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Topological design and dimensioning of Agile All-Photonic Networks

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Abstract

We present the design and analysis of an Agile All-Photonic Network (AAPN); in the context of our study, the agility is derived from sub-microsecond photonic switching and global network synchronization. We have articulated a set of circuit design alternatives in terms of switch configurations referred to as symmetric and asymmetric designs, and two-layer and three-layer designs and discuss the implications of these alternatives in terms of transmitter and receiver design and synchronization requirements. In order to evaluate performance and cost of this range of design alternatives, we developed a set of software tools and methodologies for designing and dimensioning our vision of an AAPN. The topological design problem consists of determining the optimal number, size and placement of edge nodes, selector/multiplexers and core switches as well as the placement of the DWDM links so as to minimize network costs while satisfying performance requirements of the supported traffic. A new mixed integer linear programming formulation is presented for core node placement and link connectivity. A methodology has been developed for two-layer and three-layer network topology design and implemented in software. These tools were exercised under a wide variety of equipment cost assumptions for both a metropolitan network and a long-haul network assuming a gravity model for traffic distribution and a flat community of interest factor. Key findings include the determination of near cost optimal designs for both metropolitan (two-layer design) and a Canadian wide area network (WAN, three-layer design). We also show the cost and topology sensitivity to the selector switch size and the preferred size in terms of port count and number of switches.

Keywords: Topological design; Optical networks; Optimization

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1. Introduction

Recently there has been much attention paid to the study and development of agile transparent optical transport networks, where the electronic cross connect and add/drop multiplexing switching systems are replaced with photonic counterparts. This enables the provision of light paths linking network ingress and egress nodes where the signal is transmitted entirely in the optical domain, thus eliminating the expensive OEO conversions associated with the SONET/SDH cross connect systems. Apart from significant cost reductions, these all optical light paths are protocol and rate independent, thereby facilitating network evolution and reach. A significant body of literature exists addressing the so called routing and wavelength assignment (RWA) problem. Integer and linear programming models have been formulated and solved to determine the appropriate wave length and path assignment for light paths through the physical transmission networks to maximize throughput for a given network topology and link capacity. A variety of models have been reported which address variants and extensions of this problem including static and dynamic light path demands, network survivability, and traffic robustness [1–4], and references therein.

Due to the service architecture of the Internet that enables users to implement services at the application layer, new services will be designed and deployed without centralized authorization. In this context agility is a required network capability because it provides a degree of service quality robustness in the face of traffic forecasting errors and facility failures. Traffic forecasting necessary for capacity planning is becoming increasingly difficult as new services with unknown traffic characteristics, volume, and distribution are rapidly emerging. Agility enables operators to reconfigure the network topology on short notice in order to match observed traffic demands and in doing so keep service quality levels as high as possible given the installed capacity. In addition, network agility is essential to network survivability in the face of unpredicted failures.

While the MEMs based optical cross connects and add/drop multiplexers currently being introduced in transport networks are a valuable asset in enabling light path on demand provisioning and restoration, their one millisecond switching speeds are too slow to perform statistical multiplexing at the frame or packet level. In an all-photonic network architecture that is limited to millisecond reconfiguration times and space-switching, an entire wavelength must be allocated for an extended period of time to each data flow traversing a network edge-to-edge path. As a result, the architecture is only economically feasible if each data flow is of enormous volume, demanding that the edge switches of the all-photonic network core are accumulation points of large metropolitan areas. In order to extend the photonic core closer to the edge of the network and penetrate into smaller population centers, the capacity of a wavelength must be sub-divided by incorporating time domain multiplexing on sub-microsecond time scales in the network structure. In this way, multiple, much smaller data flows can share the capacity of the same wavelength. To efficiently transport bursty traffic such as found in the Internet, fast optical switching is required to time share light paths.

Recently considerable attention has been directed to time division multiplexing of light paths using asynchronous optical burst switching OBS, optical packet switching (OPS) architectures, and synchronous optical time division multiplexing (OTDM) techniques as a means of increasing network agility and reach. Introducing time-domain multiplexing is very challenging because switching requests come from multiple sources and the optical space-switches must be configured correctly before the arrival of the data to be switched. Techniques including just-in-time signalling architectures for WDM burst-switched networks—JumpStart [5], optical burst switching [6,7], slot-by-slot routing [8], and concepts introduced in this paper [9] are emerging as candidate approaches. We argue that a variant of OTDM called synchronous slot by slot (SlxSl) switching is a viable alternative to optical burst switching (OBS) for the supporting bursty traffic in next generation all photonic transport networks. Synchronous slot switching in photonic networks by necessity requires global synchronization due to