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Online traffic grooming using timing information in WDM–TDM networks

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Holding time;
Markov chain;
Transient probability;
Load balancing

Abstract In this paper, the effect of holding time awareness on the process of time slot assignment in WDM–TDM is considered. 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 algorithms—ASP, WSP and OTGA. Validation results have shown that the performance of the system is significantly improved in terms of bandwidth blocking ratio, network utilization and fairness.

1. Introduction

With traffic demands continuing to increase rapidly, wavelength-division multiplexing (WDM) has emerged as an attractive solution for increasing capacity in optical networks. Conventional WDM allows multiple data streams to be carried using the same fiber link, as long as each data stream occupies different wavelengths [1]. As WDM technology matures, there exists a large gap between the capacity of a WDM channel (e.g., OC-48/OC-192/OC-768) and the bandwidth requirements of a typical connection request (e.g., STS-1, STS-3, STS-12, etc.). Traffic grooming is an important and practical approach for designing WDM networks which refers to the technique of efficiently multiplexing a set of low-speed connection requests onto high-capacity optical circuits and intelligently switching them at intermediate nodes. For example, time-division multiplexing (TDM) 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 [2–6]. The resulting multi-wavelength optical time division multiplexed network is referred to as WDM–TDM network. In our work we consider all-optical wavelength-routed WDM–TDM networks with fiber delay lines as time slot interchangers OTSIs [7].

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

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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. 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 resource occupation and hence to achieve lower blocking probability for incoming request.

2. Related work

This section provides a brief overview of traffic grooming in optical WDM mesh networks: 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 [8–13]. In a dynamic environment, the connection requests arrive one at a time with different starting time and holding period. In [14–16] dynamic traffic grooming algorithms that jointly employs knowledge of holding-times and the network bandwidth availability are developed in order to balance the traffic loading and avoid creation of bottlenecks. Consequently, this has improved bandwidth blocking probability for WDM networks. On the other hand, the authors in [17,18] incorporated holding time in energy-aware traffic grooming and solved both the static and dynamic traffic grooming problems in a wavelength routing network, the objective has been to minimize the total energy consumption of the core network based on holding time awareness. For the static traffic problem, they proposed an Integer Linear Programming (ILP). On the other hand, for the dynamic traffic problem, they used the shortest path(s) in an auxiliary graph with specific weights. Their algorithms are compared to the routing algorithms in [19] based on "minimum lightpaths" that tries to minimize the number of newly established lightpaths and "minimum hops" that tries to minimize the number of lightpath hops. Simulation results have indicated that the algorithm discussed in [17] performs best under low traffic, but performs worst under high traffic.

3. Our contributions

In this paper, we develop on the work presented in [15]. Here we consider the case in which holding time awareness is used to control the time slot assignments rather than the wavelengths. In this respect, an estimate of the close-future congestion probability of network wavelengths is developed based on knowledge of the connection's durations. The estimation is, then, used to apply a holding-time-aware Time-slot/Wavelength assignment for on-line routing algorithm in a WDM–TDM mesh network. As can be seen, we have effectively combined path selection, wavelength selection as well as time-slot assignments rather than performing each of them separately [13]. This approach, which we call Online Traffic Grooming Based on Time-slot/Wavelength Congestion (TGTSWC) is expected to outperforms the existing dynamic routing (DR) approaches discussed and analyzed in [3,4]. In particular, our approach is seen to achieve a significantly better blocking probability.

The rest of the paper is organized as follows. The node architecture and network modeling are introduced in Section 4. In Section 5, an overview of the dynamic routing model is presented. In Section 6, the holding time for traffic grooming problem is formulated. Section 7, presents a statistical model to the Time-slot/Wavelength Congestion probability. This model is, then, used to devise a computationally tractable, efficient algorithm called TGTSWC for the DR problem. The findings in this paper are evaluates by simulations in Section 8. Section 9 draws some conclusions.

4. Notations

4.1. Node architecture

A WDM–TDM switched mesh network consists of switching nodes with fiber communication links interconnecting the nodes. Each fiber link carries a certain number of wavelengths and each wavelength is divided into a number of time slots. The node architecture for sub-wavelength traffic grooming in such a WDM–TDM mesh network is shown in Fig. 1. The figure represents a node supporting M links ($e_1, e_2, \ldots, e_M$), and W wavelengths per link ($w_1, w_2, \ldots, w_W$) and each wavelength is divided into TS time-slots ($t_1, t_2, ..., t_{TS}$). The data carried on an incoming time slot can be delayed using Optical Time Slot Interchangers (OTSIs). Therefore, time slots occupied by data on an incoming wavelength at an input port can be mapped on to different time slots on the same outgoing wavelength at any output port. That is, wavelength conversion is not incorporated in this architecture.

4.2. Network model

The physical topology of a WDM–TDM mesh network can be represented by an undirected graph $G = (V, E)$ consisting of $|V| = n$ nodes and $|E| = m$ links interconnecting the nodes. Each link in the physical topology is bidirectional and is modeled as a pair of unidirectional links. $W = \{w_1, w_2, \ldots, w_W\}$ is the set of available wavelengths in the network. Each wavelength is divided into number of repeated time-slots (TS) of fixed bandwidth. We denote the set of existing sub-wavelength connections on any wavelength $w' \in W$ in the network at any time by $L_{w'} = \{(s^{i,w'}, d^{i,w'}, l^{i,w'}, t_a^{i,w'}, t_h^{i,w'})\}$ where the quintuple $(s^{i,w'}, d^{i,w'}, l^{i,w'}, t_a^{i,w'}, t_h^{i,w'})$ specifies, respectively, the source node, the destination node, the route, the arrival time and the holding time for the ith connection on a wavelength w'. We associate a wavelength utilization level descriptor $v_{w'}$ to each wavelength $w' \in W$ in each link $(u, v) \in E$ in the network. Therefore, the occupation of time-slots on a wavelength can be represented as an integer set $\{v_{w'} | \forall w' \in W, 0 \le v_{w'} \le \mathrm{TS}\}$. Using $v_{w'}$, the on-line traffic grooming objective is to find minimum cost and bandwidth path(s) $P_i^{w'}$ on wavelength(s) $w' \in W$ between a source node $s^{i,w'}$ to its destination $d^{i,w'}$ at *a given* arrival time $t_a^{i,w'}$ for a duration $t_h^{i,w'}$. The overall aim is to maximize the network throughput such that the established requests must not be interrupted.

5. Dynamic routing model

In this section, an overview on dynamic routing approaches in optical networks is presented. In these approaches, bandwidth requirements for connection requests are expressed in terms of the number of time-slots. In this respect, we assume that a