**UNIVERSITY OF SOUTHAMPTON**

FACULTY OF ENGINEERING, SCIENCE AND MATHEMATICS

SCHOOL OF ELECTRONICS AND COMPUTER SCIENCE

# Near-Capacity Co-located and Distributed MIMO Systems

*by*

Lingkun Kong

*B.Eng., M.Eng.*

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

October 2010

SUPERVISOR: *Prof. Lajos Hanzo*

FREng, FIEEE, FIET, DSc, Chair of Telecommunications

and *Dr. Soon Xin Ng*

PhD, SMIEEE, MIET

School of Electronics and Computer Science

University of Southampton

Southampton SO17 1BJ

United Kingdom

**This thesis is dedicated to**

my beloved parents, sister
and parents in law
for their love and support
and my lovely wife Dr. Xiaoli LI
for her tremendous patience, love and care
as well as our unborn baby
for the joy he/she brings to us · · ·

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF ENGINEERING, SCIENCE AND MATHEMATICS
SCHOOL OF ELECTRONICS AND COMPUTER SCIENCE

Doctor of Philosophy

**Near-Capacity Co-located and Distributed MIMO Systems**

by
Lingkun Kong

Space-time transmission based colocated and distributed Multiple-Input Multiple-Output (MIMO) systems are investigated. Generally speaking, there are two types of fundamental gains, when using multiple antennas in wireless communications systems: the multiplexing gain and the diversity gain. Spatial multiplexing techniques such as the Vertical Bell-labs LAyered Space-Time (V-BLAST) scheme exploit the associated multiplexing gain in terms of an increased bit rate, whereas spatial diversity techniques such as Space-Time Coding (STC) aim for achieving a diversity gain, which results in a reduced error rate. Firstly, we concentrate our attention on a novel space-time transmission scheme, namely on Generalized Multi-Layer Space-Time Codes (GMLST), which may be viewed as a composite of V-BLAST and STC, hence they provide both multiplexing and diversity gains. The basic decoding procedure conceived for our GMLST arrangement is a certain ordered successive decoding scheme, which combines group interference nulling and interference cancellation. We apply a specifically designed power allocation scheme, in order to avoid the overall system performance degradation in the case of equal power allocation. Furthermore, the optimal decoding order is found, in order to enhance the system's performance with the aid of the channel state information (CSI) at the receiver. However, our decoding scheme relying on power allocation or on the optimal decoding order does not take full advantage of the attainable receive antenna diversity. In order to make the most of this source of diversity, an iterative multistage Successive Interference Cancellation (SIC) detected GMLST scheme was proposed, which may achieve the full receive diversity after a number of iterations, while imposing only a fraction of the computational complexity of Maximum Likelihood (ML)-style joint detection.

Furthermore, for the sake of taking full advantage of the available colocated MIMO channel capacity, we present a low-complexity iteratively detected space-time transmission architecture based on GMLST codes and IRregular Convolutional Codes (IRCCs). The GMLST arrangement is serially concatenated with a Unity-Rate Code (URC) and an IRCC, which are used to facilitate near-capacity operation with the aid of an EXtrinsic

Information Transfer (EXIT) chart based design. Reduced-complexity iterative multi-stage SIC is employed in the GMLST decoder instead of the significantly more complex ML detection. For the sake of approaching the maximum attainable rate, iterative decoding is invoked to achieve decoding convergence by exchanging extrinsic information across the three serially concatenated component decoders. Finally, it is shown that the iteratively detected IRCC-URC-GMLST scheme using SIC strikes an attractive trade-off between the complexity imposed and the effective throughput attained, while achieving a near-capacity performance.

The above-mentioned advances were also exploited in the context of near-capacity communications in distributed MIMO systems. Specifically, we proposed an Irregular Cooperative Space-Time Coding (Ir-CSTC) scheme, which combines the benefits of Distributed Turbo Codes (DTC) and serially concatenated schemes. Firstly, a serial concatenated scheme comprising an IRCC, a recursive URC and a STC was designed for the conventional single-relay-aided network for employment at the source node. The IRCC is optimized with the aid of EXIT charts for the sake of achieving a near-error-free decoding at the relay node at a minimum source transmit power. During the relay's transmit period, another IRCC is amalgamated with a further STC, where the IRCC employed at the relay is further improved with the aid of a joint source-and-relay mode design procedure for the sake of approaching the relay channel's capacity. At the destination node, a novel three-stage iterative decoding scheme is constructed in order to achieve decoding convergence to an infinitesimally low Bit Error Ratio (BER) at channel Signal-to-Noise Ratios (SNRs) close to the relay channel's capacity. As a further contribution, an extended Ir-CSTC scheme is studied in the context of a twin-relay aided network, where a successive relaying protocol is employed. As a benefit, the factor two multiplexing loss of the single-relay-aided network - which is imposed by the creation of two-phase cooperation - is recovered by the successive relaying protocol with the aid of an additional relay. This technique is more practical than the creation of a full-duplex system, which is capable of transmitting and receiving at the same time. The generalized joint source-and-relay mode design procedure advocated relies on the proposed procedure of finding the optimal cooperative coding scheme, which performs close to the twin-relay-aided network's capacity. The corresponding simulation results verify that our proposed Ir-CSTC schemes are capable of near-capacity communications in both the single-relay-aided and the twin-relay-aided networks.

Having studied diverse noise-limited single-user systems, we finally investigate a multiuser space division multiple access (SDMA) uplink system designed for an interference-limited scenario, where the multiple access interference (MAI) significantly degrades the overall system performance. For the sake of supporting rank-deficient overloaded sys-

tems, a maximum signal-to-interference-plus-noise ratio (MaxSINR) based SIC multiuser detection (MUD) algorithm is proposed for the multiple-antenna aided multi-user SDMA system, which is capable of striking a trade-off between the interference suppression and noise enhancement. Furthermore, the multiuser SDMA system is combined with channel codes, which assist us in eliminating the typical error floors of rank-deficient systems. Referring to the Ir-CSTC scheme designed for the single-user scenario, relaying techniques are invoked in our channel-coded SDMA systems, which benefit from extra spatial diversity gains. In contrast to the single-user Ir-CSTC schemes, interference suppression is required at both the base station (BS) and the relaying mobile station (MS). Finally, a more practical scenario is considered where the MSs have spatially correlated transmit antennas. In contrast to the conventional views, our simulation results suggest that the spatial correlation experienced at the transmitter is potentially beneficial in multiuser SDMA uplink systems, provided that efficient MUDs are invoked.

# Acknowledgements

I would like to express my heartfelt gratitude to my first supervisor Professor Lajos Hanzo for his outstanding supervision and support throughout my research. His guidance, inspiration and encouragement have greatly benefited me; especially his generous investment of time and energy deserve my utmost acknowledgement. Most importantly, I would like to thank him for his invaluable friendship.

Moreover, I would like to cordially thank my second supervisor Dr. Soon Xin Ng (Michael). It would simply not have been possible to produce this thesis without his extremely generous and friendly support in helping me with the program debugging and engaging in intensive and inspiring discussions, especially in the beginning phase of my Ph.D career. I also wish sincerely to thank Michael for his friendship.

Many thanks also to my colleagues and the staff of the Communications Group, both past and present, for their support, help and discussions throughout my research. Special thanks to my colleagues Dr. Robert Maunder and Dr. Ronald Yee Siong Tee for their fruitful discussions as well as for their friendship. The financial support of the China-UK Scholarship Council, as well as that of the EPSRC UK, the EU under the auspices of the Optimix project is gratefully acknowledged.

Finally, I thank my dear parents, lovely sister and parents in law who have been providing me love and motivation. Last but not least, I want to thank my beloved wife Dr. Xiaoli LI who has been supporting me all the time.

# Declaration of Authorship

I, **Lingkun Kong**, declare that the thesis entitled

**Near-Capacity Co-located and Distributed MIMO Systems**

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:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. 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;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. 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;
5. I have acknowledged all main sources of help;
6. 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;
7. Parts of this work have been published as: [69-80].

**Signed**:
**Date**: 18 October 2010

# List of Publications

## Journal Papers:

1. **Lingkun Kong**, Soon Xin Ng, Ronald Y. S. Tee, Robert G. Maunder and Lajos Hanzo, "Reduced-Complexity Near-Capacity Downlink Iteratively Decoded Generalized Multi-Layer Space-Time Coding Using Irregular Convolutional Codes", IEEE Transactions on Wireless Communications, vol. 9, no. 2, pp. 684-695, February 2010.

2. **Lingkun Kong**, Soon Xin Ng, Robert G. Maunder and Lajos Hanzo, "Maximum-Throughput Irregular Distributed Space-Time Code for Near-Capacity Cooperative Communications", IEEE Transactions on Vehicular Technology, vol. 59, no. 3, pp. 1511-1517, March 2010.

3. **Lingkun Kong**, Soon Xin Ng, Robert G. Maunder and Lajos Hanzo, "Near-Capacity Cooperative Space-Time Coding Employing Irregular Design and Successive Relaying", IEEE Transactions on Communications, vol. 58, no. 8, pp. 2232-2241, August 2010.

4. Li Wang, **Lingkun Kong**, Soon Xin Ng and Lajos Hanzo, "Code-Rate-Optimized Differentially Modulated Near-Capacity Cooperation", submitted to IEEE Transactions on Communications.

5. Shinya Sugiura, Soon Xin Ng, **Lingkun Kong**, Sheng Chen and Lajos Hanzo, "Multiple-Relay Aided Differential Distributed Turbo Coding for Asynchronous Cooperative Networks", submitted to IEEE Transactions on Vehicular Technology.

## Conference Papers:

1. **Lingkun Kong**, Soon Xin Ng and Lajos Hanzo, "Near-Capacity Three-Stage Downlink Iteratively Decoded Generalized Layered Space-Time Coding with Low Complexity", in Proceedings of IEEE Globecom'08, (New Orleans, LA, USA), pp. 1-6, 30 Nov.-04 Dec. 2008.

2. **Lingkun Kong**, Soon Xin Ng, Robert G. Maunder and Lajos Hanzo, "Irregular Distributed Space-Time Code Design for Near-Capacity Cooperative Communications", in Proceedings of IEEE VTC'09 Fall, (Anchorage, Alaska, USA), pp. 1-6, 20-23 Sept. 2009.

3. **Lingkun Kong**, Soon Xin Ng, Robert G. Maunder and Lajos Hanzo, "Successive Relaying Aided Near-Capacity Irregular Distributed Space-Time Coding", in Proceedings of IEEE Globecom'09, (Honolulu, Hawaii, USA), pp. 1-5, 30 Nov.-04 Dec. 2009.

4. Wei Liu, **Lingkun Kong**, Soon Xin Ng and Lajos Hanzo, "Near-Capacity Iteratively Decoded Markov-Chain Monte-Carlo Aided BLAST System", in Proceedings of IEEE Globecom'09, (Honolulu, Hawaii, USA), pp. 1-5, 30 Nov.-04 Dec. 2009.

5. Li Wang, **Lingkun Kong**, Soon Xin Ng and Lajos Hanzo, "To Cooperate or Not: A Capacity Perspective", in Proceedings of IEEE VTC'10 Spring, (Taipei, Taiwan), pp. 1-5, 16-19 May 2010.

6. Li Wang, **Lingkun Kong**, Soon Xin Ng and Lajos Hanzo, "A Near-Capacity Differentially Encoded Non-Coherent Adaptive Multiple-Symbol-Detection Aided Three-Stage Coded Scheme", in Proceedings of IEEE VTC'10 Spring, (Taipei, Taiwan), pp. 1-5, 16-19 May 2010.

7. Shinya Sugiura, Soon Xin Ng, **Lingkun Kong**, Sheng Chen and Lajos Hanzo, "Multiple-Relay Aided Distributed Turbo Coding Assisted Differential Unitary Space-Time Spreading for Asynchronous Cooperative Networks", in Proceedings of IEEE VTC'10 Spring, (Taipei, Taiwan), pp. 1-5, 16-19 May 2010.

# Contents