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移动自组网中的最长生命期路径*

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Longest Lifetime Path in Mobile Ad Hoc Networks

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Abstract: Dynamic topology is the essential difference between mobile ad hoc networks and other kinds. It is meaningful in both theory and industry application to study the dynamic topology of mobile ad hoc networks. In this paper, a method is proposed to study the dynamic topology with longest lifetime path. On basis of the previous research, the mathematic model of networks is improved to describe the change of topology. Based on it, the algorithm of longest lifetime path is presented and the distribution of its duration is studied. At the same time, it is proved that the re-routing is minimal with the longest lifetime paths as the routes. Simulation with NS-2 shows that the distribution of lognormal can be used to describe the duration of longest lifetime paths. The results show that the longest lifetime path and minimal re-routing are more suitable than the shortest path as the metrics to measure the dynamic of networks.
Key words: connectivity; mobile ad hoc network; path duration; re-routing; QoS

摘 要: 动态拓扑是移动自组网区别于其他形式网络的本质特征,对其进行研究具有很大的理论价值和工业应用背景.提出一种方法,利用网络的最长生命期路径来研究其拓扑的动态性.在已有研究的基础上,改进了网络的数学模型,弥补了以往模型无法很好地描述移动自组网动态拓扑的缺陷,并在此基础上提出了最长生命期路径算法.利用该算法计算网络中的最长生命期路径,深入研究了其持续时间的分布规律.同时证明了使用最长生命期路径作为路由,可以使网络的重路由次数最少.模拟实验表明,利用对数正态分布可以很好地描述移动自组网的最长生命期路径持续时间.实验结果表明,与以往利用最短路径作为研究对象相比,最长生命期路径和最小重路由更适合用来衡量网络的动态性.
关键词: 连通性;移动自组网;路径持续时间;重路由;QoS
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1 Introduction

Mobile Ad Hoc networks (MANETs) have been gaining increasing popularity in recent years because of ease of deployment. A mobile ad hoc network is a collection of mobile nodes that are capable of movement and can be connected dynamically in an arbitrary manner. There are no wired base stations or infrastructure supported, and each host communicates with one another via packet radios. There are many applications of MANETs[1], such as in the battle field, emergency, and search-and-rescue operations etc.

Recently, there has been a greater focus on the mobility and connectivity of mobile ad hoc networks and also the effect of mobility on the performance of routing protocols. Mobile ad hoc networks differ from other kinds in the change of topology structure because of mobility. Studying the properties of the mobility and connectivity is important for mobile ad hoc networks. Currently speed of movement is used to express the mobility of the networks. However, the speed can not express the topology structure change very well. High speed of movement does not always mean weak connectivity. Many researches have tried to express the connectivity of the ad hoc networks in other ways. Some properties of mobility and connectivity have been obtained by previous researchers. In Ref.[2], the authors present some fundamental stochastic properties of random waypoint model. Ref.[3] analyzes the PATH duration statistics properties and their impact on reactive MANET routing protocols. In Ref.[4], the IMPORTANT framework is proposed to systematically analyze the effect of mobility on routing protocols and some properties of link duration are presented. The path in Refs.[3,4] is the shortest path between two nodes.

While the researches have obtained some properties of the connectivity, we found there were disadvantages in the previous work. In static networks, every node has its node degree, and large node degree is not sure to result in large node connectivity. By analogy, in mobile ad hoc networks, every link has its link duration, and long link duration is not sure to result in long lifetime route. In mobile ad hoc networks, the direct effect to the communication of topology structure change is the destroy of the route. Link break will not always break the communication. Only path destroy will affect the communication. So using link duration to evaluate the connectivity of the network has disadvantages. In this paper, we use path duration to evaluate the connectivity of the networks. In mobile ad hoc networks, there may be more than one path between two nodes. Path selection corresponds to the routing algorithm. Different routing algorithms will result in different path durations. In order to make the path duration independent of the routing algorithm, we use the longest lifetime path duration as the metric. It is only related to the network itself and so can be used to evaluate the dynamic property of the network. We use the longest lifetime path as the metric instead of the shortest path because the longest lifetime path demonstrates the communication potential of the networks.

At the same time, we proved that using the longest lifetime paths as routes can result in minimal re-routing. In mobile ad hoc networks, routing protocols are challenged with establishing and maintaining multi-hops routes in the face of mobility, bandwidth limitation and power constraints, which are widely studied by the domestic researchers[5,6]. Because of the mobility, re-routing is unavoidable in mobile ad hoc networks. Avoiding the frequent re-routing is critical when the applications require stable connections to guarantee a certain degree of QoS. Reducing re-routing can bring down the load of network and bate the consumption of network resources such as energy, bandwidth and so on.

One of the earliest works in the context of reducing re-routing is on building stable route in mobile ad hoc networks. Associativity Based Routing (ABR)[7] prefers stable links over transient links. A link with lifetime of at least $A_{thresh}=2r_{tx}/v$ is considered to be stable, where r_{tx} is the transmission range and v denotes the relative speed of two nodes. In order to measure the lifetime of a link in ABR, the nodes have to broadcast hello messages periodically. Signal Stability Adaptive (SSA) routing[8] differs strongly connected links from weakly connected links. A link is considered strongly connected when it has been active for a certain predefined amount of time.

In such routing algorithms, a link with long lifetime is considered as stable. In order to predict the lifetime of a link, the distance and relative speed of two nodes must be obtained in the network. Because the signal strength between two nodes is strongly related to the distance, the change of the signal strength can be used to predict the lifetime of a link[9].

If the mobile nodes are equipped with GPS, the distance and relative speed of two nodes can be obtained by GPS. Some prediction methods based on GPS have been presented[10−12]. A further approach based on the availability of GPS measurements has been suggested in Ref.[13].

Another method of predicting the lifetime of a link is based on statistical analysis and stochastics[14,15].

With prediction of the route lifetime, routing algorithm can obtain better performance by selecting long lifetime and stable route. The heuristic algorithms can reduce the re-routing of the networks, but no work is done theoretically to show how much the re-routing can be reduced. There is no standard to evaluate the performance of such algorithms.

In our earlier work[16], we attempt to study the minimal re-routing of the mobile ad hoc networks and we have presented a method to balance the minimal re-routing and minimal route hops. In this paper, we focus on the properties of the longest lifetime paths. The longest lifetime path duration and minimal re-routing are two important properties for mobile ad hoc networks. These two metrics represent the communication potential of the network and can be used to evaluate the dynamic property of the mobile ad hoc networks.

The paper is organized in the following way. Section 2 presents the network model of this paper, which is different with previous ones and more suitable for mobile ad hoc networks. Section 3 describes the algorithm to obtain the longest lifetime path from a certain time point. In Section 4, we analyze the properties of the longest lifetime path duration in detail, and Section 5 presents the properties of the minimal re-routing of mobile ad hoc networks. Section 6 is the conclusion and future work.

2 Network Model

Graph is usually used to denote a network. The vertexes in a graph represent the nodes in networks while an edge of the graph represents a link between two nodes. In mobile ad hoc networks, graph can denote the snapshot of the network at a certain time, but it can not denote the change of the network topology. In mobile ad hoc networks, an active link will last for a period of time and then become disconnected because of the mobility. The previous graph models can not express such a change very well.

In this paper, a modified graph is presented to denote the network. Let $G=(V,E)$, where V is the set of nodes, and E is the set of (i,j,t_s,t_e) which indicates that the nodes i and j are connected in the period of $[t_s,t_e]$ and disconnected at time t_e and $t_e-\varepsilon$ for any infinitesimal positive number ε. Define $(i_1,j_1,t_{1s},t_{1e})\le(i_2,j_2,t_{2s},t_{2e})\Leftrightarrow(i_1,j_1)=(i_2,j_2)$, $t_{1s}\ge t_{2s}$ and $t_{1e}\le t_{2e}$. If there exists a path $(s=n_0,n_1,n_2,\ldots,n_{k-1},n_k=t)$ between s and t, and for each link $(n_i,n_{i+1})(0\le i\le k-1)$, $\exists e_i\in E'$, $(n_i,n_{i+1},t_1,t_2)\le e_i$, then there exists a fixed path between s and t within $[t_1,t_2]$.

Figure 1 represents such a network in [0,20], and the edges indicate that the corresponding links have existed and the active periods are listed. For example, node 0 and 1 is connected in period of [0,3], [5,10], [13,20] and disconnected in all other times.

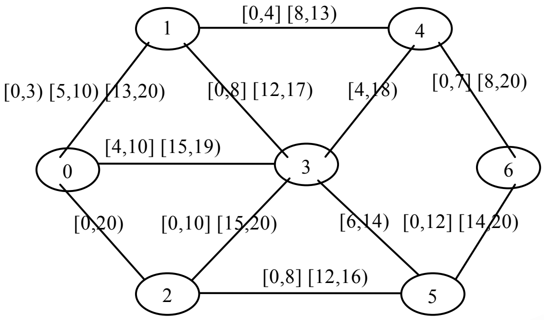

Fig.1 Network model

3 Longest Lifetime Path

In this section, we will present an algorithm to find a single longest lifetime path between two nodes from a given time point.

In this algorithm, we want to find a longest time slice from certain time point t within which there exists a fixed path. In the time slice, the path should not be destroyed, so we can derive a weighted graph $G'(t)$ from he network model we present. $G'(t)=(V',E')$, where $v\in V'\Leftrightarrow v\in V$ and e= $(i,j,w)\in E'\Leftrightarrow\exists(i,j,t_s,t_e)\in E$ and $t_s\le t<t_e$ and $w=t_e-t$. Define $w(e)$=w$(i,j)=w$ in $G'(t)$.

Figure 2 is derived from Fig.1 at time 0.

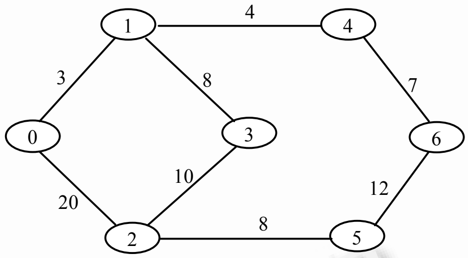

Fig.2 A weighted graph derived from Fig.1

Definition 1 (**Longest Lifetime Path** (**LLP**)). Given a graph $G'(t)=(V',E')$ and a communication request (s,t), let Δ be the delay on each node, then the problem is to find a path p from s to t such that the lifetime of p is the longest. The lifetime of p is defined as $l_p=\min_{e\in p}\{w(e)-d_p(e)\Delta\}$, where $d_p(e)$ is the sequence number of e in p in the order from s to t.

Let P be the set of all paths from s to t, then the objective of LLP is to find $\max_{p\in P}\{l_p\}$. If $\Delta=0$, which means the delay on transmitting node, including the waiting time in queue and the transmitting time can be ignored. In this case, the problem is in fact the same as the traditional bottleneck path problem and it can be solved by Dijkstra algorithm with minor modification[17].

Note that during communication, there is always delay on transmitting node, including the waiting time in queue and the transmitting time. So $\Delta\neq 0$, the problem can not be solved by Dijkstra algorithm because for those problems which can be solved by Dijkstra-like algorithm, they must satisfy the following optimal substructure property: there exists an optimal path $SP(s,t)$, if k is an intermediate node in $SP(s,t)$, then the $SP'(s,k)$ is an optimal path from s to k, where $SP'(s,k)$ is the subpath from s to k in $SP(s,t)$. Unfortunately, if $\Delta\neq 0$, this property does not hold. For example, in Fig.3, let $\Delta=1$, then the longest lifetime path from 0 to 2 is $0\rightarrow 1\rightarrow 2$, the lifetime is $\min\{5-1,6-2\}=4$, while the longest lifetime path from 0 to 3 is $0\rightarrow 2\rightarrow 3$, the lifetime is $\min\{4-1,3-2\}=1$.

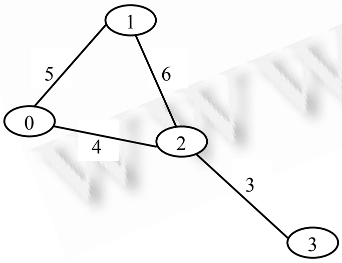

Fig.3 An example of weighted graph with transmission delay

Although the problem cannot be solved by Dijkstra algorithm, we find that LLR has the following property, which is similar to the optimal substructure property of Dijkstra algorithm.

Theorem 1. For any $u,v\in V'$, let $P(u,v)$ denote a longest lifetime path from u to v. If k is an intermediate node in $P(s,t)$, then the path $s \xrightarrow{P(s,t)} k \xrightarrow{P(k,t)} t$ is also a longest lifetime path from s to t.

Proof. Let $P'(s,k)$ and $P'(k,t)$ denote the sub-path of $P(s,t)$ from s to k and from k to t respectively. And let $P''(s,t)$ denote the path concatenated by $P'(s,k)$ and $P(k,t)$. Let h be the length of $P'(s,k)$.

Then $l_{P'(k,t)} \le l_{P(k,t)}$, and

$$\begin{aligned}
& l_{P(s,t)} \\
&= \min_{e\in P(s,t)} \{l(e) - d_{P(s,t)}(e)\Delta\} \\
&= \min\{\min_{e\in P'(s,k)} \{l(e) - d_{P'(s,k)}(e)\Delta, \min_{e\in P'(k,t)} \{l(e) - d_{P'(s,k)}(e)\Delta - h\Delta\} \\
&= \min\{l_{P'(s,k)}, l_{P'(k,t)} - h\Delta\} \\
&\le \min\{l_{P'(s,k)}, l_{P(k,t)} - h\Delta\} \\
&= l_{P''(s,t)}
\end{aligned}$$

Since $P(s,t)$ is a longest lifetime path, $\mathrm{sol}_{\{P(s,t)}=l_{P''(s,t)}$ and $P''(s,t)$ is also a longest lifetime path from s to t.

Base on the theorem, we design an algorithm for *LLP*.

Algorithm 1. An algorithm for LLP.

Begin

1) $S=\Phi$; $\overline{S}=V'$;

2) $d[j]=-\infty$ for each node $i\in V'$;

3) $d[t]=\infty$; $succ[t]=null$;

4) while $s\notin S$ do

5) let $i\in\overline{S}$ be such that $d[i]=\max\{d[j]: j\in\overline{S}\}$;

6) $S=S\cup\{i\}; \overline{S}=\overline{S}-\{i\}$;

7) for each link $e=(j,i,w)\in E'$ and $j\in\overline{S}$ do

8) if $d[j]<\min\{w-\Delta, d[i]-\Delta\}$ then do

9) $d[j]=\min\{w-\Delta, d[i]-\Delta\}$ and $succ[j]=i$;

10) end

11) end

12) end

End

Theorem 2. The path found in Algorithm 1 is a longest lifetime path from s to t, The time complexity of it is $O(m+n\log n)$ where $m=|E'|$ and $n=|V'|$.

Proof. The correctness of the above algorithm follows Theorem 1. Note that the algorithm is much similar to Dijkstra algorithm. They have the same time complexity. An implementation based on Fibonacci heap[17] runs in time $O(m+n\log n)$.

4 Distribution of the Longest Lifetime Path

In Section 3, we propose an algorithm to compute the longest lifetime path. In this section, we will study the properties of the path duration in detail.

Recently there has been a greater focus on the systematic study of the mobility and its effect on performance of routing protocols. In order to compare simulation results that have been obtained using different random mobility models, it is desired to define a metric for the “degree of mobility” of the simulated scenario. Due to the broad range of mobility models used in the literature and their various parameters, such a definition is not trivial. Apart from analyzing the effect of mobility on protocol performance, it is useful to characterize mobility independent of the protocols. Hence, there have been several attempts to propose mobility metrics[4,18]. Also the connectivity graph metrics relating the mobility metrics to the protocol performance is needed.

In previous work, link duration is widely used as the metrics to evaluate the connectivity of the networks, but since the packets are transferred along the paths, the properties of the link duration can not substitute for those of the paths. So studying the properties of path duration is more critical than link duration. Some researches have attempted to focus on it[3], but the path there is the shortest path. In this paper, we use the longest lifetime path as the criterion.

In this section, we propose a new metrics to evaluate the connectivity of the mobile ad hoc networks. We use the longest lifetime path duration to denote the communication potential of the ad hoc networks. Although *A*'s node connectivity and edge connectivity are the same with *B*'s, but *A*'s longest lifetime path duration is less than *B*'s, so *B* is more strongly connected than *A* in terms of the longest lifetime path. We use the longest lifetime path instead of the shortest path in the previous work because the longest lifetime path duration shows the communication potential. Although the routing algorithms may not make best use of the communication capability, but the network does have such a communication potential. It is the theoretic optimal result for communication. It is independent of the routing algorithm, and can be used as the metric for the connectivity of the mobile ad hoc networks.

In this section, we analyze the distribution of the longest lifetime paths duration and found that the distribution follows the lognormal distribution. We can use the parameters of lognormal distribution to evaluate the connectivity of the networks.

We used NS-2[19] to generate different scenes and computed the longest lifetime path duration. The mobility model was random waypoint, and the simulation time was 11000 seconds, the number of nodes was 50 and the maximum speed of the movement is 10m/s. The simulation was repeated for 50 times to gather sufficient data and the data gathering began from the 1000th second because the movement of random waypoint model became stable after this period[20]. We chose 10 pairs of the nodes for communication and found that the path duration varied from 0.005495s to 7474.42s, and the average path duration is 158.585s. In order to get the path duration probability density function(PDF), we let the path duration fall into the ranges (0s,1s),(1s,2s),…,(1499s,1500s), and the probability distribution is presented in Fig.4. From the figure, we can see that with the probability of about 1.21%, the path duration fall into (0s,1s), which is far larger than in other ranges. After that, the probability falls into 0.13% and then increase gradually. We found that the probability is far larger in (0s,1s) because the scenes we generated are not always connected. There are always some period within which the network is partitioned. In the moment the network is partitioned, there are always many short lifetime paths. Remove these cases, we will find that the probability density will increase gradually first and reaches the peak, and then the probability density decreases exponentially-like. We suppose that the probability density follows the distribution of lognormal, and the fitting result verified it.

The lognormal distribution function is

$$\mathrm{Log}Normal\_(a,b,c) = a \times e^{0.5(\lg(x/b)/c)^2} \text{ [21]}.$$

From the function, we can see that the probability density will increase first and reach the peak value a when x becomes b. After that, the probability density will decrease.

Fitting result is presented in Fig.5, in which the range interval is 10s. The confidence level is 95%. The fitting result shows that the probability density follows the distribution of lognormal. From the figure, we can see that the probability density will reach the peak value when the path duration is 7.065×10s and the probability is 6.19%.

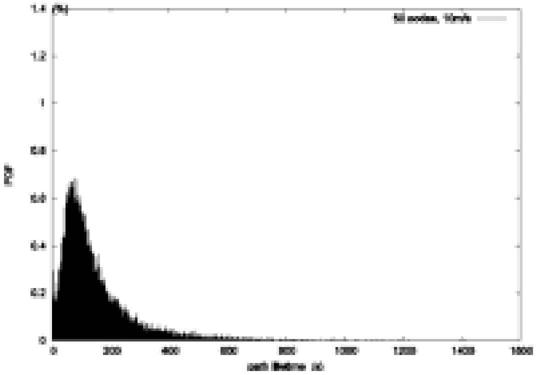

Fig.4 Path duration distribution (50 nodes and 10m/s)

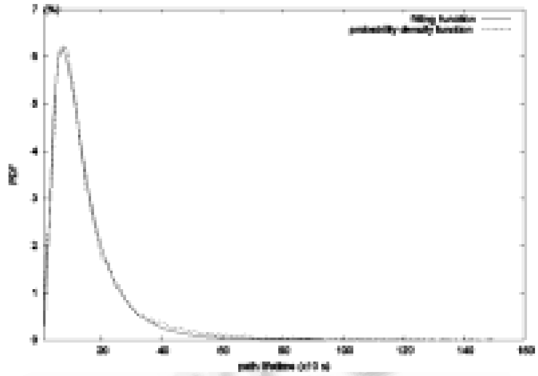

Fig.5 Path duration distribution and fitting result (50 nodes and 10m/s)

Different movement speeds and different node densities will result in different path durations. We find that the longest lifetime paths with different speeds and node densities still follow the lognormal distribution and the confidence levels are all above 95%, but the parameters of lognormal distribution are different. The parameters are listed in Table 1 and Table 2. We can see that the parameters are monotone. The distributions with different speeds are showed in Fig.6 and different node densities in Fig.8. The fitting results are presented in Figs.7 and 9. From the figures, we can find that the peak of the distribution will increase and move left as the speed of the movement increases, which means as the speed increases, the longest lifetime path duration is piled in the range of short periods. While the peak will decrease and move right as the node density increases, which means the longer lifetime path will become more and more as the node density increase.

Table 1 Fitting results

Speed (m/s)	*a*	*b*	*c*
2	1.5502891	35.3404	0.61592025
4	2.7970556	17.131028	0.65584402
6	3.9353186	11.854995	0.65941711
8	5.044549	8.7147538	0.68899562
10	6.1929512	7.065707	0.68975767
12	7.2824062	6.1093589	0.67716234
14	8.5482354	5.3392942	0.66325184
16	9.7334838	4.6815464	0.66014241

The fitting results for the probability density function with different maximum speeds when node number is 50.

Table 2 Fitting results

Node number	*a*	*b*	*c*
30	9.2689694	3.5511949	0.84623669
35	7.8156371	4.4743486	0.81903178
40	7.0601837	5.6411232	0.74397493
45	6.5929404	6.4845611	0.70124611
50	6.1929512	7.065707	0.68975767
55	6.080948	7.9156953	0.63741024
60	5.8718325	8.3030637	0.62658975
65	5.7885783	8.6543218	0.61373755
70	5.6882717	8.9045418	0.60339314

The fitting results for the probability density function with different node numbers when maximum speed is 10m/s.

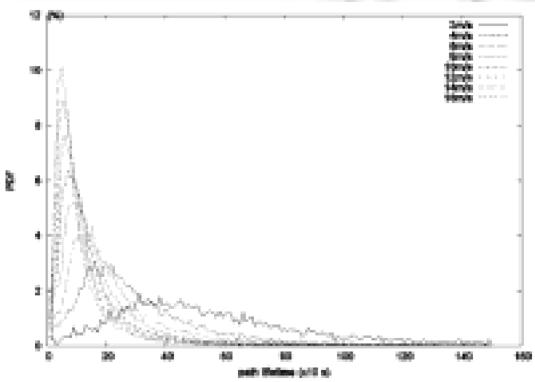

Fig.6 Different path duration distribution with different speeds when node number is 50

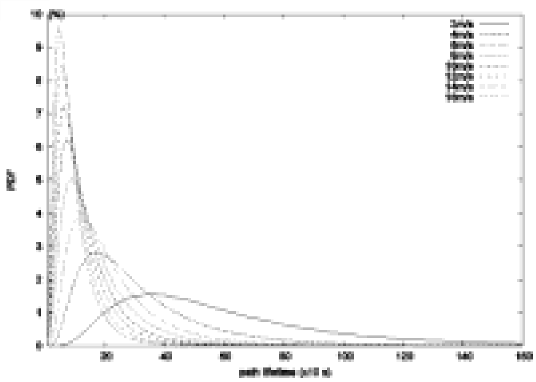

Fig.7 Fitting results with different speeds when node number is 50

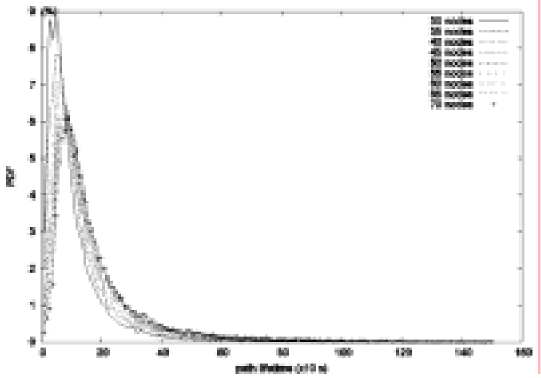

Fig.8 Different path duration distributions with different node densities when maximum speed is 10 m/s

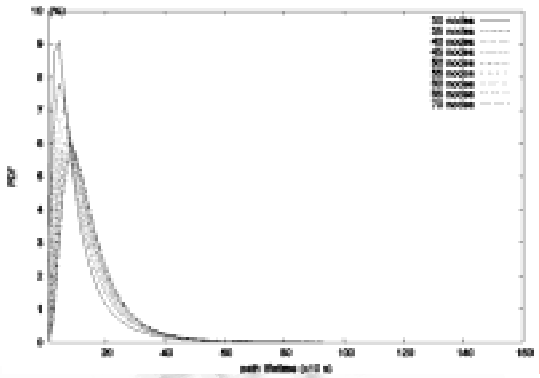

Fig.9 Fitting results with different node densities when maximum speed is 10m/s

The parameters of fitting results will change as the speed and node density change, which is showed in Fig.10 and Fig.11. From Fig.10, we can see that as the speed increases, the maximum probability path duration (corresponding to the value of b) will decrease sharply and the probability will increase linearly-like. The effect of the node density can be seen in Fig.11. As the node number increases, the maximum probability path duration will increase and the probability will decrease.

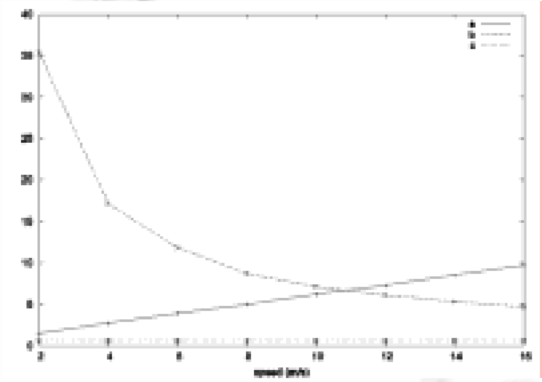

Fig.10 Parameters of lognormal distribution with different speeds when node number is 50

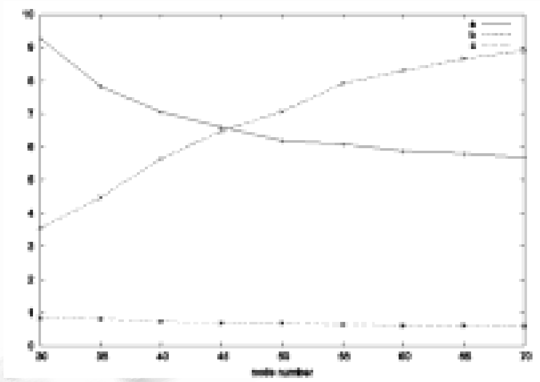

Fig.11 Parameters of lognormal distribution with different node densities when maximum speed is 10m/s

Although much work has been done on the connectivity of mobile ad hoc networks, the research in this paper is different and meaningful. In Ref.[3], the authors study the connectivity of networks with the same method, but they use link duration and the shortest path duration as the research objects. Comparing with our research, they found some probability of MANET on connectivity, but they cannot find a simple, effective and consistent mathematic function to express the probability. While from our work, we got that with lognormal, we can express the connectivity very well, which also provide a tool to study the mobile ad hoc network more deeply.

5 Minimal Re-Routing

In this section, we will prove that always using the longest lifetime paths as the routes can obtain minimal re-routing. The minimal re-routing problem is to find $k-1$ time points $(t_1,t_2,\ldots,t_{k-1})$ between 0 and T such that in $[t_i,t_{i+1}]$ there exists a fixed path and k is minimal. We can use a greedy algorithm to solve this problem: Each time the network needs a route, it will find the longest lifetime path as the route.

Theorem 3. The number of time slices got with greedy algorithm is minimal.

Proof. Suppose there exist $t_1,t_2,\ldots,t_{k-1}$ which are obtained by the greedy algorithm and $t_0=0$, $t_k=T$, and p_i is the i^{th} corresponding path. The number of re-routing is $k-1$. If there exists a better scheme, which only re-routes for $k'-1$ times and $k'<k$. That is, there exists a time separation for $[0,T]$,$[0,t'_1]$,$[t'_1,t'_2]$,…,$[t'_{k'-2},t'_{k'-1}]$,$[t'_{k'-1},t'_{k'}=T]$. We will firstly prove that $t_{k'}\geq t'_{k'}$.

1. $t_1\geq t'_1$

According to the greedy algorithm, p_1 is the longest lifetime route at time 0, so $t_1\geq t'_1$.

2. Suppose $t_i\geq t'_i$ for $1\leq i\leq k'-1$, then $t_{i+1}\geq t'_{i+1}$. Otherwise, at time t_i, the path p_{i+1} is not the longest one. There should exist another path that exists from t_i to t'_{i+1}. It is contrary to the greedy algorithm.

3. According to 1 and 2, for $1\leq i\leq k'$, $t_i\geq t'_i$. So $t_{k'}\geq t'_{k'}$.

$t_{k'}\geq t'_{k'}$ and $k>k'$, so $T=t_k>t_{k'}\geq t'_{k'}=T$, it is ambivalent.

So k is minimal.

We use NS-2 to generate different scenes and compute the re-routing times needed for the shortest path routing and minimal re-routing.

Figure 12 presents the comparison results in terms of re-routing times. We can see that the required minimal re-routing times of a network is much less than that with the shortest path routing algorithm, and the minimal re-routing times in all experiments are nearly equal. It is different with the results of minimal hops routing, in which the re-routing times in different experiments are quite different. From the results, we can see that the minimal re-routing is an inner property of the network; different scenes with the same parameter have the same properties in terms of minimal re-routing.

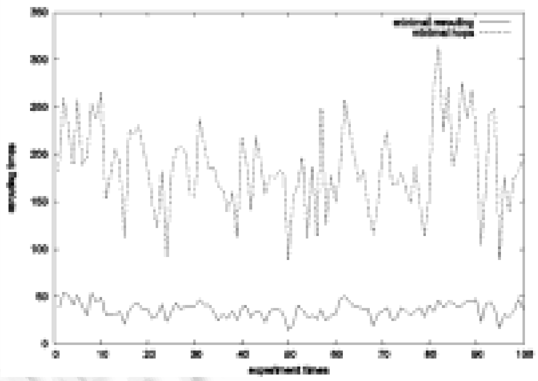

Fig.12 Re-Routing when node number is 50 and speed is 10m/s

Different speeds of movement will result in different re-routing frequencies. We had done simulation in different speeds when the number of nodes is 50. The results are shown in Fig.13. From the figure, we can see that the shortest path routing will need much more re-routing than the minimal re-routing required for a network especially when the speed of movement is high. The re-routing times will increase linearly-like as the speed increases and the minimal hops routing increases more quickly.

Results with different node densities in the speed of 10m/s are presented in Fig.14. From the figure, we can see that the node density will affect the re-routing. It is interesting that for the shortest path routing algorithm, more nodes will result in more re-routing, while for the minimal re-routing, re-routing will be decreased as the node density increases. This is because that if there are more nodes in the network, it is more likely for the shortest path routing algorithm to select the unstable path as the route.

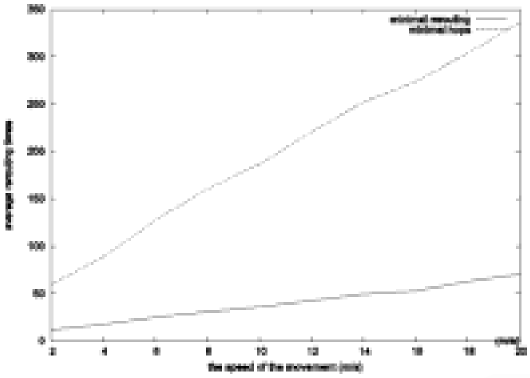

Fig.13 Average re-routing times in different speeds when node number is 50

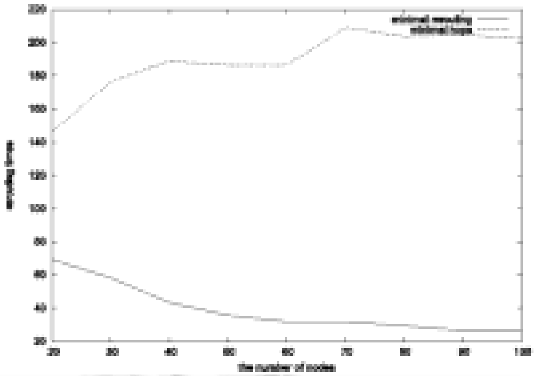

Fig.14 Average re-routing times with different node densities when speed is 10m/s

6 Conclusions

In this paper, we proposed to use the longest lifetime path duration and minimal re-routing to evaluate the connectivity of mobile ad hoc networks. We presented an algorithm to compute the longest lifetime path and analyzed the properties of the longest lifetime paths in detail with simulation. We found that the longest lifetime path duration follows the distribution of lognormal. At the same time, we proved that the longest lifetime routing can obtain theoretical minimal re-routing. It is the theoretical optimal result on reducing re-routing of mobile ad hoc networks.

The longest lifetime path duration and minimal re-routing are two important properties of mobile ad hoc networks. Analyzing these two properties can give us a deep comprehension of the connectivity and is helpful to design mobile ad hoc networks.

In the paper, we analyzed the properties of longest lifetime path and minimal re-routing using random waypoint mobility model. In future, we will study the properties with other mobility models and also the impact to the routing performance.

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