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Survivable routing and wavelength assignment performance improvement using primary-backup multiplexing with 100% fault recovery guarantee

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ABSTRACT

In this paper, we address the problem of designing survivable optical networks. Path Protection (PP) and Link Protection (LP) schemes are the main means of protecting Wavelength-Division Multiplexed (WDM) networks from the losses caused by a component failure. We here propose to use a new generalization of the PP scheme called Partial Path Protection (PPP). PPP designates a different restoration path for every link failure of every primary path. Based on the PPP scheme, an Integer Linear Programming (ILP) model and a heuristic algorithm are presented to tackle the problem of establishing a set of static connections, referred to as Dependable connections (D-connections), with fault-tolerant requirements under Shared Risk Link Group (SRLG) constraints. Both approaches aim at maximizing the overall network throughput by minimizing the total bandwidth consumption using two resource sharing techniques, namely Primary-Backup Multiplexing (PBM) and Backup-Backup Multiplexing (BBM). To the best of our knowledge, this is the first attempt to combine these two techniques when routing static D-connections and performed in such a way that 100% fault-recovery is still guaranteed for all established connections. Multiple simulation studies have been carried out on different network topologies to evaluate the performance of the proposed solutions. These performance results are also compared to those of previously proposed approaches in the literature, to outline the improvements brought by our approaches.

1. Introduction

Wavelength-Division Multiplexing (WDM) technology offers the capability of building very large wide-area networks with throughput of the order of terabits per second. Optical networks employing WDM technology provide very high data rates, low error rates, and low delay. These networks are expected to meet the bandwidth demand arising on next generation networks and the future Internet due to the emergence of several bandwidth consuming applications such as web browsing, graphics and visualization, medical image access and distribution, multimedia conferencing, and broadband services to home [1,2].

A WDM optical network consists of a set of optical cross-connects (OXCs) interconnected by communication links. Each communication link consists of a pair of unidirectional fiber-links. We here assume that all OXCs are wavelength selective, and there is no wavelength conversion in the network; the approaches to accommodate wavelength conversion are relatively straightforward [3]. WDM optical networks in which wavelength conversion is not allowed are called transparent WDM optical networks [2,3]. In such networks, any connection request from a source node to a destination node (also called a lightpath) is subject to two main constraints: the former is called the wavelength continuity constraint and states that a lightpath should occupy the same wavelength on all the

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fiber-links it traverses on the route between the source and destination node pair. The latter prohibits two lightpaths to use the same wavelength when they share at least one common fiber-link to prevent the interference of the optical signals. This constraint is called the wavelength contention constraint [4].

WDM optical networks are cable-based systems that are prone to component failures. A fiber cut causes a link failure. A node failure may be caused due to the failure of the associated OXC. Networks failures are broadly classified into three types: link failure, node failure and channel failure [5,6]. Since WDM optical networks carry high volumes of traffic (over 40 Gbps per wavelength channel), failures may have severe consequences. Therefore, it is imperative that these networks have fault-recovery methods to prevent data loss, guarantee reliable data transfer and maintain service continuity. Fault-recovery methods refer to the ability of the network to reconfigure and reestablish communication upon failure. The process of reestablishing communication through a lightpath between the end nodes of a failed lightpath is known as lightpath restoration. A lightpath that carries traffic during the normal operation is known as the primary lightpath. When a primary lightpath fails, the traffic is rerouted over a new lightpath known as the backup lightpath. Based on the time at which the backup lightpath is set up, fault-recovery methods fall into one of the following two classes: dynamic restoration or predetermined protection [7]. In the current study, we focus on predetermined protection approaches which, unlike dynamic restoration approaches, provide fast recovery and guaranteed successful restorability for all established connections by performing the backup lightpath computation at the connection's set-up time [7,8].

Three main protection-based approaches have been proposed in the literature, namely: Link-based Protection (LP), Path-based Protection (PP), and Segmented-Path-based Protection (SPP); each of which has its own advantages and disadvantages (see among others [9,10]). Nonetheless, the PP approach is considered as the most promising approach in which two link-disjoint paths are computed for each connection demand to be set up. PP provides high capacity efficiency mainly when the backup multiplexing technique is incorporated – that is, when network resource sharing is allowed between different backup lightpaths whose corresponding primaries do not fail simultaneously [9,11].

A fourth interesting protection technique, called Partial Path Protection (PPP), has been proposed in [12]. The PPP recovery scheme derives from a combination of LP and PP schemes. To protect a connection-demand, the PPP technique computes, for each fiber-link along the request's primary path, a specific backup connecting the two end-nodes of the considered demand. Each of the computed protection lightpaths needs only to be link-disjoint from the link it protects. Several recent studies have adopted the PPP scheme when dealing with the problem of establishing static connections in transparent WDM networks [12,13]. It has been proven that PPP is more capacity efficient than LP and more flexible and powerful than PP since the existence of a PP solution implies the existence of a PPP one while the reverse is not true [12,14].

To the best of our knowledge, most of the protection methods presented so far in the literature to deal with the problem of establishing static connections with fault-tolerant requirements, referred to as Dependable connections (D-connections), in WDM optical networks, considered the case of single link failures (optical cross-connect port blocking). Other failures, including fiber cuts and high Bit Error Rates (BERs), may affect all the wavelengths that pass through a link. In addition, links in an optical network may share a common resource, such as a duct or conduit through which multiple links are laid out. The failure of this resource results in the simultaneous failure of multiple links. Such failures are referred to as Shared Risk Link Group (SRLG) failures. The SRLG concept is considered as one of the most important criteria concerning the constrained-based path computation of optical channel routes [13–15]. In this paper, we focus on the latter type of failures. Even though incorporating such failures may increase significantly the complexity of the D-connection Establishment problem (DCE), the SRLG constraint has to be considered in order to guarantee the feasibility of the proposed solutions in a realistic context.

In this paper, we propose to solve the DCE problem in survivable transparent optical networks using the PPP recovery scheme under SRLG constraints. This problem is referred to as the survivable D-connection Establishment (SDCE) problem.

The main contribution brought by this study is its attempt to improve the bandwidth utilization and, hence, the overall network throughput using two different resource sharing techniques. The former is the backup multiplexing technique whereas the latter is a relatively recent technique called primary-backup multiplexing. To the best of our knowledge, this is the first time these two techniques are combined when considering the static traffic scenario and used without any compromise on the 100% fault-recovery guarantee of the established D-connections. We first propose an ILP formulation to optimally solve the SDCE problem under the aforementioned hypothesis. The ILP formulation being NP-complete, we then propose an Iterative Partial Path Protection (IPPP) heuristic to solve the problem for large scale networks (networks of real size). Our simulation results demonstrate the efficiency of the presented solutions and outline significant improvement especially in terms of network blocking performance when compared to other approaches previously proposed in the literature.

The remainder of this paper is organized as follows. Section 2 gives a detailed description of the SDCE problem. In Sections 3 and 4, we present, respectively, the ILP model and the heuristic approach. In Section 5, we give and discuss the results of the different simulations that have been carried out in order to evaluate and compare the performances of the presented approaches. Section 6 concludes the paper.

2. Description of the problem

The SDCE problem we addressed in this paper, can be defined as follows: Given a physical network topology with a fixed number of wavelengths, W, available on each fiber-link in the network and a set of static D-connections to be set up, compute a feasible routing and wavelength assignment