Impact Analysis of Communication Network Reliability Based on Node Failure

Zhao Fei
Beihang University
Network reliability group
Beijing, China
E-mail: zf_nrrg@163.com

Huang Ning
Science & Technology on
Reliability & Environmental
Engineering Laboratory
Beijing, China
E-mail: hn@buaa.edu.cn

Chen Jiaxi
Beihang University
Network reliability group
Beijing, China
E-mail: chenjiaxixi@126.com

***Abstract*—Node failure is an important factor causing network faults. Through research on node failures, mastering the effect laws of failure is a reasonable and effective method to improve network reliability. This paper summarized and classified the node failure modes of communication network. Meanwhile, combined with the classic BA network model in complex network theory, the effect laws of nodes' function failure and performance failure on network reliability were investigated with the design of simulations using MATLAB and OPNET. The results have great guidance value for the simulation of network reliability and network reliability design under limited operation cost.**

Keywords-node function failure; node performance failure; network connectivity reliability; network performance reliability; simulation

I. INTRODUCTION

Nowadays, network is growing faster and more universal. Network reliability is becoming the focus of users and the serious challenge to network providers and operators.

Nodes are important parts of network. According to the reports released by the Network Reliability Steering Committee, node failure is an important factor causing network faults. Thus, studying node failure is significant to improve network reliability. Recently, node failure modeling and analysis of its impact [1-3] are the research focuses. However, since network usage can be affected by change of flow and routing policy, these models can't conform to actual operating mechanism, e.g. capacity-load model. It does removal to all failure nodes [4] which applies to failed nodes rather than congested nodes. Therefore, different node failure types need different methods to analyze their influence on network reliability. Moreover, as node failure characteristics are closely related with cost, mastering law of node failure's impact on network can provide the network operators with references to selecting equipments in design.

To solve the problems, the communication network node failure modes are classified and summarized. Based on two different simulation tools, we take BA model [5] as the object and do node failure simulation analysis to network reliability, whose result can offer guidance to network reliability simulation and selecting network equipments under limited cost and network reliability requirements.

II. THE NETWORK RELIABILITY AND FAULTS ANALYSIS

Network reliability is the ability to complete specified function under prescribed time and stated conditions. Ref. [6] establishes three-layer frame of network reliability.

The topology/physics layer is at the bottom. Physical equipments and connections form the visible network topology, influencing the network connectivity reliability.

The regulation/configuration layer lies in the middle which consists of operating rules formed by equipment configurations. The fault derives from the performance failure of network components and affects the network performance reliability which contains data transmission integrated reliability, timely reliability and correct reliability, corresponding to packet loss, delay and error[7].

The Application/service layer corresponds to the network procedural faults caused by irrationality of network service deployment, application configuration or use strategy.

Connectivity reliability is the foundation, and the upper reliability is based on the lower one. Unlike simple systems, networks can't be optimized to meet all aspects' best needs, therefore, it is not necessary to quantize reliability of the whole network. This is why we need to evaluate network reliability from multiple aspects.

III. THE NODE FAILURE RESEARCH

According to section II, in this section we'll study and analyze the node failures of the first two layers. Since the application/service layer doesn't involve single node failure, we don't put it into the scope of investigation.

A. Causes And Modes of Node Function Failure

In topology/physics layer, the function of nodes performs to make network connected. If the node can't realize the function of data transmission within prescribed time or stated conditions, we define it as node function failure.

Numerous causes lead to node function failure, in general: energy depletion; hardware failure; equipment software failure. In topology layer, node failure means being in non-operating state although it contains different failure mechanisms and rules. Then, node function contains two states only: ON and OFF. Based on this, MATLAB is selected as the simulation tool.

B. Causes And Modes of Node Performance Failure

In regulation/configuration layer, the nodes reflect part of the network operating rules, such as data forwarding strategy.

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If the operating conditions lead to node performance degradation under normal function conditions, then define the performance degradation as node performance failure.

The difference of performance and function lies in the fact that the nodes' performance ability can be described by degradation. When the network's transmission requirement for any equipment's data forwarding ability is higher than the level of the equipment can support, then the equipment is considered as performance degradation.

Numerous causes lead to node performance failure, in general: inadequate data forwarding level of equipment; improper size of memory; inadequate lagging transmission level; inadequate performance level of other equipments influencing network communication.

Due to performance degradation, the inside-processing simulation tool OPNET is selected because it is able to simulate real network operating mechanism which reflects the performance degradation states of the nodes and provides the packet-based analysis method.

IV. SIMULATION EXPERIMENT OF NODE FAILURE IMPACT

A. Analysis of Node Function Failure Impact on Network Connectivity Reliability

1)Simulation Design

Suppose links to be completely reliable and nodes to fail independently. Consider their ON and OFF states only and choose MATLAB as the simulation tool, the main steps are as follows:

a) BA network generation: Network topology has great influence on network. In complex network theory, the new network topology model, called scale-free network, is built up. Barabási and Albert contribute the generation of scare-free network to two main factors: growth and preferential connection, i.e. network comes from continuously adding new nodes and the new nodes tend to connect nodes with more links.

According to this mechanism, determining the modeling algorithm as follows:

- Selecting the all connected ring network of three nodes as the initial network.
- When new nodes choose existed nodes to connect, the probability $\tau(i)$ of connecting node i depends on node i 's degree k_i, i.e. :

$$\tau(i) = k_i / \sum_j k_j \qquad (1)$$

Each new node introduces two edges, and we can generate the BA network according to this algorithm.

b) Design of node failure rate: Important nodes always have lower failure rates. Ref. [8] ranks node importance according to their betweenness. Number the nodes based on their betweenness, the bigger of the betweenness, the smaller of the serial number. Then, the failure rate of the nth number $\lambda(n)$ is $f(\lambda(0), \alpha, n)$ and α (i.e. alpha) is the parameter which reflects the level of the whole nodes.

c) Data sampling: The main idea of Monte Carlo sampling method is constructing random event and making its probability statistics the solution to the problem. Assume the lives of nodes obey exponential distribution, we use this method to determine their lives according to the failure rates.

d) Calculation of connectivity reliability: The relative size of the largest connected nodes R, i.e. the proportion of the size of the maximum connected nodes in node scale N is used to measure the connectivity reliability in order to solve the NP-hard problem brought by traditional calculating methods. It is frequently used in complex networks [9].

e) Plotting: Calculating the network connectivity reliability R at the specified time T, where α and R are the abscissa and ordinate, respectively, plotting the curve.

2)Simulation Analysis And Conclusions

According to the design above, set N=200 and T=100, conducting the simulation where each node's life is exponentially distributed. Number nodes according to their betweennesses and assign failure rates $y(n)$ in accordance with the formula $y(0)\times\alpha^n$, $\alpha\in(1,1.35)$, α is a parameter reflecting the overall changes of node failure rates. Select 0.01 as the step and the changing curve is shown in Fig. 1.

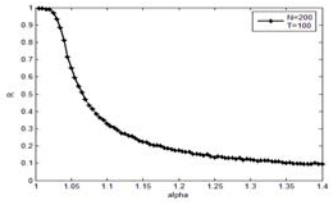

Figure 1. The impact of nodes function failure

In Fig. 1, the abscissa is the parameter α and ordinate R . The figure presents a smooth curve, and the entire network connectivity reliability decreases as α increases. When α equals 1.033, the connectivity reliability mutates.

Fig. 2 shows the simulation results when N = 100, 150, 200, 250 and T = 90. Fig. 3 shows the results when N= 200 and T=70, 80, 90,100, respectively.

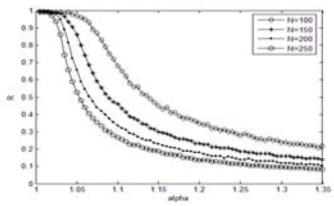

Figure 2. The impact of nodes function failure under the same T.

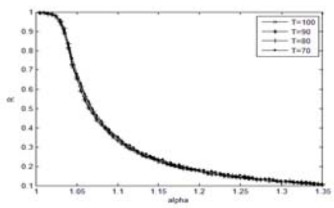

Figure 3. The impact of nodes function failure under the same N.

Analyze the data in the above two graphs, we obtain the cutoff value α_0 in each situation, shown in Table I.

TABLE I. TABLE CHANGE OF CRITICAL α_0

T	N			
	100	*150*	*200*	*250*
70	1.075	1.048	1.036	1.029
80	1.069	1.047	1.038	1.033
90	1.072	1.046	1.040	1.028
100	1.070	1.045	1.033	1.027

As shown above, these conclusions can be derived:

Changing parameter α, the network connectivity reliability mutates. Controlling α at α_0 under certain network size and specified time, we can obtain the optimal connectivity reliability under the lowest cost.

The critical point α_0 decreases as N and T increases when the function failure rates of all nodes are changed.

Compared with the prescribed time, the network size has a bigger impact on network connectivity reliability. As the network size becomes bigger, the influence becomes smaller.

The simulation curve can guide the selection of equipments under the premise of connectivity reliability and cost requirements. For example, if the operators make strict cost constraints C_0, meanwhile, requiring network to meet certain connectivity reliability R_0, then the rule of design means $R \geq R_0$ and $C \leq C_0$. Through marketing survey and curve fitting, we can obtain:

$$R = g(\alpha). \tag{2}$$

and

$$C = d(\alpha) \tag{3}$$

Since R and C display monotone decreasing with α, then:

$$d^{-1}(C_0) \leq \alpha \leq g^{-1}(R_0) \tag{4}$$

According to this simulation method, we can select the corresponding equipments to meet the requirements of cost and network connectivity reliability.

B. Analysis of Node performance Failure Impact on Network Performance Reliability

1)Simulation Design

OPNET is selected to conduct the simulation. The simulation steps are as follows:

a) BA network generation: Generate a BA network whose size is N.

b) Design of node performance failure: According to the influencing factors discussed above, giving a certain performance level to each node. Similar to node function rates, the bigger of the betweenness, the higher of the performance level. Therefore, the performance level $z(n)$ of the nth node is $G(z(0), \beta, n)$, where β (i.e.beta) is a parameter reflecting the overall performance level of nodes.

c) Flow input model: Including the source, destination, type and size of the traffic flow. Here we choose the ON/OFF traffic model [10] to analog the self-similar traffic. There are two assumptions: 1) N sources are independent of each other; 2) Set the source to two states: ON and OFF. The source transmits data at a fixed rate in the period of ON, and in the OFF period, the source doesn't transmit data. The time length of ON and OFF is subject to heavy tail distribution. The ON/OFF traffic model becomes the most commonly used self-similar traffic model in network simulation because of its simplicity, practicality and clear physical meaning.

d) Selection of routing protocols: Such as RIP distance vector routing protocol and OSPF link-state routing protocol.

e) Calculation of performance reliability: Timely reliability, integrited reliability and correct reliability are weighed to calculate the performance reliability R, just like the follows:

$$R = \left(1/3 \times (N_T / N) + 1/3 \times (N_I / N) + 1/3 \times (N_J / N)\right) \times 100\% \tag{5}$$

where N denotes the total number of packets delivered within predetermined time, N_T, N_I and N_J denote the number of packets whose delay are greater than the given threshold, which aren't lost and which don't have wrong numbers, respectively. N_T / N, N_I / N and N_J / N denotes the timely reliability, integrated reliability and correct reliability, respectively. For timely reliability analysis, the time threshold should be given, which is determined by the maximum delay when the network works normally.

f) Plotting: According to the results in the sixth step, plot the curve where β and R are the abscissa and ordinate, respectively. Fig.7 shows the flowchart.

2)Simulation Analysis And Conclusions

Take N=30, choose 100base-T as network links whose throughput are 100M. Use RPG module as the terminal which can input self-similar traffic directly and adopt the unified router model 3C_CB9000_14s_a2_ae20_fe10_ge2, ignoring the impact brought by terminals and links.

Adopting the way of full side communication and shortest path algorithm, input the end-to-end traffic whose mean is 250 packets/s and parameter Hurst=7. Set the simulation time to be one hour.

Selecting the node forwarding capability as the factor causing network fault, assigning the router forwarding capability $z(n)$ according to $z(0) \times \beta^{(n-1)}$, and $\beta \in (0.8, 1)$, which is a parameter that reflects the overall changes of node performance capabilities. Select 0.02 and 0.1 hours as the step of β and time threshold, we can get the curve shown in Fig. 4.

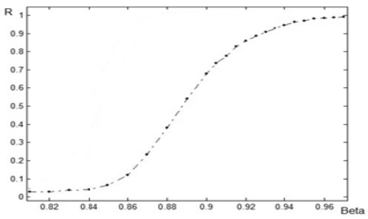

Figure 4. The impact of nodes performance failure.

In Fig. 4, the abscissa is parameter β and ordinate R. The figure presents a smooth curve, and the reliability of the entire network performance reliability increases as β increases. When β equals 0.943, the value of performance reliability mutates.

Table II shows the critical points when N = 20, 30, 40 and Traffic = 100, 150, 200, 250, respectively.

TABLE II. THE CHANGE OF CRITICAL POINT β_0

N	Traffic(packets/s)			
	100	***150***	***200***	***250***
20	0.842	0.863	0.904	0.942
30	0.848	0.919	0.897	0.943
40	0.855	0.895	0.921	0.955

As shown above, the following conclusions can be derived:

Changing parameter β that reflects the overall changes of node performance capabilities, the performance reliability mutates. Controlling β at β_0 under certain network size, traffic flow and fault criterion, the optimal performance reliability under the lowest cost can be got.

The critical point β_0 increases as network size and traffic increase, when the performance capabilities of all nodes are changed.

Compared with connectivity reliability, the network size has a bigger influence on performance reliability.

The simulation curve can guide the selection of equipments under the premise of performance reliability and cost requirements. For example, if the operators make strict cost constraints C_0, meanwhile, requiring network to meet certain performance reliability R_0, then the rule of design means $R \geq R_0$ and $C \leq C_0$. Through marketing survey and curve fitting, we can obtain:

$$R = G(\beta). \quad (6)$$

and

$$C = D(\beta) \quad (7)$$

Since R and C display monotone increasing with β, then:

$$G^{-1}(C_0) \leq \beta \leq D^{-1}(R_0) \quad (8)$$

According to this simulation method, we can select the corresponding equipments to meet the requirements of cost and performance reliability.

V. DISCUSSION

In this paper, we have proposed the classification method of node failures. The effect laws of nodes function failure and performance failure on network reliability have been investigated with simulation designs using MATLAB and OPNET.

The simulation results show that, relative to the specified time, the network size has greater impact on network connectivity reliability, as the size becomes lager, the impact will be smaller; Compared with connectivity reliability, the impact of network size on performance is more pronounced; Changing the parameter which reflects the overall node failures, the network reliability can mutate; Controlling the parameter at the critical point, we can obtain the optimal reliability under the lowest cost.

Applying this method to network reliability simulation and engineering, not only unreasonable experimental program can be reduced, but also the selection of equipments can be guided.

The BA scale-free network was chosen as network object. Since networks are divided into regular networks, random networks and scale-free networks, whether the above rules apply to other two types is a direction can be further studied.

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