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# Delay-constrained survivable multicast routing problem on WDM networks for node failure case

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ABSTRACT

With the rapid evolution of multimedia and real-time applications like audio/video conferencing, certain quality-of-service (QoS) should be guaranteed for the multicast transmission. For the given delay-constrained multicast request, the goal of *delay-constrained survivable multicast routing problem* (DCSMRP) is to provide the primary multicast tree and protecting resources so that after recovering from the link (node)-failure, the recovered tree can satisfy the delay constraint. In this article, the DCSMRP with a single node-failure case on wavelength-division multiplexing (WDM) networks is considered. Three node-failure protecting methods, includes node-disjoint trees (NDT), node-encircling p-cycles (NEPCs) and failure-independent path protecting p-cycles (FIPP p-cycles) are used in this article. For each protecting method, an algorithm is designed to solve the studied problem. Simulations are also conducted to evaluate the performance of the proposed algorithms.



## 1. Introduction

It is believed that WDM (wavelength-division multiplexing) is currently employed as the core technique of the backbone in the next generation Internet architecture. Multicast transmission is a popular service that transmits information from one source to multiple destinations simultaneously. Thus, supporting efficient multicast transmission on WDM network is a very important issue [1]. For a comprehensive survey about supporting multicast on WDM networks, the reader may refer to [1].

Recently, with the rapid evolution of multimedia and real-time applications like audio/video conferencing, certain quality-of-service (QoS) needs to be guaranteed in the multicast transmission. Hence, designing efficient multicast routing algorithms to support multicast transmission under the QoS constraint is essential for real-time multicast services. To guarantee QoS transmission, the delay from the source to all destinations should be limited under a given delay bound. The delay bound of the multicast can be decided according to the emergency degree or urgency priority of the services [2]. This problem is well known in the literature as *delay-bounded Steiner tree problem* or *delay-constrained Steiner tree problem* [3,4]. The problem of constructing minimum-cost multicast trees while imposing a delay bound on the paths remains NP-complete [3,4]. Therefore, many researchers put forward to calculating the quasi-Steiner heuristic tree, the most typical is the MPH (minimum path cost heuristic) algorithm [5], with the algorithm a computing member node can join the multicast tree by selecting the path whose cost is the least to the existing multicast tree.

A *light-tree* [1] (spanning all multicast destinations and rooted at the source node of the multicast request) is used to establish multicast connection on WDM networks. In the previous studies [6–8], the *delay-constrained multicast routing problem* (DCMRP) on WDM networks was considered. The goal of the DCMRP studied in [6] is to find a light-forest whose multicast cost defined as a weighted combination of communication cost and wavelength consumption is minimized. In [7,8] the goal of the DCMRP is to construct a delay-constrained light-tree with the minimal total cost. For WDM networks with sparse light-splitting capabilities, but without wavelength-converting capabilities, the delay-constrained multicast routing problem for minimizing the number of fibers used, or the total cost, has been studied in [9].

### 1.1. Multicast protection

A network failure (such as a fiber cut or node failure) may affect the multicast transmission, leading to loss of large amounts of data. When the failed link/node is located in a light-tree of a multicast transmission, the traffic to all the downstream destinations

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along the failed link/node will be affected. The network failure will affect more destinations, if the link/node is close to the source node [10–12]. Survivability is more sophisticated for multicast than unicast transmission on WDM networks. Therefore, several *protection* schemes have been proposed to achieve *survivability* on the optical layer on WDM networks. According the survey, five major multicast protecting schemes have been proposed in the literature, they are: (1) tree-based protection [10–12], (2) ring-based protection [13], (3) path-based protection [14,15], (4) segment-based protection [16–18] and (5) cycle-based protection [19–23].

The tree-based protection scheme [10–12] (a pair of link (node)-disjoint trees is constructed for each multicast request) is the simplest protecting method to protect the light-tree for optical multicast against link (node)-failure. In this scheme, first, a minimum-cost tree from source node to all destination node is found as the primary multicast tree. The primary tree is removed from the graph and then the same algorithm is applied again to find the backup tree. But, it has the drawback that network resources are used excessively and link/node-disjoint trees may not be found in some cases.

In [13], five protection strategies against single link failure in multicast multi-fiber WDM networks were proposed. They included *joined path recovery* (JPR), *one ring for one multicast session* (OFO) with routing-based approach (OFOR), *OFO with demand-based approach* (OFOD), *one ring for all multicast sessions* (OFA) with routing-based approach (OFAR), and OFA with demand-based approach (OFAD). The simulation results showed that the JPR scheme is the most cost-effective, whereas the ring-based protection strategies offer other advantages, i.e. fast and reliable recovery.

In the path (segment)-based protection scheme, each destination is protected by a backup path (segment) which is link/node-disjoint to the path of the primary tree. Path-based [14,15] and segment-based [16,17] protection schemes are more efficient than tree-based protection schemes since the resources of the backup paths (segments) can be shared by other backup paths (segments), if their primary paths are link/node-disjoint. In [18], for the single link-failure case, an efficient segment-based protection method has been proposed for dynamic multicast traffic (called *level protection*, LP).

The *protecting cycle* (p-cycle) protection scheme is a technique to protect a mesh network from a failure of a link, with the benefits of ring like recovery speed and mesh-like capacity efficiency. In a mesh network, the spare capacity is used to create the ring like structure. Due to the nature of the rings, assuming *bi-directional line switched ring (BLSR)*, only two end nodes are involved in a case of a link failure to switch traffic to a pre-planned cycle (path) and recover. Zhang et al. [19,20] discussed several p-cycle based multicast protection approaches, including the *link-protecting p-cycle based approach*, the *tree-protecting p-cycle based approach*, the *node-and-link based protecting p-cycle approach*, and the *flow p-cycle based approach*. They showed that these p-cycle based methods outperform other existing optical multicast protection approaches in both capacity efficiency and recovery speed. Feng et al. [21] extended path-protecting p-cycle to protect multicast. Zhang et al. [22] used p-cycles to provide combined node and link protection for the multicast protection. The p-cycle based optical multicast protection was also applied to the general networks [23].

### 1.2. Node-failure protection

Node-failure on WDM networks means that both the optical cross-connect (OXC) node and all the links which are connected to the node fail [1]. Node failures sometimes happen due to the burned switch/router, fire, or any other hardware damage. In addition, the failure might be due to network maintenance. Although node failures in a transport network are less frequent than link failures, node failure is more damaging than link failure since multiple connections may be affected by the node-failure [24].

Note that it is not possible in any protecting method to recover demands (either unicast or multicast) from a failure at their own origin/destination nodes. Node failure protection through network reconfiguration is therefore only concerned with restoring traffic flows that passed (or *transited*) through failed nodes [24]. There are three basic types of p-cycles can be used to protect all traversing paths through a single node against node failure, they are *node-encircling p-cycles* (NEPCs) [24,25], *failure-independent path protecting p-cycles* (FIPP p-cycles) [26], and path-segment (flow) protecting p-cycles [27].

### 1.3. Delay-constrained survivable multicast routing problem

For the earlier multicast protection problems on WDM networks, the goal is to find the primary tree and backup resources to transmit the multicast requests but without considering the delay-constraint of the multicast. For a given delay-constrained multicast request, if the same algorithm for the earlier multicast protection problem is applied; after recovering the primary tree from a network failure, the recovered tree may violate the delay constraint. That is, no QoS of the light-tree can be guaranteed after recovering from a failure for the delay-constrained multicast request. To guarantee that the delay constraint of the multicast request can be satisfied after recovering from a network failure, the solving method should take both delay constraint and protection of the multicast request together and design a whole new method to solve the problem.

For a given multicast request with delay constraint, a unidirectional delay-constrained primary multicast tree is first constructed. Then, backup resources are reserved for the primary tree against a network failure. In [28], Din and Jiang introduced the *Delay-Constrained Survivable Multicast Routing Problem* (*DCSMRP*) for single link-failure case. Three protection methods named as Delay Constrained Link-disjoint Tree Protection (DCLTP), Delay Constrained Disjoint-Paths Protection (DCDPP) and Delay Constrained Span p-Cycle Protection (DCSP) were proposed in [28] to solve the DCSMRP. Din et al. [29] studied the DCSMRP-SSBP (DCSMRP with shared segment-based protection (SSBP)), where the SSBP [17] is used to protect the primary tree. For the DCSMRP-SSBP problem, two heuristic algorithms were proposed.

### 1.4. Outlines and contributions

In this article, the DCSMRP on WDM networks for single node-failure case is studied. For a given WDM network and a delay-constrained multicast request, the goal is to find a delay-constrained primary tree and a set of backup resources such that after recovering the primary tree from the node-failure, the delay from source to all destinations of the request can still satisfy the delay constraint. For the node-failure case, the algorithms proposed in [28,29] for single-link failure cannot be used directly. Three protection schemes: *node-disjoint trees* protection scheme, NEPCs protection scheme and FIPP p-cycles protection scheme are used in this article for multicast protection. For each protecting method, an algorithm is proposed to solve this problem.

The rest of the article is organized as follows. First, in Section 2 the definition and assumptions of the problem are given. In Section 3 the related works are given. In Sections 4, 5, and 6 the proposed methods are described. Then, in Section 7, the performance of the proposed methods is examined. The conclusion is drawn in Section 8.

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