UNIVERSITI PUTRA MALAYSIA

MULTISERVICE RADIO OVER FIBER SYSTEM USING OPTICAL CARRIER SUPPRESSION AND POLARIZATION MULTIPLEXING METHOD

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By

MOHD HAFIZ BIN MOHAMAD NOR

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

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DEDICATION

This thesis is dedicated to all who contributed and gave tremendous support.

For the breakthroughs and discoveries that have made me humbled by the vast knowledge of the almighty creator.

My parents who taught me to do my part to contribute and share knowledge to the world.

To my friends and colleagues that collectively have taught and shared with me their own expertise towards the convergence of this study.

And to a quote I have lived by towards pushing the limits,
"because it is hard to have ideas and easy to give up".

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

MULTISERVICE RADIO OVER FIBER SYSTEM USING OPTICAL CARRIER SUPPRESSION AND POLARIZATION MULTIPLEXING METHOD

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MOHD HAFIZ BIN MOHAMAD NOR

June 2018

Chair : Associate Prof. Siti Barirah Binti Ahmad Anas, PhD
Faculty : Engineering

Radio over Fiber (RoF) technology, which is a combination of wireless and optical techniques, transports wireless signals over a shared optical infrastructure. Increasing demands for bandwidth and capacity requires huge improvements on RoF systems. Thus, multiservice RoF is the way forward. Existing methods such as wavelength division multiplexing (WDM) is limited by the cost of further deployment while sub-carrier multiplexing (SCM) has intermodulation distortion (IMD) limitations. Therefore, a different approach is needed.

The proposed study shows that two different services can be transmitted using a single wavelength through RoF system with the use of optical carrier suppression (OCS) and polarization multiplexing (PolMux) method. The combination of these two techniques enables multiservice RoF such as long term evolution (LTE) and wireless fidelity (WiFi) services to be transmitted simultaneously at different optical polarization axis at high frequency.

The proposed system measures different scenarios and its performance. Measurements include a polarization reliability test having LTE and WiFi signals at the same frequency. Other measurement includes a back to back test with and without 10 km fiber spool before the Remote Antenna Unit (RAU). Finally, a full setup with wireless transmission at the RAU of 1 m distance is proposed. Results for all setups measured are radio frequency (RF) input power, error vector magnitude (EVM) and optical receive power (ORP). Results obtained show a good reliability performance of polarization multiplexing carrying LTE and WiFi service at each polarization axis through a 10 km single mode fiber (SMF) where a full wireless transmission was then set up transmitting at 1 m wireless distance obtaining EVM for LTE of 4.5% (frequency: 875 MHz) and WiFi of 4.6% (frequency: 200 MHz). The EVM achieved is below the limit at 8% for IEEE 802.11a code rates 2/3 and 3rd generation partnership project (3GPP) for WiFi and LTE, respectively.

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

PELBAGAI PERKHIDMATAN RADIO ATAS GENTIAN OPTIK MENGGUNAKAN KAEDAH CAHAYA PENINDASAN PEMBAWA OPTIK DAN POLARISASI PEMULTIPLEKSAN

Oleh

MOHD HAFIZ BIN MOHAMAD NOR

Jun 2018

Pengerusi : Profesor Madya Siti Barirah Binti Ahmad Anas, PhD
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Tekonologi radio atas gentian optik (RoF) adalah gabungan kaedah tanpa wayar dan optik yang membawa isyarat tanpa wayar melalui infrastruktur optik. Permintaan jalur lebar dan kapasiti yang tinggi memerlukan pada penambahbaikan dalam sistem RoF. Maka, pelbagai perkhidmatan RoF adalah cara untuk maju kehadapan. Kaedah sedia ada seperti pemultipleksan bahagian gelombang (WDM) terhad pada kos yang tinggi untuk pemasangan lanjutan, manakala pemultipleksan sub pembawa (SCM) menghadapi isu herotan antara modulasi (IMD). Maka, pendekatan yang berbeza diperlukan.

Penyelidikan yang dicadangkan menunjukkan bahawa dua perkhidmatan boleh dihantar menggunakan satu jalur gelombang cahaya melalui sistem RoF melalui kaedah penindasan pembawa optik (OCS) dan pemultipleksan pengutuban (PolMux). Gabungan teknik ini membolehkan pelbagai perkhidmatan RoF seperti perkhidmatan evolusi jangka panjang (LTE) dan kesetiaan tanpa wayar (WiFi) dihantar serentak pada paksi polarisasi cahaya yang berbeza dan pada gelombang tinggi.

Sistem yang dicadangkan mengukur pelbagai senario dan prestasinya. Kaedah pengukuran termasuk ujian kebolehpercayaan di mana perkhidmatan WiFi dan LTE pada nilai gelombang yang sama. Kaedah pengukuran lain termasuk ujian belakang ke belakang (BTB) dengan dan tanpa gentian optik 10 km sebelum modul unit antenna jauh (RAU). Akhirnya, pemasangan lengkap termasuk penghantaran tanpa wayar pada jarak 1 m dicadangkan. Keputusan kesemua pemasangan pengukuran termasuk nilai input frekuensi radio (RF), magnitud vector ralat (EVM) dan kuasa optic diterima (ORP). Keputusan yang diperolehi menunjukkan prestasi kebolehpercayaan yang baik bagi pemultipleksan pengutuban yang membawa perkhidmatan LTE dan WiFi pada setiap paksi pengutuban melalui gentian mod tunggal (SMF) sebanyak 10 km dimana penghantaran tanpa wayar lengkap kemudiannya dipasang pada jarak 1 m

menghasilkan EVM untuk LTE sebanyak 4.5% (frekuensi: 875 MHz) dan WiFi sebanyak 4.6% (frekuansi: 200 MHz). EVM yang diperolehi adalah di bawah had ketetapan sebanyak 8% bagi kadar kod IEEE 2/3 802.1a dan projek perkongsian generasi ketiga (3GPP) masing-masing bagi WiFi dan LTE.

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- My colleagues particularly from Connected Mobility Lab (CML) mates in Telekom Research & Development (TM R&D) for their support and help.
- Finally, my thanks extended to all my friends for their direct and indirect help.

I certify that a Thesis Examination Committee has met on 4th June 2018 to conduct the final examination of Mohd Hafiz Bin Mohamad Nor on his thesis entitled ("Multiservice Radio over Fiber System Using Optical Carrier Suppression and Polarization Multiplexing Method") in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

RoF	Radio over Fiber
OCS	Optical Carrier Suppression
PolMux	Polarization Multiplexing
SBS	Stimulated Brillouin Scattering
WDM	Wavelength Division Multiplexing
SCM	Sub-Carrier Multiplexing
PolM	Polarization Modulator
RAU	Remote Antenna Unit
ODU	Outdoor Unit
MZM	Mach Zehnder Modulator
EDFA	Erbium Doped Fiber Amplifier
LO	Local Oscillator
PC	Polarization Controller
PBS	Polarization Beam Splitter
PBC	Polarization Beam Controller
LTE	Long Term Evolution
WiFi	Wireless Fidelity
LNA	Low Noise Amplifier
SMF	Single Mode Fiber

CHAPTER 1

INTRODUCTION

Today's telecommunications have been using the means of wired such as copper and optical and wireless such as long time evolution (LTE) and wireless fidelity (WiFi) architecture. Integration of wireless and optical layers over a shared infrastructure is foreseen as a complimentary solution through Radio over Fiber (RoF) technology. Increasing demand for speed and bandwidth in improving our life standards can be achieved by converging multiple services into the existing optical network. Another growing interest is to solve the last mile transmission to the customer premise without the need to drill holes or lay long cables. Hence, RoF have been closely studied on the possibilities to address the current telecommunication needs and problems.

The research initiatives pertaining these issues have reached a thoughtful stage and it is essential to rationalise future research on this topic in order to make a significant impact on many applications that benefit from solving this problem.

This chapter presents a brief background on the RoF technology where multiservice are adapted carrying different services using a single fiber at a single wavelength. This is then followed by the motivation of the research interests in multiservice RoF technology. This chapter will then present the details of the research problems, research significance, objectives, and the scope of this research. Finally, the organization of the overall thesis will be concluded.

1.1 Background

The increasing integration of communication technology to everyday lives makes it essential to develop newer methods that can use the existing network to elevate the services offered to the customer. RoF technology is an integration of wireless and optical layers that transmits wireless signals over a shared optical infrastructure. The RoF technology compliments the LTE and WiFi infrastructure.

When LTE and WiFi coexist, both networks can benefit by interworking and traffic offloading strategies, as a result directly improving the quality-of-service (QoS). Therefore, both heterogeneous network and network convergence have gained significant attraction, which led to multiservice topologies. Several methods have also tried to accomplish multiservice RoF such as wavelength division multiplexing (WDM) and sub-carrier multiplexing (SCM) technique.

This research proposes a more commercial favourable system with high radio frequency (RF) flexibility by combining optical carrier suppression (OCS) with polarization multiplexing (PolMux) techniques. By applying this solution, the benefits are fourfold, namely various services such as LTE and WiFi can be modulated onto an RoF system and transmitted over a single optical fiber with minimal interference and high frequency RF components can be eliminated. OCS has the flexible tuning ability to any range of frequencies provided that sufficient input is set.

Figure 1.1 illustrates the helicopter view of the proposed system depicting an actual deployment of both WiFi and LTE services over RoF technology. The WiFi signal is modulated on X-polarization axis and the LTE signal on Y-polarization axis. Both signals are carried through OCS carrier and transmitted wirelessly to a receiving point at the customer premise. The outdoor transmission is carried out at high frequency (25 to 26 GHz), and once received at the customer premise via outdoor unit (ODU), the frequencies of the signals are down converted according to the available spectrum licenses.

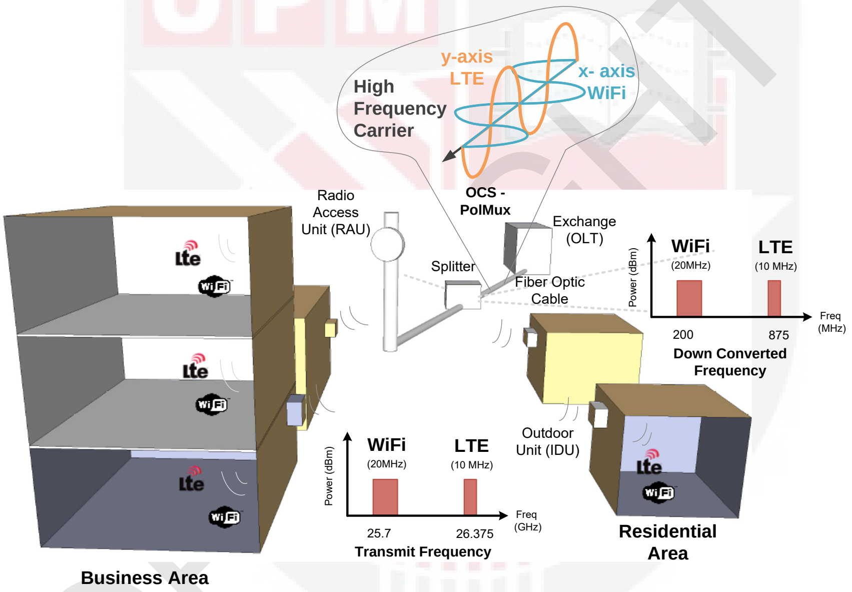

Figure 1.1: RoF multiservice technology using OCS-PolMux method transmitted at the OLT where LTE and WiFi is modulated and carried at high frequency.

1.2 Motivation and Importance of the Research

Bandwidth is certainly in high demand which is exponentially increasing following the coming years. Cisco Visual Networking Index (VNI) forecast shows the usage per month as in Figure 1.2. Compounded annual growth rate (CAGR) measures the forecast growth over the year 2016 to 2021.

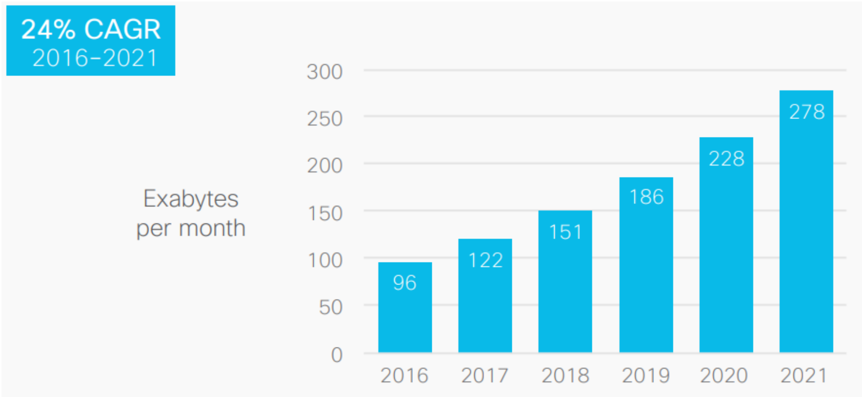

Figure 1.2: Forecasts Exabytes per Month of IP traffic (Cisco VNI Global IP Traffic)

The usage of traffic such as file sharing, online gaming, video conferencing and live streaming will continue to increase as in Figure 1.3. A high increase in traffic is also associated with gaming downloads. Newer console release such as from Xbox and PlayStation has higher storage which enable gamers to download very high definition games.

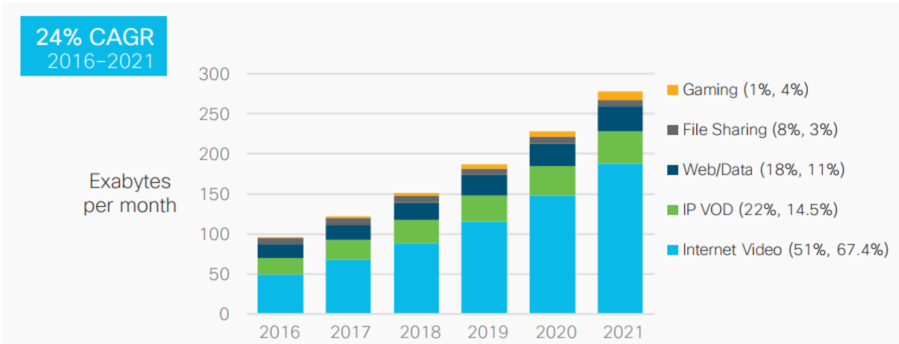

Figure 1.3: Global IP traffic by application category (Cisco VNI Global IP Traffic)

The Internet of Thing (IoT) phenomenon, where people interact with devices connected to the internet, is showing tangible growth. Globally, mobile phones continue to be the largest category of connected devices. Eventually, they are expected to be surpassed by IoT, which includes connected wearable, transports, monitoring, machines and consumer electronics.

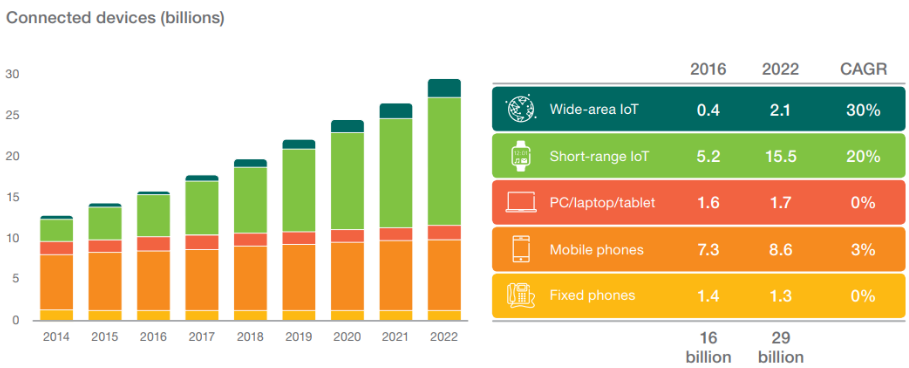

Figure 1.4: Connected devices (Ericsson Mobility Report June 2017)

Figure 1.4illustrates the statistics of connected devices by the Ericsson Mobility Report June 2017. IoT devices are expected to increase at a CAGR towards 2022. In total, around 29 billion connected devices are forecasted by 2022, of which close to 18 billion will be related to wide and short range IoT.

Multiservice RoF plays a great role in upholding the needs of increase in bandwidth. The existing PON network has big potential to grow by converging services such as LTE and WiFi onto an optical network while transmitting wirelessly at the last mile. Installation costs can be pushed down by having an integrated network rather than a separate network. The system offers the bandwidth from both services especially in the near future standards that are adapting to the needs of IoT. Having both services compliments, each other and balances the traffic load. However, the performance parameters need to be measured for reliability and effectiveness.

1.3 Problem Statement

As explained in the previous section, bandwidth is vital to the increase of usage in the near future. A reliable and competent system to cater the needs must be addressed.

Multiservice in RoF technology is an important key to this research which addresses the possibilities of such a system. However, the method towards achieving it has become a prominent subject in the field. Prior works thus far have used WDM and SCM methods to increase bandwidth and services. The WDM method is practically used, however due to high cost of further deployment and maintenance, a solution to compliment and elevate its existing usage is prominent. As for the SCM method, it has been reported on issues due to non-linearity causing intermodulation distortion (IMD). However, the PolMux method makes the usage of polarization properties of light to modulate different signals at different polarization axes of X and Y. Hence, multiplexing is achieved using a single fiber at a single wavelength. Furthermore, it can add value to both WDM and SCM methods.

In order for a transmission to travel smoothly, the carrier must be well designed. Previous works to generate optical carrier generation have been reported. For instance, dual side band (DSB) method combines two lasers with different wavelengths and Stimulated Brillouin Scattering (SBS) which uses non-linear properties of the fiber. However, disadvantages arise for these methods such as producing high phase noise and having a bulky fiber spool for non-linearity purposes. OCS is a well-known method to generate high frequency carrier in the optical domain with half the required frequency, yielding also a very low phase noise for stability. Thus, low frequency off the shelf RF components can generate stable high frequency carriers at lower price.

For any wireless transmission, regulatory bodies will be setting the spectrum license. To follow the awarded spectrum requirements, problems will emerge for using methods that are rigid to adopt. The OCS- PolMux method is the most attractive to this demand. OCS itself is a flexible tunable source for a range of frequencies. Moreover, the combination of both methods, generates sideband frequencies in respect to the carrier, giving filtering options to the intended frequency spectrum.

Installation issues are another hot topic. Last mile transmission to the customer premise will need to drill holes and lay long cables outside and inside the house. This raises issues with customers feeling hesitant to subscribe and facing tremendous complaints on site. On the operation side, high rise buildings with no fiber ready cables have made installation harder and costly. Additionally, hard to reach areas such as over rivers or rural areas faces the problem of deployment. RoF is a promising solution to ease installation as well as minimize customer complaints where the last mile is transmitted wirelessly into the premise.

1.4 Research Objectives

The main aim of this thesis is to evaluate the performance and reliability of a multiservice RoF system. Hence, to achieve the main aim, the following objectives are formulated:

1. To design and develop an optical carrier generation system using OCS method at carrier frequency of 25.5 GHz.
2. To integrate OCS system with PolMux method and modulate LTE and WiFi signals.
3. To evaluate the reliability of the system using polarization multiplexing method.
4. To evaluate the system performance over wired (fiber) and wireless (LTE and WiFi) transmission.

1.5 Research Scope

The contribution of this thesis to the advancement towards this proposed work is to enable multiservice in RoF technology. This work focuses on multiservice RoF using OCS and PolMux techniques to transmit LTE and WiFi services over a single cable at a single wavelength. The activities involve design, analysis and experimental works. Wireless transmission is at 1 m distance. The SMF spool used to test optical distance is

10 km. The reliability and optimal performance test is measured and compared to IEEE and 3GPP standards. With the aim of identifying and addressing the challenges that are associated with performance of the multiservice RoF system, specific parameters are concentrated. The pathway to achieve the objective is presented in Figure 1.5.

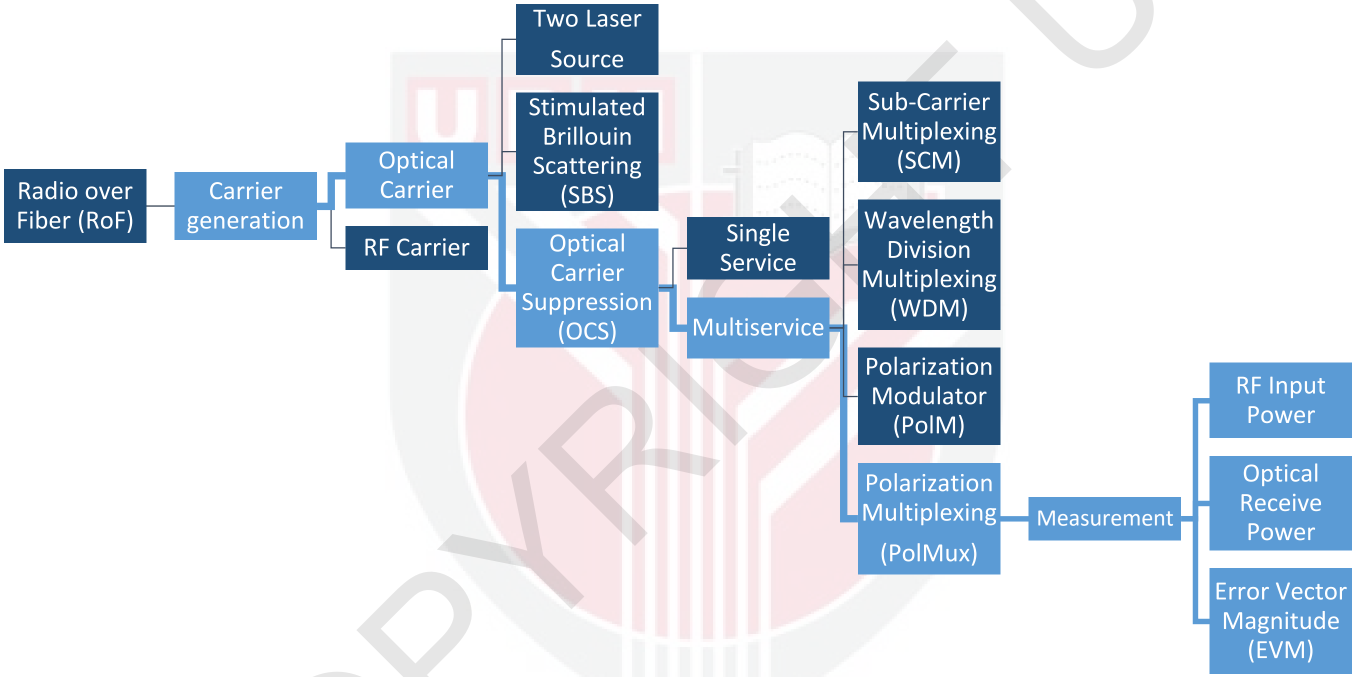

Figure 1.5: A block diagram illustrating the sequence the research scope.

1.6 Thesis Organization

A brief background and motivation of the research are presented in this chapter, as well as the research problem, significances, objectives, and research scope. The remaining chapters of this thesis are organized as follows:

Chapter 2 introduces a review on the literature of RoF system implemented in previous works. Then, it presents the previous studies in particular about the OCS technique as an optical carrier generator and PolMux as a technique to achieve multiplexing using the optical polarization properties.

Chapter 3 describes the overall research framework and discussion on the proposed framework for the design and development of the OCS technique and integration with PolMux in Multiservice RoF systems. In addition, this chapter explains about the receiver, and wireless transmission.

Chapter 4 presents the details of the measurement approach and the results obtained. Setups describe the performance results of OCS, OCS integrated with PolMux, 10 km SMF spool addition, and wireless transmission. A reliability test shows the stability and effectiveness of the system. The measurements are compared to standards.

Chapter 5 concludes the whole research, highlighting the contributions, which also includes the overall evaluation process. This chapter ends with a proposal of recommendations for future work.

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LIST OF PUBLICATIONS

International Journals (Submitted)

M.H.M. Nor, T. Kanesan, F. Maskuriy, A. Yusof, F. A. Fatah and S.B.A. Anas, "Experimental Demonstration of All Optical PolMux RoF System with Multiservice Transmission," Optical Express, 2018.

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