UNIVERSITI PUTRA MALAYSIA

MULTICASTING IN WDM SINGLE-HOP LOCAL LIGHTWAVE NETWORKS

RABI W.

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By

RABI W.

Thesis Submitted in Fulfilment of the Requirements for the Degree of Master of Science in the Faculty of Engineering Universiti Putra Malaysia

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To my family

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

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RABI W.

January 2000

Chairman : Associate Professor Borhanuddin Mohd. Ali, Ph. D.

Faculty : Engineering

In modern networks, the demand for bandwidth and high quality of service (QoS) requires the efficient utilisation of network resources such as transmitters, receivers and channel bandwidth. One method for conserving these resources is to employ efficient implementations of multicasting wherever possible. Using multicasting, a source sending a message to multiple destinations may schedule a single transmission which can then be broadcasted to multiple destinations or forwarded from one destination to another, thus conserving the source transmitter usage and channel bandwidth.

This thesis investigates the behaviour of single-hop WDM optical networks when they carry multicast traffic. Each station in the network has a fixed-wavelength transceiver and is set to operate on its own unique wavelength as a control channel. Each station also has a tuneable wavelength transceiver in order to transmit or receive signals to or from all the other stations. A transmission on each channel is broadcasted by a star coupler to all nodes.

Multicasting in single-hop WDM networks has been studied with different protocols. This thesis studies the multicasting performance adopting receiver collision avoidance (RCA) protocol as a multicasting protocol. This study takes into consideration the effect of the tuneable transceiver tuning time which is the time required to switch from one wavelength to another, and the propagation time required by a packet to propagate from one node to another.

The strategy in RCA protocol is that nodes request transmission time by sending a control packet at the head of their queues. Upon receipt of this information all nodes run a deterministic distributed algorithm to schedule the transmission of the multicast packet. With the control information, nodes determine the earliest time at which all the members of the multicast group can receive the packet and the earliest time at which it can be transmitted. If a node belongs to the multicast group addressed in the control packet, its receiver must become idle until all nodes in the group have tuned to the appropriate wavelength to receive the packet. This problem leads to poor transmission and consequently low channel utilisation. However, throughput degradation due to receiver conflicts decreases as the multicast size increases. This is because for a given number of channels, the likelihood of a receiver being idle decreases as the number of intended recipients per transmission increases.

The number of wavelengths available in a WDM network continues to be a major constraint. Thus in order to support a large number of end users, such networks must use and reuse wavelengths efficiently. This thesis also examines the number of wavelengths needed to support multicasting in single-hop optical networks.

This thesis shows that the system under study can accommodate large tuning delays and keeps with suitable throughput when the number of wavelength is equal to the number of nodes. When the number of wavelengths is comparable to the number of users the tuning time influence on the packet delay increases. This thesis also shows that when the size of multicast packet and receiver tuning delay increase the throughput decreases.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia Sebagai memenuhi keperluan untuk ijazah Master Sains.

SIARAN BERBILANG DALAM RANGKAIAN GELOMBANG CAHAYA TEMPATAN SATU LOMPATAN WDM

Oleh

RABI W.

January 2000

Pengerusi : Profesor Madya Borhanuddin Mohd. Ali, Ph. D.

Fakulti : Kejuruteraan

Dalam rangkaian moden, keperluan untuk lebarjalur dan kualiti perkhidmatan memerlukan penggunaan sumber rangkaian yang berkesan seperti penghantar, penerima dan lebarjalur saloran. Satu cara untuk memelihara sumber ini ialah dengan melaksanakan berbilang siaran dimana sesuai. Dengan penggunaan berbilang siaran, satu sumber yang ingin menghantar mesej ke beberapa destinasi boleh membuat satu penghantaran yang kemudiannya dapat disebarkan ke pelbagai destinasi atau dihantar dari satu destinasi ke destinasi yang lain, sekaligus memelihara penggunaan sumber penyebar dan lebar jalur saluran

Tesis ini mengkaji bagaimana rangkaian optik WDM satu lompatan berkelakuan apabila membawa trafik yang berbilang siaran. Kami mengambil kes di mana setiap stesyen dalam rangkaian mempunyai satu penghantan/penerima gelombang tetap dan disetkan untuk beroperasi dalam panjang gelombang tersendiri yang unik sebagai saloran kwalan.

Setiap stesyen juga mempunyai satu penghanta/penerima dengan gelombang bolehubah agar dapat menghantar atau menerima isyarat kepada atau dari stesyen-stesyen yang lain. Penghantaran dalam setiap saloran adalah disebarkan oleh satu penggaling bintang ke semua nod. Berbilang siaran dari rangkaian WDM satu lompatan telah dikaji dengan protokol yang berbeza. Tesis ini menyemak prestasi berbilang siaran menggunakan protokol penerima pengelak pertembungan (RCA) sebagai protokol berbilang siaran. Kami mengkaji kesan masa mengubah penghantar/penerima bolehuba iaitu untuk mengalih dari satu panjang gelombang ke panjang gelombang yang lain, dan masa peramtatan yang diperlukan oleh satu paket untuk menambat dari satu nod ke nod yang lain.

Strategi dalam protokol RCA ialah nod-nod meminta masa penghantaran dengan menghantar satu paket pengawal pada kepala barisan-barisan menunggu. Setelah menerima maklumat ini, semua nod melaksanakan algoritma tertabur deterministik untuk merancang penghantaran paket siaran berbilang tersebut. Dengan maklumat kawalan ini, nod-nod menentukan masa terawal di mana semua ahli dalam kumpulan berbilang siaran boleh menerima paket itu dan masa terawal di mana ia boleh dihantar. Untuk satu-satu nod dalam kumpulan siaran yang dialamatkan dalam paket kawalan, penerimanya mesti menjadi melangu sehingga kesemua nod dalam kumpulan tersebut telah diubahkan panjang gelombang tertentu untuk menerima paket tersebut. Masalah ini membawa kepada penghantaran yang lemah dan seterusnya penggunaan saloran yang lemah. Walau bagaimanapun, penurunan prestasi sistem yang disebabkan oleh konflik penerima dikurangkan apabila saiz kumpulan berbilang siaran meningkat. Ini adalah kerana bagi sejumlah saloran yang diberikan, kebarangkalian penerima melangu dikurangkan apabila

bilangan penerima bagi satu penghantaran bertambah para. Bilangan panjang gelombang yang ada dalam rangkaian WDM terus menjadi masalah utama. Oleh yang demikian, untuk menampung jumlah pengguna yang besar, rangkaian sedemikian perlu mengguna semula panjang gelombang dengan berkesan. Kami juga mengkaji bilangan panjang gelombang yang diperlukan untuk menyokong berbilang siaran dalam rangkaian optik WDM satu lompatan.

Tesis ini membuktikan bahawa sistem yang dikaji dapat menampung masa berubah yang besar dan kekal dengan penurunan prestasi sitem yang bersesuaian apabila nombor panjang gelombang adalah sama dengan nod. Apabilah bilangan panjang gelombang adalah sama dengan bilangan pengguna, masa berubah yang mempengaruhi masa paket meningkat. Tesis ini juga menunjukkan apabila saiz untuk paket berbilang dan penerima masa mengubah meningkat prestasi keseluruhan sistem akan menurun.

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I certify that an Examination Committee met on 26 January, 2000 to conduct the final examination of Rabi W. Yousif on his Master of Science thesis entitled "Multicasting in WDM Single-Hop Local Lightwave Networks" 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:

ABDUL RAHMAN RAMLI, Ph. D.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

BORHANUDDIN MOHD. ALI, Ph.D.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

SELVAKENNEDY SELVADURAI, Ph.D.
Telekom Malaysia Photonics Research Centre
Universiti Malaya
(Member)

VEERARAGHAVAN PRAKASH, Ph.D.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

MOHD. KHAZANI ABDULLAH, Ph.D.
Telekom Malaysia Photonics Research Centre
Universiti Malaya
(Member)

MOHD. GHAZALI MOHAYIDIN, Ph.D.
Professor / Deputy Dean of Graduate School,
Universiti Putra Malaysia.

Date: 14 MAR 2000

This thesis was submitted to the Senate of Universiti Putra Malaysia and was accepted as fulfilment of the requirements for the degree of Master of Science.

KAMIS AWANG, Ph.D.
Associate Professor,
Dean of Graduate School,
Universiti Putra Malaysia.

Date: 11 MAY 2000

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 degree at UPM or other institutions.

(RABI W. YOUSIF)

Date: 6/3/2000

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

AON	All-optical network
ATM	Asynchronous transfer mode
BER	Bit error rate
CC	Control channel
CDM	Code-division multiplexing
DBR	Distributed Brag reflector
DF	Distributed feedback
DQDB	Distributed queue dual bus
EDFA	Erbium-doped fibre amplifier
EPA	Fabry-Perot amplifier
EOTF	Electro-optic tuneable filter
FDDI	Fibre distributed data interface
FR	Fixed receiver
FT	Fixed transmitter
FTTH	Fibre to the home
FP	Fabry-Perot
FDM	frequency division multiplexing
Gbps	Gigabits per second
ISDN	Integrated services digital network
B-ISDN	Broadband integrated service digital network
ISO	International standardisation organisation
LAN	Local area network
LO	Local oscillator
MAC	Medium access control
MAN	Metropolitan area network
Mbps	Megabits per second
OSI	Open system interconnection
PON	Passive optical network
PSC	Passive star coupler
QoS	Quality of service
RCA	Receiver collision avoidance
ONUs	Optical network units
SBS	Stimulated Brillouin scattering
SDM	Space division multiplexing
SRS	Stimulated Raman scattering
TDM	Time division multiplexing
TR	Tuneable receiver
TT	Tuneable transmitter
TDMA	Time division multiplexing access
TO	Thermo-optic
WDM	Wavelength division multiplexing
DWDM	Dense wavelength division multiplexing

LIST OF SYMBOLS

N	Number of nodes
W	Number of channels
T	Tuning time
T_r	Receiver tuning time
D	Average packet delay
P_B	Blocking probability
S	Throughput
S_R	Receiver throughput
R	Propagation time
l	Multicast size
α	Offered load
λ	Packet generation rate
μ	Transmission time rate
D_C	Control channel delay
D_P	Data packet transmission delay
D_{CH}	Data channel delay
D_R	Propagation delay
S_X	Transition system states
$\overline{T}$	Average number of transmissions per message
$\overline{Q}$	Average number of messages waiting in the queue

CHAPTER I

INTRODUCTION

Background

Optical networks are a very promising technology for current and future requirements of fast and high bandwidth networks. An optical network consists of an interconnection of stations, switches and other devices using optical fiber. These networks promise to overcome the bottleneck problems faced by the electronic network. Wavelength division multiplexing (WDM) is a technique used to divide the tremendous optical bandwidth of optical fibers into many non-interfering wavelengths. These wavelengths which are also known as channels can operate at peak electronic speed, thus optically enabling an aggregate system capacity of several terabits/second. WDM also supports mechanisms such as multicasting at the physical layer without buffering. The traffic in WDM networks is usually grouped into sessions. A session is defined as a set of stations engaged in some activity that requires transfer of data. Multicasting in a general term is used to describe how data is transferred within a session.

In multicasting, the destination degree is defined as the number of recipients within a session. The destination degree can vary from 1 to $(N-1)$, where N is the number of stations in the network. There are many advantages for a long distance telecommunication companies in adopting optical fibre technology, one of which is that it enables them to dramatically increase their trunk capacities. This technology may be the starting point for the evolution towards the vision of all-optical networks. However, before it can be considered for commercial networks there is a need of carrying out necessary investigations into its operation, performance and implementation aspects [1].

This chapter presents the optical networks evolution, optical networks types, the enabling technology, some issues in optical network components and systems, design criteria and limitations in optical networks, research objectives and thesis organisation.

Generations of Networks

Next generation Internet multimedia applications such as bandwidth intensive applications like video conferencing, wire services and video on demand, will increase the need for high throughput and low latency. Wavelength Division Multiplexing (WDM) optical networks have the potential to achieve these two goals by offering unprecedented high bandwidths. One of the very important aspects of new Internet services is the support of multicasting. As such, support for multicasting in WDM networks is crucial if these networks were to play an active role in the next generation Internet.

Figure 1 shows the three generations of optical networks. In the first generation, the nodes are interconnected with copper links that have limited bandwidths. These networks have been designed based on a more or less reliable copper-based transmission medium. A salient characteristic of these networks is that each node has to inspect whether the incoming information is intended for it.

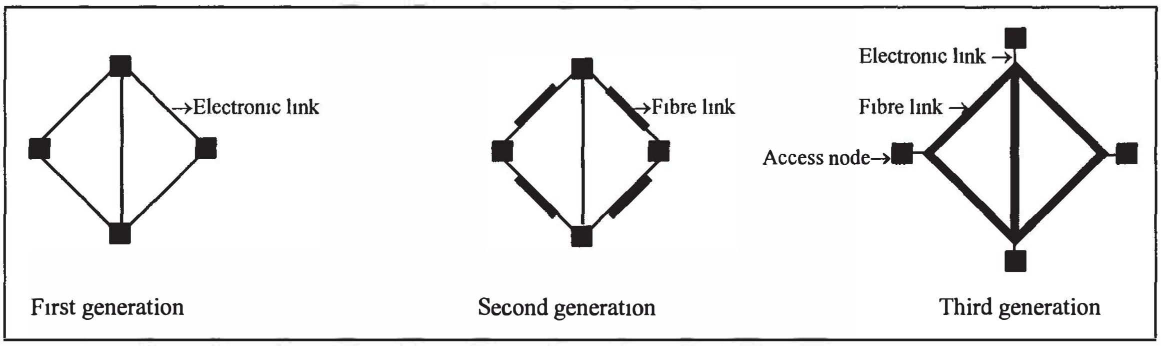

Figure 1: The three generations of optical fibre networks.

In the second generation, the optical fibre is used as a replacement for copper as the transmission mediums where data are sent over this network along multiple links with optical to electronic conversion and vice versa. However, the traditional network architectures still apply. The higher bit rate, larger repeaterless distances and higher reliability are the immediate advantages obtained using the optical fibre as the transmission medium. Examples of these networks are FDDI LAN and DQDB MAN.

A third generation network will provide a continuous optical connection for all nodes. It will fully exploit the unique features of optical fibre, like huge spectral bandwidth and the low propagation loss for maximal network utilisation. These networks will employ the lightwave techniques and devices for their implementations and operations and consequently will result in considerable increase in the network throughput. In essence, many benefits can be realised using optical carriers in multiple high capacity WDM channels that can be individually configured. This class of network is specifically termed as all-optical network [2].

Optical Communication Networks

WDM optical networks can be categorised as either multi-hop or single-hop. In the first category, each node needs to access only a small fraction of the total number of channels and packets may hop through several intermediate nodes before reaching their destinations. The second category employs WDM to provide connectivity among the nodes. WDM channels are dynamically shared by the attached nodes. The logical connections change on a packet-to-packet basis creating all-optical paths between sources and destinations (i.e. each node can directly send packets to any other node without going through any intermediate node).

Single-hop networks can be classified depending on whether they use fixed or tuneable transceivers. Fixed transceivers can only access a predetermined channel. Tuneable transceivers can utilise several optical channels by modifying its physical characteristics. Single-hop networks require the use of rapidly tuneable optical lasers and/or filters that can switch between channels at high speeds. However, they have to be custom-built and tend to be extremely expensive, accounting for a significant fraction of the overall cost of building optical network [3].

In single-hop optical networks based on broadcast-and-select system, information transmitted on any channel are broadcasted to the entire set of nodes. However, it is only received by those with a receiver listing on that channel. Coupled with the tuneability at the receiver ends a single transmission of a multicast packet can reach all receivers in the packet's destination set simultaneously. Its minimal bandwidth requirements make broadcast-and-select approach especially appealing for transmitting multicast traffic. The design of appropriate receiver tuning algorithms is complicated by the fact that the tuneable receivers take non-negligible amount of time to switch between channels and the different multicast groups may have several receivers in common [4].

In a typical WDM environment, the number of channels that will be supported within the optical medium is expected to be smaller than the number of attached nodes. As a result, each channel will have to be shared by multiple receivers and the problem of assigning receive wavelengths arises [5].

Generic optical network interconnection patterns include the bus topology, star topology and ring topology. Other modifications include combinations and variations of the above such as the mesh, cube topology and loop distribution network [6].

The transmission mediums used for networking, such as metallic cables, fibre cables or wireless have an influence on the provision of access points. Optical fibre has the potential to transmit long distances at high speeds with very low error bit rates [7]. In essence, fibre optic networks offer comparable advantages over commonly installed networks (Table1, Appendix A).

Network Architectures

Hierarchical networks are generally designed for firstly, scalability, where the size of network is easily adjusted without affecting performance. Secondly, reconfiguration, where the network adapts to allocate its resources to balance demands. Thirdly, fault-tolerant, to overcome non-performing resources. Figure 2 shows the transport network architecture principles. Table 2, Appendix A summarises generic network architectures that are commonly implemented [8, 9].

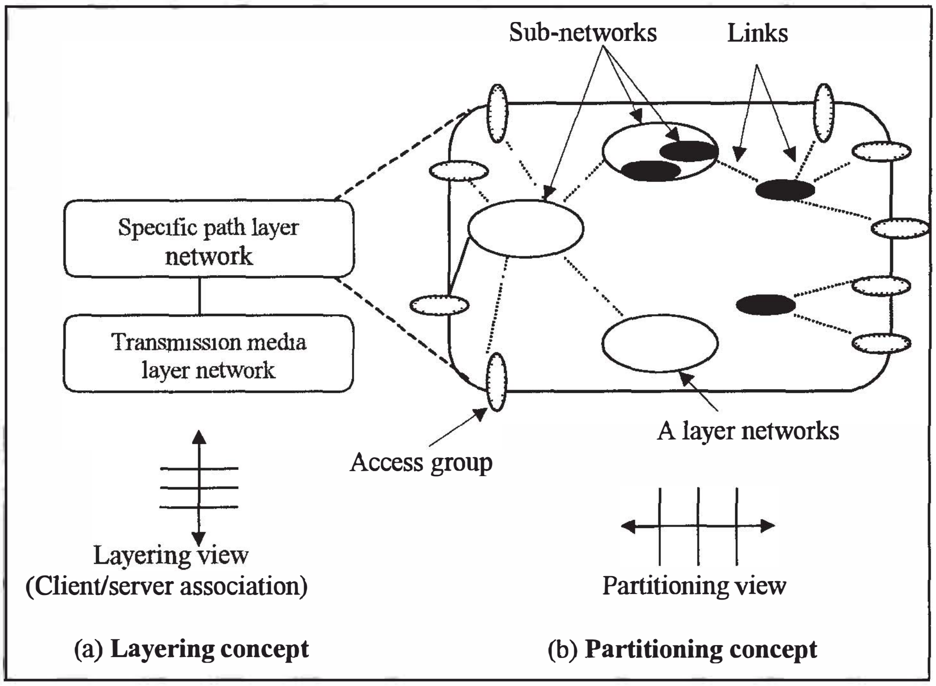

Figure 2: Principles of transport network architecture.

OSI model

There are two requirements for data communication between two hosts. First, data delivered by an end user should arrive at the destination correctly and in timely fashion. Second, data delivered to an end user should be recognisable and in proper form.