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Multi-granularity grooming using timing information in optical networks with waveband and TDM switching

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Abstract In this paper, we incorporate the idea of waveband switching in Mixed Line Rates (MLR) network design to address the problem of dynamic traffic grooming in waveband switching networks by investigating a cost function which take the effect of call holding time on the time slot assignment process of in WDM–TDM. Use has been made of Markov model in order to predict the wavelength congestion. A routing algorithm is developed based on the Markov modeling. The results are compared with existing routing algorithms – Available Shortest Path (ASP) and Online Traffic Grooming Algorithm (OTGA). Validation results have shown that the performance of the proposed system is significantly improved in terms of bandwidth blocking ratio, network utilization as well as port saving due to wavebanding.

1. Introduction

Optical networks provide a transport infrastructure with very high capacity, thanks to wavelength-division-multiplexing (WDM) technology. The WDM technology divides the enormous fiber bandwidth into a large number of wavelengths and with current technologies; each fiber can have 100 or more wavelengths (each operating at 2.5 Gb/s or higher). In a wavelength-routed WDM network, a lightpath must be established between a pair of source and destination nodes before data can be transferred. A lightpath is an end-to-end optical connection which may traverse multiple fiber links and optical cross-connects (OXCs). However, Future telecommunication networks employing WDM technology, are expected to be heterogeneous and supporting a wide variety of traffic demands. Based on the nature of the demands, it may be convenient to set up lightpaths on these networks with a variety of bit rates. Traffic grooming refers to the problem of efficiently multiplexing a set of low-speed connection requests onto high-capacity channels and intelligently switching them at intermediate nodes. Traffic grooming problem in optical wavelength routing network has been extensively studied with the aims to minimize the number of optical-electronic-optical conversions (OEOs), or maximize the total number of users served in the optical networks. Thus, the network bandwidth utilization can be optimized. The traffic-grooming problem can be formulated as follows [1–10].

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Given a network configuration and a set of connection requests with different bandwidth granularities, we need to determine how to set up lightpaths to satisfy the connection requests. Because of the sub-wavelength granularity of the requests, one or more connections can be multiplexed on the same lightpath using a multiplexing technique such as time division multiplexing technique (TDM) which divides the bandwidth's time domain into repeated time-slots of fixed bandwidth. Therefore, with TDM, multiple signals can share a given wavelength if they are non-overlapping in time [3,5–13]. The resulting multi-wavelength optical time division multiplexed network is referred to as WDM–TDM network. Hence, the available bandwidth on wavelengths can be utilized efficiently.

On another hand with the rapid advances in WDM technology, the tremendous growth in data traffic demands can be satisfied [14,15]. In practical dense wavelength division multiplexing (DWDM) and coarse wavelength division multiplexing (CWDM) technologies can divide the enormous fiber bandwidth into such a large quantity of wavelengths that each fiber can have hundred or more wavelengths. Hence, brought about a tremendous increase in the cost and size of electronic cross-connects or DXCs (e.g., OEO grooming switches). Optical (photonic) cross-connects (OXCs) that switch bypass traffic all-optically are useful in reducing the cost and size of the OEO grooming switches and to resolve the speed mismatch between the fast optical data network and electronic devices, where a network connection is maintained in the optical domain from source to destination. However, this breakthrough of WDM technology incurs a side effect. The more wavelengths a fiber link can offer, the more complex and expensive the control and management of OXCs become. Fortunately, the emergence of waveband switching (WBS) technique furnishes a solution to this problem [16–18]. With WBS technology, OXCs can efficiently aggregate a group of wavelengths into a waveband and transmit them as a unity as long as no wavelength dropping, addition, and extraction are required. Waveband switching (WBS) in conjunction with new multigranular optical cross-connects (or MG-OXCs) that can switch traffic at fiber, waveband and wavelength granularities [19–23], has been proposed to reduce this cost and complexity.

Lot of strategies for efficient lightpath routing in WDM networks have been proposed in these last years. We can classify these strategies in two main categories: alternate routing (AR) and dynamic routing (DR) [24]. In AR schemes [25–28], the route for the required connection is chosen among a set of predefined paths, which are usually assigned to each source/destination pair individually. Since the paths of such sets are usually determined priory by the network administrator, AR is not flexible enough to fully adapt to the variations in the network utilization. As for DR schemes [29,30], the connection route is dynamically determined according to the present state of the network.

Due to the evolution of services and applications over optical networks, traffic is becoming more dynamic. In a dynamic environment, a sequence of sub-wavelength requests arrives over time and each request has a random holding time. These requests need to be set up dynamically by determining a route across the network connecting the source to the destination and assigning it to a suitable time-slots on a suitable wavelength along the path.

In our work we consider all-optical WBS networks with proposed four-layer MG-OXC switching node architecture to incorporate the idea of waveband switching in Mixed Line Rates (MLR) network design. It is envisioned that, a four-layer MG-OXC switching node architecture with the capability of associated TDM-time slot switching would significantly reduce the number of ports than that of the OXCs discussed in [5] moreover solving the traffic-diversity problems by using the time division multiplexing (TDM) technique effectively. To achieve that we exploit the knowledge of connection holding time to devise an efficient algorithm for dynamic traffic grooming of sub-wavelength requests in optical WDM mesh networks. A proper utilization of connection durations allows us to minimize the network resources used for each request, which implicitly attempts to minimize the overall blocking probability.

2. Related work

Much of the research work on routing and wavelength assignment (RWA) considers routing only at the wavelength level in wavelength routed networks (WRNs) [31,32]. Due to the nature of traffic demands, where the incoming requests need only sub-wavelength capacity, the mismatch between the required bandwidth of incoming request and the total available capacity of wavelength can be eliminated by which called traffic grooming. The problem of traffic grooming in optical networks is to determine how to efficiently route traffic demands and at the same time to combine lower-rate (sub-wavelength) connections onto a single wavelength. This problem took a lot of attention in most works [1–10] to achieve efficient utilization of the total available bandwidth of network resources (wavelengths).

On the other side, optical networks support the increasing data demands in telecommunication networks by utilizing many wavelengths and employing advanced transmission and switching technologies such as wavelength division multiplexing (WDM), dense wavelength division multiplexing (DWDM), coarse wavelength division multiplexing (CWDM) and optical cross-connects (OXCs), respectively. However, with the development of WDM networks and the increased number of wavelengths in WDM, cross-connects keep increasing the hardware cost and complexity at optical nodes such as reconfigurable optical add/drop multiplexers (ROADMs) [33]. Hence, Recently research on multigranular waveband switching networks has received increasing attention [16,18,34–37]. Although wavelength routing is still fundamental to a WBS network, the challenging issues in WBS network are quite different from existing work on WRNs. For example, a common objective in designing a WRN is to reduce the number of wavelengths required or the number of wavelength hops used [31,32]. However, minimizing the number of wavelengths or wavelength hops [38] does not lead to minimization of the port count of the MG-OXCs. As the number of wavelengths is large, traditional OXCs that switch traffic only at the wavelength granularity can become huge (i.e., requiring a large number of wavelengths ports), resulting in increased cost and control complexity. This is led toward waveband switching (WBS) technique as a solution to this problem [16–18]. The main idea of WBS is to group several wavelengths together as a band, and switch the band using a single port whenever possible (e.g., as long as it carries only bypass or express traffic), and demultiplex it to switch the individual

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