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BITWISE-BASED ROUTING ALGORITHMS IN OPTICAL MULTISTAGE INTERCONNECTION NETWORKS

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By

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To

My Beloved Father and Mother,
My Brothers and Sisters

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Recent advances in electro-optic technologies have made optical communication a promising networking alternative to meet the ever increasing demands of high-performance computing communication applications for high channel bandwidth, low communication latency and parallel processing as well. Optical Multistage Interconnection Network (OMIN) is very popular in switching and communication among other types of interconnection networks.

A major problem in OMIN is crosstalk, which is caused by coupling two signals within a switching element. Crosstalk problem in a switch is the most prominent factor which reduces the signal-to-noise ratio and restricts the size of network. To avoid crosstalk in OMINs many algorithms have been proposed by many researchers such as the Four Heuristic, Simulated Annealing, Genetic, Remove Last Passes and Zero Algorithms. Under the constraint of avoiding crosstalk, the interests of these

algorithms are to find a permutation that uses a minimum number of passes and minimum execution time.

Accordingly the objective of this research is to optimize and improve the current algorithms in terms of number of passes and execution time. To achieve such goal, this research follows three approaches. In the first, the Improved Zero algorithm is proposed to solve the problem and secondly, the Bitwise Improved Zero algorithm is developed. Finally Four Heuristic and Difference Increasing and Decreasing routing algorithms based on bitwise operation are established.

The results of this study show that Bitwise Improved Zero algorithms reduce the execution time nearly seven times. This reduction is very considerable because the execution time of routing algorithms is very important to route the messages in the networks. Moreover Improved Zero algorithm was shown to be more accurate and efficient compared to other algorithms in terms of the average number of passes and execution time. Furthermore by converting Four Heuristic and Difference Increasing and Decreasing routing algorithms to bitwise algorithms the execution time was improved significantly.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
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ALGORITMA PENGHALAAN BERASASKAN BIT DALAM RANGKAIAN SALING SAMBUNG BERBILANG PERINGKAT OPTIK

Oleh

FARZANEH ABED

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Pengerusi: Profesor Madya Mohamed Othman, PhD

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Perkembangan terbaru dalam teknologi elektro-optik telah menjadikan komunikasi optik sebagai satu alternatif perangkaian yang menjanjikan permintaan yang sentiasa bertambah terhadap aplikasi komunikasi pengkomputeran prestasi tinggi dipenuhi bagi lebar jalur saluran tinggi, kependaman komunikasi rendah dan juga pemprosesan selari. Rangkaian Antarasambungan Berbilang Peringkat Optikal (OMIN) adalah sangat popular di antara jenis-jenis rangkaian antarasambungan yang lain dalam pensuisan dan komunikasi.

Satu masalah utama dalam OMIN adalah *crosstalk*, yang disebabkan oleh penggandingan dua isyarat dalam sesuatu elemen pensuisan. Masalah *crosstalk* dalam suis merupakan faktor terulung yang mengurangkan nisbah isyarat-ke-bunyi dan mengehadkan saiz rangkaian. Bagi mengelakkan *crosstalk* dalam OMIN, banyak

algoritma telah dicadangkan oleh ramai penyelidik seperti Heuristik Empat, Penyepuhlindapan Tersimulasi, Genetik, Singkir Laluan Terakhir dan Algoritma Sifar. Dengan kekangan untuk mengelakkan *crosstalk*, minat terhadap algoritma-algoritma ini adalah untuk mencari suatu permutasi yang menggunakan bilangan laluan dan masa pelaksanaan yang minimum.

Objektif penyelidikan ini adalah untuk mengoptimakan dan memperbaiki algoritma-algoritma yang sedia ada dari segi bilangan laluan dan masa pelaksanaan. Untuk mencapai matlamat tersebut, penyelidikan ini menggunakan tiga pendekatan. Pertama, mencadangkan "*Improved Zero*" algorithma untuk menyelesaikan masalah. Kedua, membangunkan algorithma "*Bitwise Improved Zero*". Akhir sekali, algoritma "*Four Heuristic and Difference Increasing and Decreasing*" yang berdasarkan kepada operasi bitwise dibangunkan.

Hasil penyelidikan ini menunjukkan algorithma "*Bitwise Improved Zero*" telah menguran masa perlaksanaan menghampiri tujuh kali. Pengurangan ini amat berpatutan kerana masa perlaksanaan bagi algorithma '*routing*' adalah sangat penting dalam proses penghantaran maklumat dalam ranggkiaian. Tambahan pulu, algoritma " *Improved Zero*" telah dibukti lebih tepat dan berkesan berbanding algorithma lain dari segi purata bilangan laluan dan masa pelaksanaan. Selain itu dengan menukarkan algorithma "*Four Heuristic and Difference Increasing and Decreasing*" kepada algorithma bitwise, masa perlaksanaan dapat dipertingkatkan dengan berkesan.

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LIST OF ABBREVIATIONS

ATM	Asynchronous Transfer Mode
BSeqInc	Bitwise Sequential Increasing
BSeqDec	Bitwise Sequential Decreasing
BDegAsc	Bitwise Degree Ascending
BdegDsc	Bitwise Degree Descending
BDifInc	Bitwise Difference Increasing
BDifDec	Bitwise Difference Decreasing
DegAsc	Degree Ascending
DegDsc	Degree Descending
DifInc	Difference Increasing
DifDec	Difference Decreasing
DSB	Dilated Slipped Banyan
GA	Genetic Algorithm
BIZ	Bitwise Improved Zero
BIZ_XY	Bitwise Improved ZeroXY
IZ	Improved Zero
IZ_X	Improved ZeroX
IZ_Y	Improved ZeroY
IP	Internet Protocol
MCN	Maximal Conflict Number
MIN	Multistage Interconnection Network
OMIN	Optical Multistage Interconnection Network
ON	Omega Network
OON	Optical Omega Network

RLP	Remove Last passes
SA	Simulated Annealing
SE	Switch Element
SeqInc	Sequential Increasing
SeqDec	Sequential Decreasing
WM	Window Method
VLSI	Very Large-Scale Integration

CHAPTER 1

INTRODUCTION

1.1 Background

Depending on the particular multiprocessor, the interconnection network may provide the means to communication between processors, or between processors and memories. A large number of different interconnection networks have been proposed (Siegel, 1985), and a variety of message routing strategies have been developed.

Multistage Interconnection Network (MINs) is popular in switching and communication applications (Varma, *et al.*, 1994; Katangur, *et al.*, 2002). MINs used as interconnection network in Gigabit Ethernet and Asynchronous Transfer Mode (ATM) switches. Such systems demand high performance of the network.

Because MINs require less switching elements compared to a crossbar switch, it is possible to create very large networks (*e.g. 1024*1024*) at low costs. Thus, MINs are efficient implementation of packet switching networks. Areas of application for MINs lie in multiprocessor systems (Gheith, *et al.*, 1996) or high-bandwidth communication networks. Internal buffering greatly increases the performance of MIN (Tutsch and Brenner, 2003).

MINs are comprised of several small-sized Switching Elements (SEs) that are arranged in stages. MINs consist of N input, N outputs and n stages that $n=Log_2N$.

Each stage is numbered from *0* to *n-1* and has *N/2* SEs. Each SE has two inputs and two outputs connected in a certain pattern.

As optical technology advances, there is considerable interest in using optical technology to implement interconnection networks and switches. Although electronic MINs and optical MINs have many similarities, there are some fundamental differences between them. The major problem in OMINs is the problem of crosstalk, which is caused by coupling two signals within a switching element. (Pan *et al.*, 1999; Katangur, *et al.*, 2000).

In order to transfer messages from source to a destination address in Omega Network (ON) without crosstalk, the message needs to be divided into several passes. The messages are transferred using one pass for each group. In each group, the paths of messages going through the network are crosstalk free. Thus, from the performance aspect, we plan to separate the messages without any conflicts with other messages in the same group as well as to reduce the total number of the group in the minimum execution time.

Many approaches have been proposed to avoid crosstalk in routing messages through an *N*N* optical network by many researches. Optical Window Method (WM) was used to find conflicts among messages to be sent to the network in OMIN (Shen *et al.*, 1999). Four Heuristic algorithms include: Sequential Increasing, Sequential Decreasing, Degree Ascending and Degree Descending are used to simulate the performance in a real time. The Degree Descending algorithm has the best performance between the four heuristic routing algorithms (Miao, 2000). Also

Genetic Algorithm (GA) (Chunyan, 2001), Simulated Annealing (SA) (Katangur *et al.*, 2002) and Remove Last Passes (RLP) (Tiehong Xiao, 2004) are used to improve the performance. Finally, Zero is proposed to optimize the solution (Mohamed *et al.*, 2005). Zero is the latest method used to route the messages in OMIN.

1.2 Problem Statement

By reason of the difference in speeds of the electronic and optical switching elements and the nature of optical signals, OMINs also keep their own challenges. Although having several advantages in switching elements, OMIN has some drawbacks as well. The main problem in OMIN is crosstalk. Crosstalk occurs when two signal channels interact with each other. There are two ways in optical paths can interact in a planar switching network. The channels carrying the signals could cross each other in order to catch a particular topology. Alternatively, two paths sharing a switch could experience some undesired coupling from one path to another within a switch. Hence, when signal passes many switches, the input signal will be warped at the output due to the loss and crosstalk is introduced on the path. Therefore, crosstalk is the most significant factor that reduces the signal-to-noise ratio and limits the size of the network. Luckily, crosstalk can be eliminated by ensuring that a switch is not used by two input signals simultaneously. Since each switch can only pass one signal at a given time, any permutation in an optical network require at least two input links on an input switch.

To avoid crosstalk many approaches have been proposed. One of them is time domain approach, which is to route the traffic through an $N*N$ optical network to

avoid coupling two signals within each other. Also many routing algorithms in time domain have been proposed to solve the crosstalk. However, most of the developed algorithms have high execution time which degrades the efficiency of the network. Moreover, some of the algorithms still need improvements to insure the consistency in various network sizes and combinations.

Therefore, Zero algorithms are improved to achieve accurate routing and minimum execution time in the network. Moreover, Bitwise Improved Zero and Bitwise Four Heuristic are developed to reduce the execution time. Bitwise Difference Increasing and Bitwise Difference Decreasing algorithms are also proposed in this thesis to optimize execution time of routing in ON.

1.3 Research Objectives

The main objective of this research is to develop routing algorithm to decrease the execution time. Details objectives are as follows:

- To improve Zero algorithms to achieve accurate routing.
- To propose Bitwise Improved Zero algorithms to lessen execution time.
- To improve Four Heuristic, Difference Increasing and Difference Decreasing routing algorithms to minimize the execution time based on bitwise operations.

1.4 Research Scope

In this research, we are interested in the network called Omega Network (ON), which has a shuffle-exchange connection pattern (Shen *et al.*, 2001). In order to connect the source address to the destination address in ON, the address is shifted one bit to the left circularly in each connection. As a comparison to other type of networks, ON is more efficient, convenient and also is very easy to implement. The number of stages is only $Log_2 N$ and it connects p processor to p memory; hence, the implementation cost is very low. The ON also allows data to be transferred from any source to any destination in a single pass across a unique path.

In this study, only one to one permutation routing is analyzed. Also, different network sizes for routing algorithms are studied to explore the results of different routing algorithms.

1.5 Research Contributions

Many routing algorithms have been proposed to route the messages without crosstalk in OMIN. Any algorithm with a fewer number of passes and execution time is an efficient algorithm in OMIN. The main contribution of this research is to develop routing algorithms with lower execution time. Keeping in mind that it is always best, to use the existing technology rather than reinventing the wheel.

Contributions can be summarized in detail as follows:

- Improving Zero algorithms to achieve accurate routing.
- Proposing Bitwise Improved Zero algorithm to reduce the execution time.