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Computer Communications 31 (2008) 2030–2038
computer communications
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Optimization of logical rings for multi-hop transmissions in WDM optical star networks

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Received 23 April 2007; received in revised form 1 January 2008; accepted 6 January 2008
Available online 17 January 2008

Abstract

In this paper, we present a multi-hop scheduling algorithm for the All-to-All Broadcast (*AAB*) problem in Wavelength Division Multiplexed (WDM) optical star networks with N nodes. To decrease the packet delay in packet transmissions, our scheduling algorithm will limit the hop distance to a constant ρ. We transfer the ρ-hop *AAB* problem to the Hamiltonian cycles problem and then generate the logical rings for physical packet transmissions. In order to minimize the scheduling length, the problem of selection of logical rings is to minimize the number of tuning operations to reduce the influence of tuning latency δ for the *AAB* problem. We propose a 2-approximation algorithm that needs only $2\lceil (N-1)/\rho \rceil$ tuning operations in an AAB scheduling. When $\rho < \frac{\delta + \sqrt{\delta^2 - 8\delta}}{2}$, the schedule length of our algorithm will be shorter than that of the optimal single-hop scheduling algorithm.

Keywords: Wavelength Division Multiplexed (WDM); All-to-All Broadcast (*AAB*); Multi-hop scheduling; Hamiltonian cycle; Approximation algorithm

1. Introduction

In Wavelength Division Multiplexed (WDM) optical networks, the broadcast-star [1,2] as Fig. 1, in which each node is connected to a passive star via bidirectional fibers, is a popular architecture. The passive star coordinates all packet communications. Firstly, it merges optically all packet transmissions on distinct wavelength channels and forwards synchronously to their destination nodes. In a WDM optical broadcast star network with N nodes and w wavelengths, the scheduling problem is to find an efficient scheduling algorithm to minimize the schedule length for given traffic demands. The All-to-All Broadcast (*AAB*) is a special case of the transmission scheduling in which each node sends exactly a packet to all other nodes. It is one of the most common communication patterns in high performance computing. There are many high-performance applications, including matrix transpose, multidimensional convolution, and data redistribution [3].

There are two methods to solve the *AAB* problem. The first method is the single-hop scheduling algorithm [4,5] in which each packet transmission is sent through only one hop distance. In [4,5], authors gave some single-hop scheduling algorithms to obtain optimal schedules. They also show that the schedule length of optimal schedules is $\max\{\lceil \frac{N}{w} \rceil (N-1), w\delta + N - 1\}$, where δ is the tuning latency for tuning from one wavelength to another. In the practical condition, the tuning latency δ is much longer than packet transmission time [1,6], and the optimal scheduling length is seriously affected by the long tuning latency. In this case, we need the second method which is called the multi-hop scheduling algorithm [7,8,10,9]. In the multi-hop scheduling, packet transmissions can be sent indirectly to destination nodes. In [8], Marsan et al. gave a multi-hop scheduling algo-

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doi:10.1016/j.comcom.2008.01.004

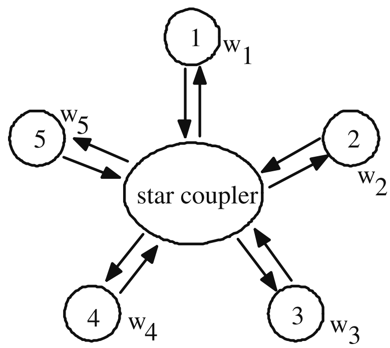

Fig. 1. WDM optical broadcast-star network with 5 nodes.

rithm to obtain a shorter scheduling length than the results by single-hop scheduling algorithms, especially with long tuning latency.

In this paper, we consider the optical and electronic transformation (O/E/O) bottleneck. Since the O/E/O operations lead to many buffer overflows in the multi-hop transmission and decreasing the system performance substantially. Therefore, we will restrict the hop distance of packet transmissions to a constant ρ. Our problem is to design a multi-hop scheduling algorithm for the *AAB* problem with maximum ρ hop distance (the ρ-*AAB* problem) in WDM optical broadcast-star networks with N nodes and w wavelengths. Let each node be equipped with a Tunable Transmitter and a Fixed Receiver (TT–FR)[11,12]. Since the number of wavelengths is often less than the number of nodes, we assume that each wavelength is at most shared by $\lceil N/w \rceil$ receivers for an uniform loading of wavelengths. For simplifying the ρ-*AAB* problem, we will firstly consider the transmission scheduling on the case of $N = w$, and then process the general case of $N \geqslant w$ by a similar scheduling method with partitioning N nodes into w groups. Assume each transmitter in the same transmission group tunes its wavelength synchronously. In order to minimize the scheduling length, we design logical rings for a transmission group of w nodes to achieve ρ-hop transmission and minimize the number of tuning operations in scheduling to decrease the influence of tuning latency.

For example, we consider the ρ-hop *AAB* problem in a WDM broadcast-star network with five nodes and the received wavelength of node i is fixed as w_i, $1 \leqslant i \leqslant 5$. Firstly, if we solve the 1-*AAB* problem by using the optimal single-hop scheduling algorithm in [4,5], the optimal schedule length is $4 + 5\delta$. Secondly, if we solve the 4-*AAB* problem on a logical ring as Fig. 2a, we need only one tuning operation of each transmitter, and then the schedule length is $10 + \delta$. Clearly, when $\delta \geqslant 2$, the schedule length of 4-*AAB* problem is better than that of 1-*AAB* problem. Finally, if we solve the 2-*AAB* problem on two logical rings as Figs. 2a and b in two steps, the schedule length will be improved to $6 + 2\delta$. In the first step, each node i tune simultaneously its transmitted wavelength to $w_{(i+1 \bmod 5)}$, $1 \leqslant i \leqslant 5$ to construct a logical ring as Fig. 2a. Now we can schedule 10 packet transmissions with one hop and two hop separately on Fig. 2a. In the second step, all nodes again tune their transmitted wavelengths to construct another logical ring as Fig. 2b. We also schedule the other 10 packet transmissions on Fig. 2b. Thus we need only two tuning operations in scheduling for the 2-*AAB* problem, and the schedule length is $6 + 2\delta$. In the 2-*AAB* problem, we reduce not only the tuning times for the 1-*AAB* problem but also the O/E/O transformations for the 4-*AAB* problem.

We design two logical rings as Figs. 2a and b for scheduling all packet transmissions of the 2-*AAB* problem. When a logical ring is transferred to another logical ring, we need a tuning operation in scheduling. If we minimize the number of logical rings designed for the ρ-*AAB* problem, we also minimize the number of tuning operations during the scheduling. Now, a subproblem of the ρ-*AAB* problem is to minimize the number of logical topologies. This subproblem is called the Logical Rings Chosen(*LRC*) problem with maximum ρ hop distance (the ρ-*LRC* problem).

The ρ-*LRC* problem is described as follows. In WDM optical broadcast star networks with N nodes and N wavelengths, construct a set of logical rings $R = \{r_1, r_2, \ldots, r_m\}$ for each pair of nodes (i,j) such that $\mathrm{Dist}(i,j) \leqslant \rho$. Note that $\mathrm{Dist}(i,j)$ is the minimal number of hop distance from node i to node j in logical rings R. Our objective is to minimize the number m of logical rings. We mention two conditions with the solution of ρ-*LRC* problem in Section 4 and propose a lower bound $2(\lceil \frac{N-1}{\rho} \rceil - 1)$ by these two conditions for our

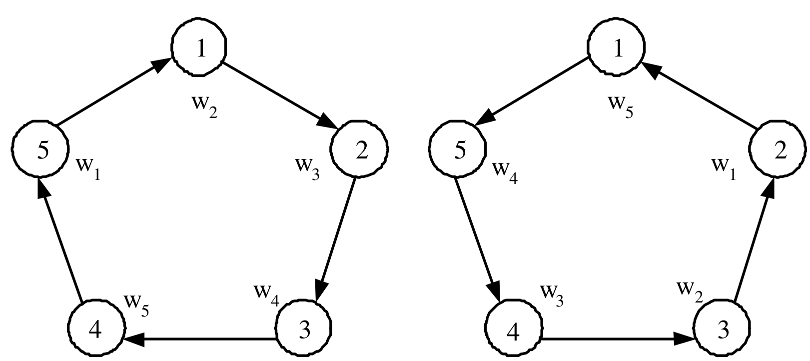

Fig. 2. Logical rings for the *AAB* problem.