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# Enlightenment on Computer Network Reliability From Transportation Network Reliability

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## Abstract

Referring to transportation network reliability problem, five new computer network reliability definitions are proposed and discussed. They are computer network connectivity reliability, computer network time reliability, computer network capacity reliability, computer network behavior reliability and computer network potential reliability. Finally strategies are suggested to enhance network reliability.

**Index Terms:** transportation network; computer network; reliability; strategy

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## 1. Introduction

In the early decades of computer age, the most important characteristic of a computer system was its speed. Thus, computers were usually judged by how fast they could perform a given task, and techniques were developed to predict it. Now with the acceleration of social information, not only does users of computers increase, but also the connect area and scale of computer network has increased. In the mean time fast computers have become affordable and widespread, but the research on the reliability of computer networks and security and confidential of the information is becoming more and more complex due to the large scale of networks. It lags far behind the development of the computer network. However, the computer network reliability problem is an important part and a key technical specification of the overall performance of computer network; it is also indispensable for the stable running of the system. So considering computer network reliability is a theme of reality and value.

This paper first introduced the transportation network reliability problem, whose theory and practice has been growing for a long time and has become very mature. Then analogy to transportation network reliability problem, five new computer network reliability definitions are proposed and the meanings of them are explained. Several strategies to improve the reliability of computer network are proposed. Finally, the conclusion is given.

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## 2. Transportation Network Reliability and Computer Network Reliability

### 2.1. Transportation network reliability

In the last decades, transportation network reliability has been receiving great attention and playing an increasingly important part in transportation area. Many related articles, conferences and books have appeared. Computer networks bear great similarities to transportation networks, many reliability theories in transportation can also apply to computer networks, which provide strong reference value. Currently, researches on transportation network reliability can be grouped into following categories:

#### 1) Transportation network connectivity reliability

Connectivity reliability is the earliest index of reliability, it is mainly about the connectivity of nodes in the network. Connectivity reliability focuses on the 0-1 status of links or nodes, that is connect or not connect. It does not consider the capacity constrain. Under the status of connect, suppose the network can meet the needs of all users, that is, the maximum capacity. Under the status of not connect, suppose the capacity is zero. Because 0-1 connectivity reliability can not truly reflect the situation when there are many different statuses in the system, Asakura[1] [2], Du and Nicholson[3] improved and extended it, their definition is:

$$R_p = \sum_y \prod_{j=1}^n r_j^{y_j} (1-r_j)^{1-y_j} \phi(y) \quad (1)$$

Where  $R_p$  is the connectivity reliability of the transportation network or OD pair (path) p,  $y_j$  is the status of link j, it is a 0-1 variable. For example, if link j does not fail in an accident, then the status variable takes 1, else takes 0.  $r_j$  is the probability that link j under normal operation, y is the vector of status variable,  $\phi(y) = \phi(y_1, y_2, \dots, y_n)$  can be defined as:

$$\phi(y) = \begin{cases} 1 & \text{if } PI(y) \leq c \\ 0 & \text{if } PI(y) > c \end{cases} \quad (2)$$

This means that if efficiency index  $PI(y)$  is smaller than or equals to given threshold, then system status is 1, else is 0. Using different efficiency index will lead to different connectivity reliability index.

#### 2) Transportation network travel time reliability

Travel time reliability is the probability of one successive travel in the given time. It reflects the effect of real travel time on the system. Using travel time reliability to evaluate the efficiency of the system can better reflect transportation characteristic than connectivity reliability does[4]. Often it takes the form of:

$$R_t = P\{t \leq t_m\} \quad (3)$$

Where  $R_r$  is travel time reliability between OD pair  $rs$ ,  $t$  is the minimum travel time between OD pair  $rs$ ,  $t_m$  is a given threshold.

This definition is similar to that of connectivity reliability in essence. Connectivity reliability is a special case of travel time reliability. However, travel time reliability should consider travelers' path choice behavior, which is different from that of connectivity reliability. In the situation of demand fluctuation, system capacity degrade and information provision, travel time reliability can have many results. Currently Scholastic User Equilibrium (SUE) is often used to study travel time reliability, and use the relationship of mean and variance of the travel time to represent it.

### 3) Transportation network capacity reliability

Capacity reliability [5] is the probability the network can meet the needs of a given OD demand. In reality, the level of service network can provide is related with the capacity of the system. Adequate capacity and proper transportation management and control can enable the stable operation of the system, thus meet the travel needs of users. So transportation planners put more emphasis on the capacity system can provide. On the basis of the concepts of the network reserve capacity, capacity reliability can be defined as the probability the network can meet the needs of a given OD demand under acceptable level of service. Reserve capacity is the maximum multiplier of OD matrix under Wardrop principle and it is the maximum capacity. At this time capacity reliability is:

$$R_c = P(\mu \geq \mu_r) \quad (4)$$

Where  $\mu_r$  is given demand level,  $\mu$  is the maximum multiplier of OD pair.

Compare capacity reliability with travel time reliability, we can see that travel time reliability applies to the evaluation of travelers on the service quality of the system, while capacity reliability applies to the evaluation of system managers on the capacity of the system.

### 4) Transportation network behavior reliability

Behavior reliability focuses on the effects of different behavior pattern on the network reliability. Since the study of transportation network reliability, a problem attracts increasing attention is the interaction between the behavior of network users and the variation of network conditions. Generally, unpredicted variation in the network such as traffic accident, unexpected road repair will affect the behavior of users, consequently affect the performance of the network. These kinds of behavior reliability can all be seen as behavior reliability. Under the Wardrop principle, these researches mainly focus on the effects of different path choice pattern on network reliability or the variation of time on travel behavior.

Travel behavior decisions often use quantitative modal. Currently quantitative modals of users travel behavior under uncertain conditions are Expected Utility Theory, Random Utility Theory and Cumulative Prospect Theory. Expected Utility Theory and Random Utility Theory are used by most of the international researchers because of their simplicity and easy to grasp while Cumulative Prospect Theory has some inherent shortcomings and receives less attention. Generally, utility theories assume maximum utility or minimum disutility.

### 5) Transportation network potential reliability

Potential reliability is a complementary and perfection of above four kinds of reliability. It considers transportation network reliability from the perspective of security and pessimist, for instance the existence of weak link of the system and its effects on network users and the whole system. For there are always exist some

key equipments and key lines, once fall into failure will exert great pressure on the whole system. Potential reliability receives much attention after the break of “9.11” terrorist attack.

## 2.2. Computer network reliability

Interconnected computers are often referred to as a computer network. The term is often used synonymously with communication system, that is, the hardware and software that permits autonomous computers to exchange information. Referring to transportation network reliability, computer network reliability can also have several categories, with only the difference in explaining their meanings:

### 2.2.1. Computer network connectivity reliability

The first and foremost consideration for a reliability measure for the computer network system is to know a set of minimum components or connections that disrupt the interaction between any pair of components completely. This means motion or information transmission is unlikely to occur to the desired level and the system is not able to perform satisfactorily. Such a consideration at the initial stage of design aims to evaluate the performance and reliability of the system in the event of the failure of a set of its components/connections. A suitable graph invariant which takes this into consideration is connectivity.

Computer network reliability which takes connectivity as its measure specifies that as long as the computer network is connecting, or users of the network can communicate with each other, or there is no failure between nodes, the computer is under normal operation. Three popular measures of network connectivity reliability are the two-terminal, all-terminal and K-terminal connectivity reliability, of which two-terminal is the basis of others. Two-terminal connectivity reliability requires that a distinguished pair of nodes, sources and destination be able to communicate with one another. All-terminal connectivity reliability requires that every node be able to communicate with every other node in the network, it is equivalent to the connectivity problem in the graph theory. K-terminal connectivity reliability requires a specified set of K target nodes be able to communicate with one another, it is the most general and includes the other two problems. K-terminal connectivity reliability reduces to two-terminal connectivity reliability when  $K=2$  and to all-terminal connectivity reliability when  $K=n$ .

### 2.2.2. Computer network time reliability

With the acceleration of life and work speed, more and more people hope they can predict the time a computer need to accomplish a given task to enhance the reliability of accomplishing a task and time certainty. Network providers also try to decrease the punctuation of task time and provide a stable service. These needs promote the study on the computer network time reliability. Analogy to transportation network time reliability, define computer network time reliability as the ability of the network to accomplish a given task or a required service in given time under normal operation. Current users put high requirement on the speed of the computer. If users haven't accomplished their tasks in given time, they will regard the time reliability of the system as low.

### 2.2.3. Computer network capacity reliability

One of the parameters which is a better estimate of reliability of the system is the capacity of the information transmission between a given node pair. As to real computer networks, all of them should reach certain communication business. Although sometimes computer networks are connected, their amount of business can not reach desired requirement, at that time capability reliability should be used to measure it. Referring to transportation network capability reliability, define computer network capability reliability as the probability that computer network can meet the needs of users. In a large complex real transportation network, simply rely on improve roads perhaps can not increase the reliability of the system substantially. New roads and links should be built to increase the capability of the system to improve the efficiency of it. The same can be applied to computer network, simply improve connectivity perhaps can not future increase the reliability and efficiency

of the system. At that time new lines and equipments should be built to increase capability reliability to meet the needs of computer network users.

#### 2.2.4. Computer network behavior reliability

Drawing on transportation network behavior reliability, we define computer network behavior reliability as the probability of successively providing satisfactory network service to users when they want to use computer networks, that is, the availability of satisfactory network service. We can see that network behavior reliability is an ability oriented toward business and network users. It reflects the service ability of the network and is also the hotspot of current research. If failure often occurs and the network often needs repair, then users can not get satisfactory service, thus the behavior reliability of the network is regarded as bad. In fact, many companies are concerned more with the probability of their systems of being available when their customers want to use them (availability) rather than with the length of time the system can operate without failure (related to reliability). As a result, the rate at which a system can be repaired becomes a critical part of the design. The repair rate can dramatically affect the availability of a system.

The availability of  $A(t)$  of a system is defined as the probability that a system will be available to perform its tasks at the instant of time  $t$ . We place the system into operation at time  $t=0$ . At some  $t = t_{current}$ , suppose that the system has operated correctly for a total of  $t_{operation}$  hours and has been in the process of repair or waiting for repair to begin for a total of  $t_{repair}$  hours. Thus  $t_{current} = t_{operation} + t_{repair}$ . The availability can be determined as:

$$A(t_{current}) = \frac{t_{operation}}{t_{operation} + t_{repair}}$$

Where  $A(t_{current})$  is the availability at time  $t_{current}$ .

#### 2.2.5. Computer network potential reliability

Potential reliability considers computer network reliability from the perspective of security and pessimist. With the industrialization of Internet crime, network terrorist has become increasingly rampant. It not only puts threat to important infrastructure, but also does huge damage to the state and society in today's information explosion era. The present situation calls for our attention to the problem of computer network security and potential reliability.

Summarizing the contents discussed above on computer network reliability, it is noted that reliability:

- increases with an increase in connectivity;
- increases with a decrease in time;
- increases with an increase in capacity;
- increases with an improvement in users' behavior;
- increases with an increase in security.

### 3. Several Strategies to Improve Computer Network Reliability

#### 3.1. Improve Nodes and Equipments to Enhance Connectivity Reliability

If network connectivity becomes bad, then no matter what the communication protocol, the routing choice algorithm and the strategy is, network congestion and network delay will be caused and performance indexes

such as throughput will deteriorate, thus reduce the quality of service of the network. The reason for a computer network connectivity to become bad is that the nodes failures and lines failures, but the effects of the nodes failure are greater. Therefore improve nodes and equipment is the most direct and effective way to enhance connectivity reliability.

### *3.2. Use Technology and Equipments Ahead of Its Actual Development Level to Enhance Time Reliability*

Improve reliability in networks need to adopt technology and equipments ahead of its actual development level and comprehensively consider the adoption of new technology. Considering the backbone network technology development and take appropriate advance of technology and equipment, can not only adapt the design of the network to the present and future development tendency, avoid the elimination of them in a short period and endow the system a long life cycle, but also meet the needs of business development to the greatest extent and provide better level of service than others who use ordinary technology and equipment. Reduce users' time for tasks and enhance computer network time reliability.

### *3.3. Construct Proper Network Structure to Enhance Capacity Reliability*

A good computer network needs not only advanced network equipments, but also advanced level and architecture structure. With the rapid development of computer network technology and computer networks throughput, distributed network services and changes switch to the user level, thus forming a new hierarchical model which better gear to the large-scale high-speed Internet. This kind of method is called multi-tiered design of modules. If the network multi-tiered design is modularized, network capacity can increase with the increase of nodes in it, thereby guarantee the capacity reliability of the network. Due to the highly degree of certainty of the multi-tiered network structure, routine maintenance work such as find and exclusion in daily operation and extension process is easy to perform.

### *3.4. Provide User-oriented Service to Enhance Behavior Reliability*

Reduce the users' complain ratio of the whole network. Reduce the failure rate caused by users' operation errors. Reduce the maintenance rate of the network system. Accelerate the maintenance speed of computer network system. Increase users' satisfaction toward the system. The above are what we should do to provide services geared to the computer users, reduce errors caused by improper operation and enhance behavior reliability.

### *3.5. Use Network Protection and Recovery Technology to Enhance Potential Reliability*

Computer network is prone to failure under human and natural factors. Enhance the survival of the network and reduce the effects on line failures on the system is an effective way to enhance potential reliability. The survival mechanism of the network includes two mechanisms: that is, protection mechanism and recovery mechanism. The basic idea of protection mechanism is set aside a part of redundancy capacity for reserve, when there is failure in the transmission line or malfunctioning nodes, switch the main system to the reserve one. The basic idea of recovery mechanism is after the failure of network, dynamically search available resources and adopt the road to the parts around the failures. Select an appropriate way can effectively improve the reliability of the network.

#### **4. Conclusion**

Computer network is a world acknowledged backbone technology, is an infrastructure of modernization, is an important way to realize enterprise informationization. Reliability is a basic requirement for large scale computer network which is an isomer to a large extent. Transportation network reliability gives an enlightenment on constructing a computer network which has high reliability, free the network from disturbance when under operation, overcome the failure of the whole network resulted from line interruption and partial paralyze, and equip with convenient recovery measures and comprehensive monitor and deploy ability. The investigation of computer network reliability will contribute to an improvement of computer network design.

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