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

Layered Turbo Trellis-Coded Modulation for Cooperative Communications

by

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Dedicated to my family and friends

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ABSTRACT

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In this thesis, we propose a suite of Turbo Trellis Coded Modulation (TTCM) aided transmission schemes designed for cooperative communications. Our objective is to combine Coded Modulation (CM) schemes with layered modulation arrangements in the context of cooperative communications for the sake of improving both the flexibility and power-efficiency of the entire system, while maintaining a moderate system complexity. Our investigations are focussed on the physical layer and on the network layer.

Specifically, we firstly introduce and study the family of Trellis-Coded Modulation (TCM) and TTCM schemes. The encoder, decoder, as well as the structure of both CM schemes is investigated in detail. The BER performance of four popular CM schemes, namely of TCM, of TTCM, of Bit-Interleaved Coded Modulation (BICM) and of BICM with Iterative Decoding (BICM-ID) is investigated, when communicating over both Additive-White-Gaussian-Noise (AWGN) and uncorrelated Rayleigh fading channels. By analysing the performance of the four CM schemes, we show that the TTCM scheme performs better than the other three CM schemes not only for transmission over AWGN but also over uncorrelated Rayleigh fading channels. When employing the TTCM scheme in Decode-and-Forward (DAF) relaying assisted cooperative communications, the BER performance of the system is substantially improved.

Then, we proposed two possible solutions for reducing the complexity of the TTCM scheme in the context of cooperative communications. The first one is based on Superposition Modulation (SPM) and the other relies on Hierarchical Modulation (HM). The transmitter may employ multiple low code-rate encoders, and the coded signal streams may be merged together by the SPM scheme to form a super-signal, so that they may be transmitted simultaneously without requiring extra transmit antennas. In this situation, the different signals exhibiting different error sensitivities may be mapped into specific SPM layers for transmissions. By contrast, a similar layered modulation scheme, namely HM may also be used, which is capable of reducing the complexity of the system. By employing the HM concept, the information in the different HM layers may be demodulated/decoded separately. Therefore, when the system is communicating based on the HM concept, it becomes quite flexible. When the relay node is capable of receiving all layers' information in the HM signal, it may opt for forwarding either all of its received streams, or only the specifically required streams, instead of fully retransmitting all information received from the source. In this way, the processing burden imposed on the relay node may be reduced.

Furthermore, the HM scheme may also be employed for improving the power-efficiency of the entire cooperative communication system. The original design objective of the HM scheme was that of providing Unequal Error Protection (UEP), while maintaining a high data rate. However, in cooperative communications, we may 're-purpose' the HM scheme for reducing the power dissipation of all the nodes in the cooperative networks. Hence, our research was then focussed on finding the appropriate HM aided cooperative strategy, which is capable of reducing the power consumption of the entire system. As a further contribution, the Discrete-input Continuous-output-Memoryless-Channel's (DCMC) capacity was also quantified. We relied on the DCMC capacity metric to find a lower-bound for the performance of HM aided cooperative communication, when assuming that a 'Perfect' capacity-achieving channel code is used. Additionally, a hybrid cooperative communication system relying on TTCM, SPM, as well as HM has also been proposed and investigated.

Finally, we employed our HM aided TTCM cooperative communication strategy in wireless *ad hoc* networks. A realistic system architecture and practical channels were considered, where the coded HM scheme was combined with an Opportunistic Routing (OR) algorithm for reducing the transmit power of each node in the cooperative network, as well as for the sake of reducing the average power consumption of the entire system. The results showed that if the system appropriately utilized the sophisticated modulation/demodulation capability of the layered modulation schemes, the flexibility of the OR algorithm may be improved, while the power consumption of the cooperative communication system may be reduced without increasing the outage probability.

Declaration of Authorship

I, **Hua Sun**, declare that the thesis entitled **Layered Turbo Trellis-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. **H. Sun**, S. X. Ng and L. Hanzo,"Turbo Trellis-Coded Hierarchical Modulation Assisted Decode-and-Forward Cooperation", IEEE Transactions on Vehicular Technology, vol. 64, no. 9, pp. 3971-3981, Oct. 2014.

2. **H. Sun**, S. X. Ng, C. Dong and L. Hanzo, "Decode-and-Forward Cooperation-Aided Triple-Layer Turbo-Trellis-Coded Hierarchical Modulation", IEEE Transactions on Communications, vol. 63, no. 4, pp. 1136-1148, Jan. 2015.

3. **H. Sun**, S. X. Ng and L. Hanzo, "The Discrete-Input Continuous-Output Memoryless Channel Capacity of Cooperative Hierarchical Modulation". IET communications, vol. 10, no. 1, pp. 65-71, Jan. 2016

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Conferences:

1. **H. Sun**, S. X. Ng and L. Hanzo, "Superposition Coded Modulation for Cooperative Communications", 2012 IEEE Vehicular Technology Conference (VTC Fall), pp.1-5, Quebec City, Canada, 3-6 Sept. 2012.

2. **H. Sun**, Y. R. Shen, S. X. Ng and L. Hanzo, "Turbo Trellis Coded hierarchical modulation for cooperative communications", 2013 IEEE Wireless Communications and Networking Conference (WCNC), pp.2789-2794, Shanghai, China, 7-10 Apr. 2013.

3. A. J. Aljohani, **H. Sun**, S. X. Ng and L. Hanzo, "Joint source and Turbo Trellis Coded Hierarchical Modulation for context-aware medical image transmission", 2013 IEEE 15th International Conference on e-Health Networking, Applications & Services (Healthcom), pp.1-5, Lisbon, Portugal, 3-6 Sept. 2013.

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