COST AND ENERGY MODEL FOR FIBER-TO-THE-SCHOOL NETWORK

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

The growing demand for broadband access drives the evolution of access networks to fiber-based solutions. School Wi-Fi that is reliable, fast, and secure will empower teachers to maximize their use of the internet in the classroom. As part of its Malaysian Education Blueprint 2013-2025, the Ministry of Education has taken another initiative in order to provide an effective learning experience for Malaysian students. The program aims to give every Malaysian public-school access to high-speed Internet access and a virtual learning environment (VLE). Energy consumption is becoming more important in schools as their network infrastructure expands, not only from an environmental standpoint but also from a capital expenditure perspective. This project proposes an efficient cost and energy model for FTTS. In this study, the focus is on exploring methods for reducing the power consumption and cost expenditure of a fiber-to-the-school access network, in order to reduce the network's footprints and encourage green networking. The energy consumption and cost of an optical access network was modelled using MATLAB software. The developed model was used to evaluate the cost and energy efficiency. Based on the results, an energy and cost-effective solution for fiber-to-the-School access networks were proposed. It has been observed that FTTS Scenario 1 has the least initial capital expenditure when compared to Scenario 2 and 3. In energy consumption, it is been discovered on FTTS through scenario two (Active state) with energy-saving approach when there is traffic across the network will save approximately 34 %.

ABSTRAK

Permintaan yang semakin meningkat untuk akses jalur lebar memacu evolusi rangkaian capaian kepada penyelesaian berasaskan gentian. Wi-Fi sekolah yang boleh dipercayai, pantas dan selamat akan memperkasakan guru untuk memaksimumkan penggunaan internet mereka di dalam bilik darjah. Sebagai sebahagian daripada Pelan Pembangunan Pendidikan Malaysia 2013-2025, Kementerian Pendidikan telah mengambil satu lagi inisiatif untuk menyediakan pengalaman pembelajaran yang berkesan untuk pelajar Malaysia. Program ini bertujuan untuk memberi setiap sekolah awam Malaysia akses kepada akses Internet berkelajuan tinggi dan persekitaran pembelajaran maya (VLE). Penggunaan tenaga menjadi lebih penting di sekolah apabila infrastruktur rangkaian mereka berkembang, bukan sahaja dari sudut alam sekitar tetapi juga dari perspektif perbelanjaan modal. Projek ini mencadangkan model kos dan tenaga yang cekap untuk FTTS. Dalam kajian ini, tumpuan adalah untuk meneroka kaedah untuk mengurangkan penggunaan kuasa dan perbelanjaan kos rangkaian akses gentian ke sekolah, untuk mengurangkan jejak rangkaian dan menggalakkan rangkaian hijau. Penggunaan tenaga dan kos rangkaian capaian optik telah dimodelkan menggunakan perisian MATLAB. Model yang dibangunkan telah digunakan untuk menilai kecekapan kos dan tenaga. Berdasarkan keputusan, penyelesaian tenaga dan kos efektif untuk rangkaian akses fiber-to-the-School telah dicadangkan. Telah diperhatikan bahawa Senario FTTS 1 mempunyai perbelanjaan modal permulaan yang paling sedikit jika dibandingkan dengan Senario 2 dan 3. Dalam penggunaan tenaga, ia ditemui pada FTTS melalui senario dua (keadaan aktif) dengan pendekatan penjimatan tenaga apabila terdapat trafik merentasi rangkaian akan menjimatkan kira-kira 34%.

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LIST OF ABBREVIATIONS

CO	-	Central Office
PON	-	Passive Optical Networks
NG	-	Next-Generation
OLT	-	Optical line termination
ONT	-	Optical Network Terminal
ONU	-	Optical network unit
UTM	-	Universiti Teknologi Malaysia
BER	-	Bit error rate
EPON	-	Ethernet passive optical network
GPON	-	Gigabit Passive Optical Network
FTTH	-	Fiber to the home
FTTS	-	Fiber to the School
QoS	-	Quality of service
AP	-	Access Point
WR	-	Wireless Router
LTE	-	Long Term Evolution
BS	-	Base Station
Wi-MAX	-	Worldwide Interoperability for Microwave Access
LAN	-	Local Area Network
LED	-	Light Emitting Diode
WAP	-	Wireless Application Protocol
P2P	-	Point-to-Point fibers
IOWA	-	Integrated Optical Wireless Access
MAC	-	Media Access Control
RoF	-	Radio over Fibre
EN	-	Edge-node
ODN	-	Optical distribution network
DSLAM	-	Digital subscriber line access multiplexer

LIST OF SYMBOLS

C_e^{ONU}	-	Cost of Optical Network Unit equipment per unit
N_{ONU}	-	Total number of ONUs
$T_i^{ONU\ \&\ AP}$	-	Total cost ONU's and Access Point installation
Pa	-	Price of AM (Access Modules)
C_i^{ONU}	-	Cost of ONU installation per unit
N_{ONU}	-	Number new ON
C_i^{AP}	-	Cost of AP installation per unit and number new APs.
C_d	-	Costs of drop plant
C_m^F	-	Cost optical fiber/m
L_d^{CBL}	-	Length of new cable in drop plant per meter
P_{ONU}	-	Power consumption of ONU
P_{FTTS}^{Cons}	-	Power consumption of fiber-to-the-school
P_{AP}	-	Power consumption of access point
N_{AP}	-	Number of access points
P_{WR}	-	Power consumption of Wireless router
N_{WR}	-	Number of wireless routers

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CHAPTER 1

INTRODUCTION

1.1 Project Background

In recent years, cost and energy consumption have become important efficiency metrics for communication networks. There is an increasing demand for energy services to facilitate economic and social development, improve health, and enhance living conditions. All countries need energy services to provide essential services (communications, lighting, mobility, etc.) and to strengthen production activities. According to estimates, the rate of growth of ICTs is about 6 to 9% per year of global electricity consumption (the share could grow to 20% in 2030 with the world's carbon footprint estimated at 2.7%) [1].

Network architecture is composed of three major segments: backbone/core, metro, and regional networks, and access networks. The metro segment connects the two major access networks and core. In the optical network system, the access network connects the Central Office (CO) to end-users and therefore represents the final segment of the link. This network carries varying amounts of data traffic, and this amount of traffic is increasing every day. Consequently, modern network architectures require mechanisms that address the challenges associated with large volumes of traffic. The transport plane has developed differently in each segment of the network (core, metro, access). Combining optical and wireless networks offers a good option for addressing this challenge since they complement each other in terms of high capacity and device mobility [2].

Passive Optical Networks (PONs) have gained a lot of interest from academics because they're a great way to get low-cost broadband. Optical technology's large capacity seems to be a good option for transmitting large amounts of data. The extension of network access and the augmentation of the data rate network, however, are likely to result in an increase in power consumption. Modern transmission

networks have increased power usage from 0.4 percent to 1% of global consumption [2].

As oil prices rise and people become more aware of climate change, energy conservation will become a more critical aspect to consider when comparing the operational costs and carbon footprint of various NG-PON2 technologies [3]. Optical access systems can be broadly used in access networks in the future because they give high bandwidth and good quality of service (QoS). The use of wireless technology in the endmost section of the access network is becoming increasingly relevant as a result of consumer demand for mobility. As a result, it is becoming increasingly necessary to integrate optical and wireless networks [4].

1.2 Problem Statement

Developing interest in fast-speed internet is the essential driver for the new access technologies which empower encountering genuine broadband. It drives telecom administrators to truly consider the high-volume carry-out of optical-fiber-based access networks. The increasing interest in fast internet drives businesses to seriously consider the roll-out of optical-fiber-based access networks. It is the fundamental driver of new access technologies that facilitate accessing true broadband [5].

The access networks are becoming a bottleneck when it comes to data transfer capacity. Optical access technology will be generally used on access networks in the future as it offers big bandwidth and good quality of service (QoS). Mobility is additionally a significant client interest; consequently, it is getting more important for utilizing wireless networks in the last section of the access network. Subsequently, the integration of optical and wireless networks is getting more significant. Simultaneously, there is a developing interest in lessening the energy utilization and the related expense of the access network.

However, since access networks are the largest contributor to network-related electricity usage, network power consumption requires special attention. In recent

years, energy and cost usage has become a major efficiency measure for communication systems. Because of the need to increase processing speed, bandwidth consumption, and transmission rate, this is the case. The concurrently rising cost of electrical energy could result in unacceptably high energy budgets for telecommunications companies, as well as a significant negative effect on environmental sustainability.

The main goal of this study is to look at methods to assess Fiber-to-the-school (FTTS) initial investment. Meanwhile, to find a way for energy conservation in Fiber-to-the-school optical access networks so, that costs and power usage can be minimized effectively. As a result, energy efficiency has emerged as an important factor for service and network providers to consider, due to the operating costs associated with energy consumption as well as increased knowledge of global warming and climate change [6].

1.3 Research Objectives

i. To model the cost and energy of the Fiber-to-the-school network.
ii. To propose an energy-saving approach for FTTS to reduce energy consumption.
iii. To analyze the cost associated with FTTS and compare the energy consumption of FTTS with and without an energy-saving mechanism.

1.4 Research Questions

i What are the different types of PON (Passive Optical Networks)?
ii How does the increasing traffic affect FTTS cost and energy consumption?
iii How to reduce Cost and Energy for FTTS Optical-Wireless Access Network?

1.5 Scope of the study

The scope of this study is as indicated below:

i Determining the network function that relates to the required Fibre-to-the-school PON

First, to study, analyse and design fibre-to-the-school aerial Passive Optical Network (FTTS PON) system specification and basic elements which are Optical Network Terminal (ONT/ONU) whereby it is connected to the fibre distribution point according to the project architecture, while, Access Point (AP) and three Wireless Router (WR) components are located at the end-user location. All transmission in a PON-based FTTH is performed between an Optical Line Terminal (OLT) and optical network units (ONUs).

ii Cost modelling for FTTS integrated optical network.

To model Fiber-to-the-school passive optical network initial cost investment, an analytical model was used in terms of FTTS capital expenditure of an optical-wireless access network.

iii Energy consumption modelling for FTTS integrated optical network.

Using MATLAB software simulation, the efficiency of the aerial Fibre-to-the-school optical access network was investigated, to propose an energy-saving approach to reduce power consumption. Evaluation of network performance in terms of power consumption with various scenarios will be used to compare energy performance with and without an energy-saving approach

1.6 Significance of the study

As internet usage is increasing day after day it is resulting in an increase in capital expenditure of optical access networks this model would also propose a cost-cutting strategy.

To propose a reference model for the research of cost expenditure and power consumption in fiber-to-the-school architecture. In this project, we proposed a simple cost and power consumption modeling as well as a possible approach for the optimized fiber-to-the-school Passive Optical Network to minimize power consumption and provide a more energy-efficient network.

Meanwhile, carbon emissions contribute to the greenhouse effect, which is caused by power machines burning fossil fuels and results in global warming, the atmosphere is a significant factor in human life. As a result, the harmful environmental and public health impacts of an interconnected access network are decreased.

1.7 Project Plan

Project planning is performed by allocating tasks to be performed within the given period of time. Careful planning is important to ensure the perfect execution of this project and to meet the requirement. A Gantt map has been drawn that consists of many milestone events and project tasks to distribute the time in the right way.

Table 1.1 Gantt Chart

Activities	Year 2021							Year 2022	
	March	April	May	June	Oct.	Nov.	Dec.	Jan.	Feb.
Study Latest technologies		(i)							
Development of Model			(ii)						
Simulation and Results				(iii)		(iv)			
Validation							(v)		
Seminar material								(vi)	
Report submission									(vii)

Milestones	
(i)	Completion of literature review. -Synopsis.
(ii)	Completion of Model - Seminar Material
(iii)	Model analysis - Proposal Presentation and Report Submission
(iv)	Implementation of Model in Simulation- Interim Report
(v)	Validation
(vi)	Seminar Material Preparation and Presentation
(vii)	Thesis Report Submission

1.8 Thesis Outline

This study is composed of five chapters, which are organized as follows:

Chapter 1 discusses a brief introduction to the description and classification of metropolitan area networks are presented, as well as some architectures of metropolitan area networks. This article looks at modern telecommunication networks, optical access networks, and their infrastructure as well as their evolution. The evolution of optical networks, project background, problem statement, research objectives, the scope of the research, and the significance of the study are discussed.

Chapter 2 discusses the literature review on the study of this project. It will introduce the PON optical access network and architecture related to previous researchers published. Finally, some analytical and simulation models from the previous research are discussed.

In Chapter 3, the project flow of this project is discussed. This chapter discusses the methodology used in this project.

- ❖ The first part proposes a cost model for a fiber-to-the-school (FTTS) network.
- ❖ The second part suggests energy consumption modeling for a fiber-to-the-school (FTTS) network.

Chapter 4, shows simulation results obtained from chapter 3 in a graphical format, results in analysis, and discussion. The discussions are divided into FTTS related cost expenditure analysis. And a comparison of energy consumption of fiber-to-the-school (FTTS) network with energy-saving approach was obtained from the chapter three methodology.

Chapter 5, provides a concise conclusion regarding how much energy could be saved and certain mechanisms to do so. On the other hand, the second part will be discussed future works which will recommend parts that need additional works that could be done in the future to improve cost and energy-saving approaches. The final section will be references that have been cited throughout this project work.

REFERENCES

[1] Bassem Kahouli, AmineNafla, HatemTrimeche, OmarKahouli, understanding how information and communication technologies enhance electric power consumption and break environmental damage to reach sustainable development, Energy, and Buildings, Volume: 255,2022.

[2] Glenda Zafir Gonzalez Diaz "Energy saving solutions for integrated optical-wireless access networks", Paris 8 Dec 2015.

[3] S. Lambert et al., "Power consumption evaluation for next-generation passive optical networks," 2013 24th Tyrrhenian International Workshop on Digital Communications - Green ICT (TIWDC), 2013, pp. 1-4.

[4] Leonid G. Kazovsky 1, Fellow, IEEE, Tolga Ayhan 1, Moises R. N. Ribeiro 1,2, Dora van Veen 3, "Energy Efficient Optical-Wireless Residential Access/In-House Networks", ICTON 2011.

[5] K. Borzycki, "FTTx Access Networks: Technical Developments and Standardization" Submitted: June 26th 2017Reviewed: October 19th 2017Published: December 20th 2017, DOI: 10.5772/intechopen.71785.

[6] A. Ramli1, M. A. Wong2, N. Zulkifli1 and S. M. Idrus1," Integrated Optical and wireless access networks", Lightwave Communications Research Group, Innovative Engineering Research Alliance, Universiti Teknologi Malaysia, UTM Johor Bahru, Johor, Malaysia, 8, OCTOBER 2015.

[7] Kun Wang, Anders Gavler, Manxing Du, Christina Lagerstedt, Maria Kihl "Power Consumption Analysis of Energy-aware FTTH Networks", Dept. Network and Transmission Lab Acreo Swedish ICT Kista, Sweden and Dept. Electrical and Information Technology Lund University Lund, Sweden, 2015.

[8] C. Lange and A. Gladisch, "Energy Efficiency Limits of Load Adaptive Networks," in Optical Fiber Communication Conference, OSA Technical Digest (CD) (Optical Society of America, 2010), paper OWY2.

[9] Daniel C. Kilper, Gary Atkinson, Steven K. Korotky, Fellow, IEEE, Suresh Goyal, Peter Vetter, Dusan Suvakovic, and Oliver Blume, Member, "Power Trends in Communication Networks", IEEE JOURNAL of selected topics in quantum electronics, vol. 17, no. 2, March/April 2011.

[10] C. Bock, T. Quinlan, M. P. Thakur and S. D. Walker, "Integrated Optical Wireless Access: Advanced topologies for future access networks," 2009 11th International Conference on Transparent Optical Networks, 2009.

[11] V. G. Transmission, W. Lanneer, S. Member, and P. Tsiaflakis, "Linear and Nonlinear Precoding Based Dynamic Spectrum Management for Downstream," vol. 65, no. 3, pp. 1247–1259, 2017.

[12] M Milosavljevic, P Kourtessis† and J M Senior, "Integrated Wireless Optical Networking", University of Hertfordshire, all content following this page was uploaded by H.T. Mouftah on 25 October 2017.

[13] A. Ramli1, N. Zulkifli2, S. M. Idrus3 "Power Consumption Modeling and Analysis of Integrated Optical-Wireless Access Network", Universiti Teknologi Malaysia, Johor, Malaysia, Vol. 7, No. 6, December 2017, pp. 3475~3483.

[14] Prachi Sharma, Suraj Pardeshi, Rohit Kumar Arora, Mandeep Singh "A Review of the Development in the Field of Fiber Optic Communication Systems", Certified Journal, Volume 3, Issue 5, May 2013.

[15] C. Gray, R. Ayre, K. Hinton, and R. S. Tucker, "Power consumption of IoT access network technologies," 2015 IEEE Int. Conf. Commun. Work. ICCW 2015, pp. 2818–2823, 2015.

[16] Y. Yan et al., "Energy Management Mechanism for Ethernet Passive Optical Networks (EPONs)," 2010 IEEE International Conference on Communications, Cape Town, South Africa, 2010, pp. 1-5.

[17] Deepak Sharma, Payal Arora, Suresh Kumar “Q Factor-Based Performance Evaluation of Bidirectional TDM PON Network Using Hybrid Amplifier Configurations”, in international journal of computer sciences and engineering, May 2018.

[18] Vinita, Khosia " A Comprehensive Review of Recent Advancement in Optical Communication Networks", International Journal of Computer Sciences and Engineering, Vol.-6, Issue-9, Sept. 2018.

[19] Juan Salvador Asensi Pla, "Design of Passive Optical Network", Brno University of Technology, Faculty of Electrical Engineering and communication, department of telecommunications, Brno, Czech Republic, May 2011.

[20] A. Ebrahim, “performance-enhancing interference management techniques for future cellular systems,”2016.

[21] Mohamed Elmagzoub Abdalla Zeinelabdin, "Comparison Study of Next-Generation FTTH PON architectures", Faculty of Electrical Engineering, Universiti Teknologi Malaysia, january 2012.

[22] S. Biswas and S. Adak, “OFDMA- PON: High Speed PON Access System,” Int. J. Soft Comput. Eng., vol. 1, no. 5, pp. 292–297, 2011.

[23] Hudda Abbas and Mark A. Gregory, “The next generation of passive optical networks: A review,” Journal Netw. Comput. Appl., vol. 67, no. March 2016, pp. 53– 74, 2016.

[24] C. Zukowski, A. Mukhopadhyay, D. B. Payne and M. Ruffini, "Cost analysis of rural roll-out using a long-reach passive optical network: trading off the upfront cost under uncertainty of the user take-up rate," in Journal of Optical Communications and Networking, vol. 13, no. 5, pp. 69-84, May 2021.

[25] K. Khairi, Z. A. Manaf, M. S. Salleh, M. N. A. Rahman, Z. Hamzah and R. Mohamad, "The first Fiber-To-The-School deployment in Malaysia," International Conference on Photonics 2010, 2010, pp. 1-5.

[26] Ahsan, N. S., Salleh, M. S., & Abdullah, F. (2014). Migration Strategy From Legacy PON System Into Next Generation PON System For Low CAPEX Telco Deployment in Malaysia. Jurnal Teknologi, 69(3). https://doi.org/10.11113/jt.v69.3141.

[27] Abhishek Dixit, Bart Lannoo, Didier Colle, Mario Pickavet, and Piet Demeester, "ONU power saving modes in next generation optical access networks: progress, efficiency and challenges," Opt. Express 20, B52-B63 (2012).

[28] A. Ramli, N. Zulkifli and S. M. Idrus, "Power Consumption Modeling in Integrated Optical-Wireless Access Network," 2018 IEEE 7th International Conference on Photonics (ICP), 2018, pp. 1-5.

[29] M. T. Hosseinabadi and N. Ansari, "Multi-power-level energy saving management for passive optical networks," in Journal of Optical Communications and Networking, vol. 6, no. 11, pp. 965-973, November 2014.

[30] https://community.fs.com/blog/how-to-design-your-ftth-network-splitting-level-and-ratio.html.

[31] https://support.myrepublic.com.sg/hc/en-us/articles/115003469974-Basic-ONT-Modem-Information-and-Troubleshooting.

[32] Mahmoud Al-Quzwini, "Design and implementation of a Fiber to the Home FTTH access network based on GPON", New Jersey Institute of Technology, March 2014, International Journal of Computer Applications.

[33] https://www.cisco.com/c/en/us/products/wireless/wireless-router.html.

[34] European Commission. "Code of Conduct on Energy Consumption of Broadband Equipment ver. 4.1." (2013).

[35] Wang, Kun, “Power Consumption Analysis of FTTH Networks”, Lund University, 2015, Published in:10th International Conference on Digital Telecommunications.

[36] T. Evens et al., "Value-added services for fibre to the home: Market potential, time horizons and user groups," Proceedings of the International Conference on e-Business, 2011, pp. 1-9.

[37] A.Ramli “Power Consumption Modeling in integrated Optical-wireless access Network”, Universiti Teknologi Malaysia, Doctor of Philosophy (Electrical Engineering), APRIL 2017.

[38] Bolla, Raffaele & Bruschi, Roberto & Davoli, Franco & Ranieri, Andrea. (2009). Energy-Aware Performance Optimization for Next-Generation Green Network Equipment. 49-54. 10.1145/1592631.1592643.

[39] https://www.netgear.com/media/WAX610_tcm148-90787.pdf

[40] https://energyusecalculator.com/electricity_wifirouter.htm#:~:text=Wi%2DFi%20routers%20are%20typically,average%20for%20a%20wireless%20router.

[41] G. Hasslinger, J. Mende, R. Geib, T. Beckhaus, and F. Hartleb, “Measurement and characteristics of aggregated traffic in broadband access networks,” in Managing Traffic Performance in Converged Networks, vol. 4516 of Lecture Notes in Computer Science, pp. 998–1010, Springer-Verlag Berlin Heidelberg, 2007.

[42] M. Kihl, C. Lagerstedt, Å. Aurelius and P. Ödling. "Traffic analysis and characterization of Internet user behavior." Ultra-Modern Telecommunications and Control Systems and Workshops (ICUMT), 2010 International Congress on. IEEE, 2010.