UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN AND ANALYSIS OF NUMBERING SYSTEM IN FIBRE TO THE HOME (FTTH) SYSTEM

This report is submitted in accordance with the requirement of Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

by

LOW LI CHUIN

B071310478

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Telecommunications) with Honours. The member of the supervisory is as follows:

……………………………….

(Project Supervisor)

ABSTRACT

Fibre to the Home (FTTH) is an emerging technology that is capable of providing high speed multimedia services directly to customers at their premises. FTTH uses fibre optics entirely, which are widely used today in telecommunications to cope with the increasing demand for high speed and large capacity data transmission. In FTTH, optical fibres are connected directly to the subscribers from an operator's switching equipment, instead of using copper cables alone or hybrid technology. This study is carried out to gain more awareness regarding Fibre to the Home (FTTH), particularly its numbering or addressing system, since the current level of knowledge concerning the addressing system of FTTH is seriously lacking and FTTH addressing may be quite difficult to comprehend. In this project, a numbering or addressing format for FTTH is proposed by scrutinizing books and research papers, and subsequently creating an animation, as well as a GUI or simulation on the topic. All these data collected are then analysed to produce a guide plan on the numbering or addressing system for FTTH and subsequently, the calculations concerning FTTH addressing are also performed. The results obtained from this study will enable the proper design of FTTH addressing for all subscribers.

Keywords: Fibre to the Home (FTTH), numbering, addressing

ABSTRAK

Gentian ke rumah (FTTH) merupakan teknologi baru yang mampu menyediakan perkhidmatan multimedia berkelajuan tinggi terus kepada pelanggan di premis mereka. FTTH menggunakan gentian optik sepenuhnya, yang digunakan secara meluas pada hari ini dalam telekomunikasi untuk menampung permintaan yang semakin meningkat untuk penghantaran data berkelajuan tinggi dan berkapasiti besar. Dalam FTTH, gentian optik disambungkan terus kepada pelanggan dari peralatan pensuisan pengendali, dan bukannya menggunakan kabel tembaga atau teknologi hibrid. Kajian ini dijalankan untuk memupuk lebih kesedaran mengenai gentian ke rumah (FTTH), terutamanya penomboran atau alamat, kerana tahap pengetahuan semasa mengenai sistem pengalamatan FTTH tidak mencukupi dan mungkin agak sukar untuk difahami. Dalam projek ini, satu penomboran atau format alamat untuk FTTH akan dicadangkan dengan mencari buku-buku dan kertas penyelidikan, dan seterusnya mereka animasi, serta GUI atau simulasi mengenai topik ini. Semua data yang dikumpul kemudiannya dianalisis untuk menghasilkan pelan panduan penomboran atau sistem alamat untuk FTTH dan seterusnya, pengiraan berkaitan alamat FTTH juga dilakukan. Keputusan yang diperolehi daripada kajian ini akan membolehkan rekaan pelan penomboran atau alamat FTTH yang betul untuk semua pelanggan.

Kata kunci: gentian ke rumah (FTTH), penomboran , alamat

DEDICATION

This paper is dedicated to my dearly loved parents, lecturers and friends for their unrelenting support and encouragement during the completion of this report.

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I would like to express my gratitude to my project supervisor, Mr. Chairulsyah bin Abdul Wasli for his guidance to ensure that this project runs efficiently. I would also like to thank co-supervisor Mdm. Siti Asma binti Che Aziz for the knowledge she imparted. This report would not have been possible without the invaluable assistance that they have provided.

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AFRINIC	-	African Network Information Centre
AON	-	Active Optical Network
APNIC	-	Asia-Pacific Network Information Centre
ARIN	-	American Registry for Internet Numbers
ATM	-	Asynchronous Transfer Mode
BPON	-	Broadband passive optical network
CAPEX	-	Capital Expenditure
CO	-	Central Office
DHCP	-	Dynamic Host Configuration Protocol
DHCPv6	-	Dynamic Host Configuration Protocol version 6
DSL	-	Digital subscriber line
DSLAM	-	DSL access multiplexer
EPON	-	Ethernet passive optical network
EUI	-	Extended Unique Identifier
FBT	-	Fused bi-conic taper
FEC	-	Forward Error Correction
FTTB	-	Fibre to the building
FTTC	-	Fibre to the curb
FTTH	-	Fibre to the home
GEM	-	GPON Encapsulation Method
GPON	-	Gigabit passive optical network
GUI	-	Graphical user interface
IEEE	-	Institute of Electrical and Electronics Engineers
IHL	-	Internet Header Length
IP	-	Internet Protocol
IPv4	-	Internet Protocol version 4
IPv6	-	Internet Protocol version 6
ISP	-	Internet service provider
ITU-T	-	Telecommunication Standardization Sector
LACNIC	-	Latin America and Caribbean Network Information Centre

LAN	-	Local area network
MAC	-	Media access control
MDUs	-	Multi-Dwelling Units
NAT	-	Network Address Translation
NIC	-	Network Interface Card
ONT	-	Optical network terminal
ONU	-	Optical Network Units
OPEX	-	Operational Expenditure
OSI	-	Open Systems Interconnection
OSP	-	Outside Plant
P2MP	-	Point-to-multipoint
P2P	-	Point-to-point
PDU	-	Protocol data unit
PON	-	Passive optical network
POP	-	Point of Presence
QoS	-	Quality of Service
RIPE NCC	-	Réseaux IP Européens Network Coordination Centre
RIR	-	Regional Internet address Registry
ROM	-	Read-only memory
SFUs	-	Single Family Units
SLAAC	-	Stateless Address Autoconfiguration
SONET	-	Synchronous Optical Networking
TOS	-	Type of Service
ULA	-	Unicast local address
VDSL2	-	Very-high-bit-rate digital subscriber line 2
Wi-Fi	-	Wireless Fidelity
WiMAX	-	Worldwide Interoperability for Microwave Access

CHAPTER 1

INTRODUCTION

1.0 Project Background

Fibre to the Home (FTTH) is a rising innovation that provides rapid interactive media benefits directly to clients at their premises. FTTH utilizes fibre optics totally, which are generally utilized today as a part of information transfer to adapt to the expanding interest for rapid and vast information transmission. Users are connected directly to the switching equipment of the operator via dedicated fibres. At the moment, the level of knowledge concerning the numbering or addressing of FTTH is deficient. IP addresses have developed from IPv4 up to the latest IPv6. The current addressing format used in FTTH may be a mixture of IPv4 and IPv6, depending on the service provider. The size of an IPv4 address is 32 bits while that of an IPv6 address is 128 bits, which is four times larger (Lammle, 2011). Since IPv6 addresses are very large, they cannot be represented in binary format like its predecessor the IPv4, and thus written in hexadecimal form. In this paper, a new addressing format will be introduced especially for FTTH, although the proposed format can also be applied in other FTTx architectures. This new addressing format should be simpler and has a shorter length. The size chosen for this new address format would be based on the overall population growth and should be sufficient to deal with the demand for IP addresses for years to come.

1.1 Problem Statement

Currently, FTTH addressing technology is still difficult for students and the laymen to understand. Also, there is no addressing technology that is used specifically for FTTH. The current pool of IPv4 addresses is depleting while the size of IPv6 is considered too large.

1.2 Objective

1. To study about FTTH in terms of theory, design and measurement especially in numbering or addressing system.
2. To propose a simplified numbering or addressing format for FTTH.
3. To create an attractive animation and interactive GUI regarding FTTH numbering or addressing system.

1.3 Scope

This project will focus on studying the literature on fibre optics and Fibre to the Home (FTTH) addressing. This project also encompasses the creation of an attractive animation which will explain the basics of FTTH, and also the creation of an interactive GUI on the addressing of FTTH by using MATLAB software. In addition, the calculation related to FTTH addressing will be found in this study. Lastly, a thesis on this project will be written and submitted to the supervisor.

1.4 Structure of Report

This report consists of five chapters. Chapter 1 is the introductory chapter to this thesis. Chapter 2 contains the literature review on research papers and books related to fibre to the home and its addressing. Chapter 3 is based on the methodologies that are involved in for the completion of this project. Chapter 4 is a section on all the results gathered and a thorough discussion on them. Finally, Chapter 5 consists of a conclusion on this project and future recommendations that can be made by other researchers who wish to improve this study.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Fibre optics function by propagating light through transparent dielectric waveguides. They are used to transmit data from one point to another. Fibre optics has become the leading communication system used due to the need for a low loss transmission medium, and lightweight transmitters and receivers. The overall duration of transmission and bit rate-distance product required have also increased (Bagad, 2013). Since the development of fibre optics, bandwidth consumption has increased. Factors that affect bandwidth consumption include culture, climate, local infrastructure and distance (Girard, 2005). To deal with this demand, FTTH can be used for high or ultra-high speed access technologies (Salgado, et al., 2016).

2.1 Fibre to the Home (FTTH)

In a fibre to the home (FTTH) network, end users are connected to an access node or point of presence (POP), which is the central point. The active electronic transmission equipment is placed in every access node in a region, which is linked to a bigger fibre network. Fibre-based access networks can connect to fixed wireless network antenna, for instance, wireless LAN or WiMAX, mobile network base stations, subscribers in SFUs (single family units) or MDUs (multi-dwelling units), big buildings for example schools and businesses, and security assemblies such as surveillance cameras and security alarms (Salgado, et al., 2016). Figure 2.1 shows a basic FTTH deployment. From the optical line terminal (OLT), fibres are split to optical network terminals (ONT) that are located at customer premises using splitters.

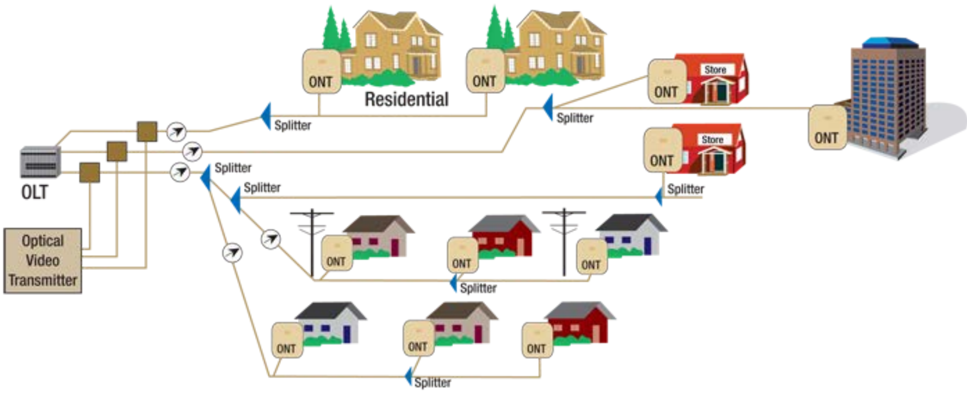

Figure 2.1: Basic FTTH deployment

2.1.1 FTTH network environment

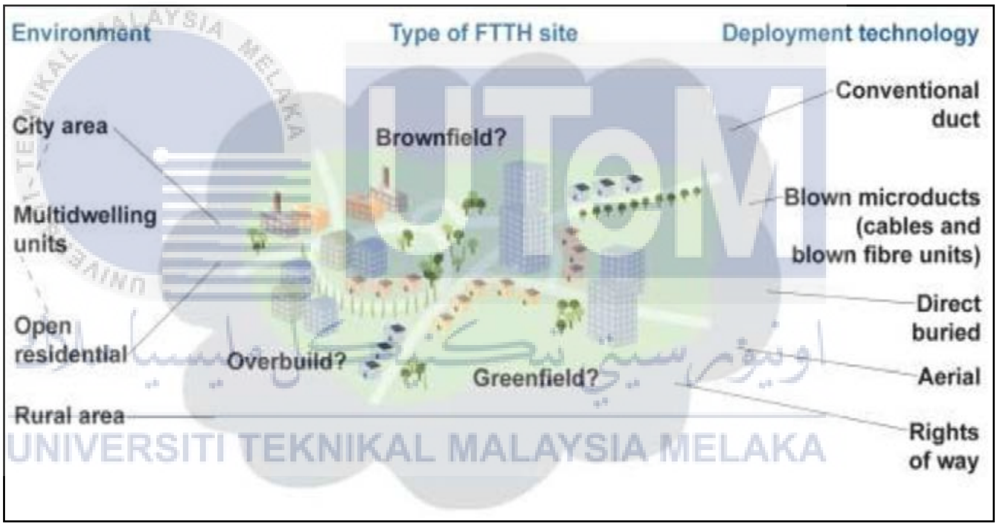

Figure 2.2: Type of FTTH site

Figure 2.2 shows the type of FTTH site. The physical environment can be divided into four main categories (Salgado, et al., 2016):

- City area
- Type of building and density, that is, multi-dwelling units or single units
- Open residential
- Rural area

Subscriber dwelling densities (per sq km) and the country conditions in which they are located must be considered. When choosing the most suitable network design and architecture, the characteristics of the site plays an important role. The three main types of sites are:

- Greenfield – a new construction where the buildings and network are installed at the same time
- Brownfield – buildings have already been built but the existing infrastructure has a low standard
- Overbuild – the existing infrastructure is added with other constructions

The method of infrastructure usage depends on the type of FTTH site, FTTH network size, preliminary expenditure of the infrastructure deployment (CAPEX), network operation and maintenance's (OPEX) management expenses, the network architecture (PON or Active Ethernet), and local conditions, such as local manpower costs, local authority limitations (traffic control).

The major requirements for a FTTH network are:

- Providing services and content with high-bandwidth to every subscriber
- A network architecture plan with a capacity that is adaptable to future requirements
- Provides support network upgrades and development
- Deployed with minimum disturbance in order to increase network operators' reception of FTTH and let subscribers enjoy its benefits

2.1.2 FTTx Network Architecture

There are a variety of network architectures, but the choice solely depends on the needs of the network provider, businesses and technical priorities. (Salgado, et al., 2016). Figure 2.3 shows the different types of FTTx networks.

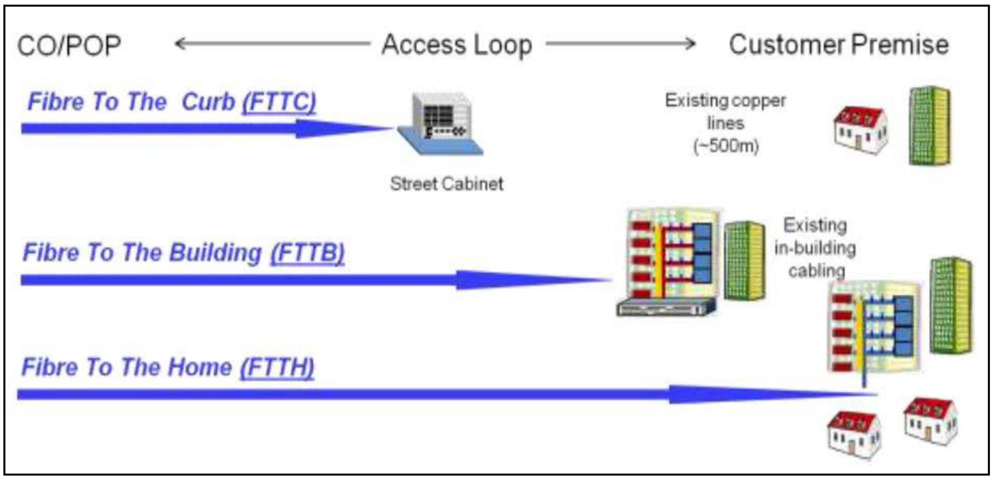

Figure 2.3: Different types of FTTx networks

Fibre to the home (FTTH) – A dedicated fibre is used to connect every subscriber to a port which is located in the POP or passive optical splitter. The feeder fibre is shared to the POP. Ethernet technology uses 100BASE-BX10 or 1000BASE-BX10 transmission while point-to-multipoint topology uses GPON (EPON) technology.

Fibre to the building (FTTB) – A dedicated fibre is used to connect every optical termination box located in the building to a port which is located in the POP or passive optical splitter. The optical termination box is usually placed in the basement of the building. Similar to FTTH, the feeder fibre is shared to the POP. Copper wires are used to connect subscribers to the building switch and Ethernet transport is used according to the medium offered in the wiring. Occasionally, building switches are interconnected using the chain or ring topology, and not connected singly to the POP. This is done to make use of the existing fibres set up in specific topologies and to reduce the fibres and ports used in the POP.

Fibre to the curb (FTTC) – A single fibre or a pair of fibres are used to connect each switch or DSL access multiplexer (DSLAM), which are located in street cabinets to the POP. The collective traffic of the locality is sent via these fibres using Gigabit Ethernet or 10 Gigabit Ethernet connection. Copper is used in the switches in the street cabinets using VDSL2 or VDSL2 Vectoring. This architecture employs active network elements and at times is referred to as “Active Ethernet”.

Out of all these network architectures, only FTTH will be focussed on in this paper.

2.1.3 FTTH Topology and Technology

Currently, point-to-point and point-to-multipoint topologies are the two most extensively employed topologies. Point-to-multipoint is usually joined with a passive optical network (PON) technology while point-to-point normally uses Ethernet transmission technologies.

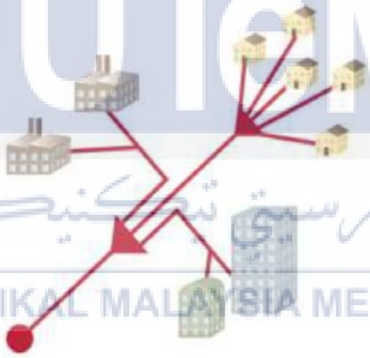

Figure 2.4: Point to Multi-Point (P2MP)

Figure 2.4 shows a basic point-to-multipoint topology. In point-to-multipoint topologies (P2MP), a “feeder” fibre is connected from the central office or POP to a splitter or branching point. From this point, dedicated fibres are deployed to every subscriber. Passive optical splitters are used in GPON and to ensure that subscribers only receive data that should be sent to them, the data is encoded. Similarly, subscriber access can be controlled in P2MP topologies by using Active Ethernet technology, which utilizes Ethernet switches (Salgado, et al., 2016). According to Girard (2005), each PON is connected with more than one ONTs through at least one splitter.

Data and voice are transmitted using downstream 1490 nm wavelength and upstream 1310 nm wavelength. Analogue video overlay uses the downstream 1550 nm wavelength. Figure 2.5 shows A typical connection of OLT, PON and ONU, where the OLT is connected to and controls more than one PON.

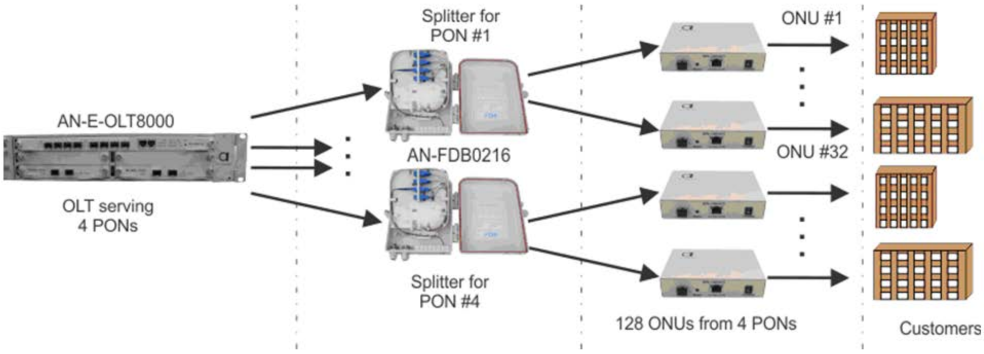

Figure 2.5: A typical connection of OLT, PON and ONU

Figure 2.6 shows a basic point-to-point topology. In point-to-point topologies (P2P), the Access Node or POP is connected to the subscriber via dedicated fibres. The optical path from the Access Node to the subscriber is continuous although it may be made from segments of fibre attached using connectors or splices. The Ethernet is used in most P2P FTTH deployments and PON technologies can be incorporated into this topology by introducing passive optical splitters in the Access Node (Salgado, et al., 2016). Girard (2005) states that the same 1310 nm wavelength upstream and downstream are used in a P2P system to transmit voice and data since this system utilizes a fibre pair. The same configuration as in P2MP is used for analogue overlay video.

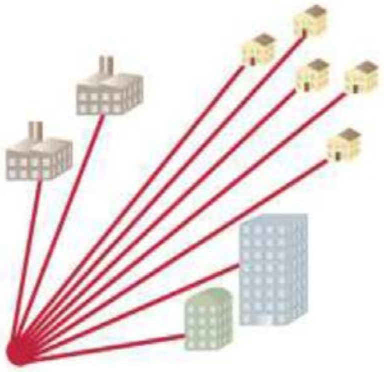

Figure 2.6: Point to Point (P2P)

2.1.4 PON Protocols

There are currently three main types of PON protocols. BPON and GPON have been standardized by ITU-T while EPON is standardized by IEEE.

The ITU-T Recommendation G.983.x series has ratified BPON. BPON uses ATM protocol to transfer any form of data, such as voice, video and IP data (Girard, 2005). BPON can transmit at a maximum of 622 Mbit/s downstream and 155 Mbit/s upstream (Gutierrez, et al., 2006).

GPON is defined in ITU-T Recommendation G.984.x series and uses ATM and GPON encapsulation method (GEM) to transport data, where GEM provides connection-oriented communication (Girard, 2005). Gigabit-capable PONs (GPON) can support high bandwidth and is able to transmit at 2.4Gbps downstream and 1.2Gbps upstream. A maximum of 64 users can be carried by GPON, causing the mean bandwidth for every user to be slightly lower than that of EPON. GPON Encapsulation Method (GEM) is able to map the entire traffic in the network. This is done by using a type of SONET/SDH framing structure to make packaging more efficient with better QoS. GPON can range up to 20 km which supports a split ratio of 1:64. In the future this ratio can increase up to 1:128 using improved optical components (Gutierrez, et al., 2006).

EPON which is defined in IEEE 802.3ah-2004, utilizes multipoint control protocol (MPCP) (Girard, 2005). Among all TDM-PON options, Ethernet-based PONs (EPON) provide the highest average bandwidth. Without Forward Error Correction (FEC), 1.25Gbps symmetrical line rates along with 32 Optical Network Units (ONUs) can be carried by EPON equipments. EPON have a range of up to 20 km, where downstream data is transmitted using 1510 nm wavelength and upstream data is transmitted using 1310 nm wavelength. EPON does not utilize ATM and SONET network elements as variable-length Ethernet frames are used to transmit data by means of Internet Protocol (IP) (Gutierrez, et al., 2006).

2.1.5 Network Layers

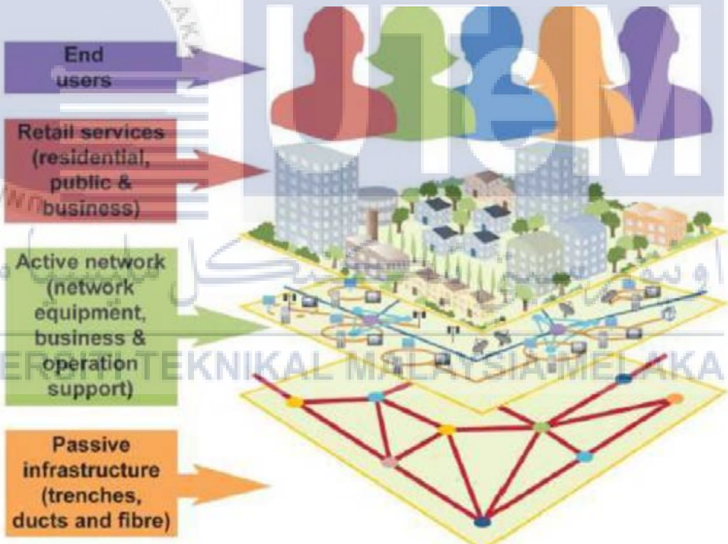

Figure 2.7: FTTH network layers

Figure 2.7 shows the network layers in FTTH. The physical elements needed to build a fibre network are located in the first layer, that is, the passive infrastructure. These elements are the optical fibres, trenches, ducts and poles, along with the fibre enclosures, optical distribution frames, patch panels and splicing shelves. In this layer, the organization in charge, which is the network owner, will be responsible in planning the network route, performing right-of-way negotiations and fibre installation.

The second layer is the active network layer. The electronic equipment and the operational support systems owned by network operators, needed for the functioning of the passive infrastructures are found here. The active equipments are designed, built and operated by those in charge in this layer.

The third layer is the retail services layer, where customers receive Internet connectivity and other services, for example IPTV from the Internet service provider (ISP). The party responsible in this layer will deal with technical support, customer service, customer acquisition and go-to-market strategies.

2.1.6 Open Access Networks

The term "open access" here refers to the access which is provided to many service providers to wholesale services. Here, service providers share the same wholesale services instead of installing a new fibre access network of their own.

There are two open access models, namely the passive open access infrastructure and active open access infrastructure. Passive open access infrastructures includes ducts, sewers, poles, dark fibre, and wave-lengths. Operators can share these passive infrastructures and also build their own. Active open access infrastructure includes Ethernet layer-2 and IP layer-3. Here, service providers can share the same active infrastructure.

2.2 Optical Networks

There are two main types of optical networks, namely active optical networks (AON) and passive optical networks (PON). Each network has its way of sending data to its destination. The following is a brief elaboration of these networks:

2.2.1 Active Optical Network (AON)

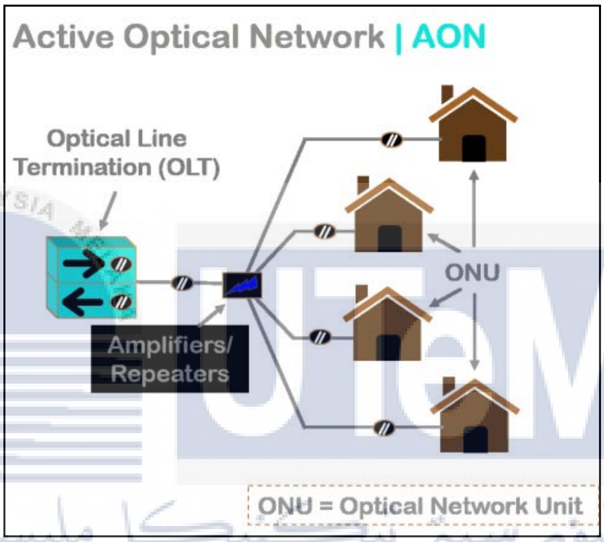

Figure 2.8: Active optical network implementation

In order to forward steady state traffic, this system requires an active configuration such as nodes (Larsen, et al., 2010). Figure 2.8 shows a typical active optical network implementation. The active optical network (AON) uses electricity powered equipments, such as routers to transmit information to users. In AON, a dedicated fibre is connected to every subscriber and the AON can cover a span of approximately 100 km. Since AON is an active network, more fibres are needed (Hymax.co.za, 2015).

2.2.2 Passive Optical Networks (PON)

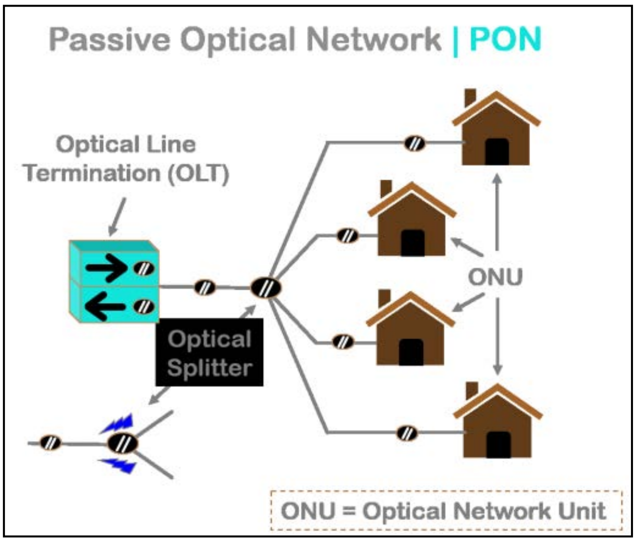

Figure 2.9: Passive optical network implementation

Figure 2.9 shows a typical passive optical network implementation. Passive optical networks also use nodes to send steady state traffic, but does not require an active configuration to achieve this (Larsen, et al., 2010). In a portion of the PON, fibre optic strands are shared. Data broadcasting speed may be slow during peak hours due to latency because dedicated bandwidth are not provided to individual subscribers. PONs have a range of approximately 20 km. Optical splitters are utilized in PONs to split signals. The signal's power is divided by half whenever it is split into two. Each half of the signal will go to each divided branch of the PON. Due to this, coverage is shorter and is limited by signal strength. PONs also have low maintenance and building costs, and is suitable to be used in residential areas. However, should a breakdown happen anywhere in the PON, it will be hard to segregate them. There are two main types of PONs, namely EPON (Ethernet PON) and GPON (Gigabit PON) (Hymax.co.za, 2015). Table 2.1 shows a summary of specifications and comparison for GPON and EPON.

Table 2.1: Comparison and specifications for GPON and EPON (The Fiber Optic Association, Inc., 2015)

ASPECT	GPON	EPON
Standard	ITU-T G.984	IEEE 802.3ah (1Gb/s), IEEE 802.3av (10Gb/s)
Downstream Bitrate	155, 622 Mb/s, 1.2, 2.5 Gb/s	1.25 Gb/s, 10.3 Gb/s
Upstream Bitrate	155, 622 Mb/s, 1.2, 2.5 Gb/s	1.25 Gb/s, 1.25 or 10.3 Gb/s
Downstream Wavelength	1490	1490, 1550
Upstream Wavelength	1310	1310
Protocol	Ethernet over ATM/IP or TDM	Ethernet
Video	RF at 1550 or IP at 1490	IP Video
Max PON Splits	64	16
Splitter Ratio	1:64~1:128	1:16~1:32
Power Budget	~13 dB (min) to 28 dB (max) w/32 split	~20 dB (min) to 29 dB (max)
Coverage	<60 km	<20 km
Bandwidth Efficiency	92%	72%
QOS	Very good, including Ethernet, TDM, ATM	Good, only ethernet
Cost	High	Low
Encryption	Part of the ITU standard, downstream only	AES-based mechanism, downstream and upstream

2.3 Optical Splitters

A splitter is a branching device with one output and many output ports. Splitters use light beams and do not require external energy source, hence are categorized as passive devices (Girard, 2005). There are two types of splitters, namely fused bi-conic taper and planar waveguide splitters.

2.3.1 Fused bi-conic taper

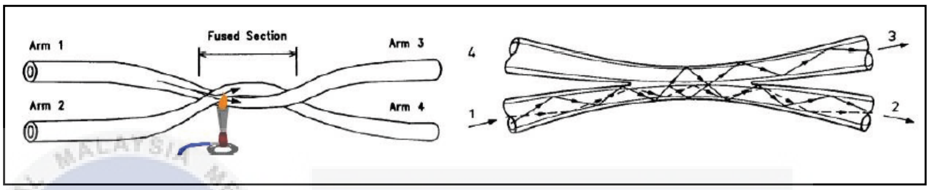

Figure 2.10: Fused bi-conic taper splitter

Figure 2.10 shows a fused bi-conic taper splitter. Two wrapped fibres are fused together to form a fused bi-conic taper (FBT) splitter. Monolithic devices have a split ratio of up to 1x4, 1x2, 1x3 or 1x4 splitters can be cascaded to obtain a split ratio bigger than 1x4. This splitter is commonly used in Outside Plant (OSP) environments. The minimum possible split ratio is 1x2 and the maximum is larger than 1x32. Compared with planar splitters, the insertion loss is higher and uniformity is lower as the split ratios increase (Salgado, et al., 2016). The FBT are used for low split counts (Girard, 2005).

2.3.2 Planar splitter

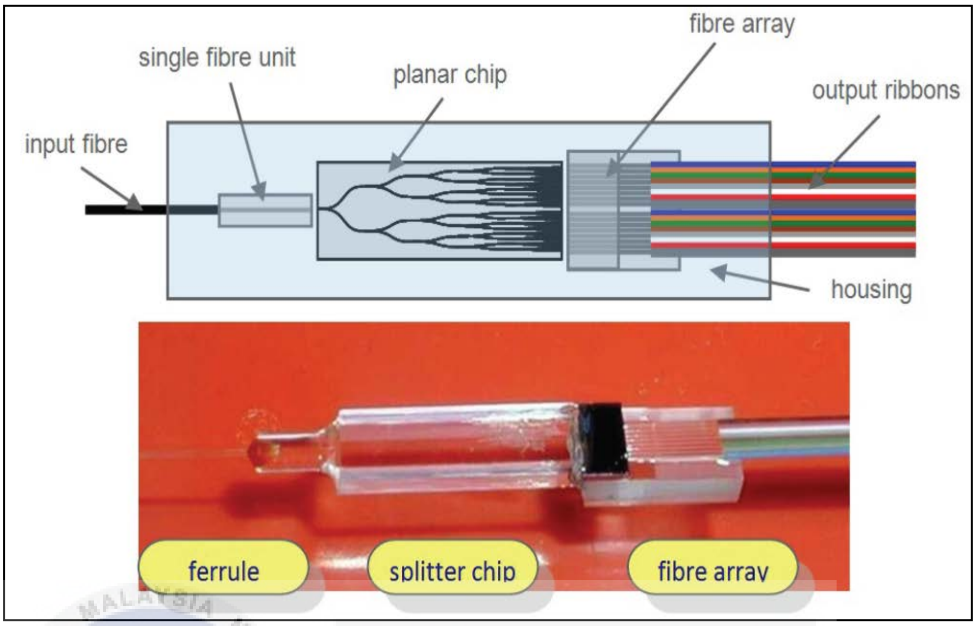

Figure 2.11: Planar splitter

Figure 2.11 shows the structure of a planar splitter. In a planar splitter, optical paths are buried inside a silica chip. The minimum split ratio is 1x4 and the maximum split ratio is more than 1x32. The planar splitter is more compact at larger split ratios without any cascading when compared to the FBT. The insertion loss and uniformity is also better compared to FBT splitters at higher wavelengths. The planar splitter is suitable to be used for longer wavelengths and has a wider spectrum (Salgado, et al., 2016). According to Girard (2005), the planar splitter is normally used for high split counts.

2.4 Fibre Cable Modes and Profiles

Optical fibres are available in a number of types. FTTH usually use single-mode fibre, yet multimode fibre can also be used in certain circumstances.

2.4.1 Single-mode Fibre

Figure 2.12: Light path in a single-mode fibre

Figure 2.12 shows the light path in a single-mode fibre. The single-mode fibre, which is widely used allows only one mode of light to pass through and has a small core diameter of <10 µm. Compared to other fibre types, the single-mode fibre has the lowest optical attenuation loss and the highest bandwidth transmission carrying capacity. However, they are more expensive than multimode fibres. The ITU-T G.652 recommendations for single-mode fibre is adequate to be used for most FTTH network applications (Salgado, et al., 2016).

2.4.2 Multimode Fibre

Figure 2.13: Light path in a multimode fibre

Figure 2.13 shows the light path in a multimode fibre. A multimode fibre allows more than one mode of light to pass through and has a core diameter of 50 µm or 62.5 µm. The input power is divided among some or all of the modes. Multimode fibres cost more than single-mode fibres but can be used with cheap optical sources and connectors. The bandwidth capability of this fibre is low and the transmission distance is limited (Salgado, et al., 2016).

2.4.3 Step Index and Graded Index Fibres

The step index fibre has a core and cladding with uniform refractive index of n_1 and n_2 respectively. The refractive index of the cladding, n_2 is less than that of the core, n_1. The typical diameter of the core is 50 µm to 80 µm while that of the cladding is 125 µm.

The core of the graded index fibre consists of many layers of glass. The refractive index of the core is not uniform, where it is the highest at the centre and decreases towards the cladding. Compared to step index fibres, graded index fibres has higher bandwidth and lower coupling efficiency. Graded index fibres have sizes of 50 µm or 62.5 µm core with 125 µm cladding (Bagad, 2013).

2.4.4 Bend Insensitive Fibre

Bend insensitive fibres have recently been available with ITU-T G.657 standard. This fibre is suitable to be used in buildings and can be installed similar to ordinary copper cables. They can operate at a bend radius from 7.5 mm to as low as 5 mm. Two categories of single-mode fibres are available, namely Category A and Category B where Category B is more suitable for in-building installations (Salgado, et al., 2016). Each category have different macro-bending loss as shown in Tables 2.2 and 2.3, which shows the loss specified at 1550 nm for Category A and Category B fibres respectively.

Table 2.2: Loss specified at 1550 nm for Category A fibre

Bend radius	Fibre loss according to fibre type	
	G.657.A1	G.657.A2
10 mm	0.75 dB/turn	0.1 dB/turn
7.5 mm		0.5 dB/turn

Table 2.3: Loss specified at 1550 nm for Category B fibre

Bend radius	Fibre loss according to fibre type	
	G.657.B2	G.657.B3
10 mm	0.1 dB/turn	0.03 dB/turn
7.5 mm	0.5 dB/turn	0.08 dB/turn
5 mm		0.15 dB/turn

2.5 Optical Fibre Parameters

- Attenuation loss

Fibre loss or attenuation causes power to be lost along the fibre, resulting in small output power. Power at distance z is given by,

$$P(z) = P(0)e^{-\alpha_p \cdot z}$$

Where $\alpha_p = \frac{1}{z} l_n \left[\frac{P(0)}{P(z)}\right]$

= fibre attenuation constant per km.

$$\alpha_{(db/_{km})} = 4.343\alpha_p \text{ per km}$$

- Scattering loss

Scattering loss in fibre optics is caused by minute differences of density of the fibre material, compositional changes, structural in-homogeneities and defects on the structure of the fibre.

For a single component glass,

$$\alpha_{scat} = \frac{8\pi 3}{3\lambda^4}(n^2 - 1)^2 k_B T_f \beta_T \text{ nepers}$$

Where, n = Refractive index

k_B = Boltzmann's constant

β_T = Isothermal compressibility of material

T_f = Fictive temperature

For multicomponent glasses,

$$\alpha_{scat} = \frac{8\pi 3}{3\lambda^4}(\delta_n^2)^2\delta v$$

Where, δ_n^2 = Mean square refractive index variation

δv = Fibre volume

- Microbending loss

Microbending loss is caused by a slight bending of the optical fibre which cannot be seen by the naked eye. This loss will cause the attenuation of the fibre to increase. The formula for microbending loss is given as,

$$F_{(\alpha\ m)} = \left[1 + \pi\Delta^2\left(\frac{b}{a}\right)^4\frac{E_f}{E_j}\right]^{-2}$$

Where, Δ = Index difference

E_f and E_j = Young's moduli of jacket and fibre

- Modal dispersion

In multimode fibres, modal dispersion occurs as a fibre will allow only a particular number of modes to pass through. Here, the pulses spread as every mode have their own propagation times. Modal dispersion can be calculated by,

$$\Delta t_{modal} = \frac{n_1 Z}{c}\left(\frac{\Delta}{1-\Delta}\right)$$

Where, Δt_{modal} = Dispersion

n_1 = Core refractive index

Z = Total length of fibre

c = Velocity of light

$\Delta = \frac{n_1 - n_2}{n_1}$, the fractional refractive index

2.6 FTTH Numbering or Addressing

The terms numbering and addressing are sometimes used interchangeably and may cause confusion. The current numbering and addressing schemes currently used are also complex and not user friendly.

2.6.1 Definition of Address

An address is used to define the “fundamental addressable object” where its format is understood by all partakers. The mapping process involves mapping to an address from a route (Karl, et al., 2011). According to Saltzer (1993), an identifier does not necessarily need to be in binary format to be considered as an address.

An IP (Internet Protocol) address is used as a software address. With IP addressing, hosts from different networks can communicate with each other (Agbinya, 2010). IP address can be divided into two main types, namely IPv4 and IPv6. Figure 2.14 shows an example of a network that uses IPv4.

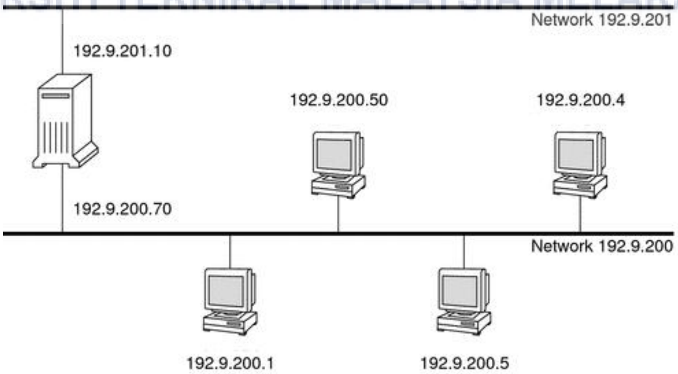

Figure 2.14: An example network using IPv4

2.6.2 IPv4

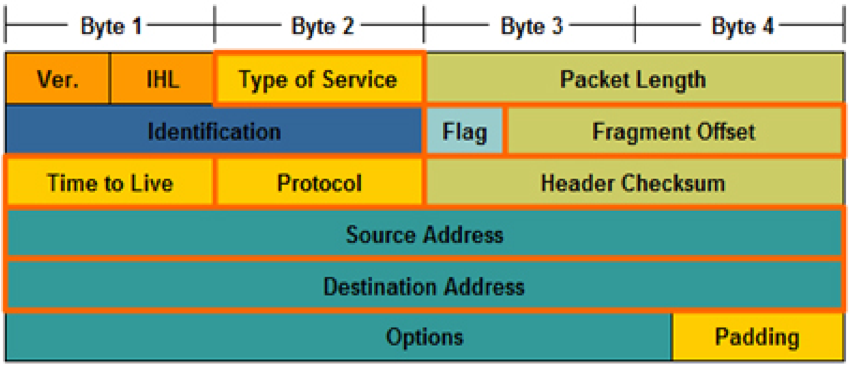

Figure 2.15: IPv4 packet header fields

There are five classes in IPv4 addressing, each with their specific range as shown below:

a) Class A: 1.0.0.1 to 126.255.255.254

b) Class B: 128.1.0.1 to 191.255.255.254

c) Class C: 192.0.1.1 to 223.225.254.254

d) Class D: 224.0.0.0 to 239.255.255.255 (reserved for multicast groups)

e) Class E: 240.0.0.0 to 254.255.255.254 (reserved)

The most common addressing classes used are classes A, B and C, while classes D and E are reserved. The IP packet contains the payload, which is also known as the data, and a header section. The length of the header is 20 bytes and it is where the destination address and source address are found, as shown in Figure 2.15 which illustrates the IPv4 packet header fields.

By referring to Figure 2.15:

a) Version: 0100 for IPv4.

b) Internet Header Length (IHL): Length of header in 4-byte words.

c) Type of Service (TOS): Either to maximize reliability, maximize precedence, minimize delay or maximize throughput.

d) Total Length: Size of the IP datagram in bytes.

e) Identification: An exclusive number to identify the datagram.

f) Flags: Only two options are available, that are, “More” (for segmentation and assembly) or “Don’t fragment” (used if segmentation is not permitted).

g) Fragment Offset: In the non-fragmented PDU, it is used to identify a fragment’s location.

h) Time-To-Live: Reduces by 1 each time a packet is routed. Indicates that the packet will be dispose of when TTL is zero.

i) Protocol: Determines the upper layer protocol that the packet will be sent to.

j) Header Checksum: Used for error detection in the header. Each router must recalculate this value.

k) Source Address: Shows the address where the data came from.

l) Destination Address: Shows the address where the datagram is intended for.

m) Options and Padding: Options can either be “Security”, “Route recording”, “Source routing”, “Stream identification” or “Time stamping”. Padding is used to make the header length an integer multiple of 4 bytes.

2.6.3 IPv6

IPv6 addressing is still new and was created to deal with the depletion of IPv4 addresses. It has a size of 128 bits compared to only 32 bits in IPv4.

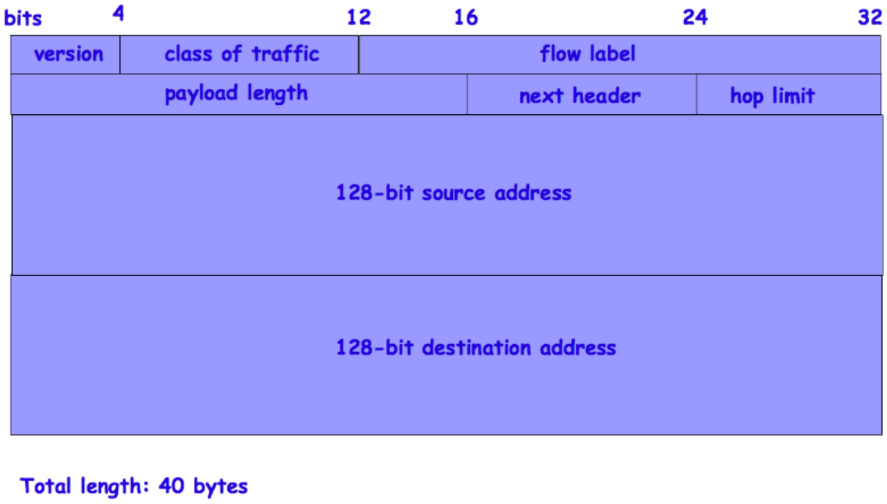

Figure 2.16: IPv6 packet header fields

IPv6 is able to support plug-and-play by auto-configuration so that networks do not need to be configured. Compared to IPv4, the header of IPv6 is more simplified with less header fields so that routing can be done faster and more efficiently, although its size is double of that in IPv4, which is 40 bytes. There are only eight items in the header of IPv6 compared to thirteen in that of IPv4. Figure 2.16 shows the IPv6 packet header fields. The fields in IPv6 are as follows:

a) Version (4 bits): Identical to that in IPv4.
b) Traffic Class (8 bits): Performs the same function as "Type of Service" in IPv4. It handles issues relating to quality of service.
c) Flow Label (20 bits): An allocated label used to indicate the destination of the packet for routing.
d) Payload Length (16 bits): Contains the datagram payload's length in bytes and the Option fields.
e) Hop Limit (8 bits): Performs the same function as TTL from IPv4.
f) Source Address: An address that indicates the source of the packet and has a size of 128 bits.
g) Destination Address: An address that indicates the destination of the packet and it also has a size of 128 bits. If a routing header is used, the address in the Destination Address does not indicate the final destination of the packet.

h) Next Header (8 bits): Used to identify the type of any headers (if any) that are located after the IPv6 header.

IPv6 address consists of a network prefix and host suffix both having the size of 64 bits. The host within the network is identified using the host suffix while a network can be located using the network prefix. IPv6 uses hexadecimal numbering instead of binary. For instance, 194.153.11.222.128.17.135.44.240.36.97.66.205.221.52.4 can made simpler using hexadecimal format to become C299:0BDE:8011:872C:F024:6142:CDDD:3404. The colon ":" is utilized as address separators in IPv6. It is used to simplify an IPv6 address that has many zeros. For example, FF80:0:0:0:0:0:0:100 is equivalent to FF80::100. Currently, IPv4 and IPv6 have to be used together, thus IPv4 addresses have to be converted to IPv6 simply by adding double colons in front of an IPv4 address, making the first 96 bits all zeros. For example, 138.25.40.1 is converted to be ::138.25.40.1.

2.6.4 IPv6 Unicast Address

A unicast address is used for delivery to only one interface. The format of a unicast address is shown in Figure 2.17 below:

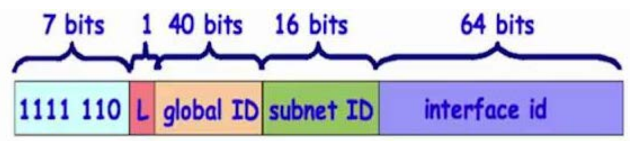

Figure 2.17: Unicast local address format

Unicast local address (ULA) are meant to be used within a network and not routed externally. ULAs can be assigned using locally or centrally assigned addresses. The prefix used by ULA is FC00::/7 which functions in identifying local unicast addresses. Bit L can be "0" or "1", where "0" indicates that the value will be defined in the future, while "1" indicates a locally assigned prefix. As determined by the IETF, addresses are centrally assigned to avoid any conflicts. In this case, bit L is set as “0”. The subnet ID is used to indicate the subnet in the site. The interface ID can be allocated by using the MAC address using the EUI-64 format, that is, the 64-bit Global Identifier.

2.6.5 IPv6 Multicast Address

A multicast address is used for delivery to more than one interface. The prefix used here is FF00::/8. This address is basically similar to a unicast address. Figure 2.18 shows the format of a multicast address.

FF<flags><scope>::<multicast group id>

1111 1111 (8 bits)	Flags (4 bits)	Scope (4 bits)	Group ID (112 bits)

Figure 2.18: Multicast address format

The first field is used to recognize the address as an IP multicast address. Flags are used to identify an address as a fixed assigned multicast address when set to “0”. It identifies a temporary address when set to “1”. In the scope field, the multicast traffic is identified as either having interface-local, link-local, site-local, organization-local, or global scope. The last field, group ID is used to recognize the multicast group.

2.6.6 IPv6 Anycast Address

An anycast address is used for delivery using the shortest route when more than one interface is available. This address can be utilized in a source route, where routing can be forced through a particular ISP without the limited routing using only the router which gives access to the ISP.

2.6.7 Media Access Control (MAC) Address

Hardware or MAC addressing is used in the Data Link layer. A MAC address is embedded into each Ethernet network interface card (NIC). The MAC address has a length of 48 bits and is written using the hexadecimal format. Figure 2.19 shows the basic MAC address format.

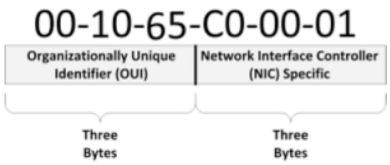

Figure 2.19: Basic MAC address format

The IEEE assigns the Organizationally Unique Identifier (OUI) to an organization, and the organization assigns a unique address to each hardware it produces (Lammle, 2011). The U/L bit, which stands for Universal/Local is used to identify how an address is dispensed. The U/L bit is located in the most significant byte of the address, at its second least significant bit. The address is dispensed locally if the U/L bit is "1", and universally when it is "0". For instance, in the address 08-00-00-00-00-00, "08" is the most significant byte in hexadecimal format. This most significant byte is equivalent to 00001000 in binary. Here, the second least significant bit is "0" which indicates that this address is universally dispensed (IEEE Standards Association, n.d.). Table 2.4 shows a comparison between IPv4, IPv6 and MAC addresses.

Table 2.4: Comparison between IPv4, IPv6 and MAC addresses

Aspect	IPv4	IPv6	MAC
Size	32 bits	128 bits	48 bits
Header length	20 bytes	40 bytes	Not applicable
Number format	Decimal	Hexadecimal	Hexadecimal
Address format	Dotted Decimal Notation eg:223.58.1.10	Hexadecimal Notation eg:2001:cdba::3257:9652	Six groups of two hexadecimal digits eg:00:1b:63:84:45:e6
Flow label	Not available	Available	Not available
Checksum field	Available	Not available	Not available
Options field	Available	Not available	Not available
Minimum packet size	576 bytes	1280 bytes	Not applicable
Address configuration	Static or dynamic DHCP	Stateless Auto-configuration	Assigned by manufacturer
Number of addresses	$2^{32} = 4.29x10^{9}$	$2^{128} = 3.4x10^{38}$	$2^{48} = 2.81x10^{14}$

2.7 Advantages and Disadvantages of IP and MAC Address

IPv4 and IPv6 along with MAC addressing have their advantages and disadvantages. One is not necessarily better than the other in all aspects. The benefits and drawbacks of the these addresses will be elaborated here.

2.7.1 Advantages and Disadvantages of IPv4 and IPv6

IPv4's address space is not enough to cater to increasing needs for addresses due to the growing Internet size and its applications (Batiha, 2013).

The size of routing tables gets larger as the number of networks swell over time when using IPv4. With IPv6, the bulk of these tables should be reduced (Fred, 1996). IPv6 provides more address space compared to IPv4. The number of addresses provided by IPv6 is approximately equivalent to 155 billion IPv4 addresses on every square milimeter on this planet. IPv6 address space would endure until year 2485, if the number of addresses used would twofold every five years (Beijnum, 2006). Beijnum (2006) also states that IPv6 is able to provide individual IP address to every IP-enabled system which the IPv4 cannot do since it is connected to Network Address Translation (NAT). In this case, more than one host share the same translated address. This will cause a problem as an external host will have trouble connecting to one particular host since many other hosts use the same translated address. IPv6 also uses stateless autoconfiguration to configure an address to a host, which does not require a server, unlike IPv4 which uses Dynamic Host Configuration Protocol (DHCP). Addresses from servers and routers can be obtained by using DHCP. However, the DHCP server can become unstable and cause the address received at a time to be different from another. Additionally, IPv6 is more efficient compared to IPv4 since it does not have a header checksum. In IPv4, whenever a packet passes a router, the header checksum will be calculated. In IPv6, the source can be signalled to transmit small packets so that they do not transmit oversized packets that need to be fragmented by routers. According to Agbinya (2010), compared to IPv4, the header of IPv6 is simpler. It only has eight fields and is more efficient as less time is required by routers to unravel IPv6's header.

In terms of mobility, the IPv6 implementations are still not as wide as that as IPv4 because the standards for Mobile IPv6 are still incomplete. The costs for switching from IPv4 to IPv6 will be high since the current hardware used for IPv4 may be incompatible with IPv6 and needs to be replaced (Beijnum, 2006). However, Agbinya (2010) states that mobility in IPv6 is better than IPv4. Since more people are using mobile devices and gadgets, more mobile routers are deployed to cater services that use IPv6. Additionally, Batiha (2013) states that the source and destination IP address in IPv6 produces large overhead since it is about 80% of the header's total size. Tables 2.5 and 2.6 shows the advantages and disadvantages of IPv4 and IPv6 respectively.

Table 2.5: Advantages and disadvantages of IPv4

IPv4	
Advantages	**Disadvantages**
• Supported by all devices • Extensively implemented	• Insufficient address space • Routing tables used are large • Cannot provide individual IP address to every IP-enabled system since NAT is used • Requires a DHCP server • Has a header checksum • Has 14 header fields (more than IPv6)

Table 2.6: Advantages and disadvantages of IPv6

IPv6	
Advantages	**Disadvantages**
• Able to provide IP address to every IP-enabled system since NAT is not used • Provides large address space • Smaller routing table • Does not have a header checksum • Has only eight header fields	• Size of source and destination address produces large overhead • IPv4-enabled hardware may be incompatible with IPv6 • Transition from IPv4 to IPv6 is costly • Not widely implemented as IPv4

2.7.2 Advantages and Disadvantages of MAC Address

Every MAC address is unique which is located in each interface's ROM, and supposedly unchangeable. Yet, in the present day MAC addresses can be changed effortlessly, with no spoofing software required. This exposes a target computer to attackers and allows the attacker access to all frames sent to that target (S. & Dr.C.V, 2013). A user can also be tracked by stalkers from the MAC address of a Wi-Fi enabled gadget that he or she is using (Cunche, 2013). Table 2.7 shows the advantages and disadvantages of MAC address.

Table 2.7: Advantages and disadvantages of MAC address

MAC Address	
Advantages	**Disadvantages**
• Unique in every device	• Can be changed easily • Exposed to attackers • Easily tracked

2.8 Area of Uses

IPv4 can be used widely in mobile and LAN networks. It can be used in web-based applications to provide vital information to government, aviation and military sectors. IPv6 which is still expanding can be used in network games which involves many users, Ad-hoc networking, joint working, home networking, peer-to-peer networking, Ambient Intelligence, medical applications, and communications within a vehicle. Ambient Intelligence is an electronic setting which is able to react when a person is within its vicinity. The MAC address is used in Ethernet to transmit data from one host to another. The ARP protocol is used to resolve an IP address in order to obtain the MAC address of a device for data transmission (Garg, et al., 2012).

2.9 IPv6 Address Plan Example

Adapted from Cisco Systems, Inc. (2013), an example of an addressing plan of a fictional ISP will be shown here. Take for example a fictional ISP, Alpha Telco which is located in San Francisco, and have branches in North America and Asia. Alpha Telco will receive a 2001:db8:1000::/36 block allocation from ARIN after applying for it. Alpha Telco have made a decision to identify the region in the first three bits, that is, either North America or Asia. The block received for North America is 2001:db8:1200::/39, while that for Asia is 2001:db8:1600::/39. This plan will focus on the site in North America. Alpha Telco have also decided to identify the regional headquarters and major facilities in the next five bits. With this five bits, 32 facilities can be identified. From the /44 prefix, each location can be assigned with subnets. Table 2.8 shows the North American /39 prefix which can be divided further to /44 prefixes.

Table 2.8: Prefix subdivision

Site	Prefix
Reserved	2001:db8:1200::/44
San Francisco	2001:db8:1210::/44
Reserved (San Francisco)	2001:db8:1220::/44
San Francisco data centre	2001:db8:1230::/44

256 sites can be attached to San Francisco by using a /52 block. The /52 prefix is able to provide 4096/64 subnets. Table 2.9 below shows some of the sites connected to San Francisco. For the San Francisco hub, the range of /52 subnets for sites linked to it is from 2001:db8:1210::/52 to 2001:db8:121f:f000::/52.

Table 2.9: Sites connected to San Francisco

Site	Prefix
San Francisco HQ	2001:db8:1210:1000::/52
Las Vegas	2001:db8:1210:5000::/52
Los Angeles	2001:db8:1210:3000::/52
Phoenix	2001:db8:1210:4000::/52

Dynamic Host Configuration Protocol version 6 (DHCPv6) is then used to assign interface identifiers to subscriber equipment, and Stateless Address Autoconfiguration (SLAAC) will be used if DHCPv6 is not supported in the equipment. The equipments can also be upgraded to support DHCPv6. DHCPv6 is equivalent to DHCP used in IPv4. With SLAAC, a host can be addressed based on a network prefix advertised by using Router Advertisements (RA), which is sent from a router within the network. The interface identifiers for servers and the entire network infrastructure will be assigned manually. In this example, a block size of /36 is used. However, other blocks can also be utilized instead of /36, for instance a /40, /44 or a /48. At the point when the underlying prefix assignment is longer than asked, the number of bits obtainable will be less. Hence, the prefix assignment and the addressing plan must be suitable with one another.

2.10 Problems Faced in Addressing

More addresses have to be assigned as the number of gadgets that connect to the network increase. Errors happen easily when addresses are tracked and updated manually. Seemingly minor errors may cause serious problems which can bring about downtime that is expensive and waste precious time. IP address conflicts occur when a centralized repository and management system are absent. Normally, the only way to detect an IP conflict is when a report is sent by a user. Besides, IP details are hard to find when IP data are maintained using manual methods such as in spreadsheets. It is also tough to maintain records of the IP assigned to every device. To make matters worse, there are no fast methods to identify whether an IP is available at the moment. The cost to maintain a high availability environment is also very costly (Solarwinds, 2014). Address resolution may not be easy in some network technologies, for instance the Ethernet interface boards. There is also no simple connection between IP and MAC addresses. Besides, the IP address will have to be mapped to a new MAC address should the interface board malfunction and have to be changed. The 32-bit IP address is too small to allow the larger MAC address to be encoded in it (Reynders & Wright, 2003). When an equipment is replaced, it will have a new MAC address but the IP address will be unchanged. Due to this, a host might connect to the wrong MAC address, seeing that erroneous MAC address information for the same IP address is placed in the ARP tables of hosts within the network. Thus, ARP tables of devices are cleared at regular intervals to avoid this problem (Tozer, 2013).

2.11 Evolution in IP Addressing

IP addressing started in the 1970’s beginning with IP version 0. Versions 0 to 3 were trial versions and was not actually implemented. In the 1980’s IPv4 was developed with a capacity of about four billion IP addresses and lasts for about three decades before it started depleting as the current world population is estimated to be almost seven billion people (ICANN, 2011). Shortly after the development of IPv4, the Internet Stream Protocol which was also referred to as IPv5, was introduced. This protocol is connection oriented and had the same addressing scheme for hosts identification as in IP. There were two versions of this protocol. In the late 1970’s, the first version was developed, while RFC1819 specified the second version a decade later. However, both were never implemented (Boucadair, 2009). In 1996, IPv6 was standardized with the aim to significantly increase the IP addressing space, that is, up to 340 undecillion addresses. Test networks were stopped by June 2006 since IPv6 have been working exceptionally well (ICANN, 2011). Table 2.10 shows the various versions of IP addresses and the years in which they were introduced.

Table 2.10: A summary of IP versions and the years they were introduced

IP address version	Year Introduced
IPv0 to IPv3	1970’s
IPv4	1980’s
IPv5	1980’s
IPv6	1996

2.12 World Population and IPv6 Address Needs

IP address utilization and the world's population is proportional to one another. A 64-bit IPv6 address will be able to provide 18,446,744,069,599,100,000 addresses which can last up to year 6748. This can lessen the IPv6 packet overhead and enhance the performance of IPv6 for more than 4000 years (Batiha, 2013). Table 2.11 shows the Total Midyear Population for the World ranging from 2000 to 2050. The table of the Total Midyear Population for the World from 1950-2050 from the United States Census Bureau shows that the overall world population increased by approximately one billion people for every 13 years in average. The world's population is expected to reach 9,408,141,302 people by 2050 (U.S. Census Bureau, 2016). The IPv4 addresses currently available are exhausting, as an IPv4 report generated at 24 May 2016 shows that the total RIR address pool currently available is 3.0894/8 block with the address pool of ARIN completely depleted. AFRINIC has the most, with an address pool of 1.5821/8 block, which is expected to last until April 2018. The remaining RIR pool for APNIC is 0.5358/8 block, that for RIPE NCC is 0.8907/8 block and that for LACNIC is 0.0808/8 block (Huston, 2016).

Table 2.11: Total Midyear Population for the World from 2000 to 2050 (U.S. Census Bureau, 2015)

Year	**Population**	**Year**	**Population**	**Year**	**Population**
2000	6,088,571,383	2017	7,412,778,971	2034	8,587,325,154
2001	6,165,219,247	2018	7,490,427,640	2035	8,646,304,704
2002	6,242,016,348	2019	7,567,402,977	2036	8,704,239,274
2003	6,318,590,956	2020	7,643,402,123	2037	8,761,189,197
2004	6,395,699,509	2021	7,718,256,830	2038	8,817,138,785
2005	6,473,044,732	2022	7,792,021,317	2039	8,872,066,537
2006	6,551,263,534	2023	7,864,725,370	2040	8,925,949,679
2007	6,629,913,759	2024	7,936,271,554	2041	8,978,822,945
2008	6,709,049,780	2025	8,006,580,553	2042	9,030,723,366
2009	6,788,214,394	2026	8,075,716,000	2043	9,081,617,002
2010	6,866,332,358	2027	8,143,729,466	2044	9,131,462,326
2011	6,944,055,583	2028	8,210,559,895	2045	9,180,225,214
2012	7,022,349,283	2029	8,276,190,519	2046	9,227,935,007
2013	7,101,027,895	2030	8,340,606,590	2047	9,274,616,811
2014	7,178,722,893	2031	8,403,880,343	2048	9,320,232,984
2015	7,256,490,011	2032	8,466,094,022	2049	9,364,750,182
2016	7,334,771,614	2033	8,527,246,205	2050	9,408,141,302

CHAPTER 3

METHODOLOGY

3.0 Introduction

In this chapter, the overall steps involved in the completion of this paper will be elaborated. The process that will be explained currently for the first part of the project is the creation of an animation and the initial research concerned with the numbering plan of FTTH. The software used to create an animation on FTTH is Adobe Flash Professional CS5.5.

3.1 Procedure

Figure 3.1 shows the overall steps involved in this research. Firstly, a general knowledge and understanding of fibre optics and fibre to the home (FTTH) were gained by searching for books and journals related to this subject. After understanding the concepts of FTTH, particularly its numbering system, an animation was created to explain FTTH in a more interesting, graphical manner. Next, the most suitable numbering system or addressing on FTTH was designed to modify the current addressing used. Calculations and simulations will be performed to test the feasibility of the numbering plan designed. If there are any errors present in the calculations or the simulation did not function according to plan, new calculations and simulation will be carried out to address the mistakes found. Once these blunders were eliminated, a thorough analysis will be performed on all the data collected on the research topic. All the theory and research findings were then documented in a report.

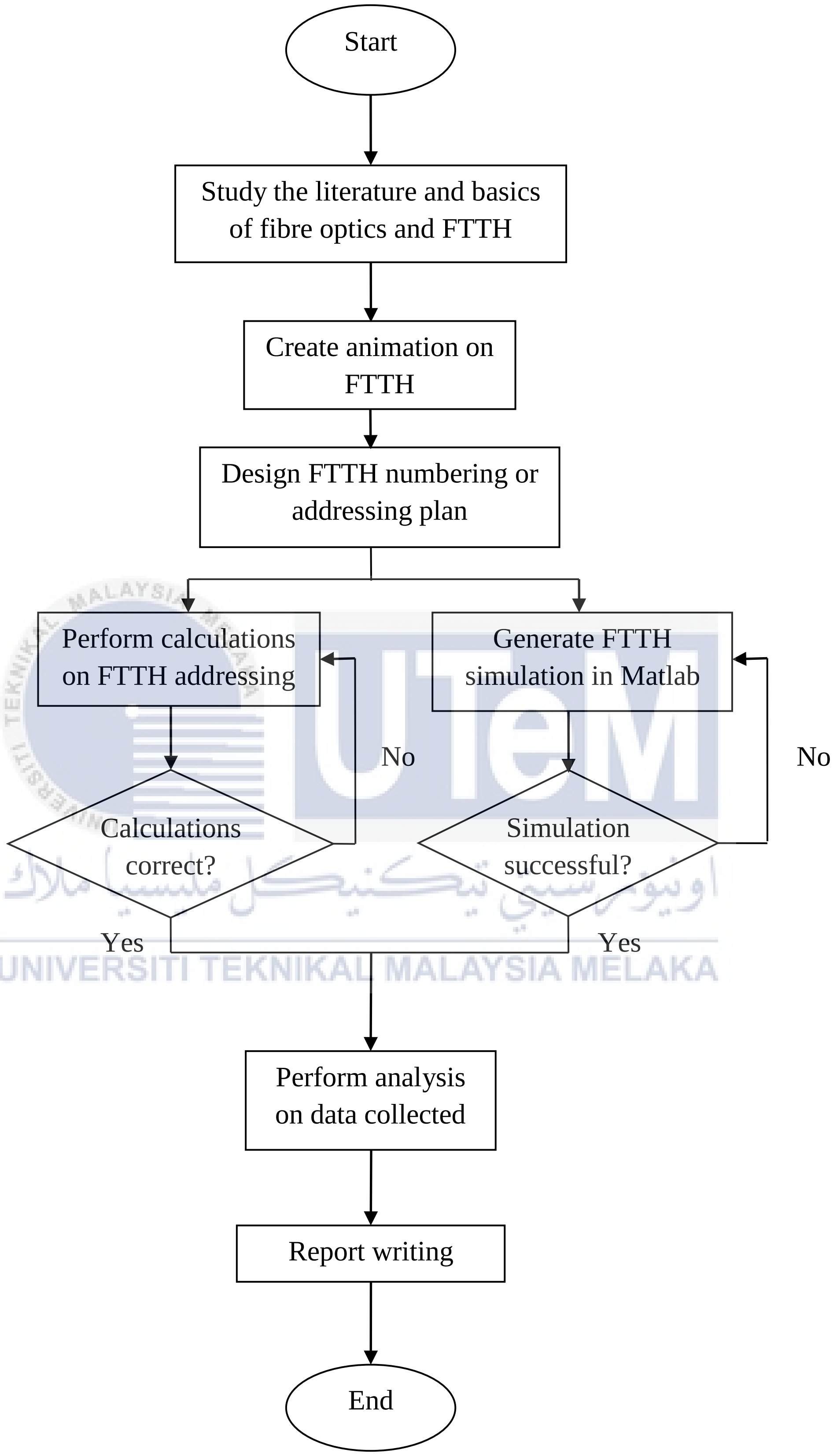

Figure 3.1: Overall project procedures

3.2 FTTH Animation

An animation on FTTH was created by using Adobe Flash Professional CS5.5. A central office, three subscribers, an optical splitter and some interactive buttons were placed in the animation to depict a general FTTH network. A picture of the central office, which represents the Optical Line Terminal (OLT), and homes that represents the subscribers or Optical Network Terminal (ONT) were pasted into the animation window. Next, the buttons were drawn by using the Rectangle Tool. Figure 3.2 shows the overall layout of the FTTH animation in Adobe Flash. The buttons and pictures were made to interact with each other by using ActionScript codes which were inserted at the timeslots in the ‘Actions – Frame’. Figure 3.3 shows a sample of ActionScript codes in the ‘Actions – Frame’. When the animation is played, lines connecting the optical splitter to the subscribers will appear indicating that they are connected. Figure 3.4 shows the complete FTTH animation.

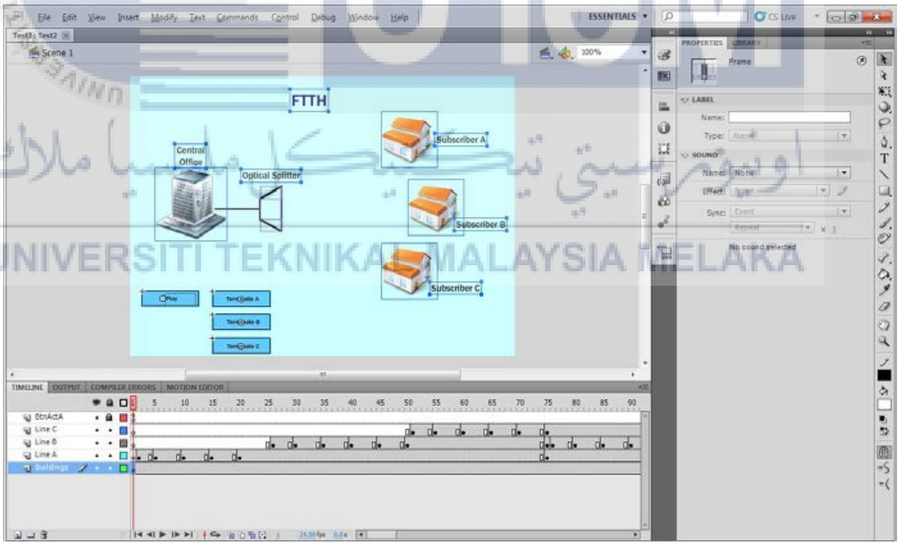

Figure 3.2: Overall layout of FTTH animation in Adobe Flash

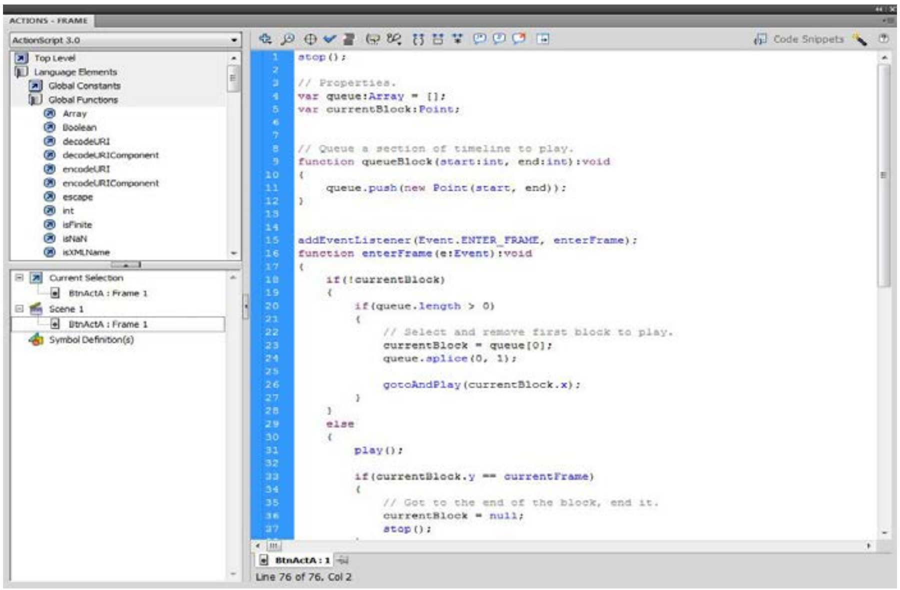

Figure 3.3: ActionScript codes in the ‘Actions – Frame’

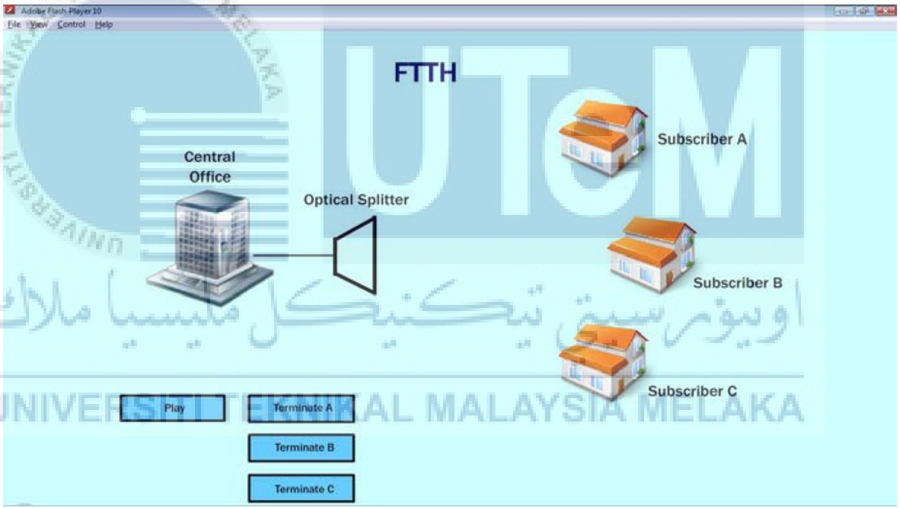

Figure 3.4: Complete FTTH animation

3.3 MATLAB GUI

A simulation which shows the projected world population and IP address capacities for years later than 2016 was created by using MATLAB R2009a’s GUI (graphical user interface) utility. Pushbuttons, static textboxes, editable text boxes, panels and an axes space were added to a blank GUI window. The static textboxes were used to display texts which cannot be edited by the user when the simulation is executed. The static textboxes used in this simulation are labelled as, “IP Address Size (bits)”, “Current World Population”, “Current Annual Percentage of Population Increase (%)”, “Estimated Number of Gadgets Per User”, “Projection Year Range”, “IP Address Capacity Available”, “IP Address Capacity Required”, and finally “World Population for Selected Projection Year”. The other text boxes used are editable when the simulation is running and users can key in values accordingly. All editable text boxes and interactive push buttons are placed with a “tag” which is used in the Callback function. A “tag” for a particular GUI component can be edited from the component’s Inspector window, as shown in Figure 3.5. The Callback function will enable each component in the GUI to be controlled by commands which were keyed into the Editor window. Figure 3.6 shows the Editor window with a portion of the commands used. The “Calculate” pushbutton will enable the user to obtain the IP address capacity available based on the number of bits of the IP address keyed in, and also the IP address capacities available and required, from the user’s data input. The “Reset” button of the GUI will clear all data for new data input. The axes space will plot a graph based on the year keyed in by the user and the calculated IP address capacity. The overall and complete layouts of the GUI are shown in Figure 3.7 and Figure 3.8 respectively. When the GUI was run, MATLAB automatically generated a list of codes in the Editor window based on the “tag” placed on each GUI component. The required formulae to produce the output was keyed into the Editor window, along with the list of codes generated earlier. The formula used, which are equations 3.1, 3.2, 3.3 and 3.4, with a calculation example are shown below:

$$\text{Number of Years, } t = (f + 1) - 2016 \tag{3.1}$$

$$\text{IP Address Capacity Available} = 2^{a} \tag{3.2}$$

$$\text{IP Address Capacity Required} = [P(1 + 0.0113)^{t}]d \tag{3.3}$$

(Matrixlab-Examples.com, 2016)

$$\text{World Population for Selected Projection Year} = P(1 + 0.0113)^{t} \tag{3.4}$$

Where,

0.0113 is equivalent to 1.13% current annual percentage of population increase

a = Number of Bits used in the IP Address

P = Current World Population

= 7,468,316,000 people

f = the Year keyed in by the user

d = Estimated Number of Gadgets Per User

Example:

For $a = 32\ bits$

$d = 2$

$f = 2024$

Number of Years, $t = (f+1) - 2016$

$= (2024 + 1) - 2016$

$=$ 9 years

IP Address Capacity Available $= 2^{a}$

$= 2^{32}$

$=$ 4,294,967,296 addresses

$$\text{IP Address Capacity Required} = [P(1 + 0.0113)^t]d$$

$$= [7{,}468{,}316{,}000\ (1 + 0.0113)^9]2$$

$$= 16{,}526{,}190{,}190 \text{ addresses}$$

World Population for Selected Projection Year

$$= P(1 + 0.0113)^t$$

$$= [7{,}468{,}316{,}000\ (1 + 0.0113)^9]$$

$$= 8{,}263{,}095{,}093 \text{ people}$$

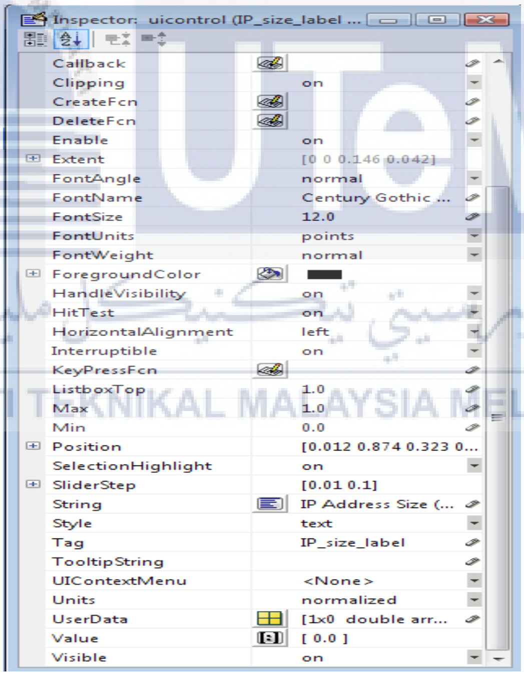

Figure 3.5: An Inspector window for a component in the GUI

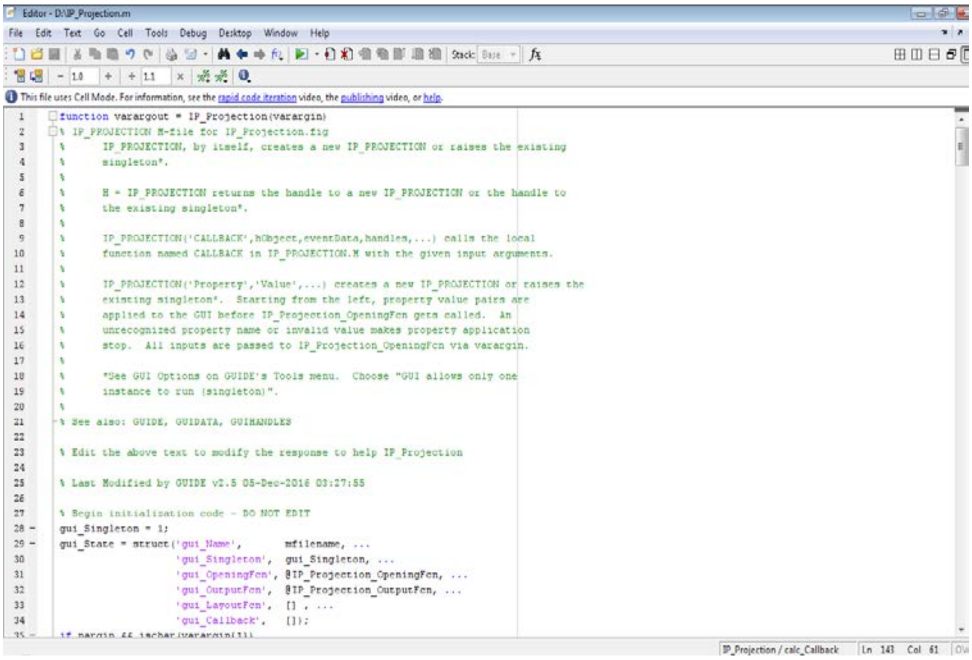

Figure 3.6: The Editor window with commands for the GUI

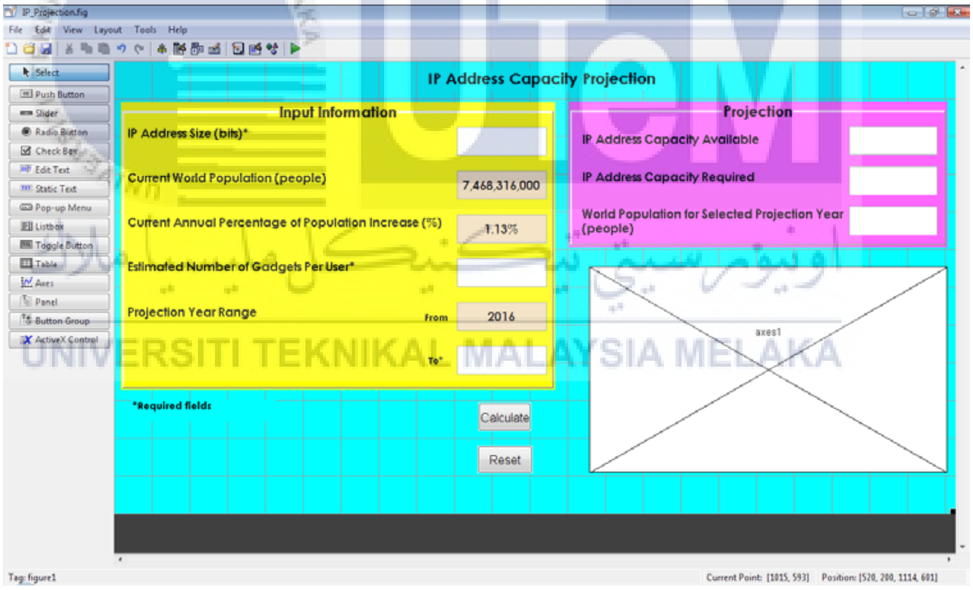

Figure 3.7: Overall layout of the MATLAB GUI

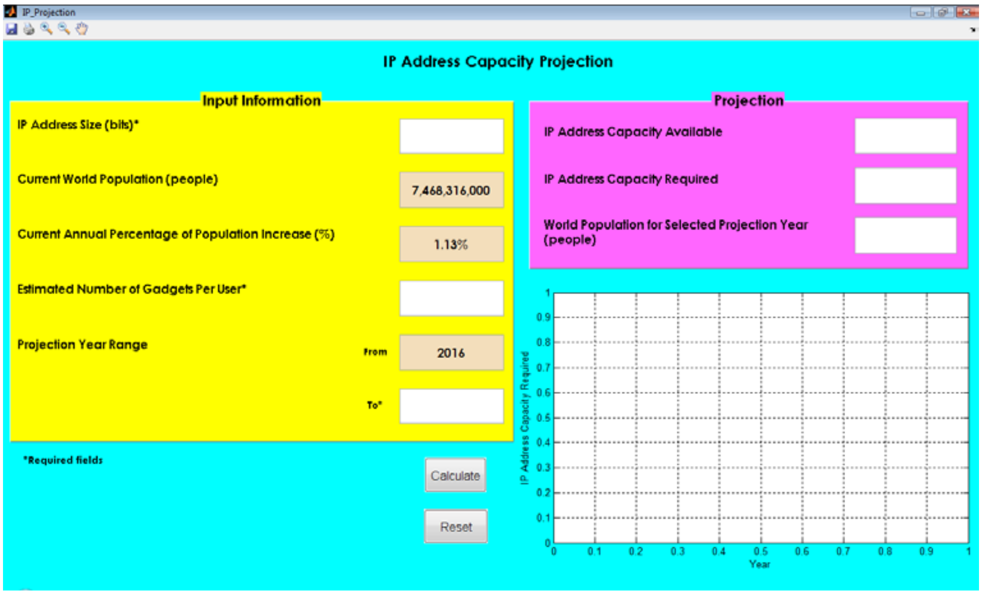

Figure 3.8: Complete MATLAB GUI

3.4 FTTH Addressing

In this section, an addressing format will be introduced for FTTH, although it can also be used in other platforms. The current addressing format used is IPv6 since IPv4 has started depleting. Since IPv6 is 128 bits long, it is considered too lengthy. Furthermore, the size of IPv6 is too tedious for the common folk. IPv6 address can provide up to $2^{128} = 340{,}282{,}366{,}920{,}938{,}463{,}463{,}374{,}607{,}431{,}768{,}211{,}456$ addresses, or simply 3.4 undecillion addresses which is much more than we require for hundreds of years to come, since according to the U.S. Census Bureau, the world's population is expected to be only about nine billion people by 2050. It is also observed that the world's population increased by a billion people by average every 13 years. Therefore, the idea here is to decrease the size of this address format to about 40 bits instead. 40 bits is able to provide $2^{40} = 1{,}099{,}511{,}627{,}776$ addresses, that is, about a trillion addresses which is sufficient to last for a long time. The network prefix and interface identifier portion of the address will both be 20 bits each instead of the original 64 bits. Thus, for an example address of

2607:f0d0:1002:0051:0000:0000:0000:0004 (the collapsed version of this address is 2607:f0d0:1002:51::4, where the string of zeros are represented by a colon ":" for simplicity in writing) is equivalent to its binary form of:

[0010011100000110.1111]000011010000.0001000000000010.0000000010 10001.[0000000000000000.0000]000000000000.0000000000000000.000000 0000000100

From here, taking only the first 20 bits of the prefix and identifier (marked in square brackets) and dividing them equally so that every block contains 10 bits will produce:

0010011100.0001101111.0000000000.0000000000

This binary address can then be converted back to hexadecimal format to produce 9C:6F:0:0 which is a simplified 40-bit IPv6 address which has sufficient size to accommodate IP addressing needs for years to come. This new address format now contains four blocks instead of eight as in the original version, where each block now contains 10 bits instead of 16 bits.

CHAPTER 4

RESULT AND DISCUSSION

4.0 Introduction

In this chapter, an analysis will be done based on the results obtained from the processes in Chapter 3.

4.1 FTTH IPv6 Addressing

IPv6 addresses that have 128 bits can be shortened to 40 bits to reduce overhead in the packet header.

128-bit IPv6 address: 2001:0db8:85a3:0000:0000:8a2e:0370:7334

Binary form:
0010000000000001.0000110110111000.1000010110100011.0000000000000000.
0000000000000000.1000101000101110.0000001101110000.0111001100110100

Reduce to 40 bits and rearrange to have 10 bits in one block:
0010000000.0000010000.0000000000.0000001000

New 40-bit IPv6 address: 80:10:0:8

Since the overhead of the original IPv6 header with 128-bit source and destination address is 40 octets (Savolainen, et al., 2013), which is equivalent to 320 bits total, a reduction to a 40-bit address will reduce the IPv6 header overhead to only 18 octets, which is equivalent to 144 bits. This corresponds to a 55% reduction in header overhead.

4.2 World Population and IP Address Capacities

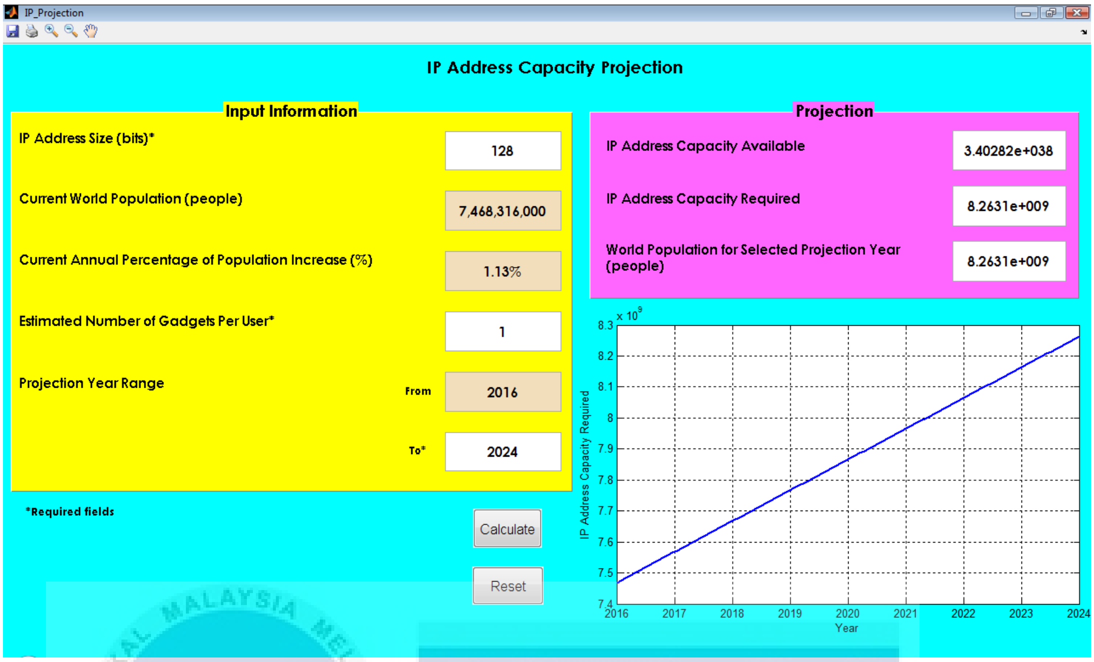

Figure 4.1: Snapshot of MATLAB GUI with filled entries

Table 4.1: Comparison between calculation and MATLAB GUI simulation

Item			Calculation	Simulation
Number of Gadgets Per User	**Number of bits**	**Projection Year Range (beginning 2016)**	**IP Address Capacity Required**	
2	40	2024	1.6526×10^{10}	1.6526×10^{10}
3	40	2024	2.4789×10^{10}	2.4789×10^{10}
4	40	2024	3.3052×10^{10}	3.3052×10^{10}
2	128	2054	2.3151×10^{10}	2.3151×10^{10}
3	128	2054	3.4727×10^{10}	3.4727×10^{10}
4	128	2054	4.6302×10^{10}	4.6302×10^{10}
IP Address Size (bits)			**IP Address Capacity Available**	
32			4.2950×10^{9}	4.2950×10^{9}
40			1.0995×10^{12}	1.0995×10^{12}
128			3.4028×10^{38}	3.4028×10^{38}
Projection Year Range (beginning 2016)			**World Population for Selected Projection Year**	
2024			8.2631×10^{9}	8.2631×10^{9}
2034			9.2458×10^{9}	9.2458×10^{9}
2054			1.1576×10^{10}	1.1576×10^{10}

For $a = 40\ bits$ (IP address size)

$d = 2$ (number of gadgets)

$f = 2024$ (year)

Number of Years, $t = (f + 1) - 2016$

$= (2024 + 1) - 2016$

$= 9$ years

IP Address Capacity Available $= 2^{a}$

$= 2^{40}$

$= \mathbf{1,099,511,627,776}$ **addresses**

IP Address Capacity Required $= [P(1 + 0.0113)^{t}]d$

$= [7{,}468{,}316{,}000\ (1 + 0.0113)^{9}]2$

$= \mathbf{16,526,190,190}$ **addresses**

World Population for Selected Projection Year

$= P(1 + 0.0113)^{t}$

$= [7{,}468{,}316{,}000\ (1 + 0.0113)^{9}]$

$= \mathbf{8,263,095,093}$ **people**

Table 4.2: Projected world population for 21 years inclusive of year 2016

Year	World Population (people)
2016	7,468,316,000
2017	7,638,050,000
2018	7,724,360,000
2019	7,811,650,000
2020	7,899,920,000
2021	7,989,190,000
2022	8,079,470,000
2023	8,170,770,000
2024	8,263,100,000
2025	8,356,470,000
2026	8,450,900,000
2027	8,546,390,000
2028	8,642,970,000
2029	8,740,630,000
2030	8,839,400,000
2031	8,939,290,000
2032	9,040,300,000
2033	9,142,450,000
2034	9,245,760,000
2035	9,350,240,000
2036	9,455,900,000

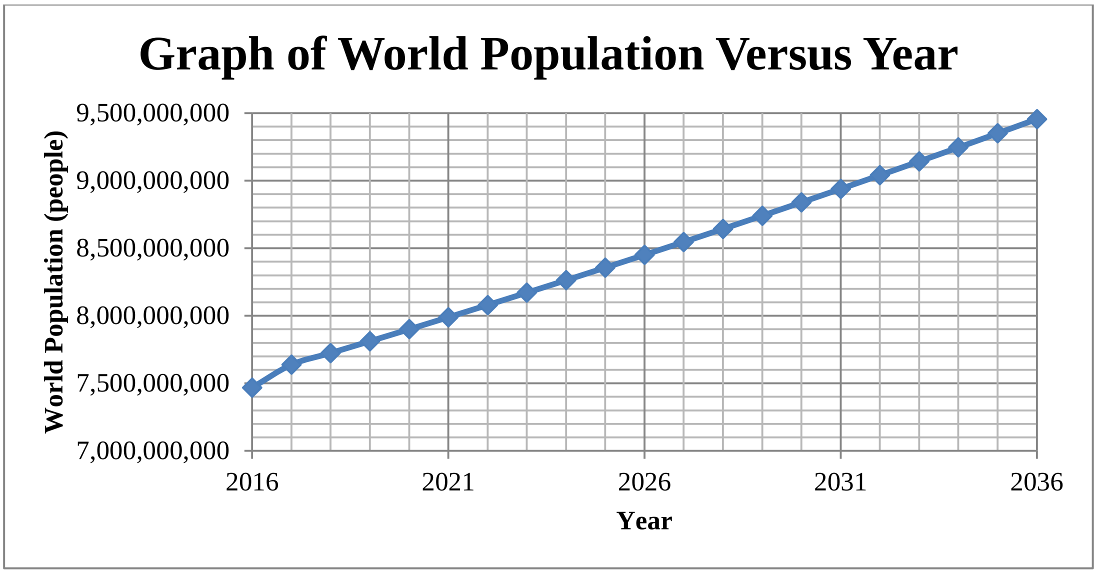

Figure 4.2: Overall world population growth trend from year 2016 to 2036

Table 4.3: IP address capacity based on the number of bits used

IP Address Size (bits)	IP Address Capacity
32	4.2950×10^{9}
40	1.0995×10^{12}
48	2.8148×10^{14}
56	7.2058×10^{16}
64	1.8447×10^{19}
72	4.7224×10^{21}
80	1.2089×10^{24}
88	3.0949×10^{26}
96	7.9228×10^{28}
104	2.0282×10^{31}
112	5.1923×10^{33}
120	1.3292×10^{36}
128	3.4028×10^{38}

Table 4.4: IP address capacity required and available from 2016 to 2035

IP Address Size (bits)	Estimated Number of Gadgets Per User	IP Address Capacity Required	IP Address Capacity Available
32	1	9.3502×10^{9}	4.29497×10^{9}
32	2	1.8701×10^{10}	4.29497×10^{9}
32	3	2.8051×10^{10}	4.29497×10^{9}
32	4	3.7401×10^{10}	4.29497×10^{9}
40	1	9.3502×10^{9}	1.09951×10^{12}
40	2	1.8701×10^{10}	1.09951×10^{12}
40	3	2.8051×10^{10}	1.09951×10^{12}
40	4	3.7401×10^{10}	1.09951×10^{12}
40	117	1.0940×10^{12}	1.0995×10^{12}
64	1	9.3502×10^{9}	1.84467×10^{19}
64	2	1.8701×10^{10}	1.84467×10^{19}
64	3	2.8051×10^{10}	1.84467×10^{19}
64	4	3.7401×10^{10}	1.84467×10^{19}
64	1.9720×10^{9}	1.8439×10^{19}	1.8447×10^{19}
96	1	9.3502×10^{9}	7.92282×10^{28}
96	2	1.8701×10^{10}	7.92282×10^{28}
96	3	2.8051×10^{10}	7.92282×10^{28}
96	4	3.7401×10^{10}	7.92282×10^{28}
96	8.4734×10^{18}	7.9228×10^{28}	7.9228×10^{28}
128	1	9.3502×10^{9}	3.40282×10^{38}
128	2	1.8701×10^{10}	3.40282×10^{38}
128	3	2.8051×10^{10}	3.40282×10^{38}
128	4	3.7401×10^{10}	3.40282×10^{38}
128	3.6393×10^{28}	3.4028×10^{38}	3.4028×10^{38}

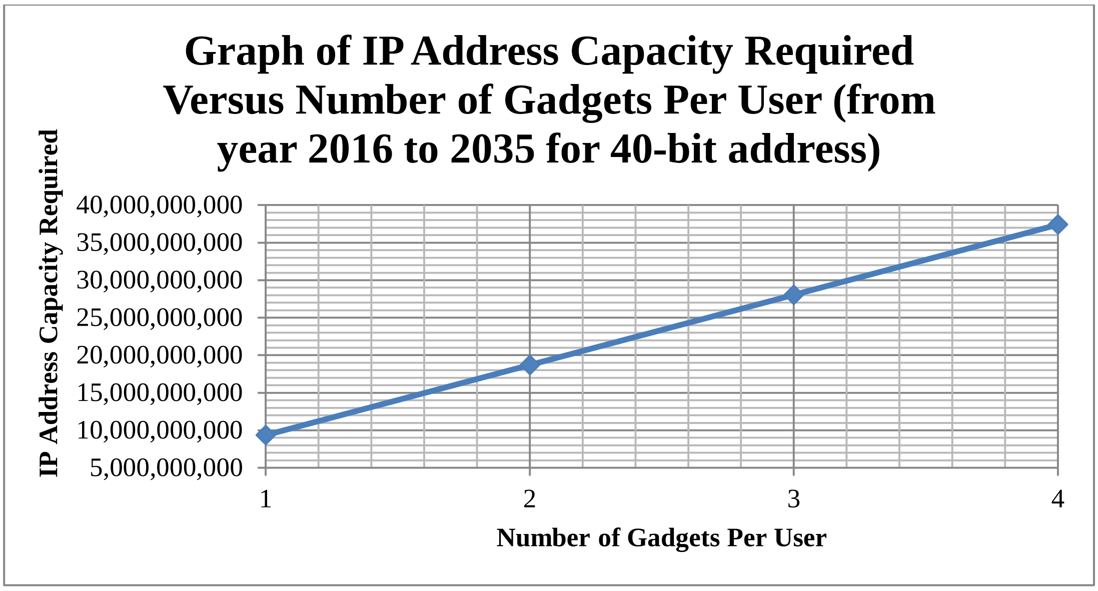

Figure 4.3: IP address capacity needed based on number of gadgets per user

Table 4.5: The year each IP address size will last, for one IP address per user

IP Address Size (bits)	IP Address Capacity Available	IP Address Capacity (at end of year range)	Year Range (from 2016)
40	1.0963×10^{12}	1.0995×10^{12}	2459
48	2.8148×10^{14}	2.7912×10^{14}	2952
56	7.2058×10^{16}	7.1864×10^{16}	3446
64	1.8447×10^{19}	1.8296×10^{19}	3939
72	4.7224×10^{21}	4.7106×10^{21}	4433
80	1.2089×10^{24}	1.1993×10^{24}	4926
88	3.0949×10^{26}	3.0878×10^{26}	5420
96	7.9228×10^{28}	7.8612×10^{28}	5913
104	2.0282×10^{31}	2.0240×10^{31}	6407
112	5.1923×10^{33}	5.1530×10^{33}	6900
120	1.3292×10^{36}	1.3267×10^{36}	7394
128	3.4028×10^{38}	3.3777×10^{38}	7887

Table 4.6: The year each IP address size will last, for three IP addresses per user

IP Address Size (bits)	IP Address Capacity Available	IP Address Capacity (at end of year range)	Year Range (from 2016)
40	1.0963×10^{12}	1.0935×10^{12}	2361
48	2.8148×10^{14}	2.7840×10^{14}	2854
56	7.2058×10^{16}	7.1679×10^{16}	3348
64	1.8447×10^{19}	1.8249×10^{19}	3841
72	4.7224×10^{21}	4.6985×10^{21}	4335
80	1.2089×10^{24}	1.1962×10^{24}	4828
88	3.0949×10^{26}	3.0798×10^{26}	5322
96	7.9228×10^{28}	7.8410×10^{28}	5815
104	2.0282×10^{31}	2.0188×10^{31}	6309
112	5.1923×10^{33}	5.1397×10^{33}	6802
120	1.3292×10^{36}	1.3233×10^{36}	7296
128	3.4028×10^{38}	3.3690×10^{38}	7789

4.3 Discussion

Fibre to the home, which is also known as FTTH in short, is a new development in fibre optics. Here, all subscribers are connected to the central office via a dedicated fibre to their homes. With fibre optics, there should not be any concern when it comes to providing customers with increasing bandwidth because it can be increased without the need to actually change the equipments, which will no doubt save cost in the long run.

IPv6 is the latest IP addressing format available to mankind which is able to provide up to 3.4 undecillion addresses. Most equipments in this age supports IPv6 but a fully IPv4-enabled system cannot run IPv6 without the help of virtual network adapters. In this project, a new IPv6 address format is proposed, in terms of a reduced size. The 128-bit IPv6 address is shrunk to be a 40-bit address. 40 bits may seem like a small number, but it can provide round a trillion IP addresses. The contents of the IPv6 header are not changed to ensure that the functions of the IPv6 header is not altered. This size reduction is suggested to make IPv6 simpler and less tedious. Routing can also be done faster as less time is needed to identify shorter addresses.

There are limitations to this new address format since it has not been tested in a real network scenario. It is currently not known if this size reduction will cause any problems or system instability to the equipment used today. All software that currently utilizes IPv6 will also have to be tweaked to be familiarized with this reduced address size. The IP address projection simulation used in this project assumes that people from the entire globe uses at least one IP address. This is just an assumption and the actual calculation should take into account the actual number of users on Earth that uses IP, since those from poor or underdeveloped countries may not have access to this service. Figure 4.1 shows a snapshot of the MATLAB GUI with IP address size of 128 bits for one gadget from 2016 to 2024.

Table 4.1 shows the comparison between the values obtained by calculation and MATLAB GUI simulation. From Table 4.1, it is observed that the values for IP address capacities and world population obtained via calculation and simulation are the same. This shows that the MATLAB GUI has been programmed correctly to produce accurate values. Table 4.2 shows the projected world population for a duration of 21 years inclusive of year 2016, from MATLAB GUI. From this table, it is observed that the overall world population increases, beginning with about more than 7,468,316,000 people, or approximately seven billion people in 2016, and will grow up to 9,455,900,000 people or approximately nine billion people in year 2036. This is also illustrated in the graph of Figure 4.2 which shows the overall world population growth trend from year 2016 to 2036. Over the course of 21 years, the world's population will increase by around two billion people, given a growth rate of about 1.13% per annum. Table 4.3 shows the IP address capacity based on the number of bits used from MATLAB GUI. The capacity for an IP address increases when its size increases from the minimum possible size of 32 bits currently in IPv4, up to the maximum of 128 in IPv6, which has the capacity of about 3.4×10^{38} as shown in Table 4.3. Figure 4.3 shows a graph on the IP address capacity needed for a range of one to four gadgets per user, for a 40-bit IP address from year 2016 to 2035. Generally, the IP address capacity required increases as the number of gadgets that requires IP address owned by every user increase as shown in the graph of Figure 4.3. However, an IP address with a size of 32 bits is insufficient to meet increasing demand as observed from Table 4.4. Table 4.4 shows the IP address capacity required and the capacity available based on the number of bits of the IP address and the estimated number of gadgets per user for a duration of 20 years, from 2016 (inclusive) to 2035. Table 4.5 shows the approximate year each IP address size will last, assuming each user uses only one IP address. The minimum IP address size that can meet these rising demands are 40 bits, which will last until year 2459 if each user requires only one IP address, that is, for around 443 years from now. Table 4.6 shows the approximate year each IP address size will last, assuming each user needs three IP addresses. If every user needs a maximum of three IP addresses, then the 40-bit address will last for 345 years until year 2361. Assuming an individual only requires one IP address, the capacity of IPv6 address can last for up to 5871 years, that is, until year 7887. If one user were to require three IP addresses, then this capacity can last for 5773 years from now, that is, until year 7789. In order to exhaust the 40-bit IP address capacity in 20 years time, each user on Earth must utilize a total of 117 IP addresses as shown in Table 4.4. Hence, an IP address with a size of 40 bits should be sufficient and there is currently no need for a 128-bit address, which is too large and only causes excess overhead.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.0 Introduction

This chapter will provide a conclusion to this project and present suggestions for future works in order to improve the IP addressing system and the software related to it.

5.1 Conclusion

It is found that IPv6 is far more advantages than IPv4. This project proposes an improved version of IPv6 to be used with FTTH, in order to increase the simplicity in addressing and improve network performance. With a better addressing format, the services provided to subscribers will also improve. If given a time span of 20 years beginning year 2016, in order to deplete the 128-bit IPv6 address available, a user can have up to 3.6393×10^{28} IP addresses. This is equivalent to 36 octillion IP addresses per person. This shows that the size of 128-bit IPv6 is indeed too large and can be reduced as such a large bit size requires larger memory space and uses sophisticated technology to be implemented. The animation created is able to show the basic overall view of FTTH while the interactive GUI can provide information on IP address capacities and world population projections effortlessly to users.

5.2 Recommendations for Future Work

1) Create a platform to test IP addresses in real network situations.
2) Conduct more research on how addressing can be improved for FTTH.
3) Create a simulation that is able to detect the actual number of IP address users.

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APPENDICES

A – ACTIONSCRIPT CODES

```
stop();

// Properties.
var queue:Array = [];
var currentBlock:Point;

// Queue a section of timeline to play.
function queueBlock(start:int, end:int):void
{
    queue.push(new Point(start, end));
}

addEventListener(Event.ENTER_FRAME, enterFrame);
function enterFrame(e:Event):void
{
    if(!currentBlock)
    {
        if(queue.length > 0)
        {
            // Select and remove first block to play.
            currentBlock = queue[0];
            queue.splice(0, 1);
```

```
            gotoAndPlay(currentBlock.x);
        }
    }
    else
    {
        play();

        if(currentBlock.y == currentFrame)
        {
            // Got to the end of the block, end it.
            currentBlock = null;
            stop();
        }
    }
}

ActA.addEventListener(MouseEvent.CLICK, lineA);
function lineA(evt:MouseEvent):void
{
            queueBlock(1, 74);
}

TA.addEventListener(MouseEvent.CLICK, TERa);
function TERa(evt:MouseEvent):void
{
            queueBlock(75, 125);
```

```
}
TB.addEventListener(MouseEvent.CLICK, TERb);
function TERb(evt:MouseEvent):void
{
	queueBlock(126, 150);
}

TC.addEventListener(MouseEvent.CLICK, TERc);
function TERc(evt:MouseEvent):void
{
	queueBlock(151, 200);
}
```

B – MATLAB GUI CODES

```
function varargout = IP_Projection(varargin)
% IP_PROJECTION M-file for IP_Projection.fig
%      IP_PROJECTION, by itself, creates a new IP_PROJECTION or raises the
%      existing singleton*.
%      H = IP_PROJECTION returns the handle to a new IP_PROJECTION or the
%      handle to the existing singleton*.
%      IP_PROJECTION('CALLBACK',hObject,eventData,handles,...) calls the local
%      function named CALLBACK in IP_PROJECTION.M with the given input
%      arguments.
%      IP_PROJECTION('Property','Value',...) creates a new IP_PROJECTION or
%      raises the existing singleton*.  Starting from the left, property value pairs are
%      applied to the GUI before IP_Projection_OpeningFcn gets called.  An
%      unrecognized property name or invalid value makes property application
%      stop.  All inputs are passed to IP_Projection_OpeningFcn via varargin.
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help IP_Projection

% Last Modified by GUIDE v2.5 05-Dec-2016 03:27:55

% Begin initialization code - DO NOT EDIT
```

```
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @IP_Projection_OpeningFcn, ...
                   'gui_OutputFcn',  @IP_Projection_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT


% --- Executes just before IP_Projection is made visible.
function IP_Projection_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to IP_Projection (see VARARGIN)
```

```
% Choose default command line output for IP_Projection
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes IP_Projection wait for user response (see UIRESUME)
% uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = IP_Projection_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;



% --- Executes on button press in calc.
function calc_Callback(hObject, eventdata, handles)
% hObject    handle to calc (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
a = str2num(get(handles.a,'string'));
```

```
d = str2num(get(handles.d,'string'));
f = str2num(get(handles.f,'string'));

if (a>0)&&(a<129)
    x=2^a;
    set(handles.a1,'String',x);
else warndlg('Please enter valid value for Number of Bits');
end

if f>=2016
else warndlg('Please enter a valid year');
end

if d<=0
    warndlg('Please enter a valid value for Number of Gadgets Per User')
else
end

p=7468316000;
t=(f+1)-2016;
q=(p*(1+0.0113)^t)*d;
set(handles.b1,'String',q);

r=p*(1+0.0113)^t;
set(handles.c1,'String',r);
```

```
j=linspace(2016,f);

k=linspace(p,q);


L1=plot(j,k,'-b');

set(L1,'LineWidth',2);

fontSize = 10; % Whatever you want.

% For the axes:

xlabel('Year', 'FontSize', fontSize);

ylabel('IP Address Capacity Required', 'FontSize', fontSize);

grid on


function a_Callback(hObject, eventdata, handles)

% hObject    handle to a (see GCBO)

% eventdata  reserved - to be defined in a future version of MATLAB

% handles    structure with handles and user data (see GUIDATA)


% Hints: get(hObject,'String') returns contents of a as text

%        str2double(get(hObject,'String')) returns contents of a as a double



% --- Executes during object creation, after setting all properties.

function a_CreateFcn(hObject, eventdata, handles)

% hObject    handle to a (see GCBO)

% eventdata  reserved - to be defined in a future version of MATLAB

% handles    empty - handles not created until after all CreateFcns called
```

```
% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function b_Callback(hObject, eventdata, handles)
% hObject    handle to b (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of b as text
%        str2double(get(hObject,'String')) returns contents of b as a double


% --- Executes during object creation, after setting all properties.
function b_CreateFcn(hObject, eventdata, handles)
% hObject    handle to b (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
```

```
    set(hObject,'BackgroundColor','white');
end



function c_Callback(hObject, eventdata, handles)
% hObject    handle to c (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of c as text
%        str2double(get(hObject,'String')) returns contents of c as a double



% --- Executes during object creation, after setting all properties.
function c_CreateFcn(hObject, eventdata, handles)
% hObject    handle to c (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function d_Callback(hObject, eventdata, handles)
% hObject    handle to d (see GCBO)
```

```
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of d as text
%        str2double(get(hObject,'String')) returns contents of d as a double


% --- Executes during object creation, after setting all properties.
function d_CreateFcn(hObject, eventdata, handles)
% hObject    handle to d (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function e_Callback(hObject, eventdata, handles)
% hObject    handle to e (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of e as text
%        str2double(get(hObject,'String')) returns contents of e as a double
```

```
% --- Executes during object creation, after setting all properties.
function e_CreateFcn(hObject, eventdata, handles)
% hObject    handle to e (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function f_Callback(hObject, eventdata, handles)
% hObject    handle to f (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of f as text
%        str2double(get(hObject,'String')) returns contents of f as a double



% --- Executes during object creation, after setting all properties.
function f_CreateFcn(hObject, eventdata, handles)
% hObject    handle to f (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
```

```
% handles    empty - handles not created until after all CreateFcns called


% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function a1_Callback(hObject, eventdata, handles)
% hObject    handle to out1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)


% Hints: get(hObject,'String') returns contents of out1 as text
%        str2double(get(hObject,'String')) returns contents of out1 as a double



% --- Executes during object creation, after setting all properties.
function out1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to out1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called


% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
```

```
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function b1_Callback(hObject, eventdata, handles)
% hObject    handle to b1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of b1 as text
%        str2double(get(hObject,'String')) returns contents of b1 as a double


% --- Executes during object creation, after setting all properties.
function b1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to b1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function c1_Callback(hObject, eventdata, handles)
% hObject    handle to c1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of c1 as text
%        str2double(get(hObject,'String')) returns contents of c1 as a double



% --- Executes during object creation, after setting all properties.
function c1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to c1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
% --- Executes during object creation, after setting all properties.
function a1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to a1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
```

```
% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



% --- Executes on button press in reset.
function reset_Callback(hObject, eventdata, handles)
% hObject    handle to reset (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
set(handles.a,'string','');
set(handles.d,'string','');
set(handles.f,'string','');
set(handles.a1,'string','');
set(handles.b1,'string','');
set(handles.c1,'string','');
cla(handles.axes1);
```