Study on load capacity-based cascading failure model in the computer network

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Received 11 July 2014 www.tsi.lv

Abstract

Studies on the cascading failure process and characteristics in the computer network are beneficial to guiding the system construction and improving the performance. Based on the load initialization capacity of the computer system, routing control strategies and node forwarding rate, this paper constructed one cascading failure model considering service performance in the computer network specific to the influence of cascading failures on the service performance of the computer system network. This model considered multiple influence parameters and effectively measured the variable values of influence parameters of cascading failures on the service performance of the computer system network. Through comprehensive analyses, this model can effectively provide practical guiding significance for the prevention and control of cascading failures in the network.

Keywords: load capacity, computer network, service performance, cascading failure

1 Introduction

In recent years, people have become more and more dependent on the computer network technology and its safe reliability has been paid more and more attention to, along with higher security requirements. Though various remedial measures have been taken, they still cannot completely prevent and control the cascading failure in the network [1] and other problems. Cascading failure refers to that some failure nodes or edges due to natural fault or artificial attack cause the redistribution of 'flow' on nodes or edges by the coupling relationship between nodes or edges and further trigger the problems of other nodes or edges. The chain-reaction finally may lead to the collapse of the network. In aspects of cascading failure in the computer network, scholars at home and abroad have carried out various profound studies and at the same time proposed many security models relevant to cascading failure. For the status in quo of real computer network, computer cascading failure model that utilizes relevant characteristics of load capacity can better conform to the demands. Thus, studies in this aspect also are more than other aspects. However, due to the initial load and weight given by the network modes, when the network is not smooth or fails, it will redistribute the load capacity according to the scheduled rules. Therefore, studies on computer cascading failure in this aspect are hotspot. However, there are still many defects of those research studies at home and abroad [1-4]. First, the initial load is preset and presents a monotonously linear relationship. However, the results of computer network data obtained by certain routing control strategies showed that there was no functional relationship between the initial load and load capacity. Second, data packet transmission, forwarding rate of network nodes and routing control strategy may generate various load changes due to cascading failure [2]. Third, current studies on computer network is partial to the network topology while ignores the service performance of the computer in the real network. In the practical situation, users pay more attention to the influences of the service performance of the computer network. Thus, constructing one cascading failure security model in consideration of both service performance of the computer network and load capacity shall provide practical guiding significance for the effective prevention and control of cascading failures.

According to various characteristics of the computer network communication technology, for example, data packet transmission, forwarding rate of network nodes and routing control strategy, this paper constructed one security model of the network data packet transmission [3]. In premise of this, associated with the change factors of load and the non-linear characteristics between the initial load and load capacity, this paper constructed the cascading failure security model in the computer network. Under the condition of guaranteeing the normal computer network topology, this paper designed various parameter factors influencing the network service performance [4] and made a comprehensive analysis and study on the detailed generating process of cascading failures.

2 Cascading failure model in the computer network

The formal description of the definition of the security model is as follows. Simple and undirected graph represents the computer network topology, noted as

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$G(V,E)$; $V=\{v_1,v_2,\ldots,v_n\}$ represents the set of various host servers and network connection devices; and $E=\{e_1,e_2,\ldots,e_j\}$ represents the physical link (with weighted value) set in the computer network connection and host server. According to the above formal description and in premise of data packet transmission mechanism in the network, one new computer network transmission model is established, DTS model for short.

2.1 CONSTRUCTION OF DTS MODEL

The construction of the security model of data packet transmission in the computer network needs the following assumptions as theoretical foundation, mainly including,

1) the general computer network routing selects OSPF computer network protocol;

2) most computer networks adopt fiber optic connection, so the physical influence of transmission lines on stream data transmission is not taken into consideration;

3) in case of the data packet dropout of the target network node, non-retransmission mechanism is adopted to maintain the unipolarity;

4) except the possibility that the computer network interchanger connects with the external interchanger LAN (local area network), only LAN of local interchanger, router or terminal node of each network is used to connect relevant network data information.

On the basis of the above assumption, DTS model is constructed as below. At time point t and data packets occurs at network node v_i and each will randomly select target network node v_j; and the data packet transmitted between two network modes is noted as U_{ij}. Through the OSPF protocol, the shortest path $P_{ij}(t)$ can be obtained and then forwarded and after it passes the target network node, it will be removed; as is said in the assumptions, if data packet loses in the forwarding process, it fails and cannot reach the target network node. The forwarding capacity is noted as F. F values of different network nodes differ from each other. If the same network node has non-transmitted data packets, these data packets will be left at the end of buffer queue of the network node. Based on the subject theory of information science and under the condition of data packet transmission rules of network nodes, DTS model is defined as below:

$$L_i(t)=\begin{cases}0, & Q_i(t)\le F_i\\ Q_i(t)-F_i, & F_i<Q_i(t)<C_i\\ Q_i(t), & Q_i(t)>C_i\end{cases}, \tag{1}$$

$$Q_i(t)=L_i(t-1)+S_i(t)+R_i(t), \tag{2}$$

$$F_i=\eta\times d_i,\eta\ge 1, \tag{3}$$

where the above formal description of definitions, the expressive connotation of each symbol is as follows, $L_i(t)$ represents the network load capacity of v_i at t; $Q_i(t)$ represents the to-be-transmitted data packets of v_i at t; $L_i(t-1)$ represents the network load capacity of v_i at $t-1$; $S_i(t)$ represents the data packet forwarding rate of v_i at t; $R_i(t)$ represents the transmitted data packets of v_i received from the neighbouring network nodes at t; d_i represents the network node degree; η represents F_i coefficient (the coefficient of forwarding capacity) and in a network system of single autonomous area, there is a linear relationship between F_i and d_i; and C_i represents the maximum forwarding load by network node v_i.

2.2 LOAD CAPACITY-BASED CASCADING FAILURE MODEL IN THE COMPUTER NETWORK

In this model, there are three influence factors of the load changes of network nodes and they may result in abnormality or failure of the computer network, which further may create conditions for cascading failures. These three factors are as follows, first, the changes of the control modes of network routes, which can influence the number of received data packets; second, the forwarding rate of data packet; third, the forwarding capacity of data packets, F. Figure 1 shows the changes of the relationship between the load of the network node and network throughput. When the network node load is small, its forwarding capacity F is enough, the network data packet R is not large, and there is no redundant data packet information in the queue. While when the network node load is large and the forwarding capacity F reaches the maximum, it is easy to generate the phenomenon of saturation and there is much redundant data packet information in the queue. The larger R is, the more prominent the redundancy and congestion of network nodes is. When the network load increases again and exceeds certain index line C, its network throughput will suddenly decrease to void value. At this time, the cascading failure occurs at this network node. The saved capacity of each network node can be described as below:

$$C_i=\alpha\times BC_i,\alpha\ge 1, \tag{4}$$

C_i represents the maximum forwardable load of network node v_i and BC_i represents the mediation number of the shortest path of the network node; represents the coefficient parameter value of C_i, indicating the size of the network node capacity. It can be known from the definition that there is a linear relationship between BC_i and C_i and the coefficient parameter value is taken as the change index. The larger BC_i is, the stronger the forwarding capacity of data packets of network nodes is. To ensure the normal operation of the computer network, C_i also needs synchronous update.

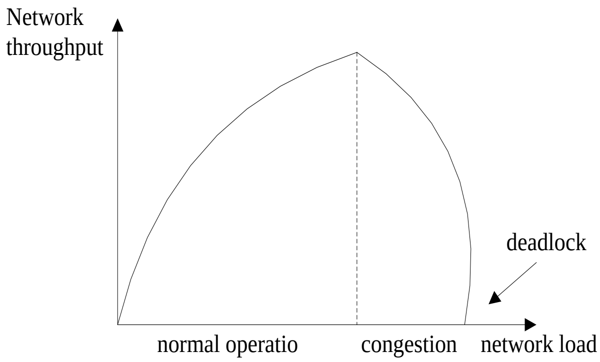

FIGURE 1 Changes of the relationship between the load of network nodes and network throughput

The above mentioned network initial load is based on the previously constructed DTS model, which is different from the traditional network initial load. For the latter, network topology model with uniqueness is the major factor while the decisive factors of the former are various, including network topology, network node load capacity and so on and it has a linear relationship with the load capacity of network nodes. It mainly is used in complex and difficult-to-be-repeatedly-constructed computer network structure model, reaching the two-layer effect results of network topology and data packet forwarding. However, under the condition that the network initial load is irrelevant to *C*, the actual phenomenon of computer network is more prominent and real [5].

The above DTS model adopts the shortest path control mode to simulate the OSPF network protocol of the computer network [6]. Among them, time interval is an important measure index and the time interval of each network node has a close relationship with the network node load, which can be expressed as below:

$$D_i(t)=\begin{cases}1, & L_i(t)\le F_i\\ 1+\dfrac{L_i(t-1)}{F_i}, & F_i\le L_i(t)\le C_i\\ \infty, & L_i(t)>C_i\end{cases}. \quad (5)$$

Equation (5) mainly describes three different conditions of network nodes, including normal operation, network congestion and cascading failure. $D_i(t)$ represents the time interval of network nodes at one moment. It can be known from each definition that the shortest path $P_{ij}(t)=\{v_i,\ldots,v_k,\ldots,v_j\}$ represents the calculation mode of the shortest path in the OSPF network protocol; U_{ij} forwards network nodes according to this mode and when cascading failure occurs, evade the occurrence network node and adjust $D_i(t)$ to the maximum so as to guarantee the normal operation of other network nodes, reaching the invariability of the structure of the whole computer network. Therefore, when cascading failure occurs, the whole network performance changes dynamically to reach the most effective condition.

It can be known from the above definitions that the whole detailed process of cascading failures can be illustrated in the following three aspects:

1) In the initial stage, no flow is transmitted and the load of each computer network is 0; from *t*=1, the network flow gradually increases and each network node starts to have data packet transmitted and the load of network nodes increases simultaneously. Until the preset time, the network is in normal operation stage.
2) If the computer network operates abnormally at *t*=*x*, the network transmission route will change and at this time the route control strategy will adjust the transmission route for redistribution and adjustment.
3) When the network routing control strategy changes, the load of network nodes fluctuates at the same time until it exceeds the preset network lad capacity. At this time, the network node is in cascading failure and the routing control strategy will again adjust the transmission route for redistribution and adjustment. At this time, the cascading failure int the computer network generates.

3 Application analysis of cascading failure model

3.1 EVALUATION COEFFICIENTS OF THE PERFOERMANCE

The evaluation coefficients of cascading failure performance in the computer network play a key role in DTS model and load capacity-based cascading failure model in the computer network [7]. The evaluation coefficients of the performance adopted by current studies mostly are designed and analyzed in aspects of network topology. However, they fail to effectively and comprehensively reflect the cascading failure in the computer network and the changes and relationship of its network service performance [8-10]. In this case, in premise of its service performance, various evaluation coefficients of cascading failure performance are proposed, including service delay time interval, load change rate and network throughput. Below is the detailed analysis of them.

Service delay time interval:

$$DA(t)=\frac{2}{N'(t)\left(N'(t)-1\right)}\times\sum_{i\ne j=1}^{N'}\Phi_{ij}(t), \qquad \Phi_{ij}(t)=\sum_{V_k\in P_{ij}(t)}D_k(t). \quad (6)$$

where, *DA(t)* represents the service delay time interval; *N'(t)* represents the number of network nodes in the computer network free from cascading failure at *t*; and $\Phi_{ij}(t)$ represents the sum of time interval changes of each network node in $P_{ij}(t)$. *DA(t)* can express the time interval size of the forwarded data packet between each network node and it shows a proportionally change relationship.

Load change rate:

$$LA(t) = \frac{\sum_{i=1}^{N} L_i(t)}{N}, \quad (7)$$

where *LA(t)* represents the load change rate of the computer network and it indicates the number of non-transmitted data packets in network nodes. Usually the data level is at millions. Moreover, *N* represents the number of network nodes and $L_i(t)$ represents the load of network nodes at time interval *t*. The change of its *LA* can demonstrate the relationship of buffer queue change in the computer network and it also presents a proportionally change relationship. At the same time, it influences the network service performance.

Network throughput:

$$TS(t) = \sum_{i=1}^{N} FR_i(t),$$
$$FR_i(t) = \begin{cases} Q_i(t), & Q_i(t) \le F_i \\ F_i, & F_i < Q_i(t) \le C_i \\ 0, & Q_i(t) > C_i \end{cases}. \quad (8)$$

where, *TS(t)* represents the computer network throughput (at time interval *t*), with unit of Mpps. Under the real condition, the computer network throughput represents the number of the treated and controlled data packets of each network node or port in unit time; N represents the number of computer network nodes; $FR_i(t)$ represents the data packet transmission rate of network nodes at time interval *t*. It can be known from the description that TS is one key factor and it can comprehensively highlight the change curve of the relationship between network throughput and time *t* and at the same time it also states the change relationship of network service performance between the cascading failure-free interval and the cascading failure interval, which also presents a proportionally change relationship.

3.2 SIMULATION EXPERIMENT

The theoretical experiment of load capacity-based cascading failure model in the computer network adopts BA scale-free computer network with 100 network nodes. Under this condition, the application analysis of the model is made. The simulation coefficients are as follows, packet sending rate *S*=1 Mpps, simulation time *T*=1000s, the parameter of the network load capacity $\alpha = 2$ and the parameter of the data packet forwarding capacity η =1. The simulation values adopt the average.

Under the normal operation condition, the network load of the computer network starts from the initial value and then distributes and adjusts. If the network operates normally, each performance coefficient maintains a relatively stable operation state in one time interval.

The cascading failure in the computer network refers to the abnormality of network nodes under the normal network condition, including external attack, artificial faulty operation and others, which may trigger the occurrence of this case. Usually, the computer network maintains stability in the middle time (*t*=50s). When *t*=100s, part of network nodes in reality will be gradually attacked and further result in the computer network cascading failure and influence the network service performance. Figures 2-4 respectively show the changes of three performance evaluation coefficients with time.

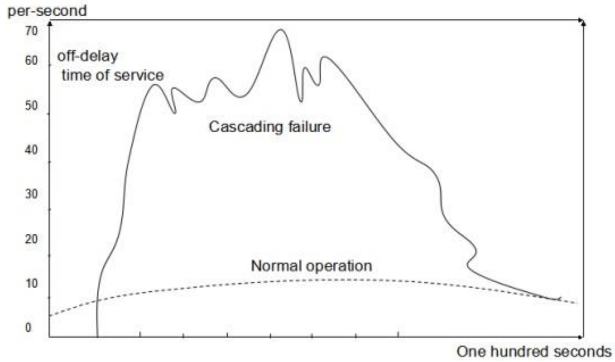

FIGURE 2 Relationship between service delay time interval and *t*

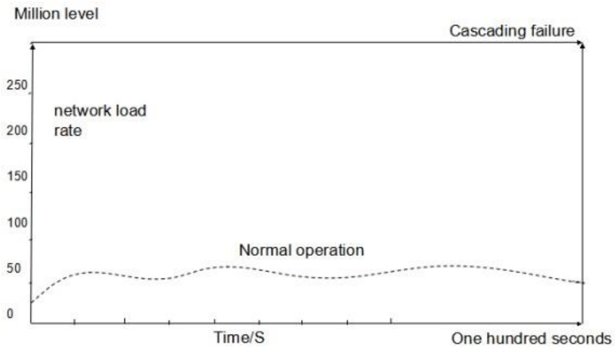

FIGURE 3 Relationship between load change rate and *t*

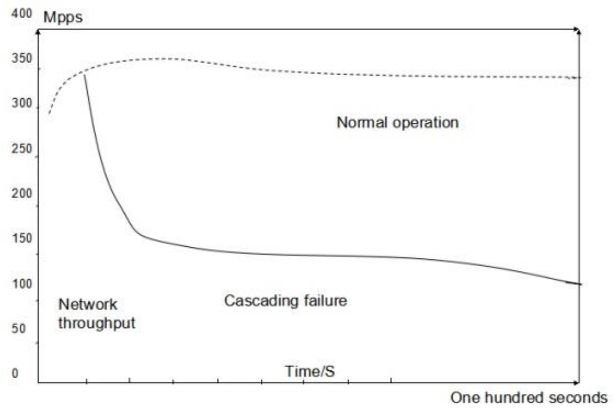

FIGURE 4 Relationship between network throughput and *t*

From the analysis of the simulation experiment, it can be known that, first, the cascading failure of the computer network makes the service delay time interval gradually reduce after the change; second, the packet loss strategy of network nodes can effectively decrease the network load pressure and effectively reduce its influence on the network service performance; third, the computer network cascading failure decreases the network throughput and increase the network load pressure, which greatly influence the network service performance.

4 Conclusion

This paper constructed DTS model. In the theoretical premise of its data packet transmission, this paper designed one new cascading failure model considering multiple factors in the computer network and made a series of application analyses on the model. Through the analysis of the simulation experiment, it is found that the change relationship between the proposed evaluation coefficients of cascading failure performance and time can effectively reflect the influence on the network service performance, which proved the feasibility of the model. In the future, further study and analysis will focus on how to effectively prevent and control the cascading failure on this model.

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