UNIVERSITI PUTRA MALAYSIA

ZERO ALGORITHMS FOR AVOIDING CROSSTALK IN OPTICAL MULTISTAGE INTERCONNECTION NETWORK

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

November 2005

Abstract of thesis present to the Senate of Universiti Putra Malaysia in fulfilment of the Requirements for the Degree of Doctor of Philosophy

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November 2005

Chairman : **Associate Professor Mohamed Othman, PhD**

Faculty : **Computer Science and Information Technology**

Multistage Interconnection Networks (MINs) are popular in switching and communication applications. It had been used in telecommunication and parallel computing systems for many years. The broadband switching networks are built from 2×2 electro-optical switches such as LithiumNiobate switches. Each switch has two active inputs and outputs. Optical signals, carried on either inputs are coupled to either outputs by applying an appropriate voltage to the switch.

One of the problems associated with these electro-optical switches is the crosstalk problem, which is caused by undesired coupling between signals carried in two waveguides. This thesis propose an efficient solution to avoid crosstalk, which is routing of traffic through an $N \times N$ optical network to avoid coupling two signals within each switching element. Under the constraint of avoiding crosstalk, the research interest is to realize a permutation that will use the minimum number of passes (to route the input request to output without crosstalk). This routing problem

is an NP-hard problem. Many heuristic algorithms have been proposed and designed to perform the routing such as the sequential algorithm, the sequential down algorithm, the degree-ascending algorithm, the degree-descending algorithm, the Simulated Annealing algorithm and the Ant Colony algorithm.

The Zero algorithms are the new algorithms that have been proposed in this thesis. In Zero algorithms, there are three types of algorithms namely; The ZeroX, ZeroY and ZeroXY algorithms. The experiments conducted have proven that the proposed algorithms are effective and efficient. They are based on routing algorithms to minimize the number of passes to route all the inputs to outputs without crosstalk. In addition, these algorithms when implemented with partial ZeroX and ZeroY algorithms would yield the same results as the other heuristic algorithms, but over performing them when the execution time is considered. Zero algorithms have been tested with many cases and the results are compared to the results of the other established algorithms. The performance analysis showed the advantages of the Zero algorithms over the other algorithms in terms of average number of passes and execution time.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ALGORITMA ZERO UNTUK MENGELAKKAN CAKAP SILANG RANGKAIAN OPTIK SALING BERHUBUNG BERBILANG PARAS

Oleh

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Rangkaian optik saling berhubung berbilang paras (MINs) adalah amat terkenal dalam applikasi pengsuisan dan komunikasi. Ia telah digunakan dalam sistem pengkomputeran telekomunikasi dan selari sejak beberapa tahun yang lalu. Rangkaian pengsuisan jalur lebar telah dibina daripada suis elektro-optik *2x2* seperti suis Lithium Niobate. Setiap suis menpunyai dua input dan dua output yang aktif. Isyarat optik yang dimasukkan melalui input akan digandingkan kepada output dengan mengaplikasikan voltan yang bersesuaian kepada suis.

Salah satu masalah yang berkaitan dengan suis eletro-optik adalah masalah cakap silang, di mana ia disebabkan oleh gandingan yang tidak diingini di antara isyarat yang dibawa oleh dua *waveguides*. Tesis ini mencadangkan penyelesaian yang cekap untuk menghindari masalah cakap silang, di mana penghalaan trafik melalui rangkaian optik *NxN* untuk menghindari gandingan dua isyarat pada setiap elemen pengsuisan. Di bawah kekangan untuk menghindari masalah cakap silang, penyelidikan ini menitikberatkan untuk mengrealisasikan satu pilihatur yang akan

meninimakan bilangan laluan. Masalah penghalaan ini adalah merupakan satu masalah *NP-hard*. Banyak algoritma heuristik telah dicadangkan dan direkabentuk oleh ramai penyelidik untuk melakukan penghalaan trafik seperti algoritma *Sequence, Degree-descending, Simulated Annealing* dan *Ant Colony*.

Algoritma *Zero* adalah satu algoritma baru yang dicadangkan di dalam tesis ini. Algoritma *Zero* terbahagi kepada tiga jenis iaitu algoritma *ZeroX, ZeroY* dan *ZeroXY*. Kajian yang telah dilaksanakan membuktikan bahawa algoritma yang dicadangkan adalah cekap dan berkesan. Ia adalah berdasarkan kepada algoritma penghalaan yang meminimakan bilangan laluan untuk semua penghalaan dari input ke output tanpa sebarang masalah cakap silang. Di samping itu sekiranya algoritma ini dilaksanakan bersama dengan algoritma *ZeroX* dan *ZeroY* separa, ia menghasilkan keputusan yang sama seperti algoritma heuristik yang lain dan prestasi yang lebih baik akan dihasilkan sekiranya masa perlaksanaan diambil kira. Algoritma *Zero* telah diuji dengan pelbagai kes dan keputusannya telah dibandingkan dengan algoritma-algoritma lain yang telah dibuktikan. Analysis prestasi menunjukkan kelebihan algoritma *Zero* bebanding algoritma-algoritma yang lain dari segi purata bilangan laluan dan masa pelaksanaan.

ACKNOWLEDGEMENTS

All praise is due to Almighty Allah as He is all merciful, most gracious and most compassionate and it is He who gathered all knowledge in its essence and our Messenger the prophet Muhammad (peace and Blessings be Upon Him) and his progeny, companions and followers. All grace and thanks belong to almighty Allah.

I would like to take this opportunity to record my gratitude towards the great people whose important support to me during the phases of this research was very heartfelt. My deepest appreciation and gratitude goes to my research Supervisor, Associate Prof. Dr. Mohamed Othman who has always the time to listen to my ideas. Patiently, answered my questions, giving invaluable guidance, encouraged fruitful discussion, and offering recommendations and suggestions to my inquiries speedily and accurately. He lead my to the many stages in the journey for success.

In addition, my deepest appreciation to my committee members Dr. Rozita Johari and Dr. Shamala Subramanian for their cooperation, efforts, and valuable comments.

Great thanks to the Faculty of Computer Science and Information Technology, the university library and University Putra Malaysia for providing the working environment to me to perform this work.

I express my warmest gratitude to my mother and father, who never let me believe I could not succeed in this work or in any other challenges in my life. Also, special thanks to my wife, brothers and sisters, for their prayers, love and encouragement during my study. Finally, I am grateful to all my friends, Mohd Awad, Qassam, Akram Zaki , Ali Al-Sharafi and my other friends for their support.

I certify that an Examination Committee met on 29th November 2005 to conduct the final examination of Mohammed Abdulhameed Ali Al-Shabi on his Doctor of Philosophy thesis entitled "Zero Algorithms for Avoiding Crosstalk in Optical Multistage Interconnection Network" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
ATM	Asynchronous Transfer Mode
DBN	Dilated Benes network
GA	Genetic Algorithm
GHz	Gigahertz
LAN	Local Area Network
MIN	Multistage Interconnection Network
OMIN	Optical Multistage Interconnection Network
OON	Optical Omega Network
PE	Processing Elements
RLF	Recursive Largest First
SA	Simulated Annealing
SE	Switch Element
SEQ	Sequential Algorithm
SEQ-DN	Sequential Down Algorithm
TSP	Travelling Salesman Problem
VLSI	Very Large-Scale Integration
WDM	Wavelength Division Multiplexing
WM	Window Method

CHAPTER 1

INTRODUCTION

1.1 Background

Multistage Interconnection Networks (MINs) are popular in switching and communication applications (Varma, *et al.*, 1994; Katangur, *et al.,* 2002). It has been used in telecommunication and parallel computing systems for many years. They are also used as interconnection networks in Gigabit Ethernet and Asynchronous Transfer Mode (ATM) switches. Such systems require high performance of the network. MINs were first introduced for circuit switching networks, as an effect it increases the performance of a MIN, thus buffered MINs were established as packet switching networks (Tutsch and Brenner, 2003).

Typical MINs consist of N inputs, N outputs and n stages with n=log N. Each stage is numbered from 0 to (n-1), from left to right and has $N/2$ Switching Elements (SE). Each SE has two inputs and two outputs connected in a certain pattern.

As optical technology advances, there is a considerable interest in using optical technology to implement interconnection networks and switches (Pan, *et al.*, 1999). In electronic MINs, electricity is used, where as in optical MINs light is used to transmit the messages. The electronic MINs and the Optical MINs have many similarities, but there are some fundamental differences between them such as the crosstalk problems in

the optical switches. In order to avoid the crosstalk problem, various approaches have been proposed by many researchers. The crosstalk problem is introduced by optical MIN, which is caused by coupling two signals within a switching element (Pan, *et al.*, 1999; Katangur, *et a*l, 2000).

In this research, the interest is in a network called Omega Network (Yang, *et al.*, 2000), which has a shuffle-exchange connection pattern. In order to transfer messages from a source address to a destination address on Optical Omega Network without crosstalk, the message needs to be divided into several groups. The messages are delivered by using one time slot (pass) for each group. In each group, the paths of the messages going through the network are crosstalk free. Therefore, from the performance aspect, the objective is to separate the messages without conflicting with other messages in the same group. An objective it is also to reduce the total number of the groups

Many approaches have been proposed to avoid crosstalk in routing traffic through an $N \times N$ optical network by many researchers. Optical Window Method (WM) was proposed for finding conflicts among messages to be sent to the network to avoid crosstalk in OMIN (Shen *et al.*, 1999). When four heuristic algorithms sequential, sequential down, ascending degree and descending degree are used to simulate the performances in real time, the degree-descending algorithm gets the best performance (Miao, 2000). Genetic Algorithm (GA) is also used to improve the performance (Chunyan, 2001). The GA had much improvement in terms of average number of passes, but it was time consuming. Also, the Simulated Annealing (SA) algorithm is

used to optimize the solution (Katangur *et al.*, 2002). Finally, the ant Colony (ACO) algorithm is proposed to optimize the solution (Katangur *et al.*, 2004a).

The Zero algorithms are the new algorithms that have been proposed in this thesis. In Zero algorithms there are three types of algorithms namely; The ZeroX, ZeroY and ZeroXY algorithms. The conducted experiments have proven that the proposed algorithms are effective and efficient. They are based on routing algorithms to minimize the number of passes to route all the inputs to outputs without crosstalk. In addition, these algorithms when implemented with partial ZeroX and ZeroY algorithms would yield the same results as the other heuristic algorithms, but over performing them when the execution time is considered.

1.2 Problem Statement

As optical technology advances, there are greater interests in using optical technology for interconnection networks and switches. However, a major problem in Omega Network called crosstalk is introduced by optical MIN. A crosstalk is caused by coupling two signals within a Switching Element (SE). This crosstalk occurs when two signal channels interact with each other. When a crosstalk happens, a small fraction of the input signal power may be detected at another output although the main signal is injected at the right output.

Hence, when a signal passes many SEs, the input signal will be distorted at the output due to the loss and crosstalk introduced on the path. For this reason, when a signal

passes many switching elements, the input signal will be distorted at the output due to the loss and crosstalk introduced on the path (Pan *et al.*, 1999). There are two ways in which optical signals can interact in a planar switching network.

i) The channels carrying the signals could cross each other in order to embed a particular topology.

ii) Two paths sharing a SE will experience some undesired coupling from one path to another within a SE (Pan *et al.*, 1999).

Apparently, a crosstalk-free optical network can not realize a permutation in a single pass, since at least the two input links on an input switch or the two output links on an output switch cannot be active in the same pass.

To avoid crosstalk, time domain approach has been proposed, which is to route the traffic through an $N \times N$ optical network to avoid coupling two signals within each SE. The more efficient algorithm is the algorithm that generates less time slots (passes). Our goal is to design efficient routing algorithms to minimize the number of time slots (passes) for sending all the messages. That means the messages will be sent out in less time.

In this research, the Zero algorithms are proposed to improve the performance OMINs with the minim number of time slots (passes) for sending all the messages without crosstalk and reduce the execution time when the execution time is considered.

1.3 Research Scope

OMIN consists of N inputs and N outputs which are interconnected by n stages (where $n=log\ N$) of switching elements (Varma *et al.*, 1994). There are two inputs and two outputs for each SE. Each stage consists of $N/2$ switching elements (Varma, *et al.*, 1994). In this research, the interest is on a network named Omega Network, which has a shuffle-exchange connection pattern (Shen *et al.*, 2001). In order to connect the source address to the destination address, the address is shifted one bit to the left circularly in each connection such as the source to the first stage, one stage to the next stage continuously.

The following assumptions are made to reflect the optical technology features:

- Circuit switching instead of message switching is used in our model. No buffer is available in the switching elements.
- Each message can be transmitted in one time slot (or one time unit). Thus, all messages have a fixed size.
- Messages are synchronized at the beginning of each slot.
- Only one-to-one permutation routing is analyzed. No broadcasting (one-to-N) or multicasting (one-to-many) is allowed.
- Off-line routing strategy is adopted. All messages and their destinations are available before we schedule the paths for the messages. Hence, no on-line routing is implemented in this research.
- Only Omega networks are studied. That is, the connections between stages are shuffle-exchange connections.

- Different network sizes will be studied to see the effects of different routing algorithms.
- Randomized permutation traffic will be adopted throughout the simulation studies. The traffic will be generated through random number generators.

1.4 Research Objectives

The main objective of this research is to propose an efficient and an effective routing algorithm in order to minimize the number of passes to route all the inputs to outputs without crosstalk.

The secondary objectives of the research are:

- To use the Zero algorithms to improve the performance of the solved crosstalk problem and optimizing the result including the average number of passes and execution time.
- To reduce the execution time of the normal heuristic algorithms by replacing it within a new proposed heuristic algorithms, which gives the same quality of result and faster execution time..

1.5 Research Methodology

To reduce the negative effort of crosstalk, many approaches have been proposed. One method to solve this problem is to use a $2N \times 2N$ regular MIN to provide the $N \times N$ connection (Thompson, 1991; Pen, *et al.*, 1999). However, in this method half of the