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A network engineering framework for upgrading service availability of optical mesh networks

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ABSTRACT

We present a network engineering process to improve service availability of optical mesh networks by employing protection links. In the existing optical mesh networks, high service availability is usually achieved by network planning with an appropriate routing and wavelength assignment (RWA) algorithm. However, network planning cannot provide upgrade paths for unpredictable new demands. To meet the requirements of practical operations, a network engineering process is developed to improve service availability in an upgrade manner. A model of integer linear programming (ILP) is proposed to minimize the upgrade cost. In addition, heuristic methods for calculating the sequence of incrementally installing protection links are presented. Our experimental results show that the proposed network engineering process can improve service availability with low cost. They also demonstrate that the network engineering process can exclude the necessity of a routing algorithm optimized for service availability because such an algorithm usually results in higher upgrade cost than those optimized for path length or link load.

1. Introduction

The life cycle of an optical network is interleaved with three optimization phases: network planning (NP), network engineering (NE), and traffic engineering (TE) [1]. NP is a process to design a new network by using static routing and wavelength assignment (RWA) algorithms optimized for intended services and forecasted traffic demand. The network design should meet all business goals with minimal capital expenditures (CAPEX). NE manipulates network facilities to accommodate new traffic demand. It moves or adds network facilities to promote the network performance or compensate the discrepancy between forecasted and realistic demands. TE manipulates traffic to meet service level agreement (SLA) by routing traffic to where network resources are available. In a wavelength-division-multiplexing (WDM) network, TE assigns dynamic end-to-end connections to lightpaths by using suitable RWA algorithms.

Since the cost of building a new network is extremely high, the useful life cycle of NP usually spans several years. In contrast, TE allocates network resources to a service demand in just several milliseconds, where the procedure of resource provisioning is performed based on the existing network deployments. NE is the only process to compensate the gap between forecasted and realistic requirements by adding necessary network resources or moving excess network resources from some regions to another regions. NE might be carried out once per several days depending on network operators' policies, as shown in Fig. 1.

We use a simple scenario to describe the relationship between NP and NE. In Fig. 2(a), NP generates an operating network with two transmission paths: one from node A to node B with 20-Gbps capacity and the other from node C to node D with 10-Gbps capacity. Assume that 10-Gbps optical tributary cards are used. A node must install two tributary cards to achieve 20-Gbps capacity. Two cases of unanticipated demands would occur in the operating network: increment and migration (Fig. 2(b–d)). In the first case, the traffic requirement from node C to node D is increased to 20 Gbps. In this case, an NE process is employed by the network operator to simply add one tributary card for both nodes. The process of lightpath provisioning is also performed to enable traffic transmission over new tributary cards. In the other case, the traffic demand from node A to node B shrinks to only 10 Gbps but the demand from node C to node D increases to 20 Gbps. Instead of adding new tributary cards, the NE process can move the tributary cards of nodes A and B to nodes C and D to fulfill the new demands without extra equipment cost.

As the explosive growth of the Internet traffic continues, network planning for varying service types with dynamic traffic

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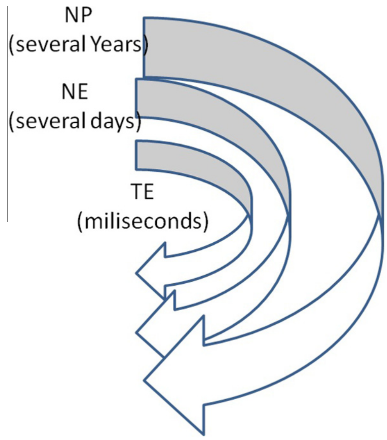

Fig. 1. Three optimization phases of optical networks.

volume is getting complicated [2]. Currently, most researchers use TE approaches to resolve the issues of fulfilling traffic demands. Only few papers address NE issues for WDM networks. Most of these papers focus on upgrading network capacity to accommodate increasing traffic [3–12]. In this paper, we devise an NE process to upgrade service availability of optical mesh networks. To our knowledge, none of the previous work addresses this issue. To meet the requirement of service availability, a model of integer linear programming (ILP) is designed to allocate redundant WDM links with the lowest cost. We also present heuristic algorithms of incremental upgrades.

The rest of this paper is organized as follows. Section 2 discusses the related work about network upgrades and service availability. In Section 3, we present an optimized NE process by conducting ILP and two heuristic algorithms for incremental upgrades. Section 4 presents the simulation results and our findings. We make some conclusions of this paper in Section 5.

2. Related work

The existing NE papers focus on upgrading network resources to satisfy certain network performance metrics. For example, Nayak and Sivaranjan assert that network operators can predict the time to upgrade their networks by calculating *exhaustion probability* [3]. They calculate extra network capacity required to achieve an acceptable exhaustion probability. Another work extends the concept of exhaustion probability and proposes another performance metric, *network cut exhausted probability* [4,5]. This technique considers the whole network instead of individual flows to predict the correct time of upgrading network. Another work optimizes client networks (i.e. IP networks) performance on multi-layered optical networks by dynamically adjusting the virtual topology of server networks [6]. In [7,8], the authors allocate network resources (e.g. multi-rate line cards [7] or high-speed line cards [8]) to accommodate incoming traffic demands. Their simulation results show that a well-designed network with their NE process can accommodate forecasted traffic with lower cost.

Recently, incremental upgrade has been considered as a practical issue for upgrading networks in stages [9–12]. Keralapura et al. have mentioned several motivations of incremental upgrade, such as budget constraint for upgrade cost and facility installation/test strategy of operators [9]. They propose a two-phase framework to find an optimal solution for upgrade networks by adding nodes and links gracefully. As an iterative upgrade process, each incremental upgrade can be defined as a single-period task by using the network status of the previous periods as its inputs [10]. To upgrade network capacity form 10 Gbps single-line-rate to 10/40/100 Gbps mixed-line-rate with only few service interruptions, Nag et al. propose an incremental upgrade strategy that considers both issues of energy efficiency and cost efficiency [11]. To further exploit unused capacity, several upgrade techniques are employed to dynamically re-provision connections with different service availability requirements [12].

As the diversity of new network services emerges (e.g. survivable cloud service [13,14]), the service availability has drawn

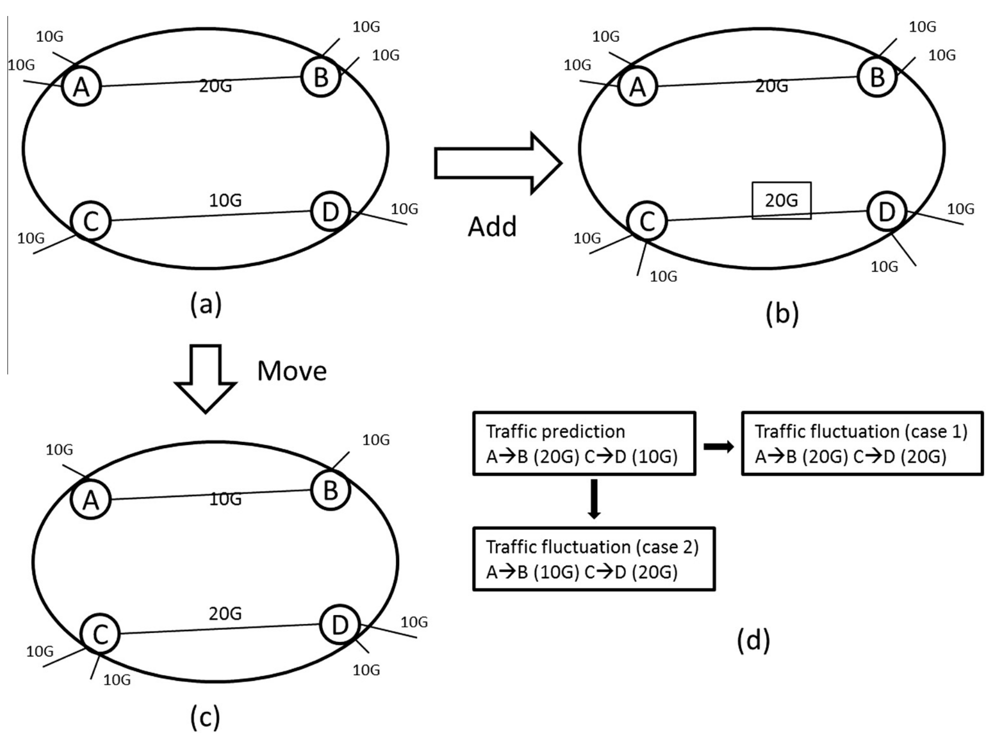

Fig. 2. A simple scenario for NE process.