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A Reliability Examination Method for Multi-source and One-Destination Network

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Abstract

In the multi-status network, data could be transmitted via different path. The network and its elements such as links and nodes are usually regarded with two statuses. However, in the real-life cases, due to the communication traffic jam and physical errors from network devices, it is a multi-state network. In order to discuss the reliability examination of such cases, this paper introduces an innovative algorithm to evaluate the reliability with continuous time intervals as constraints. Each source transmit a data sequence via a minimal path, where two paths have the same link. The time interval for generating the data and data volume obey random distribution. In this paper, Monte-Carlo simulation is used for getting the distributions. The time for transferring the data should be smaller than the constraints and such time is heavily related to the data volume. From the results, some lessons and insights could be learned. Firstly, under the random variables of data and time interval, their influences on the network reliability is great. Secondly, the end-users like network administrators can configure smaller data volume transfer and bigger time interval to achieve better network reliability.

***Keywords**: Multi-Source and One-destination, Network Reliability, Evaluation Model*

1. Introduction

In the multi-status network, data could be transmitted via different path. Most of the network reliability is based on the data which are transmitted through non-crossed paths [1]. For the crossed transmission path, there are scarce reports based on these considerations. A reliable protocol provides reliability properties with respect to the delivery of data to the intended recipient(s), as opposed to an unreliable protocol, which does not provide notifications to the sender as to the delivery of transmitted data [2].

The network and its elements such as links and nodes are usually regarded with two statuses. However, in the real-life cases, due to the communication traffic jam and physical errors from network devices, it is a multi-state network [3]. In the multi-state network, each transmission path has several state with certain probability due to the physical components like fibers, cables, and unshielded twisted pair (UTP). There are two types of reliability examination for multi-state network. They are accurate algorithm and approximate algorithm [4]. In the accurate algorithm, minimal paths approach has been widely used [5-6]. Assume that all the minimal paths set is determined, the reliability of multi-state network could be calculated under the cost limitation with certain transmission of data [7-8].

Currently, most of the studies focus on the single source and single destination. Multi-state network is scarcely reported so as to investigate the reliability. In the multi-state network, the reliability evaluation should be based on real situations that the cross paths will be possible to transmit the data. Previous studies concentrate on the considerations of some sources send some data to destinations at some time [8]. However, the more practical case that a series of data should be sent via the network is still not considered

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within a time interval. For example, in the multi-state network, users are able to open the website continuously. The continuous operations will be closed related so that each the previous click will influence the sequenced click.

In the real-life case, users from two locations or two different types may uses two different paths to send the data to the server [9]. The two paths may include same link. Assume that, all the minimal paths are determined, data could be transmitted via *k, k≥2* links. In this case, paths with non-cross indicate that there is no same links within two paths. However, the non-cross paths for transmitting the data will reduce the options to the transmission channel. Additionally, in the multi-source and multi-destination network, even there is not cross paths, the data transmission will choose the channels with crossed nodes. Figure 1 shows a multi-source single destination network, the source s_1 use the minimum path $p_1 = \{a_1, a_2, a_3\}$ and $p_2 = \{a_4, a_5, a_6\}$ to transmit the data of unit d_1. Where p_1 and p_2 are non-cross paths. s_1 use the minimum path $p_3 = \{a_7, a_5, a_8\}$ and $p_4 = \{a_9, a_{10}\}$ to transmit the data of unit d_2. Where p_3 and p_4 are non-cross paths.

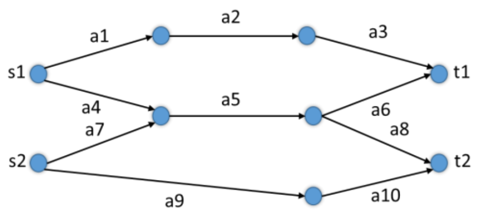

Figure 1. Multi-source Single Destination Network

However, from the above Figure, within the whole network, p_2 and p_3 have the same link a_5. When transmitting the data via a_5, the data are competitors to get the priority to use the channel. In real cases, this will be happened frequently. In order to discuss the reliability examination of such cases, this paper introduces an innovative algorithm to evaluate the reliability with continuous time intervals as constraints. Each source transmit a data sequence via a minimal path, where two paths have the same link. The time interval for generating the data and data volume obey random distribution. In this paper, Monte-Carlo simulation is used for getting the distributions [10-11]. The time for transferring the data should be smaller than the constraints and such time is heavily related to the data volume.

The rest of this paper is organized as follows. Section 2 presents the problem description for the multi-source and one-destination network where the reliability could be examined. Section 3 illustrates the proposed algorithms to solve the problem with the consideration of time constraints. Section 4 discusses the simulation and experimental results. Then, conclusions are carried out in Section 5 for concluding this paper by giving the future work.

2. Problem Description

In order to formulate the multi-source and one-destination network, several assumptions should be made to facilitate the problem. The following assumptions are given in this section:

1) In the network, every node is reliable. If there are some unreliable nodes, each of which could be replaced two reliable nodes and one unreliable link.
2) The capacity of each link is a nonnegative integer which is a random distribution. The capacity for each link is independent.

3) The network obeys conversation law of the capacity. It means the input and output data in a node in the network should be equal.
4) The priority law in the public links is based on the first come first serve mechanism.

For this network, each source will send some data to the destinations via the public links. Each node generates random data at different time slot. The time for transmitting should be less than the limitations of associated defined maximum time which is closed related to the data volume [12-13].

In this network, there are three types of delays that play important role in evaluating the reliability. They are transmission delay, sending delay, and node processing delay. Transmission delay tp is the cost of time for transmitting the electromagnetic wave within a certain distances. tp heavily relates to the length of channel and the transmission speed in the channel. In this paper, due to the predefined channel length of the links, the sending delay could be calculated by $tse_i = d / x_i$, $i = 1, 2, ..., n$. Where tse_i presents the sending delay of the terminal node connecting a_i, d is the data volume and x_i is the transmission channel bandwidth. Node processing delay occurs when a node processes the data which stored or forward so that some time is necessary [14-15]. If a piece of data arrives a node, there is no stored data, then the node processing delay t_p is zero. Otherwise, t_p is the time difference of all the stored data leaving the node and time when the data arrives.

Let $tarc_i$ presents the total time delay of data which transmitted via a_i, $tarc_i$ could be calculated by:

$$tarc_i = tp_i + tse_i + tw_i, \quad i = 1, 2, ..., n \tag{1}$$

The total time cost within the network

$$ttc = \sum_{a_i \in P_{st}} tarc_i, \quad q = 1, 2; \quad i = 1, 2, ..., n \tag{2}$$

Where P_{st} is the minimal paths set from the source s to destination t. The data generated at s is transferred to t via P_{st}.

3. Proposed Model

The proposed model is aiming to evaluate the reliability in the network which is shown in Figure 2.

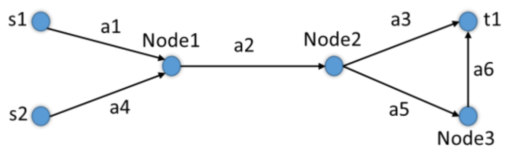

Figure 2. Network with Shared Links

Within the network, s_1 will produce a data $d_1(k)$, $k = 1, 2, ..., \alpha$, data volume of $d_1(k)$ is randomly generated. Such data will be sent from s_1 to t via $P_1 = \{a_1, a_2, a_3\}$ under the time constraints $Tth1(k)$. s_2 will produce a data $d_2(j)$, $j = 1, 2, ..., \beta$, data volume of

$d_2(j)$ is randomly generated. Such data will be sent from s_2 to t via $P_2 = \{a_4, a_2, a_5, a_6\}$ under the time constraints $Tth1(k)$.

Due to the same a_2 will deal with the transfer of data $d_1(1), d_1(2), \ldots d_1(\alpha)$ and $d_2(1), d_2(2), \ldots d_2(\beta)$, such data will be emerged into one sequence. Let m presents the node amount in the middle of network, $ta_u(k)$ and $tta_u(j)$ present the arrival time of $d_1(k)$ and $d_2(j)$ to node $u, u = 1, 2, \ldots m$. According to the arrival time to node 1, all the data could be sequenced by the increasing time series which is formed a new sequence SEQU. If $ta_1(k) = tta_1(j)$, $d_1(k)$ has the priority to use a_2.

Let $A(k)$ and $B(j)$ indicate the time when s_1 and s_2 generate the data $d_1(k)$ and $d_2(j)$ respectively. $tw_u(k)$ and $ttw_u(j)$ are the waiting time of $d_1(k)$ and $d_2(j)$ at node u. For the first generated data of s_1 and s_2, we can get $A(1) = t_{10}, tw_0(1) = 0, tw_2(1) = 0$ and $B(1) = t_{20}, ttw_0(1) = 0, ttw_2(1) = 0, ttw_3(1) = 0$. Since $d_1(1)$ and $d_2(1)$ will have the collision when using the node a_2, $tw_1(1)$ and $ttw_1(1)$ are not always equal to zero. If $d_1(1)$ is the first data arriving node 1, then $tw_1(1) = 0$, otherwise, in SEQU the data before $d_1(1)$ are generated by s_2. Let $d_2(\omega), \omega = 1, 2, \ldots, \beta$ presents the data before $d_1(1)$ in SEQU, $tw_1(1)$ could be calculated by:

$$tw_1(1) = \begin{cases} 0 & if ta_1(1) \geq tt_1(\omega) \\ tt_1(w) - ta_1(1) & others \end{cases} \tag{3}$$

Similarly, If $d_2(1)$ is the first data arriving node 1, then $ttw_1(1) = 0$, otherwise, let $d_1(\omega\omega), \omega = 1, 2, \ldots, \alpha$ presents the data before $d_2(1)$ in SEQU, $ttw_1(1)$ could be calculated by:

$$ttw_1(1) = \begin{cases} 0 & if tta_1(1) \geq t_1(\omega) \\ t_1(ww) - tta_1(1) & others \end{cases} \tag{4}$$

Let $\mathrm{T}_1(k)$ and $\mathrm{T}_2(j)$ indicate the time interval between $d_1(k)$ and $d_2(j)$, there are two data sequences:

$$A(k) = A(k-1) + \mathrm{T}_1(k-1), k = 2, 3, \ldots, \alpha \tag{5}$$

$$B(j) = B(j-1) + \mathrm{T}_2(j-1), j = 2, 3, \ldots, \beta \tag{6}$$

Due to the consideration of time constraints, the total transferring time should be calculated. Let $t_s(k)$ presents the time when $d_1(k)$ leaves s_1. $t_u(k)$ is the time when $d_1(k)$ leaves node u. $t_a(k)$ is the time when $d_1(k)$ arrives at destination t. Thus, the time could be obtained by:

$$t_s(k) = A(k) + tw_0(k) + d_1(k) / x_1 \tag{7}$$

$$ta_1(k) = ts(k) + tp_1 \tag{8}$$

$$t_1(k) = ta_1(k) + tw_1(k) + d_1(k) / x_2 \tag{9}$$

$$ta_2(k) = t_1(k) + tp_2 \tag{10}$$

$$t_2(k) = ta_2(k) + tw_2(k) + d_1(k) / x_3 \tag{11}$$

$$ta(k) = t_2(k) + tp_3 \tag{12}$$

Let $tts(j)$ presents the time when $d_2(j)$ leaves s_2, $tt_u(j)$ presents the time when $d_2(j)$ leaves node u. $tt_a(j)$ is the time when $d_2(j)$ arrives at destination t. Thus, the time could be obtained by:

$$tts(j) = B(j) + ttw_0(j) + d_2(j) / x_4 \tag{13}$$

$$tta_1(j) = tts(j) + tp_4 \tag{14}$$

$$tt_1(j) = tta_1(j) + ttw_1(k) + d_2(j) / x_2 \tag{15}$$

$$tta_2(j) = tt_1(j) + tp_2 \tag{16}$$

$$tt_2(j) = tta_2(j) + ttw_2(j) + d_2(j) / x_5 \tag{17}$$

$$tta_3(j) = tt_2(j) + tp_5 \tag{18}$$

$$tt_3(j) = tta_3(j) + ttw_3(j) + d_2(j) / x_6 \tag{19}$$

$$tta(j) = tt_3(j) + tp_6 \tag{20}$$

There are two types of waiting time: waiting time caused by homologous and heterogeneous data. $tw_0(k)$, $tw_2(k)$, $ttw_0(j)$ and $ttw_q(j)$, $k = 2,3,...,\alpha$, $j = 2,3,...,\beta$, $q = 2,3$, then, we can get:

$$tw_0(k) = \begin{cases} 0 & if A(k) \ge ts(k-1) \\ ts(k-1) - A(k) & others \end{cases} \tag{21}$$

$$tw_2(k) = \begin{cases} 0 & if ta_2(k) \ge t_2(k-1) \\ t_2(k-1) - ta_2(k) & others \end{cases} \tag{22}$$

$$ttw_0(j) = \begin{cases} 0 & if B(j) \ge tts(j-1) \\ tts(j-1) - B(j) & others \end{cases} \tag{23}$$

$$ttw_q(j) = \begin{cases} 0 & if tta_q(j) \ge tt_q(j-1) \\ tt_q(j-1) - tta_q(j) & others \end{cases} \tag{24}$$

$tw_1(k)$ and $ttw_1(j)$ could be calculated given two conditions: in the SEQU, if the data before $d_1(k)$ is $d_1(k-1)$, then $tw_1(k)$ could be calculated by:

$$tw_1(k) = \begin{cases} 0 & if ta_1(k) \ge t_1(k-1) \\ t_1(k-1) - ta_1(k) & others \end{cases} \tag{25}$$

If the data before $d_1(k)$ is $d_2(v)$, then $tw_1(k)$ could be calculated by:

$$tw_1(k) = \begin{cases} 0 & if ta_1(k) \ge tt_1(v) \\ tt_1(v) - ta_1(k) & others \end{cases} \tag{26}$$

$$ttw_1(j) = \begin{cases} 0 & if tta_1(j) \ge tt_1(j-1) \\ tt_1(j-1) - tta_1(j) & others \end{cases} \tag{27}$$

$$ttw_1(j) = \begin{cases} 0 & if tta_1(j) \geq t_1(vv) \\ t_1(vv) - tta_1(j) & others \end{cases} \tag{28}$$

Considering the time constraints, $ta(k)$ and $tta(j)$ should be less than the transmission time $A(k)+Tth_1(k)$ and $B(k)+Tth_2(j)$:

$$ta(k) \leq A(k) + Tth_1(k) \tag{29}$$

$$tta(j) \leq B(k) + Tth_2(j) \tag{30}$$

$Tth_1(k)$ and $Tth_2(k)$ related to the data volume of $d_1(k)$ and $d_2(j)$. In this paper, we assume they obey linear relationship with each other like:

$$Tth_1(k) = a \times d_1(k) + b \tag{31}$$

$$Tth_2(j) = c \times d_2(j) + d \tag{32}$$

Where, *a*, *b*, *c*, and *d* are the network parameters.

Assume that there are $q(k)$ $(d_1(k), Tth_1(k), P_1) - X, k = 1, 2, ..., \alpha$ in $\Psi_1(k)$. $\Psi_1(k) = \{X_1, ..., X_v, ..., X_{q(k)}\}$, $X_v = (x_{v1}, x_{v2}, ..., x_{vn})$. Let $\mathrm{Re}_1(k)$ presents the data success possibility of data $d_1(k)$ under the constraints $Tth_1(k)$ passing through P_1. $\mathrm{Re}_1(k)$ is the sum of all the possibility of the network capacity with X_v, $v = 1, 2, ..., q(k)$:

$$\mathrm{Re}_1(k) = \sum_{v=1}^{q(k)} \Pr\{X = X_v\}$$

$$= \sum_{v=1}^{q(k)} (\Pr\{x_1 = x_{v1}\} \times \Pr\{x_2 = x_{v2}\} \times ... \times \Pr\{x_n = x_{vn}\}) \tag{33}$$

Let $\mathrm{Re}_2(j)$ presents the possibility of data $d_2(k)$ under the constraints $Tth_2(j)$ passing through P_2, $\mathrm{Re}_1(k, i_{MC})$ and $\mathrm{Re}_2(j, i_{MC})$ present the Monte-Carlo sampling reliability of i_{MC}, $i_{MC} = 1, 2, ..., N_{MC}$. $ave\mathrm{Re}_1(k)$ and $ave\mathrm{Re}_2(j)$ are the Monte-Carlo average reliability of $d_1(k)$ and $d_2(j)$.

$$ave\mathrm{Re}_1(k) = \frac{1}{N_{MC}} \times \sum_{i_{MC}=1}^{N_{MC}} \mathrm{Re}_1(k, i_{MC}) \tag{34}$$

4. Simulation and Discussions

This section reports on the simulation experiments to evaluate the model proposed in this paper. Table 1 gives the experimental data based on Figure 2. In the experiment, two paths $P_1 = \{a_1, a_2, a_3\}$ and $P_2 = \{a_4, a_2, a_5, a_6\}$ are used to send the data. Due to the share link a_2 of P_1 and P_2, there are some collisions at a_2.

Assume that each link in P_1 will have the non-negative value, with the 1Mb volume data size, the transfer delay via P_1 is 1/800+1/600+1/800=0.00417s. The transfer delay via P_1 is $p_1 + tp_2 + tp_3 = 8 \times 10^{-6}$ s. Assume the waiting time is zero for each data, the total time for transferring $d_1(k)$ Mb size data via P_1 is $0.00417 \times d_1(k) + 8 \times 10^{-6}$ s. Similarly, the total time for transferring $d_2(j)$ Mb size data via P_2 is $0.00583 \times d_2(j) + 9.6 \times 10^{-6}$ s. The transferring time constraints are: $Tth_1(k) = 0.00417 \times d_1(k) + 8 \times 10^{-6}$ s and $Tth_2(j) = 0.00583 \times d_2(j) + 9.6 \times 10^{-6}$ s.

Table 1. Experimental Data

Link	Capacity (Mbps)	Possibility	Transfer Delay (ms)
a1	1000	0.92	0.0015
	800	0.06	
	0	0.02	
a2	1000	0.93	0.0035
	600	0.05	
	0	0.02	
a3	900	0.88	0.003
	800	0.1	
	0	0.02	
a4	1000	0.9	0.0025
	800	0.08	
	0	0.02	
a5	1000	0.94	0.0015
	800	0.05	
	0	0.01	
a6	900	0.89	0.0021
	600	0.08	
	0	0.03	

In the experiments, the simulations are based on the four group of data from s_1 and s_2. Considering the random of $d_1(k)$ and $d_2(j)$, Table 2 shows the distribution of them for carrying out the simulations.

Table 2. Distributions of $d_1(k)$ and $d_2(j)$

Data	Volume 1	Volume 2	Range
$d_1(k)$	50	210	[0, 0.1]
	80	290	[0.1, 0.25]
	150	340	[0.25, 0.5]
	170	420	[0.5, 0.7]
	210	550	[0.7, 1]
$d_2(j)$	50	50	[0, 0.1]
	80	80	[0.1, 0.25]
	150	150	[0.25, 0.5]

	170	170	[0.5, 0.7]
	210	210	[0.7, 1]

With the data, the network reliability is compared with statistics analysis. Figure 3 shows the experiments results with four simulations.

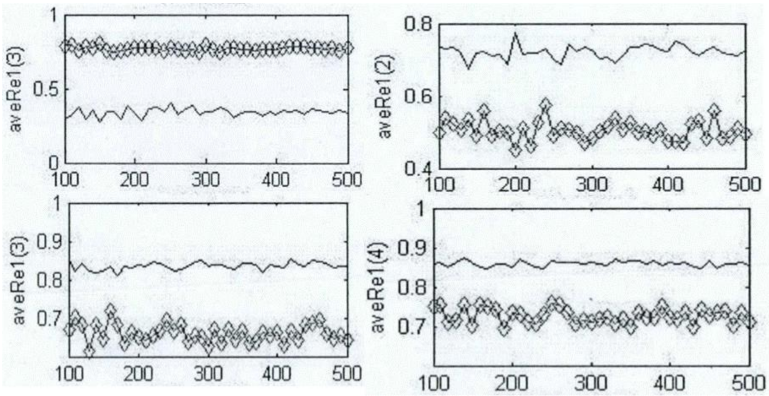

Figure 3. Experimental Results -1

From Figure 3, the reliability from the proposed model out performs that from the statistics method for getting the network reliability. When the $ave\,\mathrm{Re}_1(k), k = 2,3,4$, the network reliability from this model is much better than statistics approach. That because in the same situations, longer time interval will reduce the collisions occurred at a node. It could be observed that when the data is fixed, most of the reliability for the data will be decreased along with the reduction of time interval. Thus, under the data fixed situation, end-users are able to enlarge the time interval to get better network reliability. However, the processing time like transferring time and waiting time is thus needed to be longer.

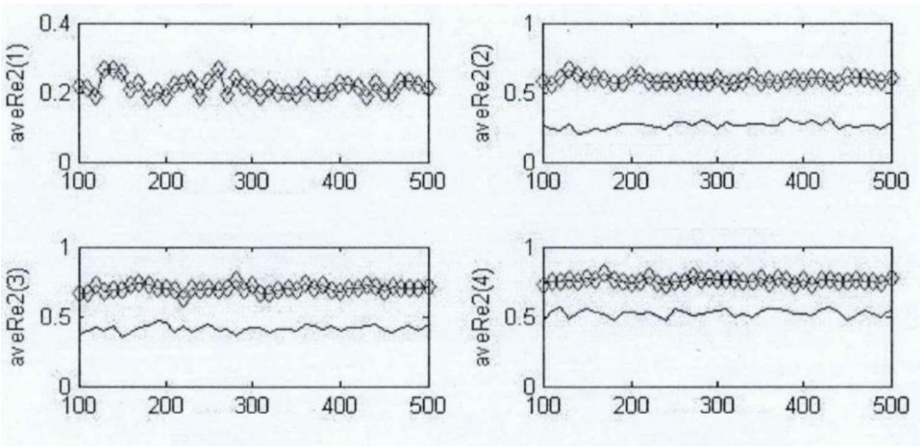

Figure 4. Experimental Results -2

Figure 4 shows the second simulation results that the $ave\,\mathrm{Re}_2(j), j = 1,2,3,4$. It could be found that the network reliability is better than the statistics analysis that because the proposed model has smaller $|\lambda_1 - \lambda_2|$ and bigger $d_1(k)$. With the parameters, the collisions in the shared links are greatly reduced thus the network reliability has been significant improved.

From the results, some lessons and insights could be learned. Firstly, under the random variables of data and time interval, their influences on the network reliability is great. Secondly, the end-users like network administrators can configure smaller data volume transfer and bigger time interval to achieve better network reliability.

5. Conclusions

This paper introduces a reliability evaluation method for multi-source and single destination network. This method is based on a model using continuous time intervals to examine the network reliability from a shared link that uses the Monte-Carlo simulation approach to carry out the simulation experiments. With the shared links and transfer time constraints, each data is sent to the destinations via the minimal path. So that, the network reliability could be examined. The experiments results show that the collision will influence the data transfer time and further negatively influence the network reliability. The results could be used for guiding the network administrators to adjust the time interval and data volume so as to improve the reliability.

Future research will be carried out from several aspects. Firstly, the time interval and data from this paper are based on Monte-Carlo simulation approach. Different data generated from different sources are different. Thus, real data set will be used for examine the model. Secondly, each link in the network obeys certain possibility distribution. In the future, big data from the network could be used for working out the exact distribution which could be used in this model for more reasonable results.

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