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ORIGINAL ARTICLE

Optical omega networks with centralized buffering and wavelength conversion

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Abstract In this paper, we study the internal blocking problem in optical Multistage Interconnection Networks (MINs). We introduce algorithms to resolve internal blocking in optical MINs based on buffering and/or wavelength conversion. Since the computations involved in some of the introduced algorithms are so little, they can be implemented in real time effectively. A simulation program has been developed to verify the performance enhancement gained using the algorithms. Simulation results indicate that the developed algorithms effectively decreased the internal blocking and thus increased the network performance.

1. Introduction

Recently, significant developments have been made in photonic switching based on Wavelength Division Multiplexing (WDM). Therefore, researchers have used this technology to implement switches such as Crossbar or Multistage Interconnection Networks (MINs) in order to upgrade the performance of the available systems that use these networks (Liboiron-Ladouceur et al., 2008; Liboiron-Ladouceur and Bergman, 2007; Shares et al., 2007; Katangur et al., 2007; Al-Shabi and Othman, 2008; Lu and Zheng, 2007; Zhang and Yang, 2006, 2007; Ngo et al., 2007; Liu, 2008). Although the crossbar does provide a powerful communication capability, it is not economically feasible as the number of inputs/outputs becomes large. Moreover, due to the random nature of input arrivals, network utilization is much less than its capacity (Lee, 1994).

MINs are used because they are less expensive, easy to control, have low delay and support large scale of inputs/outputs. One of the applications of MINs is in processor to memory communication in a parallel multiprocessing systems, in which, they allow a direct link between any processor to any memory module so the processor can access any memory module with a very small number of communication or accessing conflicts (Patel, 1981).

These multistage interconnection networks are simple, inexpensive, and easy to build in a modular fashion. However, they have a problem of internal blocking. To alleviate the problem of internal blocking in MINs based on WDM, we can use buffers (Ngo et al., 2007) or wavelength converters (Zhang and

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Notations

N	number of omega network inputs. ($N = 2, 4, 8, 16,$ or $32 \ldots$)
n	number of stages in the omega network (equals to $\log_2 N$)
ω	number of maximum wavelengths available to a specific link
BufSize	number of available buffers
WCSize	total number of available wavelength converters in the network
Inputs	input stage data structure
Outputs	output stage data structure
I	index to represent input number in a given stage ($0 \leqslant I \leqslant N-1$)
J	index to represent wavelength number in a given input link ($0 \leqslant J \leqslant K-1$)
Switch	indicates the switch number for a given stage ($0 \leqslant Switch \leqslant \frac{N}{2}-1$)
Pkt(0)	packet coming from the upper input of a switch
Pkt(1)	packet coming from the lower input of a switch
P0	status of *Pkt(0)* destination. Values meanings are: $P0 = 0(1)$ means *Pkt(0)* destined to output upper (lower) link, $P0 = -1$ means *Pkt(0)* is idle
P1	status of *Pkt(1)* destination. Values meanings are: $P1 = 0\ (1)$ means *Pkt(1)* destined to output upper (lower) link, $P1 = -1$ means *Pkt(1)* is idle
Buffer.Size	number of currently buffered packets
TotBuff	total number of input packets that have been buffered
TotDrop	total number of input packets that have been dropped
TotConv	total number of wavelength conversion operations
TotInputs	total number of input packets that entered the omega network
TotOutputs	total number of outputs that have been processed
FreeWave	set of wavelengths that are not used by both inputs in a specific switch
FreeWaves(0, 0)	unused wavelengths in the upper input link that can only go to the output upper link
FreeWaves(0, 1)	unused wavelengths in the upper input link that can only go to the output lower link
FreeWaves(1, 0)	unused wavelengths in the lower input link that can only go to the output upper link
FreeWaves(1, 1)	unused wavelengths in the lower input link that can only go to the output lower link
CurWC_No	number of free wavelength converters that can be used $0 \leqslant CurWC\_No \leqslant WCSize$

Yang, 2006). Buffering and wavelength conversion techniques have been studied in detail in all-optical networks based on circuit switching and crossbar switches (Katangur et al., 2007) and (Al-shabi and Othman, 2008). In this paper, we focus on packet switching MINs.

Solving the problem of internal blocking in MIN's has been considered in many previous researches. Amer Arafah (1997) had developed new algorithms to resolve the internal blocking in MIN in Optical domain. The developed algorithms assume that all packets of any input channel should be forwarded to a single destination. This assumption is a non realistic and restricts the application of these algorithms.

In this paper, we relax this restriction and develop new algorithms such that packets of an input channel can have different destinations. We will introduce new algorithms to alleviate the problem of internal blocking based on centralized Wavelength Division Multiplexing (WDM) and/or centralized buffering. Using centralized WDM technology, the performance of omega networks can be improved.

The performance of optical omega network in the presence of buffering and/or wavelength conversion will be studied. Simulation will be implemented to study the effect of centralized buffering and wavelength conversion in decreasing the internal dropping (and thus improving the performance) in optical omega networks.

1.1. Prior research

The multistage interconnection networks have been studied intensively in the electrical domain. But due to the speed limitation of the electronic switching, many researches have been done over these networks in the optical domain. These researches investigate the implementation of MINs based on WDM by using either Guided-Wave Fabrics, which guide the propagation of the waves along a physically constructed path, or Free-Space Fabrics which utilize the spatial bandwidth without any predefined path by using mirrors, masks, polarized beam splitter (PBS), prism gratings, lenses, etc. the main objective of these researches is to implement such networks with very high bandwidth.

In this research, our goal is to implement a control unit for multistage interconnection network which can alleviate the problem of internal blocking by using buffering and wavelength conversion, and to improve the network performance.

We redefine internal blocking as two or more packets with the same wavelength trying to access a channel simultaneously. This problem can be eliminated by increasing the number of switch elements, the number of stages, or the size of the switch element. However, all these techniques increase the cost and delay of such networks. Therefore, in this research, we attempt to use as few switch elements as possible, while maintaining the full accessibility.

To alleviate the problem of internal blocking in MINs based on WDM, we can use buffers (Ngo et al., 2007) or wavelength converters (Zhang and Yang, 2006). The advantage of wavelength conversion over buffering is the ability to utilize the available channel bandwidth and to send a packet to its destination without waiting for the next switching cycle.

Buffering and wavelength conversion techniques have been studied in detail in all-optical networks based on circuit switching and crossbar switches (Katangur et al., 2007) and (Al-shabi and Othman, 2008). In this paper, we focus on packet switching and MINs.