

SOME STUDIES ON SIM BASED SYMMETRIC AND ASYMMETRIC FSO COOPERATIVE SYSTEMS

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**BHARTI SCHOOL OF TELECOMMUNICATION
TECHNOLOGY AND MANAGEMENT
INDIAN INSTITUTE OF TECHNOLOGY DELHI
JULY 2016**

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by

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TECHNOLOGY AND MANAGEMENT**

Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2016

Certificate

This is to certify that the thesis entitled "**Some Studies on SIM based Symmetric and Asymmetric FSO Cooperative Systems**" being submitted by **Ms. Sanya Anees** to the **Bharti School of Telecommunication Technology and Management, Indian Institute of Technology Delhi**, for the award of the degree of **Doctor of Philosophy** is the record of the bona-fide research work carried out by her under my supervision. In my opinion, the thesis has reached the standards fulfilling the requirements of the regulations relating to the degree.

The results contained in this thesis have not been submitted either in part or in full to any other university or institute for the award of any degree or diploma.

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Acknowledgements

Praise be to Allah Subhanahu Wa Ta'ala for the countless blessings, patience, and strength given to me in each and every stage of my research. Peace, prayers, and blessings be upon Prophet Muhammad salla Allah alaihi wa sallam and his noble companions.

First and foremost, my deepest gratitude to my supervisor Dr. Manav R. Bhatnagar for his expert guidance, constant support, and immense encouragement throughout my Ph.D. program. His invaluable suggestions and insightful discussions made me enjoy my research. Also his enormous enthusiasm, honest dedication, and quest for knowledge is truly inspirational. My sincere appreciation also extends to Prof. Ranjan Bose, Prof. Devi Chadha, and Dr. Monika Aggarwal for their beneficial feedback and suggestions during my work. I also would like to thank Prof. Shankar Prakriya, Bharti School of Telecommunication Technology and Management, and Indian Institute of Technology Delhi for the immense help and support.

I acknowledge my friends, Santosh and Chinmoy Sir, for helping me in various phases of my research work through numerous discussions and valuable inputs. I also thank my colleagues for sharing my joys and sorrows and the amazing time I spent with them.

Most importantly, I am indebted to my parents Dr. Aneesur Rehman Siddiqui and Dr. Gayatri Agnihotri, for encouraging me to do Ph.D., consistently being there with me through thick and

thin, and understanding me in every situation. Whatever I have achieved so far, I owe it to Allah and my parents. My heartfelt gratitude to Dr. Brejesh Lall and his family for taking care of me like my own family during my stay here at IIT. He has been like a guardian angel and no amount of words can suffice for his importance in my life. I am extremely grateful to all my relatives specially Ms. Mangla Gowle and Dr. Ameenur Rehman for their continuous motivation and optimism. I feel blessed for the unconditional love and concern from all my friends. I feel obligated to all of them for their dedicated prayers for me.

Sanya Anees

Abstract

Free space optical (FSO) communication proves to be an effective alternative to the existing radio frequency (RF) communication and optic fibre communication. FSO systems are power efficient, require cheap installation and operational cost with easy deployment, use license-free spectrum, provide immunity to interference, and large bandwidth capacity (FSO systems supporting 10 Gbps are already in the market). These advantages make them appealing for various applications in terrestrial and satellite communications, for example, campus connectivity, last mile access, back-hauling, high definition transmission, security, disaster recovery, video surveillance etc. However, the performance of the FSO systems is highly dependent on the atmospheric conditions, atmospheric turbulence, and misalignment errors.

To reduce the effect of turbulence and pointing errors, various solutions have been proposed. Spatial diversity efficiently exploits multipath fading by using multiple apertures in order to increase the data rate, to reduce the fading effect on the signal, and to provide diversity gain. On the other hand, using the concepts of relaying technology in FSO systems increases the coverage area, improves the performance, and enhances the capacity. FSO systems can be used for "last mile access" and "back-hauling" as there exists a connectivity gap between the backbone

network and the last mile access network. Thus the main backbone could be considered as the FSO network and the RF links can be used for connection to end users. In FSO systems - as the fading variance is distance dependent - the serial relaying scheme not only increases the coverage area but also brings out great performance improvements against the degrading effects of fading. Thus a detailed study on serial FSO cooperative systems finds applications towards many real-time problems.

In the dissertation, we have performed a detailed performance analysis of various symmetric and asymmetric FSO cooperative systems, i.e., dual-hop asymmetric RF-FSO communication systems, dual-hop symmetric FSO communication systems, dual-hop asymmetric RF-FSO communication systems with a direct RF link, and distributed Alamouti based FSO communication system. The relays used in these systems employ either decode-and-forward relaying protocol or amplify-and-forward relaying protocol. The RF links are characterized by Nakagami- m fading and the FSO links are characterized by path loss, Gamma-Gamma atmospheric turbulence, and pointing errors. The FSO transmitter employs subcarrier intensity modulation technique to transmit the optical signal and the FSO receiver uses direct detection technique to recover back the transmitted signal. For the 2×1 distributed Alamouti scheme based FSO system, it is assumed that the two sources are able to exchange their data without any error and then forward it to the destination. In the dual branch asymmetric RF-FSO communication system, the destination uses selection combining technique to combine multiple signals received from the source and the relay.

Using novel derived mathematical expressions of statistical characteristics of the received signal-to-noise ratio, new analytical expressions are obtained for outage probability, average bit

error rate or symbol error rate of different modulation techniques, and the ergodic channel capacity under different adaptive transmission schemes, i.e., optimal rate adaptation with constant transmit power (ORA), simultaneous optimal power and rate adaptation (OPRA), and truncated channel inversion with fixed rate (TCIFR). The effects of fading, turbulence, and errors are observed on the performance metrics of these systems under different scenarios with some unique observations: (i) the performance of these systems is more severely impaired in lower modulation schemes than higher-order modulation schemes under the unified effect of turbulence and pointing errors, (ii) the performance of cooperative system with direct RF link is way better than the performance of the cooperative system without direct link due to the additional introduced diversity gain, (iii) the degradation caused by pointing errors in the performance of these systems is more prominent for weak fading and turbulence scenarios rather than for moderate or strong fading and turbulence scenarios, and (iv) the pointing errors significantly degrade the diversity of the Alamouti based FSO system.

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Abbreviations

AF	Amplify-and-Forward
APD	Avalanche Photo Diode
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CBFSK	Coherent Binary Frequency Shift Keying
CBPSK	Coherent Binary Phase Shift Keying
CDF	Cumulative Distribution Function
CSI	Channel State Information
D	Destination
DBPSK	Differential Binary Phase Shift Keying
DF	Decode-and-Forward
EGBMGF	Extended Generalized Bivariate Meijer-G Function
EGC	Equal Gain Combining
FSO	Free Space Optical Communications
G-G	Gamma-Gamma

HD	High Definition
i.n.i.d.	independent but not identically distributed
IR	Infra-Red
MGF	Moment Generating Function
MIMO	Multiple-Input Multiple-Output
M -PSK	M -ary Phase Shift Keying
M -QAM	M -ary Quadrature Amplitude Modulation
MRC	Maximal Ratio Combining
NBFSK	Non-Coherent Binary Frequency Shift Keying
NRZ	Non Return to Zero
OOK	On-Off Keying
OPRA	Optimal Power and Rate Adaptation
ORA	Optimal Rate Adaptation
OWC	Optical Wireless Communication
PDF	Probability Density Function
PPM	Pulse Position Modulation
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
R	Relay
RC	Repetition Coding
RF	Radio Frequency

RoFSO	Radio-on-FSO
RZ	Return to Zero
S	Source
SC	Selection Combining
SER	Symbol Error Rate
SIM	Subcarrier Intensity Modulation
SNR	Signal-to-Noise Ratio
STBC	Space-Time Block Code
TCIFR	Truncated Channel Inversion with Fixed Rate
UV	Ultra-Violet