Minimizing the Number of Multicast Transmissions in Single-Hop WDM Networks

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Abstract. The problem of minimizing the number of transmissions for a multicast transmission under the condition that the packet delay is minimum in single-hop wavelength division multiplexing (WDM) networks is studied in this paper. This problem is proved to be NP-complete. A heuristic multicast scheduling algorithm is proposed for this problem. Extensive simulations are performed to compare the performance of the proposed heuristic algorithm with two other multicast scheduling algorithms, namely, the greedy and no-partition scheduling algorithms. The greedy algorithm schedules as many destination nodes as possible in the earliest data slot. The no-partition algorithm schedules the destination nodes of a multicast packet to receive the packet in the same data slot without partitioning the multicast transmission into multiple unicast or multicast transmissions. Our simulation results show that (i) an algorithm which partitions a multicast transmission into multiple unicast or multicast transmissions may not always produce lower mean packet delay than the no-partition algorithm when the number of data channels in the system is limited and (ii) the proposed heuristic algorithm always produces lower mean packet delay than the greedy and the no-partition algorithms because this algorithm not only partitions a multicast transmission into multiple unicast or multicast transmissions to keep the packet delay low but also reduces the number of transmissions to conserve resources.

Keywords: single-hop WDM networks, multicast scheduling, star coupler WDM networks

1 Introduction

The demands for networks with high bandwidth and efficient multicast mechanisms are increasing. Examples such as video conferences, video on demand, and image distributions require high bandwidth and multi-destination communications. In the future, it is predicted that the per user bandwidth demand will be approximately 1 Gb/s [1,2].

The vast bandwidth of a fiber (more than 30 THz [3,4]) can be divided into a lot of high-speed channels using the wavelength division multiplexing (WDM) technology. Each of the channels is capable of operating at the peak rate of an electronic interface. The WDM network considered in this paper is a WDM star coupler network consisting of a number of network nodes connected via optical fibers to a passive star coupler as shown in Fig. 1. Each node is equipped with one or more fixed or tunable transmitters and one or more fixed or tunable receivers. The passive star coupler is able to combine all input optical signals and broadcast the combined signal to all outputs.

In single-hop WDM networks [5], a data packet can be transmitted from one node to another only when one of the transmitters of the source node and one of the receivers of the destination node are tuned to the same wavelength; i.e., a data packet is transmitted from one node to another without going through intermediate nodes. The wavelengths at which the nodes communicate with each other are referred to as channels. Since the number of channels may be less than the number of nodes and two or more nodes may want to send data packets to the same destination node, coordination among nodes that wish to communicate with each other is required. Many access protocols for coordinating data transmissions have been proposed in the literature. These scheduling algorithms can be classified into three categories, namely, random-access based [6], pre-allocation based [7–10], and reservation based scheduling algorithms [11–27].

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Reservation-based scheduling algorithms can be further classified as one-by-one scheduling [11–16] or batch scheduling [17–27] depending on whether reservation requests are processed one at a time or a batch at a time.

Packet scheduling in single-hop WDM networks is similar to packet (or cell) scheduling in input-buffered switches [28–32]. However, there are a number of differences between scheduling packets in these two systems. First of all, due to the nature of input-buffered switches, random-access based algorithms cannot be used in input-buffered switches. Secondly, the input buffers are usually integrated in the switch in an input-buffered switch; while the buffers in a single-hop WDM network are collocated with the nodes which may be located at different cites from the passive star coupler. Therefore, the status of the buffers in an input-buffered switch is readily available in the switch; while the status of the buffers in a single-hop WDM network are located distributedly in the nodes. To obtain all the status of the buffers in a single-hop WDM network, a protocol for collecting or broadcasting the buffer status is required. Thirdly, the maximum number of inputs of an input-buffered switch which can simultaneously send unicast packets to the outputs usually depends on the numbers of inputs or outputs whichever is smaller. In a single-hop WDM network, the maximum number of nodes which can simultaneously send unicast packets to other nodes depends on the number of channels for data transmissions or the number of nodes whichever is smaller. The number of data channels in a single-hop WDM network could be less than (sometimes significantly less than) the number of nodes in the network due to the characteristics of the transmitters and receivers in the nodes. Other factors which may affect the scheduling of packets in single-hop WDM networks include propagation delays, synchronization delays, and tuning delays.

A number of the scheduling algorithms for single-hop WDM networks mentioned above are designed for multicast transmissions [6,9,10,12,15,23]. Among the reservation-based multicast scheduling algorithms, the algorithms proposed in [12,15] use the one-by-one scheduling scheme. The algorithm proposed by Ortiz et al. [23] employs the batch scheduling scheme. The multicast scheduling algorithms proposed by Rouskas and Ammar [9] and Borella and Mukherjee [12] schedule multicast packets such that the receivers of all destination nodes must tune to the same channel at the same time. If the receivers of one or more destination nodes are not available, transmission of the data packet is delayed. The multicast protocols proposed by Modiano [6], Tseng and Kuo [10] and Jue and Mukherjee [15], and Ortiz et al. [23] allow a multicast transmission to be partitioned into multiple unicast or multicast transmissions. In the following we shall give a brief survey of those algorithms which are designed for multicast transmissions.

Modiano [6] proposed several random-access based multicast scheduling algorithms by combining two schemes for transmitting packets and three schemes for receiving packets. One of the schemes for transmitting packets transmits a packet continuously until it is received by all of its destination nodes. The other scheme for transmitting packets introduces random delays between retransmissions of the same packet. When two or more packets are transmitted to the same destination node at the same time, the receiver at the destination node needs to select one of the packets to receive. Three schemes for selecting one of the packets to receive were considered. The first scheme selects one of the packets randomly. The second scheme selects a packet based on the order that they were transmitted. The third scheme selects the packet which has the smallest number of remaining intended destinations. The results in [6] show that the combination of introducing random retransmission delays and selecting the packets with smallest number of remaining destinations has the best performance.

Pre-allocation based multicast scheduling algorithms can be found in [9,10]. Rouskas and Ammar [9] proposed a multi-destination communication protocol for single-hop WDM networks. In their network model, each node is equipped with one fixed node.