DEVELOPMENT OF DYNAMIC SERVICE DELIVERY MODEL IN WAVELENGTH ROUTED OPTICAL NETWORKS USING GMPLS FRAMEWORK

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To my parents (May Allah bless you both); and especially to my wife and children.

ABSTRACT

Wavelength routed optical networks has been claimed as the main technology to underpin the future telecommunication networks and therefore it has garnered widespread interests from industrial and academic researchers alike to investigate key issues that affect its implementation and deployment. The main challenge within this domain is primarily to provide a dynamic service delivery technique to match the growing demand in network capacity due to the increasing popularity of end-users applications which include the omnipresent internet connectivity, video on-demand, online gaming and multimedia services. The proliferation of next generation optical networks also known as the all optical networks has paved the way for the study in this thesis. Network functions previously performed in the electrical domain have now gradually migrated to the optical domain, thus giving a huge upgrade in terms of the network capacity and capability. While a number of works has focused on the developing network models to measure the qualitative and quantitative performances of such networks, the combination of routing algorithms, signaling and wavelength assignment schemes employed proves to have substantial effects. Thus, this research attempts to address the issue of providing dynamic service delivery for users in the optical domain from modeling perspective. A new optical network model is developed using the *GMPLS* based framework for the control plane of the overall network operation. The key feature in this model is the lightpath provisioning process for accommodating service request in dynamic fashion. The performance of this

model is then investigated by means of simulations using *OMNeT++* simulation platform. Experiments through simulations for this research have produced results showing that the network model gives consistent performance in terms of the network behaviour. Furthermore, results obtained from the simulation are also used to validate and verify the accuracy of the developed network model in this study. In addition to that, this thesis proposes a benchmarking for delivering such on-demand requests for future network services especially on the correlation between the desired network utilisation and its baseline network setup and resources.

ABSTRAK

Rangkaian optik gelombang panjang telah disarankan sebagai teknologi utama untuk menyokong rangkaian telekomunikasi masa-depan dan dengan demikian ia telah mendapat minat yang meluas dari penyelidik di sektor industri dan akademik untuk mengkaji isu utama yang mempengaruhi pelaksanaan dan penggunaannya. Cabaran utama dalam domain ini adalah untuk menyediakan teknik penyampaian perkhidmatan yang dinamik untuk menandingi permintaan yang semakin meningkat dalam kapasiti rangkaian disebabkan peningkatan populariti aplikasi pengguna seperti penyambungan internet di mana-mana, permintaan video, perkhidmatan permainan dan multimedia dalam talian. Peningkatan rangkaian optik generasi akan datang yang juga dikenali sebagai rangkaian semua-optik telah membuka jalan bagi kajian ini. Fungsi rangkaian sebelum ini yang dilakukan di domain elektrik kini telah beralih ke domain optik secara beransur-ansur, sehingga memberikan peningkatan besar dari segi kemampuan dan keupayaan jaringan. Walaupun beberapa kajian telah memberi tumpuan kepada membangunkan model rangkaian untuk mengukur prestasi kualitatif dan kuantitatif rangkaian tersebut; kombinasi algoritma penghalaan, skema isyarat dan penugasan gelombang panjang yang digunakan membuktikan terdapat kesan yang agak penting. Oleh itu, kajian ini cuba menangani isu penyampaian perkhidmatan dinamik bagi pengguna dalam domain optik dari perspektif pemodelan. Model rangkaian optik yang baharu telah dibangunkan menggunakan rangka kerja *GMPLS* untuk satah kawalan operasi rangkaian keseluruhan. Ciri utama dalam model

ini adalah proses memperuntukkan gelombang untuk menampung permintaan perkhidmatan dengan cara yang dinamik. Prestasi model ini kemudian disiasat dengan cara simulasi menggunakan platform simulasi *OMNeT++*. Eksperimen melalui simulasi untuk kajian ini telah menghasilkan dapatan yang menunjukkan bahawa model rangkaian memberikan prestasi yang konsisten dari segi tingkah laku rangkaian. Selain itu, dapatan yang diperoleh daripada simulasi juga digunakan untuk mengesahkan dan mempastikan ketepatan model rangkaian yang dibangunkan dalam kajian ini. Di samping itu, tesis ini juga mencadangkan penanda aras bagi penghantaran permintaan ke atas perkhidmatan rangkaian masa-depan terutamanya mengenai hubungan antara penggunaan rangkaian yang dikehendaki sejajar dengan persediaan dan sumber rangkaiannya.

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Last and most importantly, I am grateful to my family; my wife and children for all their support, patience and love.

APPROVAL

I certify that an Examination Committee has met on **11th July 2017** to conduct the final examination of **Fuead b Ali** on his degree thesis entitled **'Development of Dynamic Service Delivery Model in Wavelength Routed Optical Networks using GMPLS Framework'**. The committee recommends that the student be awarded the Master of Science (Computer Science).

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LIST OF ABBREVIATIONS

ASON	Automatically Switched Optical Networks
ATM	Asynchronous Transfer Mode
BGP	Border Gateway Protocol
CBR	Constraint Based Routing
DiffServ	Differentiated Service
DIR	Destination Initiated Reservation
DWDM	Dense Wavelength Division Multiplexing
ESCON	Enterprise System Connection
FDDI	Fibre Distributed Data Interface
FEC	Forwarding Equivalent Class
FSC	Fiber Switch Capable
GbE	Gigabit Ethernet
GMPLS	Generalized Multi-protocol Label Switching
HIPPI	High Performance Parallel Interface
HW	Hop-based Weight
IETF	Internet Engineering Task Force
IGP	Interior Gateway Protocol
IP	Internet Protocol
ISP	Internet Service Provider
ITU	International Telecommunication Union
ITU-T	ITU-Telecommunication Standardization Sector
LMP	Link Management Protocol
LSP	Label Switched Path

LSR	Label Switch Router
MPLS	Multi-Protocol Label Switching
MPλS	Multi-Protocol Lambda Switching
NGN	Next Generation Networks
NNI	Network to Network Interface
OADM	Optical Add/Drop Multiplexer
OBS	Optical Burst Switching
OCh	Optical Channel
OCh-P	Optical Channel-Path
OCh-S	Optical Channel-Section
OEO	Optical Electrical Optical
OIF	Optical International Forum
OMNeT++	Objective Modular Network Testbed in C++
OMS	Optical Multiplex Section
OOO	Optical to Optical to Optical
OPS	Optical Packet Switching
OSPF	Open Shortest Path First
OSPF-TE	Open Shortest Path First Traffic-Engineering
OTN	Optical Transport Network
OTS	Optical Transmission Section
OXC	Optical Cross Connect
PacNet	Pacific Network
PDH	Plesiochronous Digital Hierarchy
QoS	Quality of Service
RSVP	Resource Reservation Protocol
RSVP-TE	Resource Reservation Protocol Traffic Engineering
RWA	Routing and Wavelength Assignment
SDH	Synchronous Digital Hierarchy
SDL	Simplified Data Link

SIR	Source Initiated Reservation
SLA	Service Level Agreement
SONET	Synchronous Optical Network
TAWW	Total and Available Wavelength Weight
TE	Traffic Engineering
UNI	User Network Interface
V&V	Validation and Verification
VWP	Virtual Wavelength Path
WDM	Wavelength Division Multiplexing
WP	Wavelength Path
WR-OXC	Wavelength Routing OXC
WT-OXC	Wavelength Translating OXC
WRON	Wavelength Routed Optical Network

CHAPTER 1

INTRODUCTION

1.1 Introduction

The proliferation of optical network technology has helped to alleviate the emerging of next generation transport networks; also known as intelligent optical network. Network functions previously processed in the electrical domain have now gradually migrated to the optical domain, thus giving a huge upgrade in terms of the network capacity and capability.

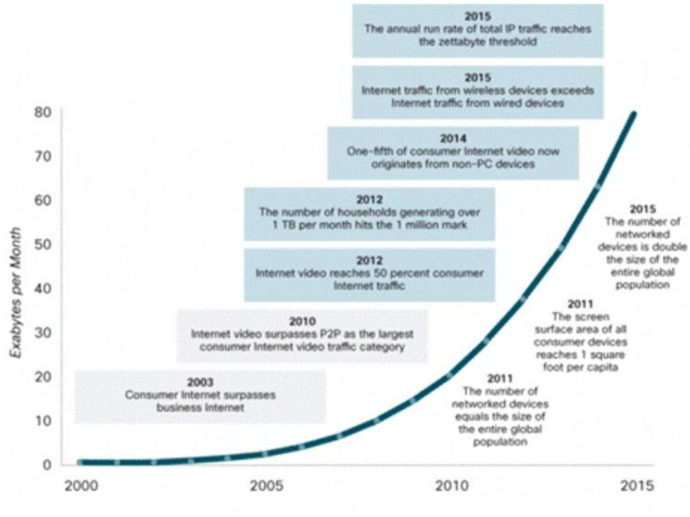
One of the main areas of interest in optical networks technology revolves on the automated service delivery for the users (Ritter (2009)). In this optical domain, this mechanism is simply defined as the provisioning of the light paths; which is also known as the optical connections. This process must be dynamic, as implemented in the IP domain for the request for connectivity between IP hosts. As such, the study in this research attempts to quantitatively analyze the performance of such network in a dynamic optical connections provisioning process. In this study, the interest is on the all optical network architecture which employs the wavelength routing scheme.

1.2 Problem Statement

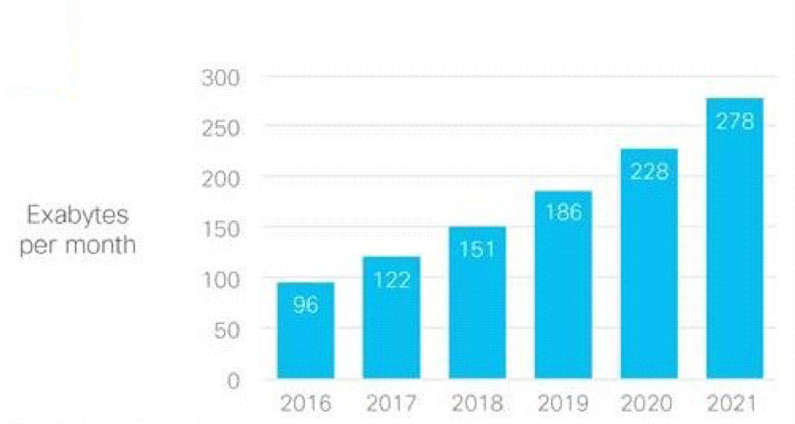
The current exponential growth of demands for internet data traffic presents a huge challenge for most network service providers. The industry analyst firm Dell'Oro Group has predicted that bandwidth consumption to grow by 40 to 50 percent on average per year (Ritter (2009)). The research conducted by the Cisco VNI Global IP Traffic Forecast (*Cisco VNI Global IP Traffic Forecast* (n.d.)), (Pepper and Sumits (2016)) and (Pepper and Sumits (2011)) as shown in Figure 1.1 also clearly indicate the exponential fashion of the network growths. The main factors that rapidly stimulate this growth are the increasing popularity of the end-user applications which include the omnipresent internet connectivity, video on-demand, on-line gaming as well as multi-media messaging services.

In order to stay competitive, Internet Service Providers (ISP) must be able to meet these demands while keeping the operation and running cost at a considerable level. As a result, deployment for a new network infrastructure seems prohibitive since it requires enormous amount of capital investments. In contrast, utilising the current network infrastructure coupled with strategies on varying and increasing the service offerings can be an interesting option (Kauffman (2005)).

The advent of Generalized MultiProtocol Label Switching (GMPLS) (Farrel and Bryskin (2006)) as optical control plane has helped transforms the future optical network technology. From being a merely point-to-point connection, optical network has reached an advanced state where a number of intelligent functions are ready to be



(a) Network Growth in Exabytes from 2000 to 2015 (*Cisco VNI Global IP Traffic Forecast* (n.d.))



(b) Expected Network Growth in Exabytes from 2016 to 2021 (Pepper and Sumits (2016))

(c) Anticipated Global IP Traffic by year 2020 (Pepper and Sumits (2011))

Figure 1.1 Growth of Network and IP Traffic - Past and Future

incorporated to the optical domain, such as routing, topology discovery and signaling. This also includes some mechanisms to offer Quality of Service (QoS) guarantees to be widely available at the IP layer. Moreover, employing GMPLS-based control plane has also created a new paradigm in optical-based service offerings to the end-users. From a traditional static-based, it is now possible to provide dynamic, on-demand, and multiple classes of services with appropriate Service Level Agreements (SLA), which is also defined as discrete level of service guarantees.

From protocol perspectives, GMPLS provides a framework where existing IP-based protocols such as OSPF (Ramaswami and Siravajan (1998)) and RSVP (Ramaswami and Siravajan (1998)) are able to function seamlessly in the optical domain. Lightpaths, which are the main entity of the connections that exist within the network can be established with ease by utilising these protocols.

From service perspectives, GMPLS can also provide traffic engineering (TE) for lightpaths within the network. TE capable optical network enables the network to focus on its performance with regard to delivering services at a much finer granularity, which in turn results in a better capacity optimisation and utilisation. In this respect, much finer QoS classifications at the optical level can be achieved to target specific users' requirements.

As outlined in (Kauffman (2005)), "network service providers are looking beyond today's clunky service delivery model. Its reliance on manual provisioning system and long-term capacity allocation have made the service model an inefficient one. A next generation network architecture is envisioned where its ability to utilise network