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Optimal all-to-all broadcast in WDM optical networks with breakdown or power-off transceivers

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Abstract

All-to-all broadcast is an interesting special case of the packet transmission scheduling in which every pair of nodes has exactly one packet to be transferred. This paper considers the all-to-all broadcast problem in wavelength division multiplexed (WDM) optical star network with some breakdown or power-off transceivers. For reaching high data transmission rates, we will focus the problem on the all-optical scheduling where the traffic reaches its destination in single-hop without being converted to electronic form. Each transmitter is tunable with an associated tuning delay and each receiver is fixed-tuned to one of available wavelengths. In this model, we study two kinds of all-to-all broadcast problems depending on whether each node transmits packets to all nodes including or except itself. We identify the lower bound of the scheduling length for each kind of problems and propose single-hop scheduling algorithms to find the optimal solution in both terms of arbitrary number of wavelengths and value of tuning latency.

Keywords: Packet scheduling; All-to-all broadcast; Single-hop scheduling algorithm; Tuning delay; Wavelength division multiplexing

1. Introduction

Wavelength division multiplexing (WDM) technology provides concurrent transmissions on an optical fiber through different channels of wavelengths. The WDM optical network with the broadcast-star architecture has found applications in local area networks with very high speed information transfer rates [1]. In such a WDM network, each wavelength channel is necessary to share among many network nodes since the number of wavelength channels is typically limited to a small number. For the efficient use of bandwidth, the tunability is usually supported in network nodes. In general, transceivers of nodes can be classified into four categories depending on the tunability of transceivers for each node: fixed transmitter(s) and fixed receiver(s) (FT-FR); fixed transmitter(s) and tunable receiver(s) (FT-TR); tunable transmitter(s) and fixed receiver(s) (TT-FR); and tunable transmitter(s) and tunable receiver(s) (TT-TR) [2]. However, the tunability is an expensive alternative, hence each node is usually equipped with one tunable transmitter and one fixed receiver (TT/FR). In this paper, we consider the transmission scheduling problem in an N-node WDM broadcast-star network with TT/FR transceivers. Each tunable transmitter has tuning latency δ to tune from one wavelength to another that will affect the performance of scheduling algorithms because the tuning latency is greater than the packet transmission time. Tuning latency limits the network throughput as nodes spend time in tuning, which could otherwise be used in useful information transfer. Therefore, how to minimize the effect of tuning latency on the transmission scheduling for a given traffic matrix is a critical issue.

This paper is concerned with the single-hop scheduling where traffic reaches its destination without being converted

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to electronic form for reaching high data transmission rate. Obviously, maintaining the data signal in single-hop will allow the all-optical transmission and eliminate the electronic bottleneck of electronic switching components [3]. In an N-node WDM broadcast-star network, the single-hop packet transmission scheduling problem can be reduced to the open shop scheduling problem when tuning latency $\delta = 0$ [4]. Packet transmission is called non-preemptive if the transmitter is not involved in any other transmission until it completes its current transmission and preemptive otherwise. The non-preemptive open shop scheduling problem is NP-complete when $N \geqslant 3$ and can be solved in polynomial time if $N = 2$ [5]. However, the single-hop packet transmission scheduling problem has been proven as NP-complete even when $N = 2$ [4].

The all-to-all broadcast problem is an interesting special case of the single-hop packet transmission scheduling problem. Every node pair has exactly one packet to be transferred for the all-to-all broadcast. If each node transmits packets to all nodes including itself, N^2 packets should be transmitted for an N-node WDM broadcast-star network. Several optimal scheduling algorithms have been proposed for the all-to-all broadcast problem in wavelength division multiplexed (WDM) optical star networks [6,7,10]. However, these scheduling algorithms do not fit anymore when failures occur in some transceivers. In this paper, we consider the all-to-all broadcast problem in WDM optical star network with some breakdown or power-off transceivers. Each node in the network is assigned a tunable transmitter and a fixed-tuned receiver. We focus the problem not only on the case when each node transmits packets to all nodes including itself [14], but also on the case when each node transmits packets to all nodes except itself. We identify the lower bounds of the minimum scheduling length for the problem and propose single-hop scheduling algorithms to find the optimal solution in both terms of arbitrary number of wavelengths and value of tuning latency.

2. Related work

When each node transmits packets to all nodes including itself on the all-to-all broadcast problem, several investigations have been carried out. In [6], Pieris and Sasaki proposed several upper and lower bounds of minimum scheduling length for the all-to-all broadcast problem. They assumed that the transmitters are tunable to any one of wavelengths with tuning latency δ, and the number of available wavelengths is large enough. If packet transmissions are allowed while a transmitter or receiver is tuning from one wavelength to another, they found that the upper and lower bounds for the minimum scheduling length of all-to-all broadcast are $(N + o(N)) * (\sqrt{\delta} + 1)$ and $(N + o(N)) * \sqrt{\delta}$, respectively. However, there is a tune-transmit separability constraint that packets cannot be transmitted while a transmitter or receiver is tuning. For satisfying the tune-transmit separability constraint, they found that the upper and lower bounds for the minimum scheduling length of all-to-all broadcast are $(N + o(N)) * (\lceil\sqrt{\delta}\rceil + \sqrt{\delta})$ and $(2N + o(N)) * \sqrt{\delta}$, respectively. In [7], Choi et al. considered an important limitation when the number of wavelengths w is significantly less than the number of transceivers N, and assumed that each wavelength is exactly shared by N/w receivers for a uniform loading of wavelengths. They established lower bounds on the minimum scheduling length to exchange packets between every node pair in a network with tunable transmitters and fixed-tuned receivers. They showed that the lower bound for the minimum scheduling length of all-to-all broadcast is at least $\max\{\delta + N^2/w, w\delta + N^2/w^2 + N - N/w\}$, and the upper bound obtained in [6] is in fact a lower bound to the optimum schedule length, i.e., the all-to-all transmission schedule presented in [6] is an optimal schedule for the case of uniform loading of wavelengths. In [8], they also consider the case when N is not divisible by w. The wavelengths are loaded with fixed-tuned receivers as uniformly as possible. They proposed optimal scheduling algorithms for three different cases depending on the range of tuning latency δ. Excepting for a very narrow range, their algorithms perform within a factor $\frac{13}{12}$ of the lower bound.

If each node transmits packets to all nodes except itself, the number of packets to be sent for the all-to-all broadcast is $N(N - 1)$. In [9], Lee et al. showed that $\max\{N(N - 1)/k, w\delta + N - 1\}$ is a lower bound for the cycle lengths of schedules and proposed an algorithm for obtaining a transmission schedule that meets this lower bound under the assumption that N is divisible by w. In [10], Yeh et al. studied both kinds of all-to-all connection problems depending on whether each node transmits packets to all nodes including or excepting itself and proposed two lower bounds for these two kinds of problems, $\max\{\lceil N/w\rceil N, w\delta + N\}$ and $\max\{\lceil N/w\rceil(N - 1), w\delta + N - 1\}$, respectively. They also proposed scheduling algorithms to find the optimal scheduling for arbitrary values of N, w, and δ.

Choi et al. [11] studied a case when transmitters may access to only a limited number of channels, i.e., the number of channels to which a laser can tune may be much smaller than the number of channels. They developed an algorithm that provides an optimal for all-to-all broadcast with limited tuning ranges. In [12], Lee et al. considered the problem as a virtual topology embedding problem. If each node is equipped with α tunable transmitters and β fixed-tuned receivers, they developed an optimal transmission schedule with schedule length $\max\{\alpha\beta N(N-1)/w, \beta(N-1) + w\delta\}$ such that each transmitter of each node transmits once to each receiver of its neighboring nodes within this time period. In [13], Li conducted probabilistic analysis of the average-case performance of a packet transmission scheduling algorithm for the cyclic all-to-all broadcast. Their result implies that by using currently available tunable optical transceivers, it is possible to build single-hop WDM networks that efficiently utilize all the wavelengths.