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Distributed dynamic QoS-aware routing in WDM optical networks ☆

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Abstract

As the WDM technology matures and the demand for bandwidth increases, dynamic provisioning of lightpaths at the WDM layer becomes an important and challenging problem. Any distributed algorithm for routing dynamic traffic should be simple, efficient, and also scalable. Most of the multimedia and real-time applications require specific quality of service (QoS), hence it is important that the routing algorithm should provide lightpaths which satisfy the required QoS. The QoS also includes fault-tolerance besides guarantees on different metrics such as bandwidth, bit-error-rate, and reliability. In this paper, we propose distributed dynamic routing algorithms for QoS constrained routing and survivable routing, based on preferred link routing approach. For QoS constrained routing, we provide a common framework for routing connections with constraints on different types of metrics such as bandwidth (a concave metric), delay and bit-error-rate (additive metrics, and should be minimum for a best QoS path), and reliability (multiplicative metric, and should be maximum for a best path). The framework considers multiple QoS constrained routing which is an NP-Complete problem. We also propose a distributed routing algorithm for fault-tolerant connections, and describe how dedicated and shared protection can be provided in the case of single link failures. We have conducted simulation experiments with bit-error-rate and reliability as the metrics to evaluate the performance of the proposed multiple constrained QoS routing algorithm. We have also studied the performance of the fault-tolerant routing in terms of call acceptance ratio, cost of the path, hop length, and call setup time, and compared the results with that of an existing approach. Our experimental results suggest that our algorithms out perform the existing methods with respect to the average number of calls accepted.

Keywords: Wavelength division multiplexing; Distributed control; Dynamic routing; Multiple constrained QoS; Fault-tolerance; Preferred link routing

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1. Introduction

Wavelength division multiplexing (WDM) technology plays a key role in providing huge bandwidth capacity in optical backbone networks. In WDM, data is transmitted through different wavelengths of an optical fiber. A WDM optical network consists of wavelength cross-connects (WXCs) interconnected by point-to-point fiber links in an arbitrary mesh topology. In these networks, a connection is established using a *lightpath*, which is an all optical communication path between the source and destination of the connection request [1,2]. The requirement that the lightpath should use the same wavelength on all the links of the chosen route is known as the *wavelength continuity constraint*. If a lightpath is established between any two nodes, traffic between these nodes can be routed without requiring any intermediate optical to electrical conversion, and buffering. Traffic demand can be either static or dynamic. In a *static lightpath establishment* (SLE), traffic demand between node pairs is known a-priori and the goal is to establish lightpaths so as to optimize a certain objective function (maximizing single-hop traffic, minimizing congestion, minimizing average weighted hop count, etc.). The nodes together with the set of lightpaths at the *optical layer* form a *virtual topology* [2]. The *dynamic lightpath establishment* (DLE) problem is concerned with establishing lightpaths with an objective of increasing the average call acceptance ratio (or equivalently reducing the call blocking probability), when connection requests arrive to and depart from the network dynamically. Several heuristic algorithms for establishing lightpaths, also known as the routing and wavelength assignment (RWA) algorithms, are available in the literature [3–6].

Connection establishment can use either centralized control or distributed control. In case of centralized control, a central controller is present, which maintains coordination among the nodes of the network in establishing and releasing connections. Centralized control is advantageous as it efficiently utilizes the network resources. But it is subject to single point failure. Also, with an increase in traffic load, the control traffic to and from the controller increases substantially. Moreover, centralized control algorithms are not scalable to large networks. To overcome these disadvantages, various distributed protocols such as forward reservation and backward reservation have been proposed [7,8]. In distributed control, the network can be thought of as a two-plane architecture consisting of a control plane and a data plane. In the control plane, control information is exchanged. One wavelength on each link can be used for this purpose. The actual data is transmitted in the data plane. In distributed control, no node has the global state information of the network. It is characterized by the control messages and the sequence of actions to be performed upon receiving these messages.

1.1. Quality of service in WDM networks

Quality of service (QoS) is the performance level of a service offered by the network to the user. The goal of QoS provisioning is to achieve a more deterministic network behavior, so that information carried by the network can be better delivered and network resources can be better utilized. QoS can be classified into two categories:

(1) *qualitative requirements* of optical signal such as bit-error-rate (BER), transmission delay, and signal quality, and requirements of components such as reliability, along the route chosen for establishing connection;
(2) *functional requirements* such as survivability. We now discuss qualitative QoS and defer the discussion on survivability to the next section.

In a wavelength-routed optical network spanning large area, an optical signal may traverse a number of intermediate nodes and long fiber segments. Each component along the path such as fiber, WXCs, and erbium-doped fiber amplifiers (EDFAs) induces some delay, jitter, and BER in the transmission signal [9,10]. Also, associated with each component is reliability, which is the probability that the component functions correctly over a period of time [11]. A reliable connection is quite different from that of a fault-tolerant