On the influence of link break problem on ad hoc mobile wireless networks

Ying-Kwei Ho
Department of Computer Science and Engineering, Vanung University
ykho@msa.vnu.edu.tw

Shuenn-Jyi Wang
Department of Computer Science, National Defense University
sjwang@ndu.edu.tw

Ching-Chuan Chiang
Department of Computer & Communication Engineering, Ming Chuan University
ccchiang@mcu.edu.tw

Ru-Sheng Liu
Department of Computer Science & Engineering, Yuan Ze University
csrobinl@saturn.yzu.edu.tw

Abstract

Ad hoc mobile wireless networks are an emerging and popular technology to the world; however, the benefits of them are actually their fragility either. It provides mobile users with ubiquitous communication capability at anytime and anywhere. Owing to mobile node movement, the link break problem always occurs in the network. It greatly influences the throughput, delay, jitter, and lots of performance metrics of a routing protocol. Hence, this article is proposed to evaluate the influence of link break problem on routing protocols for ad hoc mobile wireless networks. More precisely, we would like to explore the influence of the problem on the two categories of most popular routing protocols, i.e. table-driven and on-demand routing protocols. This article briefly discusses the main differences, building up mathematical model, setting up simulation environment, running the simulation, and finally presenting the simulation results and analyzing the performance to each of them. We conclude that the influence of link break problem on table-driven routing protocols is much serious than that on on-demand routing protocols since the former has to maintain each link of the network but the latter only the links of a specific route.

Keywords：link break problem, ad hoc mobile wireless networks, table-driven routing protocol, on-demand routing protocol, binomial distribution。

1. Introduction

To surmount the restrictions of wired backbone networks, wireless networks are proposed to provide mobile users with ubiquitous communication capability and information access regardless of their locations. The flexibility and mobility the wireless networks offer makes them the network of choice. With the aid of wireless networks, mobile users can communicate with each other anytime and anywhere. Currently, there are two categories of wireless networks, namely, infrastructure-based wireless networks and ad hoc mobile wireless networks. Only if the fixed configuration portion (infrastructure) has been set up properly, can mobile users exchange information and share the service of the network. To overcome the limitations of such kind of infrastructure, ad hoc mobile wireless networks are presented for mobile users with more flexibility and freedom.

1.1 Wireless Networks

The infrastructure-based wireless networks mainly consist of two portions: fixed configuration and mobile node portions. The fixed configuration portion, including base station, mobile switching center, etc., is linked by a wired backbone infrastructure. A mobile node can communicate with the nearest base station within its radio coverage area. The network supplies mobile users with only one-single-hop of radio communications. Only if the users reside in the radio coverage area of a base station or an access point, can they communicate with the other users. The users are also confined to the barrier of the radio coverage area of the base stations or access points.

Ad hoc mobile wireless networks are designed to overcome the natural limitation of these wired backbone networks and infrastructure-based wireless networks. Ad hoc mobile wireless networks, shown in Figure 1, are a collection of mobile nodes sharing a wireless channel and dynamically forming a temporary network topology without the existence of network infrastructure or centralized administration. Restricted by transmission range, each mobile node can only communicate with neighboring nodes within its radio coverage area;

besides, forwarding packets for other nodes, it also acts as a router. In contrast with one-radio-hop infrastructure-based wireless networks, ad hoc mobile wireless networks are also called multihop mobile wireless net-works because any message transmitting from a source node to a destination node may pass through many intermediate nodes, which requires multiple radio-to-radio hops. Ad hoc mobile wireless networks are fast deployable and suitable for the situation where setting up or maintaining a communicating infrastructure is difficult or infeasible, for example, disaster recovery (earthquake, fire), battlefield, law enforcement, and vehicle-to-vehicle networking in intelligent transportation systems.

1.2 Routing Protocols

Traditional routing protocols applied to wired networks are not suitable for ad hoc mobile wireless networks. For example, distance vector (Bellman-Ford) [1,2] and link state [3] routing schemes suffer from slow convergence to topology changes and bandwidth waste in periodical routing table exchanges. Especially, the routing loop in distance vector routing is another serious problem. Therefore, various routing protocols are proposed for ad hoc mobile wireless networks to solve the problems of routing loop and provide fast convergence to topology change. Broadly speaking, they are table-driven (e.g., DSDV [4], CGSR [5], and WRP [6]) and on-demand (or source-initiated, e.g., AODV [7], DSR [8], TORA [9], ABR [10,11], SSR [12], LAR [13, 14], ZHLS [15], ODQOS [16], and DBR [17, 18]) routing protocols [19-25].

Table-driven routing protocols demand that each mobile node should have up-to-date routing information of all nodes in the network. To achieve this goal, a routing table is maintained within each node and broadcast network-wide when network topology changes. Moreover, the routing table has to be exchanged periodically by broadcasting to all nodes in the network to keep track of the newest messages even though the network topology is not changed. Each node has routing information about all nodes of the whole network though most of it is undesired.

However, on-demand routing protocols have a totally different approach; they create routes only when needed. Having data for transmission, a source node initiates a route discovery procedure to find the destination node. Route maintenance procedure is triggered whenever a route has been discovered and is in progress until the route is no longer required. The control messages used in on-demand routing protocols record only the nodes on the route, not all nodes in the network. Without maintaining the whole network topology, only if the route is changed, do the protocols proceed to maintain the route.

1.3 Link Break Problem

Though there are so many benefits offered by ad doc mobile wireless networks, the main fragility of the networks is the problem of a broken link. A link is a physical medium, a wireless medium in wireless networks, which connects two or more network devices such as a computer, a router, or a mobile node together. Owing to mobile node movement, the link break problem always occurs in ad hoc mobile wireless networks. The problem greatly influences the throughput, delay, jitter, and lots of performance metrics of a routing protocol. Hence, this article is proposed to evaluate the influence of link break problem on routing protocols for ad hoc mobile wireless networks. More precisely, we would like to explore the influence of the problem on two categories of routing protocols, i.e. table-driven and on-demand routing protocols.

The rest of this article is organized as follows. The mathematical model is provided in Section 2 to analyze the influence of link breaks on routing protocols. Moreover; Sections 3 and 4 set up the simulation environment, run the simulation and analyze the simulation results and the performance of routing protocols. Finally, Section 5 concludes this article.

2. The Influence of Link Breaks on Routing Protocols

The two categories of routing protocols of ad hoc mobile wireless networks are table-driven routing protocols and on-demand routing protocols. Table-driven routing protocols have to maintain up-to-date routing information of all links in the network. Therefore, if any link in the network breaks, this kind of protocol has to trigger an update. This update is broadcasted network-wide till each node receives it. On the contrary, on-demand routing protocols only focus on the route they transmit packets, not on the whole networks. Hence, these protocols only need to maintain the links on a transmission route, not all the links of a network. Firstly, we would like to build up mathematical model in this section. Secondly, setting up simulation environment and running the simulation are presented in the next section. And finally propose the simulation results and analyze the performance at Section 5.

2.1 Graph Data Structure

Definition (***Graph data structure***) *The topology of the network can be represented as a graph data structure G=(V, E), where V is the set of mobile nodes and E the set of links.*

Definition (***link***) *A link (w, z) means that Node z is Node w' s one-hop neighbor within radio transmission range, and vice versa.*

2.2 Link Break Probability

Definition (***link break probability***) *Reconsidering the network topology shown in Figure 1, we can view each link l as an experiment ε with outcome $\{B, \overline{B}\}$, where B represents a link that breaks at a short time interval Δt, and $\overline{B}$ a link that does not break at the same time interval. Suppose that the probability P(B)=p. and because a link only has two state at any time, that is, break or un-break, therefore, $P(\overline{B})=1-p$.*

Definition (***link break probability as a binomial random variable***) *Consider there are total m links of a network. Each link can be viewed as an independent repetition of ε. Hence the sample space consists of all possible sequences $\{a_1, a_2,\ldots, a_n\}$, where each a_i is either B or $\overline{B}$, depending on whether B or $\overline{B}$ occurred on the ith repetition of ε. (Note that there are 2^m such sequences.) We define X=number of times the event B occurred. Then we know that X is a binomial random variable with parameters m and p.*

Theorem (Link Break Problem as a Binomial Distribution) *Let X be a binomial random variable based on m repetitions. Then*

$$P(X=k)=\binom{m}{k}p^k(1-p)^{m-k} \quad k=0,1,\ldots,m \qquad \text{…………(1)}$$

Example: Suppose that the link break probability is 0.014 during a short time interval, say 5 seconds. We also assume that the number of links in the network is 20. Then

$$P(X=k)=\binom{20}{k}(0.014)^k(0.986)^{20-k} \quad k=0,1,\ldots,20$$

By applying different values of k to the above equation, Figure 2 is plotted. According to this figure, the highest probability occurred at $P(X=2)=0.285$. It means that under such assumption the most probable number of broken links is two. Furthermore, the cumulative probability of $P(X\le 6)=0.998$. This tells us that during the short time interval the number of broken links is most likely to be less than and equal to six though there are 20 links in the network.

2.3 The Influence on Routing Protocols

The main difference between these two categories of routing protocols focuses on the links they concern. Table-driven routing protocols have to maintain up-to-date routing information of all links in the network. Therefore, the protocols are chiefly concerned about each link; if any link in the network breaks, they have to trigger an update. On the contrary, on-demand routing protocols only focus on the route they transmit packets, not on the whole networks. Hence, these protocols only need to maintain the links on a transmission route, not all the links of a network. If a link in the transmission route breaks, they trigger an update either. Firstly, We utilize analytical methodology to find the update probability for each category of routing protocol and make some comparisons.

Firstly, we would like to analyze table-driven routing protocols. Suppose that there are 10 nodes and average 15 links in a network[1]. Further, assume that the link break probability is 0.1 during a short time interval, say 5 seconds. To obtain up-to-date information, the protocols have to notice about each link condition, that is, if any link breaks, the protocol will launch an update. The following equation is the best representative of the update probability P_{ud}.

$$\begin{aligned}P_{ud} &= P(X>0)\\ &= P(X=1)+P(X=2)+\ldots\ldots+P(X=15)\end{aligned} \qquad \text{……………(2)}$$

Substituting each term of Equation (2) by Equation (1), we obtain

[1] In the simulation section, we have tested various numbers of nodes and get different average links.

$$P_{ud} = \binom{15}{1}(0.1)(0.9)^{14} + ... + \binom{15}{15}(0.1)^{15}(0.9)^{0} = 0.794 \quad ……………..(3)$$

This means that during 5-second interval, table-driven routing protocols have an update probability of 0.794. The highest probability of Equation (3) occurred at $P(X=1)=0.343$. That is, under such assumption the most probable number of broken links is one.

As for on-demand routing protocols, we assume that there are also 10 nodes and the link probability is 0.1 either during 5-second interval. However, the maximum number of links is five links in the transmission route. If any one of the five links breaks, the protocols will trigger an update. Hence, the update probability P_{ud} of the protocols is

$$P_{ud} = P(X > 0) = P(X = 1) + ... + P(X = 5) \quad ………….(4)$$

Substituting each term of Equation (4) by Equation (1), we obtain

$$P_{ud} = \binom{5}{1}(0.1)(0.9)^{4} + ... + \binom{5}{5}(0.1)^{5}(0.9)^{0} = 0.41 \quad ……………..(5)$$

This means that during 5-second interval, on-demand routing protocols have an update probability of 0.41. The highest probability of Equation (5) occurred at $P(X=1)=0.328$. That is, under such assumption the most probable number of broken links is one.

According to the above specific assumption, on-demand routing protocols are better than table-driven routing protocols because on-demand routing protocols have a lower rate to launch an update. The update probabilities of table-driven and on-demand routing protocols are 0.794 and 0.41 respectively. That is the reason why tale-driven routing protocols have to trigger routing table update constantly.

3. Simulation Environment

The objective of the simulation is to set up a simulation environment, to run the simulation, and finally analyze the influence of link break on the two categories of routing protocols, i.e. table-driven and on-demand routing protocols.

The network consists of a predefined number of mobile nodes roaming at random in all directions in a network area of size 1000 x 1000 square meters at a predefined average speed; radio transmission range of each mobile node is fixed to be 250 meters and free space propagation channel is assumed. The simulation varies the number of mobile nodes, from 10 to 90; thus, there are different combinations of average links in the simulation. Moreover, the average moving speeds of mobile nodes are fixed to be 10, 30, and 50 km/hr, which represent low, moderate, and high moving speeds respectively.

4. Simulation Results and Performance Analysis

The simulation results are provided and used as evidences to analyze the performance of the two categorizes of the routing protocols table-driven and on-demand routing protocols. The first issue we would like to discuss is the update probability. With update probabilities we know the fragility of the protocols. The last one is to discuss the most probable number of broken links. We will show the most probable number of broken links in a network or in a route under some predefined condition, e.g. link=15 and speed=10 km/hr.

To verify the update probability for these two categories of routing protocols, we ran our simulation and obtained the following two tables. Table 1 presented the update probability of table-driven routing protocols. The number of mobile nodes are 10, 20, …, 80, and 90 each with different average links, which are recorded during the simulation runs and averaged. Generally speaking, the average links should include fractional portion, but in our calculation, we rounded it off to cope with the requirement of binomial distribution. The moving speeds are 10, 30, and 50 km/hr, which termed as low, moderate, and high speeds respectively. Further, the link break probabilities p_b for the low, moderate, and high speeds are 0.01, 0.02, and 0.03 respectively.

In Table 1, we testify that the update probability increases with both the number of mobile nodes and the moving speed. When the moving speed is low, the update probability P_{ud} reaches 0.583 if the number of mobile nodes is 30. For moderate speed, P_{ud} already reaches 0.581 when the number of mobile nodes is equal to 20. However, at high speed, P_{ud} achieves 0.730 when the number of mobile nodes is 20. If P_{ud} exceeds 0.5, it means that at each short time interval Δt, the network has more than half the chance to perform routing table updates. More precisely, table-driven routing protocols focus on each link of the networks, not only on the number of mobile nodes. This table tells us that as the number of mobile nodes increase, the average links highly increase. That is the reason why the update probabilities increase so rapidly as average number of links increases.

On the contrary, on-demand routing protocols focus only on the links of a concern route. During the whole simulation runs, we found that maximum number of links of all routes are less than and equal to 9 regardless of the number of mobile nodes in the network. Table 2 showed the update probability of on-demand routing protocols when varying the average speeds and the number of links in a route. Taking "low speed (p_b=0.01)" for consideration first, the maximum update probability is 0.086, which is much more less than its counterpart of table-driven routing protocols, shown in Table 1. As for "low speed (p_b=0.02)" and "low speed (p_b=0.03)", the maximum update probabilities are 0.166 and 0.240 respectively. Needless to say, they also have superior update probabilities than that that of table-driven routing protocols.

5. Conclusions

Though there are so many benefits offered by ad doc mobile wireless networks, the main fragility of the networks is the problem of a broken link. A mobile node could freely move without the constraints of wired backbone. This also presents the fragility of the networks. To enable the transmission, table-driven routing protocols have to maintain the whole topology of a network, i.e. all the links. If any link breaks, the protocols must trigger an update to maintain up-to-date routing information. Therefore, as the number of mobile nodes and moving speeds increase, routing table update increases rapidly. This seriously degrades the performance of table-driven routing protocols. On the contrary, on-demand routing protocols focus only on the links of a specific route, not the whole links of a network. Excluding the unnecessary information, the protocols largely reduce the update probability as compared with table-driven routing protocols. The evidences have been shown by using mathematical model and simulation result, which are presented at Section 2, 3, and 4.

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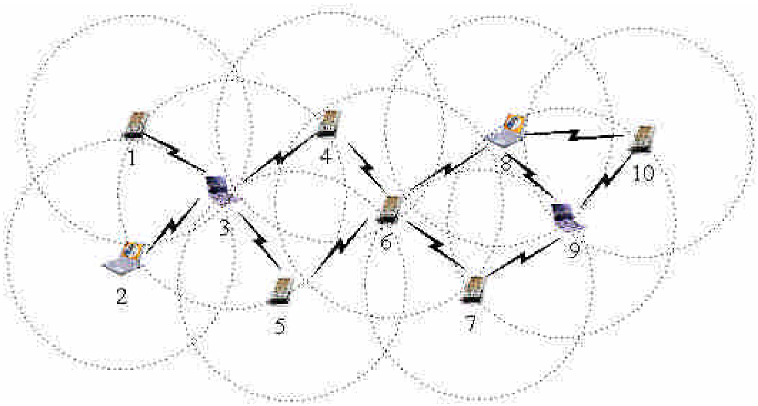

Figure 1 Ad hoc mobile wireless networks

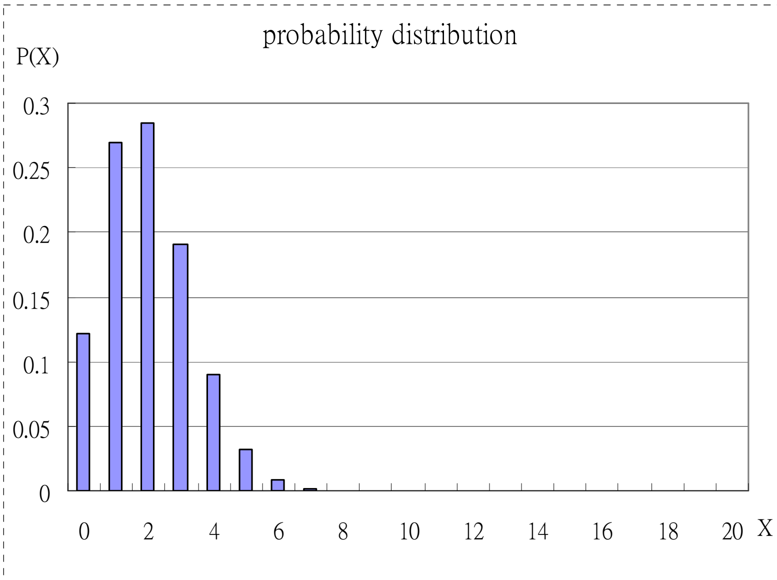

Figure 2 probability distribution

Table 1: update probability of table-driven routing protocols

No. of nodes(n_i)	10	20	30	40	50	60	70	80	90
Average links (m_i)	14.67	43.49	86.88	105.37	132.73	181.52	251.27	348.46	416.44
P_{ud}(low speed)	0.140	0.351	0.583	0.652	0.737	0.839	0.920	0.970	0.985
P_{ud}(moderate speed)	0.261	0.581	0.828	0.880	0.932	0.975	0.994	0.999	1.000
P_{ud}(high speed)	0.367	0.730	0.929	0.959	0.983	0.996	1.000	1.000	1.000

Table 2: update probability of on-demand routing protocols

Number of links	1	2	3	4	5	6	7	8	9
P_{ud}(low speed)	0.010	0.020	0.030	0.039	0.049	0.059	0.068	0.077	0.086
P_{ud}(moderate speed)	0.020	0.040	0.059	0.078	0.096	0.114	0.132	0.149	0.166
P_{ud}(high speed)	0.030	0.059	0.087	0.115	0.141	0.167	0.192	0.216	0.240