The Course Project Guidelines, Winter 2025

The project for this course includes a mini literature review about a specific problem selected by a student and approved by an instructor and a mini-research of this problem by a student. Topics should be relevant to the course content (i.e. include MIMO system in some form or shape), but otherwise arbitrary. Double submission of the same work (e.g. for thesis and as project for this course as well as two students submitting identical or nearly identical work) is not acceptable.

The project includes a brief presentation (about 5-10 min.) of the selected papers in **late February - early March,** a final presentation (about 15-20 min.) of its activities by the end of the semester and a project report, by a student. Schedule and deadlines will be announced later on.

What to do:

1. Find and read 3-5 (the more, the better) major, i.e. full-length (>=5pages), journal papers, preferably – by different authors/groups, published in major (reputable) journals (e.g. IEEE Transactions etc.). Use IEEE Xplore. Papers should be recent (i.e. within 5 years). Older papers are acceptable if they are of major value. Try to identify major papers (i.e. most important). Avoid IEEE Communication Magazine (and similar) papers as they do not provide enough details to repeat the simulations and have very limited value. Be aware that many conference papers are of low value and hence should be avoided (unless you make sure that the selected papers are of significant value). Looking for citation numbers on Google Scholar can give some indication of value (however, keep in mind that recent papers need time to collect citations and some low-value "review" papers can have disproportionally large citations).
2. Clearly identify key ideas/results in each paper (usually, not more than 3 per paper). What is their strength? Weakness? Importance? Are they correct/wrong? Why? Concentrate here and elsewhere on the results related to the course.
3. Compare the results/ideas in the different papers you read. Give comparative analysis.
4. Select one most important paper and repeat the key simulations. Do you get the same results? Why?
5. Explain how the results can be extended/improved? Justify this and do simulations for an extended case. Compare with the original results and make conclusions.
6. Summarize what you have learned in this project. Suggest directions for future research. If you would do MS/PhD research in this area, what in particular would you do?
7. For the presentation, prepare about 15-20 slides, which should fit into a 15-20 min. talk. Bring both ppt and pdf files of your presentation on a memory stick and a print-out (4 slides/page) for the instructor. See the course web page on how to prepare a good/bad presentation. It is essential that you practice presentation several times before making it in the class (also to make sure that you fit into 15-20 min. time slot, which will be strictly enforced).

A list of suggested papers will be provided, from which you should select one or more papers. However, since the list will not cover all the topics, you are not required to do so if your topic is not covered.

Things to remember when preparing your project report:

- The report must include the following parts: Title page, Table of contents, Summary (abstract), Introduction, Main part (review of the current literature, critical discussions and comparisons, your own contribution), conclusion, list of references, appendices. The papers you used must be attached as an appendix.
- Include explicit statement of the novelty at the beginning (after the abstract), explaining what is your own novel contribution to the field.
- All the ideas borrowed from other sources must include an explicit reference to those sources (otherwise it will be considered a plagiarism). If you use a word-by-word extract, you must use quotation marks rather than just a reference.
- When marking the report, I will be looking for your personal contribution to the field. Please keep this in mind when preparing the report.
- Please do not include just a re-phrased abstracts and conclusions of the papers you read. Include your own assessment of the results and techniques, emphasizing their advantages and drawbacks. Your report must indicate that you do understand those papers.
- Please remember what year is today. Hence, up-to-date references must be included (not just papers published 10-20 years ago). For the main papers, please include citation numbers (use Google Scholar to find it, scholar.google.com). Try to find at least 1-2 papers with large citation count (> 1000) so that you can see how influential/popular papers look like.
- There is a certain quality difference between journal and conference papers, the former being, as a rule, of much better quality. Keep this in mind when looking for the references.
- Do repeat some simulations reported in the references. This will insure that you understand the main techniques and will give you some ideas about the credibility of the results (in the papers as well as your own).
- Use 12 points font with 1 inch margins everywhere, single spacing and single column format. An approximate size of the report is about 20 pages without appendices. However, what matters is quality rather than just a page count.
- The report has to be bounded; the main 3-5 papers have to be attached as an appendix; all equations have to be numbered. Use standard book formatting as an example.
- Include the simulation code flaw chart in the main text (and explain it in details) and the source code in an appendix.
- Give clear and detailed enough explanations so that the report can be read without reading the references.

The points above are important as they are telling you what I am going to look for when marking the report.

Please keep in mind that copying (either from papers/books or from other students' reports) will be penalized and your mark will be significantly reduced. If you need to quote something, quotation marks and a reference to a source are mandatory.

Criteria for marking:

- Ability to clearly present the research topic, including concise literature review (in both the report and presentation)
- Ability to demonstrate good understanding of all key points
- Ability to critically analyze selected 3-5 papers (what is good, bad in each paper, which paper is the best, why so)
- Ability to support each conclusion/judgment by clear arguments
- Original contributions of the project
- Justified suggestions of how to improve the reported results and/or the problems found
- How efficient the report/presentation is in communicating the message to the audience
- How closely the guidelines above have been followed

Suggested Project Topics (feel free to suggest your own, but you will need my approval):

1. MIMO channel models: analysis, simulation, measurements
2. Fundamental limits in MIMO communications
3. The capacity analysis of fixed MIMO channels, including impact of correlation etc.
4. Optimal/sub-optimal transmission strategies over MIMO channels
5. Optimal precoding for MIMO systems
6. Impact of power constraints : total power constraints (TPC), per-antenna power constraints (PAC), interference power constraint (IPC).
7. Impact of channel state information (CSI) on the capacity and optimal signaling.
8. Channel state estimation for MIMO.
9. Impact of channel uncertainty and compound MIMO channels. Robust signaling strategies.
10. MIMO receiver architectures, performance analysis (e.g. V-BLAST, SIC-MMSE etc.)
11. Space-time codes: construction, performance analysis etc.
12. Fading MIMO channels: models, ergodic and outage capacities, performance analysis, optimal transmission strategies
13. Massive MIMO, including 5/6G applications, pilot contamination etc.
14. mmWave MIMO systems.
15. Hybrid beamforming for MIMO
16. MIMO radar.
17. MIMO cognitive radio.
18. Physical-layer security for MIMO systems.
19. MIMO system prototypes, measurements and applications.
20. Multi-user MIMO: Multiple access (MAC), broadcast (BC) and interference (IC) MIMO channels; fundamental limits and practical signaling strategies.
21. Cellular and cell-free (distributed) MIMO.

22. Holographic MIMO
23. Intelligent reflective surfaces (IRS), also known as reconfigurable intelligent surfaces (RIS)

Your project must have a significant MIMO component (at least 50%).

If you wish, you can also concentrate on one specific problem and develop its numerical/analytical solutions (e.g. using toolbox CVX). Feel free to talk to me if you wish to do so.

List of Recommended Journals/Conferences

The following list includes journals and conferences of good reputation. This means that an average paper from those journals/conferences is of reasonably good quality. Use any other journals/conferences at your own risk. Make sure that the papers you selected are of good quality and show them to me for approval.

- IEEE Transactions on Information Theory
- IEEE Transactions on Communications
- IEEE Transactions on Wireless Communications
- IEEE Journal on Selected Areas in Communications
- IEEE Transactions on Signal Processing
- IEEE Journal on Selected Topics in Signal Processing
- IEEE Signal Processing Magazine
- IEEE Transactions on Antennas and Propagation
- Proceedings of the IEEE
- Bell Labs Technical Journal
- Foundations and Trends in Communications and Information Theory
- IEEE International Symposium on Information Theory (ISIT)
- IEEE Information Theory Workshop
- International Zurich Seminar on Communications (IZS)
- Annual Allerton Conference on Communication, Control, and Computing
- IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)

To be used with care (some papers are good, some are not):

- IEEE Transactions on Vehicular Technology
- IEEE Vehicular Technology Conference

- IEEE Communication Letters (short papers, up to 4 pages, may be not enough for a project)
- IEEE Wireless Communication Letters (same as above)
- IEEE International Conference on Communications (ICC)
- IEEE Global Communications Conference (GlobeCom)
- Canadian Workshop on Information Theory
- IEEE Wireless Communications and Networking Conference
- IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)
- IEEE International Symposium on Personal, Indoor and Mobile Radio Communications

Sample List of Papers

The purpose of this list is to let you know how good papers look like. You have to add some papers that are not indicated here into your project. Please do include recent papers, not just those published 10-20 years ago. Papers from this list are known to be of good quality so you can use them as examples of how good-quality papers look like.

Basic MIMO Principles/Architectures

1. I.E. Telatar, "Capacity of Multi-Antenna Gaussian Channels," AT&T Bell Lab. Internal Tech. Memo., June 1995 (European Trans. Telecom., v.10, N.6, Dec.1999).
2. G.J Foschini, 'Layered space-time architecture for wireless communication in a fading environment when using multiple antennas', Bell Lab. Tech. J., vol. 1, N. 2, pp. 41-59, 1996.
3. G. J. Foschini and M. J. Gans, "On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas", Wireless Personal Commun., vol. 6, no. 3, March 1998.
4. Rayleigh, G.G., Gioffi, J.M.: "Spatio-Temporal Coding for Wireless Communications," IEEE Trans. Commun., v.46, N.3, pp. 357-366, 1998.
5. S. M. Alamouti, "A simple Transmit Diversity Technique for Wireless Communications", IEEE Journ. on Selected Areas in Comm., vol. 16, no. 8, Oct. 1998.
6. L. Zheng, D.N.C. Tse, Diversity and multiplexing: a fundamental tradeoff in multiple-antenna channels, IEEE Transactions on Information Theory, v. 49, N.5, pp. 1073-1096, May 2003.
7. B. Hassibi and B. Hochwald, "How much training is needed in multiple-antenna wireless links?", IEEE Trans. Inform. Theory, v. 49, pp. 951-963, Apr. 2003.
8. S.A. Jafar, A. Goldsmith, Transmitter optimization and optimality of beamforming for multiple antenna systems, IEEE Transactions on Wireless Communications, v.3, N.4, pp.1165-1175, July 2004.
9. C. Rao, B. Hassibi, Analysis of multiple-antenna wireless links at low SNR, IEEE Transactions on Information Theory, v. 50, N.9, pp. 2123 – 2130, Sept. 2004
10. D. Chizhik, Slowing the time-fluctuating MIMO channel by beam forming ; IEEE Transactions on Wireless Communications, v. 3, N.5, pp. 1554 – 1565, Sept. 2004.
11. Special Issue on Gigabit Wireless, Proceedings of the IEEE, v. 92, N.2, Feb. 2004.
12. Special Issue on Space-Time Transmission, Reception, Coding and Signal Processing, IEEE Trans. Information Theory, v. 49, N. 10, Oct. 2003.
13. Special Issue on MIMO Systems, IEEE Journal Selected Areas Comm, v. 21, N. 3 and 5, April and June 2003
14. Special Issue on MIMO Systems, IEEE Transactions on Signal Processing, v. 50, N. 10, Oct. 2002.
15. 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.

BLAST

16. G.J Foschini et al, Simplified Processing for High Spectral Efficiency Wireless Communication Employing Multi-Element Arrays, IEEE Journal on Selected Areas in Communications, v. 17, N. 11, pp. 1841-1852, Nov. 1999.
17. G.J. Foschini et al, Analysis and Performance of Some Basic Space-Time Architectures, IEEE Journal Selected Areas Comm., v. 21, N. 3, pp. 281-320, Apr. 2003.
18. E. Biglieri, G. Taricco, A. Tulino, Decoding space-time codes with BLAST architectures, IEEE Trans. Signal Proc., v.50, N.10, pp. 2547-2552, Oct. 2002
19. Z. Hong; K. Liu; R.W. Heath, A.M. Sayeed, Spatial multiplexing in correlated fading via the virtual channel representation, IEEE Journal on Selected Areas in Communications, v.21, N.5, pp.856 – 866, June 2003.
20. N. Prasad and M. Varanasi, "Analysis of decision feedback detection for MIMO Rayleigh fading channels and optimum power/rate allocations," IEEE Trans. Inf. Theory, v.50, N.6, pp. 1009-1025, June 2004.
21. Z. Yan et al, Optimal diagonal precoder for multiantenna communication systems, IEEE Transactions on Signal Processing, v. 53, N.6, pp. 2089- 2100, June 2005.
22. T. Guess, M.K. Varanasi, An information-theoretic framework for deriving canonical decision-feedback receivers in Gaussian channels; IEEE Transactions on Information Theory, v. 51, N. 1, pp. 173 – 187, Jan. 2005
23. W.J. Choi, R.Negi, J.M. Cioffi, Combined ML and DFE decoding for the V-BLAST system, IEEE ICC 2000, v.3, pp. 1243 -1248, June 2000

Space-Time Coding/Modulation

24. V. Tarokh, N. Seshadri, A.R. Calderbank, Space-Time Codes for High Data Rate Wireless Communication: Performance Criterion and Code Construction, IEEE Trans. Information Theory, v. 44, N. 2, pp. 744-765, Mar. 1998.
25. B.M. Hochwald, T.L. Marzetta, "Unitary Space-Time Modulation for Multiple-Antenna Communication Systems," IEEE Trans. Information Theory, v.46, N. 2, pp. 543-564, Mar. 2000
26. B. Hassibi and B. Hochwald, High-rate codes that are linear in space and time, IEEE Tran. Inform. Th., pp. 1804-1824, July 2002.
27. H. El Gamal, On the robustness of space-time coding, IEEE Trans. on Signal Processing, pp. 2417.2428, Oct. 2002.
28. B.M. Hochwald, T.L. Marzetta, B. Hassibi, Space-time autocoding, IEEE Transactions on Information Theory, v. 47, N. 7, pp. 2761 – 2781, Nov. 2001 .
29. E. Visotsky, U. Madhow, Space-time transmit precoding with imperfect feedback, IEEE Transactions on Information Theory, v.47, N.6, pp. 2632 – 2639, Sept. 2001.

MIMO Channels/Capacity

30. D.Gesbert, H.Bolcskei, D.Gore, and A.Paulraj, "Outdoor MIMO wireless channels: Models and performance prediction", IEEE Trans. Commun., Dec. 2002.
31. H. Bolcskei, D. Gesbert, and A. J.Paulraj, "On the capacity of OFDM-based spatial multiplexing systems", IEEE Trans. Commun., vol. 50, pp. 225-234, Feb. 2002.
32. A.M. Sayeed, Deconstructing multi-antenna fading channels, IEEE Trans. Signal Processing, pp. 2563-2579, Oct. 2002.
33. B.M. Hochwald, T.L. Marzetta, V. Tarokh, Multiple-antenna channel hardening and its implications for rate feedback and scheduling, IEEE Transactions on Information Theory, v.50, N.9, pp. 1893 – 1909, Sept. 2004.
34. A. Goldsmith et al, Capacity limits of MIMO channels IEEE Journal on Selected Areas in Communications, v.21, N. 5, pp. 684 – 702, June 2003.
35. E.A. Jorswieck, H. Boche, Channel capacity and capacity-range of beamforming in MIMO wireless systems under correlated fading with covariance feedback, IEEE Transactions on Wireless Communications, v. 3, N.5, pp.1543 – 1553, Sept. 2004.
36. T. Marzetta and B. Hochwald, "Capacity of a mobile multiple-antenna communication link in Rayleigh flat fading," IEEE Trans. Inform. Theory, vol. 45, pp. 139-157, Jan. 1999.
37. J.P Kermoal et al, A stochastic MIMO radio channel model with experimental validation, IEEE Journal on Selected Areas in Communications, v.20, N. 6, pp.1211 – 1226, Aug. 2002.

Massive MIMO

38. T.L. Marzetta, Massive MIMO: An Introduction, Bell Labs Technical Journal, v. 20, 2015.
39. Special Issue on Signal Processing for Large-Scale MIMO, IEEE Journal of Selected Topics in Signal Processing (JSTSP), Vol. 8, No. 5, Oct. 2014.
40. Special Issue on Large-Scale Multiple Antenna Wireless Systems, IEEE Journal on Selected Areas in Communications (JSAC), vol. 31, no. 2, Feb. 2013.
41. 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.
42. L. Lu et al., An Overview of Massive MIMO: Benefits and Challenges, IEEE Journal Sel. Topics in Sig. Proc., v. 8, n.5, Oct. 2014.
43.

Other MIMO topics

44. R W. Heath Jr et al, An Overview of Signal Processing Techniques for Millimeter Wave MIMO Systems, IEEE Sel. Topics in Sig. Proc., v. 10, n.1, Feb. 2016.
45. G. Scutari, D. P. Palomar, and S. Barbarossa, Cognitive MIMO Radio, IEEE Sig. Proc. Mag., vol. 25, no. 6, pp. 46-59, Nov. 2008.

46. R. Zhang and Y.-C. Liang, Exploiting Multi-Antennas for Opportunistic Spectrum Sharing in Cognitive Radio Networks, IEEE Journal Sel. Topics in Sig. Proc., vol. 2, no. 1, pp. 88-102, Feb. 2008.
47. A. Khisti, G.W. Wornell, Secure Transmission With Multiple Antennas – Part I: The MISOME Wiretap Channel, IEEE Trans. Info. Theory, v. 56, No. 7, July. 2010.
48. A. Khisti and G. W. Wornell, Secure Transmission With Multiple Antennas−Part II: The MIMOME Wiretap Channel, IEEE Trans. Info. Theory., vol. 9, no. 4, pp. 1494-1502, Apr. 2010.
49. F. Oggier, B. Hassibi, The Secrecy Capacity of the MIMO Wiretap Channel, IEEE Trans. Info. Theory, v. 57, no. 8, Aug. 2011.
50. H.Q. Ngo, A. Ashikhmin et al, Cell-free Massive MIMO Versus Small Cells, IEEE Trans. Wireless Comm., v. 16, no. 3, pp. 1834-1850, Jan 2017.