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ALGORITHM DESIGN FOR RELIABILITY ANALYSIS IN MOBILE COMMUNICATION NETWORKS

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ÖZET

Çevresel koşullar, hareketli ana bilgisayarların değişen konumları ve kablosuz bilgisayar ağındaki değişen yapı sistemin güvenilirliğini kolayca etkileyebilmekte ve değiştirebilmektedir. Bununla birlikte bir hareketli düğümün değişen konumu, belirli bir trafik ortamına sahip sistemin güvenilirliğinin analiz edilmesine engel olan asıl problem olarak düşünülmüştür.
Bu çalışmada klasik iki-terminal güvenilirliği, kablosuz bilgisayar ağı için genişletilmiştir. Bu amaçla Markov Zincirleri hareketli düğümlerin değişen konumları için tahmin edici olarak kullanılmış ve başlama/bitiş durumlarına göre farklı şekiller oluşturabilen hareketli düğümü/ düğümleri içeren bilgisayar ağlarının güvenilirliğini analiz etmek için bir grup algoritma önerilmiştir. Ayrıca bilgisayar ağlarının farklı uygulamalarında erişim noktasının alanı dışında kalan hareketli düğüm için boşluk pozisyonunun tanımlanması gibi bazı esnek çözümler önerilmiştir. Algoritmaların doğrulanması için bir benzetim gerçekleştirilmiş ve sonuçlar değerlendirilmiştir.

ABSTRACT

The environmental conditions, the changing locations of the mobile hosts and the changing structure in the wireless computer network can easily affect and change the system reliability. Nevertheless the changing locations of a mobile node are considered the main problem to obstruct analyzing the reliability in a definite traffic setting of the system.
In this study, the classical two-terminal reliability is extended for wireless computer network. To this end, Markov Chains are used as the predictor for the changing locations of the mobile node(s) and a set of algorithms is proposed to analyze the reliability of the computer networks including mobile nodes which may form different conditions related to its starting and finishing situation. Furthermore some flexible solutions such as the definition of a blank position for the mobile node which is not in the range of any access point are proposed for the different applications of the computer networks. In order to verify the algorithms, a simulation is performed and the results are evaluated.

Key Words: *Reliability, Mobility model, Tie-set/cut-set (graph theory)*

1. INTRODUCTION

The reliability analysis of the computer networks has emerged as a necessity for a long time but wireless computer networks have just come out in this area and there are some problems about benefiting from the classical methods for the wireless ones. However the reliability of a given computer network has to be analyzed to realize the system capability performing its functions successfully and/or detect the possible deficiency of the system which causes failure and so it can be corrected or necessary precaution can be taken for a more reliable network.

A computer network contains a collection of machines intended for running user (i.e., application) programs. These machines are called hosts. Mostly, the host and the node can be used interchangeably. All the hosts that are away from home and still want to be connected are called mobile hosts. All hosts are assumed to have a permanent home location. The routing goal in systems with mobile hosts is to make it possible. In wireless computer networks, there are one or more foreign agents which are processes that keep track of all mobile hosts visiting the area and also a home agent, which keeps track of hosts whose home is in the area, but who are currently visiting another area [1].

The definition of the reliability is the probability that the system operates successfully for a given period of time under environmental conditions including temperature, atmosphere, weather, and also system load or traffic. A computer network is a complex system so it must be broken into components to be analyzed. The term successful operation can have many interpretations for the computer network. One of the primary ones also used here is that if communication between a pair of nodes is focused on where *s* is the source node and *t* is the target node, then successful operation is defined as the presence of one or more operating paths between *s* and *t*. This is called the two-terminal problem, and the probability of successful communication between *s* and *t* is called two- terminal reliability [2].

While the packets are being forwarded through the network, some losses are inevitable especially in the wireless network. Wireless computer networks are apt to failures and loss of access due to environmental conditions, the changing locations of mobile nodes and the changing components. Especially the changing location of the mobile nodes among the ranges of the access points seems to be the main problem of the wireless networks for analyzing the reliability. Because the other factors change automatically anyway in every location change and also some mean values for the related components of a mobile node can be got in the range of an access point in a definite traffic setting of the system. From this point of view, a new set of algorithms to analyze the reliability of the wireless and wired parts of the computer communication network is proposed in Section 3 as a comprehensive solution in spite of the uncertainty of the wireless computer networks.

In Section 2 and 4, the related studies and a simulation performed to prove the validity of these algorithms are mentioned, respectively. Finally, the conclusion of this study is presented in Section 5.

2. RELATED WORKS

Analyzing the reliability of a computer network includes some major difficulties especially in the wireless sections of the computer network. Some important studies and related ones are presented in the following.
In [2], methods based on graph theory (cut-sets and tie-sets) are systematically developed for analysis of a network after the use of reliability and availability computations is mentioned as a means of comparing fault-tolerant designs.

In [3], highly mobile network infrastructure is focused on, and some metrics are introduced to quantify the aggregate benefit and cost of reliable server pooling in a system.

In another work [4], OPNET simulator is used to develop a new model suitable for university environment. This model is evaluated to measure the performance of the wireless local area network for such university environment. It is tested against three types of applications (ftp, http, and database) in two sites and it is found that among a set of other parameters throughput and response time are highly affected by the number of users per application.

In [5], the primary difference between wired and wireless systems is declared as uncertainty which first manifests itself at the physical layer. It destroys standard Internet protocols. In order to cope with uncertainty in wireless mobile networks, an overarching theoretical framework is proposed for representing relevant network information in terms of underlying entropies, entropy rates and their inter-relationships. This study investigates the applicability of this framework in designing optimal mobility tracking and resource management, and also coping with uncertainty in traffic load, topology control and routing.

In [6], two related problems are focused on: computing a measure for the reliability of wireless distributed sensor networks (DSN), and computing a measure for the expected and the maximum message delay between data sources (sensors) and data sinks in an operational DSN. Two algorithms are presented for computing the reliability, and the expected message delay is presented for arbitrary networks. Finally, some numerical results are given.

Also there are some different definitions to describe the network properties in another aspect and tries to quantify them such as survivability. Survivability is defined as the ability of the network computing system to provide essential services in the presence of attacks and/or failures, and recover full service in a timely manner [7].

In [8], in order to conduct a survivability analysis, performance-oriented survivability metrics are identified along with techniques for evaluating the metrics over various modes of operation. The modes of operation include normal, single-failure and multiple-failure modes. Examples of possible survivability metrics are packet loss rate, TCP session timeout, and throughput, etc.

In [9], the question of how congestion in a network can be estimated using point-to-point link reliability is studied. In order to quantify link quality or link reliability between the sniffer and an access point (AP), they make use of the periodic transmission of beacon management frames from the AP. An AP's link reliability can be measured on a percentage scale from 0% to 100%. Therefore, the reception of beacons from an AP is a constant measure of the reliability of the link between the sniffer and the AP.

Wireless network systems inherit the unique handoff characteristic which leads to different communication structures with various components and links. Therefore, the traditional definition of two-terminal reliability presented in [2] is not seen to be applicable anymore and a new approach is sought to define the reliability metric in wireless networks. A new term, end-to-end expected instantaneous reliability, is proposed to integrate those different communication structures into one metric, which includes not only failure parameters but also service parameters. The end-to-end expected instantaneous reliability and its corresponding MTTF is evaluated quantitatively in different wireless communication schemes. This analysis is conducted on wireless CORBA platforms but it is claimed to be easily extensible to generic wireless network systems [10]. Naturally, the thought of the extension of the traditional methods for the wireless computer networks is not shared here. In this study, the two-terminal reliability including mobile node(s) is analyzed by extending the classical methods.

3. NEW ALGORITHMS

The components and their appropriate contents are analyzed and a set of algorithms for wired and wireless sections of the computer network is introduced.

3.1. Overview

In general, the nodes and links are considered to form both serial and parallel structures according to their location in the network. But wireless nodes and links are always serial elements. Also the links (edges) are assumed to be bidirectional.

Although there are some kinds of failures affecting the reliability, only congestion, blocking and breakage are used for the reliability analysis of the computer network. They cause to block the usage of the links or nodes.

The traffic of the computer network system is very important on the success of delivering packets. It should be remembered that when too much traffic is offered, congestion occurs and performance degrades sharply. A unique failure rate for the system may be incorrect or misleading. The best conduct to analyze it is to segregate the success probability of the system according to the traffic classification like heavy, moderate or light.
The related notations are given in the following.

G(N,E,MN)	network
N	nodes in network
E	links (edges) in network
MN	mobile nodes in the network
T_i	tie set *i*
α_i, β_i	success probability of node *i* and link *i*

A complex system should be decomposed into functional entities. In the wireless computer networks, although links and nodes have the same functional properties with the wired ones, their structure, abilities and dynamics are different from the wired ones and also the mobility of the mobile hosts differentiate them from the wired ones so a given computer network system are separated into wireless and wired section, called subnetwork. Also a wired network using hierarchical addressing in a large area can be separated according to its domain so when the reliability of the system is analyzed, every domain can be considered as a subnetwork. In this situation, there is no difference between functional entities of the domains but geographical situation, and access way between them necessitates breaking them to simplify the analysis.

An access point is an intersection of both a wired and a wireless subnetwork. The access point is considered as a part of the wired computer subnetwork. Mobile nodes can not communicate with each other without access point. It is necessary to separate the network into small parts only when source node and target node are in different wireless and wired subnetworks, and also in the network using hierarchical addressing or similar one. Therefore general formulation of the reliability for consecutive wireless and wired subnetworks is as follows:

$$R_{st}(t) = \prod_{i}^{k} R_i(t) \tag{3.1}$$

i	number of subnetwork which can be separated.
k	total number of subnetworks system.
$R_i(t)$	the reliability of the subnetwork *i* from the mask source node to mask target node in subnetwork *i*.
mask source, mask target	the entrance and exit points of the subnetwork while the data is forwarded from real source to real target.

The mobile nodes can change their location while the packet or frames are forwarded, so the analysis depending on only decomposition of the computer network is not sufficient. Furthermore there may be some outages and reconnections in a session even if it is very short time.
On the reliability analysis of computer communication network, Markov Chains are used to determine the locations where mobile node(s) may exist. The

movement area of the mobile nodes in one time interval should be determined. Also in this model, one more row and column can be defined for the condition of the mobile host as out of the range of access points according to its model. This situation is called "blank position". In short, a constraint area and time intervals must be taken into consideration for the reliability analysis of a given computer network.
The access points in this area(s) are possible connection points for mobile node(s). There are four conditions according to the starting-finishing points.

1. Static to static
2. Mobile to static
3. Static to mobile
4. Mobile to mobile

3.2. Static to static

A static source node connects to another static destination node. Tie-set/cut-set (graph theory) can be used in this condition. The related algorithm is as follows:

1. If the source and target node are in different domains according to hierarchical addressing or similar to this kind of addressing, the network is separated into subnetworks in accordance with the domains.
2. Determine mask source and mask target nodes as defined the above. Note that entrance point and exit point of domains in hierarchical addressing are fixed and the route out of the subnetwork is fixed to arrive at one destination's subnetwork.
3. Define all tie-sets in different subnetworks.
4. Compute the reliability in subnetworks.
5. Compute the reliability between subnetworks.

3.3. Mobile to Static

A mobile source node connects to a static target node. The following algorithm is used to find the reliability of any computer communication network.

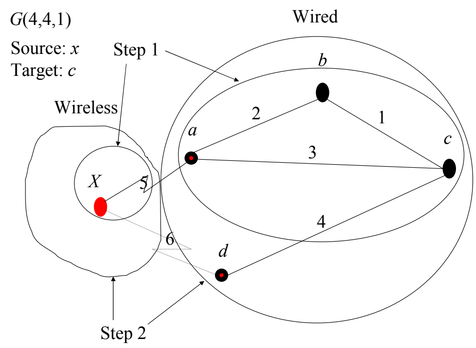

Figure 1. Mobile to static map.

1. Separate the network as wireless and wired section according to their connections. Suppose that the source node x wants to connect to the target node c in Figure 1.
2. Define possible access points of the mobile node and its district. Also up to these access points, the range of wired subnetwork may increase. Let's say a and d possible access points, then the range of the wired subnetwork increases like Figure-1.
3. Determine all possible sketches between the source and the target according to possible access points. Possible access points are the signs of the sketches at the same time. For the Figure 2, mobile node x may connect to one possible access point named d beyond its initial access point. Therefore access points a and d indicate Sketch I and Sketch II.

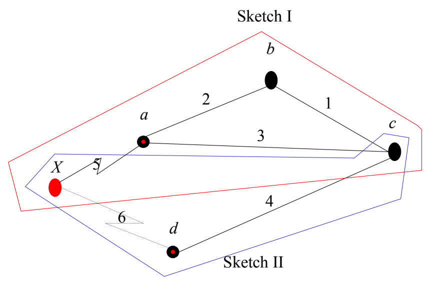

Figure 2. Possible sketches.

4. Determine minimal tie-sets in wired section according to these sketches. Minimal tie-sets derived from Figure 2 is as follows:

$$T_1 = \alpha_c \times \beta_1 \times \alpha_b \times \beta_2 \times \alpha_a$$

$$T_2 = \alpha_c \times \beta_3 \times \alpha_a$$

$$T_3 = \alpha_c \times \beta_4 \times \alpha_d$$

5. Compute the reliability of these different wired and wireless subnetworks. The reliability of the wired subnetwork:

$$R_{ac} = P(T_1 \cup T_2) = P(T_1 + T_2)$$

$$R_{dc} = P(T_3)$$

The reliability of wireless subnetwork:

$$R_{xa} = \alpha_x \times \beta_5$$

$$R_{xd} = \alpha_x \times \beta_6$$

6. Compute the reliability of every sketch. The connection of the mobile node may be provided by one of two access points named node *a* and *d* at one time.

$$R_{cx-I} = R_{ca} R_{xa}$$

$$R_{cx-II} = R_{cd} R_{xd}$$

7. Use transition probability matrix of the mobile node to define its mobility model. Here blank position is neglected.

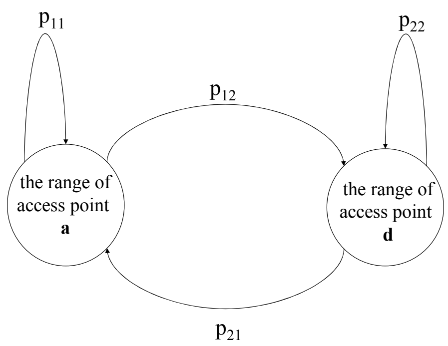

Figure 3. Markov chain model for the mobile node.

$$P_X = \begin{array}{c} \\ a \\ d \end{array} \begin{array}{c} \begin{array}{cc} a & d \end{array} \\ \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} \end{array}$$

8. Apply initial position of the mobile node to get the probabilities of the next positions. The number of time steps is decided to find the reliability of computer network according to time interval and total time. The initial position of the mobile node is given by

$$p(0) = [p_i \quad p_{i+1} \quad p_{i+2} \quad ..]$$

where *i* represents the location probability of the mobile node. Here,

$$p(0) = [p_a \quad p_d] = [1 \quad 0]$$

$$p(n) = p(0) P_x^n$$

where *n* is the number of next time steps.

9. Compute partial reliability for next time steps according to the related position probability. The partial reliability, $PR_{st}^n(i)$, for n[th] time step under the probability of location *i* can be expressed by

$$PR_{st}^n(i) = p_i(n)\ R_{st}(i)$$

10. Add partial reliabilities to get an average reliability.

$$R_{av} = \sum_i^l PR_{st}^n(i) = \sum_i^l p_i \times R_{st}^n\ (i)$$

where *l* is the total number of sketches in the district.

11. After n[th] time step, the smallest one of them in total time is the minimum reliability of the two-terminal reliability and the biggest one is the maximum of two-terminal reliability.

3.4. Static to mobile

The home agent and foreign agent must be taken into account in this condition. If the mobile node roams outer space of the home agent as online, the home agent follows one of these two following directions. Firstly, it sends the packets to the foreign agent. After foreign agent gets the packets, it sends them to the mobile host. Secondly, the home agent tells the source to henceforth send packets to the mobile host by addressing to the foreign agent. Subsequent packets can now be routed directly to the host via the foreign agent, bypassing the home location entirely [1].

Each situation determined by the network feature implies a little change in the previous algorithm. In this subsection, the first situation is tried. It includes continuously extra paths in which packets are rerouted. Only differences are given in the following.

3. This step is similar to 3[rd] step of the previous algorithm. Sketches are formed in accordance with the first situation defined above.

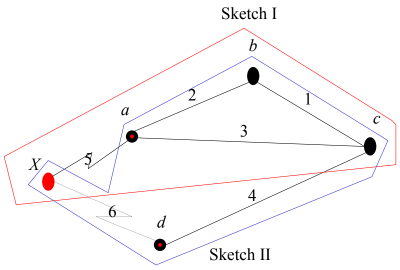

Figure 4. Possible sketches.

5. The reliability of the situation from source node to foreign location is analyzed by using three-step procedure.
   1) Two-terminal reliability analysis from source node to home agent is computed.
   2) Two-terminal reliability analysis from home agent to target node is computed.
   3) Two-terminal reliability analysis from source node to target node is computed.

3.5. Mobile to mobile

The same situation in Static to Mobile is also valid in this situation. In this subsection, the second situation is tried and so blank position is more suitable to analyze the network. The following steps point out only the differences between mobile to static and mobile to mobile condition. It includes 12 steps.

7. Use transition probability matrixes of the mobile nodes to define their mobility models.

v dummy value to provide multiplication

s blank position

Let's say

$$P_x = \begin{array}{c} \\ a \\ d \\ v \end{array} \begin{array}{c} \begin{array}{ccc} a & d & v \end{array} \\ \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix} \end{array}$$

$$P_y = \begin{array}{c} \\ c \\ d \\ s \end{array} \begin{array}{c} \begin{array}{ccc} c & d & s \end{array} \\ \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix} \end{array}$$

9. Compute new location probabilities of entire sketches for mutual access points.

$$p^{xy} = (p^x(n))' \times p^y(n) = \begin{bmatrix} p_{ij} & p_{i,j+1} & \cdots \\ p_{i+1,j} & p_{i+1,j+1} & \cdots \\ \cdots & \cdots & \cdots \end{bmatrix}$$

10. Compute partial reliability for next time steps according to the related position probability. The partial reliability, $PR_{st}^{n}(ij)$, for n^{th} time step under the probability of location i and j of the mobile nodes can be expressed by

$$PR_{st}^{n}(ij) = p_{ij}(n) R_{st}(ij)$$

11. Add partial reliabilities to get an average reliability.

$$R_{av} = \sum_{i}^{r} \sum_{j}^{s} PR_{st}^{n}(ij) = \sum_{i}^{r} \sum_{j}^{s} p_{ij} \times R_{st}^{n}(ij)$$

where r and s is the total access points to which each mobile node may access. i and j represent a sketch.
$r \times s$ = total number of sketches in the district.

4. SIMULATION AND NUMERICAL RESULTS

4.1. Overview

The topology $G(41, 51, 4)$ (in Figure 5), various traffics, different time intervals, packet sizes and protocols are defined randomly. But the observed traffics have the similar properties not to mislead the simulation results. The packets which arrive successfully at the destination are assumed to show the reliability indicator of the system.

$$\text{RI}(t) = \frac{\text{Arrived\_packets}}{\text{Sent\_packets\_from\_source}}$$

where RI(t) is the reliability indicator.

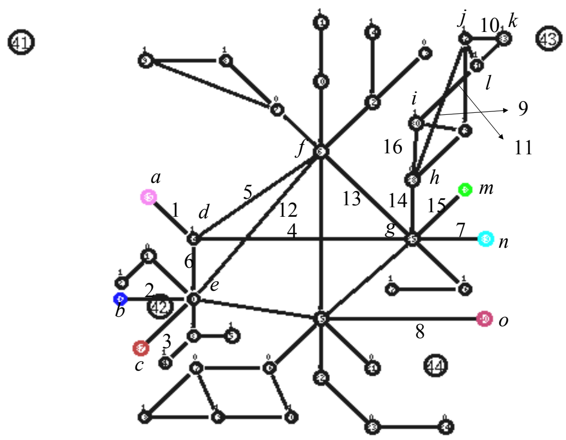

Figure 5. The topology of wired and wireless computer network, used in the simulation.

Links or nodes are broken in every defined time to provide the failures. Loss-rate is used to give the failure to the wireless links. This scenario uses hierarchical addressing so the failure rate between domains directly affects the reliability of the network (static to static algorithm). In clusters of the domains, a failure is not defined. Only some links and nodes between the domains have a failure to make the computations easy and tie-sets in clusters are shown through one path. In the simulation, constant bit rate (CBR) is used for traffic generation of the observed nodes. RI_{ms}, RI_{sm} and RI_{mm} represent the reliability indicator of the mobile to static, static to mobile and mobile to mobile condition, respectively. The proposed algorithms are used with the same inputs of the simulation. The notations and the approximate mobility model of one mobile host are assumed as the follows:

$p_{m(i)}$	initial position of the mobile host *i*
$P_{m(i)}$	transition probability matrix of mobile host *i*
$BS(g)$	base station *g*
$MH(h)$	mobile host *h*
g, h	any given number

$$p_{m(0)}(0) = [1 \quad 0 \quad 0]$$

The transition probability matrix of $MH(0)$:

$$P_{m(0)} = \begin{array}{c} \\ BS(0) \\ BS(1) \\ BS(2) \end{array} \begin{array}{c} \begin{array}{ccc} BS(0) & BS(1) & BS(2) \end{array} \\ \begin{bmatrix} 0.7 & 0.3 & 0 \\ 0.299 & 0.001 & 0.7 \\ 0 & 0.3 & 0.7 \end{bmatrix} \end{array}$$

$$p_{m(1)}(0) = [0 \quad 1 \quad 0]$$

The transition probability matrix of $MH(1)$ among possible locations is given as follows:

$$P_{m(1)} = \begin{array}{c} \\ BS(0) \\ BS(1) \\ BS(2) \end{array} \begin{array}{c} \begin{array}{ccc} BS(0) & BS(1) & BS(2) \end{array} \\ \begin{bmatrix} 0.1 & 0.9 & 0 \\ 0.05 & 0.45 & 0.5 \\ 0 & 0.7 & 0.3 \end{bmatrix} \end{array}$$

$$p_{m(2)}(0) = [1 \quad 0 \quad 0]$$

The transition probability matrix of $MH(2)$ among possible locations is given as follows:

$$P_{m(2)} = \begin{array}{c} \\ BS(3) \\ BS(4) \\ BS(5) \end{array} \begin{array}{c} \begin{array}{ccc} BS(3) & BS(4) & BS(5) \end{array} \\ \begin{bmatrix} 0.4 & 0.6 & 0 \\ 0.39 & 0.6 & 0.01 \\ 0 & 0.99 & 0.01 \end{bmatrix} \end{array}$$

4.2. Static to static algorithm

Static to static algorithm is not explained here. Wired and wireless structure of the simulation necessitates the hierarchical addressing and routing in the wired part so it is used in the other conditions anyway.

4.3. Mobile to static algorithm

Source host is $MH(0)$ and destination host is $W(33)$. The application of the algorithm is as follows:

1. $MH(0)$ around the base station $BS(0)$ forms a wireless section of the computer network. Destination host is three domains (subnetwork) away.
2. Possible base stations are $BS(1)$ and $BS(2)$ except its home base station.
3. In this simulation, it is not necessary. Because hierarchical addressing is used for the wired section. This step and the next step can be done together.
4. Hierarchical addressing necessitates defined routes among domains so there is only one tie-set, one point to another point between two domains. Here in order to provide practicality, tie-sets are defined by the numbers and letters given in Figure 5 and one letter and one number is used.

$$T_0 = a1d4g14h9j10k$$
$$T_1 = b2e12f13g14h11j10k$$
$$T_2 = c3e12f13g14h11j10k$$

In clusters of the domains, a failure is not defined (also in the simulation). Only some links and nodes between the domains have a failure to make the computations easy and tie-sets in clusters are shown through one path.

$T_0 = 0.9$, $T_1 = 0.9$, $T_2 = 0.81$

5. This is hierarchical addressing so

$$\left.\begin{aligned} R_{ak} &= T_0 \\ R_{bk} &= T_1 \\ R_{ck} &= T_3 \end{aligned}\right\} \text{wired part of the network}$$

$R_{ma} = R_{mb} = R_{mc} = \alpha_1$ → wireless part of the network

where *m* is $MH(0)$

6. $R_{mk-I} = R_{ma} \times R_{ak} = 0.8 \times 0.9 = 0.72$

$R_{mk-II} = 0.8 \times 0.9 = 0.72$

$R_{mk-III} = 0.8 \times 0.81 = 0.648$

7. It is defined in the initial part of this section.

8. First time step (first 10 min.): $p(1) = p(0) \times P_x^1 = [0.7 \quad 0.3 \quad 0]$

Second time step (second 10 min.): $p(2) = [0.58 \quad 0.21 \quad 0.21]$

Third time step (third 10 min.): $p(3) = [0.49 \quad 0.24 \quad 0.29]$

9-10. 1st time step reliability→

$$R_{mk}(1) = 0.7 \times 0.72 + 0.3 \times 0.72 + 0 \times 0.648 = 0.72$$

2nd and 3rd time step reliability→

$R_{mk}(2) = 0.7049$

$R_{mk}(3) = 0.6988$

11. After 3rd time step, every time step denotes 10 minutes, the smallest reliability of them in 30 minutes is the minimum of two-terminal reliability and the biggest one is the maximum of two-terminal reliability so,

$R_{\min}(30\min) = 0.6988$

$R_{\max}(30\min) = 0.7200$

The simulation result of this condition is $RI_{ms}(30\min) = 0.70147$.

Standard deviation of the simulation result can be found as:

$$R_{mean}(30\min.) = (R_{mk}(1) + R_{mk}(2) + R_{mk}(3))/3$$

where $R_{mean}(30\min.)$ is the mean reliability value of the algorithm results.

$\sigma_{ms} = |R_{mean}(30\min.) - RI_{ms}(30\min.)|$

$\sigma_{ms} = 0.0064$

4.4. Static to mobile algorithm

Source host is $W(31)$ and destination host is $MH(0)$.

1. Steps 1, 2 and 3 are the same with the previous algorithm.
4. This simulation sends the packets to the home agent location and home agent resends them to the foreign agent location. Hierarchical addressing is used in this simulation so there is one tie-set from source to home agent and from home agent to target (also no failure is given in the clusters) and they are combined as one tie-set as follows:

$T_0 = k10j9h14g4d1a$

$T_1 = k10j9h14g4d1a1d6e2b$

$T_2 = k10j9h14g4d1a1d6e3c$

$T_0 = 0.9$

$T_1 = 0.9 \times 0.9 = 0.81$

$T_2 = 0.9 \times 0.9 \times 0.9 = 0.729$

5. $$\left.\begin{aligned} R_{ak} &= T_0 \\ R_{bk} &= T_1 \\ R_{ck} &= T_2 \end{aligned}\right\} \text{wired part of the network}$$

$R_{ma} = R_{mb} = R_{mc} = \alpha_1$ → wireless part of the network

where *m* is $MH(0)$

6. $R_{km-I} = R_{ak} \times R_{km} = 0.8 \times 0.9 = 0.72$

$R_{km-II} = 0.81 \times 0.8 = 0.65$

$R_{km-III} = 0.8 \times 0.729 = 0.58$

7. It is defined in the initial part of this section.
8. First time step (first 10 min.)

$$p(1) = p(0) \times P_x^1 = [0.7 \quad 0.3 \quad 0]$$

2nd and 3rd time step

$$p(2) = [0.58 \quad 0.21 \quad 0.21]$$

$$p(3) = [0.49 \quad 0.24 \quad 0.29]$$

9-10. 1st time step reliability:

$$R_{mk}(1) = 0.7 \times 0.72 + 0.3 \times 0.65 + 0 \times 0.58$$
$$= 0.6990$$

2nd and 3rd time step reliability:

$$R_{mk}(2) = 0.6759$$

$$R_{mk}(3) = 0.6622$$

11. After 3rd time step, every time step denotes 10 minutes, the smallest reliability of them in 30 minutes is the minimum of two-terminal reliability and the biggest one is the maximum of two-terminal reliability so,

$$R_{\min}(30\min) = 0.6759$$

$$R_{\max}(30\min) = 0.6990$$

The simulation result of this condition is

$$RI_{sm}(30\min) = 0.67979$$

Standard deviation of the simulation results of static to mobile condition can be found as:

$$\sigma_{sm} = 0.00079$$

4.5. Mobile to mobile algorithm

Source host is $MH(1)$ and destination host is $MH(2)$.

1. $MH(1)$ around the base station $BS(1)$ and $MH(2)$ around the base station $BS(3)$ form two wireless parts of the computer network.
2. Possible base stations for $MH(1)$ are $BS(0)$ and $BS(2)$ except its home base station. Possible base stations for $MH(2)$ are $BS(4)$ and $BS(5)$ except its home base station.
3. This step and the next can be done for this simulation as explained before.
4. $T_0 = 0.9$ 0→3 (the tie set from BS(0) to BS(3))

$$T_1 = 0.9 \times 0.9 \times 0.9 = 0.729$$
0→4: resending to foreign agent

$$T_2 = 0.9 \times 0.9 = 0.81$$
0→5: resending to foreign agent

$T_3 = 0.9$ 1→3

$$T_4 = 0.9 \times 0.9 \times 0.9 = 0.729$$
1→4: resending to foreign agent

$$T_5 = 0.9 \times 0.9 = 81$$
1→5: resending to foreign agent

$T_6 = 0.9 \times 0.9 = 81$ 2→3

$$T_7 = 0.9 \times 0.9 \times 0.9 \times 0.9 = 0.656$$
2→4: resending to foreign agent

$$T_8 = 0.9 \times 0.9 \times 0.9 = 0.729$$
2→5: resending to foreign agent

5-6.

$$R_{mm-I(am)} = \alpha_1 T_0 \alpha_2 = 0.8 \times 0.9 \times 0.9 = 0.648$$
$$R_{mm-II(an)} = \alpha_1 T_1 \alpha_2 = 0.8 \times 0.729 \times 0.9 = 0.5249$$
$$R_{mm-III(ao)} = \alpha_1 T_2 \alpha_2 = 0.8 \times 0.81 \times 0.9 = 0.5832$$
$$R_{mm-IV(bm)} = \alpha_1 T_3 \alpha_2 = 0.8 \times 0.9 \times 0.9 = 0.648$$
$$R_{mm-V(bn)} = \alpha_1 T_4 \alpha_2 = 0.5249$$
$$R_{mm-VI(bo)} = \alpha_1 T_5 \alpha_2 = 0.5832$$
$$R_{mm-VII(cm)} = \alpha_1 T_6 \alpha_2 = 0.5832$$
$$R_{mm-VIII(cn)} = \alpha_1 T_7 \alpha_2 = 0.4723$$
$$R_{mm-IX(co)} = \alpha_1 T_8 \alpha_2 = 0.5249$$

7-8.

$$p^{m1}(1) = [0.05 \quad 0.45 \quad 0.5]$$
$$p^{m1}(2) = [0.03 \quad 0.6 \quad 0.38]$$
$$p^{m1}(3) = [0.03 \quad 0.56 \quad 0.41]$$
$$p^{m2}(1) = [0.4 \quad 0.6 \quad 0.0]$$
$$p^{m2}(2) = [0.394 \quad 0.6 \quad 0.006]$$
$$p^{m2}(3) = [0.3916 \quad 0.6023 \quad 0.0061]$$

where $m1$ and $m2$ denote $MH(1)$ and $MH(2)$, respectively.

9.

$$p^{m1m2}(1) = \begin{bmatrix} 0.02 & 0.03 & 0 \\ 0.18 & 0.27 & 0 \\ 0.2 & 0.3 & 0 \end{bmatrix}$$

$$p^{m1m2}(2) = \begin{bmatrix} 0.0118 & 0.018 & 0.0002 \\ 0.2364 & 0.36 & 0.0036 \\ 0.1497 & 0.228 & 0.0023 \end{bmatrix}$$

$$p^{m1m2}(3) = \begin{bmatrix} 0.0117 & 0.0181 & 0.0002 \\ 0.2193 & 0.3373 & 0.0034 \\ 0.1606 & 0.2469 & 0.0025 \end{bmatrix}$$

10-11.

$$R_{av}(1) = 0.5454$$
$$R_{av}(2) = 0.5522$$
$$R_{av}(3) = 0.5499$$

12. After 3rd time step, every time step denotes 10 minutes, the smallest reliability of them in 30 minutes is the minimum of two-terminal reliability and the biggest one is the maximum of two-terminal reliability so,

$$R_{\min}(30\,\text{min}) = 0.5454$$
$$R_{\max}(30\,\text{min}) = 0.5522$$

The simulation result of this condition is

$$RI_{mm}(30\,\text{min}) = 0.5895.$$

Standard deviation of the simulation results of mobile to mobile condition can be found as:

$$\sigma_{mm} = 0.04$$

The simulation result of Mobile to Mobile condition is over the maximum result of the related algorithm and also its standard deviation is higher than the others . Because the mobility models of the related mobile nodes (*MH*(1) and *MH*(2)) do not reflect exactly their movements in the scenario.

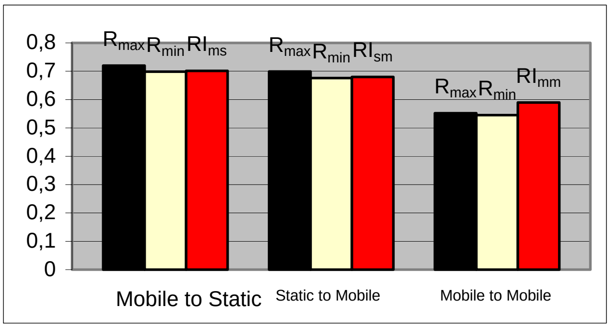

Figure 6. The results of simulation and algorithms are presented.

The simulation and the algorithm results of all conditions in Figure 6 demonstrate that if the mobility model of the mobile nodes are correct then the real result can be obtained between the minimum and maximum two-terminal reliability values derived from the proposed algorithms.

5. CONCLUSION

A mobility model is used to predict the next locations of the mobile nodes and Markov chains are benefited in the algorithms as the predictor of this mobility model.
There are four conditions according to the starting and finishing points in the network and so four algorithms are proposed to analyze the reliability of these conditions. But the algorithm for static to static one is proposed only for certain situations including hierarchical addressing. Three algorithms related to the mobile nodes determine the minimum and maximum two-terminal reliability in the time interval. In the algorithms, the differences of the computer networks are evaluated as soon as possible.
A simulation is performed and the results of the algorithms and the simulation show that the proposed algorithms are appropriate to the mobility character of the wireless computer network.

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