



## Practical Approaches for Estimating End-To-End Delay in Multi-Hop Networks

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**Abstract:** In this work, we present a practical approach which analyses and estimates end-to-end delay networks. The proposed practical results of the end-to-end delay distribution are validated through simulation( C program). Communication reliability is one of the most important concerns and fundamental issues in network systems, such as in cyber systems, where network components are interconnected with each other. In such systems, a single connection failure, or communication delay could lead to causes sudden great damage. So, there is an urgent demand on efficient methodologies to model and analyze the delay distribution of messages or signals, especially when networks becomes more complex and more heterogeneous. In this paper we can model and analyze the reliability of communication in large-scale compositional networked systems. Several network structures (e.g. serial, parallel and circular) are defined as building blocks to model a wide variety of connections in networked systems. The advantages of the proposed practical framework over the traditional approaches include the capability to capture higher order moments of system to analyze the reliability of complex systems.

**Keywords :** Network Structure, Delay

### I. Introduction

A networked system can be modeled as a graph with a set of nodes and links which is shown in the figure 1 below.

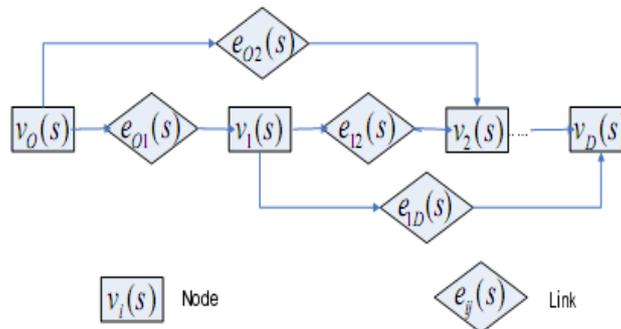


Figure. 1. An example networked system

$V = \{v_i(s)\}$  represents a reliability function of a node (or component or device), and  $E = \{e_{ij}(s)\}$  denotes a reliability function of a link. Figure 1 shows an example networked system, where rectangular and rhombic blocks represent states of vertices and links respectively. To study the communication reliability, we accumulate the delay on links, and assume that  $v_i(s)=1$  on nodes for the convenience to present our idea[1].

Most networked systems are composed of direct connection, serial, k-parallel, circular structures [2]. Hence, we can use these structures for the analysis, and then generalize the analytical framework for end-to-end delay modeling and reliability analysis in general networked systems.

### II. Related Work

Direct connection: The below figure shows the direct connection between two nodes, the end- to-end delay is the sum of delays on individual components or links from  $v_1$  to  $v_2$ .

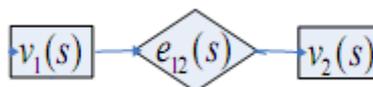


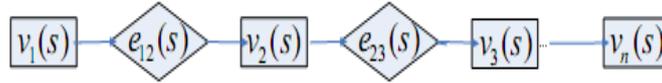
Figure 2. Direct connection

So the direct connection between two nodes is defined as

$$DC = \sum_{i=0}^n \sum_{j=0}^n p_{ij} e_{ij}(s) \dots \dots \dots (1)$$

**Serial Structure:**

In the serial structure shown in Figure 3, each device takes data from one direction and moves to other. The end-to-end delay is the sum of all delays on individual components or links from  $v_1$  to  $v_n$ . In end-to-end delay distribution of such a structure can be estimated as the convolution of delays on individual blocks, i.e.,  $v_1 * e_{12} * v_2 * e_{23} * \dots * v_n$ . Here, we accumulate the delays on links, and assume that  $v_i(s)=1$  on nodes.



**Figure 3.** Serial Structure

Let us consider a serial structure under node failure . All nodes are completely functional. However, nodes are vulnerable to failure for variety of reasons. So new decision fusion algorithms for serial network topology which are more robust to node failure than the conventional algorithms is proposed. [3].

Let us assume that there are 2 routers and a switch Router 2 has an availability of 99.97 percent, Router 1 has an availability of 99.98 percent, and the switch has an availability of 99.99 percent. shows the computation of the availability between Segment A and the server.

$$e_{1n}(s) = \prod e_{ij}(s) = e_{12}(s) \cdot e_{23}(s) \dots \dots e_{(n-1)n}(s) \dots \dots \dots 2$$

$$serial\ Availability = \prod_{i=1}^n availability_{(i)}$$

- Router 1 = 0.9997
- Router 2 = 0.9998
- Switch = 0.9999

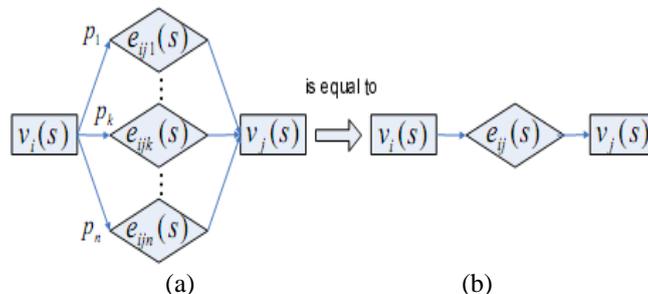
Let us consider data from Node A to B

$$= 0.9997 * 0.9998 * 0.9999$$

$$= 0.9994$$

**k-parallel Structure:**

In the parallel structure shown in Figure 4(a), several alternative paths exist from a source to a destination. A path  $e_{ijk}$  from  $v_i$  to  $v_j$  is selected with a certain probability  $p_k$ . Without loss of generality, we assume  $p_1 + p_2 + \dots + p_n = 1$  under the trustable routing agent. Suppose that the delay distribution of an individual link is  $e_{ijk}(s), k = 1, 2, \dots, n$  and they are independent of each other. We can describe the end-to-end delay distribution of the parallel structure  $e_{ij}(s)$  in Figure 4(b) as follows:



**Figure 4.** k-parallel Structure.

$$e_{ij}(s) = \sum_{k=1}^n p_k \cdot e_{ijk}(s) = p_1 \cdot e_{ij1}(s) + p_2 \cdot e_{ij2}(s) + \dots + p_n \cdot e_{ijn}(s) \dots \dots 3$$

Let us eliminate single points of failure. We know that eliminating all single points of failure is a financially expensive proposition. Notice the serial nodes between Routers 1 and 2, and also notice that the switches at either end are single points of failure. For simplicity, assume that all four routers are the same and have availability equal to 99.9 percent. As we assume the serial availability of a single path (Routers 1 and 2) is 99.8 percent. Running 99.8 percent in this topology through the parallel equation results in 99.9996 percent, which is an excellent result.

$$Availability(router\ 1\ \&\ 2) = 0.999 * 0.99$$

$$= 0.998$$

**Circular Structure**

The circular structure shown in Figure 4(a) contains two nodes  $v_i(s)$  and  $v_j(s)$ , and two links  $e_{ij}(s)$  and  $e_{ji}(s)$ , where  $e_{ji}(s)$  is a self-circular or a feedback loop. To get the closed form of end-to-end delay probability density function of circular structure represented by  $e_{ij}^*(s)$  in Figure 4(c), we use the block shown in Figure 4(b) to approximate the circular

structure. For an infinite n, Figure 4(a) and Figure 4(b) are equivalent. Note that we can use the circular structure to model packet loss and retransmission behavior.

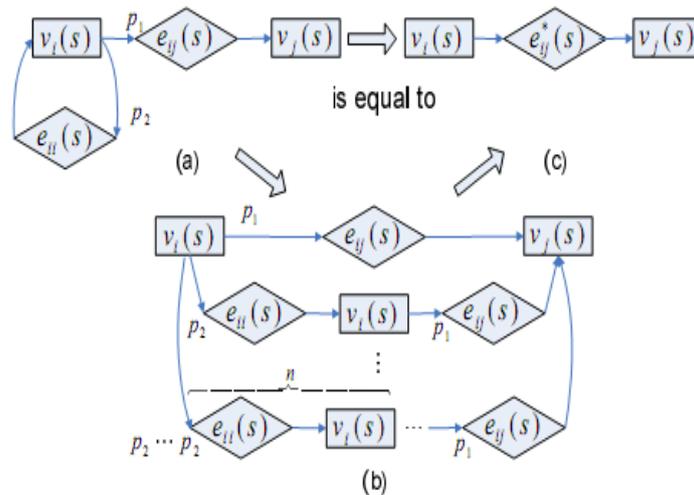


Figure 5: Circular Structure.

$$e_{ij}^*(s) = p_1 \cdot e_{ij}(s) + p_2 \cdot e_{ii}(s) \cdot p_1 \cdot e_{ij}(s) + [p_2 \cdot e_{ii}(s)]^2 \cdot p_1 \cdot e_{ij}(s) + \dots$$

$$= p_1 \cdot e_{ij}(s) \cdot [1 + \sum_{n=1}^{\infty} (p_2 \cdot e_{ii}(s))^n]$$

Based on power series  $1 + x + x^2 + \dots = (1 - x)^{-1}$  we have

$$e_{ij}^*(s) = \frac{p_1 \cdot e_{ij}(s)}{1 - p_2 \cdot e_{ii}(s)}$$

### III. Experimental Results

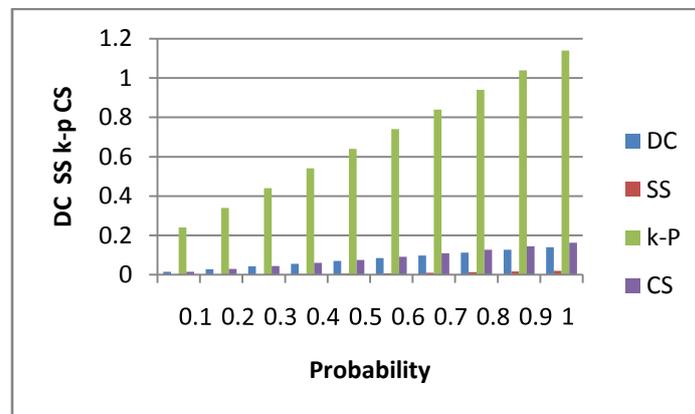


Figure 5: As probability increases structure efficiency increases.

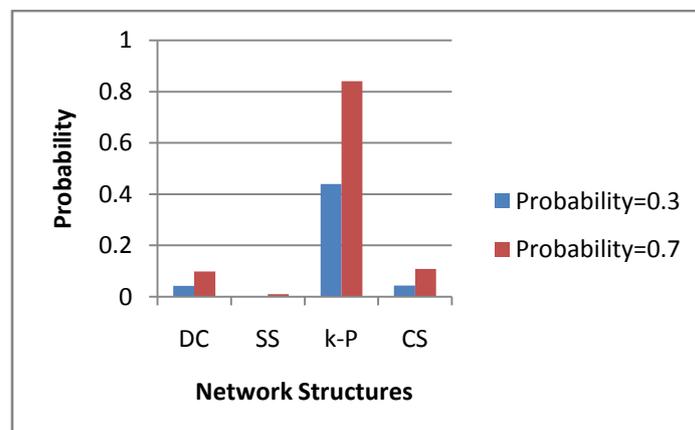


Figure 6: Comparison between 2 probability values.

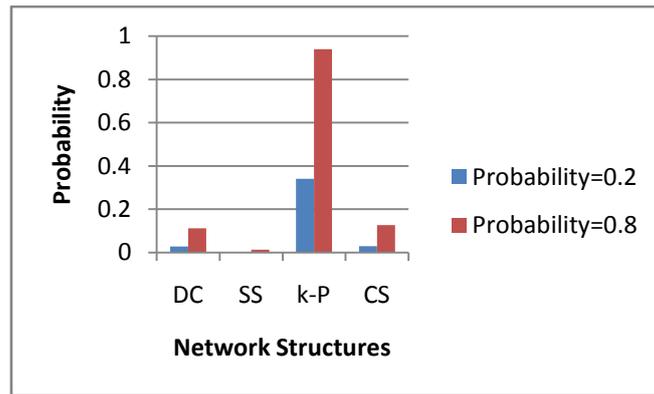


Figure 7: Comparison between 2 probability values.

#### IV. Conclusion

In this paper, we propose a practical framework to model and analyze the communication delay in networked compositional systems. The contribution of this paper includes the following aspects like serial, parallel, and circular networked structures, so that the reliability analysis can easily generated to model wide variety of networks. We can also apply the proposed structure to conduct sensitivity analysis to determine the bottleneck links in a network, and evaluate performance of different communication protocols.

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