Postgraduate Course
From Array Processing to MIMO Communications
(MSc)

Instructor Information

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Course Information

Course Description

This course presents the fundamental concepts and techniques of multiple-input multiple-output (MIMO) communications over wireless communication channels. MIMO communications, which involve the use of multiple antennas at the transmitter and receiver, employ the use of signal processing techniques to enhance the reliability and capacity of communication systems without increasing the required spectral bandwidth. MIMO techniques are currently used or planned in many commercial and military communications systems. Topics include the derivation and application of the theoretical MIMO communications capacity formula; channel fading and multipath propagation; the concepts of transmit and receive space diversity; space-time block coding, with a special emphasis on Alamouti coding; space-time trellis coding; spatial multiplexing; and fundamentals of OFDM modulation and its relation to MIMO communications. Examples and applications will be presented as well as related MATLAB homework assignments.

Prerequisites

Digital Communication fundamentals.

Probability and Stochastic Processes for Engineers

Advanced Digital Signal Processing

In addition, a working knowledge of MATLAB is required.

Course Goal

To develop an understanding of the concepts and mathematical techniques that underlie MIMO wireless communications.

Summary of intended course outcomes

The students will understand fundamentals as well as advanced concepts in array processing and MIMO Systems. They will be able to learn the recent developments such as opportunistic and multi-user multiple input multiple output (MIMO) communication techniques. These techniques have brought completely new perspectives on how to communicate over wireless channels. They will be able to quantify the wireless channel capacities and degrees of freedom regions for different channel models, such as multiple access channels, broadcast channels, interference channels, etc. Finally, they will be able to design and analysis the advanced cellular systems, for example interim of spectral and energy efficiencies, coverage, etc.By the end of the course, students should be able to:

- Grasp the phenomenology and theory that give rise to improved reliability and the dramatic increases in data rates enabled by MIMO.
- Analyze, design, and simulate MIMO communication systems.
- Be familiar with practical applications of MIMO communications.

Syllabus

Introduction
Overview of information theory
MIMO channel modelling

This chapter is based on textbooks [1, chapter 5] and [6, chapter 2].
Additional material on broadband channel model will be provided by the instructor.
Discussion papers [1, 4]
Assignment: development of Matlab computer programs to simulate and study different channel models. Location: assigned room (or laboratory)

Array Processing
Optimum Beamforming
Adaptive Beamformers
Subspace Methods

This chapter is based on textbooks [1, chapter 5] and [6, chapter 2].
Additional material on subspace methods will be provided by the instructor.
Discussion papers [1, 4]
Assignment: development of Matlab computer programs to simulate and study various beamforming strategies. Location: assigned room (or laboratory)

Single user communications
Diversity combining
Alamouti coding
Space-time block coding
Space-time trellis coding
Spatial multiplexing
Multi-layered space-time coding
Broadband MIMO techniques

This chapter is based on textbooks [1, chapter 5] and [6, chapter 2].
Additional material on subspace methods will be provided by the instructor.
Discussion papers [1, 4]
Assignment: development of Matlab computer programs to simulate and study various beamforming strategies. Location: assigned room (or laboratory)

Multiuser communications
Multi-User MIMO - Multiple Access Channels (Uplink)
Multi-User MIMO - Broadcast Channels (Downlink)
Multi-User MIMO - Scheduling and Precoding (Downlink)

This chapter is based on textbooks [1, chapter 5] and [6, chapter 2].
Additional material on subspace methods will be provided by the instructor.
Discussion papers [1, 4]
Assignment: development of Matlab computer programs to simulate and study various beamforming strategies. Location: assigned room (or laboratory)

Multiuser multicell communications
Cooperative communications
Optimization of relaying communications
Network coding

This chapter is based on textbooks [1, chapter 5] and [6, chapter 2].
Additional material on subspace methods will be provided by the instructor.
Discussion papers [1, 4]

Assignment: development of Matlab computer programs to simulate and study various beamforming strategies. Location: assigned room (or laboratory)

Massive MIMO
Fundamentals and limitations
Uplink and downlink optimization
This chapter is based on textbooks [1, chapter 5] and [6, chapter 2].
Additional material on subspace methods will be provided by the instructor.
Discussion papers [1, 4]
Assignment: development of Matlab computer programs to simulate and study various beamforming strategies. Location: assigned room (or laboratory)

Textbooks:

D. Tse and P. Viswanath, *Fundamentals of wireless communications*, Cambridge Press 2005.

Recommended reading material:

1. B. Vucetic and J. Yuan, *Space-time coding*, Wiley, 2002.
2. A. Paulraj *et al.*, *Introduction to space-time wireless communications*, Cambridge Press, 2003.
3. H. Jafarkhani, *Space-time coding*, Cambridge Press, 2005.
4. G. B. Giannakis *et al.*, *Space-time coding for broadband wireless communications*, Wiley, 2006.
5. M. K. Simon and M.-S. Alouini, *Digital communication over fading channels: a unified approach to performance analysis*, 2nd edition, Wiley 2005.
6. A. Goldsmith, *Wireless communications*, Cambridge Press 2005.
7. E. G. Larsson and P. Stoica, *Space-time block coding for wireless communications*, Cambridge University Press, 2003.
8. T. M. Cover and J. A. Thomas, *Elements of information theory*, 2nd edition, John Wiley & Sons, 2006.
9. Y. Raymond, *Information theory and network coding*, 2nd edition, New York, Springer, 2008.

Student Assessment Criteria

Overview of selected papers (3)	10%
Final Exam	60%
Project (computer simulations)	30%

Since it is often difficult to develop simple closed-form solutions for the performance of MIMO communication systems, numerous graded projects will be assigned throughout the semester that involve the development of Matlab computer programs to simulate and study various aspects of MIMO. These projects are an indispensible means of gaining an indepth understanding of MIMO concepts.