PERFORMANCE OF COOPERATIVE DIVERSITY SYSTEMS WITH DECODE AND FORWARD RELAYING

by

M. D. SELVARAJ

DEPARTMENT OF ELECTRICAL ENGINEERING

Submitted

in fulfillment of the requirements of the degree of

Doctor of Philosophy

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI
JULY 2009

Certificate

This is to certify that the thesis entitled **"Performance of Cooperative Diversity Systems with Decode and Forward Relaying"** being submitted by M. D. Selvaraj to the Department of Electrical Engineering, 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 him 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.

(Prof. Ranjan K. Mallik)
Thesis Supervisor
Department of Electrical Engineering
Indian Institute of Technology, Delhi
Hauz Khas, New Delhi 110016
India

Acknowledgements

I first thank my supervisor Prof. Ranjan K. Mallik for his enthusiastic guidance of my research. I have not only learned how to solve research problems and write papers from him, but also his attitude of conducting research. I can never forget the days when we transferred emails till early in the morning. He has helped me to reach several milestones as a research student, and prepared me to reach many more.

I would to like to thank my student-research committee members Prof. Arun Kumar, Prof. Shankar Prakriya, and Prof. Brejesh Lall. Their encouragement and support have helped me tremendously throughout my research. I will always be thankful to my teachers at IIT Delhi for all the hard work and efforts they have put in for educating me.

I would like to thank all the laboratory and supporting staff of EE department and Bharti School for their great support and help. I am thankful to my friends for providing a homelike environment in IIT Delhi. Finally, I thank my mother Nagammal, brother Shanmugavelu, and sister Bakialakshmi for letting me do what I always wanted to do. I salute them for their unconditional love and sacrifice.

M. D. Selvaraj

Abstract

Diversity techniques mitigate the adverse effects of fading in wireless communications. One of the several forms of diversity is spatial diversity, which creates multiple fading paths between the transmitter and the receiver. Achieving spatial diversity in a mobile unit requires the use of multiple antennas, which, in turn, increases its hardware complexity and size. To overcome this problem, a recent development envisages a type of spatial diversity called "distributed spatial diversity", where mobile units which are distributed in different geographical locations generate multiple communication paths. Practical implementation of distributed spatial diversity requires some sort of cooperation among the mobile units, which is achieved through a method called "user cooperation". In this method, single antenna mobile units share their antennas with other mobile units, thereby creating space diversity.

A variety of low complexity protocols has been developed to enhance performance of cooperative communication. One such protocol is the *decode and forward (DF)* protocol, where one or more relays detect the source's data and forward it to the destination. We focus on a scenario where, for the transmission of a data symbol from the source to the destination, the relays cooperate with the source through the DF protocol. We consider flat Rayleigh fading, and assume perfect channel state information (CSI) at the relays and at the destination. Although it has been shown that cooperative diversity systems with error correcting codes can improve the system performance considerably, to bring out analytically the effect of the system parameters on the raw data error performance, we focus on only uncoded cooperative diversity systems.

In this thesis, we first consider a single-relay cooperative diversity system consisting of a source, a relay and a destination. A selection combining scheme is used to obtain an easily implementable receiver structure at the destination. We derive, in closed form, the end-to-end symbol error probability (SEP) of the system for binary phase-shift keying (BPSK). By means of a paired error approach, the analysis is extended to the case of M-ary phase-shift keying (MPSK).

Next, we consider a multi-relay cooperative diversity network consisting of a source, N relays, and a destination. In a conventional signal-to-noise ratio (SNR) based selection combining scheme at the destination, the effect of the source-to-relay links is not accounted for when choosing one link from the set consisting of the source-to-destination link and the N relay-to-destination links. To overcome this drawback, we modify the conventional scheme by including, in the selection process, a deterministic scale factor that incorporates the effect of the source-to-relay links. We call this modified scheme a scaled selection combining scheme. For statistically independent links that undergo flat Rayleigh fading, we derive, in closed form, the end-to-end SEP of this scheme for both BPSK and MPSK constellations. We also give a method of obtaining the optimum scale factor that minimizes the end-to-end SEP.

Finally, the performance of the optimum receiver is analyzed for a single-relay cooperative diversity system. The optimum receiver for this system is presented, and, from the decision rule, the end-to-end SEP is analyzed. We propose a suboptimum receiver which does not need the CSI of the source-to-relay link and performs close to the optimum receiver.

Contents