Transmission Resource Allocation in Multi-Antenna Wireless Communication Systems with Channel Uncertainty

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Declaration

The contents of this thesis are the results of original research and have not been submitted for a higher degree to any other university or institution.

Much of the work in this thesis has been published or has been submitted for publication as journal papers or conference proceedings. These papers are:

Journal articles

J1. Xiangyun Zhou, Parastoo Sadeghi, Tharaka A. Lamahewa, and Salman Durrani, "Optimizing Antenna Configuration for MIMO Systems with Imperfect Channel Estimation", *IEEE Trans. Wireless. Commun.*, vol. 8, no. 3, pp. 1177-1181, Mar. 2009.

J2. Xiangyun Zhou, Parastoo Sadeghi, Tharaka A. Lamahewa, and Salman Durrani, "Design Guidelines for Training-based MIMO Systems with Feedback", *IEEE Trans. Signal Processing*, vol. 57, no. 10, pp. 4014-4026, Oct. 2009.

J3. Xiangyun Zhou, Tharaka A. Lamahewa, Parastoo Sadeghi, and Salman Durrani, "Two-way Training: Optimal Power Allocation for Pilot and Data Transmission", *IEEE Trans. Wireless Commun.*, vol 9, no. 2, pp. 564-569, Feb. 2010.

J4. Xiangyun Zhou and Matthew R. McKay, "Secure Transmission with Artificial Noise over Fading Channels: Achievable Rate and Optimal Power Allocation", submitted to *IEEE Trans. Veh. Technol.*, revised in May 2010.

Conference papers

C1. Xiangyun Zhou, Tharaka A. Lamahewa, Parastoo Sadeghi, and Salman Durrani, "Capacity of MIMO Systems: Impact of Spatial Correlation with Channel Estimation Errors", in *Proc. IEEE Int. Conf. on Commun. Syst. (ICCS)*, Guangzhou, China, Nov. 2008, pp. 817-822.

C2. Xiangyun Zhou and Matthew R. McKay, "Physical Layer Security with Artificial Noise: Secrecy Capacity and Optimal Power Allocation", in *Proc. Int. Conf. on Signal Processing and Commun. Syst. (ICSPCS)*, Omaha, NE, Sept. 2009, pp. 1-5.

C3. Xiangyun Zhou, Tharaka A. Lamahewa, Parastoo Sadeghi, and Salman Durrani, "Optimizing Training-based Transmission for Correlated MIMO Systems with Hybrid Feedback", in *Proc. IEEE Global Commun. Conf. (Globecom)*, Honolulu, HI, Nov. 2009, pp. 1-6.

C4. Xiangyun Zhou, Parastoo Sadeghi, and Tharaka A. Lamahewa, "Optimizing Training-based MIMO Systems: How Much Time is Needed for Actual Transmission?", in *Proc. IEEE Veh. Tech. Conf. (VTC-Spring)*, Taipei, Taiwan, May 2010, pp. 1-5.

The following publications are also the results from my Ph.D. study but not included in this thesis:

Journal articles

J5. Tharaka A. Lamahewa, Parastoo Sadeghi, and Xiangyun Zhou "On Lower Bounding the Information Capacity of Amplify and Forward Wireless Relay Channels with Channel Estimation Errors", submitted to *IEEE Trans. Wireless. Commun.*, May 2010.

Conference papers

C5. Xiangyun Zhou, Tharaka A. Lamahewa, Parastoo Sadeghi, and Salman Durrani, "Designing PSAM Schemes: How Optimal are SISO Pilot Parameters for Spatially Correlated SIMO?", in *Proc. IEEE Int. Symp. on Personal, Indoor and Mobile Radio Commun. (PIMRC)*, Cannes, France, Sept. 2008, pp. 1-6.

C6. Xiangyun Zhou, Tharaka A. Lamahewa, and Parastoo Sadeghi "Kalman Filter-based Channel Estimation for Amplify and Forward Relay Communications", in *Proc. IEEE Asilomar Conf. on Signals, Syst. and Computers (ACSSC)*, Pacific Grove, CA, Nov. 2009, pp. 1-5.

The research work presented in this thesis has been performed jointly with Dr. Parastoo Sadeghi (The Australian National University), Dr. Tharaka A. Lamahewa (The Australian National University), Dr. Salman Durrani (The Australian National University), and Prof. Matthew R. McKay (Hong Kong University of

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Abstract

In this thesis we investigate the design of transmission resource allocation in current and future wireless communication systems. We focus on systems with multiple antennas and characterize their performance from an information-theoretic viewpoint. The goal of this work is to provide practical transmission and resource allocation strategies taking into account imperfections in estimating the wireless channel, as well as the broadcast nature of the wireless channel.

In the first part of the thesis, we consider training-based transmission schemes in which pilot symbols are inserted into data blocks to facilitate channel estimation. We consider one-way training-based systems with and without feedback, as well as two-way training-based systems. Two-way training enables both the transmitter and the receiver to obtain the channel state information (CSI) through reverse training and forward training, respectively. In all considered cases, we derive efficient strategies for transmit time and/or energy allocation among the pilot and data symbols. These strategies usually have analytical closed-form expressions and can achieve near optimal capacity performance evidenced by extensive numerical analysis.

In one-way training-based systems without feedback, we consider both spatially independent and correlated channels. For spatially independent channels, we provide analytical bounds on the optimal training length and study the optimal antenna configuration that maximizes an ergodic capacity lower bound. For spatially correlated channels, we provide simple pilot and data transmission strategies that are robust under least-favorable channel correlation conditions.

In one-way training-based systems with feedback, we study channel gain feedback (CGF), channel covariance feedback (CCF) and hybrid feedback. For spatially independent channels with CGF, we show that the solutions to the optimal training length and energy coincide with those for systems without feedback. For spatially correlated channels with CCF, we propose a simple transmission scheme, taking into account the fact that the optimal training length is at most as large as the number of transmit antennas. We then provide a solution to the optimal energy

allocation between pilot and data transmissions, which does not depend on the channel spatial correlation under a mild condition. Our derived resource allocation strategies in CGF and CCF systems are extended to hybrid CCF-CGF systems.

In two-way training-based systems, we provide analytical solutions to the transmit power distribution among the different training phases and the data transmission phase. These solutions are shown to have near optimal symbol error rate (SER) and capacity performance. We find that the use of two-way training can provide noticeable performance improvement over reverse training only when the system is operating at moderate to high signal-to-noise ratio (SNR) and using high-order modulations. While this improvement from two-way training is insignificant at low SNR or low-order modulations.

In the second part of the thesis, we consider transmission resource allocation in security-constrained systems. Due to the broadcast nature of the wireless medium, security is a fundamental issue in wireless communications. To guarantee secure communication in the presence of eavesdroppers, we consider a multi-antenna transmission strategy which sends both an information signal to the intended receiver and a noise-like signal isotropically to confuse the eavesdroppers. We study the optimal transmit power allocation between the information signal and the artificial noise. In particular, we show that equal power allocation is a near optimal strategy for non-colluding eavesdroppers, while more power should be used to generate the artificial noise for colluding eavesdroppers. In the presence of channel estimation errors, we find that it is better to create more artificial noise than to increase the information signal strength.

List of Acronyms

AWGN	additive white Gaussian noise
CCF	channel covariance feedback
CGF	channel gain feedback
CSI	channel state information
EVD	eigenvalue decomposition
GSM	global system for mobile communications
LMMSE	linear minimum mean square error
MIMO	multiple-input multiple-output
MISO	multiple-input single-output
OFDM	orthogonal frequency-division multiplexing
PSAM	pilot-symbol-assisted modulation
PSK	phase shift keying
QAM	quadrature amplitude modulation
QoS	quality of service
QPSK	quadrature phase shift keying
SER	symbol error rate
SIMO	single-input multiple-output
SINR	signal to interference and noise ratio
SNR	signal-to-noise ratio
TDD	time-division duplex
UCA	uniform circular array
WLAN	wireless local area network
WMAN	wireless metropolitan area network
ZMCSCG	zero-mean circularly symmetric complex Gaussian

Notations

$\boldsymbol{A}^\dagger$	complex conjugate transpose of matrix $\boldsymbol{A}$
$\boldsymbol{a}^\dagger$	complex conjugate transpose of vector $\boldsymbol{a}$
$\boldsymbol{A}^T$	transpose of matrix $\boldsymbol{A}$
$\boldsymbol{a}^T$	transpose of vector $\boldsymbol{a}$
$\boldsymbol{A}^*$	complex conjugate of matrix $\boldsymbol{A}$
$\boldsymbol{a}^*$	complex conjugate of vector $\boldsymbol{a}$
$\|\boldsymbol{a}\|$	Euclidian norm of vector $\boldsymbol{a}$
$\lvert\boldsymbol{A}\rvert$	determinant of matrix $\boldsymbol{A}$
$\lvert a\rvert$	absolute value of scalar a
$\mathrm{tr}\{\boldsymbol{A}\}$	trace of matrix $\boldsymbol{A}$
$\boldsymbol{I}_n$	$n \times n$ identity matrix
$E\{\cdot\}$	mathematical expectation
$\Gamma(\cdot)$	the Gamma function
$\mathrm{E}_n(\cdot)$	the generalized exponential integral
$\mathrm{B}(\cdot,\cdot)$	the Beta function
${}_2\mathrm{F}_1(\cdot)$	the Gauss hypergeometric function

Contents

List of Figures

List of Tables