ELG7177: MIMO Communications

Instructor: Dr. Sergey Loyka, CBY A608

Course web page: http://www.site.uottawa.ca/~sloyka/ (lecture slides, announcements and other info will be posted there)

Lectures: Tue. 16:00 – 18:50, SMD 226 (real)

Office hours: You are encouraged to ask questions during lectures (additionally, some time will be allocated at the end of each lecture).

Pre-(Co) requisites: solid knowledge of digital communication theory; wireless communications and information theory are a plus. Mathematics: basic probability theory, calculus and linear algebra. Matrix theory is a plus.

- ELG4179, or ELG5133, or ELG5132, or Instructor permission.

Marking scheme:

Course project + presentation	50%
Final exam	50%

Lots of bonus points to everybody who takes active part in the course.

Final exam: will be scheduled by the university; 3h, open book.

Course project: info will be posted soon.

Calendar Description: Wireless communications and antenna arrays. MIMO (multi-antenna) systems: Information-theoretic limits, optimal signaling and system architectures. Channel models. V-BLAST and space-time codes. Diversity and multiplexing gains. Impact of channel state information. Beamforming and isotropic signaling. Water-filling algorithm. Fading channels and ergodic capacity. Multi-user MIMO: MAC, BC and IC; capacity region; symmetric and sum capacities. Massive MIMO and 5/6G. Physical-layer security via MIMO.

Week-by-week Description (approximate):

1. Wireless communications: benefits and challenges. Introduction to antenna arrays; performance improvement in single-user and multi-user systems.
2. MIMO (multi-antenna) systems: information-theoretic limits (channel capacity), optimal signaling strategies and system architectures. Channel models.
3. V-BLAST and successive interference cancellation; application to cognitive radio. Alamouti scheme and space-time codes. Diversity and multiplexing gains.
4. Impact of channel state information (CSI). Full CSI and no CSI at the transmitter. Transmission on channel eigenmodes and water-filling algorithm. Optimality of beamforming and isotropic signaling.
5. Fading channels and ergodic capacity. Statistical CSI.
6. Incomplete CSI: compound channel model and capacity. Robust transmission strategies.

7. Multi-user MIMO: multiple access channel (MAC), broadcast channel (BS), interference channel (IC). Performance gains due to MIMO. Capacity region, symmetric and sum capacities (total throughput). Optimal signaling.
8. Massive MIMO and 5/6G.
9. Physical-layer security via MIMO: wiretap channel, secrecy capacity, wiretap codes and optimal secure signaling.

Rationale: Why?

Since its discovery around 1995, MIMO (multiple-input multiple-output or multi-antenna) wireless systems have gained wide-spread popularity and acceptance in both academia and industry due to its unprecedentedly high spectral efficiency. This is clearly illustrated by the reference list above with a large number of books and even larger number of papers published every year (including special issues of almost all relevant journals in the field, and special sessions in almost every related conference), in addition to being included in key industrial standards, e.g. IEEE 802.11 (WiFi), LTE and 5G (cellular). A few years ago, a significant new spike of interest in this area was observed in a form of massive MIMO, which is considered now a key technology to meet the demands of 5/6G systems, which are currently under extensive R&D by all leading telecommunications companies and standardization bodies.

Textbook: there is no single textbook to cover all topics. The following books will be used on a need-to-know basis:

1. D. Tse, P. Viswanath, Fundamentals of Wireless Communications, Cambridge University Press, 2005. *(this is a comprehensive well-written textbook on a wider topic, but approx. 50% of it deal with MIMO systems or closely-related subjects while giving a good introduction of basic digital communications and information theory as it relates to wireless communications. You are strongly encouraged to read this book not only to learn the technical subject but also to learn how to write well in technical English. Solving end-of-chapter problems is essential for deep understanding of the material.*)

2. R.W. Heath, A. Lozano, Foundations of MIMO Communications, Cambridge University Press, 2019.

3. J.R. Barry, E.A. Lee, D.G. Messerschmitt, Digital Communications (3rd Ed.), Kluwer, Boston, 2004. – see Chapters 10 and 11.

4. T.L. Marzetta et al, Fundamentals of Massive MIMO, Cambridge University Press, 2016.

5. D.W. Bliss, S. Govindasamy, Adaptive Wireless Communications: MIMO Channels and Networks, Cambridge, 2013.

6. P.P. Vaidyanathan et al, Signal Processing and Optimization for Transceiver Systems, Cambridge University Press, 2010.

7. E. Biglieri et al, MIMO Wireless Communications, Cambridge University Press, 2007.

8. H. Bolcskei et al (Eds.), Space-Time Wireless Systems: From Array Processing to MIMO Communications, Cambridge University Press, Cambridge, 2006.

9. G. Larsson, P. Stoica, Space-Time Block Coding for Wireless Communications, Cambridge University Press, 2003.

10. M. Bloch and J. Barros, Physical-Layer Security: From Information Theory to Security Engineering, Cambridge University Press, 2011.

Additionally, the following special issues of leading journals provide comprehensive review articles as well as many original research papers on the topic:

1. T.L. Marzetta, Massive MIMO: An Introduction, Bell Labs Technical Journal, v. 20, 2015.

2. E. Biglieri, G. Taricco, Transmission and Reception with Multiple Antennas: Theoretical Foundations, Foundations and Trends in Communications and Information Theory, v. 1, no. 2, pp. 183-332, 2004. (this is a book-size article, with extensive coverage of important topics)

3. D.P. Palomar, Y. Jiang, MIMO Transceiver Design via Majorization Theory, Foundations and Trends in Communications and Information Theory, v. 3, no. 4-5, pp. 331–551, 2006. (this is a book-size article)

4. Special Issue on Signal Processing for Large-Scale MIMO, IEEE Journal of Selected Topics in Signal Processing (JSTSP), Vol. 8, No. 5, Oct. 2014.

5. Special Issue on Large-Scale Multiple Antenna Wireless Systems, IEEE Journal on Selected Areas in Communications (JSAC), vol. 31, no. 2, Feb. 2013.

6. F. Rusek et al, Scaling up MIMO: Opportunities and Challenges with Very Large Arrays, IEEE Signal Processing Magazine, vol. 30, no. 1, pp. 40-46, Jan. 2013.

7. Special Issue on Massive MIMO, Journal of Communications and Networks (JCN), vol. 15, no. 4, Aug. 2013.

8. Special Issue on Gigabit Wireless, Proceedings of the IEEE, v. 92, N.2, Feb. 2004.

9. Special Issue on Space-Time Transmission, Reception, Coding and Signal Processing, IEEE Trans. Information Theory, v. 49, N. 10, Oct. 2003.

10. Special Issue on MIMO Systems, IEEE Journal Selected Areas Comm, v. 21, N. 3 and 5, April and June 2003

11. Special Issue on MIMO Systems, IEEE Transactions on Signal Processing, v. 50, N. 10, Oct. 2002.

12. P.A. Regalia et al (Eds.), Secure Communications via Physical-Layer and Information-Theoretic Techniques (Special Issue), Proceedings of the IEEE, v. 103, N. 10, Oct. 2015.

To review basic communication theory or/and probability:

1. J.M. Wozencraft, I.M. Jacobs, Principles of communication engineering, Wiley: New York, 1965.
2. J.R. Barry, E.A. Lee, D.G. Messerschmitt, Digital Communications (3rd Ed.), Kluwer, Boston, 2004.
3. R.E. Ziemer, R.W. Peterson, Introduction to Digital Communication, Prentice Hall, 2000.
4. R.E. Ziemer, W.H. Tranter, Principles of Communications, Wiley, New York, 2009.
5. A. Papoulis, S.U. Pillai, Probability, Random Variables and Stochastic Processes, McGraw Hill, 2002.

This is an exceptionally good book on information theory:

6. T.M. Cover, J.A. Thomas, Elements of Information Theory, John Wiley & Sons, 2006.

How to Study: Learning Efficiency Pyramid

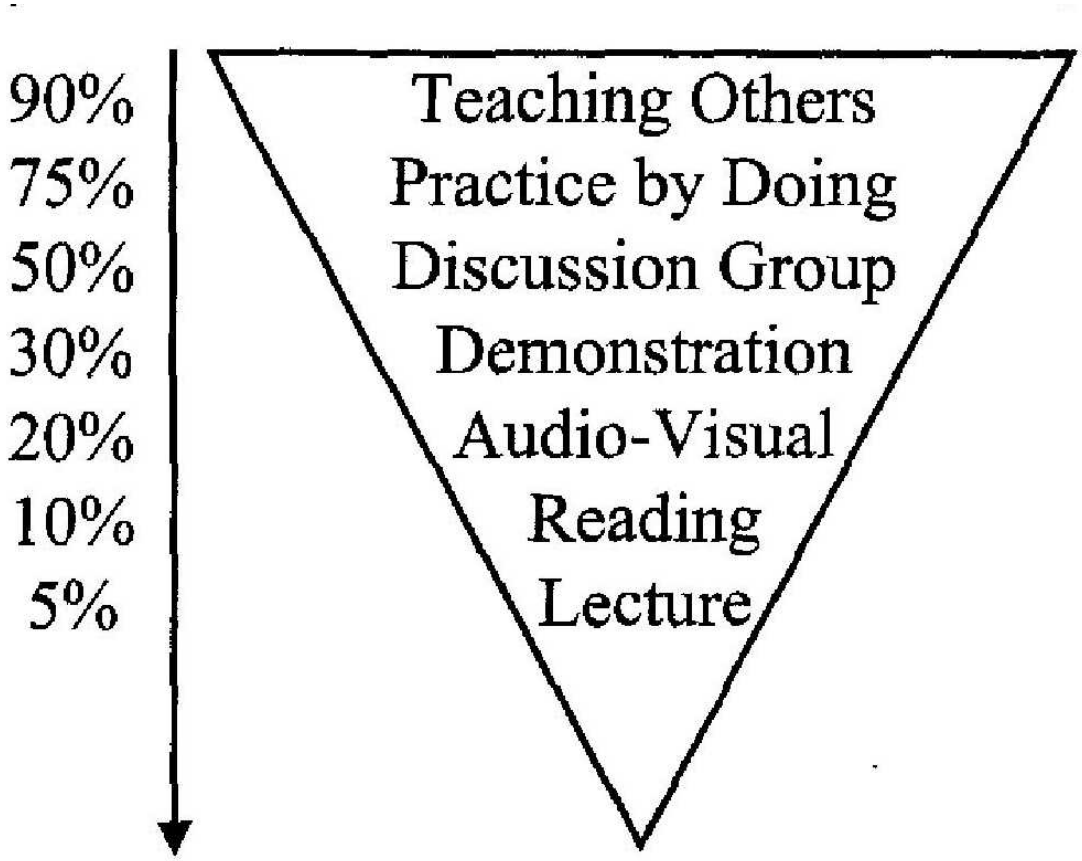

Figure 1. The Learning Pyramid, adapted from David Sousa, *How the Brain Learns*, Reston, VA, The National Association of Secondary School Principals, 1995, ISBN 0-88210-301-6.

"Tell me and I'll forget; show me and I may remember; involve me and I'll understand." – old Chinese proverb.

"No pain, no gain" – common wisdom.

How to Study

Learning efficiency pyramid is a good guideline

- Reading is necessary, but taken alone is not efficient
- Solving problems ("practice by doing") is much more efficient
    - examples, assignments, end-of-chapter problems
- Group discussions
    - help provided you contribute something
- Systematic study during the semester
    - is a key to a success.
    - do not leave everything to the last day/night before exams!
- Lectures
    - should be supplemented by the items above
- There is no substitute for active learning! "Seat and watch" approach does not work!