Final Report: Power Amplifiers and Massive MIMO

5-month project (from 2014-01-01 to 2014-05-09)

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This projects has investigated good precoding strategies in multiple-input and multiple-output (MIMO) systems and massive MIMO (MaMi) systems, taking the power amplifier (PA) into account. The project is terminated on PI Daniel Persson's own request since he leaves Linköping University for industry (Qamcom Research & Technology, Gothenburg). This report is prepared according to the CENIIT final report guidelines.

1 Scientific results

The following list details obtained results.

1. **PA-aware frequency-flat fading single-user (SU) multiple-input and single-output (MISO) capacity.** PA-aware frequency-flat fading SU MISO capacity was investigated in [1]. We obtained analytical solutions for capacity and a capacity-achieving precoder, both for the case with full channel state information, and for the ergodic case. In both cases, antenna selection is optimal.

2. **PA-aware frequency-flat fading SU MIMO capacity.** PA-aware frequency-flat fading SU MIMO capacity is investigated in [2]. We showed that the capacity-optimal solution is in fact the linear precoder, and that antenna selection is optimal in many situations, just as in the MISO case.

3. **PA dimensioning for typical MaMi scenarios.** Following requests at the MAMMOET project start meeting in Villach, Austria in January 2014, we have dimensioned the PAs for typical MaMi scenarios [3], including channel estimation and multi-user (MU) interference, and found this to be in the order of 50-100 milli-Watt. The results were presented at the MAMMOET telco 2014-03-10. The report further shows that the power of uplink pilots is a system bottleneck.

4. **Operation of MaMi in low traffic scenarios.** We have investigated how to operate MaMi systems with zero forcing and maximum ratio transmission precoding in low traffic scenarios,

taking both PAs and signal processing into account [4]. Closed form solutions were given for the transmit power at the base station. The results indicated that antenna selection is a good solution.

5. **PA-aware frequency-selective fading full MU MIMO capacity.** We have implemented a linear MU precoding algorithm for frequency-flat fading that comprises solving three convex problems iteratively. In the important special case of one receive antenna per user, we found the optimal linear solution by solving a convex problem, i.e., a problem that can be solved with very low computational complexity. Moreover, we have found an information-theory-based achievable non-linear MU precoder. We have made extensions to frequency-selective fading. This will be a submitted as an IEEE journal paper. Prof. Erik G. Larsson guarantees that Ph.D. student Victor Cheng will be able to work a few weeks beyond the end of the CENIIT project to submit the paper.

6. **Massive MIMO with 1-bit analog-to-digital conversion (ADC).** Added value in green radio and hardware-aware communication has been created in collaboration with Prof. Stefano Buzzi, University of Cassino and Southern Lazio. Prof. Buzzi sent one of his Ph.D. students, Chiara Risi, as a visitor to LiU for 4 months to work on MaMi ADC. We have shown that we can remove the whole ADC chain in many MaMi receiver settings without losing performance [5].

2 Degrees and promotions obtained

Daniel Persson has obtained the Docent title in Communication Systems on 2014-02-24 with his presentation ”Multiple-antenna systems for robust wireless communications”. A major part of his docent presentation discussed how to increase capacity by PA-aware precoding. The CENIIT project will also contribute to Ph.D. student Victor Cheng’s licentiate degree planned for autumn 2015. Victor Cheng is co-supervised by Daniel Persson.

3 Student theses within the scope of the project

No student thesis has been conducted within the scope of the project.

4 Persons financed by the project

Ph.D. student Victor Cheng has spent 80% effort on the project from 2014-01-01 to 2014-05-09. Daniel Persson has spent 90% effort on the project from 2014-01-01 to 2014-05-09.

5 Industrial collaboration

Contact persons are in bold font.

- Together with Daniel Persson, **Dr. Peter Stenumgaard, FOI, Linköping**, has led the work in the LiU Security Link area Robust wireless communications for crisis and security. As already described in Section 2, the CENIIT project filled a major part of Daniel Persson's docent presentation "Multiple-antenna systems for robust wireless communications", where it was discussed how an increase in capacity, harvested by PA-aware precoding, can be used for increasing robustness.

- The MAMMOET project deals with implementation aspects and feasibility of MaMi and identifies the PA as a very important component in future MaMi systems. MAMMOET and the CENIIT project create added value for each other, though the two projects are not overlapping.

  Until his parental leave in May 2014, Daniel Persson has lead the LiU effort in Task 1.1 of the FP7 MAMMOET project. MAMMOET Task 1.1 deals with fundamental limits, practical trade-offs, and specifications, and involves all industry partners, e.g., Ericsson AB, and **Scientific leader Prof. Liesbet Van der Perre, IMEC, Belgium**. At the MAMMOET project start meeting, the question on the PA power in typical MaMi scenarios was raised. We have answered that question within the scope of CENIIT, see Point 3 in Section 1.

- Initial results and ambitions of the CENIIT project were presented to Dr. Thomas Marzetta at Bell Labs, Alcatel-Lucent, USA. In the following discussion, Dr. Marzetta pointed out that it is important to consider frequency-selective channels. We have now enforced the inclusion of frequency-selectivity in our investigations.

- Together with **Dr. Gunnar Bark, Ericsson Research, Linköping**, Daniel Persson has submitted a Vinnova Innovativ IKT application titled "MaMi Media Access Control (MAC) layer (MACMaMi)". The application was not granted this time, but can still serve as an excellent base for future collaboration.

- Daniel Persson has been invited to the technical paper committees of the conferences IEEE Globecom 2014 (IEEE International Workshop on Massive MIMO: From theory to practice), IEEE ICC 2015, IEEE PIMRC 2014, and IEEE CECNET 2014. Globecom and ICC are top conferences in the field.

6 Contact with other CENIIT projects

CENIIT project "Verifiable real-time coordination for safe cooperative driving" leader Assistant Prof. Mikael Asplund wants to discuss vehicle-to-vehicle and vehicle-to-infrastructure communication. A first meeting is scheduled.

7 New research group formation

With Daniel Persson leaving to industry, a new research group has not been formed.

8 Publications

We have published [1], [2], [3], [4] and [5], and a final paper is planned, see Point 5 in Section 1.

References

[1] D. Persson, T. Eriksson, and E. G. Larsson, "Amplifier-aware multiple-input single-output capacity," *IEEE Transactions on Communications*, vol. 17, no. 6, pp. 1112–1115, Jun. 2013.

[2] H. V. Cheng, D. Persson, and E. G. Larsson, "MIMO capacity under power amplifiers consumed power and per-antenna radiated power constraints," in *IEEE International Workshop on Signal Processing Advances in Wireless Communications*, Jun. 2014, pp. 179–183.

[3] H. V. Cheng and D. Persson, "Per-antenna power consumption calculation for single-cell massive MIMO system with conjugate beamforming precoding," svn:/mammoet/Meetings-Telcos/2014/20140310, 2014.

[4] H. V. Cheng, D. Persson, E. Björnson, and E. G. Larsson, "On the operation of massive MIMO in low traffic scenarios," in *accepted at IEEE International Conference on Communications*, Jun. 2015.

[5] C. Risi, D. Persson, and E. G. Larsson, "Massive MIMO with 1-bit ADC," Submitted to IEEE Transactions on Communications, 2014, http://arxiv.org/abs/1404.7736.