UNIVERSITI PUTRA MALAYSIA

IMPROVEMENT OF FREE SPACE OPTICAL COMMUNICATIONS USING DOUBLE CARRIER MODULATION/DIFFERENTIAL DETECTION

SALASIAH HITAM

IMPROVEMENT OF FREE SPACE OPTICAL COMMUNICATIONS USING DOUBLE CARRIER MODULATION/DIFFERENTIAL DETECTION

SALASIAH HITAM

DOCTOR OF PHILOSOPY
UNIVERSITI PUTRA MALAYSIA

2006

IMPROVEMENT OF FREE SPACE OPTICAL COMMUNICATIONS USING DOUBLE CARRIER MODULATION/DIFFERENTIAL DETECTION

By

SALASIAH HITAM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of Requirement for the Degree of Doctor of Philosophy

December 2006

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

IMPROVEMENT OF FREE SPACE OPTICAL COMMUNICATIONS USING DOUBLE CARRIER MODULATION/DIFFERENTIAL DETECTION

By

SALASIAH HITAM

December 2006

Chairman: **Associate Professor Mohamad Khazani Abdullah, PhD**

Faculty: **Engineering**

Free Space Optical (FSO) communications receive growing attention for use in high data rates wireless link with recent commercialization successes. It is an interesting solution to achieve high bandwidth in the 'last-mile' problem with economical and fast deployment. However, in the poor weather such as the heavy rainfall and low visibility lead to degradation of the links performance, particularly over ranges of several hundred meters or longer.

Rare usage of FSO communications might be related to factors which are classified as scintillation, absorption, and scattering. In this purpose of studies, the heavy rainfall and low visibility data in Subang Airport, Malaysia were used for the analysis on conventional technique that is Intensity Modulation/Direct Detection (IM/DD) and a new technique namely Double Carrier Modulation/Differential Detection (DCM/Diff.D) as the worst case scenario.

Currently, most FSO communication systems are using the IM/DD which are still subjected to many problems. The main problems associated with FSO transmission systems are; atmospheric loss, geometric loss, mispointing loss, and the inability of the receiver circuit to regenerate the transmitted bits because of low signal power. Another prevalent problem is that of its masking noises. The recovery technique in the IM/DD technique uses an injected voltage level as a threshold into a decision circuit, which decides whether the incoming bit is a ‘0’ or a ‘1’. This technique has two inherent problems; the instability of the injected threshold voltage, and the complexity of a dynamic threshold processing. Due to these problems, a new technique based on the automatic decision making known as DCM/Diff.D is provided to improve the transmissions.

The performance of IM/DD and DCM/Diff.D was simulated by using commercial simulation software, OptiSystem Version 3.1 and 4. From the simulation results, it appears clearly that the DCM/Diff.D technique improves for more than twice the distance supported by the IM/DD technique under the conditions of heavy rainfall and hazy days. The theoretical development on probability of error and digital signal-to-noise ratio for the worst case scenario also support these results. Another outcome in this thesis is the theoretical derivation on positioning a passive reflector with a time delay produced can be acceptable until 2.5 Gbps.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBAIKAN KOMUNIKASI OPTIK RUANG BEBAS MENGGUNAKAN PEMODULATAN PEMBAWA BERGANDA/PENGESAN BERBEZA

Oleh

SALASIAH HITAM

Disember 2006

Pengerusi: **Profesor Madya Mohamad Khazani Abdullah, PhD**

Faculti: **Kejuruteraan**

Opik Ruang Bebas (ORB) mendapat sambutan yang menggalakkan untuk kegunaan talian wayarles kadar data tinggi dengan kejayaan pengkomersilan sejak kebelakangan ini. Ia adalah satu penyelesaian yang penting untuk mendapat lebar jalur besar dan masalah 'batu-terakhir' yang lebih ekonomi dan cepat dalam metropolitan. Walaubagaimanapun, dalam cuaca buruk seperti hujan lebat dan jarak penglihatan yang rendah mengakibatkan prestasi talian degradasi, selalunya terhadap jarak beberapa ratus meter atau lebih.

Penggunaan komunikasi ORB yang jarang mungkin berkaitan dengan faktor-faktor di mana ianya dikelaskan sebagai sintilasi, penyerapan dan penyerakan. Untuk tujuan penyiasatan ini, data hujan lebat dan jarak penglihatan rendah di Lapangan Terbang Subang, Malaysia digunakan untuk analisis teknik yang menjadi kebiasaan iaitu Pemodulatan Keamatan/Pengesanan Terus (PK/PT) dan satu teknik baru dinamakan

Pemodulatan Pembawa Berganda/Pengesan Berbeza (PPB/PB) sebagai senario kes terburuk.

Pada masa sekarang, semua sistem-sistem komunikasi ORB menggunakan PK/PT di mana masih tertakluk kepada beberapa masalah. Masalah utama yang berkaitan dengan sistem penghantaran ORB ialah; kehilangan atmosfera, kehilangan geometrik, kehilangan tidaktumpu dan ketidakbolehan litar penerima menjana semula bit penghantaran disebabkan kuasa isyarat yang lemah. Di antara masalah lain yang wujud ialah diakibatkan oleh hingar. Teknik pemerolehan semula dalam PK/PT menggunakan aras voltan suntikan sebagai satu ambang kepada satu litar keputusan, di mana memutuskan samada bit yang datang adalah 0 atau 1. Skim ini ada dua masalah semulajadi, ketidakstabilan voltan ambang suntikan, dan kerumitan pemprosesan ambang dinamik. Berikutan dari masalah-masalah ini, satu teknik baru berdasarkan pembuat keputusan automatik dikenali PPB/PB dihasilkan untuk membaiki penghantaran.

Prestasi PK/PT dan PPB/PB disimulasi dengan menggunakan perisian simulasi komersil, OptiSystem Versi 3.1 dan 4. Dari keputusan simulasi, ia dilihat dengan jelas bahawa teknik PPB/PB membaiki jarak yang disokong oleh PK/PT sebanyak lebih dari dua kali di bawah keadaan hujan lebat dan berjerebu. Pembangunan teori bagi kebarangkalian ralat dan nisbah isyarat-kepada-hingar digit untuk senario kes paling buruk juga menyokong keputusan ini. Hasil yang lain dari tesis ini ialah penerbitan teori untuk meletakkan satu pembalik pasif di mana masa tunda yang dihasilkan boleh diterima sehingga 2.5 Gbps.

ACKNOWLEDGEMENTS

Praise is to ALLAH the almighty, for His help and support during the course of life and the moment of truth.

I would like to express my appreciation and sincere gratitude to my supervisor, Associate Professor Dr Mohamad Khazani Abdullah for his continuous support, encouragement and endless patience towards completing the research. These special thanks also dedicated to my supervisory committee member; Associate Professor Dr Mohd Adzir Mahdi and Associate Professor Dr Kaharudin Dimyati for their invaluable guidance and constructive criticisms throughout the success of this project.

My special thanks to Mrs. Bibi Sarpinah Sheikh Naimullah and Mrs. Wan Azizun Wan Adnan for their help and solving of problems in this project. Special thanks to all my colleagues from, Photonics Lab for their support and encouragement. Working with all of you is a good experience that could never be forgotten. I would also like to express my appreciation to En. Azhar and all staff of Malaysian Meteorological Department, Climate Division, Petaling Jaya for their assistance in data collection.

A huge appreciation to my beloved husband, daughters and son for their continual support and patience made me strong in completing the thesis. Last but not least, I would like to thank my mother-in-law, and the rest of my family who keep encouraging and supporting me in whatever I do. Thank you very much.

I certify that an Examination Committee has met on 21st December 2006 to conduct the final examination of Salasiah Hitam on her Doctor of Philosophy thesis entitled "Improvement of Free Space Optical Communications Using Double Carrier Modulation/Differential Detection" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Borhanuddin Mohd Ali, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Sudhanshu Shekar Jamuar, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Khairi Yusof, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Farid Ghani, PhD
Professor
School of Electrical and Electronic Engineering Studies
Universiti Sains Malaysia
(External Examiner)

____

HASANAH MOHD. GHAZALI, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

Mohammad Khazani Abdullah, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Adzir Mahdi, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Kaharudin Dimyati, PhD
Associate Professor
Faculty of Engineering
Universiti Malaya
(Member)

____
AINI IDERIS, PhD
Professor/Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 12 APRIL 2007

DECLARATION

I hereby declare that the thesis is based on my original work except for the quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

SALASIAH HITAM

Date: 9 FEBRUARY 2007

LIST OF ABBREVIATIONS

APD	Avalanche Photodiode
ASE	Amplifier Spontaneous Emission
ASIC	Advanced application-Specific Integrated Circuit
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
BPFs	Band-Pass Filters
BS	Base Station
CATV	Cable Television
CCR	Corner-Cube Retroreflector
CD	Compact Disc
CD	Chromatic Dispersion
CDRH	Center for Devices and Radiological Health
CLEC	Competitive Local Exchange Carrier
CMRR	Common Mode Rejection Ratio
CNR	Carrier-to-Noise Ratio
CW	Continuous Wave
DPSK	Differential Phase-Shift Keying
DSNR	Digital Signal-to-Noise Ratio
DWDM	Dense Wavelength Division Multiplex
EDFA	Erbium Doped Fiber Amplifier
FDA	Food and Drug Administration

FDDI	Fiber Distributed Data Interface
FEC	Forward Error Correction
FOV	Field-of-View
FSK	Frequency Shift Keyed
FSO	Free Space Optical
FWM	Four Wave Mixing
GL	Geometric loss
HF	High Frequency
i.i.d	Identically Distributed
IEC	International Electrotechnical Commission
IM/DD	Intensity Modulation/Direct Detection
InGaAs	Indium Gallium Arsenide
IR	Infra-Red
ISI	Inter-Symbol Interference
ITU-R	International Telecommunication Union-Radio Communication
LANs	Local Area Networks
LD	Laser Diode
LED	Light Emitting Diode
LO	Local Oscillator
LOS	Line-of-Sight
LPFs	Low Pass Filters
MANs	Metropolitan Access Networks

MSL	Mode-Selective Loss
MST	Malaysian Standard Time
NDSF	Non-Dispersion Shifted Fiber
NRZ	Non Return-to-Zero
OC	Optical Carrier
OOK	On-Off Keying
OSI	Open Systems Interconnect
PC	Personal Computer
PRBS	Pseudo Random Binary Sequence
PSD	Power Spectral Density
RF	Radio Frequency
RIN	Relative Intensity Noise
RMS	Root-Mean-Square
Rx	Receiver
SDH	Synchronous Digital Hierarchy
Si	Silicon
SNR	Signal-to-Noise Ratio
SONET	Synchronous Optical Network
SPM	Self Phase Modulation
ST	Station Time
STM	Synchronous Transfer Mode
Terabps	Tera bit per second
THOR	TeraHertz Operational Reachback

Tx	Transmitter
VCSEL	Vertical-Cavity Surface-Emitting Laser
WDM	Wavelength-Division Multiplexing
XPM	Cross Phase Modulation

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS