Simulator for Network Reliability Estimation

P. K. Suri[1], Bharat Bhushan[2]

[1]*Department of Computer Science & Applications, Kurukshetra University, Kurukshetra (Haryana) India,*

[2]*Department of Computer Science & Applications, Guru Nanak Khalsa College, Yamuna Nagar (Haryana) India.*

Summary

Day to day increase in frequency and complexity of modern systems of telecommunications, information transmission, transportation and distribution give rise to reliability problems. These networks usually have large numbers of computers and each computer is connected by dozens of other computers/terminals. The network, being a large number of computers attached to each other and multiple transmission paths among them cause data transmission congestion and hence delays. Due to this, it becomes difficult for a network to have maintained a reliable operational status. Keeping in view the criticality of each transmission path, a simulator is developed to estimate the reliability of communication network.

Keywords: *Network Reliability, Simulation, path, Transmission path, Critical Index, Communication network.*

Introduction

Recent technological advances in computer science and information technology have made networks ubiquitous in communication and business. The term ubiquitous computing was coined by Mark Weiser to describe a state of computing in which users are no longer aware of computation being done [1]. The objective of communication network is resource sharing with considerable economy among various remote computers in order to make their services available to more users. The major problems in computer communication network include topology, delay, congestion, throughput, flow-control etc. and to establish an effective communication among the nodes. All these require that the network should be reliable one. Network reliability is usually measured based on whether the nodes or the link between two nodes, operate properly. The network reliability (also called network availability) is the probability of successful transmission of data between source and sink or between two specific nodes.

Hui-Ling Liu and Shooman M.L. [2] describe simulation programs for packet switching networks with model congestion, routing and link failures. A computer network is modeled by a graph consisting of nodes (computers) and links (communication lines). Various routing rules (algorithms) are stored at the nodes to continue communication, via alternate paths, when congestion and/or link failures occur.

Tongdan Jina and David W. Coitb [3] proposed a new algorithm to approximate the terminal-pair network reliability based on minimal cut theory. The model estimates the reliability by summing the linear and quadratic unreliability of each minimal cut set. Given component test data, the model provides tight moment bounds for the network reliability estimate. Those moment bounds can be used to quantify the network estimation uncertainty propagating from component level estimates.

Lynn et al. [4] discussed methods and approximation algorithm reliability analysis. Network reliability implies the search for algorithms that effectively calculate the reliability of any general network configuration provided that the reliabilities of components (or links) are known.

Agrawal [5] surveyed exact algorithms for computing network reliability.

Harms et al. [6] provided a comprehensive review of current combinatorial algorithms. Because the computation cost of exact methods increases exponentially as the network size increases, significant efforts were made to search reliability bounds. Though existing methods generate the exact results or provide efficient approximations, they fail to address the estimation uncertainties by assuming that individual component (or link) reliability is known explicitly. By explicitly recognizing the uncertainty, more realistic and useful bounds can be determined for networks.

Tang J. et al. [7] used Bayesian approach used to derive the posterior reliability distribution based on prior information of components or the system. The Bayesian approach is quite limited and it is only effective to a simple network. Realizing the computational difficulties of the Bayesian approach for complex network systems, they focused on moment approximations for system reliability and uncertainty estimation. Moments of reliability estimates provide rich information for uncertainty estimations.

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Mastran and Singpurwalla [8] estimated the moments of coherent system reliability estimates based on attribute test data from component level.

Coit [9] used the first and second moments (or the variance) of component reliability estimates to calculate the variance of the complex system reliability estimate based on a decomposition approach.

Natvig and Eide [10] proposed six different lower and upper moment bounds for two terminal network reliability estimate based on minimal cuts and minimal paths theory. These moments bounds assume that all components reliability estimates, among and within the cut and path sets, are statistically independent. Lindqvist [11] compared six upper moment bounds and concluded that none of them dominates over others in the entire range of possible reliability values. The algorithm described can rectify many of the shortcomings of existing models and provides better lower-bounds of moments of the network reliability estimate. The entire approach of system reliability assessment is established upon non-parametric modeling techniques and extensively tested on sample problems.

Gary Hardy et al. [12] proposed an algorithm based on Binary Decision Diagram (BDD) for computing all-terminal reliability defined as the probability that the nodes in the network can communicate to each other, taking into account the possible failures of network links. The effectiveness of this approach is demonstrated by performing experiments on several large networks represented by stochastic graphs.

Jain, S.P. and Gopal, K [13] defined and evaluated Global reliability of a network using spanning trees of the network graph. An algorithm for generating spanning trees (termed, appended spanning trees) that are mutually disjoint is proposed. Each appended spanning tree represents a probability term in the final global reliability expression. The algorithm gives the global reliability of a network directly. The algorithm is fast, requires very little memory, is adaptable to multiprocessors and can be terminated at an appropriate stage for an approximate value of global reliability.

Proposed Model

One of the important parameters for a communication network is network reliability or network availability. Network reliability is usually characterized by terminal reliability or overall reliability. The terminal reliability is the probability of successful transmission path between two specified nodes, source and sink, whereas overall reliability, also called global availability means that the network is at least connected. A simulation model is designed to evaluate point to point reliability by giving appropriate weights to the critical transmission path on the basis of critical index. Box-Muller transformation is used to incorporate the randomness in the behavior of transmission time of data from one node to another. In this model, it is assumed that the reliability of each terminal is known and it is in working order. Using reliability of each link, the weighted reliability of each link is computed. Warshal algorithm [14] is implemented to compute the reliability between source and sink.

Terms and Notations

SRUN: Number of Simulation run
N: total number of activities
M: total number of nodes
S[i]: start node number of i^{th} link
F[i]: finish node number of i^{th} link
μ[i]: mean time of i^{th} link defined by probability distribution i.e. MUE[i]
σ[i]: Standard deviation of i^{th} link defined by probability distribution i.e.
SIGMA[i]
T[i]: Data transmission time of i^{th} link
C[i]: Critical Index of i^{th} link
R[i]: Reliability of i^{th} link
W[i]: Weighted reliabilities of i^{th} link

Algorithm:

1. Read the number of simulation runs (SRUN)
2. Read the total number of Terminals/nodes (M)
3. Read the total number of links (N)
4. For i=1 to N
   (a) Read start node of i^{th} link (S[i])
   (b) Read finish node of i^{th} link (F[i])
   (c) Read μ [i] i.e. mean time of i^{th} link (MUE[i])
   (d)Read σ [i] i.e. Standard deviation of each link (SIGMA[i])
   (e)Read reliability of i^{th} link (R[i])
   End For
5. FOR k=1 to SRUN
For i=1 to N
[Compute T[i], Data transmission time for i^{th} link using Box-Muller transformation process]
(a) Generate a pair of pseudorandom numbers (r1, r2) from a random number generator using different seeds.
(b) Compute $s = (-2 * \log_e (r1))^{1/2} * \cos(2 * 3.1415*r2)$
(c) $T[i] = \sigma[i] * s + \mu[i]$
(d) Traverse forward pass for each transmission path
(e) Traverse backward pass each transmission path
(f) Update critical index counter only for those communication paths which become critical during Simulation runs
End For
End For
6. Calculate critical index of each communication path

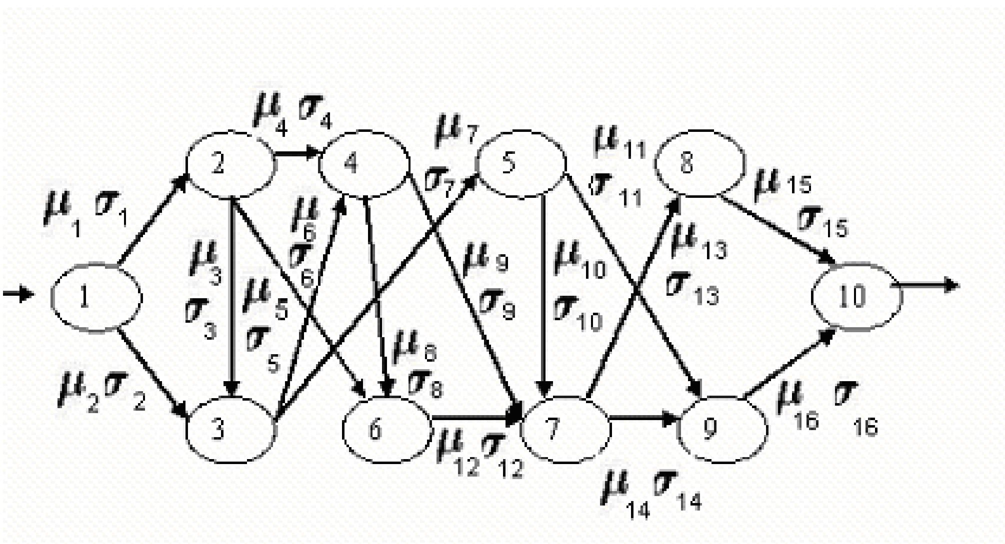
7. Calculate weighted reliabilities W of each communication path.
8. Generate minimal path sets through Warshall algorithm.
9. Stop.

Case Study:

Considered here is a network with 16 links and 10 terminals shown in figure below and labeled with μ and σ, corresponding to each link. The duration of data transmission for each link has been generated using Box-Muller transformation from the probability distribution for each link such as (μ_i and σ_i) for i^{th} link. The table 1 shows the link id, start and finish of each terminal. Here source is node 1 and sink is node 10.

The identity for links between various nodes, their start ode and finish node are given as

Link Id	Start node	finish node
1	1	2
2	1	3
3	2	3
4	2	4
5	2	6
6	3	4
7	3	5
8	4	6
9	4	7
10	5	7
11	5	9
12	6	7
13	7	8
14	7	9
15	8	10
16	9	10



Implementation:

(a) For 1000 simulation runs

Input: Reliability matrix for each link

Node	1	2	3	4	5	6	7	8	9	10
1	1	0.93	0.98	0	0	0	0	0	0	0
2	0	1	0.24	0.87	0	0.46	0	0	0	0
3	0	0	1	0.2	0.93	0	0	0	0	0
4	0	0	0	1	0	0.76	0.07	0	0	0
5	0	0	0	0	1	0	0.81	0	0.27	0
6	0	0	0	0	0	1	0.2	0	0	0
7	0	0	0	0	0	0	1	0.64	0.66	0
8	0	0	0	0	0	0	0	1	0	0.98
9	0	0	0	0	0	0	0	0	1	0.09
10	0	0	0	0	0	0	0	0	0	1

Output:

Critical index matrix:

Node	1	2	3	4	5	6	7	8	9	10
1	0	0.876	0.163	0	0	0	0	0	0	0
2	0	0	0.755	0.141	0	0.021	0	0	0	0
3	0	0	0	0.713	0.22	0	0	0	0	0
4	0	0	0	0	0	0.684	0.178	0	0	0
5	0	0	0	0	0	0	0.205	0	0.016	0
6	0	0	0	0	0	0	0.697	0	0	0
7	0	0	0	0	0	0	0	0.533	0.517	0
8	0	0	0	0	0	0	0	0	0	0.533
9	0	0	0	0	0	0	0	0	0	0.527
10	0	0	0	0	0	0	0	0	0	0

Weighted reliability matrix:

Node	1	2	3	4	5	6	7	8	9	10
1	0	0.876	0.86515	0.82987	0.2156	0.01953	0	0	0	0
2	0	0	0.755	0.31212	0.0528	0.61608	0.47548	0	0	0
3	0	0	0	0.713	0.22	0.1368	0.22625	0	0.01488	0
4	0	0	0	0	0	0.684	0.70772	0.03731	0.03619	0
5	0	0	0	0	0	0	0.205	0.43173	0.43477	0.14229
6	0	0	0	0	0	0	0.697	0.1066	0.1034	0
7	0	0	0	0	0	0	0	0.533	0.517	0.68894
8	0	0	0	0	0	0	0	0	0	0.533
9	0	0	0	0	0	0	0	0	0	0.527
10	0	0	0	0	0	0	0	0	0	0

Total Transmission path reliability matrix:

Node	1	2	3	4	5	6	7	8	9	10
1	0	0.876	0.86515	0.82987	0.2156	0.01953	0.4206	0.12613	0.12293	0.35789
2	0	0	0.755	0.31212	0.0528	0.61608	0.2578	0.34943	0.34831	0.19509
3	0	0	0	0.713	0.22	0.1368	0.22625	0.2434	0.01488	0.36229
4	0	0	0	0	0	0.684	0.70772	0.03731	0.03619	0.56319
5	0	0	0	0	0	0	0.205	0.43173	0.43477	0.14229
6	0	0	0	0	0	0	0.697	0.1066	0.1034	0.6304
7	0	0	0	0	0	0	0	0.533	0.517	0.68894
8	0	0	0	0	0	0	0	0	0	0.533
9	0	0	0	0	0	0	0	0	0	0.527
10	0	0	0	0	0	0	0	0	0	0

(b)For 5000 simulation runs

Input: Reliability matrix for each link

Node	1	2	3	4	5	6	7	8	9	10
1	1	0.01	0.92	0	0	0	0	0	0	0
2	0	1	0.41	0.04	0	0.94	0	0	0	0
3	0	0	1	0.15	1	0	0	0	0	0
4	0	0	0	1	0	0.45	0.11	0	0	0
5	0	0	0	0	1	0	0.42	0	0.47	0
6	0	0	0	0	0	1	0.84	0	0	0
7	0	0	0	0	0	0	1	0.45	0.81	0
8	0	0	0	0	0	0	0	1	0	0.06
9	0	0	0	0	0	0	0	0	1	0.39
10	0	0	0	0	0	0	0	0	0	1

Output:

Critical order matrix:

Node	1	2	3	4	5	6	7	8	9	10
1	0	0.8716	0.1764	0	0	0	0	0	0	0
2	0	0	0.7536	0.1442	0	0.0186	0	0	0	0
3	0	0	0	0.7094	0.2242	0	0	0	0	0
4	0	0	0	0	0	0.6932	0.1614	0	0	0
5	0	0	0	0	0	0	0.2072	0	0.021	0
6	0	0	0	0	0	0	0.7062	0	0	0
7	0	0	0	0	0	0	0	0.5302	0.5246	0
8	0	0	0	0	0	0	0	0	0	0.5302
9	0	0	0	0	0	0	0	0	0	0.5384
10	0	0	0	0	0	0	0	0	0	0

Weighted reliability matrix :

Node	1	2	3	4	5	6	7	8	9	10
1	0	0.8716	0.183936	0.65409	0.206264	0.000186	0	0	0	0
2	0	0	0.7536	0.435054	0.091922	0.046328	0.670284	0	0	0
3	0	0	0	0.7094	0.2242	0.10398	0.23141	0	0.021	0
4	0	0	0	0	0	0.6932	0.47919	0.058322	0.057706	0
5	0	0	0	0	0	0	0.2072	0.222684	0.241332	0.253048
6	0	0	0	0	0	0	0.7062	0.445368	0.440664	0
7	0	0	0	0	0	0	0	0.5302	0.52469	0.674694
8	0	0	0	0	0	0	0	0	0	0.5302
9	0	0	0	0	0	0	0	0	0	0.5384
10	0	0	0	0	0	0	0	0	0	0

Total Transmission path reliability matrix:

Node	1	2	3	4	5	6	7	8	9	10
1	0	0.8716	0.183936	0.65409	0.206264	0.000186	0.413464	0.428948	0.204936	0.459312
2	0	0	0.7536	0.435054	0.091922	0.046328	0.299122	0.314606	0.333254	0.34497
3	0	0	0	0.7094	0.2242	0.10398	0.23141	0.446884	0.021	0.477248
4	0	0	0	0	0	0.6932	0.47919	0.058322	0.057706	0.588522
5	0	0	0	0	0	0	0.2072	0.222684	0.241332	0.253048
6	0	0	0	0	0	0	0.7062	0.445368	0.440664	0.975568
7	0	0	0	0	0	0	0	0.5302	0.5246	0.674694
8	0	0	0	0	0	0	0	0	0	0.5302
9	0	0	0	0	0	0	0	0	0	0.5384
10	0	0	0	0	0	0	0	0	0	0

(c)For 10000 simulation runs

Input: Reliability matrix for each link

Node	1	2	3	4	5	6	7	8	9	10
1	1	0.38	0.56	0	0	0	0	0	0	0
2	0	1	0.43	0.62	0	0.17	0	0	0	0
3	0	0	1	0.96	0.57	0	0	0	0	0
4	0	0	0	1	0	0.98	0.17	0	0	0
5	0	0	0	0	1	0	0.4	0	0.85	0
6	0	0	0	0	0	1	0.66	0	0	0
7	0	0	0	0	0	0	1	0.04	0.94	0
8	0	0	0	0	0	0	0	1	0	0.61
9	0	0	0	0	0	0	0	0	1	0.16
10	0	0	0	0	0	0	0	0	0	1

Output:

Critical index matrix

Node	1	2	3	4	5	6	7	8	9	10
1	0	0.8675	0.1837	0	0	0	0	0	0	0
2	0	0	0.7443	0.1486	0	0.0183	0	0	0	0
3	0	0	0	0.7094	0.2177	0	0	0	0	0
4	0	0	0	0	0	0.6983	0.1597	0	0	0
5	0	0	0	0	0	0	0.2036	0	0.018	0
6	0	0	0	0	0	0	0.711	0	0	0
7	0	0	0	0	0	0	0	0.5282	0.5285	0
8	0	0	0	0	0	0	0	0	0	0.5282
9	0	0	0	0	0	0	0	0	0	0.5404
10	0	0	0	0	0	0	0	0	0	0

Weighted reliability matrix:

Node	1	2	3	4	5	6	7	8	9	10
1	0	0.8675	0.466534	0.453732	0.121912	0.006954	0	0	0	0
2	0	0	0.7443	0.453642	0.093611	0.451246	0.219884	0	0	0
3	0	0	0	0.7094	0.2177	0.670368	0.269364	0	6	0.010260
4	0	0	0	0	0	0.6983	0.85648	0.0897948	0.089845	0
5	0	0	0	0	0	0	0.2036	0.2112810	0.2294	0.45934
6	0	0	0	0	0	0	0.711	0.348612	0.34881	0
7	0	0	0	0	0	0	0	0.5282	0.5285	0.529104
8	0	0	0	0	0	0	0	0	0	0.5282
9	0	0	0	0	0	0	0	0	0	0.5404
10	0	0	0	0	0	0	0	0	0	0

Total Transmission path reliability matrix:

Node	1	2	3	4	5	6	7	8	9	10
1	0	0.8675	0.466534	0.453732	0.121912	0.006954	0.325512	0.333192	0.351312	0.581252
2	0	0	0.7443	0.453642	0.093611	0.451246	0.219884	0.304891	0.323011	0.552951
3	0	0	0	0.7094	0.2177	0.670368	0.269364	0.42898	0.01026	0.55066
4	0	0	0	0	0	0.6983	0.85648	0.089794	0.089845	0.617994
5	0	0	0	0	0	0	0.2036	0.21128	0.2294	0.45934
6	0	0	0	0	0	0	0.711	0.348612	0.34881	0.876812
7	0	0	0	0	0	0	0	0.5282	0.5285	0.529104
8	0	0	0	0	0	0	0	0	0	0.5282
9	0	0	0	0	0	0	0	0	0	0.5404
10	0	0	0	0	0	0	0	0	0	0

(d)For 20000 simulation runs

Input: Reliability matrix for each link

Node	1	2	3	4	5	6	7	8	9	10
1	1	0.65	0.27	0	0	0	0	0	0	0
2	0	1	0.29	0.13	0	0.002	0	0	0	0
3	0	0	1	0.35	1	0	0	0	0	0
4	0	0	0	1	0	0.54	0.71	0	0	0
5	0	0	0	0	1	0	0.08	0	0.12	0
6	0	0	0	0	0	1	0.28	0	0	0
7	0	0	0	0	0	0	1	0.48	0.48	0
8	0	0	0	0	0	0	0	1	0	0.8
9	0	0	0	0	0	0	0	0	1	0.61
10	0	0	0	0	0	0	0	0	0	1

Output:

Critical index matrix:

Node	1	2	3	4	5	6	7	8	9	10
1	0	0.8653	0.1854	0	0	0	0	0	0	0
2	0	0	0.7432	0.14725	0	0.0177	0	0	0	0
3	0	0	0	0.70515	0.2198	0	0	0	0	0
4	0	0	0	0	0	0.6966	0.1563	0	0	0
5	0	0	0	0	0	0	0.20555	0	0.0191	0
6	0	0	0	0	0	0	0.70895	0	0	0
7	0	0	0	0	0	0	0	0.5302	0.52455	0
8	0	0	0	0	0	0	0	0	0	0.5302
9	0	0	0	0	0	0	0	0	0	0.5373
10	0	0	0	0	0	0	0	0	0	0

Weighted reliability matrix:

Node	1	2	3	4	5	6	7	8	9	10
1	0	0.8653	0.66848	0.286103	0.059346	0.011505	0	0	0	0
3	0	0	0.7432	0.351743	0.063742	0.108258	0.021737	0	0	0
5	0	0	0	0.70515	0.2198	0.24381	0.260255	0	0.0191	0
4	0	0	0	0	0	0.6966	0.539133	0.376442	0.372431	0
5	0	0	0	0	0	0	0.20555	0.042416	0.06106	0.06447
6	0	0	0	0	0	0	0.70895	0.148456	0.146874	0
7	0	0	0	0	0	0	0	0.5302	0.52455	0.5124
8	0	0	0	0	0	0	0	0	0	0.5302
9	0	0	0	0	0	0	0	0	0	0.5373
10	0	0	0	0	0	0	0	0	0	0

Total Transmission path reliability matrix:

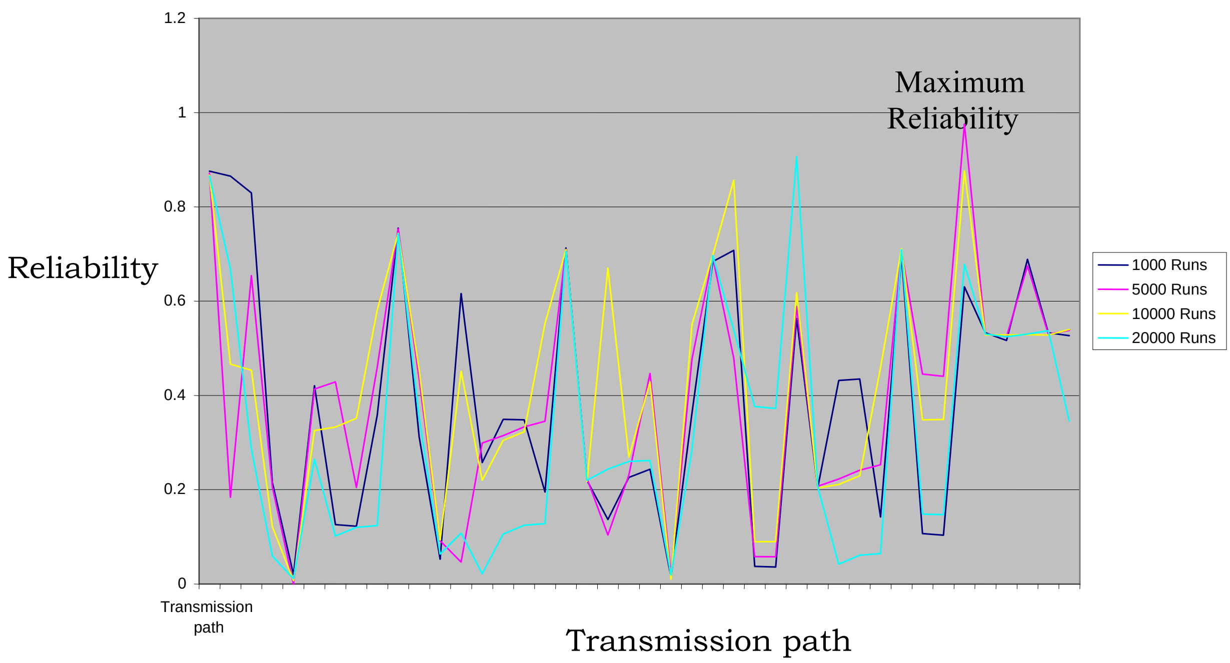
Node	1	2	3	4	5	6	7	8	9	10
1	0	0.8653	0.66848	0.286103	0.059346	0.011505	0.264896	0.101762	0.12041	0.123822
2	0	0	0.7432	0.351743	0.063742	0.108258	0.021737	0.106158	0.124806	0.128218
3	0	0	0	0.70515	0.2198	0.24381	0.260255	0.262216	0.0191	0.284276
4	0	0	0	0	0	0.6966	0.539133	0.376442	0.372431	0.906642
5	0	0	0	0	0	0	0.20555	0.042416	0.061064	0.064476
6	0	0	0	0	0	0	0.70895	0.148456	0.146874	0.678656
7	0	0	0	0	0	0	0	0.5302	0.52455	0.5124
8	0	0	0	0	0	0	0	0	0	0.5302
9	0	0	0	0	0	0	0	0	0	0.5373
10	0	0	0	0	0	0	0	0	0	0

Result and Discussion

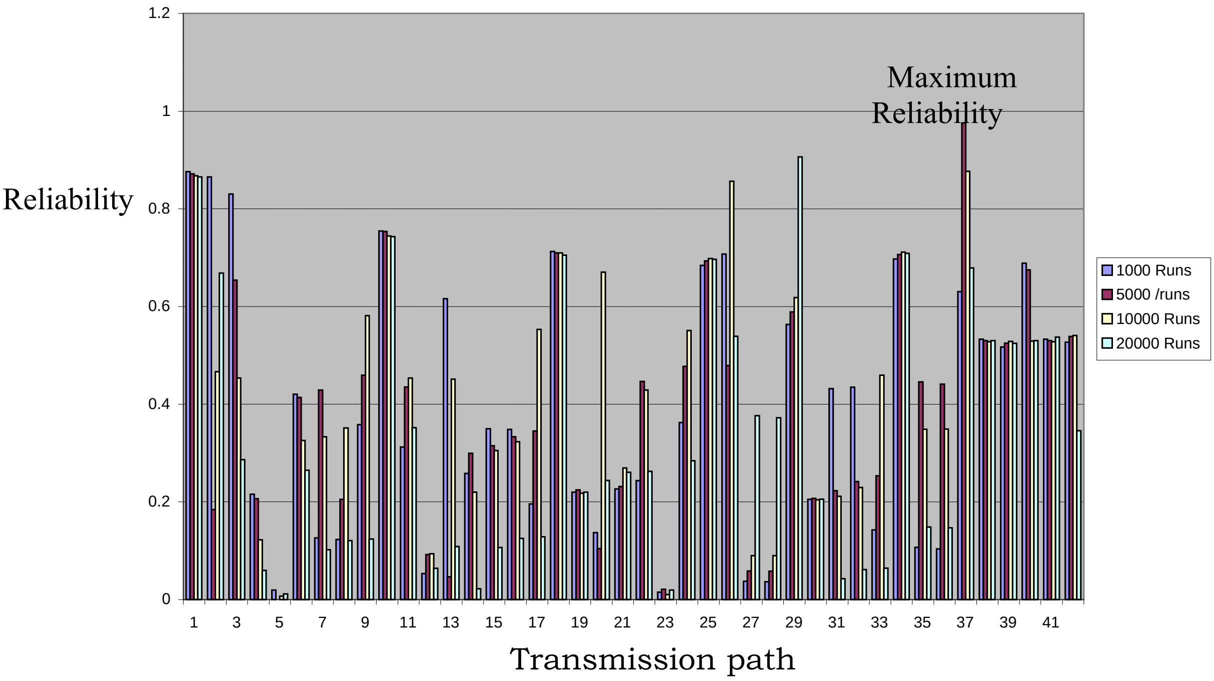
For the successful transmission of data on a network, reliability is one of the important factors to be considered. More the reliability of the transmission path, more the probability of successful transmission of data.
The simulator designed evaluates point to point reliability by giving appropriate weights to the critical transmission path on the basis of critical index and Warshal algorithm for minimal path sets.

The simulator is executed on a network having 16 links and 10 terminals. It is found that transmission path 6 to 10 has maximum reliability i.e. 0.975568. This means that the data transmission will be most reliable when it will move from node 6 to 10.
The graphs are plotted between reliability and transmission path. The point of maximum reliability is depicted.
This simulator will be helpful in selecting the most reliable path for data transmission.

Reliability vs Transmission path



Reliability v/s Transmission path



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P.K. Suri received his Ph.D. degree from Faculty of Engineering, Kurukshetra University, Kurukshetra, India and Master’s degree from Indian Institute of Technology, Roorkee (formerly known as Roorkee University), India. He is working as Professor in the Department of Computer Science & Applications, Kurukshetra University, Kurukshetra - 136119 (Haryana), India since Oct. 1993. He has earlier worked as Reader, Computer Sc. & Applications, at Bhopal University, Bhopal from 1985-90. He has supervised five Ph.D.’s in Computer Science and thirteen students are working under his supervision. He has more than 100 publications in International / National Journals and Conferences. He is recipient of 'THE GEORGE OOMAN MEMORIAL PRIZE' for the year 1991-92 and a RESEARCH AWARD – “The Certificate of Merit – 2000” for the paper entitled ESMD – An Expert System for Medical Diagnosis from INSTITUTION OF ENGINEERS, INDIA. His teaching and research activities include Simulation and Modeling, SQA, Software Reliability, Software testing & Software Engineering processes, Temporal Databases, Ad hoc Networks, Grid Computing , and Biomechanics.

Bharat Bhushan received the M Sc. (Physics), from Panjab Univ. Chandigarh and M.Sc. (Comp. Sc.), MCA degrees from Guru Jambeshwar University respectively. Presently working as Head, Department of Computer Science and Applications, Guru Nanak Khalsa College, Yamuna Nagar (affiliated to Kurukshetra University, Kurukshetra- Haryana, India) and senior most teacher of computer science in Haryana since 1984. He has been a member of Board of Studies of Computer Science, Kurukshetra University and member of Advisory Board of educational program (EDUSAT) launched by Govt. of Haryana to impart online education. His research interest includes Software engineering, Digital electronics, networking and Simulation Experiments.