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Grade-of-service differentiated static resource allocation schemes in WDM networks

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Abstract

This paper presents a study on the Grade-of-Service (GoS) differentiation of static resource allocation in lightpath routed WDM networks, where lightpath requests between node pairs are given. Each request is associated with a service grade. The goal is to maintain certain service levels for the requests of all grades. The service levels are measured in terms of their acceptance ratios. We solve this network optimization problem by adopting a penalty-based framework, in which network design and operation goals can be evaluated based on cost/revenue. We propose a static GoS differentiation model as one minimizing the total rejection and cost penalty, in which the rejection penalty reflects the revenue of accepting a request, and the cost penalty reflects the resource consumption of providing a lightpath to a request. Then, a solution based on the Lagrangian relaxation and subgradient methods is used to solve the proposed optimization problem. Three different application scenarios are presented: static GoS differentiation of requests between the same node pair, static GoS differentiation of requests between different node pairs, and an integration of static GoS differentiation into the network profit objective. The fairness issues and the impact of relative penalty factors are discussed to provide guidelines for network planning.

Keywords: Resource allocation; Wavelength routed WDM networks; Routing and wavelength assignment; Service grade; Service differentiation; Fairness issues; Network profit optimization

1. Introduction

Grade-of-Service (GoS) is important in the design of Wavelength Division Multiplexing (WDM) networks, since optical networks serve an increasing number of services, each having different requirements. As Quad-play (data, voice, video and mobile communications) and high-performance computing traffic converge to IP and optical networking architectures, the resource allocation schemes in WDM networks must be able to provide GoS for the mixed traffic, i.e., the Routing and Wavelength Assignment (RWA) algorithms have to consider diversified requirements of the Quad-play traffic, such as the fairness of the request acceptance and resource allocations.

Classical RWA algorithms do not consider the distribution of accepted requests for different node pairs and for different service grades. There is no

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differentiated service grade in existing RWA algorithms, since they assume that all requests have the same priority (grade). Static RWA algorithms are used to allocate resources when lightpath requests are given. These algorithms typically aim at minimizing the overall resource requirement to accommodate all requests, or maximizing the overall utilization of a network that serves a single grade of requests. The latter is modeled as one minimizing the average number of fibre hops, minimizing the average node-to-node transmission delay, and minimizing network congestion. For a review, see [1,2]. However, with the network evolution from single to multiple services, it is important to provide a controlled GoS. Service grades can be defined according to network management policies [3,4]. In short, we use the terminology "static GoS differentiation" standing for GoS differentiated static resource allocation. In this paper, we focus on point-to-point logic connections (i.e., lightpaths) in wavelength routed WDM networks.

The challenge in providing a controlled GoS is that certain service levels should be maintained for requests of every grade. Meanwhile, pursuing maximal overall revenue of a converged transport network becomes even more challenging than that in single-grade traffic situation. The differentiation of service grades adds a dimension to the classical RWA problem, which requires new resource allocation algorithms. Although a high-grade request should have a better chance to be accepted (i.e., a high-grade request should experience a higher service level than a low-grade one), by no means a low-grade request can only be accepted after all high-grade requests are accepted. Requests of different grades generally share the same pool of resources. After allocating resources for all high-grade requests, resources may not be sufficient to maintain the service level of the low-grade. In contrast, rejecting a small set of high-grade requests could make a lot of critical resources available for low-grade requests, thus service levels are maintained for every grade. As such, service differentiation trade-offs must be studied. Specifically, the selection of rejected high-grade requests, and its impact on the network operation objectives should be investigated.

Static and dynamic GoS differentiations use distinct mechanisms. We study the static GoS differentiation, where all requests must be handled together as a whole. In contrast, in the dynamic GoS differentiation, requests are handled one by one. From the algorithm design point of view, the searching space of the global optimal solution of a static resource allocation is several orders greater than that in the dynamic case. None of the existing dynamic GoS differentiation mechanisms can be readily adapted for the static case. Three types of mechanisms are used to provide the dynamic GoS differentiation: resource preservation for future high-grade requests, in which each grade has a set of pre-determined wavelengths [5–7]; different routing for different grades, in which a high-grade request has more candidate routes, and thus has a better chance to be routed through than a low-grade one [7]; and controlled preemption of low-grade lightpaths [7,8].

We model the static GoS differentiation using a penalty/price-based optimization formulation. Assigning a high rejection penalty to a request makes the request less likely to be rejected than others. By assigning a proper relative rejection penalty for each request, a desired GoS differentiation can be achieved. The basis of our formulation is that all objectives such as GoS, fairness, and load-balancing can be integrated into one ultimate goal of maximizing the profit, and then be evaluated in monetary values. In our previous work [9], we optimized static resource allocations for a single grade of service by maximizing the revenue, which was also modeled as one minimizing the rejection penalty. However, we did not discriminate lightpaths using different network resources, and did not study the service differentiation. Here, we propose a new formulation considering both GoS differentiation and resource consumption.

Fairness deserves more study in the static GoS differentiation. The term fairness can be defined in different ways. Due to the wavelength continuity constraint, a request between two distant nodes suffers from a higher blocking ratio than a request between two nearby nodes [10]. A. Szymanski, et al., investigated the fairness in dynamic GoS differentiation [7]. Their computation results show that although the majority of node pairs in the high-grade service perceive a low blocking ratio, a few node pairs in the high-grade service perceive a much higher blocking ratio than the average. The GoS service contract of these unfairly treated node pairs may be violated. In our previous work, we studied the fairness of a static RWA algorithm for a single grade of requests [9]. So far, no study has been conducted on the fairness issue of the static GoS differentiation in the literature.

Specifically, the major contributions of this paper are as follows:

1. Proposal of a static GoS differentiation model as one minimizing the rejection and cost penalty: The rejection penalty reflects the revenue of accepting a request, while the cost penalty reflects the resource consumption of providing a lightpath to a request;