UNIVERSITY OF SOUTHAMPTON
FACULTY OF PHYSICAL SCIENCES AND ENGINEERING
SCHOOL OF ELECTRONICS AND COMPUTER SCIENCE

Coherent and Non-coherent Coded Modulation for Cooperative Communications

by

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ABSTRACT

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The design trade-offs of coherent versus non-coherent coded modulation conceived for cooperative communications are explored. More specifically, coherent versus non-coherent coded modulation designed for traditional point-to-point communications is investigated first, before we extend the application of coded modulation to cooperative communications.

Firstly, we focus our attention on coherent coded modulation, when communicating over Additive White Gaussian Noise (AWGN) and uncorrelated Rayleigh fading channels, followed by the investigation of the adaptive coded modulation (ACM), when transmitting over both quasi-static as well as over shadow-and-fast Rayleigh fading channels. Furthermore, soft-decision aided non-coherent coded modulation designed both for fixed modes and adaptive modes is proposed. More specifically, we conceive soft-decision aided Differential Amplitude and Phase-Shift Keying (DAPSK) for low-complexity wireless communications, since it dispenses with high-complexity channel estimation. We commence by designing soft-decision based demodulation for 16-level DAPSK, or l6-level Star Quadrature Amplitude Modulation, which is then invoked for iterative detection aided Bit-Interleaved Coded Modulation (BICM-ID). It is shown that the proposed 16-DAPSK based BICM-ID scheme achieves a coding gain of approximately 14 dBs in comparison to the identical-throughput 16-level Differential Phase-Shift Keying (16DPSK) assisted BICM scheme at a Bit Error Ratio (BER) of 10^{-6}. Then, we derive the soft-output probability formulas required for a soft-decision based demodulation of high-order DAPSK, in order to facilitate iterative detection by exchanging extrinsic information with an outer Turbo Code (TC). Furthermore, when the TC block size is increased, the system operates closer to the channel capacity. Offset DAPSK is also considered in order to facilitate the employment of a less stringent linear power amplifier specification at the transmitter. Compared to the identical-throughput TC assisted 64-ary Differential Phase-Shift Keying (64-DPSK) scheme, the 4-ring based TC assisted 64-ary DAPSK arrangement has a power-efficiency improvement of 4.2 dB at a BER of 10^{-5}. Furthermore, when the TC block size is increased, the system operates closer to the channel capacity. More specifically, when using a TC block length of 400 modulated symbols, the 64 DAPSK(4, 16) scheme is 11.25 dB away from its capacity curve, while it operates within 2.7 dB of the capacity, when using a longer TC block length of 40 000 symbols. Furthermore, for the sake of an improved energy efficiency, we proposed the adaptive modes for non-coherent coded modulation.

Then, we considered coded modulation schemes designed for cooperative communications.

Firstly, an attractive hybrid method of mitigating the effects of error propagation that may be imposed by the relay node (RN) on the destination node (DN) is proposed in Chapter 4. We select the most appropriate RN location for achieving a specific target BER at the relay and signalled the RN-BER to the DN. The knowledge of this BER is then exploited by the decoder at the destination. Our simulation results show that when the BER encountered at the RN is low, we do not have to activate the RN-BER aided decoder at the DN. However, when the RN-BER is high, significant system performance improvements may be achieved by activating the proposed RN-BER based decoding technique at the DN. For example, a power-reduction of up to about 19 dB is recorded at a DN BER of 10^{-4}. Secondly, the basic principle of ACM invoked for cooperative communications is detailed in the context of three main structures: single RN aided ACM, twin RN aided ACM and single RN aided ACM additionally combined with the source-to-destination (SD) link at the DN. Then we propose an adaptive TTCM (ATTCM) aided Distributed Space-Time Trellis Coding (STTC) scheme for cooperative communication over quasi-static Rayleigh fading channels. Specifically, an ATTCM scheme is employed by the source node during the first transmission period for reliably conveying the source bits to N RNs by appropriately adjusting the code-rate and modulation mode according to the near-instantaneous channel conditions. It is shown that the proposed ATTCM-DSTTC scheme requires 12 dBs less transmission power in comparison to a standard TTCM scheme when aiming for a Frame Error Ratio (FER) of 10^{-3}.

Finally, we focus our attention on non-coherent coded modulation conceived for cooperative communications. Firstly, we investigate a 16-StQAM-TC assisted NC scheme relying on the popular butterfly network topology. As expected, the achievable BER performance is affected by the location of the RN. More specifically, when the transmit powers at the SNs and RN are identical, the RN located at the centre of the butterfly network topology achieves the best performance. However, when the appropriately designed power sharing approach is invoked in Section 5.2.1.2, the optimum RN location is closer to the DNs, and another 1 dB of power gain can be attained. Then, the NC capacity was quantified and the simulation results of Figure 5.5 showed that the achievable capacity of the NC scenario is improved compared to the single-link scenario. Secondly, as a novel application example, our soft-decision M-DAPSK scheme is incorporated into an AF based cooperative communication system. We found that an AF based cooperative communication system obtains a 4.5 dB SNR improvement for a TC block length of 40 000 modulated symbols, compared to that of the traditional point-to-point transmission. Finally, we propose a low-complexity amalgamated cooperative wireless and optical-fiber communication scheme for uplink communication in a FFR based multicell, multiuser system. The FFR principle is invoked for improving the cell-edge performance without reducing the throughput of the cell-center. Each cell is illuminated with the aid of six Remote Antennas (RAs), which are connected to the central base-station with the aid of realistically modelled imperfect optical-fiber links. When a Mobile Station (MS) is located at the cell-edge, the two nearest RAs can be invoked for detecting and forwarding the user's signal to the base-station, based on the Single-Input Multiple-Output (SIMO) principle. Furthermore, we employ both the Digital Fiber Optic (DFO) and Analogue Radio-over-Fiber (AROF)

principles for the optical fiber link. We then design a Turbo Coded (TC) 16-level Star-Quadrature Amplitude Modulation (StQAM) scheme for supporting optical-fiber-aided cooperative wireless transmissions, where the receiver does not have to estimate the channel state information. Hence, a lower detection complexity can be achieved, when compared to coherently detected schemes, albeit naturally, at a 3 dB power-loss. We also investigate the effect of phase-rotations imposed by imperfect optical-fiber links. Our non-coherent TC-StQAM scheme is robust to both wireless and optical-fiber imperfections. More explicitly, the proposed TC-StQAM-SIMO scheme is capable of removing 6 out of 12 BER peaks at the cell-edge, despite dispensing with CSI for both the wireless and optical-fiber links. As a further improvement, the adaptive turbo-coded soft-decision aided differential detection (ATSDD) scheme is employed by the Mobile Station (MS) for reliably conveying the source bits to a pair of nearby Remote Antennas (RAs) by appropriately adjusting the modulation mode according to the near-instantaneous wireless and AROF channel condition. The ATSDD switching thresholds are specifically adjusted for ensuring that the BER remains below 10^{-5}. We also investigated the effect of phase-rotations routinely imposed by practical imperfect Radio-over-fiber (ROF) links. We demonstrate that our ATSDD scheme is robust to both wireless and optical-fiber imperfections.

Declaration of Authorship

I, **Dandan Liang**, declare that the thesis entitled **Coherent and Non-coherent Coded Modulation for Cooperative Communications** and the work presented in it are my own and has been generated by me as the result of my own original research. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University;
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- Where I have consulted the published work of others, this is always clearly attributed;
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- Parts of this work have been published.

Signed: .... Date: ....

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List of Publications

Journals:

1. **D. Liang**, S. X. Ng and L. Hanzo, "Soft-decision Star-QAM aided BICM-ID", IEEE Signal Processing Letters, vol.18, no.3, pp.169-172, 2011.
2. **D. Liang**, S. X. Ng and L. Hanzo, "Near-Capacity Turbo Coded Soft-decision Aided DAPSK/Star-QAM for Amplify-and-forward based Cooperative Communications", IEEE Transactions on Communications, vol.61, no.3, pp.1080-1087,2013.
3. C. Xu, **D. Liang**, S. X. Ng and L. Hanzo, "Reduced-Complexity Non-coherent Soft-Decision-Aided M-DAPSK Dispensing with Channel Estimation", *accepted by* IEEE Transactions on Vehicular Technology.
4. C. Xu, **D. Liang**, S. Sugiura, S. X. Ng and L. Hanzo, "Reduced-Complexity Approx-Log-MAP and Max-Log-MAP Soft PSK/QAM Detection Algorithms", *accepted by* IEEE Transactions on Communications.
5. **D. Liang**, V. A. Thomas, X. Xu, S. X. Ng, M. El-Hajjar and L. Hanzo, "Adaptive Soft-decision aided Differential Modulation for Cooperative Wireless and Optical-Fiber Communications", *will be submitted to* IEEE Signal Processing Letters, 2013.
6. L. Wang, L. Li, C. Xu, **D. Liang**, S. X. Ng and L. Hanzo, "Multiple-Symbol Joint Signal Processing for Differentially Encoded Single- and Multi-Carrier Communications: Principles, Designs and Applications", *submitted to* IEEE Communications Surveys & Tutorial.

Conferences:

1. S. X. Ng, C. Qian, **D. Liang** and L. Hanzo, "Adaptive Turbo Trellis Coded Modulation Aided Distributed Space-Time Trellis Coding for Cooperative Communications", Proceedings of IEEE Vehicular Technology Conference (VTC) Spring, 16-19 May 2010, Taipei, Taiwan.
2. **D. Liang**, S. X. Ng and L. Hanzo, "Relay-Induced Error Propagation Reduction for Decode-and-Forward Cooperative Communications ", Proceedings of IEEE GLOBECOM 2010, 6-10 December 2010, Miami, Florida, USA.
3. **D. Liang**, S. X. Ng and L. Hanzo, "Near-Capacity Turbo Coded Soft-decision Aided DAPSK/Star-QAM", Proceedings of IEEE Vehicular Technology Conference (VTC) Fall, 5-8 September 2011, San Francisco, USA.
4. **D. Liang**, M. Song, S. X. Ng and L. Hanzo, "Turbo Coded and Cooperative Network Coded Non-Coherent Soft-Decision Star-QAM Dispensing with Channel Estimation", Proceeding of IEEE GLOBECOM 2011, Houston, TX, USA.

5. C. Xu, **D. Liang**, S. Sugiura, S. X. Ng and L. Hanzo, "Reduced-Complexity Soft-Decision Aided PSK Detection", Proceeding of IEEE Vehicular Technology Conference (VTC) Fall, 3-6 September 2012, Qubec City, Canada.

6. **D. Liang**, X. Xu, S. X. Ng and L. Hanzo, "Turbo-coded star-QAM for cooperative wireless and optical-fiber communications", Proceeding of IEEE 3rd International Conference on Photonics, Penang, Malaysia, 01 - 03 Oct 2012, pp. 267-271.

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