Applied Mathematical Modelling 38 (2014) 263–277

Contents lists available at SciVerse ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Optimal double-resource assignment for the robust design problem in multistate computer networks

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ARTICLE INFO

Article history:
Received 22 August 2012
Received in revised form 28 April 2013
Accepted 24 June 2013
Available online 4 July 2013

Keywords:
Multistate computer network
Double-resource assignment
Robustness
Critical analysis
Structural analysis
Network reliability

ABSTRACT

This paper proposes a novel approach to get the exact optimal double-resource assignment for the robust design problem in multistate computer networks. A multistate computer network consists of links and vertices where both kinds of resources may have several states due to failure, partial failure or maintenance. Therefore, each link (vertex) in the network should be assigned sufficient capacity to keep the network functioning normally. The robust design problem (RDP) in a multistate computer network (MCN) is to search for the minimum capacity assignment of each link and vertex such that the network still survived even under both kinds of failures. However, how to optimally assign the capacity to each resource is not an easy task. This paper proposes an efficient approach to do such assignment and illustrates the efficiency of the proposed approach by some numerical examples.

1. Introduction

Computer network is now an important infrastructure in the modern corporations. Maintaining a reliable computer network becomes an important issue in the daily business operations. A multistate computer network usually consists of links (class I resource) and vertices (class II resource) where both kinds of resources may have several states due to failure, partial failure or maintenance. In practice, a link is composed of several physical lines such as optic fibers, coaxial cables or twisted pairs. A vertex (transmission facility) comprises hubs, switches, routers, etc. All of them may have specific capacities or fail. Such a computer network is treated as a typical multistate network [1–7], and called a multistate computer network (MCN) [8,9]. Therefore, each link (vertex) in the network should be assigned sufficient capacity to keep the network functioning normally. The robust design problem (RDP) in a MCN is to search for the minimum capacity assignment of each link and vertex such that the network still survived even under both kinds of failures. From the viewpoint of quality management, any surplus of resources assigned to each link (vertex) without improving the robustness of the entire network is a waste of resources.

The robustness of a MCN can be measured by the system reliability which is the probability of a live connection between a source node and a sink node [10]. The term "live" means the maximal flow through the network should be no less than a demand *d*. Otherwise, the network is broken. Two types of methods are popular in the evaluation of network reliability, namely minimal paths (MPs) [3,11,12] and minimal cuts (MCs) [3,8,13]. A path is a set of links whose existence results in the connection of source node and sink node. A MP is a path whose proper subset is not a path. A cut is a set of links whose removal results in the disconnection of source node and sink node. A MC is a cut whose proper subset is no longer a cut. When the network is live, there are several minimum path vectors respect to system state *d*, called lower boundary vectors (LBV), can be found. Then, the network reliability is the union probability of all these LBVs.

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http://dx.doi.org/10.1016/j.apm.2013.06.020

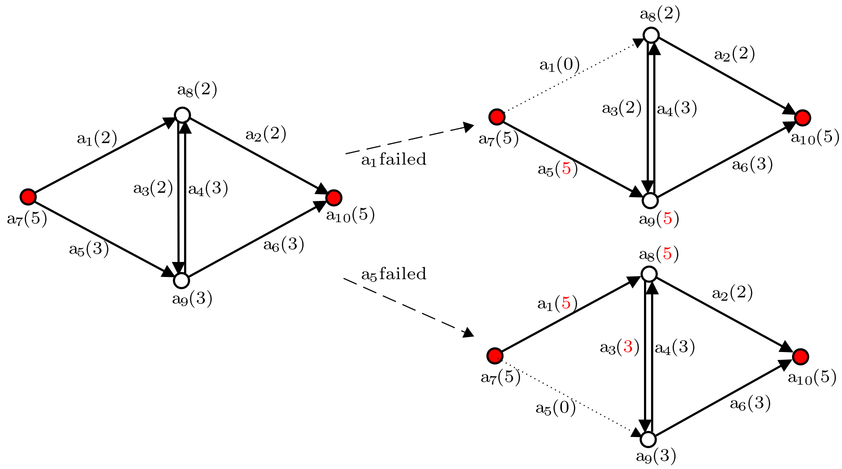

Fig. 1. The first example with failure schemes.

Many researches have discussed different criteria to solve the assignment problem (AP), such as commodity allocation [14–16], flow assignment [17,18], delay criteria [19], location allocation [20], and topology design [21–23,10,24]. In most of the cases, APs only consider the assignment of one kind of resource, such as the works in [25,26]. Lin and Yeh [9,27] began to solve the AP with the consideration of two kinds of resources. They proposed an evolution method to search for the near optimal solutions of the problem for maximizing the network reliability under double-resource assignment. Chen [28] proposed an exact and efficient algorithm to solve the optimal single resource assignment for the robust design problem (RDP) in capacitated flow networks. There are very limited studies regarding the searching for the minimum double-resource assignment of the links and vertices such that the network still survived even under both kinds of failures. Moreover, most of the literature only provided near optimal solutions for these APs.

This paper proposes an efficient approach, namely RDPMCN-E, to solve the *exact* solution of the RDP in MCN in which each link (vertex) has several possible capacities or states. Normally, such kind of problem can be constructed as a non-linear integer programming problem and be solved by the implicit enumeration method (IEM). However, IEM is impractical even for a small-size network. A novel and very efficient approach RDPMCN-E is proposed in terms of LBVs. A LBV expresses the capacity state of each link (vertex) when the network flow equals d. So, the LBVs describe the minimum possible range of capacities needed for each link (vertex) when the network remains live. To cope with the condition of failures, one can disable the link (vertex) one by one, and observes the derived capacity ranges on each link (vertex) for a live network. For example, the left side of Fig. 1 denotes a popular bridge network with 5 links and 4 vertices, where the parenthesized number denotes the maximum capacity for that component (link or vertex for short). We take more general views for two kinds of resources with capacities and neglect the differences between resource brands. Also, the two directions of data transmission on a single link can be asymmetric. This is explicitly denoted by directed arc on that link. Originally we randomly assigned the maximum capacity for each component to supply the demand of 5. If a_1 failed, a_5 and a_9 should increase the maximum capacity to 5 to keep the network survived. If a_5 failed, a_1 and a_8 should increase the maximum capacity to 5, and a_3 to 3 to keep the network survived. The LBVs observation of this approach is similar to the above example. However, not all LBVs are required in solving the RDP. A filtering process can be developed to further improve the efficiency of the search. Such a reduction greatly improves the efficiency of the search to the RDP. The compared results show that the proposed approach is very efficient.

The remainder of the work is described as follows: The nomenclature and assumptions are given in Section 2. A multistate computer network model under an assignment is described in Section 3. The RDP problem in MCN is then formulated in Section 4. Section 5 develops the proposed approach for this problem. Then, some numerical examples from the literature are studied and compared in Section 6. Section 7 draws the conclusion and comes to the discussions of this paper.

2. Nomenclature and assumptions

The notations used in this paper are defined as follows: