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Migration Strategy From Legacy PON System Into Next Generation PON System For Low CAPEX Telco Deployment in Malaysia

N. Shuhada Ahsan[a*], M. Shahril Salleh[b], F. Abdullah[c]

[a]Computational Science , TM Research & Development, Cyberjaya, Selangor, Malaysia
[b]Communication Technology, TM Research & Development, Cyberjaya, Selangor, Malaysia
[c]Center for Photonic Technologies, College of Engineering, UNITEN, Kajang, Selangor, Malaysia

*Corresponding author: nurulshuhada@tmrnd.com.my

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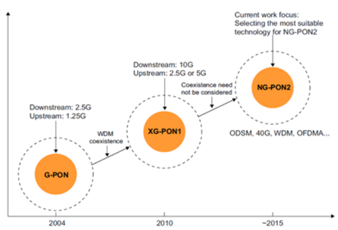
Graphical abstract



Abstract

Migration of legacy Passive Optical Network (PON) to Next Generation PON (NG- PON) system is a must for broadband provider to survive in telecommunication competitive industry. Instead of the responsibility to cater the exhaustion of Malaysian's user to higher bandwidth, the financial impact to any Telco's account statement must be considered. Thus, the strategy to have lower capital expenditure (CAPEX) deployment cost is to be put as the highest priority consideration during the initial migration plan. The objective of this project is to compare migration strategy from GPON to NG-PON1 with GPON to NG-PON2 in term of CAPEX deployment cost for Telco in Malaysia. Another objective is to predict the cost effective migration scenario depending on the internet take up rate and bandwidth utilization. Objective of this project was achieved through collecting and analyzing data of CAPEX deployment cost for each of PON architecture. CAPEX deployment cost was generated using Davim and Pinto CAPEX cost model. In-depth data has also been collected by simulating the deployment of each PON architecture at small area with 320 homepass and urban areas 3447 number of homepass. In order to economically migrate the service, comparison between each topology has been discussed and assessed in term of cost of the components used. Migration of GPON to NG-PON1 has lower CAPEX deployment cost than migration from GPON to NG-PON2. The result of this project can be a basis strategy for any Telco to migrate from current Gigabit Passive Optical Network (GPON) system to Next Generation PON system.

Keywords: Legacy PON; next generation PON; NG-PON1; NG-PON2

■1.0 INTRODUCTION

Broadband networks act as a huge information pipeline that connects directly to homes and workplace to deliver unlimited information with a population of 29.52 million in total land area of 329,758 square km as of October 2013 [1]. Malaysians are rapidly exhausting the available bandwidth and demanding for more. According to Malaysian Communication and Multimedia Commission, (MCMC), the broadband penetration rate for households is rising to 63.7 per cent in the second quarter of 2012 from 62.3 per cent in 2011. In Malaysia, broadband subscription is categorized into wired and wireless technology. Most popular wired broadband services currently is Fiber to The Home (FTTH) and Digital Subscriber Line (DSL).

In Malaysia, MCMC has certified number of telecommunication companies or Telco as last mile broadband service provider. However, the major market share for wired broadbands belongs to Telekom Malaysia (TM), Maxis and TIME dotCom Berhad (TIME). The Government launched National Broadband Implementation (NBI) Strategy on 24th March 2010. The goal of this is to generate adequate supply in terms of broadband infrastructure, via various available technologies deemed appropriate by 2008 and also to stimulate demand to ensure efficient take-up of broadband services via suitable content and applications services. Part of the initiatives or plan is the introduction of the High Speed Broadband (HSBB) project which will bring high speed broadband exceeding 10 Mbps to high density critical areas and developing regions. In this project, government is partnering with Telekom Malaysia (TM) in a Public-Private Partnership (PPP) arrangement to roll out the infrastructure for HSBB project [2].

Under this HSBB initiative, TM rolled out last mile access network to homes and businesses to facilitate HSBB services by using 3 main technologies. The technologies are Fiber to the Home (FTTH), Ethernet to the home (ETTH) and Very High Speed Digital Subscriber Line (VDSL2). In addition, TM also rolled out its Next-Generation Network (NGN) core backbone based on an all IP Platform. TM rolled out the HSBB services with a product named UniFi. Currently, UniFi service is available at 94 areas nationwide in key economic and industrial zones including Klang Valley, Cyberjaya, Putrajaya, Kulim Hi-Tech Park and Bayan Baru industrial area with over 1.29 million premises pass[3]. As a result, TM strengthen their position, as they quadrupled the number of broadband customers by establishing themselves with the fastest growing FTTH service in Southeast Asia as well as one of their competitive advantage[4].

FTTH is broadly deployed due to its attractive features which can provide higher bandwidth compare with noise limited access technology over copper network, DSL and will eventually become the technology of choice by 2035 [5]. It also has more than enough bandwidth to support video applications compared to WiFi and WiMAX and low maintenance cost due to its passive nature. The most cost-effective solution for FTTH is a Passive Optical Network (PON) technology which is Point to Multipoint (P2MP) architecture [6]. The PON technology is divided into legacy PON and Next Generation PON (NG-PON) [7, 8]. In today's world, most of service provider will prefer Ethernet PON or Gigabit PON as their choice of PON system as it was the most attractive optical access-network solutions[9]. In Malaysia, TM is one of the first South East Asia carriers who initiated GPON for FTTH service [10].

1.1 Research Objective & Research Question

The main objectives of this research are as follows:

- RO1: To compare CAPEX for migration of GPON to NG-PON1 and GPON to NG-PON2 architecture in Malaysia.
- RO2: To find out bandwidth received per user for each NG-PON1 and NG-PON2 architecture based on different deployment scenario in Malaysia.

The research questions that can be derived from the above research objectives are as follow:

- RQ1: Which NG-PON architecture has the lowest deployment CAPEX?
- RQ2: How does the different architecture of NG-PON1 and NG-PON2 with the different deployment scenario will affect the deployment CAPEX?

1.2 Problem Statement

Migration from GPON to NG-PON1 or NG-PON2 is a next business strategy for Telco in Malaysia due to exploding demand for higher speed and more bandwidth, the growing popularity of social networking applications, personalized services, triple play services and teleconference are some examples that adding even greater bandwidth demand [11]. The decision on migrating strategy made by Telco will only make sense if it is cost efficient, bandwidth efficient and what most important is minimal impact to current traffic. [8, 12, 13].

1.3 Literature Review

PON has been selected as the preferred FTTH technology solution other than active optical network (AON) architecture which is also known as Point-to-Point Ethernet. PON with the architecture of P2MP has tremendous benefit which can offer large capacity, small attenuation loss, low operational expenditures, longevity and futureproof but also provide the lowest energy consuming solution for broadband access [15]. PON technology has been patented by researchers at British Telecom Laboratories in 1990 [16, 17].

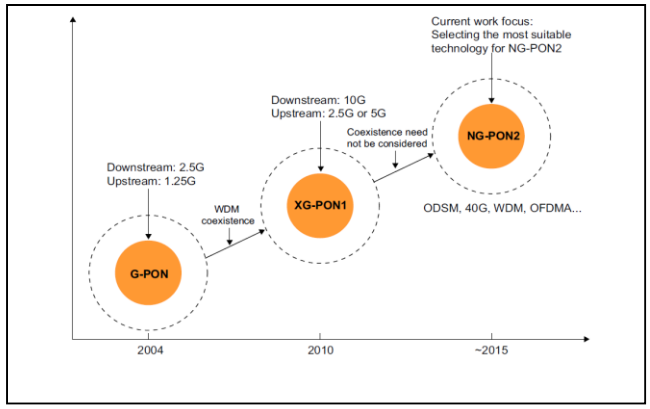


Figure 1 Roadmap of next generation PON

Current deployment and future PON technologies can be divided into three groups as discussed in Full Service Access Network (FSAN) Group as illustrated in Figure 1 [18, 7, 8]:

- Legacy PON
- NG-PON1
- NG-PON2

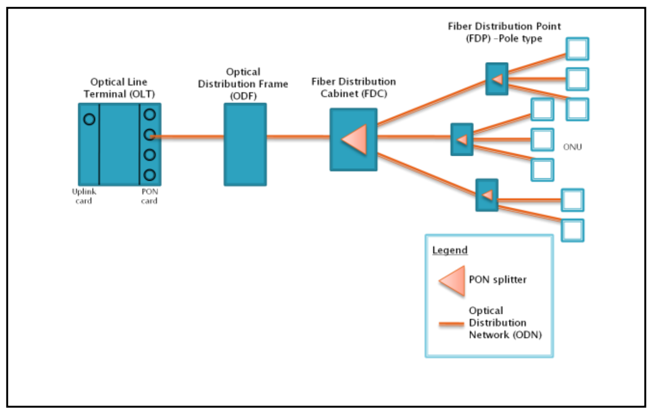


Figure 2 PON network architecture

Each PON network consists of optical line terminal (OLT), splitter, optical network terminal (ONT) components and fiber cable. The optical fiber connecting OLT to ONTs through the passive splitters is called optical distribution network (ODN) as in Figure 2 [19].

1 OLT: In International Telecommunication Union Telecommunication (ITU-T) G.984.3 standard (2008), OLT consists of three major parts, as shown in Figure 3.
   - service port interface function
   - cross-connect function
   - ODN interface

2 Splitter: A splitter is a passive device that splits the light beam carried from the OLT to a number of fibers that connect to the ONTs. While in the opposite direction, splitter carries the light beams sent from the ONTs to a fiber that connects to the OLT.

3 ONT: ONT is a Customer Premise Equipment (CPE) that works as network termination for PON which is reside at customer premise. It is functioned as receiver for optical signals from the OLT and converts the optical signals to electrical signal. The signal carried voice, video and internet

packets to the users. Figure 4 illustrate the ONT block diagram as stated in G.984.3.

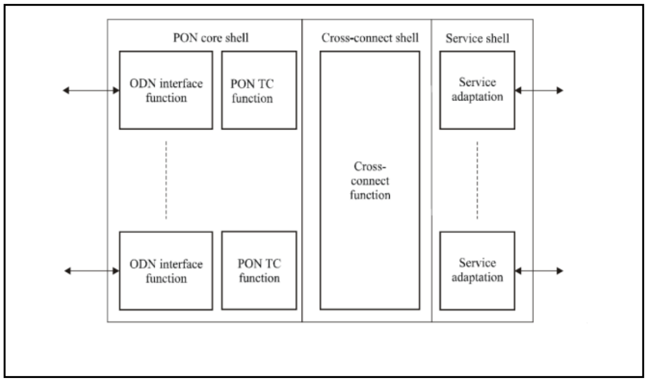


Figure 3 OLT block diagram

4 Fiber: ODN provides the optical transmission medium for the physical connection from ONT to OLTs. This optical fiber connecting OLT to splitter is called feeder fiber and drop or distribution fiber for fiber cable that connect splitter to ONTs at user's end [14].

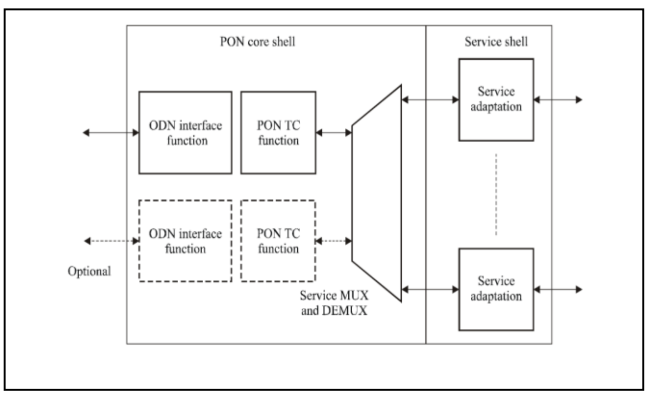


Figure 4 ONT block diagram

Legacy PON comprises of two major standard systems. IEEE 802.3ah EPON based on Ethernet frame transmission and ITU-T G.984 series for GPON, which is based on GPON Encapsulation Method (GEM) fragment transmission [17]. Both architectures are standardized solution for optical access network which are currently been deployed by high speed broadband service provider. GPON and EPON technology solutions have experienced great market penetration and been widely deployed in Asian market as Japan and South Korea [20]. The strategic choice of deploying either GPON or EPON in the networks is a challenge due to many reasons and it is not always based on the clear technical reasons. Telco in Malaysia such as TM and TIME has served Malaysian with their products and services which are based on classical Time Division Multiplexing (TDM) signals such as PCM, E1 and STM-1. Therefore, the decision to adopt GPON is more due to the existing network carrying TDM traffic, which will make synchronization much easier [6]. Another factor leading to the decision is perhaps cost reduction on Telco's operating cost such as training, human resource and asset depreciation by maintaining the current TDM services.

Following ITU-T G.984.1 recommendation, GPON downlink transmission rate is 2.4 Gbps while uplink is 1.25Gbps per GPON port interface.. The recommended split ratios is 1:64 with acceptable power budget. The maximum physical reach between ONT and OLT is set as 10km or 20 km depending on ONT's component used [21].

NG-PON1 includes two major types of XG-PON (where X stands for the roman number 10) which is XG-PON1 and XG-PON2 [22]. XG-PON1 is asymmetrical transmission architecture with 10Gbps only in downstream direction and one or more parallel 2.5Gbps channels in the upstream direction shared. While, XG-PON2 is a symmetrical transmission architecture with 10Gbps downstream and upstream direction [7, 17, 23]. Standardization of NG-PON1 is already completed which cover terminology and references (G.987), service requirements (G.987.1), physical layer (G.987.2) and transmission convergence (G.987.3). XG-PON system can confirmed that the components in its architecture will deliver 10Gbps bandwidth performance. Furthermore, it can be coexisted with GPON system and video overlay systems plus some improvements on the midspan reach extender. Considering most of the high speed users will use P2P or web hosting applications that need bigger upstream bandwidth, this NG-PON1 system will promising on serving higher upstream speed [7]. Standardization of NG-PON1 can extend the longevity of existing ODNs and allow co-existence with the current generation PONs. The operational impact on existing users will be minimized if Telco is planning for migration from its existing GPON [20]. NG-PON1 can be very attractive alternative due to it can offer passive transmission along entire path between customer premise and metro access node provided that costs of NG-PON1 OLT interfaces and ONTs will not be significantly higher than GPON technology [8, 24, 25].

In ITU-T G.987 recommendation, requirements of NG-PON1 are

- Operate asymmetrically at nominal line rate of 10Gbps for download and 2.5Gbps for upload per PON interface which is broadcasted or shared to all user. The migration to this NG-PON1 asymmetric line rate is chosen due to growth of broadcast services that need higher downstream bandwidth. The real reason of choosing lower upstream bandwidth due to consideration of more expensive cost if adding the 10Gbps upstream capability to the ONT [12].
- The minimum requirement split ratio will be the same as GPON considering many Telco already deploying 1:64 of their ODN.
- The maximum distance for the fiber must of at least 20 km. This NG-PON1 architecture basically, will inherit most features in GPON since it can coexist with GPON system.

The additional components that are required for migration from GPON to NG-PON1 are:

- New NG-PON1 OLT with two new wavelength band for downstream and upstream
- Introduce WDM filter that is located in the central office to combine and isolate the wavelengths of NG-PON1 and G-PON signals. This component will only be needed if the Telco's strategy to maintain current GPON system.
- New NG-PON1 ONT specification to support the new wavelength band [7, 26].

Figure 5 showing the wavelength plan that has been reserved for GPON and NG-PON1 upstream and downstream wavelengths. Note here, that there is no overlap plan for ease of migration plan and maintenance.

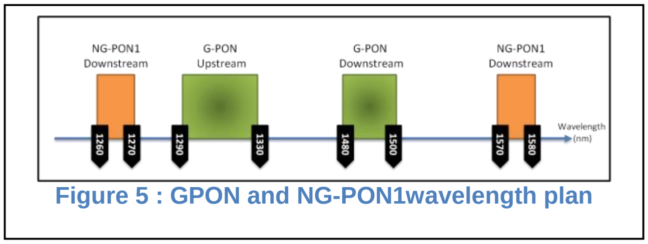


Figure 5 GPON and NG-PON1 wavelength plan

FSAN begin working on NG-PON2 immediately after the 10Gbps passive optical network or NG-PON1 project was handed over to the International Telecommunication Union (ITU) as early in 2011. FSAN has considered several options for NG- PON2 to support the requirement of having 40Gbps bandwidth. Wavelength Division Multiplexing PON (WDM-PON) , coherent ultra dense WDM-PON (UDWDM PON), orthogonal frequency division Multiplexing (OFDM) PON, 40 Gbps TDM PON and , TWDM-PON (TDM/TWDM-PON) are among the technologies options suggested for NG-PON2 [27].

One of the options for NG-PON2 is WDM-PON. This system uses multiple wavelengths in a single fiber to multiply the capacity without increasing the data rate. The advantages of the basic architecture of the WDM PON with its various colorless schemes system are its ability to facilitate symmetric applications and its flexibility in future scaling of bandwidth, reach, and user count [23]. WDM-PON based technologies are the suitable candidates for the next generation green optical access networks in next generation OAN because it can incorporate well with intelligent power management, traffic aggregation and protection mechanism [28]. The required capacity for WDM-PON is at least 40Gbps aggregate capacity per PON interface for downstream and 10Gbps in the upstream which maximum downstream line rate is 2.5Gbps per channel and maximum upstream line rate can also be 2.5Gbps per channel [29]. WDM-PON architecture has a star topology serving a total of up to 32 (extendable to 40) subscribers through its passive component of 1x32 arrayed waveguide gratings (AWGs) with 100GHz spacing at the remote node (RN). The cost of this AWG depends basically on the numbers of ports served [30, 31]. To date, the commercially available WDM-PON optics cost roughly twice that of GPON or EPON [32].

The most popular choice by the FSAN experts for NG-PON2 is the TWDM-PON system architecture [33]. TWDM-PON increases the aggregate PON rate by stacking XG-PONs via multiple pairs of wavelengths. The system introduces 4 pairs of wavelengths which is able to provide 40Gbps downstream and 10Gbps for upstream bandwidth. The ONT can provide 10Gbps downstream and 2.5Gbps upstream bandwidth. The TWDM-PON basic architecture is shown in Figure 6. The colorless ONTs are actually ONTs that have new tunable transmitter and receiver that can be tuned to any 4 of downstream wavelengths and any 4 of upstream wavelengths. The backward compatibility features of TWDM-PON with G-PON and NG-PON1 has been successfully tested without affecting the quality of service. Four XG-PONs are stacked by using four pairs of wavelengths and the ONUs are equipped with tunable transmitters and receivers which can be tuned to any of the four upstream wavelengths. Optical amplifiers (OAs) are used at the OLT side to boost the downstream signals as well as to preamplify the upstream signals to achieve acceptable power budget. TWDM-PON is regarded as the best choice which balances the network upgrade requirements and the cost model consideration in the access network market [33].

Finally, in the middle of 2012, industry experts in FSAN come into agreement to opt for TWDM solution with optional wavelength division multiplexed (WDM) overlay extensions designed as the systems for NG-PON2. The decision was based on operator network requirements, desired availability timeframe, and technology risk [27]. As a result, ITU-T has finalised the general requirement standards for 40 gigabit capable PON, NG-PON2 in G.989.1 and was approved in March, 2013 [34]. To date, the current status of this standard is "In-Force".

As stated in G.989.1 standards, the summary of the general requirement for NG-PON2 are:

- 40 Gbps downstream capacity and 20 km reach
- 10 Gbps upstream capacity and 20 km reach
- Minimum requirement for split ratio is at least 1:64 split
- The minimum distance for the fiber cable must at 20 km. Longer distances with lower split ratios are also possible

The additional components required for migration from GPON to TWDM-PON are:

- The new TWDM PON OLT
- AWG Filter to mux and demux the stacking of XG-PON
- Colorless ONT with tunable transmitter and receiver to tune for receive and transmit the TWDM's wavelength.

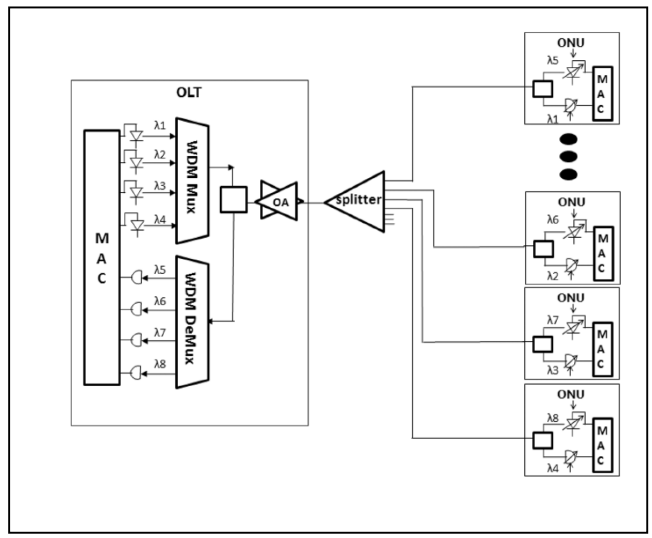


Figure 6 Roadmap of next generation PON

Next generation PON benefits Telco by its simplicity, transparency, low power consumption, better efficiency and flexibility and low energy consumption. However, cost is a major concern to service provider to deploy a new network [12, 13]. The cost is categorized into CAPEX and operational expenditure (OPEX). CAPEX is a budgeted funds used by an operator to acquire physical assets such as equipments. Legacy PON System of EPON and GPON are sufficient for today's most mainstream applications but it is likely that competitive service provider or aggressive equipment vendor will break into markets with NG-PON systems in the foreseeable future. Economical components and current mass-market demand for higher bandwidth is still in study for the deployment to NG-PON [9]. Its technology act as a further migration step can be a very attractive alternative in future because it will offer passive transmission along the entire path between customer premise and metro access node. PON is now deployed as an accepted solution for FTTH due to its ability to share equipment and fiber among a number of customers and thereby reduce costs [35]. However, the huge bandwidth capability in the access will strain the total network viability as metro and core networks will need to be upgraded to support the bandwidth demand, but with little return on investment. A pre-requisite to migration step, is that the costs of NG- PON OLT interfaces and ONTs will not be significantly higher compared to GPON technology [24].

Analysis of wavelength spectrum migration from classical PON to NG-PON is possible provided that major carriers' requirements and concerns for broadband access networks deployment listed below must be fulfilled [8, 12, 13].

- Maximum utilization of the ODN installed for existing PONs. This approach will lead to cost-effective upgrading activity by minimizing the civil engineering cost.
- Capability to provide higher bandwidth or capacity than existing PONs.
- Optimized technology combinations in terms of cost, performance and energy saving.
- Minimize outage during migration to avoid or reduce service disruption. Only the affected user will experience the disruption during the migration process and not the entire network.
- The next generation PON must support the legacy elements or backward compatibility features.

Other than the above requirements, the necessity to realize loss budgets that are not less than those of existing PON systems also must take into consideration prior to migration [36].

Through analysis by using techno-economic, infrastructure installation remains the higher cost component [22]. If these costs can be reduced, say by using existing duct availability, or reducing the cost of civil works, then the prospects of both NG-PON deployment scenarios will be improved significantly. In addition, the configuration of splitter is also a way to optimize the fiber layout. A study by Eira shown that cost effective network design and planning can be achieved by deploying the two-stage splitter configuration. This two stage splitter configuration or cascaded splitter scheme architecture will require less fiber [16].

1.4 Research Gap

Various PON architectures have been described in details in the literature sections. The important to migrate to next generation PON due to emerging of new applications and network services in Malaysia is the responsibilities of the Telco. However, every migration deployment will affect Telco's revenue. But , the justification on the migration cost to reach Telco's return on investment (ROI) will only be successfully achieved with an extensive and comprehensive cost study and the wise decision on selection of deployment of PON network architecture . The needs to study each elements in each PON architecture with the calculation of CAPEX cost of varies migration scenario in Malaysia can very much assist Telco in making a judgment for its growth strategy.

■2.0 METHODOLOGY

The scope of this research paper is covering the existing deployment of GPON systems for small area of Taman Pinggiran Cyber with 320 homepass.

Technical requirement and deployment cost for deploying GPON , NG-PON1 and NG-PON2 of ideal case of 64 home pass are the first thing been and analyzed by using data observation in the subsequent chapter to make a base understanding of the PON's migration scenario. Two different migration or deployment scenario has been chosen for this study. The two scenarios are the migration of GPON to NG- PON by using Brownfield or Straight-forward scenarios. Telco can remain their existing GPON infrastructure like OLT and fiber access if opt for Brownfield scenario. While, the Straight-forward deployment scenario is where they can only maintain their investment on the fiber access and passive splitter but they have to totally change the other infrastructure which are OLT and ONT.

This explanatory research project is on the cross-sectional time research. Deductive approach had been chosen for this research in which a clear theoretical position has been developed that will formulate hypothesis prior to the collection of qualitative and quantitative data. The primary data of the network deployment architecture of GPON, NG-PON1 and NG-PON1 are simulated from the literature review's reading. Later, the CAPEX cost of each architecture has been calculated by using a simple CAPEX cost model retrieved from the literature. Davim and Pinto (2010) found that proposed CAPEX model in their study can be used to estimate the CAPEX cost in any PON system architecture and can also provide an estimate of the components required to provide PON services to any given area [14].

I. PON

$$C_T = C_{OLT} + C_{ONT} + C_S + C_F$$

C_{OLT} and C_{ONT} represent the cost of the OLTs and ONTs, C_S represents the cost of the splitters, and C_F represents the cost of the fiber, and its installation .

II. OLT

$$C_{OLT} = C_{CS} + C_{CX} + C_{SS}$$

The OLT is given by the sum of the the cost of the Core Shell (C_{CS}), the Cross-Connect (C_{CX}) and the Service Shell (C_{SS})

III. Splitter

Assume the cost of splitter is constant

IV. ONT

$$C_{ONT} = C_{CS} + C_{SS}$$

The cost ONT is given by the sum of the cost of the Core Shell (C_{CS}) and the Service Shell (C_{SS}).

V. Fiber

$$C_F = C_f + C_{cw}$$

The cost of fiber is given by the sum of the cost of fiber (C_f) and the cost of civil work (C_{CW}).

In line with the different PON system architectures found in the literature, the study formulated the research hypotheses based on the initial explanation of below research questions.

RQ1: Which NG-PON architecture has the lowest CAPEX deployment cost?

- H1 : NG-PON1 has the lowest CAPEX cost
- H2 : NG-PON2 has the lowest CAPEX cost

RQ2: How does the different architecture of NG-PON1 and NGPON2 with the different deployment scenario will affect the CAPEX deployment cost?

- H1 : Brownfield scenario affect more CAPEX deployment cost than Straight-forward scenario for deployment of NG-PON1
- H2 : Straight-forward scenario affect more CAPEX deployment cost than Brownfield scenario for deployment of NG-PON1
- H3 : Brownfield scenario affect more CAPEX deployment cost than Straight-forward scenario for deployment of NG-PON2

- H4 : Straight-forward scenario affect more CAPEX deployment cost than Brownfield scenario for deployment of NG-PON2

■3.0 RESULTS AND DISCUSSION

3.1 Ideal Case

The ideal deployment architecture is a good analysis way to illustrate the ideal CAPEX cost of each PON network architecture. This ideal case of deployment will be the basis measurement for all NG-PON architecture that will be discussed in the following sections. A good understanding of this basis requirement of migration to NG-PON will assist in more detail understanding and detail analysis of the other major scope of this research which will cover migration to NG-PON for small areas of Taman Pinggiran Cyber, Sepang and urban areas of Klang Town. The ideal deployment architecture will include the maximum capacity of each PON interface and splitter as well as maximum number of fiber length. Single method of splitter deployment or single splitter scheme is considered as an ideal architecture since this method will give maximum impact to fiber length and indirectly reflect the high value of CAPEX cost other than cascaded splitter scheme [14].

For this research, the ideal deployment architecture is based on assumption of 64 home pass in one area in which the maximum number of each PON interface is 64. The maximum split ratio will be 1:64 which means 1 PON interface can hold up to 64 users with the assumption the length of the ODN or the fiber length between OLT and ONT is 10km.

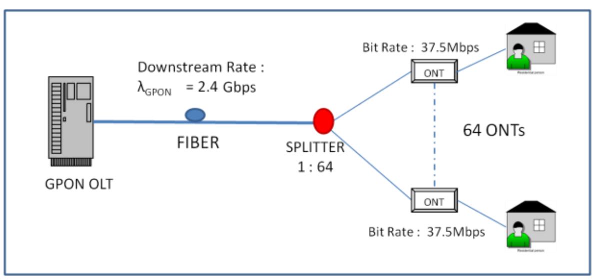


Figure 7 GPON idle network deployment architecture

Simulation of ideal network deployment architecture for each PON interface can be applied in two different scenarios. Telco can have an option either to migrate from their current GPON network architecture to NG-PON1 or to NG-PON2 network architecture and also can choose to deploy the architecture either using Brownfield scenario or Straight-forward scenario. Telco can remain the existing GPON infrastructure like OLT and fiber access if opt for Brownfield scenario. Telco also can choose to opt for Straight-forward deployment scenario where they can maintain only on their existing investment on the fiber access and passive splitter. But for this Straight-forward deployment scenario, Telco have to totally change the other GPON infrastructure. Refer Figure 7 on the ideal GPON network architecture. One way to have an optimum deployment of GPON architecture to an ideal network is one GPON port interface at OLT will have a bit rate of 2.4Gbps download bit rate and 1.2Gbps upload bit rate. Every ONT will get maximum 37.5 Mbps for download bandwidth per user by using one passive splitter with the capability split ratio of 1:64 where each GPON port interface can go up to 64 users in between the OLT and the ONTs. Since the splitter used here is 1:64, the more split ratio will increase the optical splitting which will affect to the increment of power budget [21]. To tolerate with the increment of power budget, the physical reach between ONT and OLT can only be 10km distance of fiber layout.

Brownfield scenario is one way of deploying NG-PON1 technology where it can coexist with existing GPON deployments or infrastructures. The reason to counted in this scenario where in an area, there is still customer that have small pocket money will only go for lower bandwidth. However, for the high demand bandwidth user, they know the higher the bandwidth they want to consume, they would expect a higher figure amount on their bill. For this scenario, NG-PON1 can coexist with GPON over the same fiber to meet the requirement of each customer. Eventually, the migration from GPON to NG-PON1 will protect the investments of Telco on GPON access infrastructure. NG-PON1 architecture as shown in Figure 8 is introducing WDM filter, XG-PON OLT and XG-PON ONT as the new components. The function of this WDM filter which located at the central office is combining and isolating the wavelengths of XG-PON and G-PON signals as stated in ITU-T G.987.1. By assuming the take up rate is 50% for GPON and the rest for NG-PON1, the maximum download bandwidth per user will be 75Mbps for GPON and 312.5Mbps for NG-PON1. Figure 8 is illustrating the existing and additional components for migration from GPON to NG-PON1.

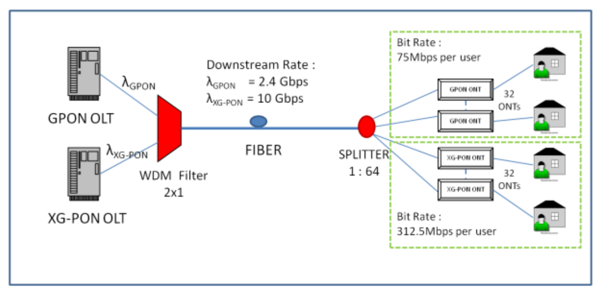


Figure 8 NG-PON1 network deployment architecture for Brownfield Scenario

While, in order for migration from GPON direct to NG-PON2 technology in this Brownfield scenario deployment, GPON OLT and GPON ONTs are maintained at site. With the same assumption of 50-50 take up rate for GPON and NG-PON2, the low bandwidth demand customer, will experience the same bandwidth as before which is 75Mbps for each user. However, the emerging of new applications and network services, there is certain group of customers that demand for more bandwidth higher than GPON can serve. To meet the market demand, Telco will plan to deploy new infrastructure which will have TWDM-PON OLT, AWG and WDM Filter as well as the colorless TWDM-PON ONT as shown in Figure 9. Those components or elements are the generic requirement for Telco to migrate to NG-PON2 technology. Now, the existing fiber will carry not only the GPON wavelength with the downstream rate of 2.5Gbps, but they will also carry the new TWDM-PON wavelength which will carry 40Gbps bandwidth for downstream. After going to the passive splitter, this downstream bandwidth of TWDM-PON will then be divided the bandwidth equally to different 32 users. As a result, every user in this bandwidth hunger group of customer will enjoy 1.25 Gbps per user which is exactly 4 times more bandwidth than if Telco choose to migrate to NG-PON1.

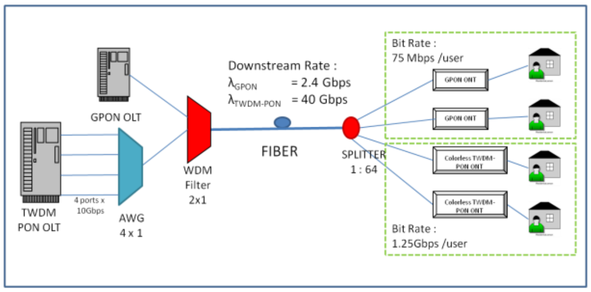


Figure 9 NG-PON2 network deployment architecture for Brownfield

To make clearer understanding, those elements or components that is needed for the migration of GPON to NG-PON1 and NG-PON2 is summarized in Table 1. Since the main reason Telco chooses the Brownfield scenario deployment is to maintain their investment on GPON technology. Thus, the GPON's OLT and ONTs as well as the fiber and the passive splitter is still remain in the network whenever the Telco plan for its growth strategy.

Table 1 Summary component required to migrate GPON to NG-PON for Brownfield scenario

Components	GPON	Brownfield	
		NG-PON1	NG-PON2
GPON OLT	✓	✓	✓
GPON ONT	✓	✓	✓
Fiber	✓	✓	✓
Splitter	✓	✓	✓
XG-PON OLT		✓	
XG-PON ONT		✓	
WDM Filter		✓	✓
TWDM-PON OLT			✓
TWDM-PON ONT			✓
AWG			✓

Straight-forward scenario is another way to deploy NG-PON architecture where Telco can only remain the existing fiber layout and the 1:64 splitter of GPON system. The other GPON elements like OLT and ONT will be obsolete or removed. It then is replaced with the new type of OLT and ONTs which meant for NG-PON1. Telco may opt this scenario because of the higher cost of maintenance of the existing GPON infrastructure and also due to tremendous bandwidth demand from which is more than GPON can do. Suggested deployment of NG-PON1 by adopting the Straight- forward scenario is illustrated in Figure 10. XG-PON OLT and XG-PON ONTs will totally replace the GPON system in this NG-PON1 deployment architecture. WDM filter is not applicable here because the need to coexist with GPON system is not necessary. Each PON interface will carry 10Gbps download bandwidth and the splitter will split the bandwidth to 64 users by using the same 1:64 splitter as in the GPON system. As a result, every user will enjoy download bandwidth rate of 156.25Mbps per user. Although the customer experience half lower the bandwidth per user compare than if Telco opt for the Brownfield scenario, but still in this area all the 64 users will experience the same higher bandwidth compare to GPON bandwidth capability. This method of deployment will make the maintenance team easy to install and repair the service line because of the same technology used everywhere.

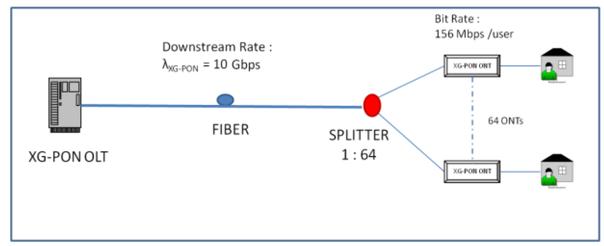


Figure 10 NG-PON1 network deployment architecture for Straight-forward Scenario

NG-PON2 deployment architecture by adopting Straight-forward scenario is shown in Figure 11. The NG-PON2 OLT which using the TWDM PON OLT and colorless ONTs will replace GPON OLT and ONTs. Total bandwidth of 40Gbps from 4 PON port interfaces of 10Gbps each, is being given equally to 64 users by using a 1:64 passive splitter. Each user will experience bandwidth of 625Mbps which is good enough to cover every household bandwidth demand. The same justification on the lower bandwidth compares to the Brownfield adoption scenario, whereby here all the 64 users will enjoy the same bandwidth rate and ease for maintenance. Table 2 below show the required components to migrate to NG-PON1 and NG- PON2 if Telco choose to deploy using the Straight-forward scenario. All the GPON's elements removed and also the filter to maintain the coexistence of GPON also has been taken out. The only left investment is on the fiber and splitter.

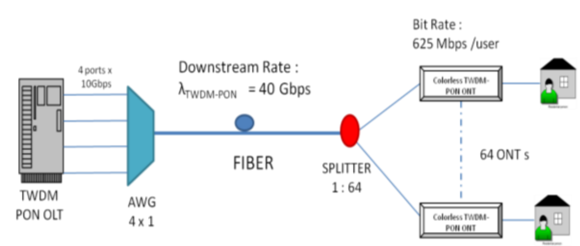


Figure 11 NG-PON2 network deployment architecture for Brownfield Scenario

Table 2 Summary component required to migrate GPON to NG-PON for Straight-forward scenario

Components	GPON	Brownfield	
		NG-PON1	NG-PON2
GPON OLT	✓		
GPON ONT	✓		
Fiber	✓	✓	✓
Splitter	✓	✓	✓
XG-PON OLT		✓	
XG-PON ONT		✓	
WDM Filter			
TWDM-PON OLT			✓
TWDM-PON ONT			✓
AWG			✓

The CAPEX cost of each PON architecture has been extracted from the result of simulation of every PON network deployment architecture discussed in section 4.1.1 by using the proposed CAPEX cost model by Davim and Pinto [14]. The result of CAPEX deployment cost of each deployment architecture has been achieved and compared by adopting both Brownfield and Straight-forward scenario. The reference CAPEX cost for GPON is tabled out in Table 3. The total cost of deploying GPON for 64 home pass is USD37, 965.

Table 3 CAPEX cost for GPON Deployment in Malaysia

No.	Components	Quantity	Cost Per Unit (USD)	Total Cost (USD)
1	GPON OLT Port Interface	1	1,800	1,800
2	48 Core Fiber Cable	10,000	2.8	28,000
3	Installation & Splicing	10	145	1,450
4	Splitter (1: 64)	1	315	315
5	GPON ONT	64	100	6,400
	TOTAL			**37,965**

Figure 12 shows the CAPEX deployment cost and bandwidth per user for each architecture namely GPON, NG-PON1 and NGPON2 for Brownfield scenario. CAPEX deployment cost for migration of GPON to NG-PON1 is increased by 35% compared to the increase of around 100% or double for migration of GPON to NG-PON2. The NG-PON2 cost is higher due to the cost of colorless TWDM PON ONT is about double the price of NG-PON1 ONT due to additional of new tunable transmitter and transceiver. Refer Table 4 for the summary price of the new major component used for NG-PON 1 and NG-PON2.

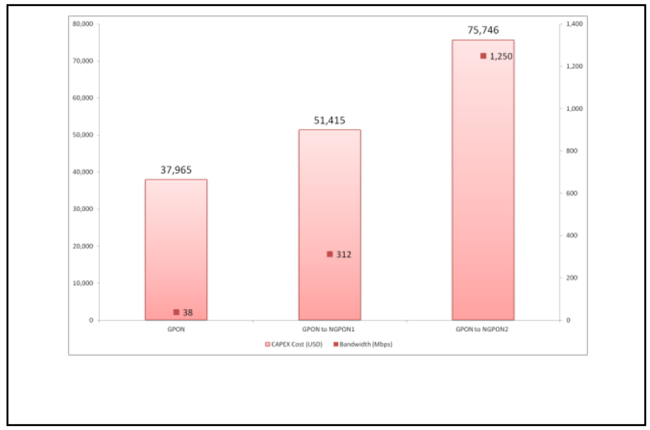


Figure 12 CAPEX cost of migration from GPON to NG-PON for Brownfield Scenario

Here, cost of NG-PON1 ONT and OLT is expected to be 3-5 times of GPON ONT and OLT [38]. In addition, cost of each NG-PON2 PON port interface is the same as XG-PON port interface due the TWDM-PON technology is using four stackable of 10Gb PON interface to supply 40Gbps downstream capacity. The CAPEX cost of NG-PON1 deployment in this Brownfield scenario is still can be controlled by the fact that the lower cost of GPON system is still exist. Varies of take up rate of GPON and NG-PON1 may give variant to the cost of NG-PON1 deployment. However, NG- PON2 deployment will promise twelve times higher bandwidth per user compare to NG-PON1 deployment. The bandwidth of 2.5Gbps for download bandwidth rate per user is more than enough for home user where normally home networking technology will limit residential service tiers to the 100-200 Mbps range. A 1 Gbps service rate will be possible for business and power users that have a direct Gigabit Ethernet connection and applications [39]. This Brownfield scenario adaptation will permit Telco to maintain their existing GPON components which are the GPON OLT and fiber, thus lowering the investment cost.

Table 4 Summary cost of each new components for NG-PON1 and NG-PON2

Number	Component	Cost per Unit (USD)
1	OLT XG-PON Port Interface	3,750
2	ONT XG-PON	400
3	TWDM PON Port Interface	3,750
4	TWDM PON Colorless ONT	800

The comparison of CAPEX deployment cost for migration of GPON to NG-PON1 with NG-PON2 for second scenario of Straight-forward is shown in Figure 13. By maintaining the existing layout of 10km fiber, the CAPEX cost is still low at NG- PON1 compare to NG-PON2 where its only cost the Telco about USD 20k more than GPON deployment. However, NG-PON2 deployment will cost almost triples the cost of NG-PON1. The CAPEX cost of NG-PON1 is a bit higher in this straight-forward scenario by USD 7.7k compared to Brownfield scenario where all the 64 user is totally upgrade to NG-PON1 which give more bandwidth of 156Mbps. The standardization of NG-PON2 of choosing TWDM-PON will eventually increase the cost of OLT, thus affecting total CAPEX deployment cost for migrating GPON direct to NG-PON2. The Telco have to invest on another USD 60K to deploy NG-PON2 for their network upgrading process. However, the minimum cost of migration from GPON to NG-PON will be achieved if Telco chooses the effective way to deploy it.

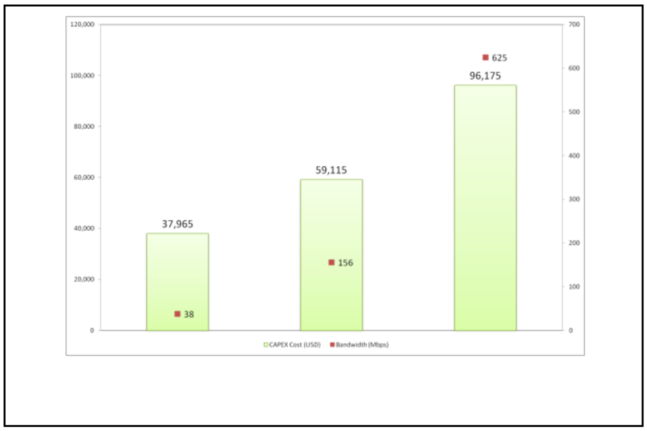


Figure 13 CAPEX cost of migration from GPON to NG-PON for straight-forward scenario

3.2 Case Study: Taman Pinggiran Cyber, Selangor

In this research, a small scale of area in Malaysia is chosen to discuss the research objective and to answer research question by analyzing CAPEX cost of PON architecture. Taman Pinggiran Cyber in Selangor, Malaysia consists of 7 link houses blocks with 320 number of home pass. It is located next to Cyberjaya, the Malaysia's Silicon Valley. Assuming the broadband penetration factor is 100%, 320 units of home pass need to be covered. The migration from current GPON to next generation PON system has to be considered in this area because of overwhelming demand of bandwidth in this area. Most of the people living here are university students, contingent workers from multinational company in Cyberjaya as well as family. The data of the network deployment architecture of GPON, NG-PON1 and NG-PON1 were simulated based on the ideal deployment architecture.

Simulation of network deployment architecture for GPON, NG-PON1 and NG-PON2 for Taman Pinggiran Cyber, Selangor has been done in two different scenarios. Telco can have an option either to migrate from GPON to NG-PON1 or NG-PON2 by using Brownfield scenario or Straight-forward scenario. Telco may remain the existing GPON network elements like OLT and passive splitter as well as fiber access if opt for Brownfield scenario. While, Telco also can choose Straight-forward deploying scenario where they can only maintain their investment on the fiber access and passive splitter but they have to totally change the other network elements.

Deployment of GPON in Malaysia is using cascaded splitter topology rather than centralized/single splitter topology. Cascaded splitter for GPON deployment architecture is suitable to be used in Malaysia due to geographical factors, the fiber route deployment and also served houses are clustered in smaller groups. The geographical distribution of the ONUs has to foreseen during the network planning as one of the factor to choose type and mechanism to deploy splitter. The cost advantage of cascaded splitters is where only several shared fibers will be used because the minimum distance from the last splitter to the ONTs in contrast with single splitter scheme which consume much more fiber [40]. For instance, splitter is normally being put inside the Outdoor Fiber Distribution Cabinet (OFDC) at the roadside as a main distributor to other Fiber Distribution Point (FDP). Inside the FDP, there will be another splitter to split the PON service to home users. It is the last point to terminate Telco's fiber optic cable prior to internal wiring. In case of Malaysia, typical splitter used in OFDC is 1:8 or 2:8 splitter which the other 1 for protection. Normally, 1:8 splitter will be inside the FDP where each fiber core from OFDC will be distributed to 8 houses. Refer Figure 14 on the GPON network architecture deployment in Malaysia. Since Taman Pinggiran Cyber has 320 home pass, 5 OLTs PON interface is required here to meet the residence's demand.

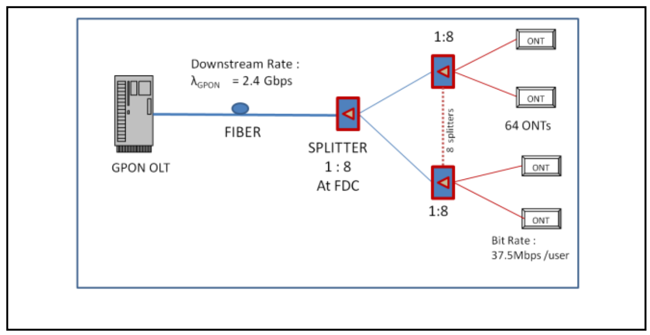


Figure 14 Gpon network deployment architecture

This Brownfield scenario is one of way of deploying PON architecture where it can coexist with existing GPON deployments or infrastructures. One way to have an optimum deployment of GPON architecture to an ideal network is per 1 GPON port interface at OLT will have a bit rate of 2.4Gbps download bit rate and 1.2Gbps upload bit rate. By using a cascaded splitter mechanism with the split ratio of 1:8 at OFDC and FDP, every ONT for 320 home pass will obtain 37.5 Mbps at maximum for download bandwidth per user. Figure 15 show the splitter placement and fiber access route for Taman Pinggiran Cyber, Selangor with 7 blocks of 320 link houses.

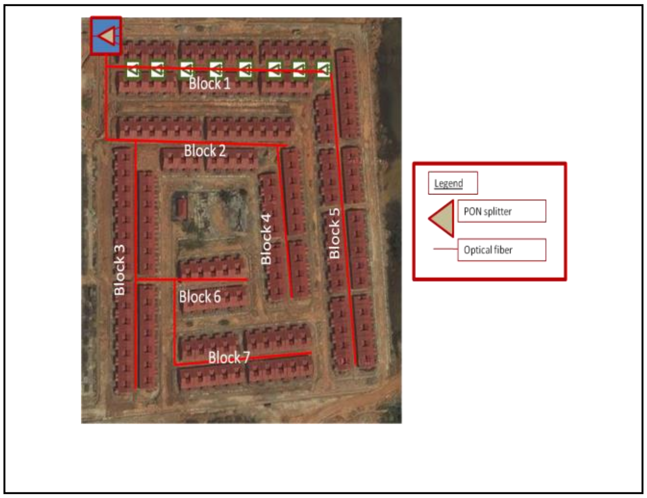


Figure 15 Splitter placement and fibre acess route of Taman Pinggiran Cyber, Sepang

NG-PON1 coexists with GPON over the same fiber, thereby the migration from GPON to NG-PON1 will protect the investments of Telco on GPON infrastructure. NG-PON1 is introducing WDM filter, XG-PON OLT and XG-PON ONT as the new components. By assuming the take up rate is 40% for GPON and the rest for NG-PON1 for Taman Pinggiran Cyber, the maximum download bandwidth per user will be 37.5Mbps for GPON and 256Mbps for NG-PON1. The bandwidth per user experienced by NG- PON1 user is lower than the ideal case is due to broadcasting attribute of PON. The bandwidth 3 XG-PON is divided to 192 home pass which is 60% of user that demand for higher bandwidth. The existing and additional components for migration from GPON to NG-PON1 is been illustrated at Figure 16.

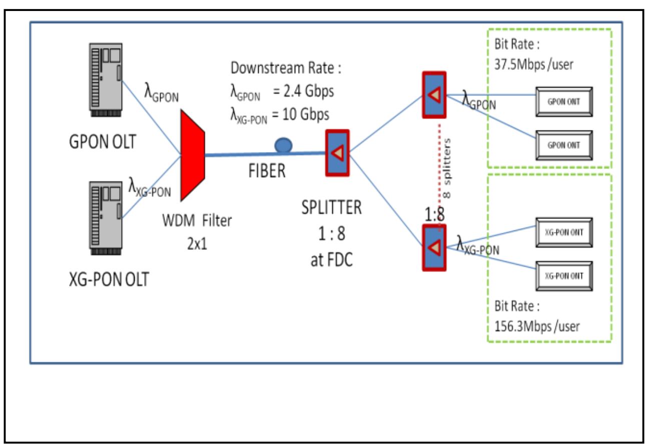


Figure 16 NG-PON1 network deployment architecture of Brownfield scenario

In order for migration from GPON to NG-PON2 technology, TWDM-PON wavelength will concurrent with GPON wavelength travelling in the same fiber from their own OLTs to each of their own ONTs. Since PON is a broadcast network where all the wavelength will going through each devices, ONT is the element that can recognize their own wavelength and discard others. TWDM-PON ONT will only accept their TWDM-ON wavelength. Here, the 60% of Taman Pinggiran Cyber's residence that subscribe for higher bandwidth can get up to 625Mbps per user which is about 17 times better than the GPON users. Illustration of NG-PON2 deployment for Brownfield scenario is depicted in Figure 17.

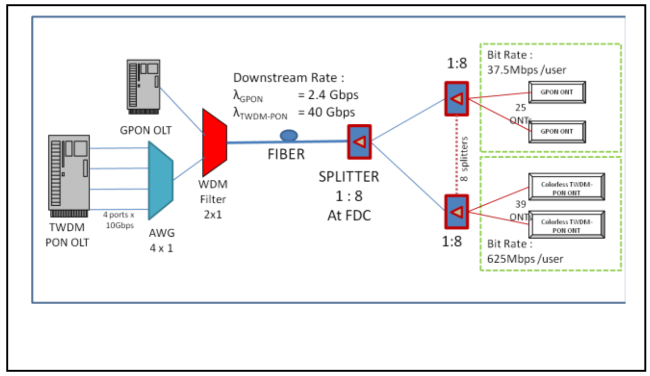


Figure 17 NG-PON2 network deployment architecture for Brownfield scenario

Straight-forward scenario is another way to deploy PON architecture where Telco can remain the existing fiber layout and the passive splitter of GPON system. The other GPON elements like OLT and ONT will be obsolete and being replaced with the new type of OLT and ONTs. Telco may opt this scenario because of the higher cost of maintenance and also higher bandwidth demand from user that need to upgrade the whole infrastructure. Figure 18 illustrate the way to deploy NG-PON1 by adopting Straight-forward scenario.

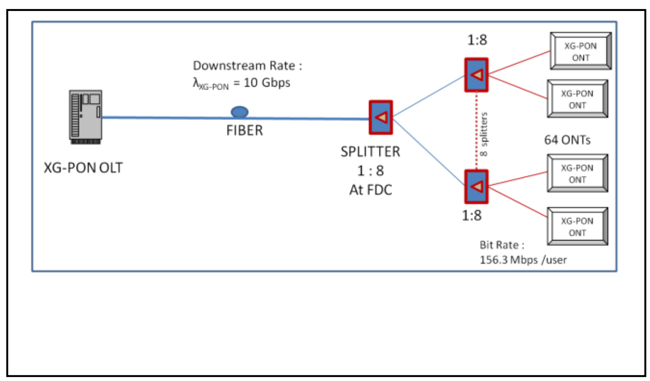


Figure 18 NG-PON1 network deployment architecture for Straight-forward scenario

XG-PON OLT and XG-PON ONT will totally replace the GPON system in this NG- PON1 deployment architecture as in the Figure 18. WDM filter is not applicable anymore because there is no need to coexist with GPON system. Each XG-PON wavelength will carry 10Gbps download bandwidth and be splitted by using the same passive splitter as in the GPON system. Here, every 320 residence will enjoy download bandwidth rate of 156.3Mbps.

In addition, Figure 19 illustrating the NG-PON2 deployment architecture by adopting Straight-forward scenario. The NG-PON2 OLT which is the TWDM PON OLT and colorless TWDM-PON ONTs will replace GPON OLT and ONTs. Total bandwidth of 40Gbps from 4 PON port interfaces of 10Gbps each, is being given equally to 320 users by using passive splitter. Each user will experience bandwidth of 625Mbps which is good enough to cover every household bandwidth demand.

The CAPEX cost of each PON architecture has been extracted from the result of simulation of every PON network deployment architecture discussed in previous section for Taman Pinggiran Cyber, Selangor by using the proposed CAPEX cost model by Davim and Pinto (2010). The result of CAPEX deployment cost of each deployment architecture has been achieved and compared by adopting both Brownfield and Straight-forward scenario. The next subsection will discuss about the comparison of CAPEX deployment cost of each migration of GPON to NG-PON1 and GPON to NG- PON2 depending on the scenario chosen.

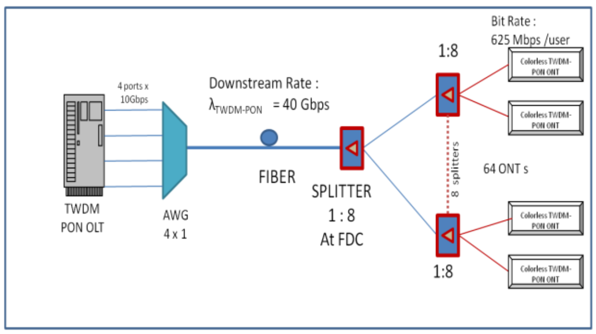


Figure 19 NG-PON1 network deployment architecture for Straight-forward scenario

Figure 20 shows the comparison graph of migration cost from GPON to NG-PON1 and NG-PON2 of Brownfield deployment scenario for Taman Pinggiran Cyber. In this scenario, the CAPEX migration cost increased from GPON to NG-PON1 by 2 times compared to the increase of 3.7 times higher for migration of GPON to NG-PON2. The NG-PON2 cost is higher due to the higher cost of stackable 10Gb PON port interface which contribute half of the whole deployment cost other than the colorless ONT's cost. This result agreed with the other previous study where the equipment deployment incurred 80% of the whole CAPEX cost of FTTH network and the cost of NG-PON1 ONT and OLT is expected to be 3-5 times of GPON ONT and OLT [31]. The CAPEX cost of NG-PON1 deployment in this Brownfield scenario is still can be controlled by the fact that the lower cost of GPON system is still exist. In addition, varies of broadband take up rate also may give variant to the migration cost to NG- PON1 deployment.

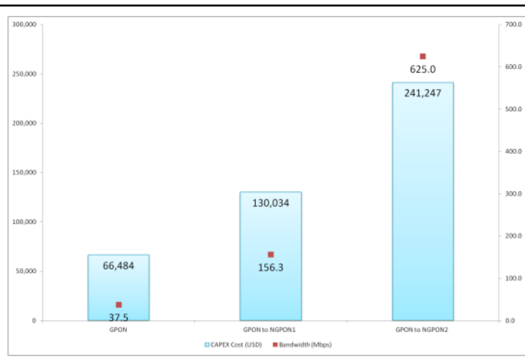


Figure 20 Capex Cost Calculation and Bandwidth per user for Taman Pinggiran Cyber, Selangor

Even though the migration cost to NG-PON2 is so much higher compare to NG-PON1 deployment but its deployment is promising seventeen times higher bandwidth per user. However, the NG-PON1 bandwidth of 156.3Mbps for download bandwidth rate per user is more than enough to cater for home user's needs where home networking technology will only limit the residential service tiers to the 100-200 Mbps range. A 1 Gbps service rate will be possible only for business and power users that have a direct Gigabit Ethernet connection and applications [32]. So, the bandwidth of NG-PON2 of 625Mbps can suitable serve to business and power users rather than home user. This Brownfield scenario deployment will permit Telco to maintain their existing GPON components which are the GPON OLT, passive splitter and Fiber access, thus result in low investment cost.

By maintaining the existing layout of fiber access, the CAPEX cost is still low for migration to NG-PON1 where its only cost the Telco about two and half times compare to NG-PON2, five times more than GPON cost as depicted in Figure 21. NG- PON2 deployment will eventually about double the deployment cost of NG-PON1. The migration cost of NG-PON1 is a bit higher in this straight-forward scenario by USD 40k compared to Brownfield scenario because all the 320 users is totally upgrade to NG-PON1 which give more bandwidth of 156.3Mbps. Same goes with migration to NG-PON2, the Straight-forward deployment cost is higher than adopting Brownfield scenario because of the higher cost of 20 TWDM-PON port interfaces.

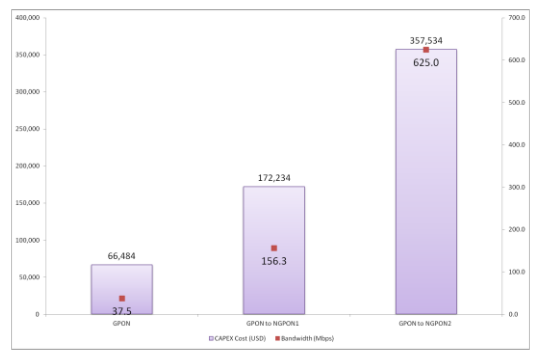


Figure 21 Capex cost calculation and Bandwidth per user for Straight-forward scenario Cyber, Selangor

4.0 CONCLUSION

The empirical results of the current study provide finding that has suggested migration strategy from GPON to NG-PON1 has the lowest CAPEX cost. From the hypothesis declared in methodology, one of the hypotheses is accepted and the other one is rejected. According to the results mentioned and discussed above, the accepted hypothesis is:

RQ1: Which NG-PON system architecture has the lowest CAPEX deployment cost?

- H1 : NG-PON1 has the lowest CAPEX cost

RQ2: How does the different deployment of NG-PON1 and NGPON2 with the different migration scenario will affect the CAPEX deployment cost?

- H2 : Straight-forward scenario affect more CAPEX deployment cost than Brownfield scenario for deployment of NG-PON1
- H3 : Brownfield scenario affect more CAPEX deployment cost than Straight-forward scenario for deployment of NG-PON2.

This research paper has provided findings to achieve its objective of this project are to compare migration strategy from GPON to NG-PON1 with GPON to NG-PON2 in term of CAPEX deployment cost for Telco in Malaysia. From the findings of the study it is found that migration strategy from GPON to NG-PON1 has the lowest CAPEX cost with two ways of deployment. However, migration of GPON to NG-PON2 is still considered high at this few years even though it give higher bandwidth compared with NG-PON1. This study is opening up the research on the migration strategy related with bandwidth demand forecast in Malaysia. TELCO will not need to invest a lot for first time, but the decision to expense in CAPEX can be depend on the take up rate.

Acknowledgement

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