Tutorial: Coding and Modulation for Communication at the Ultimate Shannon Limit

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After attending this ISWCS 2016 tutorial, the participant is able to use off-the-shelf components to design coding and modulation systems that can operate within 1 dB of $\log_2(1+\mathrm{SNR})$ for any desired spectral efficiency. Furthermore, the participant knows how to optimize the components further to decrease the gap to capacity well below 0.5 dB.

The tutorial follows a lecture style with interactive participation by examples and code snippets, which can be accessed via a website and can be used with an ordinary smart phone.

Outline of the tutorial

Part I: Modulation (Georg Böcherer): 1h 15min

In the first part, we discuss the design of modulation systems that enable spectral efficiencies close to capacity. The addressed topics are:

Signal Shaping at the Transmitter

- Review of shaping techniques (geometric and probabilistic) for high spectral efficiencies and their adaption in current standards (3GPP, DVB-NGH, ATSC 3.0).
- *Probabilistic amplitude shaping* (PAS) [3] for conventional QAM constellations and off-the-shelf forward error correction (FEC).
- Generation of shaped signals via *distribution matching* [4].
- Assessment of the advantages of PAS over previously considered approaches in terms of flexibility and implementation complexity.

Demapping at the Receiver

- Information-theoretic tools for performance assessment accounting for bit-wise demapping and shaping [5].
- Off-the-wall bit-wise demapping of conventional constellations.

Part II: Coding (Fabian Steiner): 1h 15min

The second part of the tutorial combines the shaping and modulation approaches of Part I with state-of-the art FEC techniques based on low-density parity-check (LDPC) codes.

Interleaver Design

- Impact of the interleaver on the coded system performance.
- Examples using DVB-S2 and 802.11 off-the-shelf LDPC codes.

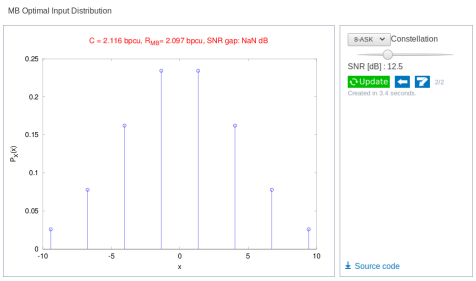

Figure 1: Calculating the optimal distribution in the interactive web demo.

[3] G. Böcherer, F. Steiner, and P. Schulte, "Bandwidth Efficient and Rate-Matched Low-Density Parity-Check Coded Modulation," *IEEE Trans. Commun.*, vol. 63, no. 12, pp. 4651–4665, Dec. 2015

[4] P. Schulte and G. Böcherer, "Constant Composition Distribution Matching," *IEEE Trans. Inf. Theory*, vol. 62, no. 1, pp. 430–434, Jan. 2016

[5] G. Böcherer, "Achievable Rates for Shaped Bit-Metric Decoding," *arXiv preprint*, 2016

Code Design for Higher-Order Modulation

- Key challenges of LDPC code design for higher-order modulation [6].
- Joint code and bit-mapper design using surrogate channels.

FEC Performance Assessment and Practical Systems

- Offline FEC performance evaluation for low error rates [7].
- Performance assessment without encoding.

[6] F. Steiner, G. Böcherer, and G. Liva, "Protograph-Based LDPC Code Design for Shaped Bit-Metric Decoding," *IEEE J. Sel. Areas Commun.*, vol. 34, no. 2, pp. 397–407, Feb. 2016

[7] F. Buchali, F. Steiner, G. Böcherer, L. Schmalen, P. Schulte, and W. Idler, "Rate Adaptation and Reach Increase by Probabilistically Shaped 64-QAM: An Experimental Demonstration," *J. Lightw. Technol.*, vol. 34, no. 7, pp. 1599–1609, Apr. 2016

Curriculum vitae

Georg Böcherer was born in Freiburg im Breisgau, Germany. He obtained his M.Sc. degree in Electrical Engineering and Information Technology from the ETH Zürich, Switzerland, in 2007, and his Ph.D. degree from the RWTH Aachen University, Germany, in 2012. He is now a senior researcher and lecturer at the Institute for Communications Engineering, Technical University of Munich. His current research interests are coding, modulation, and probabilistic shaping for optical, wireless, and wired communications. He served as a co-chair of the Munich Workshop on Coding and Modulation (MCM 2015) and chaired the special session on recent advances in coding for higher order modulation at the 2016 International Symposium on Turbo Codes & Iterative Information Processing. He received the E-plus award for his Ph.D. thesis and his proposal on probabilistic shaping for capacity achieving and rate adaptive communication won the third prize at the 2015 Bell Labs Prize.

Fabian Steiner was born in Prien am Chiemsee, Germany. He received the B.Sc. degree and M.Sc. degree (with high distinction) in electrical engineering from the Technical University of Munich (TUM), Germany, in 2011 and 2014, respectively. He is now working toward the Ph.D. degree in a joint research project of the Fachgebiet Methoden der Signalverarbeitung, TUM, and UC Irvine, CA, USA. He is supervised by Prof. Utschick, Prof. Nossek and Prof. Swindlehurst. He is supported by the Institute for Advanced Study, TUM, as part of Prof. Swindlehurst's Hans Fischer Senior Fellowship. His current research interests include coding, modulation and multi-user massive MIMO systems. He received the Prof. Dr. Ralf Kötter memorial award for his master's thesis and won the third prize of the 2015 Bell Labs Prize with his proposal on probabilistic shaping for capacity achieving and rate adaptive communication.