Ad Hoc Networks Routing Protocols Efficiency With Respect To Connection Availability

Trajanov Dimitar[1], Filiposka Sonja[2], Cilku Bekim[3], Aksenti Grnarov[4]

Abstract—One of the most important issues in the main applications of mobile ad hoc networks (as rescue and military operations) is to know the availability of the system. We developed an analytical model in order to investigate the routing protocol efficiency using real measurable parameters that concern the performances of mobile ad hoc networks. We analyzed the routing protocol efficiency with respect to connection availability for rescue mission example application.

Keywords—Ad hoc Network, Connection Availability, Routing Protocols Efficiency, Availability Model

I. INTRODUCTION

One of the most vibrant and active "new" fields today is that of mobile ad hoc networks (MANET). Within the past few years, though, the field has seen a rapid expansion of visibility and work due to the proliferation of inexpensive, widely available wireless devices as well as of the network community's interest in mobile computing. An ad hoc network is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. The nodes are expected to act cooperatively to establish the network "on-the-fly" and route data packets possibly over multiple hops. As a result of the multihop environment, the routing protocol has become a very important part of the ad hoc network layered architecture. Its primary goal is correct and efficient route establishment between pair of nodes so that messages can be delivered in a timely manner. MANETs are often used in critical mission 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 [1]. Because of their importance, in this paper we investigate the impact of routing protocols to connection availability in ad hoc networks.

The previous work of ad hoc networks availability includes work on link availability model for enhancing the performance of routing algorithms that is proposed in [2]. In [3] prediction about the average link expiration times for a simple network scenario is investigated. In [4] the continuous time Markov chain (CTMC) is used in order to represent a connection availability model for a simple ad hoc network. The proposed connection availability model incorporates the physical faults that affect the end-to-end connection in communication systems, however not incorporating any characteristics of ad hoc routing protocols. In [5] an improved connection availability model based on commonly used ad hoc reactive routing protocols like the Dynamic Source Routing Protocol (DSR) [7] and the Ad hoc On-demand Distance Vector routing protocol (AODV) [8] is designed. In [6], based on the ad hoc network connection availability model, the connection resilience to nodes failures is evaluated.

The main motivation for this work is to analyze the impact of routing protocols to ad hoc network connection availability. In order to make this analysis we define two measures: routing protocol efficiency (RPE) and relative routing protocol efficiency (RRPE).

II. AD-HOC NETWORK MODEL DESCRIPTION

We use a common ad hoc network model that corresponds to the models used in the referenced papers. In order to give a simplified, but reasonable model 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. Hence, the node radio coverage shape is a perfect circle with radius r. In our model we have N+2 nodes placed in area A. Two of them are the source and the destination nodes for the end-to-end connection. The rest-N nodes can be part of a 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, MN_s and MN_d (l is the distance between MN_s and MN_d $r<l<2r$), the communication path has to go through one of the nodes (MN_1, MN_2) that are currently located in the intersection area B between MN_s and MN_d (see Figure 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. In order to simplify the modeling of the node mobility we place the coordinate system origin in MN_s, while MN_d lays on the x-axis as shown on Figure 1. According to this assumption we only consider the distance between MN_s and MN_d and the mobility of the rest of the nodes relative to this coordinate system. Similary to [4] and [3] we use a two-hop scenario because of the complexity of an analytical model development for multihop scenario.

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III. ROUTING PROTOCOLS EFFICIENCY WITH RESPECT TO CONNECTION AVAILABILITY

In order to analyze the impact of the routing protocols to connection availability, we start with the connection availability model proposed in [5] and enhanced in [6]. 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 [1]. The connection availability model [5] 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 in 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 modeled with the connection reestablishment delay $1/\delta_r$.

The connection availability model is a parallel system of N components with N repair facilities. It depends on the leaving rate λ (failure rate), returning rate μ (repair rate), number of participants in the network N, average switching delay $1/\delta$ and connection reestablishment delay $1/\delta_r$. 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 (see Fig. 2) are labeled with tuple (i,j) where $i\in\{0,1,2,\dots,N\}$ 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 is given by summation of all no faulty states (states whose second index equals 0):

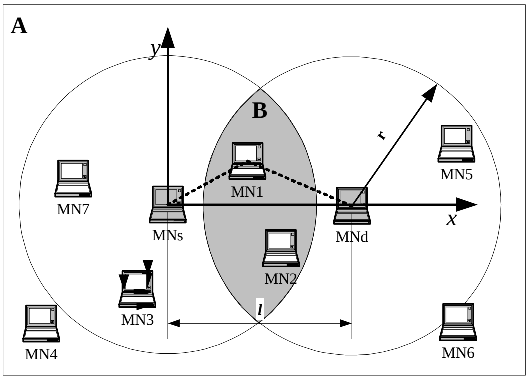

Figure 1. Ad hoc network model

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

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

In order to evaluate the efficiency of the routing protocols to connection availability we must make model for ideal ad hoc network routing protocol behavior. The ideal routing protocol should have the average switching delay and connection reestablishment delay equal to zero. This means that when the routing node leaves intersection region the switching to a new available routing node is made immediately. Also, when there are no nodes in the intersection region and the connection is down, the connection reestablishment is made immediately when the new node enters the intersection region. The CTMC model for ideal routing protocol is shown on Fig. 3. The connection availability for ideal routing protocol is:

$$A_I = 1 - \frac{1}{(1-\mu/\lambda)^N} \qquad (3)$$

We define two measures in order to express the impact of routing protocols to ad hoc network connection availability: routing protocol efficiency (RPE) and relative routing protocol efficiency (RRPE). The routing protocol efficiency is defined as 1 minus the difference between the ideal routing protocol availability and real routing protocol availability:

$$RPE = 1-(A_I - A_S) \qquad (4)$$

This measure gives the decreasing of availability as a result of the routing protocol. The values of RPE close to 1 represent efficient routing protocol and the lower values show that the routing protocol is not so efficient with respect to the connection availability.

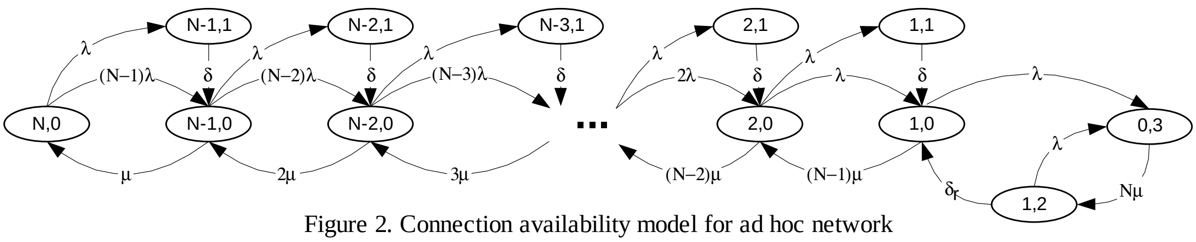

Figure 2. Connection availability model for ad hoc network

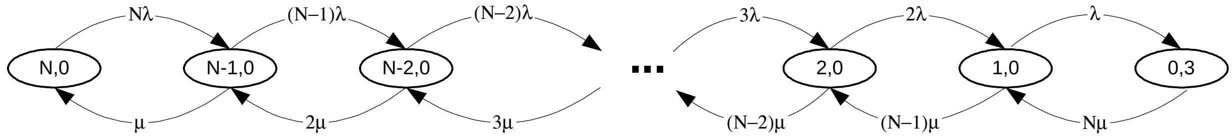

Figure 3. Connection availability model for ad hoc network (Ideal Case)

The relative routing protocol efficiency represents the relative efficiency of the routing protocol with respect to the connection availability:

$$RRPE = 1 - \frac{A_I - A_s}{A_I} \qquad (5)$$

It has values between 0 and 1. The values close to 1 represent great effectiveness of the ad hoc routing protocol network, while the values close to 0 represent the routing protocol ineffectiveness.

IV. Mobility Parameters Modeling

Connection availability of ad hoc networks depends on many factors: routing protocol, number of participants in the network, distance between source and destination, nodes velocity, mobility model, transmission range and size of the area wherein the participants in the ad hoc network are scattered. One of the main goals of this paper is to obtain the influence of these factors over the ad hoc network routing protocols efficiency.

The influence of the routing protocol is represented through the average link switching delay $1/\delta$ and the average connection reestablishment delay $1/\delta_r$ parameters. By the means of series of simulations using the NS2 [11] network simulator the numerical values of these parameters for AODV and DSR routing protocol are obtained in [6].

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

$$B = r^2\left(2ArcCos\left(\frac{a}{2}\right) - a\sqrt{1-\frac{a^2}{4}}\right) \qquad (6)$$

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 nodes mobility affects the leaving rate 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. 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. The most commonly used models are Random Walk and Random Waypoint [9]. In the both mobility models linear motion and uniformly distributed speed is used. In order to simplify analytical modeling 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 constant speed. Presuming these conditions, the time needed to pass the intersection region is given by $t = d/v$, where d is the path length that MN passes, while moving through the intersection region and v is the MN speed. The speed v is an uniformly distributed random variable. The path d is a random variable and its value depends only on the entry point into the intersection region and the entry angle. The average time that a node passes into the intersection region [6]is given by

$$\bar{t}_B = \frac{\ln(\bar{v}+\sigma\sqrt{3}) - \ln(\bar{v}-\sigma\sqrt{3})}{2\sigma\sqrt{3}}\bar{d} \qquad (7)$$

where $\bar{d}$ is the average path length, $\bar{v}$ is the average speed of the node and σ is the standard deviation. The average time that a MN passes outside the intersection region B [6] is

$$\bar{t}_C = \frac{p_C}{p_B}\bar{t}_B \qquad (8)$$

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

V. Routing Protocol Efficiency Analysis

The analysis of the routing protocol efficiency with respect to connection availability is made for an example rescue mission application of ad hoc networks. The mobile nodes are located in area A=1km^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 an ad hoc network with N>>1 nodes and homogeneous node density $\rho=N/A$ nodes per unit area is isolated, the node transmission radius r according [10] must be set to

$$r \geq \sqrt{\frac{-\ln(1-p^{1/N})}{\pi}\cdot\frac{A}{N}} \qquad (9)$$

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 (8) for A=1km^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 MN_s and MN_d nodes is a=1.5 (average distance) in all cases. The node speed standard deviation σ is 0.01, hence the node speed is nearly constant.

The dependence of RPE on the relative node distance for AODV and DSR routing protocols is shown on Fig. 4. It can be seen that the AODV routing protocol has greater efficiency than DSR. The routing protocol efficiency drops with the increasing relative distance until it reaches a minimum value after which it again rises as a result of the very small values of the connection availability. On Fig. 5 the dependence of RRPE on the relative distance between the communication nodes for different values of the average node speed is shown. The increasing relative distance decreases the RRPE. This is a consequence of the smaller intersection region because of which there are more route requests for new routes and the protocol frequently enters the connection reestablishment stage. The delays between the subsequent route requests do not allow immediate discovery of the nodes that entered the intersection region. The increasing average node speed decreases the RRPE.

Fig. 6 represents the RRPE depending on the number of

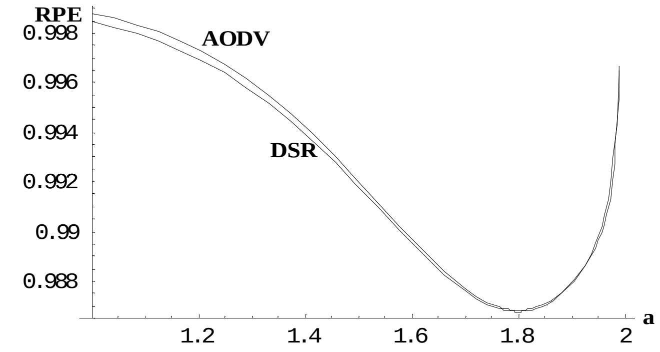

Figure 4. RPE depending on the routing protocol and relative distance between communicating nodes.

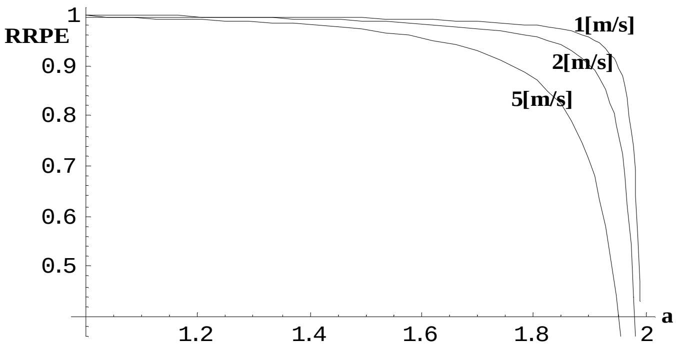

Figure 5. RRPE depending on the average node speed and relative distance between communicating nodes.

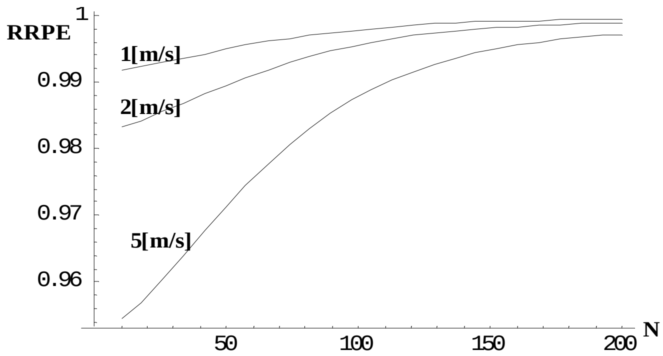

Figure 6. RRPE depending on the node speed and number of nodes in the ad hoc network.

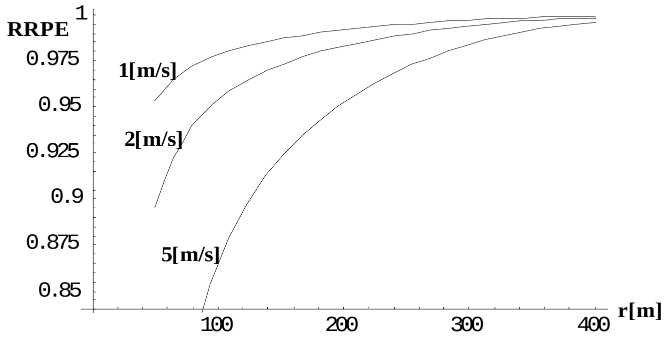

Figure 7. RRPE depending on the node speed and transmission radius.

nodes in the ad hoc network for various average node speeds. The increasing number of nodes increases RRPE, while the increasing average node speed decreases RRPE. When the number of nodes increases, the routing protocol seldom enters the connection reestablishment stage which yields to improved routing protocol efficiency. RRPE depending on the node transmission radius for various average node speeds is given on Fig. 7. The increasing node transmission radius increases the RRPE, while the increasing average node speed leads to decreased RRPE, just like in the other examples. Larger transmission radius leads to larger intersection region which decreases the need for frequent route reestablishment.

VI. CONCLUSION

In this paper the impact of routing protocols to connection availability for ad hoc networks is presented. Firstly, the 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 MANET participants are scattered. In order to quantify the impact of the routing protocols we introduced two new measures: routing protocol efficiency and relative routing protocol efficiency. RRPE and RPE are evaluated for one important mobile ad hoc networks application, the rescue mission. According to the obtained results, the AODV routing protocol shows better performance than DSR. The increased node velocity leads to poorer RRPE. The node mobility must be considered when some level of connection availability is needed. This is especially the case, when transmission radius is smaller and thus the impact of mobility is significant.

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