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

Cooperative Communication for Cognitive Radio Networks

by

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B.Sc., M.Sc.

A doctoral thesis submitted in partial fulfilment of the
requirements for the award of Doctor of Philosophy
at the University of Southampton

May 2015

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Dedicated to my family

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ABSTRACT

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Doctor of Philosophy

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A Cooperative Cognitive Radio (CCR) network, which integrates a conventional cooperative system and cognitive radios (CRs) into a holistic system, is a promising paradigm for the next generation mobile communication systems. The spectral efficiency, power efficiency, bandwidth reduction and system complexity in CCR networks are the fundamental parameters of our system design and optimization. In this thesis, we focus our attention on opportunistically exploiting the underutilized spectrum band in the CR network with the aid of cooperative protocols. Furthermore, we invoke channel coding schemes in our CCR system in order to improve the overall system throughput. In our CCR system, the overlay based cooperation scheme of Primary Users (PUs) and Cognitive Users (CUs) is considered, which has the potential of leading to a transmission power reduction and transmission rate improvement for both the PU and the CU. More explicitly, our cooperative protocol allows a group of CUs to serve as Relay Nodes (RNs) for relaying the signal of the PUs' transmitters to the PUs' intended destinations. To elaborate further, both one-way relaying and two-way relaying schemes are used in our proposed system, so that the bandwidth requirement of the PUs is reduced. Alternatively, the freed bandwidth may be leased to a group of CUs for their secondary communications. Our numerical and simulation results show that the bandwidth reduction attained by the proposed two-way relaying based CR scheme may approach as much as 80% of the PU's bandwidth. Moreover, an Adaptive Dynamic Network Coding (ADNC) scheme is also conceived for this overlay CCR system, which is designed for supporting communications between multiple PUs and a common Base Station (BS). More particularly, the near-instantaneously Adaptive Turbo Trellis Coded Modulation (ATTCM) is employed for appropriately adjusting both the modulation mode as well as the channel coding rate and the network coding rate, according to the near-instantaneous channel conditions. In order to facilitate the recovery of the source information at the BS, the CUs invoke the ADNC technique, which is assisted by our cooperative protocol operating by exchanging the CCR-based control information between the near-instantaneously ATTCM and network coding codec as well as between the CUs and the BS. Additionally, the network encoder may also be activated in its adaptive mode for supporting the CUs, depending on the Boolean value of the feedback flags generated based on the success/failure of the ATTCM decoder and of the network decoder, which is evaluated and fed back by the BS. Quantitatively, it was found that the joint holistic design of our ATTCM-ADNC-CCR scheme is either capable of freeing up an approx-

imately 40% of the PU's bandwidth in comparison to its non-cooperative counterpart, or increasing the attainable throughput by as much as 2 bit/symbol. Furthermore, a Pragmatic Distributed Algorithm (PDA) is proposed for supporting the efficient spectral access of multiple PUs and CUs in CCR networks. The novelty of our PDA is that the PUs negotiate with the CUs concerning the specific amount of relaying and transmission time, and the CU will decide either to accept or to decline this offer. These CUs relay the signal received from the PUs to the PUs' receiver, but only when both the PUs' and the CUs' minimum rate requirements are satisfied. Moreover, we show that the cooperative spectral access based on our PDA reaches an equilibrium, when it is repeated for a sufficiently long duration. These benefits are achieved, because the PUs are motivated to cooperate by the incentive of achieving a higher PU rate, whilst defecting from cooperation can be discouraged with the aid of a limited-duration punishment. Therefore, our proposed PDA outperforms the benchmark, despite its significantly lower overhead and lower complexity. Finally, we present the joint design of coding, modulation, user-cooperation and CR techniques, which may lead to significant mutual benefits for both the PUs and the CUs.

Declaration of Authorship

I, **Wei Liang**, declare that the thesis entitled **Cooperative Communication for Cognitive Radio Networks** 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: .....

Acknowledgements

First of all, I would like to give the greatest gratitude to both of my supervisors Dr. Soon Xin Ng and Prof. Lajos Hanzo. I really appreciate their generous and insightful guidances as well as wise advices in the past four years of my PhD study, which encourage me to insist on my own career that I passionate about. Thanks for sharing with me about their precious experiences, not only in science, but also in life.

Secondly, I would also like to thank all the other colleagues in Southampton Wireless Group for their help and supports. In particular, I wish to express my appreciation to Dr. Dandan Liang, Dr. Jing Zuo, Dr. Li Li, Dr. Shaoshi Yang and Miss Xuan Li for their kindly help and valuable ecouragement. I am very grateful for the collaboration with Dr. Jiao Feng and Dr. Hung Vietnguyen.

Thirdly, I would like to thank my parents, Dr. Peikang Liang and Ms Jing Li, as well as my parents in law, Mr Yajun Shi and Ms Fendi Yang for their endless love and full support on my PhD study.

Last but not the least, I would like to express my deepest appreciation to my husband, Dr. Jia Shi. Thanks for his love, understanding and support.

List of Publications

Journal Papers

1. **Wei Liang**, Soon Xin Ng and Lajos Hanzo, "Cooperative Communication Between Cognitive and Primary Users", *IET Communications*, Vol. 7, pp. 7-17, November 2013.

2. **Wei Liang**, Soon Xin Ng, Jiao Feng and Lajos Hanzo, "Pragmatic Distributed Algorithm for Spectral Access in Cooperative Cognitive Radio Networks", *IEEE Transactions on Communications*, Vol. 62, pp. 1188-1200, April 2014.

3. **Wei Liang**, Hung Viet nguyen, Soon Xin Ng and Lajos Hanzo, "Adaptive TTCM Aided Near-Instantaneously Dynamic Network Coding for Cooperative Cognitive Radio Networks", *IEEE Transactions on Vehicular Technology*, accepted, March 2015.

Conference Papers

1. **Wei Liang**, Soon Xin Ng and Lajos Hanzo, "TTCM-Aided SDMA-Based Two-Way Relaying", *2011 IEEE Vehicular Technology Conference (VTC2011-Fall)*, 5-8 September, San Francisco, USA.

2. **Wei Liang**, Soon Xin Ng and Lajos Hanzo, "Adaptive Turbo Trellis Coded Modulation Aided Cooperative Cognitive Radio", *2012 IEEE Wireless Communications and Networking Conference (WCNC 2012)* , 1-4 April, Paris, France.

3. **Wei Liang**, Soon Xin Ng, Siavash Bayat, Yonghui Li and Lajos Hanzo, "Opportunistic Spectral Access in Cooperative Cognitive Radio Networks", *2014 IEEE Vehicular Technology Conference (VTC2014-Fall)*, 14-17 September, Vancouver, Canada.

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