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OPTICAL PACKET SWITCHING CONTENTION RESOLUTION BASED ON A HYBRID WAVELENGTH CONVERSION-FIBER DELAY LINE SCHEME

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

OPTICAL PACKET SWITCHING CONTENTION RESOLUTION BASED ON A HYBRID WAVELENGTH CONVERSION-FIBER DELAY LINE SCHEME

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Due to the convergence of computer communication and telecommunication technology, data traffic exceeds the telephony traffic. Thus, existing connection oriented and circuit switched network will need to be upgraded toward optical packet switched network. Optical packet switching has characteristics like high speed, data rate/data format transparency and configurable. Wavelength Division Multiplexing is the technology of combining a number of wavelengths in a single fiber. It is a tremendous trend to harness larger bandwidth for enormous delivery. WDM optical devices for multiplexing and switching in simple configuration are now available at a reasonable cost. It is a very appealing solution for development of optical packet switching.

The issue of contention arises when two or more packets contend for the same output port in a switch with the same wavelength, which results to packet loss. The packet loss probability is addressed as the most inevitable and significant measurable performance parameter with QoS provisioning that is dominated by wavelength contention in optical packet switches. In electronic domain packet switched network, the contention is resolved by store and forward technique using the available electronic random access memory (RAM). Due to the immaturity of optical memory storage technology, there is no available ready-to-use optical random access memory.

In order to overcome this bottleneck, several approaches have been adopted to resolve the contention problem from three domains: time, space and wavelength as stated: fiber delay line (time), deflection routing (space) and wavelength conversion (wavelength). Consequently, contention resolution in wavelength domain has attracted considerable interest among the optical communications community instead of implementing optical buffering and deflection routing that have been studied previously.

This thesis proposes a bufferless, single stage, non-blocking fully connected optical packet switch for synchronous optical packet switching network, followed by a prioritized scheduling algorithm in association with hybrid contention resolution schemes. This iterative prioritized scheduling comprises of a set of preemptive selective policies for contention resolution. It is a hybrid technique that integrates wavelength conversion with feedback mechanism realized by fiber delay lines (FDL).

By means of simulation, the proposed scheme has been investigated and compared with the conventional baseline scheme. A sensitive description of the satisfied packet loss probability and average packet delay as a function of main design parameters such as switch size, number of wavelengths, traffic load, degree of conversion and number of fiber delay lines have been carried out with significant improvement.

Simulation results proved that the proposed scheme is an efficient approach in resolving packet contention with less complexity in execution. Relatively, number of wavelength, traffic load and degree of conversion has significant impact to packet loss ratio. The implementation of fiber delay lines results on average packet delay. Simulation results demonstrated that the switch size mildly affect the performance parameter.

Respectively, packet loss ratio below 10^{-10} is obtained via simulation by the means of wavelength conversion without conventional buffering delay. The packet loss ratio is further reduced with the method as aforementioned with the insertion of fiber delay lines where *PLR* below 10^{-13} is achieved, which is much lower than the benchmark value. Furthermore, the obtained simulation results show that by classifying packet priority, the proposed scheduling scheme and architecture are able to offer differentiated class of service.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

PENYELESAIAN PERTELAGAHAN PENSUISAN PAKET OPTIK BERDASARKAN SKIM HIBRID PENUKARAN GELOMBANG-GARIS LENGAH GENTIAN

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Penumpuan teknologi komunikasi komputer dan telekomunikasi menandakan bahawa teknologi WDM merupakan satu haluan hebat dalam menggunakan banyak lebar jalur yang tersedia untuk penghantaran yang sangat besar apabila trafik data melebihi trafik telefoni. Isu pertelagahan muncul apabila dua atau lebih paket yang bertanding untuk terminal output yang sama sementara mempunyai gelombang yang sama telah menyumbang kepada kebarangkalian gugur paket. Kebarangkalian paket gugur telah dialamatkan sebagai parameter prestasi tersukatan yang tidak terelak dan bererti dengan penyediaan perkhidmatan berkualiti (QoS) yang disebabkan oleh pertelagahan gelombang dalam suis bingkisan optik.

Dalam rangkaian pensuisan bingkisan domain elektronik, pertelagahan boleh diselesaikan oleh teknik simpan dan hantar disebabkan oleh ketersediaan ingatan capaian rawak (RAM). Disebabkan oleh kekurangan teknologi storan ingatan optik, didapati tiada kesediaan ingatan capaian rawak optik.

Sebagai percubaan untuk mengatasi rintangan ini, beberapa pendekatan telah diterima untuk menyelesaikan masalah pertelagahan dalam tiga domain berikut: masa, ruang dan gelombang seperi yang dinyatakan: penimbal optik (garis lengah gentian), penukaran gelombang (penukar gelombang bertala) dan penghalaan pesongan (ruang). Akibatnya, penyelesaian pertelagahan dalam domain gelombang telah menarik banyak juga minat daripada komuniti komunikasi optik sebagai ganti penggunaan penimbal optik dan penghalaan pesongan yang telah dikaji sebelum ini.

Demikian, tesis ini mencadangkan satu suis paket optik tanpa penimbal, satu peringkat, tiada sekatan yang disambung dengan sepenuhnya untuk rangkaian pensuisan bingkisan optik segerak. Kemudian, tesis ini mencadangkan satu algoritma penjadualan pengutamaan yang bersekutu dengan skim penyelesaian pertelagahan hibrid. Tesis ini memperkenalkan satu teknik hibrid yang mengabungkan pernukaran gelombang dengan mekanisme suap balik yang dilaksanakan oleh garis lengah gentian (FDL). Penjadualan pengutamaan berlelar ini mengandungi satu set polisi hak pemilihan terdahulu dalam penyelesaian pertelagahan.

Dengan cara simulasi, tesis ini menyelidik pendekatan tak tradisional sebagai ganti kepada penggunaan penimbal optik lazim dan penghalaan pesongan yang telah dikaji sebelum ini. Satu perihalan yang peka tentang kebarangkalian paket hilang yang dikehendaki sebagai fungsi parameter reka bentuk seperti bilangan input dan output rangkaian gentian, bilangan gelombang, beban trafik, darjah penukaran dan garis lengah gentian telah dilaksanakan.

Keputusan simulasi membuktikan bahawa skim yang dicadangkan merupakan satu pendekatan yang berkesan dalam meyelesaikan pertelagahan paket dengan kerumitan pelaksanaan yang kurang. Bilangan gelombang, beban trafik dan darjah penukaran mempunyai kesan yang bererti kepada kebarangkalian gugur paket, diikuti oleh bilangan garis lengah gentian. Sementara itu, keputusan simulasi menunjukan bahawa bilangan input dan output rangkaian gentian kurang mempengaruhi parameter prestasi. Berikutan itu, kebarangkalian paket hilang dibawah 10^{-10} didapati melalui simulasi dengan cara penukaran gelombang tanpa perlengahan penimbalan lazim.

Kebarangkalian paket hilang telah dikurangkan selanjutnya meggunakan cara yang disebut dengan sisipan garis lengah gentian di mana kebarangkalian paket hilang di bawah 10^{-13} telah diperolehi, ia adalah jauh lebih rendah daripada nilai piawai. Selanjutnya, keputusan simulasi yang didapati menunjukan bahawa dengan mengelaskan keutamaan paket, skim penjadualan dan seni bina yang dicadangkan mampu menawarkan perbezaan kelas dalam perkhidmatan.

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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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Date:

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CHAPTER 1

INTRODUCTION

1.1 Background

Expanding Internet-based services are driving the need for more bandwidth in the network backbone. These needs will grow further as new real-time multimedia applications become more feasible and pervasive. Currently, there is no other technology on the horizon that can effectively meet such a demand for bandwidth in the transport infrastructure other than WDM technology [1].

Thus, the dramatic expansion of fiber optic technology has been augmented with the drastic drop of the installation price. It becomes the most economical solution for displacing those initial technologies. There are three significant reasons that draw the attentions of developers to move from microwave field to fiber optical communication technology: a confining transmission media via light with very low loss per length, a light source modulation technique at high data rates with long lifetime and an amplifier of light signal in the media.

1.2 WDM Optical Network

The technology to support WDM optical networks is advancing drasticaly, the most important recent development being the commercialization of Erbium Doped fiber amplifiers (EDFA). Respectively, a fast growing market for wavelength multiplexing

(WDM) transmission systems has emerged among network operators who need to increase their capacity to respond to an increased demand for broadband services [2]. The enormous usable bandwidth of a single fiber is a great asset and a great challenge. It is technologically impossible to exploit all of that bandwidth using a single high-capacity channel.

Thus, to make efficient use of the fiber, it is essential to *channelize* its bandwidth. This is most easily accomplished by superimposing many concurrent signals on a single fiber, each on a different wavelength; that is by using WDM [3]. The relative ease of signal manipulation in the wave domain, as opposed to the time domain, suggests that current optical technology is particularly suited to multi wavelength technique. In WDM networks, each optical transmitter (receiver) is tuned to transmit (receive) specific wavelength and there are many signals operating on different wavelengths.

It is important to note that the in band control information carried with the data in IP (packet-based) or ATM (cell-based) networks is the key to achieving a high degree of virtual connectivity in these networks [4]. Three main windows can allocate the wavelength spectrum used for optical network. Initially, researchers focused on the first window (800-900 nm) for communication usage which can be called 1970s window. The range for second window is around 1300 nm which is also called 1980s window. This is where the standard fiber optic system SONET/SDH operates. Recently, the trends are shifting to the third window which lies from 1510 nm to 1600 nm [5].

The snag is that the cost of the light source for the third window is expensive and the signal tends to be degraded due to the dispersion. So the fiber recommended for WDM is non-zero dispersion-shifted fiber (NZ-DSF) where the dispersion is low but not zero [6]. This is because the main problem in the transmission signal in optical network is the dispersion of light caused by the different propagation time of different wavelengths.

In other words, single wavelength can travel faster with less dispersion. But there are several drawbacks in the real world. The major limitations of using single wavelength in the optical network systems are: interval between serial bits is small, speed-specific repeaters needed and expensive to run new fibers [7].

1.3 Problem Statement & Motivations

The growth of existing and new broadband services is continuing to increase the traffic flow in the telecommunication networks, thus push for larger bandwidth. As a next step, future networks are expected to utilize WDM techniques for optical functionalities capable of handling multi-gigabit signals. WDM based optical packet switching is flexible, scalable and has high information handling capability for photonic broadband communication networks of the future. It remains consistent with the present deployment of packet networks such as IP and ATM with WDM networks.

High-speed computer file transfers, video-on-demand, interactive digital multimedia services, teleworking, telelearning or teleshopping, contribute to the reduction of transport congestion and pollution. However, due to the immaturity of optical communication development, there are some problems remain unsolved including packet contention.

Accordingly, contention arises whenever two or more packets try to leave the switch from the same output port at the Optical Packet Switching Router (OPSR). The unsuccessful packets will be dropped due to the limited number of channels and wavelength contentions. Contentions in WDM optical switch can be categorized as bandwidth contention and wavelength contention, but wavelength conversion cannot resolve bandwidth contentions. In OPSR, packet loss ratio (PLR) is the most critical measurable performance parameter.

The PLR is caused by wavelength contention and can be resolved by wavelength conversion. Furthermore, the PLR can be significantly reduced by increasing the number of wavelength, hence, this shortcoming is not critical. In electronic packet switched network, the contention is resolved by store and forward technique using the available electronic random access memory (RAM). However, due to the immaturity of optical memory storage technology, there is no available ready-to-use optical random access memory. To overcome this bottleneck, some of the approaches had been adopted.

To resolve the contention problem, three domains can be explored: time, wavelength and space via fiber delay line (time), wavelength conversion (wavelength) and deflection routing (space) respectively. Consequently, contention resolution in wavelength domain has attracted considerable interest from the research community, instead of implementing optical buffering and deflection routing. By employing wavelength conversion, the contending packets can be converted to an alternative wavelength at the same output port to resolve the conflict, this will improve the packet loss ratio. Previous research has successfully demonstrated that in order to achieve the packet loss probability of 10^{-10} using up to 40-50 fiber delay lines [7].

Thereby, the issues like fiber lengths and the number of gates needed to control the buffers form all the major issues. Optical buffering realized as fiber delay line is spacious, inconvenient and obviously the delayed packets cannot be retrieved. For delaying a packet for 1 μs, more than 200 m fibers are needed. Optical buffers are extremely hard to implement [7].

On the other hand, if large numbers of buffer are employed, the physical size of the switch will increase. At the same time, channel cross talk and noise will degrade the signal after switching. The implementation of large buffers implies an additional long fiber path that packets have to go through. This will cause further degradation of the signal with the accumulation of amplifier spontaneous emission noise [8]. Accordingly, additional effort will be performed to improve the signal quality compatible to the network specification at the output of the switch.

To overcome the aforementioned problems, this thesis focuses on wavelength domain by eliminating the buffers in resolving contention. This thesis studies wavelength conversion method instead of employing optical buffering while maintaining a high network throughput. It develops a buffer-less, synchronous optical packet switch with fixed packet length and investigates the WDM-based wavelength conversion technique as logical buffer for contention resolution.

The proposed WDM packet switch consists of N input and output fibers. Each fiber supports M wavelengths of WDM signal. Any input and output channel is characterized by the couple (i, λ_j) where $i(i\in\{1,\ldots,N\})$ indicates the input or output fiber and λ_j $(j\in\{1,\ldots,M\})$ identifies the wavelength. Assume packets are fixed size and their arrivals are synchronized in certain time slot. Time slot basis illustrates the duration of time period needed to transit a single packet that is given by T time unit. The switch implies r numbers of tunable optical wavlength converter at the inputs channels. The node takes an incoming packet, read its header and switch it to the appropriate output port. It must handle contention for output ports.

If two incoming packets arrive at different inbound port and need to go out on the same outbound port, one of the packets is proposed to be converted to another wavelength. Wavelength conversion is adopted instead of buffering which is realized by fiber delay line. Ideally, all the functions inside the node would be performed in the optical domain. But in practice, certain functions, such as processing the header and controlling the switch, are done in electronic domain. This is because of the very limited processing capabilities in the optical domain. The header itself could be sent at a lower bit rate than the data so that it can be processed electronically.

1.4 Objectives of Thesis

- This thesis proposes a single stage, fully non-blocking WDM-based optical packet switch architecture.

This proposed optical packet switch is a bufferless high-speed switch for synchronous optical communication network with tunable optical wavelength converter (TOWC). For achieving better performance of the optical packet switch in terms of packet loss ratio, a small amount of fiber delay lines (FDL) have been inserted to the switch to perform feedback mechanism.

- This thesis also introduces a resolution scheme for packet scheduling during packets contention.

It develops a set of policies to schedule the contending packets that have both the same output port address, carried by the same wavelength. The algorithm employs the concept of wavelength conversion by utilizing tunable optical wavelength converter (TOWC) to resolve the contention instead of exploring the optical buffering and deflection routing domain.

- The algorithm implies a technique that integrates both prioritized selective and random selective iterative scheduling by examining two important information at packet header, which are the destination address and packet priority bit.

The design parameters are the number of wavelengths, size of the switch, traffic load, conversion degree and the amount of fiber delay lines. The performance parameter will be the packet loss probability due to packets contention.

- Hence, this thesis acts as a step towards realizing the contention-less all-optical terabit packet switch that could support the future demand of ultra dense WDM technology to accommodate IP packet and data traffic.

Powered by the features as aforementioned, thus this thesis is expected to be a stepping-stone that emerges to meet the challenges in not-too-distant future arena. The dramatic increase in network capacity coupled with improved cost effectiveness will lead to a large-scale deployment of such technology over next few years.

1.5 Organization of Thesis

This thesis is organized into six chapters. This chapter in an introductory chapter in which the evolution of WDM optical network from the past few years until recent development including types of today's optical network, the concept of wavelength division multiplexing, classification of switching techniques, problems statements and motivations of this thesis.

Chapter 2 reviews several types of switching techniques in optical network including optical circuit switching, optical burst switching and finally optical packet switching. This chapter also examines the recent advancements within the context of synchronization, asynchronization, contention resolution schemes, network bottleneck issues, classification of contention and conversion techniques, optical components and devices for WDM network are introduced.

Chapter 3 mainly presents the research methodology of the proposed optical switch architecture and the packet-scheduling algorithm for contention resolution incorporating with the policies and related techniques to determine the conversion and feedback mechanism. This chapter discusses the prioritized scheduling mechanism, packet grouping method, fiber delay lines implementation, packet format utilized, the realization of synchronization as well as the network reference model adopted.

Chapter 4 is devoted to the description of the simulation model, which is developed with Matlab to compute the packet loss probability via the proposed architecture and algorithm. Respectively, traffic modeling generated by Binomial and bursty arrival process investigates the current state-of-art in the optical network by testing the proposed work with different design parameters. Relatively, hardware implementation of the proposed scheduling algorithm is introduced briefly.

Chapter 5 reports the simulation results with a descriptive discussion of each graph by investigating the impact of different design parameters over performance parameter. The performance also has been evaluated with class differentiation support by comparing wavelength conversion technique and recirculation technique under different environments.

Chapter 6 concludes this thesis with a brief discussion on possible future enhancement that can be upgraded from the proposed work to accommodate the expected future traffic demand. Following this, main contributions of this thesis are elaborated and several major conclusions from the obtained simulation results are discussed. This chapter also explores the relevant works in this area and outline of future work.

1.6 Conclusion

In the following chapter, a wide review on wavelength division multiplexing (WDM), WDM All-Optical Network, classification of switch, optical switching techniques, classification of contention, contention resolution, optical packet switching (OPS) bottlenecks, components and devices for WDM network as well as support of service differentiation will be presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

In parallel with the development of IP protocol, developments in wavelength division multiplexing have yielded an enormous capacity on fiber optic links. Advances in TDM technology are occurring at a much slower pace. Time division multiplexing (TDM) is a technology where multiple data streams share a common fiber path by dividing it into time slots. TDM acts as a front-end for WDM by combining several low data rates channels into a higher data rate channel.

This is because the higher data rate channel only requires a single wavelength of the WDM. Thus, this method provides an increasing number of low-speed channels. WDM can readily support many hundred of gigabits per seconds on a single fiber. WDM technology can be protocol and bit-rate independent. It does not require the maximum bit rate in order to support more traffic [8]. It is better to maintain a modest transmission bit rate, say 10 Gb/s with multi wavelengths over a fiber, instead of using higher bit rate with fewer wavelengths.

2.2 Wavelength Division Multiplexing

Entering the 20th century, WDM has become the most promising technology in optical networks. It accelerates communication society to explore a new era of advance optical communication technology. WDM is an optical version for FDM that takes advantage of high bandwidth of optical fiber link without requiring extremely high modulation rates at transceiver [8]. WDM technology allows the user to harness an enormous bandwidth that tends to multiply the capacity of the network.

The fundamental concept is that the bandwidth is partitioned, so that multiple signals can be transmitted in a single fiber at the same time with different wavelengths [9]. Wavelength division multiplexing system can be classified into several categories according to their spacing and number of channels. Coarse WDM is the simplest WDM system that typically only implies 2 to 3 wavelengths which is widely spaced, the most common case being 1300 nm and 1550 nm. However, it is not widely used in data communication network.

For wide spectrum WDM systems, 16 wavelengths are carried in a single fiber that is comparatively far apart. However, there is no standardized wavelength spacing currently defined for such system. Relatively, it is also known as Sparse WDM (SWDM) system that is considered as one of the alternative for the emerging 10 Gb/s Ethernet standard. Dense wavelength division multiplexing (DWDM) system employs closer channel spacing of 0.8 nm (100 GHz) near 1550 nm according to International

Telecommunication Union (ITU) standard. The first generation of DWDM implements 8 wavelengths, followed by second generation of DWDM, which uses up to 16 wavelengths. Third generation of DWDM uses 32 wavelengths and finally the latest introduction of Ultra-dense WDM employs up to 40 wavelengths with spacing of 0.4nm (50 GHz), which is still under laboratory research level. WDM system has positive characteristics such as signal transparency, scalability and flexibility. The significant drawbacks are that it needs flat gain amplifiers, level of noise increments proportional to the amount of channels, the limitations in channel spacing and the stringent laser requirement (narrow line width) [10].

2.3 WDM All-Optical Network

The rapidly growing Internet traffics are driving the demands for higher transmission capacity and higher processing speed. The electronic switch for recent technology is based on centralized bus or distributed switching architecture. It can process several million packets per second, however its maximum line-speed does not exceed 40 Gb/s. Currently its processing capacity is approaching to the electronic processing bottleneck, but still does not satisfy the need of high throughput in backbone network [10].

Relativly, it is imperative that the packets processing should evolve from electronic to optical, hence the future Internet would be WDM based all-optical network. All-optical network shows great promise for providing the bandwidth needed for the Next Generation Internet and its high-demand applications. Thus, the switching and routing of packets in optical network are performed totally in optical field that must rely on the