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REGULAR PAPER

Two rapid test methods for assessing transmission time reliability of a multiple-channel network with Poisson arrival and service rates

Ruiying Li [a,b,*], Meinan Li [a,c]

[a] School of Reliability and Systems Engineering, Beihang University, Beijing 100191, PR China
[b] Science and Technology on Reliability and Environmental Engineering Laboratory, Beijing 100191, PR China
[c] China Academy of Aerospace Standardization and Product Assurance, Beijing 100071, PR China

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ABSTRACT

To shorten the duration of the network transmission time reliability test, two rapid methods are proposed for a multiple-channel network with Poisson arrival and service rates. For a network whose service rate is given and can be increased in practice, a rapid test can be conducted on a similar network with higher arrival and service rates. The test conditions are derived using the similarity theory, and the data collected in the test can be used to estimate the reliability of the original network. For a network whose service rate is unknown, a rapid test analogous to accelerated test can be applied, which only increases the arrival rate. The analytical expression of transmission time reliability is used to derive the accelerated model, and the data collected in the test can be used to extrapolate the network reliability under normal arrival rate. Our numerical study shows that the two proposed methods are efficient and the reliability estimates are quite accurate compared to the empirical estimate obtained from verification tests. In the rapid tests, the data collected in a given period of time increases along with the arrival rate, and the test duration can be shortened without affecting the sample size of packets.

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1. Introduction

With the rapid growth of network usage and the heavy load of its traffic, the end-to-end delay caused by network congestion has become one of the core issues of network performance, namely transmission time reliability [1,2]. Network transmission time reliability can be defined as the probability that the network end-to-end delay does not exceed the allowable range determined by the customer. Nowadays, the real-time network transmission is widely applied in our daily life for various purposes (e.g., the airborne network, the healthcare monitoring network system, the financial and banking network system). Such network system is sensitive to network delay, so the reliability test is usually conducted to assess the network transmission time reliability before a new network is built or a new service is developed.

Networks require high reliability. In order to assess the transmission time reliability effectively, we need a large number of packet samples. For example, according to the binomial test design [3], if we want to demonstrate whether the network satisfies a reliability requirement of 0.99999 with 95% confidence level, at least 299, 571 samples are needed if no failures are expected to occur in the test, and at least 474, 385, 629, 578 and 775, 364 samples are needed if the allowed numbers of failures are 1, 2, and 3, respectively. It is a new challenge for the network reliability test technology. How to conduct the network reliability test efficiently without reducing the sample size of packets is a practical problem.

To design a rapid test method for network reliability, the failure mechanism of the end-to-end delay must be fully understood. In practice, an end-to-end delay failure occurs when the delay exceeds the maximum delay threshold determined by the customer. Among the four components of the end-to-end delay (i.e., processing delay, transmission delay, propagation delay and queueing delay), the queueing delay is the main contributor to it. The remaining three components which depend on the node processing speed and propagation velocity of channels are much smaller than the queueing one and can be ignored [4]. The basic queue, the single channel queue with Poisson arrival and service rates (i.e., M/M/1 queue), was analyzed in [5], and a rapid test method was proposed based on the similarity theory [1]. The numerical study verified that the test duration could be shortened under acceptable accuracy by

* Corresponding author at: School of Reliability and Systems Engineering, Beihang University, Beijing 100191, PR China. Tel.: +86 10 82338651.
E-mail address: liruiying@buaa.edu.cn (R. Li).

[1] Similarity and similitude are interchangeable in our paper.

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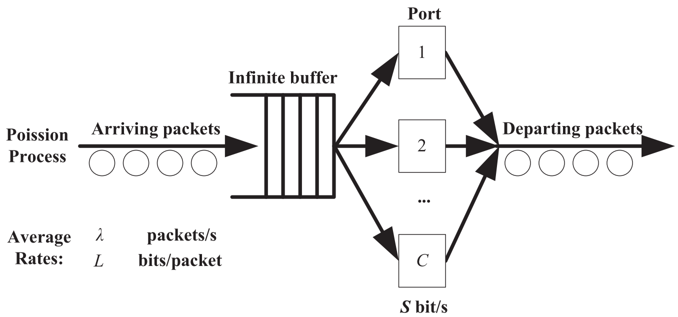

Fig. 1. M/M/C queueing process.

conducting the test on a similar network with higher arrival and service rates. However, M/M/1 is the simplest queue, which is not so commonly used in communication networks, as the multi-channel data exchange technology is already widely applied in communication networks. Moreover, in some situations, the service rate of the network is unknown or cannot be changed due to technical reasons, and this type of rapid test method cannot be used.

In this paper, two rapid test methods are proposed for the network transmission time reliability of a multiple-channel queue with Poisson arrival and service rates (i.e., M/M/C queue). The M/M/C queue is widely used in communication networks, such as ad hoc networks [6], air defense communication systems [7,8]. The first rapid test method is proposed based on the similarity theory, and both arrival and service rates need to be increased in the test. The second rapid test method is proposed based on the accelerated lifetime testing method, and we only need to increase the packet arrival rate in the test. The remainder of the paper is organized as follows. The basic concepts of the M/M/C queue and the network transmission time reliability are presented in Section 2. Section 3 proposes the two rapid test methods under two different situations. Section 4 presents numerical verification results. Finally, concluding remarks are provided in Section 5.

2. Basic concepts

2.1. M/M/C queue

In the M/M/C queue of networks, packet arrivals occur at rate λ according to a Poisson process, packet lengths have an exponential distribution with mean L, service rate is constant S, C ports serve from the front of the queue, and the buffer is of infinite size. The queueing process of M/M/C is shown in Fig. 1. If there are less than C packets in the queueing system, some of the ports will be idle. If the number of the packets exceeds C, the packets will queue in the buffer. Only if the traffic intensity $\rho = \frac{\lambda L}{CS} < 1$, the queueing system can achieve a statistical equilibrium. Otherwise, the queue will continue to grow as time goes on, and the network queueing delay will get longer and longer.

2.2. Network transmission time reliability

As mentioned earlier, queueing delay is the major contributor of the end-to-end delay, and it mainly depends on arrival rate λ, packet length L, service rate S and the number of ports C. According to its definition in Section 1, the network transmission time reliability can be expressed as

$$R(\lambda, L, S, C) = Pr(D(\lambda, L, S, C) \le D_{\max}) = \int_0^{D_{\max}} f_{D(\lambda,L,S,C)}(t)dt, \quad (1)$$

where D is the queueing delay, and $D_{\max}$ is the maximum allowable delay.

After conducting a reliability test under a specific setting of [λ, L, S, C], the empirical estimate of the network transmission time reliability can be calculated by

$$\hat{R}(\lambda, L, S, C) = \frac{N_n}{N_t}, \quad (2)$$

where N_t is the total number of packets transmitted, and N_n is the number of packets whose delay does not exceed $D_{\max}$.

For M/M/C queues, the distribution function of network transmission time reliability is the probability that packet sojourn time (i.e., the sum of both waiting time and service time in the queueing theory) in system is not larger than $D_{\max}$. Let $\mu = \frac{S}{L}$ and $\rho = \frac{\lambda}{C\mu}$, p_0 and p_c, the probabilities that no packet and C packets sojourn in the network are denoted as

$$p_0 = \left[\sum_{n=0}^{C-1} \frac{(C\rho)^n}{n!} + \frac{(C\rho)^C}{C!\,(1-\rho)}\right]^{-1} \quad (3)$$

and

$$p_c = \frac{(C\rho)^C}{C!} p_0, \quad (4)$$

respectively. When $\rho < 1$, the distribution function of the sojourn time can be expressed as

$$R(\lambda, L, S, C) = Pr(D(\lambda, L, S, C) \le D_{\max})$$
$$= \begin{cases} 1 - \left(1 + \dfrac{p_c \mu D_{\max}}{1-\rho}\right) e^{-\mu D_{\max}}, & \left(\rho = 1 - \dfrac{1}{C}\right), \\ 1 - (1+G)\, e^{-\mu D_{\max}} + G e^{-C\mu(1-\rho)D_{\max}}, & \left(\rho \ne 1 - \dfrac{1}{C}\right), \end{cases} \quad (5)$$

where $G = p_c/(C-1-C\rho)(1-\rho)$. The detailed derivation process and application can be seen in [9,10].

By combining Eqs. (3)–(5), the distribution function of network transmission time reliability can be written as

$$R(\lambda, L, S, C) = Pr(D(\lambda, L, S, C) \le D_{\max})$$
$$= \begin{cases} 1 - \left(1 + \dfrac{SD_{\max}}{L} A\right) e^{-\frac{SD_{\max}}{L}}, & \left(\rho = 1 - \dfrac{1}{C}\right), \\ 1 - (1+B) e^{-\frac{SD_{\max}}{L}} + B e^{-\left(\frac{1}{\rho} - 1\right)\lambda D_{\max}}, & \left(\rho \ne 1 - \dfrac{1}{C}\right), \end{cases} \quad (6)$$

where $A = \dfrac{C(C-1)^C}{C!\left[\sum_{n=0}^{C-1} \frac{(C-1)^n}{n!} + \frac{C(C-1)^C}{C!}\right]}$ and

$B = \dfrac{(C\rho)^C}{C!(C-1-C\rho)\left[(1-\rho)\sum_{n=0}^{C-1} \frac{(C\rho)^n}{n!} + \frac{(C\rho)^C}{C!}\right]}$.

3. Two rapid test methods

3.1. Scenario 1: S is given and can be increased

The similarity theory [11–13] is about the science of the conditions under which physical phenomena are similar. In engineering, a model that has similarity with the real application is usually used to study complex dynamics problems, which allows testing of a design prior to building. If the governing equation can be built based on the physical laws, we can assign scale constants to each physical quantity in the equation and obtain the governing equation of the scaling phenomena. By comparing the scale model and application, the scaling laws which dictate model testing conditions can

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