UNIVERSITI PUTRA MALAYSIA

# DESIGN AND OPTIMIZATION OF FTTH ARCHITECTURE

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# DESIGN AND OPTIMIZATION OF FTTH ARCHITECTURE

By

MOHD NOOR DERAHMAN

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science**

**February 2002**

*To my mom & dad, wife & daughter*

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

**DESIGN AND OPTIMIZATION OF FTTH ARCHITECTURE**

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**February 2002**

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**Faculty : Engineering**

Recently, the growth of Internet and uses of digital contents have significantly increased the demand for high-speed access network. Similar cases are also seen for the use of intranet and extranet services. The limitation of current access network such as the asymmetric digital subscriber line (ADSL) in terms of low bit rate and short of coverage span resulted in the exploration on fibre access scenario. Fibre-to-the-home (FTTH) brings the broadband access network capabilities directly to the customer premises with high splitting ratio and wide fibre span. It is seen as the linchpin technology to enable the future applications such as voice, video and data run, satisfying the ever-increasing need for bandwidth.

This thesis shows the study of FTTH access network based on passive optical network (PON). The two types of FTTH; A-PON and Super-PON have been studied thoroughly to optimize their architecture to help network engineers in designing the system. The cost analysis is also carried out. The simulation is done using OptSim 3.0 and the result is verified with the experiment in the laboratory. It is found that the optimum configuration of a A-PON FTTH access systems with the bit rate of 2Gb/s with the use of 32 branching number is at the distance of 20 km. The power

enhancement offered by Erbium-doped Fibre Amplifier (EDFA) provides for large distribution branches (thus the subscribers) and the length of fibre span can be extended up to 100 km.

The relationship in design parameters namely the bit rate, transmit power, branches, and distance are well studied in view of their effects to the performance parameters namely BER, eye-opening, jitter and Q value. It is shown here that the BER improves with the transmit power, and deteriorates with the bit rate, distance and branch number. The optimization can be achieved by increasing the power level since the increment of the power level will reduce the BER. The normalized jitter must be verified in order to get the absolute performance indication rather than the jitter itself. The cost incurred with the S-PON system is practical if there is an adequate customer sharing the same line.

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

**REKA BENTUK DAN PENGOPTIMUMAN SENIBINA FTTH**

**Oleh**

**MOHD NOOR DERAHMAN**

**Februari 2002**

**Pengerusi: Profesor Madya Mohamad Khazani Abdullah, Ph.D.**

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Kebelakangan ini, pertumbuhan Internet dan penggunaan kandungan digital telah meningkatkan permintaan terhadap rangkaian capaian kelajuan tinggi. Kes yang sama juga dikenalpasti dalam perkhidmatan intranet dan extranet. Kekangan rangkaian capaian semasa seperti Laluan Pendaftaran Digital Asimetri (ADSL) dari segi kadar bit yang rendah dan liputan yang terhad menjurus kepada senario pencarian capaian fiber. *Fibre-to-the-Home* (FTTH) berupaya menawarkan rangkaian capaian jalur lebar secara terus ke kediaman pelanggan dengan kadar pecahan yang tinggi dan rangkuman fiber yang luas. Ia dilihat sebagai teknologi pelengkap untuk membolehkan aplikasi masa depan seperti suara, video dan data memenuhi keperluan jalur lebar yang sentiasa meningkat.

Tesis ini menunjukkan kajian tentang rangkaian capaian FTTH yang berasaskan kepada rangkaian optik pasif (PON). Dua jenis FTTH; A-PON dan Super-PON telah dikaji secara mendalam untuk mengoptimumkan senibinanya. Analisa kos juga diambil kira. Simulasi dijalankan dengan menggunakan OptSim 3.0 dan keputusannya disahkan secara ujikaji. Adalah didapati bahawa konfigurasi optimum

bagi sistem capaian A-PON FTTH dengan kadar bit sebanyak 2 Gbps menggunakan 32 cabang adalah dalam jarak 20 km. Peningkatan kuasa yang ditawarkan oleh Erbium-doped Fiber Amplifier (EDFA) menyediakan pembahagian cabang yang luas (iaitu pengguna) dan jarak fiber boleh dipanjangkan hingga 100 km.

Hubungan diantara parameter rekabentuk seperti kadar data, kuasa penghantaran, cabang dan jarak adalah dikaji secara teliti tentang kesannya kepada parameter persembahan iaitu BER, bukaan-mata, *jitter* dan nilai Q. Adalah dikenalpasti bahawa BER meningkat dengan penghantaran kuasa dan berkurang dengan kadar bit, jarak dan bilangan cabang. Pengoptimuman boleh dicapai dengan meningkatkan tahap kuasa yang mana peningkatan tahap kuasa akan mengurangkan BER. Pernormalan jitter mestilah dikenalpasti untuk memperolehi indikator persembahan yang mutlak berbanding jitter itu sendiri. Kos yang yang dihadapi dengan sistem S-PON adalah praktikal sekiranya pelanggan yang berkongsi laluan adalah mencukupi.

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I certify that an Examination Committee met on 7th February 2002 to conduct the final examination of Mohd Noor Derahman on his Master of Science thesis entitled "Design and Optimization of FTTH Architecture" 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 for the candidate are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master Science.

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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 degree at UPM or other institutions.

(MOHD NOOR DERAHMAN)

Date: 11 APRIL 2002

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## ABBREVIATIONS

| | |
|---|---|
| ACTS | Advanced Communications, Technologies and Services |
| ADSL | Asymmetric Digital Subscriber Line |
| AN | Access Network |
| AN-SMF | Access Network Systems Management Function |
| A-PON | Asynchronous Transfer Mode-Passive Optical Network |
| ATM | Asynchronous Transfer Mode |
| BER | Bit Error Rate |
| BT | British Telecommunications |
| CATV | Cable TV |
| CF | Core Function |
| COO | Cost of Ownership |
| DCD | Duty Cycle Distortion |
| DDJ | Data-Dependent Jitter |
| DS | Digital Signal |
| EDFA | Erbium Doped Fibre Amplifier |
| FBT | Fibre Biconical Taper |
| FITL | Fibre to the Loop |
| FOA | Fibre Office Application |
| FSAN | Full Service Access Network |
| FT | France Telecom |
| FTTC | Fibre-to-the-Curb |
| FTTH | Fibre-to-the-Home |
| FTTx | Fibre to the x |
| HDSL | High bit rate Digital Subscriber Line |
| HFC | Hybrid Fibre/Coax |
| IDLC | Integrated Digital Loop Carrier |
| ISDN | Integrated Service Digital Network |
| ITU-T | International Telecommunication Union-Telecommunication |
| NRZ | Non-Return to Zero |
| NTT | Nippon Telegraph and Telephone Corporation |
| OC | Optical Channel |
| ONT | Optical Network Termination |
| ONU | Optical Network Unit |
| OSA | Optical Spectrum Analyzer |
| OSNR | Optical Signal to Noise Ratio |
| OTN | Optical Transport Network |
| PE | Phase-encoded |
| PLANET | Photonic Local Access NETwork project |
| PON | Passive Optical Network |
| POTS | Public Old Telephone System |
| PRBS | Pseudo Random Binary Sequence |
| RJ | Random Jitter |
| RZ | Return to Zero |
| SDH | Synchronous Digital Hierarchy |
| SDH/PDH | Synchronous Digital Hierarchy/Pleusynchronous Digital Hierarchy |
| SDSL | Single/Symmetrical line Digital Subscriber Line |
| SMF | Single Mode Fibre |
| SOA | Semiconductor Optical Amplifier |

| | |
|---|---|
| SOHO | Small Office Home Office |
| SPF | Service Port Function |
| SPT | Spectral Propagation Technique |
| STS | Synchronous Transport Signal |
| TDM | Time Division Multiplexing |
| TDMA | Time Division Multiple Access |
| TF | Transport Function |
| TOBASCO | Towards Broadband Access System for CATV Optical Network Project |
| UPF | User Port Function |
| VBS | Variable Bandwidth Simulation |
| VDSL | Very high rate Digital Subscriber Line |
| VOD | Video on Demand |
| WDM | Wavelength Division Multiplexing |
| WOTAN | Wavelength-agile Optical Access Network |
| WWW | World Wide Web |
| XDSL | x-Digital Subscriber Line |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The emergence of the broadband age has begun with the explosive growth of World Wide Web (WWW) and increasing of digital contents to the customer premises. The demand for high-speed Internet access has thus increased dramatically. Figure 1.1 shows the trend of the worldwide demand for Internet. Many access network (AN) technologies are subsequently introduced. Among them, Asymmetric Digital Subscriber Line (ADSL) with the capabilities of 1.5 Mbps to 8 Mbps is well liked (Chen, 1999). However, it will not be able to reach the customer's need beyond 2004 when the access bandwidth is expected to be in excess of 10 Mbps. It is expected that there will be 2.8 million connections to support the increasing users of 550 million by 2005 (Copley, 2000). Thus it is crucial to discover an access network with high bit rate and low cost.

Asynchronous Transfer Mode-Passive Optical Network (ATM-PON or A-PON) seems to be the most suitable choice to satisfy the user's requirement in the future (Steve et al., 1998). The help of low loss silica fibre makes it possible. Today, optical fibre has been installed at a rate of about 3,000 miles per hour. Commercial systems of 400 Gbps over a single fibre are now available (Alastair et al., 1990).

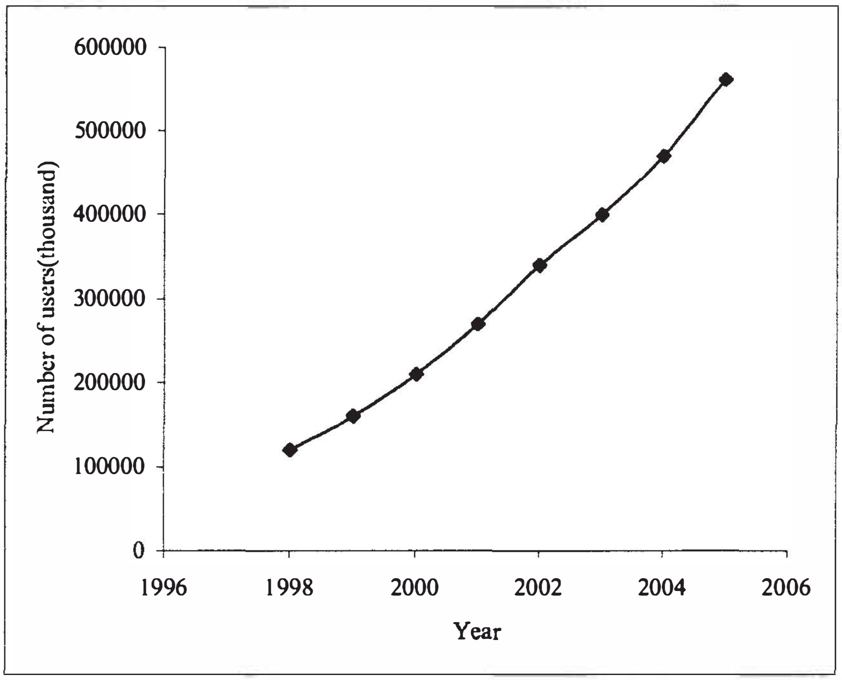


Figure 1.1: Growth in the number of users on the Internet
(adopted from Copley, 2000)

Many trials have been in place to implement the fibre to the home (FTTH) since 1970's (Paul and Snelling, 1991). In the recent years, the high demand of bandwidth due to the use of heavy multimedia data type to the customer premises for entertainment, small office home office (SOHO) such as video on demand (VOD), high definition television (HDTV), real time transaction, medical online require unlimited medium capabilities to transmit at higher bit rates to support the applications. The medium includes copper wire, coaxial cable, microwave transmission and optical fibre. FTTH is the best candidate to accommodate the whole solution to the customers (Van der Plas et al., 1995).

The FTTH brings the access network capabilities to the home with fibre connection up to optical network unit (ONU) at customer premises. Integrated services can be offered to the customer with the combination of narrowband and broadband communications. This system also uses passive optical network (PON) by the use of passive splitters, to reduce the operation and maintenance cost. The reduced cost in the future due to the volume of the fibre communication will lead the technology to be more effective.

The FTTH comes with three opportunities (Kettler et al., 2000). First, the end-to-end optical fibre, which offers the potential to achieve the vision of being able to provide virtually unlimited bandwidth to customer premises. Second, the opportunity of customer to choose the capabilities of the interfaces provided by optical network termination. Finally, it offers the opportunity for self-provisioning communications instrument, increasing customer satisfaction and lowering provisioning cost by eliminating truck rolls.

The FTTH also comes with its challenges. The first challenge is the demand of volume production to achieve cost reduction. Secondly, the optical network termination (ONT) will be customer owned and customer-powered (power backup needed compared to public old telephone system-POTS). The third challenge is to simplify the installation process, to lower the cost, and to improve the reliability of fibre connection and splicing technology in order to reduce the losses.

A-PON systems have been standardized by G.983 Recommendation as in table 1.1 (Chand, 1999; G.983, 1998). The Full Service Access Network (FSAN) consortium has identified the A-PON as the most cost-effective architecture for broadband fibre in the loop (FITL) deployment (Tajima et al., 1999). The system consists of 32 branches and 20 km range and has proven their viability for delivery of broadband services in several trials (Figure 1.2(a)). However the need arises to upgrade the A-PON system on the level of range, splitting factor, numbers of supported ONU and bit rates. The proposed upgrade is mainly motivated by three factors (Van de Voorde and Martin, 2000). The increase in FTTH range can support the expecting switching node consolidation in the core network and result in cost savings for the operation of the network. The Fibre-to-the-Curb (FTTC) plant can be extended to the home by inserting an optically amplified splitter. The gain in bandwidth efficiency due to statistical multiplexing increases with the number of users connected to a single line termination (G.983, 1998; Maeda, 2001; Yamashita, 1996; Wilson et al., 1999).

Table 1.1: ITU-T G.983 specification

| **Item** | **Unit** | **ITU-T G.983 Specification** | | |
|---|---|---|---|---|
| Direction | | Downstream | | Upstream |
| Branches | | 32 | | Not applicable |
| Distance | km | 20 | | 20 |
| Wavelength | nm | 1480-1580 | | 1260-1360 |
| Bit error ratio | | $<10^{-10}$ | | $<10^{-10}$ |
| Bit Rate | Mbps | 155.52 | 622 | 155.52 |
| Minimum mean launched optical power, Class B/C | dBm | -4/-2 | -2/-2 | -4/2 |
| Minimum receiver sensitivity, Class B/C | dBm | -30/-3 | -28/-33 | -30/-33 |

The use of optical amplifier in the A-PON architecture will increase the power budget. The important advantage of using optical amplifier instead of electrical amplifier is in terms of their transparency to the format, bit rate, wavelength, and their simple management (Van de Voorde et al., 1996). The whole system is known as Super-PON (S-PON) architecture with a wide range and long fibre span. Figure 1.2(b) shows the generic architecture of a S-PON with a target of optical split at 2048 and maximum range of 100 km. A bit rate of 2.5 Gbps is distributed to the optical network unit by time division multiplexing (TDM) in the downstream direction, whereas a time division multiple access (TDMA) is used for upstream connection (Ransom, 1997).

The FTTH uses A-PON technology at the beginning years with an idea to save the cost. Because of the urge on the demand on the bit rate, high fibre span and large split, the A-PON system may no longer be the best system. The active component such as an optical amplifier is introduced to the conventional system (Morita et al., 1992; Takano et al., 2000). Thus, the higher split and wider range can be developed with high bit rate in order to cope with future trend of telecom networks. Figure 1.2 shows the characteristic and evolution of A-PON to S-PON.