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A call admission control for service differentiation and fairness management in WDM grooming networks

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Abstract

We investigate a call admission control (CAC) mechanism for providing fairness control and service differentiation in a WDM network with grooming capabilities. A WDM grooming network can handle different classes of traffic streams which differ in their bandwidth requirements. We assume that for each class, call interarrival and holding times are exponentially distributed. Using a Markov Decision Process approach, an optimal CAC policy is derived for providing fairness in the network. The Policy Iteration algorithm is used to numerically compute the optimal policy. Furthermore, we propose a heuristic decomposition algorithm with lower computational complexity and good performance. Simulation results compare the performance of our proposed policy with those of Complete Sharing and Complete Partitioning policies. Comparisons show that our proposed policy provides the best performance in most cases. Although this approach is motivated by WDM networks, it may be deployed to determine the optimal resource allocation in many problems in wireless and wired telecommunications systems.

Keywords: Wavelength division multiplexing (WDM); Service differentiation; Markov decision process (MDP); Traffic grooming; Fairness control

1. Introduction

Wavelength division multiplexing (WDM) with grooming capabilities is a promising candidate for handling the bandwidth demand of future Wide Area Networks. In WDM networks, each optical path must be established with a specific wavelength between the members of each source–destination pair. This is known as *wavelength continuity constraint* and can be relaxed by using wavelength converters at intermediate nodes. Although each wavelength can have a transmission capacity up to ten gigabits per second (e.g., OC-48 or OC-192), some traffic streams may require lower bandwidth (e.g., OC-3 or OC-12). To utilize the wavelengths more efficiently, traffic grooming is deployed for sharing the capacity of a wavelength among users with different bandwidth granularities by multiplexing/demultiplexing the lower rate traffic onto high capacity wavelengths. Therefore, the bandwidth of

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each wavelength may be divided into a set of time slots. Depending on the bandwidth requirement of a traffic demand, one or multiple time slots can be used to accommodate the traffic [16].

In WDM grooming networks, nodes are equipped by optical add/drop multiplexers (OADMs) and optical cross-connects (OXCs). OXCs can have wavelength converter (WC) and time slot interchanger (TSI) devices. TSIs are used to switch a set of time slots from one wavelength to another, whereas WCs convert an incoming wavelength to another outgoing wavelength.

Many heuristic algorithms such as First-Fit, Most-Used, Max-Sum and Random wavelength assignment have already been proposed for the case where each call occupies the whole wavelength [15]. The objective of these algorithms is typically to minimize the overall call blocking probabilities in a *single-rate* WDM network. Some complementary studies related to this problem can be found in [1,3,17]. A few analytical models have been proposed in the literature for computing the blocking probabilities in *multi-rate* WDM networks with grooming capabilities [10,12, 13]. In [13], a capacity correlation model is presented for evaluation of blocking probabilities in a multi-hop single-wavelength path, whereas [12] discusses the numerical computation of the blocking rates in a two-class network without capacity correlation between the links. An analytical model is provided in [10] for evaluating the blocking performance in WDM–time division multiplexing (TDM) networks. The fairness issue in WDM grooming networks is investigated in [14]. In this study, a CAC mechanism is used to improve the fairness in the network. The CAC algorithm is implemented on the basis of current statistics results (i.e., blocking probabilities of different classes in the whole network). This mechanism can be used only after the network passes the transient condition. This is because the blocking probabilities of the system may not be known or accurate. This algorithm is dependent on such a warm-up period, and during this period the algorithm cannot provide fairness [14].

The purpose of this paper is to develop a call admission control to provide fairness control and service differentiation in WDM grooming networks. We first define a Markov decision process (MDP), with the objective of maximizing class-based utilization in a single-wavelength single-link network. On the basis of MDP formulation, a CAC scheme can be determined as a function of current capacity usage on each wavelength. The Policy Iteration algorithm can be deployed to determine the optimal CAC policy [8]. Since implementing an MDP-based CAC mechanism is very difficult for a complex network topology, we develop heuristics and make some assumptions to extend the result of the single-wavelength single-link network to apply to multi-wavelength multi-link tandem and ring networks. A tandem topology is an arrangement or sequencing of links in which the output terminal of one link is directly connected to an input terminal of another link. A two-hop tandem network is shown in Fig. 2. In this study, we concentrate on developing an estimation of a CAC scheme which provides accurate results with lower computational complexity. In many admission control and resource allocation problems, it has been shown that under some conditions, an optimal policy for an MDP exists and it is stationary and monotone [7].

The rest of the paper is organized as follows. In Section 2, we introduce the network model. Section 3 deals with MDP formulation for a single-wavelength single-link network and the discounted reward function associated with the problem in the infinite horizon case. Section 4 shows the structure of the optimal policy and Section 5 describes our proposed heuristic algorithm. Section 6 compares the performance of the proposed policy with those of other standard policies. Conclusions are presented in Section 7.

2. Network model

We consider a WDM grooming network consisting of L links. The network includes M origin–destination (o–d) pairs, indexed by $m = 1, 2, \ldots, M$. All nodes are equipped with OADMs. Each link carries one fiber with W wavelengths, and each wavelength includes T time slots. In this paper, we consider two types of network in terms of WC and TSI usage: networks with WCs and TSIs and networks without any WC or TSI. In a WDM network without WCs and TSIs, the *wavelength continuity constraint* is considered. The network supports K classes of traffic streams, $c_1, c_2, \ldots, c_K$, which differ in their bandwidth requirements. Class c_k traffic requires t_k