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PERFORMANCE STUDIES OF A DOUBLE-LAYERED ALL·OPTICAL NETWORK ARCIDTECTURE

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PERFORMANCE STUDIES OF A DOUBLE-LAYERED ALL-OPTICAL NETWORK ARCHITECTURE

By

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LIST OF ABBREVIATIONS

ACK	acknowledgement (packet)
ANSI	American National Standards Institute
AON	all-optical network
APD	avalanche photodiode
ATM	asynchronous transfer mode
B-ISDN	broadband-ISDN
bps	bits per second
CCITT	*International Consultative Committee on Telegraphy and Telephony*
CDM	code-division multiplexing
CDMA	code-division multiplexed access
CSMA/CD	carrier sense multiple access with collision detection
DSM	distributed shared memory
DWDM	dense wavelength division multiplexing
FDDI	fiber distributed data interface
FDM	frequency division multiplexing
FDMA	frequency division multiplexed access
FTTH	fiber to the home
Gbps	Giga bits per second
IEEE	Institute of Electrical and Electronic Engineers
ISDN	Integrated Services Digital Network
ISO	International Organization for Standardization
ITU-T	*International Telecommunication Union - Telecommunications Standardization Sector*
I-hub	intelligent hub
I-TDMA	a TDMA protocol variant
LAN	local area network
LED	light emitting diode
LLC	logical link control
MAC	medium access control
Mbps	Mega bits per second
OSI	Open Systems Interconnection
PDH	pleisiochronous digital hierarchy
QOS	quality of service

SA	slotted Aloha
SDH	synchronous digital hierarchy
SMP	semi-Markov process
SONET	synchronous optical network
SS7	Signalling System Number 7
STM	synchronous transfer mode
subnet	sub-network
Tbps	Tera bits per second
TDM	time division multiplexing
TDMA	time division multiplexed access
VCI	virtual channel identifier
VPI	virtual path identifier
WAN	wide area network
WDM	wavelength division multiplexing
WDMA	wavelength division multiplexed access
WP	wavelength partitioner

LIST OF SYMBOLS USED

B	buffer
C	channel
D	delay
G	global
L	local
S_i	event State i, where $0 < i < M$
β	probability of a single packet being generated
ρ	denotes a global bound packet
$(1-\rho)$	denotes a local bound packet
λ	packet generation rate (Poisson)
τ_i	sojourn time of being in state S_i
tr	sojourn time of being in the residual wait state
tw	sojourn time of being in the full wait state
pr	probability of m packets being generated during RW
pw	probability of m packets being generated during FW
T_G	probability of the global token arriving first
$1-T_G$	probability of the local token arriving first
p[*x*,*y*]	probability of transition from State *x* to State *y*
V_i	limiting probability of the embedded Markov chain
P_i	limiting probability of the semi-Markov process
D_{global}	average delay per global bound packet
D_{local}	average delay per local bound packet

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PERFORMANCE STUDIES OF A DOUBLE-LAYERED ALL-OPTICAL NETWORK ARCHITECTURE

By

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April 1999

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

Faculty: **Computer Science and Information Technology**

Transmission in complete lightform is now realised with advancements in technology. These include new developments in fabricating the fiber carrier medium, low loss fiber coupling devices, optical switching components for routing lightwave transmission; laser light sources and sensitive photonic detectors. The increasing speeds of new generation electronic microprocessors, is capable of resolving the differences in processing and transmission speeds. Access to the medium is regulated by the medium access control protocol, that permits multiple users to share limited transmission resources of the network. The double-layered hierarchical all-optical network architecture is proposed, that consists of an upper layer to interconnect sub-networks of the lower layer. The data packets are differentiated for the two layers. The architecture implements wavelength-space transmission of wavelength division multiplexed channels. The architecture affords

spatial reuse of channels in the lower layer. A non-contentious token-passing medium access protocol is utilised. The token-passing variant that uses one token to provide access to multiple channels is introduced.

The performance of the arrayed transmitter of the access node is gauged to determine the suitability of the architecture with the access protocol in supporting multiple accesses. The transmitter can queue a number of data packets awaiting transmission depending on the size of the buffer. Performance indication can be obtained from probabilistic modelling of the changing event states of the transmitter. Performance causal parameters which include the number of nodes, channel allocation and buffer size are defined. The results from the probabilistic models are then analysed and verified with simulation. The architecture provides an inherent feature termed as the bypass that is capitalised to improve performance of the lower layer. Performance indication shows that the architecture is capable of supporting the two types of data packets effectively, and the access protocol is suitable for its purpose. Performance indication of average packet delay improves when the when the bypass feature is implemented. The probabilistic models are found to provide a logical and systematic approach to study and gauge performance of the token-passing access protocol. In conclusion, the double-layered hierarchical AON architecture and the medium access protocol, together serve as a reference for the study of similar scaleable network architectures and their performance.

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KAJIAN PRESTASI REKABENTUK RANGKAIAN OPTIK-KESELURUHAN DENGAN DUA LAPISAN

Oleh

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Penghantaran secara lengkap dengan pancaran cahaya kini telah tercapai dengan peningkatan dalam tahap teknologi. Di antara pembaruan teknologi dalam bidang tersebut merangkumi process pengeluaran gentian optik, peralatan antara-muka untuk penyambungan gentian optik, peralatan untuk penghantaran cahaya dalam rangkaian; sumber pancaran laser dan pengesan photonik yang sensitif. Kelajuan mikropemproses elektronik semakin meningkat dengan setiap generasinya yang baru, dan berupaya mengurangkan perbezaan antara kelajuan pemprosesan dan kelajuan penghantaran. Pencapaian ke bahantara dikawal oleh protokol MAC yang membolehkan lebih ramai pengguna berkongsi sumber penghantaran. Jumlah sumber penghantaran adalah terhad dalam rangkaian. Suatu rekabentuk rangkaian optik-keseluruhan berhierarki dengan dua-lapisan dicadangkan. Ia mengandungi satu lapisan-atas untuk menghubungkan rangkaian-kecil yang menwujudkan

lapisan-bawah. Paket data yang berbeza digunakan dalam kedua lapisan berasingan. Rekabentuk rangkaian menggunakan saluran WDM dengan penghantaran secara wavelength-space. Rekabentuk tersebut mengamalkan penggunaan saluran penghantaran rangkaian-kecil dalam lapisan bawah secara serentak. Protokol token-laluan tampa pertelagahan digunakan. Token-laluan yang menggunakan satu token untuk mencapai saluran penghataran berganda akan diperkenalkan.

Prestasi penghantar berjenis selari pada nod akan dipertimbangkan untuk meninjau kesesuaian rekabentuk berserta protokol token-laluan. Penghantar boleh mengaturkan sejumlah paket data bergantung kepada saiz penimbal sebelum penghantaran. Petanda prestasi boleh diperolehi dari model kebarangkalian perubahan keadaan peristiwa alat penghantar. Parameter penyebab petanda prestasi ditakrifkan merangkumi bilangan nod, agihan saluran dan saiz penimbal. Keputusan dari model kebarangkalian kemudiannya akan dianalisa dan disahkan secara simulasi. Rekabentuk rangkaian membekal ciri semulajadi yang dikenali sebagai lencongan *bypass* yang diutamakan untuk membaiki prestasi lapisan bawah. Petanda prestasi menunjukkan rekabentuk rangkaian dapat menampung kedua jenis paket dengan berkesan, dan protokol tersebut bersesuaian untuk tujuan yang dikehendaki. Purata kelewatan paket menurun apabila ciri lencongan *bypass* digunakan. Model kebarangkalian didapati boleh memberi pendekatan yang logik dan sistematis untuk mengkaji dan menjangka prestasi capaian protokol token laluan yang digunakan. Rekabentuk rangkaian hierarki dengan dua lapisan berserta protokol pencapaian ke bahantara, sesuai digunakan sebagai bahan rujukan untuk pengajian rekabentuk rangkaian skalar dan petunjuk prestasi.

CHAPTER I

INTRODUCTION

Lightwave or optical communication was first implemented over two decades ago. The idea of using light for communication over long distances has been historically documented. The ancient Greeks and Phoenicians used sunlight reflected off mirrors for signalling between tall towers in the line-of-sight. Alexander Graham Bell in the late 19th century demonstrated the Photophone which used sunlight as the signal carrier for sending voice signals. His work characterised the attempt to embed signals into a light beam for transmission over far distances. Atmosphere is the first transmission medium tested for lightwave signalling [1].

Communication by light beams was not practicable because a clear and unobtrusive line-of-sight is required. The use of mirrors offered some respite in allowing light to bend around corners. Glass was soon discovered as a medium for light propagation as its constant nature affords long distance transmission with little degradation, while also allowing the light inside to be bent around corners. Light in the glass medium is unaffected by the external environmental variations [2,3].

The basic mechanisms for optical transmission are the light source, the optical fiber medium and the light detector. The light source modulates the light according to electrical signal input. The optical fiber carries the modulating light to the detector at the opposite end that converts the light back to similar electrical signals. The basic techniques for optical transmission [4] are analogue modulation, digital modulation, and digital modulation with analogue-to-digital conversion. Lightwave in the optical fiber medium travels in one direction unless it is also transmitted from the opposite direction. Therefore, for full-duplex communication, two identical sets of opposing modulation and detection devices are implemented. Figure 1.1 depicts the basic mechanisms and techniques for optical transmission.

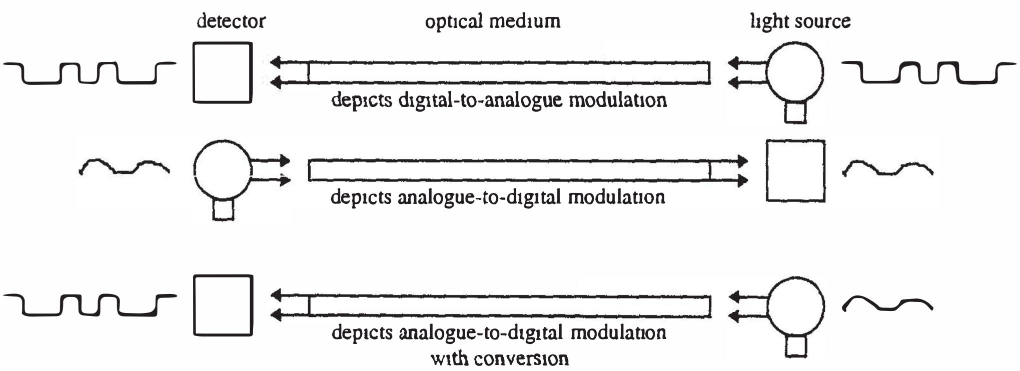

Figure 1.1: Optical fiber transmission basics.

Communications by optical means are becoming increasingly popular due to the inherent benefits of lightwave and the carrier medium characteristics [3,5]. The advantages include the large transmission capacity at high speeds and long haul before signal regeneration is needed. The optical medium is insulated and is non-sparking, while its small bulk and light weight are suitable for installation in varied building conditions. Optical fiber offers immunity to electrical interference, provides transmission security and presently has a high degree of versatility. Some of these characteristics are reviewed in the next chapter. Although lightwave transmission offers many advantages over other forms of signal transmission, it also has some drawbacks. These include the need for electrical-to-optical conversion of signals [6,7], greater complexity in optical components and network designs [8], and higher fabrication and maintenance costs [9]. In handling fiber optic, right-of-way regulations are required for laying of fiber cables [10]. Installation and maintenance of optical fibers require specially trained personnel, high skill levels and handling techniques, as well as management and monitoring expertise.

Communication Networks

In a distributed computing environment where data exchange is necessary among multiple processors and with the various supporting peripheral devices, the interconnection provides the framework for computing operations. Interconnection can be viewed at the micro level, as enabling communications, for example, among processors and the storage elements [11]. The network, meanwhile enables communications among distributed processing entities, such as among a group of computers. The manner in which interconnection is established, determines network functionality and performance, which underpin the basis for communications study.

The emphasis in this work is on all-optical network (AON) where transmission is maintained in optical form, throughout its route from the source to the destination. In a conventional local area network (LAN), a transmission can be routed through the network intermediate devices, for example, bridges or routers where some processing and retransmission can occur. As with any network implementation, a network can be scaled [12] from a small size LAN to cover a wide area as a wide area network (WAN); which may include extensive geographical coverage. The number of nodes that are attached to a network can be very large. Simultaneous access to use the network by the large number of nodes, necessitates some form of regulation to prevent traffic congestion. Medium access procedures are broadly categorised as contention-based and non-contentious. The Ethernet is contention-based, offers transmission speeds of 10 Mbps, 100 Mbps and up to 1000 Mbps (at this rate it is known as Gigabit networks) [13]. A common example of non-contentious access is the token-passing protocol [14].

The network configuration also determines the performance level and the service provisions that can be made available. The network configuration can be dependent on the medium access protocol that proves most efficient. Generic network interconnection patterns include the bus topology, star topology and the ring topology [15-17]; modifications which include combinations and variations such as the mesh and cube topology [18], and loop distribution network [19]. The choice of transmission medium for networking, such as using metallic cables, fiber cables or wireless; affects the provision of access points. The combination of services and value-added functions that can be offered, transmission security, transmission capacity, transmission loss caused by the carrier, effects from external causes on the carrier medium, are among the other issues to be observed.

A suitable medium access protocol operates for a designated network configuration primarily to deliver the lowest error rates, if possible non at all. Optical fiber has the potential to transmit long distances, at high speeds and with very low error bit rates. In essence, fiber optic networks offer comparable advantages over commonly installed wired networks, (broadly summarised as Appendix 2) [9,19,20,21]. Besides the physical aspects and access procedures to improve communications, the following sections introduce some approaches to maximise transmission capacity of an optical medium; and network architecture design concepts that can effectively manage high traffic loads.

Transmission Capacity

The physical medium can maximise its capacity by adopting the suitable transfer mode to transmit information across the layered network. The transfer mode can be viewed as a quanta of transmission capacity, for example, a time slot, which is a partition or division of the flowing carrier signal. These slots are used to carry plain data and intelligence signals used to identify the carrier channel or to instruct connections in a layered network. The transfer modes are distinguished by the way it is configured, that is, the switching and multiplexing of channels (or slots) that are performed. The transfer mode can be created using the time, frequency and space dimension [21]. The time-based and frequency-based transfer modes are most commonly used. The latter requires bundling many transmission channels physically. This proved to be ineffective both for actual application and cost wise, i.e. installation, management and maintenance of a multitude of links [21].

The time-based transfer mode is categorised by the way the time slots that belong to a channel are identified. The synchronous mode identifies the time slots from a channel by the position within a time frame. The asynchronous mode labels all the time slots. Time division multiplexing (TDM) prescribes the synchronous approach. The synchronous transfer mode (STM) [22] defines equal transmission capacity for channel time slots of each hierarchy level. The pleisiochronous digital hierarchy (PDH) [23] preludes the introduction of the synchronous digital hierarchy (SDH) which has now been adopted as the standard STM for Europe [24]. The American variant of SDH is the synchronous optical network (SONET). Operational standards of the SDH can be found from the ITU-Recommendation publications. Some overview and literature on SDH and SONET are available from [25,26,27]. The asynchronous transmission mode (ATM) is devised to take advantage of the differences at the higher transmission levels, by multiplexing different data sources as cells in a transmission stream. The higher speeds and non-synchronous transmissions, permit the coupling of different speeds and different protocol networks, to the ATM carrier. The cells are reassembled at the receiving end with characteristic as delivered from the source. [28-32]. ATM utilises labelling of cells (with payload and header), channels and paths, i.e. virtual channel identifier (VCI) and virtual path identifier (VPI). The ATM exemplifies a time-based method to enhance transmission capacity through multiplexing input onto a fast carrier. Important ATM characteristics broadly include, small fixed-size cells, asynchronous transmission and time slot labelling [28,29,30].

The frequency-based transfer mode identifies the carrier signal by the position in the frequency spectrum. The frequency division multiplexing (FDM) is an example of the analogue telephony service, where each frequency is used to carry one voice signal. The use of optical devices has enabled multiple channels to be bundled to create large capacity carriers, for example, wavelength division multiplexing (WDM). Such lightwave carriers can be constructed to coexist with other transfer modes, for example, SDH and ATM.

Different network topologies are used depending on implementation factors. These include the system application, service requirements, choice of transfer mode, carrier medium and investı

Network Architecture

The network architecture serves to provide interconnection functionality, that caters for the ease of incorporating physical extensions, for example, new nodes and devices. It also considers protocol interoperability, the choice of transfer mode, provisions for network statistical gathering and network management. The network is usually partitioned to isolate traffic among groups of commonly intercommunicating nodes. The grouped networks are bridged as a larger network with communications between two distant nodes routed through the (grouped) networks. This forms an apparent hierarchy, where interacting groups of networks are layered such that the upper levels carry traffic for among the networks of the lower levels. Hierarchical networks are generally designed for: