Multiuser Communications in Wireless Networks

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Course period	21 Sep 2011 - 30 Nov 2011

Course Description: The class focuses on fundamental aspects of modern wireless communication systems. The course starts by reintroducing the concept of channel capacity as the basic performance measure of communication channels. A single-user single-antenna setting is revisited followed by the multiple access problem over (non-)fading channels both in uplink and downlink. After reviewing the basics in a single-user multiple-input multiple-output (MIMO) communications, the main focus is shifted to multiuser multiantenna communications. Capacity optimal transmission strategies for both uplink and downlink directions are addressed. Finally, optimal multiuser MIMO communications in a multi-cell scenario is discussed.

Keywords: Channel capacity, multiuser communications, MIMO (multiple input multiple output) communications, opportunistic communications, capacity of wireless network, interference management, coordinated multi-cell transmission, scheduling, radio resource management, convex optimisation

Time span: The lectures begin **21 September 2011** and last until 30 November 2011.

Place and time: Weekly three-hour lectures are given on Wednesdays at 13:15 – 16:00 in the lecture room TS407.

Homework assignments: Before attending a lecture, students must read from the text book the currently covered chapter. Students are also asked to solve few homeworks. Homework solving sessions are organised on Tuesdays at 12:15 – 14:00 by Harri Pennanen in the lecture room TS133.

Credits: The course can be taken by both master and doctoral students. The number of credit points is seven (7).

Exam: The exam date(s) and the form of examination will be communicated later.

Prerequisites: A prerequisite for this course is a working knowledge in digital communications, random processes, linear algebra, and detection theory. Also, students are asked to read chapters 1-4 from the textbook before attending the course. Some prior knowledge of information theory and convex optimisation is very useful but not mandatory.

1 Course Material

- D. N. C. Tse and P. Viswanath, Fundamentals of Wireless Communication. Cambridge University Press, 2005, Chapters 5-10

In addition, some of the lectures will be based on the following journal publications. A subset (4-5) of the papers will be included in the mandatory reading material.

- G. Caire and S. Shamai, On the achievable throughput of a multiantenna Gaussian broadcast channel, IEEE Trans. Inform. Theory, vol. 49, no. 7, pp. 1691–1706, Jul. 2003.
- S. Vishwanath, N. Jindal, and A. Goldsmith, Duality, achievable rates, and sum-rate capacity of Gaussian MIMO broadcast channels, IEEE Trans. Inform. Theory, vol. 49, no. 10, pp. 2658–2668, Oct. 2003.
- P. Viswanath and D. Tse, Sum capacity of the vector Gaussian broadcast channel and uplink-downlink duality, IEEE Trans. Inform. Theory, vol. 49, no. 8, pp. 1912–1921, Aug. 2003.
- W. Yu and J. Cioffi, Sum capacity of Gaussian vector broadcast channels, IEEE Trans. Inform. Theory, vol. 50, no. 9, pp. 1875–1892, Sep. 2004.
- H. Weingarten, Y. Steinberg, and S. Shamai, The capacity region of the Gaussian multiple-input multiple-output broadcast channel, IEEE Trans. Inform. Theory, vol. 52, no. 9, pp. 3936–3964, Sep. 2006
- W. Yu, W. Rhee, S. Boyd, and J. Cioffi, Iterative water-filling for Gaussian vector multiple-access channels, IEEE Trans. Inform. Theory, vol. 50, no. 1, pp. 145–152, Jan. 2004.
- S. Ye and R. S. Blum, Optimized signaling for MIMO interference systems with feedback, IEEE Trans. Signal Processing, vol. 51, pp. 2839–2847, Nov. 2003.
- N. Jindal, S. Vishwanath, and A. Goldsmith, On the duality of Gaussian multiple-access and broadcast channels, IEEE Trans. Inform. Theory, vol. 50, no. 5, pp. 768–783, May 2004.
- W. Yu, Uplink-downlink duality via minimax duality, IEEE Trans. Inform. Theory, vol. 52, no. 2, pp. 361–374, Feb. 2006.
- W. Yu and T. Lan, Transmitter optimization for the multi-antenna downlink with per-antenna power constraints, IEEE Trans. Signal Processing, vol. 55, no. 6, part 1, pp. 2646–2660, Jun. 2007.
- N. Jindal, W. Rhee, S. Vishwanath, S. Jafar, and A. Goldsmith, Sum power iterative water-filling for multi-antenna Gaussian broadcast channels, IEEE Trans. Inform. Theory, vol. 51, no. 4, pp. 1570– 1580, Apr. 2005.
- H. Viswanathan, S. Venkatesan, and H. Huang, Downlink capacity evaluation of cellular networks with known-interference cancellation, IEEE J. Select. Areas Commun., vol. 21, no. 5, pp. 802–811, Jun. 2003.

Supporting material

- Cover & Thomas, "Elements of Information Theory", John Wiley & Sons
- Boyd & Vandenberghe, "Convex Optimization", Cambridge University Press, 2004

2 Content

1. Introduction
   - 1.1 Course objective
   - 1.2 Wireless systems
   - 1.3 Course outline
2. Capacity of point-to-point wireless channels
   - 2.1 AWGN channel capacity
   - 2.2 Resources (power and bandwidth) of the AWGN channel
   - 2.3 Linear time-invariant Gaussian channels
     - 2.3.1 Single input multiple output (SIMO) channel
     - 2.3.2 Multiple input single output (MISO) channel
     - 2.3.3 Frequency-selective channel
   - 2.4 Capacity of fading channels
     - 2.4.1 Slow fading channel
     - 2.4.2 Receive diversity
     - 2.4.3 Transmit diversity
     - 2.4.4 Time and frequency diversity
     - 2.4.5 Fast fading channel
     - 2.4.6 Transmitter side information
     - 2.4.7 Frequency-selective fading channels
3. Multiuser capacity
   - 3.1 Uplink AWGN channel
     - 3.1.1 Capacity via successive interference cancellation
     - 3.1.2 Comparison with orthogonal multiple access
     - 3.1.3 General K-user uplink capacity
   - 3.2 Downlink AWGN channel
     - 3.2.1 Symmetric case: two capacity-achieving schemes
     - 3.2.2 General case: superposition coding achieves capacity
   - 3.3 Uplink fading channel
     - 3.3.1 Slow fading channel
     - 3.3.2 Fast fading channel
     - 3.3.3 Full channel side information
   - 3.4 Downlink fading channel
     - 3.4.1 Channel side information at receiver only
     - 3.4.2 Full channel side information
     - 3.4.3 Frequency-selective fading channels
   - 3.5 Multiuser diversity
     - 3.5.1 Multiuser diversity gain

- 3.5.2 Multiuser versus classical diversity
- 3.6 Multiuser diversity: system aspects
  - 3.6.1 Fair scheduling and multiuser diversity
  - 3.6.2 Channel prediction and feedback
  - 3.6.3 Opportunistic beamforming
  - 3.6.4 Multiuser diversity in multicell systems

4. Point-to-point MIMO
   - 4.1 Multiplexing capability of deterministic MIMO channels
     - 4.1.1 Capacity via singular value decomposition
     - 4.1.2 Rank and condition number
   - 4.2 Physical modeling of MIMO channels
   - 4.3 Fast fading MIMO channel
     - 4.3.1 Spatial multiplexing of independent streams: capacity achieving architecture
     - 4.3.2 Capacity with CSI at receiver
     - 4.3.3 Performance gains
     - 4.3.4 Full CSI
   - 4.4 Receiver architectures
     - 4.4.1 Linear decorrelator
     - 4.4.2 Successive cancellation
     - 4.4.3 Linear MMSE receiver
     - 4.4.4 Information theoretic optimality
   - 4.5 Slow fading MIMO channel
     - 4.5.1 Coding across transmit antennas: an outage-optimal architecture

5. Multiuser multiple antenna uplink communication
   - 5.1 Multiple antenna receiver – single antenna transmitters
     - 5.1.1 Space-division multiple access
     - 5.1.2 SDMA capacity region
     - 5.1.3 System implications
     - 5.1.4 SDMA and orthogonal multiple access
     - 5.1.5 Slow fading
     - 5.1.6 Fast fading
     - 5.1.7 Multiuser diversity revisited
     - 5.1.8 Opportunistic communication and multiple receive antennas
   - 5.2 MIMO uplink
     - 5.2.1 SDMA with multiple transmit antennas
     - 5.2.2 System implications
     - 5.2.3 Fast fading

6. Multiuser multiple antenna downlink communication

- 6.1 Multiple transmit antennas – single antenna receivers
  - 6.1.1 Degrees of freedom in the downlink
  - 6.1.2 Uplinkdownlink duality and transmit beamforming
  - 6.1.3 Precoding for interference known at transmitter
  - 6.1.4 Precoding for the downlink
  - 6.1.5 Fast fading
- 6.2 MIMO downlink
  - 6.2.1 Capacity optimal transmission
  - 6.2.2 Generic power constraints
  - 6.2.3 "Network MIMO" – capacity optimal solution for multi-cell networks

7. MIMO diversity–multiplexing tradeoff
   - 7.1 Formulation
   - 7.2 Scalar Rayleigh channel
   - 7.3 Parallel Rayleigh channel
   - 7.4 MISO Rayleigh channel
   - 7.5 2×2 MIMO Rayleigh channel
   - 7.6 $N_\mathrm{T} \times N_\mathrm{T}$ MIMO i.i.d. Rayleigh channel