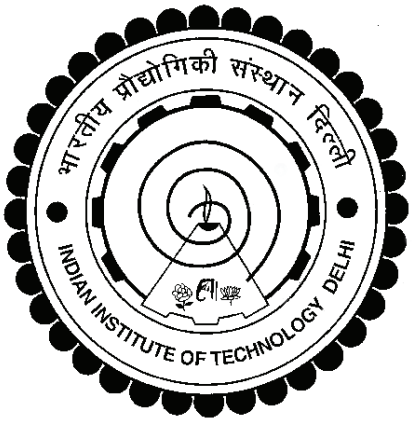
PERFORMANCE OF SPECTRUM-SHARING PROTOCOLS IN CELLULAR NETWORKS

DILEEP KUMAR VERMA



DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI

JUNE 2015

©Indian Institute of Technology (IITD), New Delhi, 2015

PERFORMANCE OF SPECTRUM-SHARING PROTOCOLS IN CELLULAR NETWORKS

by

DILEEP KUMAR VERMA

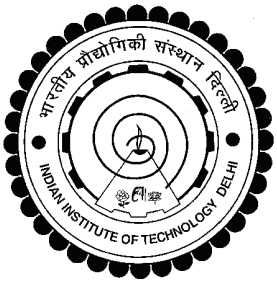
DEPARTMENT OF ELECTRICAL ENGINEERING

submitted

in fulfillment of the requirements of the degree of

Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

JUNE 2015

Certificate

This is to certify that the thesis titled **Performance of Spectrum-Sharing Protocols in Cellular Networks**, submitted by **Dileep Kumar Verma**, to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a bona-fide record of the research work done by him under my supervision.

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.

Prof. Shankar Prakriya
Supervisor
Department of Electrical Engineering
Indian Institute of Technology Delhi
Hauz Khas, New Delhi 110016

Place: New Delhi

Acknowledgements

Foremost, I offer my sincere gratitude to my supervisor Prof. Shankar Prakriya for continuous guidance and support of my Ph.D. for patience and motivation. His vast and deep technical knowledge was always inspiring and motivating for my research. His invaluable suggestions have broadened the horizon of thinking. I could not have imagined having a better mentor for my Ph.D. study.

Besides my supervisor, I would like to express my gratitude to my student research committee members Prof. S.D. Joshi, Prof. Brejesh Lall, and Prof. Monika Aggrawal for their invaluable remarks on my research work. I would also like to thank Prof. Surendra Prasad and Prof. S.D. Joshi for his encouragement and suggestions during course work. My sincere thanks goes to all the faculty members from whom I learned something new during my Ph.D. study.

I would like to thank Dr. Prabhat Kumar Upadhyay, Dr. Pravesh Biyani and Dr. S.M. Zafaruddin for their support, suggestions and enlightening me the first glance of research. I would also like to thank Mr. Anup Kumar Mandpura, Mr. Komal Janghel, Mr. M. Sudhakar, Mr. Bhupendra Sharma, Mr. Pratik chakraborty and all my friends of IIT Delhi.

Finally, I would like to express my greatest gratitude to my parents Sh. Ram Pratap Verma and Smt. Krishna Devi Verma, for their blessings. I would like to thank my younger brother Ajit Kumar Verma. Last but not the least, I would like to thank my wife Nutan Gangwar Verma and son Aadya Dev Verma for being the encouragement for me.

Dileep Kumar Verma

Abstract

Ever increasing demand for high-rate data services has resulted in acute spectrum shortage. A lot of research in recent years has focussed on techniques that allow for more efficient utilization of the spectrum. Use of smaller cell-sizes and a higher frequency reuse factor have been suggested. Increase in resulting interference needs to be dealt with–use of inter-cell coordination and shared relays have been studied in this context.

Signalling techniques that allow for efficient use of the spectrum *within* a cell are attractive from an implementation point of view. In recent years, cooperative spatial multiplexing has been studied. In these systems, the base-station multiplexes data to two users. It has been shown that user selection can yield performance gains. In this thesis, outage and ergodic rate expressions are derived to show that relay selection can further improve performance of these systems.

Simultaneously, there has been concerted effort to develop cognitive radio technologies. By allowing unlicensed users to use the spectrum when the licensed user is inactive, it has been shown that the spectrum can be more efficiently utilized. In recent years it has been shown that the unlicensed users can be allowed to transmit even when the licensed user is utilizing the spectrum, provided it controls its power to limit interference to the licensed user. These dynamic spectrum access (DSA) systems have potential to increase spectrum utilization. However, they require licensing agreements between networks, and some limited communication between the networks. There are also security issues, which make practical implementation of these systems difficult. In this thesis, it is shown that use of DSA principles to allow two cellular users of the *same* network to utilize the spectrum is simpler,

and can be very beneficial. In particular, it is shown that use of these principles in a cooperative multiplexing network with relay and user selection can result in good outage performance. Expressions are derived for the outage probability and ergodic rate to demonstrate this. It is also shown that these principles can be used to spatially multiplex uplink and downlink of cellular systems. Two protocols are discussed, and their performance is analysed. These protocols exploit the rate asymmetry in uplink and downlink of a cellular system. The outage probability analysis presented clearly brings out the potential of these protocols in improving spectrum utilization efficiencies in cellular networks.

Table of Contents

Acknowledgements **i**

Abstract **ii**

List of Tables **vii**

List of Figures **ix**

Abbreviations **x**

Notation **xi**

1 Introduction **1**

1.1 Introduction 1

1.1.1 Cooperative Multiplexing 3

1.1.2 Cognitive Radio 4

1.2 Literature Survey 7

1.3 Motivation 9

1.4 Contributions 11

1.5 Organization of Thesis 12

2 Performance Analysis of a Cooperative Multiplexing and Scheduling Scheme **13**

2.1 Introduction 13

2.2 System Model Description 14

2.2.1 AF-Relaying 17

2.2.2 DF-Relaying 20

2.3 Outage Performance & Power Control 22

2.3.1 Outage probability for AF-relaying 23
2.3.2 Outage probability for DF-relaying 26
2.4 Ergodic Sum-rate 28
2.4.1 Ergodic sum-rate for AF-relaying 28
2.4.2 Ergodic sum-rate for DF-relaying 32
2.5 Numerical and Simulation Results 34
2.6 Conclusion 42
2.7 Appendices 43

3 Performance Analysis of a Cooperative Multiplexing Scheme in DSA Framework 45

3.1 Introduction 46
3.2 System Model Description and Problem Formulation 47
3.2.1 Signal Transmission 49
3.2.2 Node selection Schemes 51
3.3 Performance Analysis 54
3.3.1 Outage Probability 54
3.3.2 Achievable Ergodic Rate 65
3.4 Simulation Results and Discussion 69
3.5 Conclusion 77
3.6 Appendices 78
3.6.1 Appendix A 78
3.6.2 Appendix B 81

4 Performance Analysis of Simultaneous UL/DL Transmission 83

4.1 Introduction 83
4.2 UL/DL multiplexing with relay selection in DL 84
4.2.1 Outage Analysis with Relay Selection in DL 89
4.2.2 Simulation Results and Discussion 94
4.3 UL/DL Multiplexing with Beamforming in DL 97
4.3.1 Outage Performance Analysis 100

4.3.2 Simulation Results and Discussion 104
4.4 Conclusion 108

5 Conclusions and Future Work **109**
5.1 Conclusions 109
5.2 Future Work 110

Bibliography **111**

List of Tables

2.1 Outage sub-optimal power allocation factor (ζ_{BS}) with AF-relaying for various $\{J, K\}$. 34

2.2 Outage sub-optimal power allocation factor (ζ_{BS}) with DF-relaying for various J, K. 35

List of Figures

1.1 Two-hop relay network. 2

1.2 Cooperative multiplexing network 3

1.3 DSA Framework 4

2.1 Cellular communication network using CMS scheme. 15

2.2 An outline of the sequence of steps in CMS scheme. 15

2.3 An illustration of outage performance of AF and DF relaying in CMS scheme. 36

2.4 Outage performance of AF relaying for various cluster sizes. . . 37

2.5 Outage performance of DF relaying for various cluster sizes. . . 38

2.6 An illustration of ergodic sum-rate performance of AF and DF relaying in CMS scheme. 39

2.7 Ergodic sum-rate performance for varying cluster size of relays. 40

2.8 An illustration of ergodic sum-rate performance for fixed number of nodes in SU and relays in cluster. 41

3.1 System model for cooperative downlink multiplexing scheme using DSA framework. 48

3.2 An outline of the sequence of steps in cooperative downlink multiplexing scheme using DSA framework. 49

3.3 An illustration of outage probabilities versus PDA factor α. . . . 70

3.4 Secondary outage probability $p_{o,s}$ versus SNR γ in dB where the best possible PDA factor α for each scheme is taken. 71

3.5 Secondary outage probability $p_{o,s}$ versus number of secondary nodes. 72

3.6 Secondary outage probability $p_{o,s}$ versus number of nodes J with consideration of the best possible PDA factor α for each scheme. Here total $J + K = 8$ secondary nodes are considered. 73

3.7 An illustration of secondary outage probability $p_{o,s}^{\text{HS}}$ versus PDA factor α for demonstrating the impact of distances. For this, the optimal $\alpha_{\text{hs}}^{\star}$ for each case is also presented. 75

3.8 An illustration of ergodic rate $\overline{R}_s$ versus PDA factor α with $d_{h_1} = 0.8$ and $d_{h_2} = 1.2$. 76

3.9 Ergodic rate $\overline{R}_s$ versus SNR γ in dB for the best possible PDA factor α for each SNR with $d_{h_1} = 0.8$ and $d_{h_2} = 1.2$. 77

4.1 System model for cooperative DL multiplexing scheme using DSA framework. 85

4.2 An outline of the sequence of steps in cooperative DL multiplexing scheme using DSA framework. 86

4.3 Uplink outage probability $p_{o,s}$ versus SNR γ in dB for various ITLs. 95

4.4 Uplink outage probability $p_{o,s}$ versus τ ratio of UL data rate to DL data rate. 96

4.5 An outline of the sequence of steps in UL/DL multiplexing with beamforming in DL scheme. 97

4.6 An illustration of outage performance of UL network for target $p_{o,p}^{\star} = 10^{-3}$. 105

4.7 An illustration of outage performance of UL network for target $p_{o,p}^{\star} = 10^{-3}$ at high SNR $\gamma = 21$ dB. 106

4.8 The outage performance of UL network for illustrating the effect of unequal target rate. 107

Abbreviations

AF	Amplify and Forward
AWGN	Additive White Gaussian Noise
BS	Base Station
CDF	Cumulative Distribution Function
CMS	Cooperative Multiplexing and Scheduling
CRN	Cognitive Radio Network
CSI	Channel State Information
DF	Decode and Forward
DSA	Dynamic Spectrum Access
DL	Downlink
GS	Gain based Selection
HS	Hybrid Scheme
IC	Interference Cancellation
ITL	Interference Tolerance Limit
PDA	Phase Duration Allocation
PDF	Probability Density Function
PU	Primary User
RS	Relay Station
SINR	Signal to Interference plus Noise Ratio
SNR	Signal to Noise Ratio
SS	SINR based Selection
SU	Secondary User
UL	Uplink

Notation

$\sim$	Distributed as
α	PDA factor
$\mathcal{A}$	Set or cluster of nodes
$\|\mathcal{A}\|$	Cadinality of set $\mathcal{A}$
$\mathbf{a}$	Vector
$\|\mathbf{a}\|$	Euclidean norm of $\mathbf{a}$
$\mathbf{a}^T$	Transposition of $\mathbf{a}$
$\mathbf{a}^H$	Hermitian of $\mathbf{a}$
$\Gamma(m)$	Gamma function of m defined as $\Gamma(m) = \int_0^\infty t^{m-1}e^{-t}\ \mathrm{d}t$
$m!$	Factorial of integer m
$\gamma_{\text{inc}}(k,x)$	Lower incomplete Gamma function defined as $\frac{1}{\Gamma(k)}\int_0^x t^{k-1}\exp(-t)\ \mathrm{d}t$
$\Gamma_{\text{inc}}(k,x)$	Upper incomplete Gamma function defined as $\frac{1}{\Gamma(k)}\int_x^\infty t^{k-1}\exp(-t)\ \mathrm{d}t$
$\mathbf{E}_k(x)$	Exponential integral of order k defined as $\int_1^\infty \frac{\exp(-xt)}{t^k}\ \mathrm{d}t$
$\mathcal{CN}(m,\sigma^2)$	Circularly symmetric complex Gaussian distribution with mean m and variance σ^2
$\mathcal{E}[X]$	Expected value of X
$\overline{R}$	Ergodic rate $\mathcal{E}[R]$
ϵ	Path-loss exponent
ζ	Power allocation factor