rather than a destination point. Nodes move along this direction until they reach the boundary of the given area. At the boundary, similar to Random Waypoint model, they wait for a pause time, choose a new direction angle from $(0^o, 360^o]$, and so on.

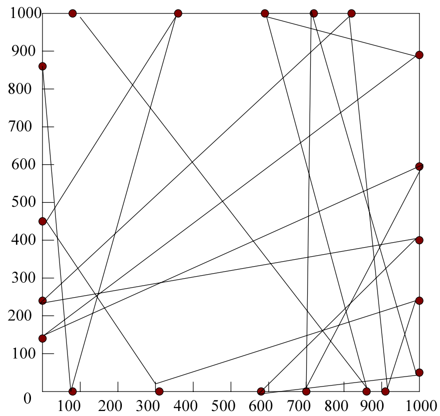

Figure2. Track of node in Random Direction model

C. Gauss-Markov Model

In Random Waypoint Model and Random Direction Model, the movements of nodes in different movement periods are independent. Gauss-Markov Model [13] is designed to different levels of random via one tuning parameter. Movement of nodes occurs by changing their speed and direction according to their current value, i.e., the value of speed and direction at the nth movement period can be calculated based on the value of speed and direction at the (n-1)th movement as well as a random variable. The equation of Gauss-Markov model is as follows:

$$v_n = \alpha v_{n-1} + (1-\alpha)\overline{s} + \sqrt{1-\alpha^2}\, v_{x_n-1},$$

$$d_n = \alpha d_{n-1} + (1-\alpha)\overline{d} + \sqrt{1-\alpha^2}\, d_{x_n-1}$$

Here, v_n and d_n are the new speed and direction angle of mobile node at nth movement period; α, which is in [0,1], is a parameter used to adjust the random variable; $\overline{v}$ and $\overline{d}$ are the mean value of speed and direction as $n \to \infty$; v_{x_n-1} and d_{x_n-1} are random variables from a Gaussian distribution.

At the nth movement, the position of node can be calculated by the equations:

$$x_n = x_{n-1} + v_{n-1}\cos d_{n-1},\ y_n = y_{n-1} + v_{n-1}\sin d_{n-1}$$

Here, (x_n, y_n) and (x_{n-1}, y_{n-1}) are the coordinates of the node at the nth movement and the (n-1)th movement.

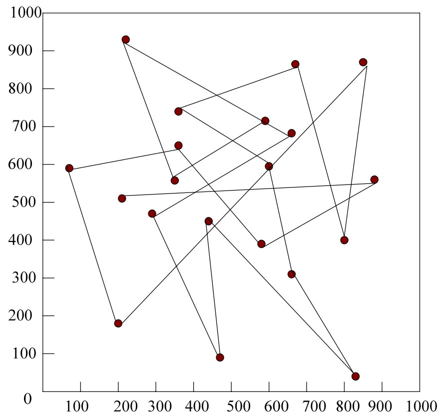

Figure3. Track of node in Gauss-Markov Model

III. CONNECTIVITY OF MOBILE AD HOC NETWORK

Network connectivity has been a hot field of research in graph theory [14]. We suppose that the nodes in ad hoc network have omnidirectional antenna, and the same communication range. If two nodes can communicate with each other directly, the two nodes are neighbors. That is to say that there is a communication link between these two nodes. Thus an ad hoc network can be seen as an undirected graph $G(V, E)$. V is the set of nodes of ad hoc network, E is the set of links of ad hoc network. In an undirected graph that has n vertexes, the strongest connectivity is that there is a link between every two nodes when there are $n(n-1)/2$ links in the network. The worst connectivity is that there are no links in the network. We use $\rho = 2E/n(n-1)$ to describe the level of ad hoc network connectivity. E is the link number in ad hoc network. If $\rho = 1$, it shows that there is a link between every two nodes in the ad hoc network.

When $\rho = 0$, it shows that every node of the ad hoc network is isolated.

Because of the nodes' mobility, the topology of the mobile ad hoc network changes with time, so do the connectivity level of the ad hoc network. To describe the connectivity of the mobile ad hoc network accurately, we calculate a mean value of connectivity in a period. That is in $[0,T]$, we sample the mobile ad hoc network in every $t(t<T)$, that is to say, in every period t, all nodes calculate the number of their neighbors. $N(i,j)$ is the number of neighbors of node i in time j. Thus an ad hoc network of n nodes has $\sum_{i=1}^{N} N(i,j) \Big/ 2$ links in time j, at this time the connectivity is $\rho = \sum_{i=1}^{N} N(i,j) \Big/ n(n-1)$. In $[0,T]$, the mean value of connectivity of the mobile ad hoc network is as follows:

$$\rho = \frac{\sum_{j=1}^{T/t} \sum_{i=1}^{N} N(i,j) \Big/ n(n-1)}{T/t}$$

IV. Simulation and analysis of three mobility models of ad hoc network

We complete the C program code files (mobilenode.c and mobilenode.h) in NS2 and implement the Random Waypoint Model, Random Direction Model and Gauss-Markov Model, then simulated the three mobility models of ad hoc network in an area of 1000m×1000m. Two simulation cases were adopted to study the relationship of the number of nodes, the range of nodes and the connectivity of mobile ad hoc network. Every mobility model is simulated for 1000 seconds and computes the neighbors of all nodes per second. So the connectivity can be calculated by

$$\rho = \frac{\sum_{j=1}^{1000} \sum_{i=1}^{N} N(i,j) \Big/ n(n-1)}{1000}$$

To get a stable state and reduce the influence of movement, every mobility model is simulated ten times. The mean of them is the connectivity of the mobile ad hoc network. [10] indicates that if $V_{\min} = 0$ in Random Waypoint Model, the mean of nodes' speed in the ad hoc network will decrease over time and the mobility model can't have a stable state. So we give $V_{\min} = 1m/s$ in the simulation.

A. Simulation of Three Mobility Model

Case 1: the range of nodes is 100m, and its speed is a randomly value in 1~10 m/s; the number of nodes is 20, 40, …200 respectively. In this case, the relationship between the number of nodes and the connectivity of the ad hoc network is showed in Fig4.

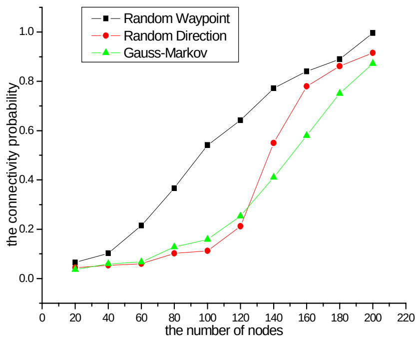

Figure4. The relation between the number of nodes and the connectivity probability

Case 2: the number of nodes is 100, and its speed is a randomly value in 1~10 m/s, the range of nodes is 50m, 60m, …160m respectively. In this case the relationship between the range of nodes and the connectivity of the ad hoc network is showed in Fig5.

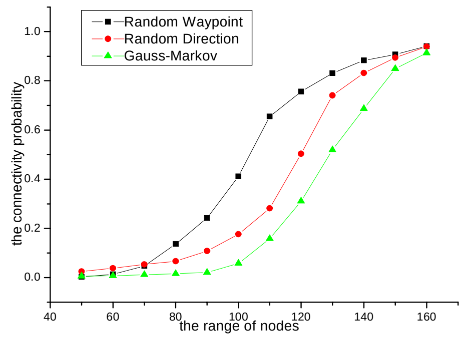

Figure5. The relation between the range of nodes and the connectivity probability

B. Analysis of the Simulation

The curve-fitting that uses Boltzmann[15] function y = A2 + (A1-A2)/(1 + exp((x-x0)/dx)) to the number of nodes, the range of nodes and the connectivity of mobile ad hoc network is as Fig6 and Fig7. Here, n is the number of nodes, r is the range of the nodes and ρ is the connectivity of the mobile ad hoc network.

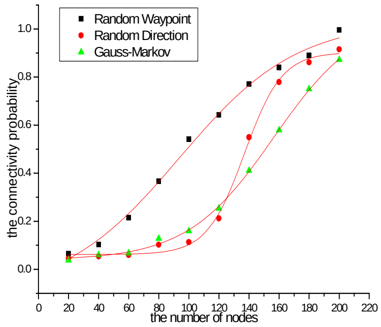

Figure6 the curve-fitting to the number of nodes and the connectivity probability

Take Random Waypoint model for example, we can get the equation of the number of nodes and the network connectivity, and the equation of the range of nodes and the network connectivity respectively from Fig6 and Fig7. It is as follows:

$$n = 39\ln\frac{\rho}{1-\rho} + 94,\ r = 11\ln\frac{\rho}{1-\rho} + 100$$

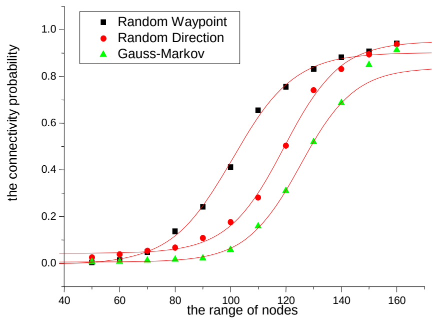

Figure7 the curve-fitting to the range of nodes and the connectivity probability

Multiply the two equations, we can get the equation.

$$nr = 429(\ln\frac{\rho}{1-\rho})^2 + 4943\ln\frac{\rho}{1-\rho} + 9400$$

This equation shows the relationship of the number of nodes, the range of nodes and the connectivity of the ad hoc network in Random Waypoint model. Similarly, we can get the computational formula of Random Direction model and Gauss-Markov:

$$nr = 120(\ln\frac{\rho}{1-\rho})^2 + 2798\ln\frac{\rho}{1-\rho} + 16303$$

$$nr = 290(\ln\frac{\rho}{1-\rho})^2 + 5185\ln\frac{\rho}{1-\rho} + 19500$$

These formulas provides a judgment criterion for mobile ad hoc networking in practice, by which we can choose the suitable number of nodes or adjust the range of nodes to ensure the connectivity level of the mobile ad hoc network.

V. CONCLUSION

With the development of ad hoc network technology, its mobility models have recently emerged as a hot area of research. Several current ad hoc mobility models were introduced in this paper, and a formula to calculate the connectivity probability of mobile ad hoc network was proposed. Three of those mobility models were simulated, and the relationship among the number of nodes, the range of nodes and the connectivity probability was given by using curve-fitting firstly in this paper, which provides a judgment criterion for ad hoc networking.

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