Modelling the Reliability of Ring Topology IP Micro Mobility Networks

Sándor Imre
Department of Telecommunications
Budapest University of Technology and Economics
Magyar Tudósok krt. 2., Budapest, Hungary, H-1117
+36-1-463-3256
imre@hit.bme.hu

Máté Szalay
Department of Telecommunications
Budapest University of Technology and Economics
Magyar Tudósok krt. 2., Budapest, Hungary, H-1117
+36-1-463-3227
szalaym@hit.bme.hu

ABSTRACT

The telecommunications, computer sciences and media of today seem to converge to an all IP network. Not only IP backbone will be used but also IP access networks. At the same time there is an increasing need for mobility. MobileIP cannot provide fast handovers in an always-on scenario. Therefore IP micro mobility solutions are needed. IP micro mobility networks have several special requirements. They have to provide fast handovers and special routing is needed. Most of the IP micro mobility solutions are based upon a tree topology network. The most important weakness of the tree topology networks is vulnerability. An alternative solution for micro mobility networks can be the ring topology. In this paper we introduce a reliability model for micro mobility networks and an algorithm to compute the reliability of ring topology micro mobility networks. By means of this algorithm the reliability of different topologies can be compared and it can be a useful tool when designing the parameters of ring topology micro mobility access networks.

Categories and Subject Descriptors

B.8.2 [Performance and Reliability] Performance Analysis and Design Aids

General Terms

Performance, Reliability

Keywords

Micro Mobility, Network Topology

1 INTRODUCTION

Nowadays three separate areas: telecommunications, computer sciences and media are converging towards a common so-called ‘infocom’ network. The common aspect of the trends lies in the network layer, where IP will be the common basis of the systems. Therefore there is an increasing need for IP mobility. The mobility provided by IETF MobileIP [1] cannot properly fulfil the requirements in an always-on scenario; hence micro mobility is needed to extend macro mobility. There are several micro mobility protocol recommendations introduced in the literature, see [2,3]. Most of them are based on a physical or logical tree topology network with the root of the tree functioning as the gateway to the IP backbone. The most important and severe weakness of tree topology is its poor reliability. We have presented a reliability model for tree topology micro mobility networks in [11], in this paper we present an approach for modelling the reliability of ring topology micro mobility networks. This enables us to compare tree and ring topology micro mobility networks from a reliability point of view. Our reliability measure is especially designed for micro mobility networks.

This paper is structured as follows:

After a short introduction in Section 3 we define a reliability measure and a reliability function for ring topology micro mobility networks. A recursive algorithm is introduced that can be used to exactly compute the reliability function of ring topology networks. In Section 4 we examine how the change of various parameters of the topology affects reliability. In Section 5 the reliabilities of tree and ring topology micro mobility networks are compared. In Section 6 we explain how this method can be extended to study different topologies and to compare their reliability. Using our algorithm a tool can be developed for analysing and designing reliable micro mobility network topologies.

2 RELATED WORK

2.1 IP Micro Mobility

The Internet and most telecommunication networks have or will have an IP backbone. In the future IP will be taken to the terminals. At the same time user requirements are changing, there is a growing need for security and mobility for example. The standard IP mobility solution, Mobile IP (Mobile IPv4 or Mobile IPv6) is not suitable for an always-on scenario with frequent handovers [4]. When handovers are frequent micro mobility has to be used. Micro mobility provides local mobility within a well-defined area, for example in an access network. While the mobile equipment stays in the same micro mobility domain handovers are handled locally, the Mobile IP home agent or the corresponding nodes are not notified, as the IP address of the mobile node is not changed.

There are several published IP micro mobility protocol recommendations, see [2,3]. Most of them are designed for IPv4 but with modifications they can be applied in IPv6 networks too.

In a micro mobility network the positions of the mobile nodes have to be stored in a database to route packets correctly. Because of routing considerations most of the micro mobility solutions are based on a tree topology network, but other topologies may work as well.

The tree topology suits most of the requirements of a micro mobility network (e.g. efficient routing, scalability), the chief disadvantage is, however, the poor reliability [9]. If a link or node breaks down a whole subtree is separated from the network. The ring topology is much more reliable as we will see, the weakness is poor scalability.

In micro mobility networks service access points (SAP) are called base stations (BS), because usually wireless links are used. Mobile nodes are connected to the base stations of the network, gateways relay IP packets between the IP backbone and the access network. In a ring topology micro mobility network all the base stations and gateways are connected in a ring. All the nodes have two neighbouring nodes. In micro mobility networks the number of base stations is typically much higher then the number of gateways. A small ring topology micro mobility access network with two gateways and five base stations is depicted in Figure 1.

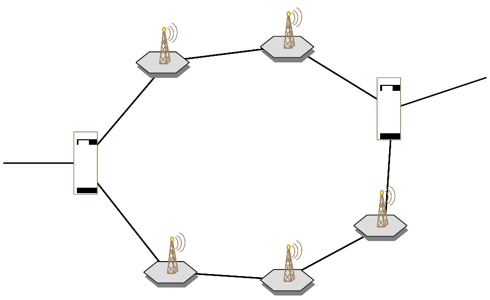

Figure 1. Ring topology micro mobility network

2.2 Reliability

Reliability modelling and analysis can be briefly summarized as follows [5]:

- definition of adequate reliability measures,
- determination of the possible states of the network,
- determination of the impact of failures on reliability measures.

A graph model of the network will be used. The edges of the graph represent the links connecting the nodes. In our model only link breakdowns are considered, the nodes are totally reliable. A binary model will be used for unreliable links. The links have two states: up (working) state, and down (broken) state. All the links have an independent and equal probability of being in the down state.

Reliability means that faults in the system do not degrade the performance of the system too much. To formalize this statement a performance function is introduced as a reliability measure. This performance function tells the performance of the system in a state, see [6].

Maximum performance is the value of the performance function in the faultless state of the system. If the performance of the system in a given state is divided by the maximum performance we get the relative performance.

Given the probability of the states of the network and the reliability measure there are several methods to get the expected value or the distribution of the relative performance. Some of these methods are exact, some are estimates and some give only upper or lower bounds for the mean value [7].

A reliability measure and an algorithm for getting the exact distribution of the performance for ring topology networks will be introduced in Section 3.

3 RING TOPOLOGY

3.1 The Reliability Measure

The general graph model of the network was given in Section 2.2. In a given state some of the links are up and some of them are down. Our reliability measure for micro mobility networks is the following: The performance of the network in a given state is the number of base stations that can reach the backbone, see [11].

Let B denote the number of base stations in the network. B^* is the number of base stations that can reach the backbone, hence the performance is

$$Perf = B^* .$$

The maximum performance is obviously the number of base stations in the network:

$$Perf_{\max} = B .$$

The relative performance is the proportion of the base stations that can reach the backbone among all of the base stations:

$$Perf_r = \frac{B^*}{B} .$$

In a ring topology network if only one of the links breaks down, the relative performance remains 1 since all the base stations can still reach a gateway.

In the network of Figure 1, if two of the links break down, the relative performance may vary between 0.4 and 1 depending on which two of the links break down. This is because with two link failures at least 2 out of the 5 base stations can reach one of the gateways, but it is possible that despite of the failures all the base station can still reach a gateway. These two cases are shown in Figure 2 and Figure 3.

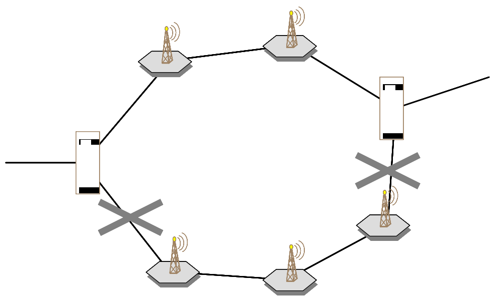

Figure 2. Two failures, relative performance is 0.4

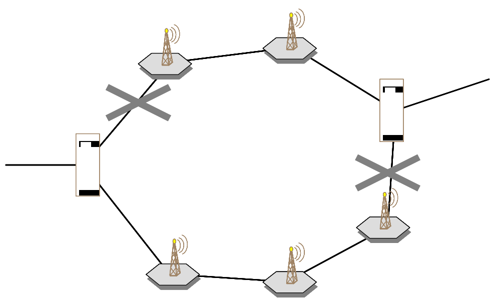

Figure 3. Two failures, relative performance is 1.0

3.2 The Distribution Function

For ring topology micro mobility networks with the reliability measure described in Section 3.1. we constructed an algorithm in order to calculate the exact distribution function of the relative performance.

In our model we did not consider gateway breakdowns. All the gateways in the ring are completely reliable. This assumption is close to real life because gateways should be much more reliable than base stations and links.

Two gateways and a series of base station nodes in between are called a "section" of the ring. A section has two gateways at the ends. Figure 4 shows a section of a ring. If the number of gateways in a ring is *M*, it is made up of *M* sections.

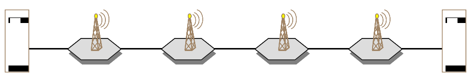

Figure 4. A "section" of a ring topology network

We introduce a simple notation for ring topology networks. The section lengths are listed in brackets. For example (2,3) denotes the example network of Figure 1. The ring consists of two sections. One section has 2 base stations the other section has 3. Note that a network has several "names", for example (5,6,8,10) refers to the same network topology as (6,8,10,5) or (8,10,5,6).

We define a vector **m**=$\left(m_0,\ldots,m_s\right)$ for each section of the ring, where *s* refers to the number of base stations in the section. The length of the vector is (*s*+1) and the elements are indexed from 0 to *s*. The element m_i equals to the probability of exactly *i* base stations being able to reach one of the two gateways. **m** is called the performance vector of the section.

How can this performance vector be computed? If the link error probability is *p* and the length of the section is *s*, then the probability that all the base stations can reach a gateway is

$$m_s = (1-p)^{s+1} + p(1-p)^s,$$

because all the base stations can reach a gateway when there are no link errors or there is only one. If there are more than one link errors in a section, then not all the base stations can reach a gateway.

We will call one of the two gateways "left" gateway, the other will be the "right" gateway. If less then *s* base stations can reach a gateway, no base station is able to reach both of the gateways. Each of them can reach only the left, only the right or neither of them. What is the probability that exactly *i* base stations can reach a gateway, when $0 \le i < s$? There are (*i*+1) cases: *j* base stations reach the left gateway and ($i-j$) base stations reach the right gateway where *j* runs from 0 to *i*. If the link error probability is *p* then the probability that exactly *i* base stations can reach a gateway is:

$$m_i = i \cdot p^2 \cdot (1-p)^i$$

For example the performance vector of the section of Figure 4 with a link error probability of 0.1 is the following:

m=(0.0100, 0.0180, 0.0243, 0.0292, 0.9185).

Note that the sum of the elements of **m** equals to 1 and that the distribution function of the performance can be computed easily from this vector, as this vector is actually the density function of performance.

If the link error probabilities are not all the same, the algorithm becomes a bit more complex, but still works. We have to consider all the cases where *x* base stations can reach the left gateway and *y* base stations can reach the right gateway, where $0 \le x < s$ and $0 \le y < s-x-1$. The computational complexity is still $\mathrm{O}\left(s^2\right)$.

Now we know how to compute the performance vector of a ring section, but how to compute the performance vector of the whole ring? The answer is simple and rather straightforward. As all the sections are independent and the number of base stations that can reach a gateway in the ring is the sum of the base stations that can reach a gateway in the sections, the performance vector of the ring is the convolution of all the performance vectors of the ring sections.

For example the network of Figure 1 consists of two sections. The performance vectors of the two sections are:

$\mathbf{m}_1$=(0.0100, 0.0180, 0.09997),

$\mathbf{m}_2$=(0.0100, 0.0180, 0.0243, 0.9477).

The performance vector of the ring topology network is the convolution of the previous two vectors:

m=(0.0001, 0.0004, 0.0103, 0.0274, 0.0407, 0.9212).

4 RING PARAMETER CONSIDERATIONS

4.1 The Program

We have written a function in Mathworks MATLAB[8] to calculate the distribution function of performance of ring sections. The function is called "rsection", the name stands for "ring section". The definition of the function is the following:

```
function perf=rsection(p,s)
```

The meaning of the parameters is the following: p is the error probability of the links, s is length of the section (i.e. the number of base stations). The function returns the performance vector of the ring section.

Another function called "rrel" (ring reliability) computes the performance function of ring topology networks. The definition is the following:

```
function perf=rrel(p,r)
```

As before, p is the link error probability (same in all sections) and r is a vector containing the lengths of the ring sections.

On our plots we used unavailability instead of the relative performance which is one minus the relative performance. In normal situations the relative performance should be close to 1 with a high probability, so the relative unavailability should be close to 0. Usually logarithmic scale is used on the probability axis.

In this Section it is elaborated how the parameter changes affect the reliability of a ring topology micro mobility network.

4.2 Link Error Probability

Of course the smaller the link error probability is the more reliable network we have. The probability of the network being totally down (relative performance equals to 0) is p^{2S}, where S is the number of sections in the ring, and p is the link error probability. It is because the network is totally down when all the links right at the gateways are broken down, and there are $2S$ such links.

Our example network was a (25,15,10) ring. It means that the ring has 50 base stations and 3 gateways. Four reliability functions were computed with different link error probabilities. The link error probabilities were: 0.1, 0.01, 0.001 and 0.0001. Our function written in MATLAB generated the plot shown in Figure 5.

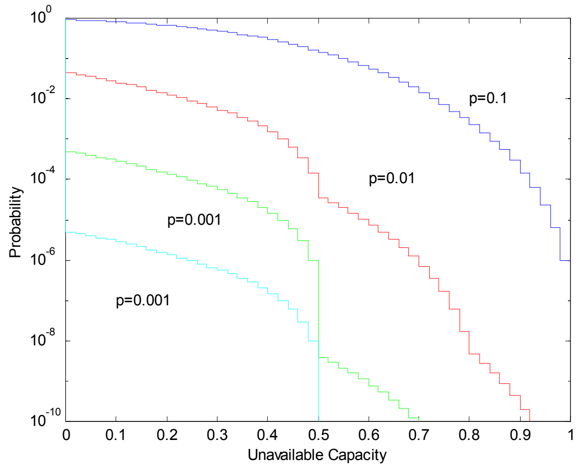

Figure 5. The effect of link error probability

4.3 Number of Gateways

We examined the effect of a change in the number of gateways. The gateways were always evenly distributed along the ring.

After analytical considerations we expect that the unavailability plot of the function of a ring with given number of gateways always runs below the plot of a ring with less gateways, if the link error probability is the same. The number of base stations is 60, the link error probability is 0.01, and only the number of gateways is varying. Figure 6 shows the unavailability functions of four rings containing 2,3,4,5 gateways. The notations for the rings are (30,30), (20,20,20), (15,15,15,15) and (12,12,12,12,12).

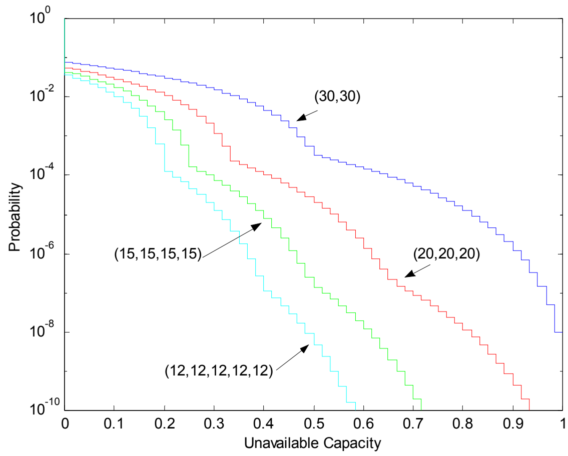

Figure 6. The effect of the number of gateways

We get exactly what we have expected. The functions run lower as more gateways are used.

4.4 Size of the Ring

If the link error probability and the number of gateways remain the same while the size of the ring grows the reliability should degrade. What kind of degradation do we expect? When the unavailability is high the difference should not be much. But as we look at the states with low unavailability the size of the ring should have more effect. Figure 7 depicts the unavailability function of four ring topology networks. The link error probability is 0.01 and the number of evenly placed gateways is 3 in all cases. The sizes of the rings are 30,90,300,900.

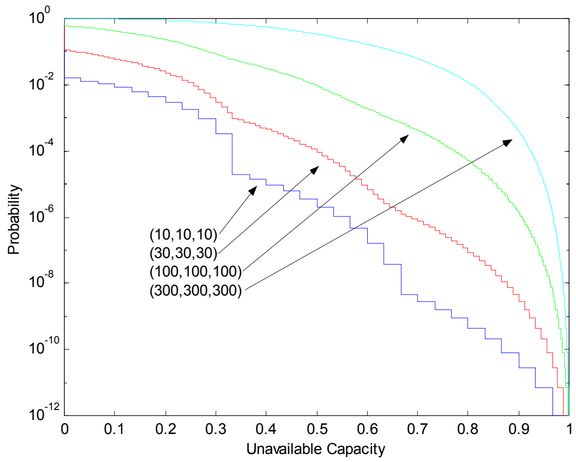

Figure 7. The effect of the size of the ring

4.5 Placement of Gateways

In most of the previous topologies gateways were evenly placed (i.e. the sizes of the sections were the same). How does it affect the performance if the sizes of the sections are different? We feel that even placing of gateways probably gives higher reliability, but it cannot be easily proved. And is it really true? Consider two ring topology networks: (50,50) and (25,75). Link error probabilities are the same. Is it true that the second network will have a relative performance below 0.70 with higher probability than the second network? Probably yes, but it is not easy to prove analytically. Our computations show that it is true. Three functions are plotted in Figure 8. Link error probability is 0.01 in all cases, the network topologies are: (50,50), (25,75) and (10,90).

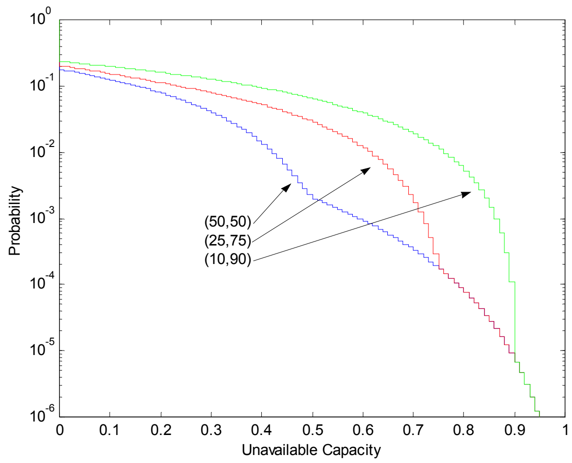

Figure 8. The effect of gateway placing

It can be read from Figure 8 that the more evenly gateways are placed the higher reliability we get.

5 COMPARISON OF THE TREE AND RING TOPOLOGIES

We have already developed similar algorithms and written similar programs for tree topologies in [11], it is straightforward to compare the reliabilities of the two topologies.

It is hard to compare such different topologies. There are several parameters that have to be negotiated. The ring topology is expected to have better reliability qualities, although for example the number of gateways in the ring the depth of the tree and the link error probabilities may have strong effects on the results.

The reliability functions of three networks were computed. One of them was a ring, two were trees. We decided to use two gateways in the ring. A ring with one gateway is not really a ring; more gateways would have given too much advantage for the ring. There were 64 base stations in all of the three networks. The link error probability was set to 0.01. The ring was a (24,40). One of the trees was a binary tree of depth 6, the other tree was a 3-deep tree with a branching-factor of 4 at each level. The binary tree was named "2-tree", the other one was named "4-tree". Figure 9 shows the unavailability functions of all the three networks in one plot.

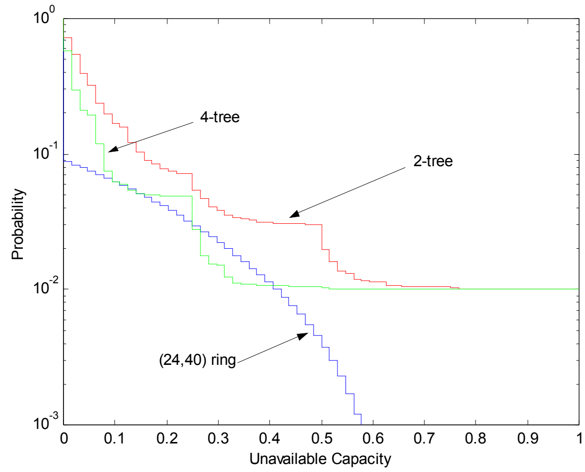

Figure 8. Comparing the Tree and the Ring

The 2-tree seems to be the weakest topology. The function of the 4-tree runs below the function of the rings but the ring topology is more reliable especially in the very low unavailability domain (left side of plot). There the reliability of the ring is about ten times better than that of the trees. The difference becomes even more if the link error probability becomes lower. At this link error probability (0.01) the probability that the performance of the 4-tree is better than the performance of the ring is below 3%.

6 CONCLUSIONS AND FUTURE WORK

A method was proposed that enables to study the reliability of ring topology micro mobility networks. A simple reliability measure was defined then an algorithm was introduced to compute the exact distribution function of the relative performance of the network. Earlier in [11] we have defined similar measures and algorithms for tree topology networks.

We are planning to extend and generalize the MATLAB code to handle other micro mobility networks, unreliable gateways, different kind of links with different error probabilities.

We have introduced a reliable micro mobility topology earlier in [10]. This new topology is called the hierarchy of rings. The reliability of the hierarchy topology, the tree topology and other micro mobility topologies will be compared using the algorithm presented here. This way the good reliability qualities of the hierarchy could be proven analytically and not only by simulations as in [12].

ACKNOWLEDGEMENTS

The project is supported by OTKA F032268 (Hungarian Scientific Research Found) and COST 279.

REFERENCES

[1] C. Perkins, "IP Mobility Support", IETF RFC 2002, http://www.ietf.org/rfc/rfc2002.txt, 1996

[2] A. T. Campbell, J. Gomez, C. Y. Wan, S. Kim, Z. Turanyi, A. Valko, "Cellular IP", draft-ietf-mobileip-cellularip-00.txt, IETF Internet Draft, 1999

[3] R. Ramjee, T. La Porta, S. Thuel, K. Varadhan, L. Salgarelli, "IP micro-mobility support using HAWAII", draft-ietf-mobileip-hawaii-01.txt, IETF Internet Draft, 1999

[4] B. Gloss, C. Hauser, "The IP Micro Mobility Approach", EUNICE 2000, September 2000, Eschende pp. 195-202.

[5] L. Jereb: "Network Reliability: Models, Measures and Analysis", in Proceedings of the 6th IFIP Workshop on Performance Modelling and Evaluation of ATM Networks, Tutorial Papers, Ilkley, UK, 1998, pp. T02/1-T02/10

[6] L. Jereb: "Efficient Reliability Modeling and Analysis of Telecommunication Networks", 6th International Conference on Telecommunication Systems, Nashville, 1998, pp. 236-241.

[7] C.J. Colbourn, "Reliability issues in telecommunications network planning", in: Telecommunications Network Planning (B. Sanso, ed.) Kluwer Academic Press, 1999, pp. 135-146.

[8] Mathworks homepage www.mathworks.com

[9] S. Imre, M. Szalay: "Reliability Considerations of Micro Mobility Networks", DRNC2001, Budapest, Hungary, October 7-10, 2001.

[10] S. Imre, M. Szalay: "Ring Based Reliable IP Micro Mobility Network", ConTEL 2001, Zagreb, Croatia, June 13-15, 2001, pp. 113-120.

[11] M. Szalay, S. Imre: "Reliability Modeling of Tree Topology IP Micro Mobility Networks", *submitted to* Performance 2002, IFIP WG 7.3 International Symposium on Computer Performance Modeling, Measurement and Evaluation, Rome, Italy, September 23 - 27, 2002.

[12] S. Imre, M. Szalay, I. Bagdi, M. Székely: "Reliability Simulation of IP Micro Mobility Protocols Over Different Network Topologies", *submitted to* CSNDSP 2002, Communication Systems, Networks and Digital Signal Processing, Staffordshire, United Kingdom, 15-17 July 2002.