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LINK RELIABILITY ANALYSIS IN AD HOC NETWORKS

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1. INTRODUCTION

Mobile Ad-hoc NETworks (MANET) have become more and more popular, during the last ten years. Mobile hosts such as notebook computers are now easily affordable and are becoming quite common in everyday business and personal life. At the same time, network connectivity options for use with mobile hosts have increased dramatically, including support for a growing number of wireless networking products based on radio and infrared. With this type of mobile computing equipment, there is a natural desire and ability to share information between mobile users.

MANETs are suitable for situations where infrastructure is either not available, not trusted, or should not be relied on in times of emergency, like in critical mission applications, wherein fault tolerance is of great importance. For wireless (and wire line) networks, the network's ability to avoid or cope with failure is measured in three ways: reliability, availability and survivability, all of which have long been important areas of research [1]. Because of its importance, in this paper we investigate the link reliability for ad hoc networks, which can be used as important global measure of performances of ad hoc networks. It also can be utilized to improve localized route repairs by the means of connection mean time to failure (MTTF) as a parameter that allows predicting of the link expiration time (LET). Consequently global connection repairs are more seldom necessary, since the route maintenance routine of the routing algorithm could create disjoint bypass routes in advance based on calculated connection mean time between failures.

The previous work of ad hoc network reliability includes work on calculating link expiration times (LET) as in [2], where statistical LET in mobile ad hoc networks is reviewed. The authors predict the probability that a link between two nodes exists at time t2, in case the link existed at the starting time t0. They use the random waypoint model as a basic movement model. No forecasts about the duration of uninterrupted link can be made, since the link may cease to exists at time t1 with $t0 < t1 < t2$. In [3] prediction-based link availability estimation is introduced, while [4] gives a statistical derivation to forecast the average distance when the routing node is within the scope of the two other nodes. With these statistical calculations, the paper investigates the possibility of predictions of the average link expiration times and deviations for different node velocities, independent from the nodes radio transmission ranges and the distances between each other. In [5] a mobility prediction, which allows the creation of new routes in advance for mobile ad hoc networks, is introduced. The routing algorithm determines when a node will shortly leave the proximity of another node and can handoff the connection. Unfortunately this approach requires data from an external global positioning system (GPS) interface to determine the position, the velocity and the moving direction of all nodes plus a synchronized clock in all nodes. Qin and Kunz [6] perform a prediction of link breakage time using the mobile node's signal power strength from the received packets. The source node can perform a pro active route rebuild to avoid disconnection. Sadagopan at al. [7] examine the varying of the statistics of path durations including PDFs with parameters such as mobility model, relative speed, number of hops and radio range. They suggest that at moderate and high velocities the exponential distribution with appropriate parameterizations is a good approximation of the path duration distribution for a range of mobility models.

In this paper a link reliability model for two hop ad hoc networks is presented. The main motivation for this work is to use this model for MTTF calculation for a given link, which can be used to forecast the local route repairs. The prediction of link breakage is made on statistical basis and accordingly does not require additional devices like GPS or some special features in the wireless receiver that will enable measurement of the signal strength. The proposed model is validated through series of simulations using NS-2 simulator and application of proposed model is also presented.

2. AD-HOC NETWORK MODEL DESCRIPTION

We use a common ad hoc network model where all the mobile nodes have the same fixed transmission power and are equipped with omni directional antenna, thus having equal transmission range r.

In existing reactive protocols, a sending node utilizes the discovered route until it expires or is broken. The problem occurs when a route gets disrupted due to host mobility or poor signal strength. Whenever a node finds that its link to the next hop is broken, it will send a route error packet back to the source node, which will then invoke another route discovery procedure. However, this is costly as route discovery procedures activate a network flooding. Route consisting of multiple hops most frequently breaks because of the failure of a single link caused by the relative movement of only one node. This results in the wastage of scarce wireless bandwidth as well as long delays. The problem worsens when mobility is high, leading to more frequent route errors and route discovery packets. To solve this problem in [10] the local route repair (LRR) is used to patch a broken route between the two nodes of the path through some other node placed in the intersection region of the two nodes. The zone in which the route-repair packet propagates is limited to two hops.

According to this presumptions we model a part of an ad hoc network that represents a two hop ad hoc network. This network consists of $N+2$ nodes placed in area A. Two of the nodes are part of a multihop connection between the source MN7 and the destination MN5, one on the source side MNs and one on the destination side MNd, while the rest, N nodes, can enter the intersection region between the two-hop neighbors, and therefore play the part of possible routers. In order to establish a communication between the two-hop neighbor nodes, MNs and MNd, (l is the distance between MNs and MNd $r<l<2r$), the communication path has to go through one of the nodes (MN1, MN2) that are currently located in the intersection area B between MNs and MNd. Due to its shape, the intersection region is called the "eye of coverage" (see Fig 1.). While moving around in A, a node can enter the B area and, after a certain period of time, leave B and enter area C defined as A-B. This process is continuously repeated.

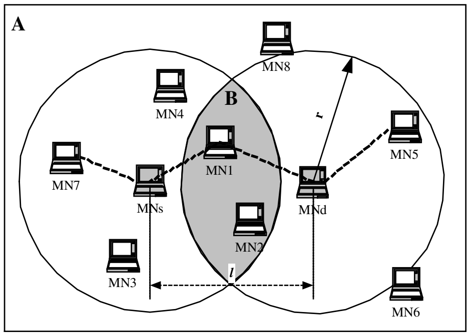

Fig. 1. Ad hoc network model.

3. LINK RELIABILITY MODEL

Reliability is a network's ability to perform a designated set of functions under certain conditions for specified operational times, while availability is a network's ability to perform its functions at any given instant under certain conditions. In order to calculate the link reliability we need the distribution of the time a MN spends in the intersection region.

The MN movement is described by a given Mobility Model (MM). There are several MM that are used in performance evaluation simulations for ad hoc networks. One of the most commonly used is Random Walk. In the Random Walk MM (also known as Random Direction MM), a MN moves from its current location to a new location by randomly choosing travel direction and speed. The new speed and direction are both chosen from pre-defined ranges, [speedmin; speedmax] and [0;2π] respectively. Each movement in the Random Walk Mobility Model occurs in either a constant time interval or a constant distance travelled, at the end of which a new direction and speed are calculated. If a MN, that moves according to this model, reaches the simulation boundary, it "bounces" off the simulation border with an angle determined by the incoming direction. The MN then continues along this new path.

Because the intersection region is very small when compared to the area wherein the nodes are scattered, a small number of changes of the direction will happen and, to simplify the solution, we can presume that the node passes the intersection region in a straight line with constant speed. Presuming these conditions, the time needed to pass the intersection region is given by $t = d/v$, where d is the length of the path that the MN passes, while moving through the intersection region. The MN speed v is a uniformly distributed random variable. The eye path d is a random variable and its value depends only on the entry point into the intersection region and the entry angle. According to this, d and v are statistically independent random variables.

In order to get the probability distribution of the time a MN spent in the intersection region we made series of simulations with TopoSim [9]. TopoSim is a wireless ad hoc network topology simulator created for the purpose of simulating purely topological characteristics of an ad hoc network, while incorporating the dynamical changes caused by the node's mobility. The simulations scenarios consist of 100 mobile nodes uniformly scattered in 1000m x 1000m area. There are two additional static nodes that represent the source and the destination placed on a given distance. The mobile nodes are moving according to the Random Walk MM with an average speed from 0.5m/s to 5m/s for the different series of simulations. The node transmission radius is set to 250m. During the simulations we measure the path length and the time spent in the intersection region for every mobile node.

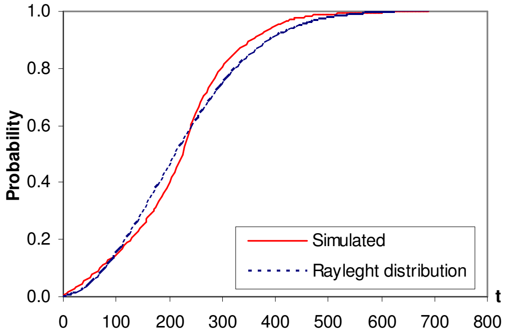

Fig. 2. Link duration time distribution.

The probability distribution of the time that a MN spends in the intersection region is shown on Fig. 2. On the same figure the Rayleight distribution with the same average value is shown. It can be seen that these two distributions are very similar. Thus, in order to obtain a closed form solution, we substituted this distribution with Rayleight distribution with the same average value.

The Rayleight distribution is given by

$$f(t) = Kte^{\frac{Kt^2}{2}} \tag{1}$$

With average value

$$\bar{t} = \sqrt{\frac{\pi}{2K}} \tag{2}$$

The parameter K depending on the average value is

$$K = \frac{\pi}{2\bar{t}^2} \tag{3}$$

In order to calculate the parameter K we need the average time that a MN spends in the intersection region. This time is given by [8]:

$$\bar{t}_B = \frac{\ln(\bar{v}+\sigma\sqrt{3}) - \ln(\bar{v}-\sigma\sqrt{3})}{2\sigma\sqrt{3}}\bar{d} \tag{4}$$

Where $\bar{v}$ is the average speed, σ is the speed's standard deviation, and $\bar{d}$ is the average value of the eye path, which is given by [8]:

$$\bar{d} = \pi r\left(2 - \frac{l\sqrt{4-l^2}}{8\,ArcSec(2/l)}\right) \tag{5}$$

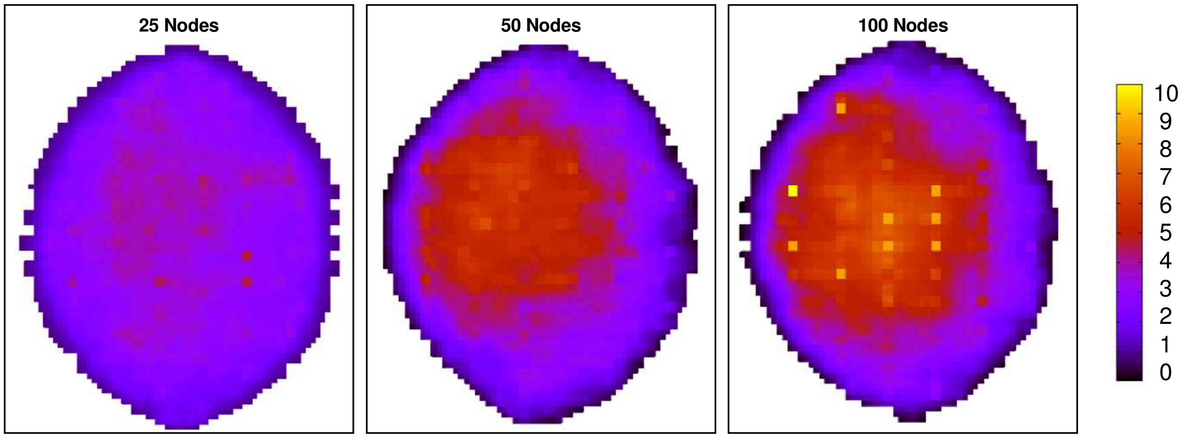

Fig. 3 Density map of routing node start positions in the 'eye of coverage'

When the current routing node leaves the intersection region, the routing protocol searches for another node from the intersection region to re-establish the connection. In order to find the link reliability we need to know what is the time that a chosen node spends in the intersection region. The nodes enter the intersection region, spend some time in it and then leave the intersection region. As the time spent in the intersection region grows, the probability that the node will be discovered by the routing protocol is bigger. This observation leads to the conclusion that the nodes that spend more time in the intersection region are more frequently used. The probability that the time spent by a MN will be equal to X is proportional to the length of the interval and to the probability that the given length will appear:

$$P(t=x) = \frac{x}{\int_0^\infty x f(x)dx} f(x) \qquad (6)$$

The average value of the time that the found nodes will spend in the intersection region is

$$\overline{x} = \int_0^\infty x P(t=x)dx \qquad (7)$$

The found node can be placed at any point along its path through the intersection region. According to this observation the node will pass only some fraction of this path. The fraction of path that will be passed is ½ if the node passes the path with constant speed, which is the case with Random Walk mobility model.

The link reliability is given by

$$R(t) = 1 - \int_0^t f(t) = e^{-\frac{Kt^2}{2}} \qquad (8)$$

The mean time to the failure (MTTF) of the system is defined as the average time for the system to go from the working state to the failure state. Now that an expression of the link reliability function is known, we can derive the MTTF of the system:

$$MTTF = \int_0^\infty R(t)dt = \sqrt{\frac{\pi}{2K}} \qquad (9)$$

For this system model, the reliability does not depend on the starting state in which the system is found. This is logically, since it represents the reliability of a given link that depends on the mobility of the routing node, but not on the number of nodes in the intersection region.

5. MODEL VALIDATION

In order to verify the theoretical results we made series of simulations using the NS-2 simulator [11]. The simulations scenarios consist of 25, 50 and 100 MN uniformly scattered in 1000m x 1000m area. There are two additional nodes that represent the source and the destination placed on a distance of 255m. The mobile nodes are moving according to the Random Walk MM with an average speed of 1m/s. The transmission radius is set to 250m. During the simulations we measure the link duration (this is MTTF).

The calculated MTTF for this network according to (9) is 146.6 seconds. The results obtained from simulations are shown in Table 1.

Table 1 MTTF simulation results

Simulation	MTTF	Error
25 nodes	148.3 seconds	1%
55 nodes	134.9 seconds	8%
100 nodes	132.6 seconds	10%

The table shows that for network with 25 nodes the calculated MTTF and the MTTF obtained from simulations are very close. When there are more nodes in the ad hoc network the MTTF obtained from simulations is smaller than the calculated. In order to investigate this difference, in simulations we also record the positions of nodes in moments when they are chosen as router nodes. From this position the node continues to move and packets are routed through this node until it leaves the intersection region. From the density map of start node positions (see Fig. 3) it can be seen that the nodes that are closer to the source node are more frequently chosen. This nodes are also closer to the border of the intersection region and the remaining time that they spend in the intersection region is smaller than average.

This phenomena is a result from the fact that when all nodes are perfectly identical then the closer nodes have fastest responses. But in reality this problem don't exist because it is nearly impossible to have perfectly identical nodes. First the nodes that participate in the ad hoc network can be of different types and can have different load, different programs that are currently running etc.

6. LINK RELIABILITY ANALYSIS

The reliability analysis of ad hoc networks is made for an example of rescue mission application for MANETs. The mobile nodes are located in area A=1,000,000m^2, while the use of IEEE 802.11 protocol results in transmission range r=250m. The standard deviation for the node speed σ is 0.01, hence the node speed is nearly constant.

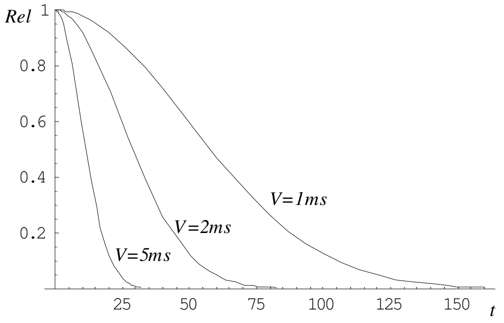

Fig. 4. Link reliability for different average speeds.

In order to investigate the impact of the previously mentioned parameters on the link and connection reliability for ad hoc networks we make several observations. The link reliability for different average node speeds is shown on Fig. 4. It can be seen that the rising average node speed reduces the link reliability.

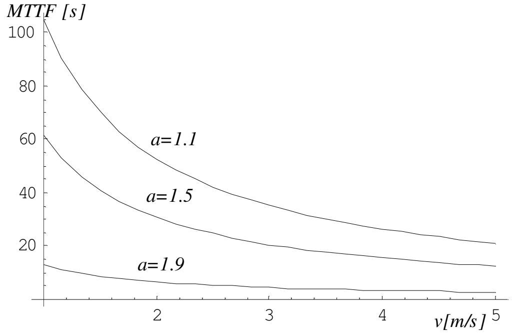

Fig. 5. MTTF depending on the speed for different relative distances between the two-hop neighbours.

Besides using the link reliability, the characteristics of a given link in the ad hoc network can be described more efficiently using the MTTF, which in fact represents the link expiration time. The dependence of MTTF on the average node speed for different relative distances between the two-hop neighbours is shown on Fig. 5. For relatively small average speeds, MTTF has bigger values that approach infinity when the average speed approaches 0. The increased speed leads to decreasing MTTF, which is a result of the shorter time that a MN spends in the intersection region. These two parameters can be used by the ad hoc routing protocol in order to create a disjoint route in advance that can be used for the LRR mechanism.

7. CONCLUSION

In this paper link reliability model for ad hoc networks is presented. The LRR techniques repair routes when they are broken. The created reliability model could be used for a statistical forecast of LRR, consequently escalating the ad hoc network performances. LRR are localized to a two-hop circular zone radius with the upstream node as a centre. Accordingly, this behaviour can be modelled using a simple two hop ad hoc network.

According to these models, analytical expressions for calculating the link MTTF is given. Using the calculated link MTTF, the ad hoc routing protocol can forecast the link expiration time and create a new disjoint route in advance using another node placed in the intersection region. This leads to increased performances of the ad hoc network, and will provide achievement of a satisfying level of QoS.

Besides the use of the calculated results in order to make a LRR, they can also be used for reviewing the ad hoc network performances depending on real measurable parameters.

8. REFERENCES

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Abstract: Reliability is a network's ability to perform a designated set of functions under certain conditions for specified operational times. We developed a link reliability model for ad hoc networks using real measurable parameters that concern performances of mobile ad hoc networks. By the means of the calculated mean time to failure, the frequent link breaks between two-hop neighbour nodes can be forecasted and incorporated in the local route repair techniques. The model can be used to enhance the ad hoc network performances and easier support QoS requirements due to the reduced connection breaks.

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