Secrecy Analysis and Performance Improvement of FSO Communication Systems

A Thesis submitted by
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in partial fulfillment of the requirements for the award of the degree of
Doctor of Philosophy

॥ त्वं ज्ञानमयो विज्ञानमयोऽसि ॥

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Declaration

I hereby declare that the work presented in this Thesis titled *Secrecy Analysis and Performance Improvement of FSO Communication Systems* submitted to the Indian Institute of Technology Jodhpur in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy is a bonafide record of the research work carried out under the supervision of Dr. Aashish Mathur. The contents of this thesis in full or in parts have not been submitted to and will not be submitted by me to, any other Institute or University in India or abroad for the award of any degree or diploma.

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Certificate

This is to certify that the thesis titled *Secrecy Analysis and Performance Improvement of FSO Communication Systems*, submitted by *Gyan Deep Verma (P18EE001)* to the Indian Institute of Technology Jodhpur for the award of the degree of *Doctor of Philosophy* is a bonafide record of the research work done by her under my supervision. To the best of my knowledge, the contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Aashish Mathur
Ph. D. Thesis Supervisor

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List of Abbreviations

3GPP	Third-Generation Project Partnership
6G	Sixth Generation
ACK	Positive Acknowledgment
AF	Amplify and Forward
ALO	At Least Once
ARQ	Automatic Repeat Request
ASC	Average Secrecy Capacity
AT	Atmospheric Turbulence
AWGN	Additive White Gaussian Noise
B5G	Beyond Fifth Generation
BER	Bit Error Rate
CC	Chase Combining
CDF	Cumulative Distribution Function
CRC	Cyclic Redundancy Check
DF	Decode and Forward
DFB	Distributed Feedback
EDFA	Erbium Doped Optical Amplifier
FEC	Forward Error Correction
FPGA	Field Programmable Gate Array
FTTH	Fiber to the Home
FSO	Free Space Optical
Gbps	Gigabits/second
GEO	Geosynchronous Earth Orbit
H-ARQ	Hybrid Automatic Repeat Request
HD	Heterodyne Detection
IID	Independent and Identically Distributed
IM/DD	Intensity Modulation/Direct Detection
INR	Incremental Redundancy
IR	Infrared
IRS	Intelligent Reflecting Surface
ITU	International Telecom Union
LDPC	Low Density Parity Check
LEO	Low Earth Orbit
LO	Local Oscillator
LoS	Line of Sight
LTE	Long Term Evolution
Mbps	Megabits/second
MGF	Moment Generating Function
MRC	Maximum Ratio Combining
NACK	Negative Acknowledgement
NR	New Radio
NRZ	Non Return to Zero
OOK	On Off Keying

OSA	Optical Spectrum Analyser
OWC	Optical Wireless Communication
PDF	Probability Density Function
PE	Pointing Error
PER	Packet Error Rate
PIN	Positive Intrinsic Negative
PPM	Pulse Position Modulation
PRBS	Pseudo Random Binary Sequence
RF	Radio Frequency
RIS	Reconfigurable Intelligent Surface
Tbps	Terabits/second
TRAI	Telecom Regulatory Authority of India
SISO	Single-Input Single-Output
SNR	Signal-to-Noise Ratio
SFP	Small Form Factor Pluggable
SOP	Secrecy Outage Probability
SPSC	Strictly Positive Secrecy Capacity
ST	Secrecy Throughput
UAV	Unmanned Area Vehicle

List of Symbols

η_0	Responsivity of the photodetector
s	Transmitted optical signal
h_a	Malaga atmospheric turbulence channel gain
h_p	Pointing error attenuation
h_l	FSO link path loss
w	AWGN with zero mean and power spectral density N_0
α	Large scale scintillation parameter
β	Small scale scintillation parameter
g	Average power of the scattering component received by off-axis eddies
b_0	Half average power of total scatter components
ρ	Amount of power coupled to the LOS component
$\Omega^{'}$	Average power from the coherent component
Ω	Average power of the LOS component
ϕ_a	Deterministic phases of LOS term
ϕ_b	deterministic phases of coupled to LOS scatter term
R	Radial displacement vector
R_x	Horizontal displacement from the receiver plane
R_y	Vertical displacement from the receiver plane
μ_x	Horizontal boresight
μ_y	Vertical boresight
σ_x	Horizontal jitter
σ_y	Vertical jitter
θ_z	Divergence angle of transmitted laser beam
w_z	Beam width of laser light at distance D_z
ψ_{mod}	Pointing errors parameter with jitter and boresight effect
μ_{rB}	Received electrical SNR at Bob
μ_{rE}	Received electrical SNR at Eve
C_{th}	Threshold secrecy capacity
ψ	Pointing error parameter with jitter
μ_r	Average SNR for the HD and IM/DD techniques
N	Number of H-ARQ transmission rounds
h_{SR_a}	Atmospheric turbulence channel gain between source to relay
h_{SR_p}	Pointing error attenuation between source to relay
h_{SR_l}	FSO link path loss between source to relay
w_R	AWGN with zero mean and variance σ_R^2 at the relay node
M	Number of IRS reflecting plates
γ_0	Average SNR of single reflecting plate
d_1	Distance between relay to IRS
ν	Pathloss exponent of relay to IRS to destination links
θ_i	Phases shift on relay to IRS link
ξ_i	Phases shift on IRS to destination link
α_i	Fading channel coefficients of relay to IRS
δ_i	Fading channel coefficients of IRS to destination
Θ_i	Phase deviation due to imperfect phase estimation at IRS

I_{RD_j}	Equivalent channel gain between relay to IRS to destination
μ_{RD}	Common mean of M complex variables of Nakagami distribution
m	Shaping parameter of Nakagami distribution
k	Concentration parameter of Von Mises distribution
$\bar{\gamma}_{SR_r}$	Average SNR on the source to destination link for the HD and IM/DD techniques
N_1	Number of H-ARQ transmission rounds on the source to IRS link
N_2	Number of H-ARQ transmission rounds on the source to IRS to destination link
γ_{RD}	Average SNR of relay to IRS to destination link