SPATIAL PARAMETERS AND CONNECTION AVAILABILITY IN AD HOC NETWORKS

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Abstract: The fluctuation of the ad hoc network spatial parameters not only alters the network topology but also introduces severe changes in the ad hoc network performances. Based on a given ad hoc network connection availability model, in this paper we investigate the influence of several spatial parameters that affect the ad hoc network connection availability which is often used as an important measure of the ad hoc networks fault tolerance. These parameters include: size of the area wherein the participants in the mobile ad hoc network are scattered, node density, transmission range, distance between the communicating nodes.

Keywords: mobile ad hoc networks, connection availability model, spatial parameters

1 Introduction

Within the past few years, the field of mobile ad hoc networks (MANET) [1] has seen a rapid expansion of visibility and work due to the explosive network community's interest in mobile computing as well as the widely available inexpensive wireless devices. An ad hoc network is a infrastructure free collection of wireless mobile nodes dynamically forming a temporary network without the use of any centralized administration. The nodes are expected to act cooperatively playing the part of routers for data packets over possibly multiple hops in order to establish the network "on-the-fly". Node mobility and limited power introduce rapid changes in network topology, connectivity and links characteristics.

Ad hoc networks are suited for use in situations where infrastructure is either not available, not trusted, or should not be relied on in times of emergency. Therefore, MANETs are often used in mission critical applications, in which fault tolerance is of great importance. For wireless (and wireline) 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 2. Because of their importance, we take into consideration the connection availability for ad hoc networks, which can be used as important global measure of performances of ad hoc network.

The previous work of ad hoc network availability includes work on models for path availability for random way point mobility model [3] and link availability for enhancing the performance of routing algorithms [4]. Instead of modeling link or path availability, in [5] a connection availability model based on commonly used ad hoc reactive routing protocols like Dynamic Source Routing Protocol (DSR) [6] and the Ad hoc On-demand Distance Vector Routing Protocol (AODV) [7] is introduced. The connection availability is mathematically described using a continuous time Markov chain (CTMC). The parameters used in this availability model are based on real mobile ad hoc network parameters such as: routing protocol, nodes velocity, number of nodes in the network, distance between the source and the destination and transmission range. In [8] an extension to the proposed connection availability model is presented. The extension includes an analytical expression for the impact of node mobility to connection availability incorporating mobility models like Random Walk and Random Way Point.

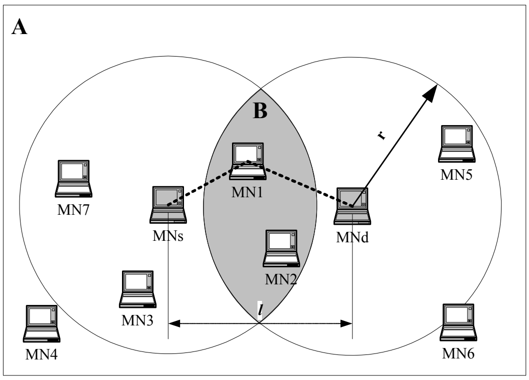

Figure 9: Ad hoc network model

Based on the connection availability model proposed in [7] and [8], in this paper the impact of several spatial parameters on the ad hoc network connection availability is investigated. These parameters include: size of the area wherein the participants in the mobile ad hoc network are scattered, node density, transmission range, distance between the communicating nodes. The analysis of the connection availability that depends on the spatial parameters is made for an example rescue mission application for ad hoc networks

2 Ad Hoc Network Model Description

Since real world radio networks are influenced by many factors like irregular terrain, asymmetry radio transmission, and radio interference, in order to give a simplified, but reasonable model we make some assumptions. To simplify our study, we assume that the terrain is perfectly flat while all the mobile nodes have the same fixed transmission power and are equipped with omni directional antenna, thus having equal transmission range r. This assumption turns the node radio coverage shape into a perfect circle with radius r.

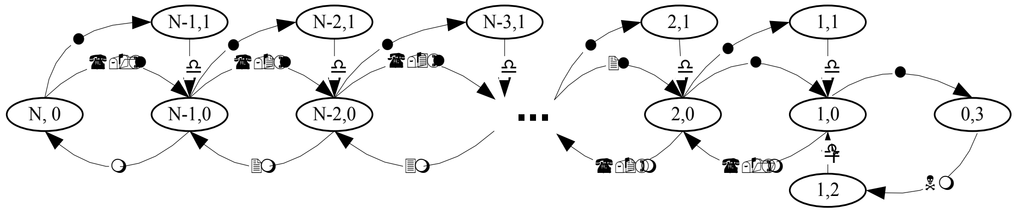

Figure 2: Connection availability model for ad hoc network

In our model we use N+2 nodes placed in area A. Two of the nodes are the source and the destination nodes for the end-to-end connection, and the rest, N nodes, can be part of the connection path between the source and the destination, therefore playing the part of routers in this end-to-end connection. In order to establish a communication between the two 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 (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.

Similar to [9] and [10] we use a two-hop scenario because of the complexity of the development of an analytical model for multihop scenario.

3 Connection Availability Model

Availability is a network's ability to perform its functions at any given instant under certain conditions. Steady state availability is a function of how often something fails and how long it takes to recover from a failure [2]. While path availability models between two nodes depend on both, node speed and movement pattern, the connection availability model [7] includes the influence of ad hoc routing protocols in the moments when a change of route is needed, given that the previously used route becomes unavailable. Hence, connection availability includes availability of possibly different source-destination paths each existing in their own time period.

The routing protocols like AODV and DSR react on all physical faults in the same fashion, that is by issuing route-error and, afterwards, activating the route discovery mechanism. According to this behavior, node and link faults can be modeled in the same way, considering only the average switching delay $1/\delta$. When there are no nodes in the intersection area, the routing protocols react on a different way than the one previously described: if no available route can be found after a short while, in order to limit the rate at which new route discoveries for the same destination are initiated, the protocols use an implementation dependent back-off algorithm. In this case, the average time needed for connection reestablishment is the connection reestablishment delay $1/\delta_r$.

The connection availability is modeled as parallel system of N components with N repair facilities that depends on the leaving rate λ (failure rate), returning rate μ (repair rate), number of participants in network N, average switching delay $1/\delta$ and connection reestablishment delay $1/\delta_r$ (see Fig. 2). For the purposes of simplifying the CTMC model the following assumptions are made: all entering and leaving events in the intersection region are mutually independent, exponential distribution is assumed for time of occurrence of each enter and leave event, and the average switching delay is small compared to the average time a routing node spends in the intersection region. The states of the CTMC model are labeled with tuple (i,j) where $i\in\{0,1,2,\ldots,N\}$ represents the number of nodes currently in the intersection region (the total amount of nodes is $N+2$), and $j\in\{0,1,2,3\}$ represents the state of the connection ($j=0$ no fault, connection is up, $j=1$ route discovery state, $j=2$ waiting for route reestablishment, $j=3$ no routing nodes available). The failure rate λ is the rate of leaving the intersection region B, while the repair rate μ, is the rate of the nodes returning into the B region.

The steady state connection availability A_{ss} is

$$A_s = \sum_{k=1}^{N} \frac{N!}{k!(N-k)!} \left(\frac{\mu}{\lambda}\right)^N \pi_{0,3} \tag{1}$$

$$\pi_{0,3} = \frac{1}{\left(1+\frac{\lambda}{\delta}\right)\left(1+\frac{\mu}{\lambda}\right)^N - \frac{\lambda}{\delta}\left(1+N\frac{\mu}{\lambda}\right) + N\frac{\mu}{\delta_r}} \tag{2}$$

In order to confirm the connection availability model we simulated a number of simple two hop ad hoc scenarios using the NS2 network simulator [13]. We analyzed the time of connection existence using the discrete moments of the constant bit rate sending interval. The simulation scenario was made in several series using both, different source-destination node placement in order to avoid the central effects of the Random Way Point mobility model. The results have corresponded to the anticipated connection availability obtained using the model on Fig 2.

4 Mobility Parameters

Connection availability of ad hoc networks depends on many factors: routing protocol, number of participants in network, distance between source and destination of connection, nodes velocity, mobility model, transmission range and size of the area wherein the participants in the ad hoc network are scattered.

By the means of series of simulations using the NS2 network simulator in [7] the numerical values for both, average link switching delay and the average connection reestablishment delay for AODV are obtained. The link switching delay is 0.125s, while the measured average time needed for a new router in the interconnection area to get the request for route from the source is 4.844 s.

Both, the transmission range and the distance between the nodes affect the size of the intersection area *B*:

$$B = r^2(2ArcCos(\frac{a}{2}) - a\sqrt{1-\frac{a^2}{4}}) \qquad (3)$$

where *r* is transmission radius, *a* is relative distance between the nodes *a=l/r* and *l* is distance between the nodes ($l\in[r,2r]$, $a\in[1,2]$).

The mobility of nodes affects the leaving and returning rate. In order to obtain the leaving rate, we must obtain the average time $\bar{t}_B$ that a MN spends in the intersection region between the two communicating nodes MNs and MNd. Due to the shape of the intersection region, it is called the "eye of coverage" (see Fig 1.). The MN movement is according a given Mobility Model (MM). There are several MM that are used in performance evaluations simulations for ad hoc networks. The most commonly used models are Random Walk and Random Waypoint [11]. In the both MMs linear motion and uniformly distributed speed is used. If the intersection region is reasonably small relative to the whole area, we can presume that no changes of direction happen in the intersection region, namely the node passes the intersection region in a straight line with a constant speed. At these conditions the time needed to pass the intersection region is given by *t=d/v*, where *d* is length of path that MN passes trough the intersection region (eye path) and *v* is speed of MN. The 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 intersection region and the entry angle.

The average time that a node passes into the intersection region can be expressed in relation to the average eye path, average speed $\bar{v}$ and standard deviation σ:

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

For the average time that a node passes outside the intersection region we have

$$\bar{t}_C = \frac{p_C}{p_B}\bar{t}_B \qquad (5)$$

The leaving rate for the intersection area *B* is $\lambda = 1/t_B$ and the leaving rate for area *C* (returning rate for intersection area *B*) is $\mu = 1/t_c$.

5 Spatial Parameters Influence Analysis

In order to investigate the impact of several spatial parameters on the ad hoc networks connection availability we decides to take into consideration one example ad hoc application which will be the basis for the ad hoc networks parameter values we use. We made several observations of the influence of the deviation of a given spatial parameter, while keeping the rest constant.

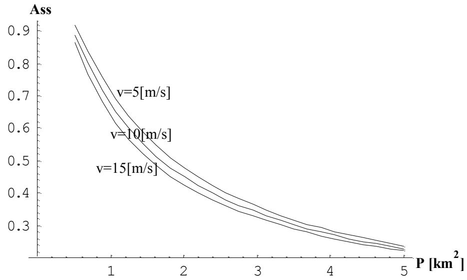

Fig. 3: A_{ss} depending on the area size

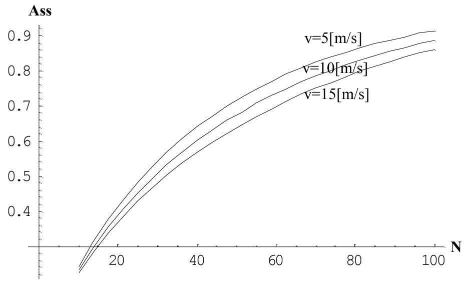

Fig. 4: A_{ss} depending on the number of nodes

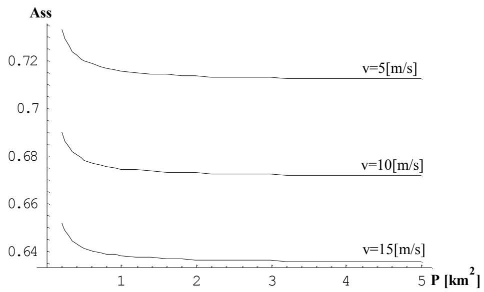

Fig. 5: Ass depending on the area size when ρ=const=50 node per km2

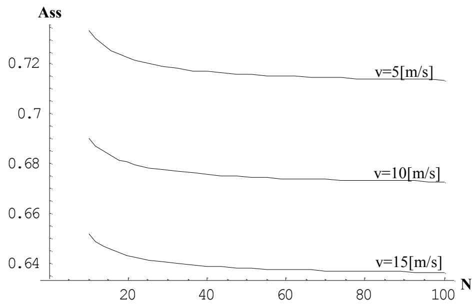

Fig. 6: Ass depending on the number of nodes when ρ=const=50 node per km2

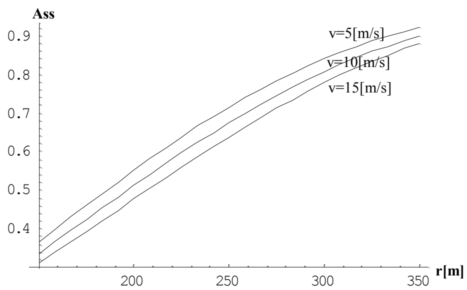

Fig. 7: A_{ss} depending on the transmission radius

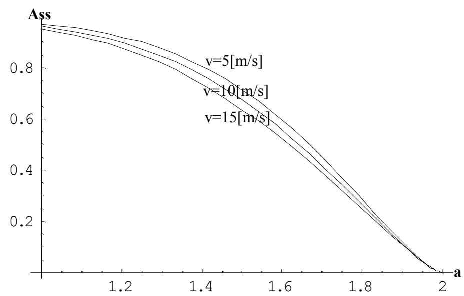

Fig. 8: A_{ss} depending on the source destination relative distance – a

The impact of the spatial parameters on the ad hoc network connection availability is monitored for an example rescue mission application of ad hoc networks. The mobile nodes are located in area A with size P=1,000,000m^2, while the use of IEEE 802.11 protocol results in transmission range r=250m. In order to be sure, with a probability of at least p, that no node in a ad hoc network with $N>>1$ nodes and homogeneous node density $\rho=N/P$ nodes per unit area is isolated, the node transmission radius r according [12] must be set to

$$r \geq \sqrt{\frac{-\ln(1-p^{1/N})}{\pi} \cdot \frac{P}{N}} \qquad (6)$$

The no-isolated-node probability is a measure of the ad hoc network connectivity and here it is used to calculate the number of nodes needed to achieve connected ad hoc network for a given area A and transmission range r. Solving equation (6) for P=10^6m^2 and r=250m we get N=42 nodes (because of the border effects we use N=50). The value of the relative distance between MNs and MNd nodes is taken to be a=1.5m in all cases, while the node speed is varied between [5, 10,15] m/s. The standard deviation for the node speed σ is 0.01, hence the node speed can be considered as nearly constant.

The impact of the size of the area wherein the participants in the ad hoc network are scattered is shown on Figure 3. The increasing area size decreases the connection availability since within the larger area it is far more difficult to obtain high availability because of the node movements. This decreasing is more apparent when the area size was relatively small, while, when the area size becomes rather big, the decreasing of the connection availability is less significant. On Figure 4 the impact of the number of nodes – participants in the ad hoc network is presented. As one can expect, the increasing number of nodes has a positive effect on the ad hoc network connection availability. It is interesting to note that this effect has a steady growth, that is the connection availability increases up to the moment when it reaches its maximum.

The ad hoc network connection availability depending on the area size, while keeping the node density constant to a level of 50 nodes per km^2, is shown on Figure 5. It can be seen that the area size fluctuation has a big impact when it is relatively small, in which cases it can be hardly compensated with the deviation of the number of nodes in the network. For larger area sizes the change in the number of nodes efficiently keeps the connection availability a bit bellow the firstly calculated level, that is the constant node density parameter compensates for the increasing of the area size. On Figure 6 is shown the dependence of the connection availability on the number of nodes in the network, while keeping the node density constant. The effects of these parameters are similar, as it is expected, to the previous case with the difference that here the constant node density factor can not maintain the connection availability at a steady level even for larger number of nodes. The connection availability keeps decreasing but noticeably slowly compared to the case when the number of nodes is small. It is also interesting to note that, for relatively small number of nodes, the decreasing of the connection availability is more rapid when compared to Fig 5.

The dependence of the ad hoc network connection availability on the node transmission radius is shown on Figure 7. With the increasing node transmission radius the connection availability also increases since the nodes become aware of their distant neighbors. The impact of the source destination relative distance on the connection availability is shown on Figure 8. As expected, the connection availability decreases with the increasing source destination distance. This decreasing starts off slowly to become more evident for relative distances greater that 1.6.

6 Conclusion

In this paper the impact of several ad hoc spatial parameters on connection availability for ad hoc networks is presented. Firstly the used model of connection availability for ad hoc networks is presented and the parameters affecting this model are defined. The model includes measurable parameters like routing protocol, number of participants in network, source destination distance, node velocity, mobility model, transmission radius and size of the area wherein the participants in MANET are scattered.

The proposed models are used to evaluate the influence of different spatial parameters on the steady state connection availability for an example rescue mission application for ad hoc networks. The spatial parameters taken into consideration are: size of the area wherein the participants in the mobile ad hoc network are scattered, node density, transmission range, distance between the communicating nodes. Our observations have shown that these spatial parameters have a great influence on the ad hoc network connection availability. The spatial parameters impact analysis have shown that using well tuned values for these parameters one can achieve significantly better ad hoc network performances.

7 References

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