Interference Management in 5G Cellular Networks

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Certificate of Authorship

I certify that the work in this dissertation has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged within the text.

I also certify that the dissertation has been written by me. Any help that I have received in my research work and the preparation of the dissertation itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the dissertation.

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Abstract

This dissertation is concerned with the nonconvex optimization problems of interference management under the consideration of new disruptive technologies in the fifth-generation cellular networks. These problems are the key to the successful roll-out of these new technologies but have remained unsolved due to their mathematical challenge. Therefore, this dissertation provides novel minorants/majorants of the nonconvex functions which are then used for the successive convex approximation framework.

The first considered technology is heterogeneous networks (HetNet) in which base stations (BSs) of various sizes and types are densely deployed in the same area. Although HetNet provides a significant improvement in spectral efficiency and offloading, designing an optimal power transmission and association control policy is challenging, especially when both quality-of-service (QoS) and backhaul capacity are considered. Maximizing the total network throughput or the fairness among users in HetNet are challenging mixed integer nonconvex optimization problems. Iterative algorithms based on alternating descent and successive convex programming are proposed to address such problems.

Next, we consider a full-duplex multi-user multiple-input multiple-output (FD MU-MIMO) multicell network in which base stations simultaneously serve both downlink (DL) users and uplink (UL) users on the same frequency band via multiple antennas to potentially double the spectral efficiency. Since the use of FD radios introduces additional self-interference (SI) and cross interference of UL between DL transmissions, the minimum cell throughput maximization and the sum network throughput maximization with QoS guarantee are nonconvex challenging problems. To solve such challenging optimization problems, we develop path-following algorithms based on successive convex quadratic programming framework. As a byproduct, the proposed algorithms can be extended to the optimal precoding matrix design in a half-duplex MU-MIMO multicell network with the Han-Kobayashi transmission strategy.

Finally, the last research work stems from the need of prolonging user equipments' battery life in power-limited networks. Toward this end, we consider the optimal design of precoding matrices in the emerging energy-harvesting-enabled (EH-enabled) MU-MIMO networks in which BSs can transfer information and energy to UEs on the same channel using either power splitting (PS) or time switching (TS) mechanisms. The total network throughput maximization problem under QoS constraints and EH constraints with either PS or TS in FD networks is computationally difficult due to nonconcave objective function and nonconvex constraints. We propose new inner approximations of these problems based on which a successive convex programming framework is applied to address them.

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Abbreviations

1G	First generation
3GPP	Third Generation Partnership Project
5G	Fifth generation
BS	Base station
CDMA	Code division multiple access
CoMP	Coordinated multipoint transmission/reception
CPU	Central processing unit
CR	Cognitive radio
CSI	Channel state information
d.c.	Difference of convex functions
DCD	Dual Coordinate Descent
DCI	Difference-of-convex iterations
DL	Downlink
DLU	Downlink user equipment
DPC	Dirty paper coding
DSL	Digital Subscriber Line
EH	Energy harvesting
FBS	Femto base station
FD	Full-duplex
HD	Half-duplex
HetNet	Heterogeneous network
H-K	Han-Kobayashi
IA	Interference aware
IC	Interference coordination
ID	Information decoding
IN	Interference network
JP	Joint signal processing
KKT	Karush-Kuhn-Tucker

LOS	Line-of-sight
LTE	Long Term Evolution
MBS	Macro base station
MIMO	Multiple-input multiple-output
MISO	Multiple-input single-output
MMSE-SIC	Minimum mean square error - Successive interference cancellation
MU	Multi-user
NOMA	Non-orthogonal multiple access
NP-hard	Non-deterministic polynomial-time hard
PBS	Pico base station
PoP	Point of Presence
PS	Power splitting
QCQP	Quadratically constrained quadratic program
QoS	Quality-of-Servive
QPI	Quadratic programming iterations
RF	Radio frequency
RHS	Right hand side
s.t.	Subject to
SCQP	Successive convex quadratic programming
SDN	Software-defined networking
SDP	Semi-definite programming
SI	Self-interference
SINR	Signal-to-interference-plus-noise ratio
SISO	Single-input single-output
SNR	Signal-to-noise ratio
SOCP	Second-order-cone programming
SU	Single-user
SVD	Singular value decomposition
TS	Time switching
UE	User equipment
UL	Uplink
ULU	Uplink user equipment

Notations

$\mathbb{R}$	Set of real numbers
$\mathbb{R}^+$	Set of positive real numbers
$\mathbb{C}$	Set of complex numbers
$\emptyset$	Empty set
$\|\mathcal{S}\|$	Cardinality of set $\mathcal{S}$
$\mathcal{S}_1 \setminus \mathcal{S}_2$	Elements of set $\mathcal{S}_2$ are excluded for set $\mathcal{S}_1$
x	Vector of constants
$\mathbf{x}$	Vector of variables
X	Matrix of constants
$\mathbf{X}$	Matrix of variables
I_n	Identity matrix of size $n \times n$
$1_{n\times m}$	All-one matrix of size $n \times m$
X^H	Hermitian transpose of a matrix X
X^T	Transpose of a matrix X
$\|x\|$	Absolute value of a complex scalar x
$\|A\|$	Determinant of a square matrix A
$\langle A\rangle$	Trace of a matrix A
$\langle X,Y\rangle = \langle X^H Y\rangle$	Inner product of X and Y
$\\|x\\|$	Norm of a vector x
$\\|X\\|$	Frobenius norm of a matrix X
$\\|X\\|^2 = \langle XX^H\rangle$	Frobenius squared norm of a matrix X
$A \succeq B$	$A - B$ is a positive semidefinite matrix
$\mathbb{E}[.]$	Expectation operator
$\mathrm{Re}\{.\}$	Real part of a complex number
$(x)^+$	$\max\{x, 0\}$
∇f	Gradient of a scalar function f
X^*	Optimal solution of an optimization program

Notations

$\forall$	for all
$\mathcal{O}$	Big O notation

Author's Publications

The contents of this dissertation are based on the following papers that have been published, accepted, or submitted to peer-reviewed journals and conferences.

Journal Papers:

1. **H. H. M. Tam**, H. D. Tuan, and D. T. Ngo, "Successive convex quadratic programming for quality-of-service management in full-duplex MU-MIMO multicell networks," *IEEE Transaction on Communication*, vol. 64, no. 6, pp. 2340-2353, June 2016.

2. E. Che, H. D. Tuan, **H. H. M. Tam**, and H. H. Nguyen, "Successive interference mitigation in multiuser MIMO interference channels," *IEEE Transaction on Communications*, vol. 63, no. 6, pp. 2185-2199, June 2015.

3. **H. H. M. Tam**, H. D. Tuan, D. T. Ngo, T. Q. Duong and H. V. Poor, "Joint load balancing and interference management for small-cell heterogeneous networks with limited backhaul capacity," *IEEE Transaction on Wireless Communications*, vol. 16, no. 2, pp. 872-884, February 2017.

4. **H. H. M. Tam**, H. D. Tuan, A. A. Nasir, T. Q. Duong and H. V. Poor, "MIMO energy harvesting in full-duplex MU-MIMO networks," *IEEE Transactions on Wireless Communication*, 2017.

5. **H. H. M. Tam**, H. D. Tuan, D. T. Ngo, and H. H. Nguyen, "Precoding design for Han-Kobayashis signal splitting in MIMO interference networks," *IEICE Transactions on Communication*, December 2016.

6. Zhichao Sheng, H. D. Tuan, **H. H. M. Tam**, and Ha H. Nguyen, "Energy-Efficient precoding in multicell networks with full-duplex base stations," *EURASIP Journal on Wireless Communications and Networking*, March 2017.

7. H. D. Tuan, D. T. Ngo, and **H. H. M. Tam**, "Joint power allocation for MIMO-OFDM full-duplex relaying communications," *EURASIP Journal on Wireless Communications and Networking*, January 2017.

Conference Papers:

1. **H. H. M. Tam**, E. Che and H. D. Tuan, "Optimized linear precoder in MIMO interference channel using D.C. programming," in *Proc. 7th International Conference on Signal Processing and Communication Systems (ICSPCS)*, pp. 1-5, December 2013.

2. H. H. Kha, H. D. Tuan, H. H. Nguyen and **H. H. M. Tam**, "Joint design of user power allocation and relay beamforming in two-way MIMO relay networks," in *Proc. 7th International Conference on Signal Processing and Communication Systems (ICSPCS)*, pp. 1-6, December 2013.

3. **H. H. M. Tam**, H. D. Tuan and E. Che, "Coordinated downlink beamforming in multicell wireless network," in *Proc. 2014 IEEE Fifth International Conference on Communications and Electronics (ICCE)*, pp. 83-86, July 2014.

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8. Z. Sheng, H. D. Tuan, Y. Fang, **H. H. M. Tam** and Y. Sun, "Data rate maximization based power allocation for OFDM System in a high-speed train environment," in *Proc. 2015 IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, pp. 265-269, December 2015.

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10. H. D. Tuan, D. T. Ngo and **H. H. M. Tam**, "Joint power allocation for MIMO-OFDM communication with full-duplex relaying," to appear in *Proc. 10th International Conference on Signal Processing and Communication Systems (ICSPCS)*, pp. 1-5, December 2016.