UNIVERSITI PUTRA MALAYSIA

DESIGN RELATED INVESTIGATIONS FOR MEDIA ACCESS CONTROL PROTOCOL SERVICE SCHEMES IN WAVELENGTH DIVISION MULTIPLEXED ALL OPTICAL NETWORKS

SELVAKENNEDY SELVADURAI

FSKTM 1999 12

DESIGN RELATED INVESTIGATIONS FOR MEDIA ACCESS CONTROL PROTOCOL SERVICE SCHEMES IN WAVELENGTH DIVISION MULTIPLEXED ALL OPTICAL NETWORKS

By

SELVAKENNEDY SELVADURAI

Dissertation Submitted in fulfilment of the Requirements for the Degree of Doctor of Philosophy in the Faculty of Computer Science and Information Technology Universiti Putra Malaysia

March 1999

Dedicated to my late father,

Mr. P. Selvadurai PPN AMK,

my mother and my family members.

ACKNOWLEDGEMENTS

After intensive research and writing, the accomplishment of my thesis is a fact. Recalling the time, I have experienced many sweet and bitter moments in the process. There have been many people who helped me, directly and indirectly, to fully enjoy the ups and overcome the downs. I take the opportunity here to convey my heartfelt regards to them.

It is my pleasure to express my deep gratitude to my supervisor, Assoc. Prof. Dr. Ashwani Kumar Ramani. He has been there to help me since the very first day of my research. He incessantly motivated and encouraged me to produce good research. He has gone through every single work I have carried out, to bring them to acceptable quality. I feel honoured to have had him as my supervisor.

I would like to extend my thanks to Dr. Md. Yazid Mohd. Saman and Dr. Veeraraghavan Prakash, my co-supervisors, for giving constructive comments and advices on improving my work during the course of my research. They have consistently encouraged me throughout the research.

I would like to thank Dr. Zainal Aripin Zakariah, General Manager, Telekom Malaysia R&D Division, Prof. Dr. Harith Ahmad, Director, Photonics Research Centre, Telekom Malaysia and my colleagues at this centre for extending their cooperation. My regards and thanks to Prof. Hj. Muhamed Awang, Dean, Faculty of Science and Environmental Studies, Dr. Abdul Aziz Abdul Ghani, Dean, Faculty of Computer Science and Information Technology, for their support and encouragement throughout the research. I am also indebted to UPM Graduate School and the faculty's postgraduate committee for their support. I am obliged to Prof. Tan Sri Dato' Dr. Syed Jalaludin Syed Salim, the Vice Chancellor of Universiti Putra Malaysia for his moral support and kind encouragement.

I am extending my gratitude to the lecturers and administrative staffs of Faculty of Computer Science and Information Technology, who have extended their all-possible help along the way.

Finally, let me thank my family members, for being there for me and taking care of my well-being, without which I could not have been this far. I am extending my special thanks to Miss J. Shanthi for constantly encouraging me during the course of this work.

15 April 1999 *S. Selvakennedy*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

AON	All-optical network
ATM	Asynchronous Transfer Mode
CDM	Code-division multiplexing
CSMA	Carrier sense multiple access
DBR	Distributed Bragg Reflector
DFB	Distributed Feedback
DQDB	Distributed queue dual bus
EMI	Electromagnetic interference
FCFS	First-come first-serve
FDDI	Fibre distributed data interface
FTTH	Fibre to the home
Gbps	Gigabits per second
HIPPI	High-performance parallel interface
I-SA	Interleaved slotted Aloha
I-TDMA	Interleaved TDMA
LAN	Local area network
LED	Light-emitting diode
MAC	Media access control
MAN	Metropolitan area network
Mbps	Megabits per second
ONA	Optical network adapter
OTDM	Optical TDM
PDFA	Praseodymium-doped fibre amplifier
PSC	Passive star-coupler
QoS	Quality of service
SDH	Synchronous digital hierarchy

SMP	Semi-Markov process
SONET	Synchronous optical network
TDM	Time-division multiplexing
TDMA	Time division multiple access
TP	Token-passing
TRT	Token rotation time
WAN	Wide area network
WDM	Wavelength-division multiplexing

LIST OF SYMBOLS

M	Number of nodes
C	Number of channels
W	Waiting time
T	Token cycle time
T_R	Time between packet arrival and first token access
BUSY	Probability one of (M-1) nodes is using a channel
Y(*k*)	Probability that there are *k* free channels
P_i	Steady-state probability of being in state i
V_i	Limiting probability of state I in embedded Markov chain
τ_i	Sojourn time of state i
η_i	Probability of leaving state i
λ	Packet generation rate
β	Probability of generating a packet in a slot
ρ	Probability indicating a particular traffic type generation
τr	Residual-wait time
τw	Full-wait time
B	Buffer size
γ	Upper limit of non real-time queue
α	Lower limit of non real-time queue
ω	Value function
D	Average delay
R	Blocking probability
Γ	Throughput

Abstract of dissertation presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy.

DESIGN RELATED INVESTIGATIONS FOR MEDIA ACCESS CONTROL PROTOCOL SERVICE SCHEMES IN WAVELENGTH DIVISION MULTIPLEXED ALL OPTICAL NETWORKS

By

SELVAKENNEDY SELVADURAI
March 1999

Chairman: Associate Professor Ashwani Kumar Ramani, Ph.D.

Faculty: Computer Science and Information Technology

All-optical networks (AON) are emerging through the technological advancement of various optical components, and promise to provide almost unlimited bandwidth. To realise true network utilisation, software solutions are required. An active area of research is media access control (MAC) protocol. This protocol should address the multiple channels by wavelength division mutiplexing (WDM) and bandwidth management. Token-passing (TP) is one such protocol, and is adopted due to its simplicity and collisionless nature. Previously, this protocol has been analysed for a single traffic type. However, such a study may not substantiate the protocol's acceptance in the AON design. As multiple traffic types hog the network through the introduction multimedia services and Internet, the MAC protocol should support this traffic. Four different priority schemes are proposed for TP protocol extension, and classified as static and dynamic schemes. Priority assignments are a priori in static scheme, whereas in the other scheme, priority reassignments are carried out dynamically. Three different versions of dynamic schemes are proposed. The schemes are investigated for performance through analytical modelling and simulations. The semi-Markov process (SMP) modelling approach is extended for the analyses of these cases. In this technique, the behaviour of a typical access node needs to be considered. The analytical results are compared with the simulation results. The deviations of the results are within the acceptable limits, indicating the applicability of the model in all-optical environment.

It is seen that the static scheme offers higher priority traffic better delay and packet loss performance. Thus, this scheme can be used beneficially in hard real-time systems, where knowledge of priority is a priori. The dynamic priority scheme-1 is more suitable for the environments where the lower priority traffic is near real-time traffic and loss sensitive too. For such a scheme, a larger buffer with smaller threshold limits resulted in improved performance. The dynamic scheme-2 and 3 can be employed to offer equal treatment for the different traffic types, and more beneficial in future AONs. These schemes are also compared in their performance to offer constant QoS level. New parameters to facilitate the comparison are proposed. It is observed that the dynamic scheme-1 outperforms the other schemes, and these QoS parameters can be used for such QoS analysis. It is concluded that the research can benefit the design of the protocol and its service schemes needed in AON system and its applications.

Abstrak disertasi yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah.

KAJIAN MENGENAI REKABENTUK SKEMA SERVIS UNTUK PROTOKOL KAWALAN CAPAIAN MEDIA DALAM RANGKAIAN OPTIK-PENUH DENGAN MULTIPLEKS PANJANG GELOMBANG

Oleh

SELVAKENNEDY SELVADURAI
Mac 1999

Pengerusi: **Profesor Madya Ashwani Kumar Ramani, Ph.D.**

Fakulti: **Sains Komputer and Teknologi Maklumat**

Rangkaian optik-penuh semakin menjadi kenyataan dengan perkembangan pelbagai peralatan optik dan menjanjikan kapasiti muatan yang hampir tidak terhad. Untuk mencapai keupayaan tersebut, penyelesaian melalui perisian diperlukan. Salah satu bidang penyelidikan yang pesat adalah protokol kawalan capaian media (MAC). Protokol ini perlulah mengambilkira aspek pelbagai saluran melalui multipleks panjang gelombang dan pengurusan kapasiti. Protokol pindah-token adalah satu protokol dan ia dipilih kerana ia mudah and bercirikan penghantaran data tanpa pelanggaran. Sebelum ini, protokol tersebut pernah dikaji untuk satu jenis trafik sahaja. Walaubagaimanapun, hasil kajian tersebut mungkin tidak memadai untuk digunakan dalam rekabentuk rangkaian optik-penuh. Memandangkan pelbagai jenis trafik menggunakan perkhidmatan multimedia dan Internet, protokol MAC perlulah mengambilkira semua

jenis trafik yang wujud. Empat jenis skema prioriti dicadang untuk lanjutan protokol pindah-token dan ia boleh dikelasifikasikan sebagai skema statik dan dinamik. Pengumpukan prioriti adalah perlu untuk skema statik tetapi skema dinamik melibatkan pemberian prioriti yang dinamik. Tiga jenis skema dinamik dicadangkan. Prestasi skema tersebut dikajiselidik dengan menggunakan pemodelan analitik dan simulasi. Kaedah proses semi-Markov (SMP) dilanjutkan untuk analisis ini. Dalam teknik ini, kelakuan sesuatu nod capaian diperhatikan. Hasil analitik dibandingkan dengan hasil simulasi. Perbezaan hasil adalah di dalam had yang boleh diterima, menjadikannya satu model yang boleh digunakan untuk persekitaran rangkaian optik-penuh.

Dari kajian, didapati bahawa untuk trafik dengan berprioriti tinggi, skema statik memberikan dengan lebih baik dari segi masa penghantaran dan prestasi kehilangan paket. Oleh itu, skema tersebut sesuai digunakan dalam sistem masa-sebenar yang mana memerlukan maklumat prioriti. Skema dinamik-1 pula lebih sesuai untuk persekitaran dengan trafik berprioriti rendah untuk trafik dekat masa-sebenar dan yang sensitif terhadap kehilangan. Untuk skema ini, saiz ingatan yang lebih besar tetapi dengan tahap yang kecil memberikan prestasi yang lebih baik. Skema dinamik-2 dan 3 boleh digunakan untuk memberi layanan yang serupa kepada pelbagai jenis trafik yang berlainan dan lebih sesuai digunakan dalam rangkaian optik-penuh masa hadapan. Skema ini dibandingkan untuk menilai prestasi mereka bagi paras QoS yang sama. Paramater baru untuk perbandingan dicadangkan. Hasil kajian menunjukkan bahawa skema dinamik-1 mempunyai prestasi terbaik dan parameter yang diperkenalkan ini boleh digunakan secara berkesan dalam analisis QoS. Secara kesimpulannya, penyelidikan ini boleh membantu dalam rekabentuk protokol dan skema servisnya untuk sistem rangkaian optik-penuh dan aplikasinya.

CHAPTER I

INTRODUCTION

Optical network is a very promising technology for current and future requirements of fast and high bandwidth networks. These networks promise to overcome the bottleneck problems faced by the electronic networks. All-optical network (AON) is the ideal optical network being envisioned whereby the signal does not undergo optoelectronic conversion, along its path from source to destination node. AON employs wavelength division multiplexing (WDM) technology, which enables transmission of multiple data streams independently on a single fibre, using different light wavelengths for effective use of the bandwidth. There are many advantages for the long distance telecommunication companies (telcos) in adopting this technology, as it enables them to dramatically increase their trunk capacities without going into the painful process of laying more fibres. The technology adoption by these telcos may be the starting point for the evolution towards the envisioned AONs. However, before this technology is considered for commercial networks, there is a need of carrying out necessary investigations into its operation, performance and implementation aspects. The focus of the present research is to study the communication protocol design issues for the AON architectures, and consequently, propose better schemes for their applications. This chapter introduces the AON evolution, the enabling technologies, some issues in AON systems, objectives of the present research and the dissertation organisation.

Generations of Networks

Considering the evolution of the wired communication networks in the past, they may be categorised according to the role of optical fibre in their topologies. This categorisation was initially made by Green [1].

First Generation Networks

The first generation networks did not utilise the optical fibre. Traditional LANs, like, Ethernet and the IEEE 802-family, fall in this category. Wide-area networks (WANs) like ARPAnet [2] are also in the first generation networks. 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.

Second Generation Networks

In the second generation networks, the copper-based transmission part of the networks is replaced by lightwave transmission system, thereby replacing electrical transmission with optical transmission. However, the traditional network architectures still apply to them. The higher bit rate, larger repeaterless distances and higher reliability are the immediate advantages obtained using the optical fibre as the transmission medium. An increase in the network throughput is the direct consequence, entirely due to the higher transmission rates, while individual nodes still have to process the information intended for many other nodes. The larger distances that could be covered between nodes caused the emergence of metropolitan area networks (MANs). Examples of these second generation networks are FDDI LAN [3] and DQDB MAN [4]. Surveys of these networks can be found in [5], [6]. SONET and SDH on optical fibre can be considered as the second generation WANs.

Third Generation Networks

The third generation networks 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 increment in the network throughput. In essence, many benefits can be realised using optical carriers in multiple high capacity WDM channels, which can be individually configured in the network. This class of network is specifically termed as all-optical networks.

The Vision in All-Optical Networking

Looking at the evolution of communication networks and standards, they may seem to become more and more complex (and less manageable) as time goes by. This trend is partially due to the increase in their sizes and bit-rates, but mainly because of the diversity in the network traffic. The vision of WDM optical networks offers a much-anticipated change in this course of evolution into much simpler network architectures [7]. Their data transparency, abundance in resources and passive nature may eliminate the need for sophisticated mechanisms to optimise the utilisation, and management and control of the integrated network environment. The architectural simplicity is achieved through traffic segregation as opposed to the current trend of traffic aggregation. Thus, the focus has shifted to the endpoint issues, like, design of the computers that can make use of such large bandwidth, and how the new applications will capitalise on the huge bit-rates and very low error rates.

On the futuristic scenario, the fibre infrastructure will be extended to the home, commonly known as fibre-to-the-home (FTTH). Efficient use of the hundreds of wavelengths that may be theoretically multiplexed into a single fibre can be made. The global network will be made of fibres interconnected by optical cross-connects and wavelength routers, with optical multiplexers at the endpoints. The endpoints of the connections will have ultra-high speed, low noise pipe between them, equivalent to a private fibre that serve them exclusively. The network, acting as a passive piece of glass, is neither sensitive to the protocol nor the bit-rate. It may even be insensitive to the nature of the data, be it digital or some analogue signal. As a result, these networks will only need few simple protocols to govern the communications.

The scenario is in contrast with the complexity and extensive monitoring and management required by 'traditional' networks like SONET, B-ISDN and ATM. It is enough to see how much standardisation effort is put into other alternatives for high-bandwidth, integrated networks, to realise the promise that AONs can provide. ATM standardisation bodies, researchers and implementers are struggling with definitions of different traffic classes, congestion control mechanisms, quality of service definitions and the implications of these features on the switching architectures, policing mechanisms, resource allocation problems, dealing with cell losses, buffer management and pricing. All these issues become simpler or trivial when considering optical networks instead.

Evolution of Optical Networks

The bandwidth available in the low-attenuation passbands (Figure 1.1) within a standard single-mode optical fibre is about 50 THz (25 THz at second and third telecommunication windows, respectively) [8]. The maximum rate that the end-users - which can be workstations or gateways - can access the network is limited by the electronic speeds (up to a few Gbps). Realising this limitation, the key aspects in design of the optical communication networks (to exploit the bandwidth) is to introduce concurrency among multiple user transmissions into