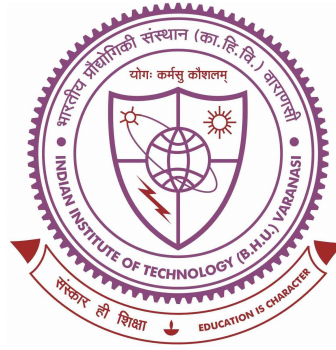


Performance Analysis of Intelligent Reflecting Surfaces Aided Next-Generation Wireless Networks



Thesis submitted in partial fulfillment

for the Award of Degree

Doctor of Philosophy

by

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Rahul Kumar Hindustani

Dedicated to My Mother

Contents

List of Figures	xv
List of Tables	xix
Abbreviations	xxi
Symbols	xxv
1 Introduction	1
1.1 Evolution of Wireless Standards	1
1.2 Motivation for the Thesis	4
1.3 Intelligent Reflecting Surfaces	5
1.4 Fading Channel Models	7
1.5 Diversity Techniques	11
1.5.1 Diversity Combining Receiver	12
1.6 Non-Orthogonal Multiple Access	16
1.7 Ultra-Wideband	18
1.8 Performance Measures and Evaluation	20
1.9 Literature Review	22
1.10 Research Objective	24
1.11 Organization of Thesis	25
2 Multi-IRS-Assisted SISO System Over Rician Fading	29
2.1 Introduction	29
Contributions:	31
2.2 System and Channel Models	32
2.3 Outage Probability Analysis	35
2.3.1 Approximate OP Expression	36
2.3.1.1 CLT-Based Method	36
2.3.1.2 LSE-Based Method	37
2.3.2 Asymptotic OP Expression	38
2.3.3 Diversity Order and Coding Gain	39
2.4 Numerical and Simulation Results	40

2.5 Summary	45
2.6 Appendix	46
3 Multi-IRS-Assisted System With Switched Diversity	49
3.1 Introduction	49
Contributions:	52
3.2 System and Channel Models	52
3.2.1 Switching Operation for SSC Scheme	55
3.2.2 Switching Operation for SEC Scheme	56
3.3 Outage Probability Analysis	56
3.3.1 Exact Outage Probability Expression for SSC Scheme	57
3.3.2 Exact Outage Probability Expression for SEC Scheme	57
3.3.3 Effect of Branch Unbalance on Exact Outage Probability of SSC Scheme	58
3.3.4 Approximate OP Expressions for SSC and SEC Schemes	58
3.3.5 Asymptotic OP Expression for SSC and SEC Schemes	60
3.3.6 Diversity Order and Coding Gain	62
3.4 Numerical and Simulation Results	63
3.5 Summary	68
4 Multiple-IRS Aided Wireless Networks Over Nakagami-m Fading Channels	71
4.1 Introduction	71
4.1.1 Related Works	72
Contributions:	75
4.2 System and Channel Models	76
4.3 Analysis of Outage Probability	79
4.3.1 Approximate OP Expression	79
4.3.1.1 CLT Approach	80
4.3.1.2 LSE Approach	80
4.3.2 Asymptotic OP Expression	81
4.3.2.1 Non-Identical Fading Conditions	82
4.3.2.2 Identical Fading Conditions	84
4.3.3 Diversity Order Analysis	86
4.4 Results and Discussion	87
4.5 Summary	90
5 IRS-Assisted Downlink NOMA System	93
5.1 Introduction	93
Contributions:	94
5.2 System and Channel Models	95
5.3 BER Analysis of Downlink NOMA	98

5.3.1	Accurate BER Expression for $N_u \gg 1$	99
5.3.1.1	BER Expression for Far User f	99
5.3.1.2	BER Expression for Near User n	100
5.3.2	Asymptotic BER Expressions	101
5.3.2.1	Asymptotic MGF for γ_u	101
5.3.2.2	Asymptotic BER Expression for Far User f	103
5.3.2.3	Asymptotic BER Expression for Near User n	103
5.3.3	Diversity Order Analysis	104
5.4	Numerical and Simulation Results	104
5.5	Conclusion	108
5.6	Appendix	110
5.6.1	$\mathcal{I}_u^{(j)}\left(\frac{\pi}{2}\right)$	110
5.6.2	$\mathcal{I}_{u,\infty}^{(j)}\left(\frac{\pi}{2}\right)$	111
6	IRS-Assisted UWB System	113
6.1	Introduction	113
	Contribution	115
6.2	Proposed IRS-UWB System Model	116
6.3	Reflection Optimization	119
6.3.1	Signal Detection	121
6.4	Simulations and Discussion	122
6.5	Summary	128
7	Conclusion and Future Scope	131
7.1	Conclusion	131
7.2	Future Scope	134
	References	137
	Author's Publications	155

List of Figures

1.1	Evolution of Wireless Standards	3
1.2	RIS-assisted SISO system.	6
1.3	Block diagram of diversity receiver system.	13
1.4	SIC implemented at NU.	17
2.1	Multiple-IRS-aided SISO communication system with SC receiver.	32
2.2	OP performance with varying N for $M = 2$. The marker, solid and dashed lines denote the simulation, analytical (CLT), and analytical (LSE) results, respectively.	41
2.3	OP performance with varying both M and N_m . The marker, solid, and dashed lines denote the simulation, analytical (CLT), and analytical (LSE) results, respectively.	42
2.4	Asymptotic OP performance with varying both N_m and M . The solid lines and dashed lines denote the simulation and analytical results, respectively.	42
2.5	OP performance with varying N for $M = 2$. The dashed and dotted lines denote the analytical (LSE) and asymptotic results, respectively.	43
2.6	OP performance with varying K . The solid lines and marker denote the analytical and simulation results, respectively.	43
2.7	OP performance with varying M . The solid lines and marker denote the analytical and simulation results, respectively.	44
2.8	OP performance w.r.t d_1 for $M = 2$ and fixed $N_m = 64$. The solid lines and marker denote the analytical and simulation results, respectively.	45
3.1	Multiple IRS-aided SISO communication system with switched diversity schemes.	54
3.2	OP performance w.r.t P (dBm) for without diversity scheme ($M = 1$), SSC scheme ($M = 2$) and SEC scheme ($M = 3, 4$).	64
3.3	OP performance w.r.t P (dBm) for without diversity scheme ($M = 1$) and switched diversity schemes ($M = 2, 3, 4$).	65
3.4	Asymptotic OP performance with varying the number of IRS elements N_m for SSC scheme.	65

3.5	Asymptotic OP performance with varying the number of IRS elements N_m for SEC scheme.	66
3.6	OP performance with varying the fading parameter K for SEC scheme.	66
3.7	OP performance with varying the number of IRS elements in the panels $N_m = 32, 64, 128$ and $M = 4$ for SEC scheme.	67
3.8	OP performance w.r.t threshold γ_{th} of SSC ($M = 2$) and SEC ($M = 3, 4$) schemes at fixed $N_m = 64$	68
3.9	OP performance w.r.t distance d_1 of SEC for $M = 4$ and fixed $N_m = 64$ for SEC.	68
4.1	Multiple IRS-aided SISO wireless network with IRS panel selection.	77
4.2	OP performance with varying N and a fixed $L = 2$	88
4.3	OP vs. P with varying the fading parameter m	89
4.4	OP vs. P with varying IRS Panels (L).	90
4.5	OP vs. P with varying both L and N_l	91
5.1	Two users IRS-assisted downlink power domain NOMA communication system.	96
5.2	BER w.r.t SNR performance of near and far users for fixed $N_m = 64$. The solid lines and marker denote the analytical and simulation results, respectively.	106
5.3	BER performance w.r.t SNR (dB) with varying the fading parameter K . The solid lines and marker denote the analytical and simulation results, respectively.	106
5.4	BER performance with varying the number of IRS elements in the panels $N_m = 32, 64, 128$. The solid lines and marker denote the analytical and simulation results, respectively.	107
5.5	BER performance w.r.t. SNR (dB) with varying the near use power coefficient α . The solid lines and marker denote the analytical and simulation results, respectively.	108
5.6	BER performance of near user w.r.t distance d_1 with varying SNR. The solid lines and marker denote the analytical and simulation results, respectively.	109
5.7	BER performance of far user w.r.t distance d_3 (in meters) with varying SNR. The solid lines and marker denote the analytical and simulation results, respectively.	109
6.1	Proposed IUWB system model. Only 2 channel taps in all the three channels are depicted.	117
6.2	Normalized SNR plot by considering PPS, RPS, and strongest-path methods at the RIS panel for $N = 2$	119
6.3	Average BER of IUWB for $N = 16, 64, 128$ over IEEE 802.15.4a CM1 channel.	123
6.4	BER performance of IUWB and conventional UWB without IRS.	124
6.5	BER performance of IUWB based on IRS position.	124

6.6	The sum-rate vs SNR performance of IUWB system over IEEE 802.15.4a CM1 channel.	125
6.7	Average BER of IUWB for $N=16$ over IEEE 802.15.4a CM1 channel.	126
6.8	Coverage probability versus SNR analysis of IUWB.	127
6.9	Average energy efficiency of IUWB system by varying number of reflecting elements.	128
6.10	Average ToA performance of IUWB. Solid and dashed lines denote the PPS and RPS performance, respectively.	129

List of Tables

1.1	A summary of IRS related works	23
1.2	A summary of NOMA related works	24
4.1	A summary of related works	75
5.1	Experimental values used for simulation and validation	105

Abbreviations

1G	First generation
2G	Second generation
3G	Third generation
4G	Fourth generation
5G	Fifth generation
6G	Sixth generation
ABER	Average bit error rate
AF	Amplify-and-forward
AI	Artificial intelligence
ASER	Average symbol error rate
AWGN	Additive white Gaussian noise
BF	Beam-forming
BER	Bit error rate
BPSK	Binary phase shift keying
BS	Base station
CDF	Cumulative distribution function
CDMA	Code division multiple access
CIR	Channel impulse response
CLT	Central limit theorem
CPS	Coherent phase shift
CSI	Channel state information
D2D	Device-to-device

DF	Decode-and-forward
EGC	Equal gain combining
FCC	Federal Communications Commission
FDMA	Frequency division multiple access
FU	Far user
GHz	Gigahertz
GSM	Global System for Mobile communications
i.i.d.	Independent and identically distributed
i.n.i.d.	Independent and non-identically distributed
IRS	Intelligent reflecting surfaces
IoT	Internet of Things
ISI	Inter-symbol interference
IUWB	IRS-aided ultra-wideband
LoS	Line-of-sight
LSE	Laguerre series expansion
LTE	Long term evolution
MGF	Moment generating function
MIMO	Multiple-input multiple-output
MISO	Multiple-input single-output
ML	Maximum-likelihood
mmWave	Millimeter wave
MRC	Maximal ratio combining
MS	Mobile station
NLoS	Non-line-of-sight
NOMA	Non-orthogonal multiple access
NU	Near user
OMA	Orthogonal multiple access
OP	Outage probability
OTFS	Orthogonal time frequency space

PDF	Probability density function
PLE	path loss exponent
PSK	Phase shift keying
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
Rx	Receiver
RF	Radio-frequency
RIS	Reflecting intelligent surfaces
RQAM	Rectangular quadrature amplitude modulation
RRS	Randomly reconfigurable surfaces
RV	Random variable
SC	Selection combining
SEC	Switch and examine combining
SER	Symbol error rate
SIC	Successive interference cancellation
SISO	Single-input single-output
SNR	Signal-to-noise ratio
SINR	Signal-to-interference plus noise ratio
SQAM	Square quadrature amplitude modulation
SSC	Switch and stay combining
Tx	Transmitter
TDMA	Time division multiple access
ToA	Time-of-arrival
UAV	Unmanned aerial vehicle
UE	User equipment
UMTS	Universal Mobile Telecommunications System
UWB	Ultra-wideband

Symbols

$ \cdot $	Absolute value
${}_1F_1(\cdot, \cdot; \cdot)$	Confluent hypergeometric function
$F_X(\cdot)$	Cumulative distribution function of random variable X
$\mathbb{E}[\cdot]$	Expectation operator
$\exp(\cdot)$	Exponential
$\lfloor \cdot \rfloor$	Floor function
$\Gamma(\cdot)$	Gamma function
$Q(\cdot)$	Gaussian Q -function
$\Im\{\cdot\}$	Imaginary part operator
$\mathcal{L}^{-1}[\cdot]$	Inverse Laplace transform operator
$\kappa - \mu$	Kappa-Mu fading channel
$\mathcal{L}[\cdot]$	Laplace transform operator
$\log_{10}(\cdot)$	Logarithm with base 10
$I_0(\cdot)$	Modified Bessel function of first kind and order zero
$I_\nu(\cdot)$	Modified Bessel function of first kind and order ν
min	Minimum
$Q_\nu(\cdot, \cdot)$	Marcum Q -function of order ν
$\ln(\cdot)$	Natural log
$\ \cdot\ $	Norm
$\prod_{i=1}^n$	Product
$f_X(\cdot)$	Probability density function of random variable X

$\Pr[E]$	Probability of an event E
$\Re\{\cdot\}$	Real part operator
\in	Set membership
$\text{Var}[\cdot]$	Variance

Abstract

With the rapid evolution of wireless communication technologies, the demand for higher data rates and improved quality of service continues to grow, emphasizing the need for increased spectral and energy efficiency. Researchers are actively exploring novel wireless technologies and assessing their performance to meet the requirements of next-generation wireless systems. Intelligent reflecting surfaces (IRS) are recognized as a promising technology capable of augmenting the spectral and energy efficiencies of wireless networks through a cost-effective solution. Therefore, there is considerable interest and demand for the analysis and evaluation of IRS-aided wireless system performance in the context of next-generation networks.

The outage probability (OP) performance of multiple-IRS-assisted single-input-single-output (SISO) wireless communication systems over Rician fading channels, focusing on IRS panel selection is analyzed. Using the central limit theorem (CLT) and Laguerre series expansion (LSE), approximate closed-form expressions for OP are derived. Additionally, a straightforward asymptotic OP is derived to determine diversity order and coding gain. Each system parameter's impact on OP performance is thoroughly examined.

Next, the OP analysis of multiple IRS-assisted SISO systems with switched diversity schemes is presented. OP expressions for the dual-IRS-panel-aided switch and stay combining (SSC) system and multiple-IRS-panel-aided switch and examine combining (SEC) system are analyzed over Rician fading channels. Tight approximate OP expressions in closed form are derived for a large number of IRS elements, along with

a simple asymptotic OP to study diversity order and coding gain. Numerical OP results are provided, accompanied by simulated OP results to validate the accuracy of the analytical analysis.

Further, multiple IRS within a wireless system contribute to enhanced performance, efficiency, and flexibility in wireless networks. The OP for wireless systems aided by multiple IRS panels operating over Nakagami- m fading channels is analyzed. Two closed-form expressions for OP utilizing the CLT and LSE are derived. Moreover, a novel asymptotic OP expression is developed, leading to the discovery of a unique diversity order. The diversity order of the system model in question is contingent on the minimum fading parameter (m) existing between the transmitter-IRS panel and IRS panel-receiver links, alongside the count of IRS panels. A thorough investigation into the impact of system parameters is conducted, and the validity of our analytical findings is confirmed through comprehensive simulations. The results demonstrate the significance of the diversity order, which is closely tied to the minimum fading parameter (m) between the transmitter-IRS panel and IRS panel-receiver links, the number of elements within each IRS panel, and the total number of IRS panels.

Next, bit error rate (BER) performance of an IRS-assisted downlink power domain non-orthogonal multiple access (NOMA) system is analyzed by considering successive interference cancellation (SIC) errors. In this setup, direct links between the base station (BS) and users are obstructed by deep shadowing in IRS-NOMA. The IRS-assisted NOMA system is assumed to experience independent and non-identically distributed (i.n.i.d.) Rician fading channels. Closed-form BER expressions for each user in the IRS-assisted NOMA system are derived. The study investigates the impact of varying IRS element count, IRS-to-BS distance, Rician factor, and power coefficient fluctuations of users on BER performance, validated through simulations.

Lastly, an IRS-assisted ultra-wideband (UWB) communication system, referred to as IUWB, is studied to enhance energy efficiency. To address the limitations of coherent

phase shift schemes at IRS, a novel strongest-path-based phase optimization method is proposed, leveraging time-resolved UWB multipath characteristics. Analysis encompasses the evaluation of BER and sumrate performance of IUWB, comparing it against a standard UWB system without IRS. Impact of various parameters including the number of reflecting elements, diverse UWB channel models, and IRS positioning on the performance of IUWB is considered. Simulation outcomes highlight the advantageous attributes of IUWB, particularly in terms of energy efficiency and sumrate.