HIGH SPEED INTER-SATELLITE OPTICAL WIRELESS COMMUNICATION NETWORKS INCORPORATING ADVANCE MODULATION FORMAT

by

ABDALLAH AHMAD MOHAMMAD SHATNAWI
(1530211766)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NO. **PAGE**

LIST OF ABBREVIATIONS

APD	Avalanche Photo Diode
ATS	Acquisition Tracking Sensor
BER	Bit Error Rate
CW	Continuous Wave
DPSK	Differential Phase Shift Key
EDFA	Erbium-Doped Fiber Amplifier
FDM	Frequency Division Multiplexing
FSO	Free Space Optics
FWM	Four Wave Mixing
GUI	Graphical User Interface
HAP	High Altitude Platform
IM-DD	Intensity – Direct Detection
IS-OWCN	Inter-Satellite Optical Wireless Communication Networks
ITU	International Telecommunication Union
LOS	Line of Sight
NRZ	Non-Return to Zero
OFDM	Orthogonal Frequency Division Multiplex
OOK	On/Off Key
OWC	Optical Wireless Communication
PC	Polarization Controller
PI	Polarization Interleave
PON	Passive Optical Networks
PPM	Pulse Position Modulation
PS	Polarization Splitter
QAM	Quadrature Amplitude Modulation
RF	Radio Frequency
ROF	Radio Over Fiber
RZ	Return to Zero
SM	Square Modulator
SNR	Signal to Noise Ratio
SOP	State of Polarization

SOA	Semiconductor Optical Amplifier
TDM	Time Division Multiplexing
WDM	Wavelength Division Multiplexing
XPM	Cross Phase Modulation

Rangkaian Komunikasi Tanpa Wayar Antara-Satelit Berkelajuan Tinggi Yang Menggabungkan Format Modulasi Termaju

ABSTRAK

Inter-satelit komunikasi optik (IS-OWC) adalah salah satu teknik revolusi baharu yang boleh digunakan untuk menghantar tarikh berkelajuan tinggi antara satelit untuk mencapai komunikasi angkasa. Dalam erti kata lain, teknik ini boleh digunakan untuk menyambung satelit antara satu sama lain pada kadar yang lebih cepat kerana kapasiti jalur lebar yang lebih tinggi, berkesan utiliti sumber kekerapan, berisiko rendah gangguan elektromagnet (EMI), dan keperluan kuasa yang lebih rendah. Tujuan utama tesis ini adalah untuk meneroka penggunaan format modulasi dahulu iaitu alternatif tanda penyongsangan (AMI) untuk pelaksanaan kelajuan yang tinggi dan panjang sehingga IS-OWC sistem komunikasi yang siap dalam tiga bahagian. Dalam bahagian pertama, ia menyeluruh mengenai penyelesaian untuk mencari jurang dan teknik yang sedia ada dalam sistem IS-OWC. Bahagian kedua meliputi pelaksanaan hibrid sistem AMI-IS-OWC dalam skim polarisasi interleaving (PI) dan skim pembahagian panjang gelombang multipleks s (WDM) yang mempunyai keupayaan untuk menghantar 160 Gbps up-to 5000 km bawah gegaran atau pergolakan ruang. Bahagian ketiga meliputi penilaian dicadangkan sistem AMI-IS-OWC bawah pengaruh pergolakan ruang dari segi nisbah isyarat kepada hingar (SNR), gambar rajah dan jumlah kuasa penerima Kata. Hasil yang dilaporkan menunjukkan penghantaran berjaya data 160 Gbps lebih dari 5000 km dengan SNR diterima, menerima kuasa dan gambar rajah mata..

High Speed Inter-Satellite Optical Wireless Communication Networks Incorporating Advance Modulation Format

ABSTRACT

Inter-satellite optical wireless communication (IS-OWC) is one of the revolutionary techniques that can be used to transmit the high-speed data between satellites to accomplish space communication. However, speed and transmission distances of Is-OWC system is limited by space turbulences particularly pointing losses at transmitter as well as receiver side. The main intention of this thesis is to explore utilization of advance modulation format particularly alternate mark inversion (AMI) for implementation of high speed IS-OWC communication system with longer transmission distances which is carried out in three phases. In the first phase, extensive literature review is completed to find the gaps and existing techniques in IS-OWC systems. The second part covers implementation of AMI based IS-OWC system in conjunction with polarization interleaving (PI) scheme and wavelength division multiplexing (WDM) scheme, which has capability to transmit 160 Gbps up-to 5000 km under no space turbulences with acceptable signal to noise ratio (SNR), bit error rate (BER) and eye diagrams. The third part covers the evaluation of proposed AMI-IS-OWC system under the influence of space turbulences particularly transmitting pointing error and receiving pointing error. The reported results show improvement in IS-OWC system as compared to previous systems in terms of capacity as well as distance.

CHAPTER 1 : INTRODUCTION

This thesis is focused on the design of high speed and long reaches inter-satellite communication networks by adopting advance modulation formats with wavelength division multiplexing scheme and polarization interleaving scheme. This chapter aims to place this thesis into context by first providing an introduction in Section 1.1. This lays the foundation for the Research Motivation in Section 1.2, Problem Statement in Section 1.3, followed by Research Questions in Section 1.4 and Research Objectives in Section 1.5. The scope of research is presented in Section 1.6 followed by the organization of the rest of the thesis in Section 1.7.

1.1 Introduction

As shown in Figure 1.1, Optical Networks is broadly divided into two categories, i.e., Fiber communication networks and Optical wireless communication networks. In optical fiber communication networks, fiber is used as medium (Channel) for communication whereas in optical wireless communication networks, information is transmitted without using optical fiber. Optical wireless communication networks is again subdivided into two categories i.e. free space optics (FSO) and inter-satellite optical wireless communication networks (IS-OWCN). FSO is used for ground or terrestrial communication whereas IS-OWCN is used for communication between satellites. This outline is focused on Inter-Satellite Communication Network.

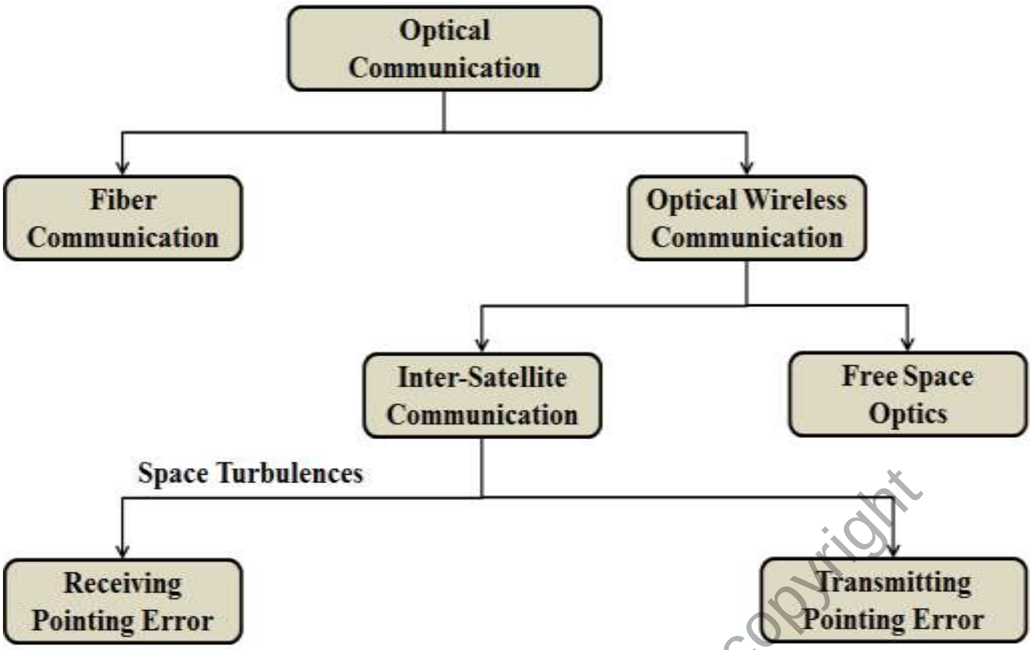

Figure 1.1: Optical Communication Networks Classification

As reported by previous researchers, there are two major challenges in inter-satellite networks -receiving pointing error and transmitting pointing error which results in limited transmission distance and capacity. However, Figure 1.2 illustrates techniques to improve transmission distance and capacity. The most popular techniques is wavelength division multiplexing (WDM) (Aparna & Chandran, 2015; Lam & Liu, 2014; Mbah, Walker, & Phillips, 2014; Patel et al., 2014; Shahidinejad, Amiri, & Anwar, 2014), Polarization Interleaving (PI) (Che et al. 2014; Duan, Marvdashti, & Ellerbee, 2015; Shi, Zhou, & Long, 2014; X. Zhou et al., 2015; Y. Zhou, Liu, & Guo, 2015) and advance modulation formats (Ban et al., 2015; Bansal, Kaur, & Chaudhary, 2015; Houtsma et al., 2015; Suh et al., 2015) such as alternate mark inversion, Duobinary modulation, Manchester modulation in Non Return Zero (NRZ) and Return to Zero (RZ) technique.

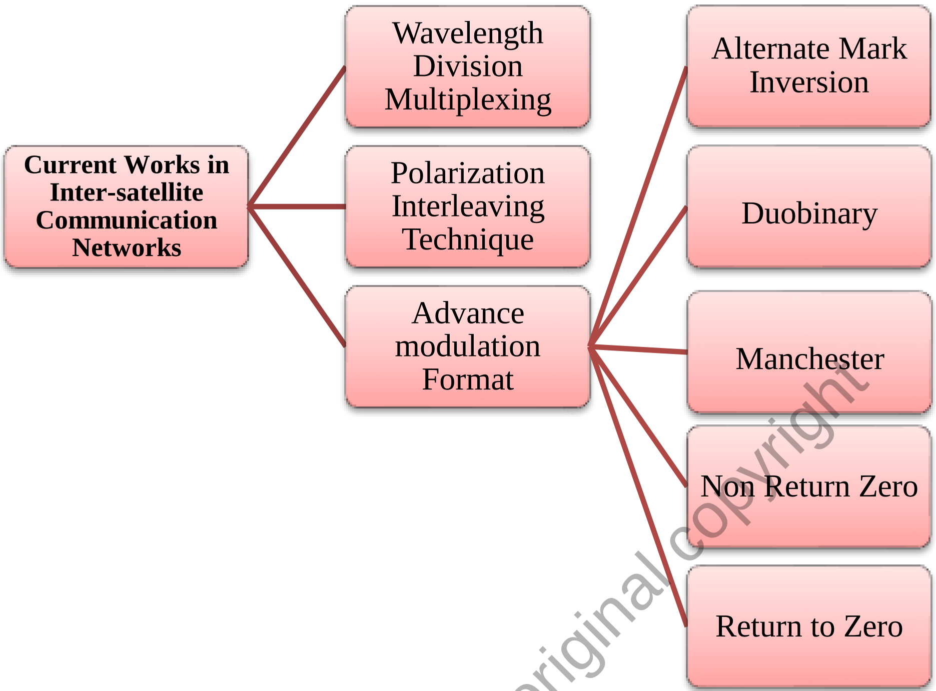

Figure 1.2: Techniques to improve transmission capacity and distance in Optical Networks.

1.2 Research Background

Optical remote communication is considered appropriate for advanced remote broadband applications, both indoor and outdoor, that ranges from short-run remote connection systems to last-mile communication systems with access between end clients, existing fiber optic, and inter-space laser connections (Kanmani and Sankaranarayanan, 2013). Indoor optical remote communication is known as remote infrared communication whereas outdoor optical remote communication is known as free space optical (FSO) communication. One of the most significant applications of FSO is that it is used for transmitting inter-satellite optical wireless communication (IS-OWC) between satellite and space interchanges within a short span.

In case of the applications of wireless infrared communication, non-directed links without any transmitter-receiver alignment are required which are known as line-of-sight (LOS) and diffuse links. While LOS links need a specified path to have seamless communication, diffuse links use multiple optical paths connected from the surface reflection. IS-OWC uses specified links – LOS and point-to-point laser – to transmit between transmitter and receiver through atmosphere. OWC technology provides broadband connection aptitudes through non-licensed optical wavelengths.

But temperature and atmospheric pressure-related differences tend to create variations in refractive index via transmission route. This further leads to variations related to temperature and position in the optical intensity on the receiver that results in fading (Deng et al., 2015). Moreover, the faded links can adversely affect system performance which can increase bit error rate (BER) and transmission delay.

The application of IS-OWC network is in inter-satellite communication with similar or distinctive circles with the lightwave transmission of 3×10^8 m/s through which information can be transmitted with larger data and less constriction (P. Kaur et al., 2015). Higher quantity of information can be sent to a longer distance by using optical connection over radio frequency (RF) technology with fewer payloads. Moreover, OWC networks use RF wavelength which is more suitable than lasers in terms of beam-width, resulting in lower attenuation (Kumar, 2014b). IS-OWC systems are quickly deployable and provide secure communication frameworks which are compatible with any advanced sensor communication system.

1.3 Problem Statement

No doubt, IS-OWC has lot of rigorous advantages, but there are some challenges which causes poor performance of its link. Space Turbulences such as transmitting pointing errors and receiving pointing errors results in increase of attenuation which causes shut down of inter-satellite communication link (Chaudhary, 2014; Chaudhary et al., 2016). This increased attenuation can affect the transmission rate and distance. So these turbulences must be taken under consideration while designing IS-OWC transmission networks. However current modulation schemes does not meet the requirement of high speed data and longer transmission distances for IS-OWC systems. Thus, the concise problem of this thesis is impact of transmitting pointing errors and receiving pointing errors which should be minimized in order to increase the performance of IS-OWC systems.

1.4 Research Questions

1. How the advance modulations formats influence in designing high speed and long reach inter-satellite networks?
2. How is the performance of the proposed inter-satellite network evaluated under transmitting pointing error and receiving pointing error?

1.5 Research Objectives

This thesis is mainly focused on designing high speed and long reach inter-satellite network by adopting advance modulation scheme such as alternate mark inversion (AMI) technique. This aims can be subdivided into following objectives:

1. To design a high speed and long reach inter-satellite network by adopting an advance modulation formats.
2. To evaluate the performance of proposed inter-satellite network under the impact of transmitting pointing errors and receiving pointing errors in terms of total received power, Signal to Noise Ratio (SNR) and eye diagrams.

1.6 Scope of Research

This research is focuses on adopting wavelength division multiplexing (WDM)-polarization interleaving (PI) in conjunction with advance modulation format for Inter-Satellite communication system in order to increase performance as well as bandwidth under turbulences. The scope of this study is focused on adopting advance modulation format for inter-satellite network, which is not reported in any previous works, highlighted by a circle in Figure 1.3.

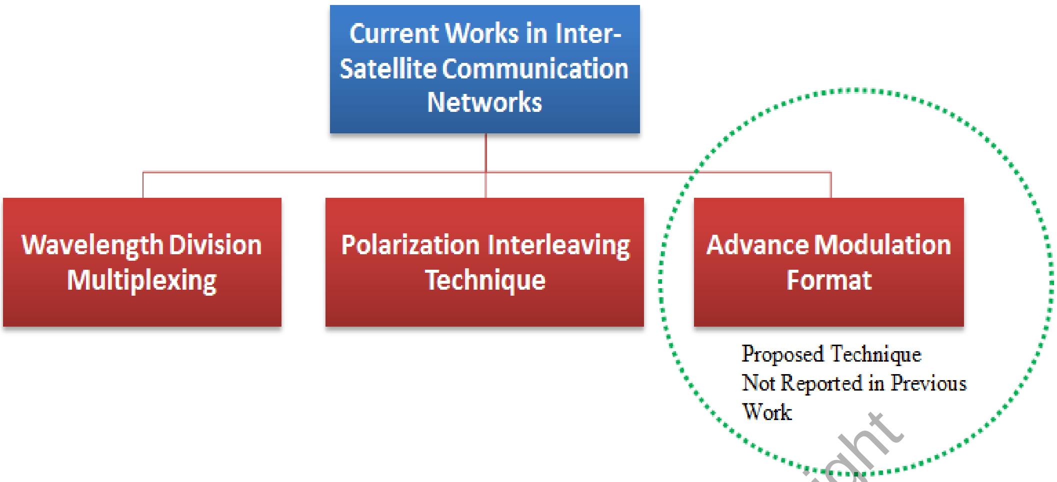

Figure 1.3: Research Scope

1.7 Research Contributions

The research contributions of this proposal are stated as follows:

1. The proposed model can be used to transmit high speed data between satellites.
2. The proposed model can be used to transmit data over longer distances between satellites.
3. The proposed model can be used to carry data over inter-satellite link under the influence of space turbulences particularly transmitting pointing error and receiving pointing error.

1.8 Thesis Organization

This thesis consists of three chapters organized as follows:

- **Chapter 1:** covers the introduction of IS-OWC networks, motivation of the research, problem statement, research questions, research objectives and scope of the research.

- **Chapter 2**: provides an extensive literature review outlining an overview of optical communications, classifications of optical communication networks, Optical Wireless Communication (OWC) Vs. Radio Frequency (RF) Technology, wavelength division multiplexing scheme, factors affecting WDM, factors affecting optical wireless channels, and some previous prior works in the field of IS-OWC networks.

- **Chapter 3:** is focused on the research methodology used for achieving the research objectives.
- **Chapter 4:** is focused on proposed WDM-PI-AMI inter-satellite communication networks without space turbulences as well as under the impact of space turbulences particularly transmitting and receiving pointing errors.

- **Chapter 5:** is focused on future and conclusion of this thesis.

CHAPTER 2 : LITERATURE REVIEW

This chapter is focused on extensive literature survey on Inter-satellite communication system. The remaining of this chapter is divided as following: Section 2.1 describes about brief overview of optical communication, Section 2.2 describes evolution of optical communication system, Section 2.3 describes the classification of optical communication system, Section 2.4 shows Optical Wireless Communication (OWC) Vs. Radio Frequency (RF) Technology, Section 2.5 shows Wavelength Division Multiplexing (WDM) System, Section 2.6 shows factors affecting WDM, Section 2.7 shows polarization interleaving scheme whereas Section 2.8 shows factors affecting optical wireless communication followed by some previous works on inter-satellite communication system.

2.1 Background

The concept of laser technology to space communications was developed in the early 1960s in order to secure communication between a satellite and a submarine. In the present course of time, the application has witnessed remarkable technical advancement particularly in optical wireless communication as implemented widely by government authorities, corporates, and higher academics.

As an essential part of our everyday life, we use different modes of communication including data, voice, images, and video communication. From last decade, optical communication systems has witnessed remarkable growth due to increased demand of these services. Due to high bandwidth, system capacity, and seamless integration with existing networks, optical transmission networks are widely employed in all telecommunication areas (Shaddad et al., 2014; Shao et al., 2014). In case of light wave system, the transmission capacity can increase enormously over several megabytes (Mbps) up to 100 terabytes (Tbps) and beyond (Simmons, 2014). In the current perspective, fiber optic systems in optical communication have become an integral part of information infrastructure.

Initially used for long haul or submarine transmission and point-to-point communication, the application of optical fibers and particularly light-wave systems now extends to almost all metro networks. Fiber optic communication systems are mainly used for information transmission between different places by sending light through optical fiber. Optical fibers have transformed telecommunication industry with advanced electronic transmission speed, while replacing copper wire communications. Optical fibers are widely preferred due to their low loss, high-speed data transmission capacity, huge bandwidth reliability, and seamless long distance transmission (H. Liu et al., 2013). Simultaneous data transmission by different users over various communication channels using bandwidth availability through optical fibers is employed in fiber optic communication which is known as a multiple access technique. This technique can be of two types: synchronous and asynchronous.

In case of asynchronous multiple access, network access occurs randomly and collisions are subject to LANs with low traffic demand (Chaouchi & Laurent-Maknavicius, 2013). But asynchronous access methods lead to increasing delay mainly due to the increasing traffic intensity. In case of synchronous access methods, transmissions are usually scheduled more accurately and hence become successful in comparison to the asynchronous methods (Wu et al., 2013).

2.1.1 Evolution of Optical Communication Networks

Communication using light has been practiced in Asia for a very long time right from the development of the Roman Empire to the Mars expedition of current period. The simplest kind of lightwave system is known as the point-to-point optical communication which contains three major components: a transmitter, transmission channel, and a receiver. With the development of laser technology in 1960 (Maiman, 1960), the use of light waves was practiced as an important source of information transmission. The use of optical fiber as lightwave transmission medium was first proposed by Kao and Hockman in 1966, who argued that impurities cause attenuation of optical fibers (telecom-grade fibers with a loss of 20 dB/km) which can be removed. Five years later, researchers have realized this prediction (Kapron et al., 1970). Later in 1979, researchers realized low loss fiber (with a loss of 0.2 dB/km) at the operating wavelength of 1550 nm (Murata & Inagaki, 1981). Further, the concurrent accessibility of laser and low loss optical fiber paved the way for five distinct generations of optical fiber communication systems (Chun, 2008; Downing, 2004).

The first generation of lightwave systems was realized at the operating wavelength of 800 nm by using GaAs semiconductor lasers at 45 Mbps and a repeater spacing of up to 10 km which was limited by fiber dispersion. The operation of lightwave systems at a wavelength of 1300 nm in the 1970s resulted in increased repeater spacing, reduced fiber dispersion, and condensed fiber loss to less than 1 dB/km. This further led