TRAFFIC AWARE ROUTING ALGORITHMS FOR ENERGY EFFICIENT OPTICAL-WIRELESS ACCESS NETWORKS

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DEDICATION

It is dedicated to my father, who has taught me the meaning of will and wisdom, and has always inspired me to challenge myself. It is also dedicated to my mother, who has always believed in me and has motivated me to believe in myself.

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ABSTRACT

Next generation communication networks will bring forth technologies that will integrate optical-wireless systems, these networks are expected to deliver huge potential bandwidth and increase the energy consumption. Therefore, efficient utilization of bandwidth and effective reduction of energy consumption is being considered and evaluated with every possible solution. The objective of this project is to propose algorithms that will perform real-time bandwidth and wavelength allocation while assuring quality of service, for integrated optical-wireless access networks. The solution is based on the analysis of traffic request and polling cycles in Next Generation-Passive Optical Network (NG-PON2). The approach has several notable merits, for instance better utilization of available resources, delay constrained network, and increased energy efficiency. The methodology adapted in this work is to divide the algorithm in three phases and assign tasks accordingly. A comprehensive verification using Matlab, has been be carried out to determine the effectiveness of the concept. The simulation and performance is evaluated in optical line terminal (OLT) and optical network unit (ONU), for Time and Wavelength Division Multiplexing (TWDM-PON) architectures. The expected goal was to improve energy consumption in access networks, and it was observed from calculations that, energy efficiency as high as 27% at each ONU and 50% at the OLT could be achieved using routing algorithms. Hence, greener and energy efficient converged optical-wireless system can be introduced in next generation access networks.

ABSTRAK

Rangkaian komunikasi generasi akan datang akan mengenalkan teknologi yang akan menyepadukan sistem tanpa wayar dan optik, rangkaian ini dijangka menyediakan lebar jalur dengan potensi yang besar dan ini akan meningkatkan penggunaan tenaga. Oleh itu, penggunaan lebar jalur dan pengurangan penggunaan tenaga yang cekap kini dipertimbangkan dan dinilai dengan setiap kemungkinan yang ada. Matlamat projek ini adalah untuk mencadangkan algoritma yang akan melaksanakan peruntukan masa sebenar jalur lebar dan panjang gelombang di samping menjamin kualiti perkhidmatan, untuk rangkaian akses tanpa wayar optik bersepadu. Penyelesaiannya adalah berdasarkan kepada analisis permintaan trafik dan kitaran pengundian dalam Rangkaian Optik Pasif Generasi Akan Datang (NG-PON2). Pendekatan ini mempunyai beberapa merit yang nyata, contohnya penggunaan lebih baik untuk sumber tersedia, kekangan kelewatan rangkaian, dan peningkatan kecekapan tenaga. Metodologi yang diadaptasi di dalam kerja ini adalah untuk membahagikan algoritma kepada tiga fasa dan memberikan setiap fasa tugasan yang sewajarnya. Pengesahan komprehensif menggunakan Matlab telah dijalankan untuk menentukan keberkesanan konsep ini. Simulasi dan prestasi dinilai dalam terminal talian optik (OLT) dan unit rangkaian optik (ONU), untuk seni bina Pembahagian Pemultipleksan Masa dan Panjang Gelombang (TWDM-PON). Matlamat yang diharapkan adalah untuk memperbaiki penggunaan tenaga dalam rangkaian akses, dan ianya diperhatikan daripada pengiraan, bahawa kecekapan tenaga setinggi 27% pada setiap ONU dan 50% pada OLT boleh dicapai dengan menggunakan algoritma penghalaan. Oleh itu, sistem tanpa wayar optik yang lebih hijau dan cekap dapat diperkenalkan dalam rangkaian akses generasi akan datang.

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LIST OF ABBREVIATIONS

BBU	-	Baseband Unit
CO	-	Central Office
CPRI	-	Common Public Radio Interface
DWBA	-	Dynamic Wavelength and Bandwidth Allocation
ENB’s	-	Evolved Node B’s
FTTB	-	Fiber to the Business
FTTH	-	Fiber To The Home
GHG	-	Green House Gases
IOT	-	Internet of things
VOIP	-	Voice Over IP
MAC	-	Medium Access Control
MSC	-	Mobile Switching Centre
NGPON-2	-	Next Generation-Passive Optical Network
ODN	-	Optical Distribution Network
OLT	-	Optical Line Terminal
ONT	-	Optical Network terminal
ONU	-	Optical Network Unit
PON	-	Passive Optical Networks
QoS	-	Quality of Service
RRH	-	Remote Radio Head
TWDM	-	Time and Wavelength Division Multiplexing
TSA	-	Time slot Assignments
VCSEL	-	Vertical Cavity Surface emitting Lasers
WMA	-	Wavelength Minimization Assignment

LIST OF SYMBOLS

λ_N	-	Number of active wavelengths
λ_T	-	Total Wavelengths
η	-	Energy Saving Coefficient for ONU
α	-	Energy Saving Coefficient for OLT
BW_{AVG}	-	Average Bandwidth
BW_{LIM}	-	Bandwidths Limit
$BW_{CONGESTION}$	-	Congestion Bandwidth
$BW_{GRANTED}$	-	Granted Bandwidth
D_{AVG}	-	Average Delay
D_{CNS}	-	Constrained Delay
$Mode_{DOZE}$	-	Doze mode
$Mode_{SLEEP}$	-	Sleep Mode
E_{ONU}	-	Single ONU
$Energy_{eac\,h\_cycle}$	-	Energy Each Cycle
N_c	-	Number of Cycles
$Power_{active}$	-	Active Power
$Power_{Doze}$	-	Doze Power
$Power_{active\ \_OLT}$	-	OLT Active Power
R_{ONU}	-	Request of each ONU
TBW_{REQ}	-	Total Bandwidth Requested
$Time_{poll}$	-	Polling Time
$Time_{prc}$	-	Processing Time
$Time_{Poll\_max}$	-	Maximum Polling Time
$Time_{roundtrip}$	-	Round-trip Time
$Time_{active}$	-	Active Time
$Time_{Doze}$	-	Doze Time
$Time_{Sleep}$	-	Sleep Time

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CHAPTER 1

INTRODUCTION

1.1 Project Background

5G networks are expected to bring forward a new era of communication protocols that will be able to deliver voice over IP (VOIP), support Internet of things (IOT) devices, do remote monitoring, deliver real time output, and be able to perform machine to machine communication and several other operations that are still unforeseen. As such the demand for bandwidth has been predicted to increase exponentially by 2020 and it has been forecasted that over 50 billion devices will be connected to the internet. All operations of such networks needs to be done with the least possible latency and to execute above mentioned operations in the wireless network nodes, only optical infrastructures can offer the ability to ensure optimum performance [1].

It is therefore inevitable that the most promising candidate for next generation access networks are integrated optical-wireless systems. Because of its ability to offer high capacity and support desired quality of service with reduced latency for real time communication, also permitting mobility which is one of the crucial factor for ubiquitous networks. As such the available bandwidth required by these networks is not very redundant, and power consumption of these access networks is also expected to increase the total power consumption of the entire planet which is already 4%, thus increasing the cost of maintenance with increased emission of carbon dioxide which is already 2% of the total emission [2] .

Therefore, a network, that will be able to predict the required bandwidth based on the dimensioning of network request, has the potential to allocate required bandwidth with better efficiency and improve the power consumption, hence reducing the emission of Green House Gases (GHG). The purpose of the project is to

develop greener and more efficient access network, by introducing algorithms that can perform bandwidth allocation, and it will be done according to upload traffic request and polling mechanism. The design, simulation and performance will be evaluated for Time and Wavelength Division Multiplexing (TWDM) architectures based on the standard [3] of Next Generation-Passive Optical Network (NG-PON2), which supports Fibre to the home (FTTH), Fibre to the Business (FTTB) and wireless access network simultaneously. The expected goal is to prove that reduction of power consumption using the algorithm, by efficiently routing bandwidth, is possible in these access networks.

1.2 Problem Statement

The next generation integrated optical-wireless access networks will have complicated network architecture, maintenance in terms of manually routing traffic and monitoring will be very difficult as the network will always be required to ensure Quality of Service (QOS). The execution of these operations will result in huge power consumption and increased emission of Green House Gases (GHG). It is therefore imperative to look into the possibilities for every alternative to improve energy efficiency.

The potential to improve energy efficiency, is still being explored, the network nodes will consume power even when they are idle and will not have proper utilization and it has been proposed that introducing a technique called a sleep/doze mechanism will sufficiently reduce power consumption. Consequently, if bandwidth allocations are done according to demand of network, a better utilization of this resource is expected. Hence, energy efficient algorithms that can perform Dynamic Wavelength and Bandwidth Allocation (DWBA), with the ability to initiate sleep and doze mode while keeping the delay constrained in the network, are thought to be the key factors to propose greener networks. From the above mentioned problems and expected solution, we therefore device the existing theory using algorithms for next generation integrated networks to validate the solution.

1.3 Research Objectives

i. To develop a DWBA routing algorithm that can improve energy efficiency of integrated access network.

ii. To maintain a delay constrained environment and ensure QoS.

iii. To implement the algorithm using Matlab and validate results.

1.4 Scope of Work

The developed algorithm is designed only for TWDM-PON systems in context to standards set by Full Service Access Network (FSAN) and International Telecommunication Union (ITU-T). Hence, it is not backward compatible; therefore previous network architectures will not support the execution of the algorithm.

The execution of the algorithm will be done in simulation with analysis of NGPON2 network architecture that refers to properties of TWDM-PON and Centralized RAN (CRAN). And the algorithm is only designed to operate and do traffic allocations between Optical Network terminal (ONU) and Optical Line Terminal (OLT). The ONU will be connected to Baseband Unit (BBU). Traffic allocation between BBU, Mobile Switching Centre (MSC) and Remote Radio Head (RRH) are beyond the scope of this project.

The inferences made, for the analysis of results, to achieve validation, are taken from journals that evaluate typical performance of NGPON-2 networks. Since real world performance data, to the best of our knowledge, is unavailable due to the fact that such networks are still in research phase.

1.5 Work Schedule

The work plan of the project is illustrated in the research design matrix and then reflected in a Gantt chart with representations of milestones

Table 1.1 Research Design Matrix

Activities	Literature review	Algorithm	Simulation	Validation
Purpose (objective of activity)	To study and understand the current research being conducted for next generation converged Optical-Wireless Access Networks.	To develop and propose an algorithm, based on TWDM architecture, that can do dynamic wavelength and	To test the developed algorithm using software. (Matlab).	To validate the energy efficiency of the algorithm created for the access network by analysis from simulation and results
Time	1 month	2 months	3 months	4 months
Facilities/Tools	Available: Journals, publications, UTM library.	None: Journals on proposed algorithms for TWDM architecture.	Available: Matlab.	Available: Journals, publications, standards set by ITU-T, FSAN and 3GPP, BBF.
Technical Support	To attend MKEL 1333 and MKEL 1473 classes.	To attend lectures with supervisor for development of algorithm.	Attned courses on C++ and algorithm development in Matlob.	Data required for components of the working elements in the network.

Table 1.2 Gantt chart

Activities	Year 2018																	
	March		April		May		June		July		August		Sept.		Oct.		Nov.	
Study Latest technologies		(i)																
Proposed Algorithm						(ii)												
Algorithm development								(iii)										
Algorithm Implementation										(iv)								
Simulation and Validation																		(v)

Milestones	
(i)	Completion of literature review. - Synopsis.
(ii)	Proposal of Algorithm - Seminar Material Submission.
(iii)	Develoment of Algorithm - Presentation and Report Submission
(iv)	Algorithm Implementation- Interim Report
(v)	Simualtion, Validation and Completion of Project - Final Report

1.6 Report Outline

The project report comprises of five chapters which explain the details of the project, its methodology on how to develop the algorithm and its implementation. The results achieved from the simulation are analyzed by calculation and then comparison is made for validation and conclusion. To better understand the work done in this project, an overall summary is done with the help of a V-diagram approach, this diagram summarizes the entire work of the project in simplest terms and the report outline is set according to this summary.

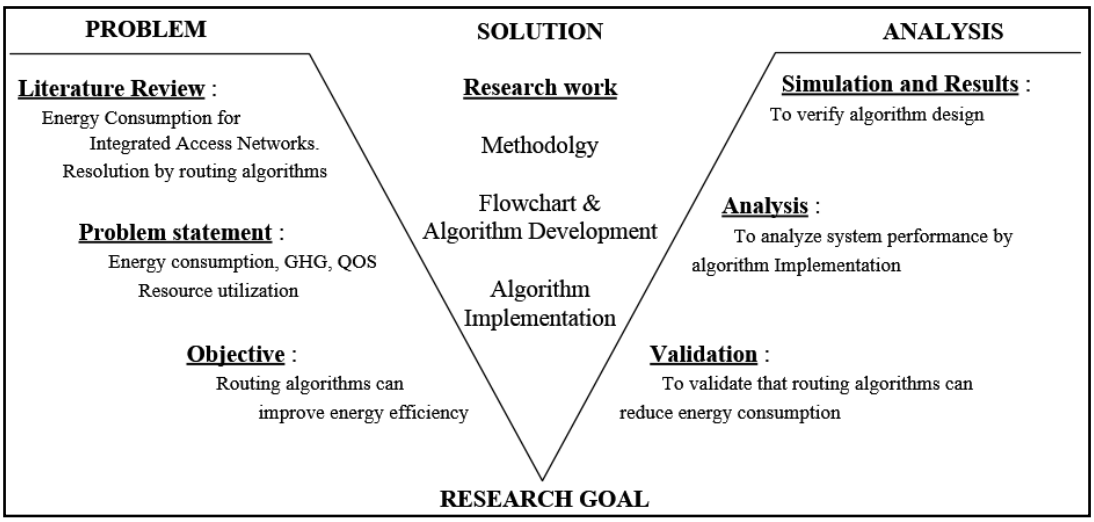

Figure 1.1 V-diagram approach

The first chapter introduces the motivation of the project and an overview with a brief context of next generation access networks. It includes the problem statement, objectives, scope of the project and concludes with the work schedule.

The second chapter explains the literature review done for the study of the project. It contains the next generation optical network and its architecture, the best candidate for future wireless architecture and their integrated optical-wireless infrastructure. The chapter concludes by briefly describing routing algorithms.

The third chapter emphasises on the methodology of the project work flow for the algorithms, contains all the information, protocols and factors required and

considered to model the algorithms and explains the working principle of the algorithms.

The fourth chapter contains the simulation results that were obtained and analysis of the results is done to evaluate the work of routing algorithms by calculation, hence validation of the work of this project is done.

The fifth chapter contains the conclusion and findings, based on the overall work of the project and also provides recommendation for future development of the algorithms, for integrated access networks.

REFERENCES

1. Jahangir Saqlain, "IoT and 5G history evolution and its architecture their compatibility and future.," Metropolia University of Applied Science, Thesis 2018.
2. Ericsson, "Ericsson Energy and Carbon Report," *Results from the first ever Natinal assessment of the environmental impact of ICT*, p. 12, November 2014.
3. ITU-T, "40-Gigabit-capable passive optical networks," *Recommendation ITU-T G.989.1*, vol. 1, p. 26, March 2013.
4. Kyeong Soo Kim, "Integration of OMNeT++ Hybrid TDM/WDM-PON Models into INET Framework," *ICST*, 2011.
5. BBF, "NGPON 2 Track," in *Broadband Success Summit Event*, 2017.
6. BBF, "The first PON standard optimized for service convergence: NG-PON2.," in *Broadband forum NG-PON2 Wallchart*, 2017.
7. Juan Camilo Velásquez Micolta, "Analysis of performances and tolerances of the second generation passive optical networks (NG-PON2) for FTTH systems.," Universitat at Politecnica de Catalunya, Masters Thesis 2014.
8. Ning Cheng, "Flexible TWDM PON system with pluggable optical transceiver modules.," no. OSA, 2014.
9. Denis A. Khotimsky, "NG-PON2 Transmission Convergence Layer: A Tutorial.," *Journal of Lightwave Technology*, vol. VOL. 34, NO. 5, 2016.
10. Sterling Perrin, "Evolving to an open C-RAN architecture for 5g," *A heavy reading white paper produced for Fujitsu.*, no. Heavy Reading, 2017.
11. Olli Vierimaa, "Cost Modeling of Cloud-Based Radio Access Network," Masters Thesis 2017.
12 Matteo Fiorani, "Modeling Energy Performance of C-RAN With Optical Transport in 5G Network Scenarios," *Journal of Optical Communication Networking* , vol. 8, no. 11, 2016.
13. Fujitsu, "Centralized Radio Access Network (C-RAN) Transport," Fujitsu

Application Note , 2017.

14. Nokia, "Evolution to Centralized RAN with mobile front haul," *Technology overview: White Paper*, 2016.

15. et. Al. M. P. I. Dias, "Energy-efficient framework for time and wavelength division multiplexed passive optical networks," *Journal of Optical Communications and Networking*, vol. 7, no. 6, pp. 496–504, 2015.

16. Abdallah Shami Maysam Mirahmadi, "Traffic-prediction-assisted dynamic bandwidth assignment for hybrid optical wireless networks," *Esevier Computer Networks*, no. 44–259, 2012.

17. S. Ou, K. Guild, H Chen, K. Yang, "Convergence of ethernet pon and broadbandaccess networks and its QOS aware dynamic bandwidth allocation scheme," *IEEE journal on selected areas in communications*, vol. 27, no. 2, pp. 101-106, 2009.

18. A. Dixit, B. Lannoo, P. Demeester, and M. Pickavet D. Colle, "Novel DBA algorithm for energy efficiency in TWDM-PONs," in *39th European Conference and Exhibition on Optical Communication (ECOC 2013)*, 2013, pp. 1179–1181.

19. Arnab Mitra, Goutam Das Chayan Bhar, "Constrained Receiver Scheduling in Flexible Time and Wavelength Division Multiplexed Optical Access Networks," *JOURNAL OF LATEX CLASS FILES*, vol. 14, no. 8, AUGUST 2015.

20. Susana Goncalves, *Transceivers for TWDM*.: Universidade de Aveiro, 2014.

21. Erik Haglund, *VCSELs for High-Speed, Long-Reach and Wavelength-Multiplexed Optical Interconnects*. Goteborg, Sweden: Chalmers Univeristy of Technology, 2015.

22. G. Kramer, *Ethernet Passive Optical Network*.: McGraw-Hill, 2005.

23. Timothy G. Smith, *Dynamic Bandwidth Allocations for Extended-Reach Passive Optical Networks*. Melbourne, Australia: The University of Melbourne, 2014.

24. M.Muller, C.A.Chan E.wong, "Energy efficiency of optical network unitswith vertical cavity surface emitting lasers," vol. 20, no. 14, 2012.

25. D.P.van, M.P.I.Dias L.Valcarenghi, "Energy efficient dynamic wavelength and bandwidth allocationalgorithm for TWDM-PON's with tunable VCSEL ONUs," 2014.

26. Maluge Pubuduni Imali Dias and Elaine Wong, *Sleep/doze controlled dynamic*. Melbourne Asutralia: University of Melbourne, 2013, vol. 3010.

27. Seamas McGettrick, Pedro Alvarez, Giuseppe Talli, Giuseppe Talli, Rene Bonk Alan Hill, "Design and Implementation of a Dynamic Badwidth protocol for TWDM-PON, and FPGA based LR-PON OLT ad ONU prototypes," vol. FP7, no. GA318137, 2015.

28. Renuka Bhalerao. (2014, May) rcrwireless.com. [Online]. https://www.rcrwireless.com/20140505/opinion/reader-forum-emergence-c-ran-lte-deployments

29. Adam Kapotvits Marius Corici, *Assessing Satellite terrstrial integration oppurtunities in 5G environment*.: European Space Agency ARTES, September 2016.

30. Matteo Fiorani et. Al., "Modeling Energy Performance of C-RAN With Optical Transport in 5G Network Scenarios," *Journal of Optical Communication Networking* , vol. 8, no. 11, 2016.

31. Ning Cheng et. Al., "Flexible TWDM PON system with pluggable optical transceiver modules.," no. OSA, 2014.

32. M. P. I. Dias et Al., "Bayesian estimation and prediction based dynamic bandwidth allocation algorithm for sleep/doze mode passive optical networks," *J. Lightwave Technology*, vol. 32, no. 14, pp. 2560–2568, 2014.