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Routing scheme of a multi-state computer network employing a retransmission mechanism within a time threshold

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ABSTRACT

Because of packet unreliability, retransmission mechanisms are typically used to ensure data transmission at the sink without incurring data loss. Many application protocols have been developed on the basis of retransmission mechanisms. The multipath transmission control protocol guarantees quality of service (QoS) and reduces data transmission time in modern computer networks. A computer network that employs a retransmission mechanism can be called a multi-state computer network with a retransmission mechanism (MSCNR), because communication lines used by such a network can experience different states such as failure, partial failure, and maintenance. This study firstly evaluates the network reliability of a MSCNR for transmitting data d successfully through multiple minimal paths (MPs) within a time threshold T. An algorithm is proposed for generating all lower boundary vectors (LBVs) that can satisfy a time threshold. Then, the network reliability is computed in terms of all LBVs for (d, T) using the recursive sum of disjoint products algorithm. Furthermore, a routing scheme with spare MPs is adopted to reinforce the system reliability (referred to as the spare reliability). The spare reliability can also be easily computed by the proposed procedure.

1. Introduction

Computer networks support information and communication, which are two of the most important strategic issues crucial to the success of an enterprise. A computer network is a telecommunications network that allows computers to exchange data. Its structure includes a group of computer systems and other computing hardware devices that are linked together through communication lines. Each branch in a computer network denotes a communication line and each vertex denotes a transmission station. In fact, a communication line is combined with several physical lines, such as twisted pair, coaxial, and fiber cables. A physical line can experience failure, partial failure, or maintenance, which results in varying capacities of the communication lines. Hence, a computer network can be considered to be multi-state [14–19,23,28,29].

In modern enterprises, the stability of computer networks plays a major role in data transmission and influences the quality of service (QoS) of the entire business. However, packet unreliability is an important factor in ensuring a high QoS. Data is transferred in the form of packets, and packet unreliability is the number of erroneous packets over the number of transmitted packets during a studied time interval. In order to ensure data transmission at the sink without incurring data loss in a computer network, data retransmission mechanisms are employed by computer network protocols. A

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retransmission mechanism involves retransmission of packets that have been either damaged or lost, by automatic repeat requests. Major errors are corrected via requests for retransmission and erroneous packets can be recovered by the data retransmission mechanism to ensure that all data arrived at the sink without errors [26]. Many application protocols have been developed on the basis of a retransmission mechanism, e.g., transmission control protocol (TCP) [12,22,30]. The TCP restricts data transmission through only a single path, and hence some researchers have been investigating new protocols that allow data transmission through k ($k > 1$) minimal paths (MPs). For convenience, we n k-MP to denote k MPs. The multipath transmission control protocol (MPTCP) is an emerging protocol that allows TCP to transmit and retransmit data across k-MP simultaneously [9,10,25]. In January 2013, the Internet Engineering Task Force (IETF) finalized the MPTCP specifications and published the MPTCP standard in RFC 6824 [10]. This new networking protocol can reduce data transmission time by transmitting data through multiple MPs. Apple iOS7 was the first commercial operating system to support this networking standard. It is believed that an increasing number of operating systems will support MPTCP to ensure data integrity and reduce data transmission time.

Although data retransmission ensures data integrity, it results in higher data transmission time and degrades network performance. Data transmission time is another key parameter for measuring network performance. The lower the data transmission time, the more real-time is information exchange. A version of the shortest path problem, the quickest path problem, to calculate data transmission time was studied by Chen and Chin [8]. This problem finds the quickest path with minimum transmission time to transmit a specific amount of data through a computer network. In this problem, each branch has two attributes: capacity and lead time [3–8,13,16–18,20,21,23], where the former is the maximum bandwidth of the branch, and the latter is the required time period to transmit a data unit through the branch. In addition to the constrained quickest path problem [3,4,7,8], other quickest path problems including the all-pairs quickest path problem [13] and the first k quickest path problem [5,6] are discussed.

In this paper, a multi-state computer network with a retransmission mechanism (MSCNR) is studied. Each branch in an MSCNR is specified by three parameters: lead time, packet unreliability, and capacity. Many researchers have evaluated network reliability of multi-state flow networks, which is defined as the probability of successful transmission of data from the source vertex to sink vertex through the computer network under certain constraints such as transmission time [16–18], cost [19,28], vertex failures [16] and accuracy rate [16,17]. Lin and Pan [18] proposed an algorithm to assess network reliability through one specific MP under time threshold. However, the advantage of MPTCP is that can recover error data through data retransmission and reduce transmission time by sending data through k-MP. No studies have been carried out that consider both criteria together for evaluating network reliability such that the demand of a sink can be satisfied a time threshold through k-MP in an MSCNR. Hence, this paper firstly evaluates the network reliability of such networks. An algorithm is proposed to generate data quantities due to data retransmission, and to find all lower boundary vectors (LBVs) that form the minimal capacity vectors that can satisfy the demand at the sink vertex through k-MP. Thus, network reliability can be obtained by applying the recursive sum of disjoint products (RSDP) method [31] on these LBVs. For enhancing network reliability, a routing scheme is predetermined by the network administrator to indicate the major and spare k-MPs. When the major k-MP fails, the spare k-MP would be responsible for transmission. The network reliability with routing scheme is named spare reliability and can be computed easily by applying the proposed solution procedure.

The remainder of this paper is organized as follows. In Section 2, the network model considering retransmission mechanism and k-MP is formulated. In Section 3, an algorithm to generate all minimal capacity vectors that fulfill a time threshold and a network reliability evaluation method are proposed. The routing scheme and spare reliability are discussed in Section 4. An illustrative example and an application of the proposed LBV algorithm to the GÉANT network are demonstrated in Sections 5 and 6, respectively. Numerical experiments for the CPU time to show the efficiency of the proposed algorithm are performed in Section 7. Finally, conclusions and discussions are summarized in Section 8.

2. MSCNR model

Let the network $G \equiv (V, B, L, U, M)$ be a MSCNR with a source vertex and a sink vertex. The detailed notations are introduced as follows:

V: the set of vertices,
$B = \{b_i | 1 \le i \le n\}$: b_i is the ith branch,
$L = (l_1, l_2, \ldots, l_n)$: l_i is the lead time of b_i,
$U = (u_1, u_2, \ldots, u_n)$: u_i is the packet unreliability of b_i,
$M = (M_1, M_2, \ldots, M_n)$: M_i is the maximal capacity of b_i.

The capacity is defined as the maximal number of data sent through the medium (a branch or an MP) per unit of time. Further, G is assumed to satisfy the following assumptions:

1. The capacity of each branch is multi-state with a probability distribution observed from historical statistics.
2. The capacities of each branch are statistically independent.
3. All data are transmitted through k-MP simultaneously.
4. Data retransmission mechanism can be operated infinitely until all correct data arrives the sink.