Optimized Transmission and Selection Designs in Wireless Systems

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Abstract

Most modern wireless communication systems are hierarchical complex systems which consist of many levels of design elements and are subject to limited resources (e.g. power or bandwidth). Thanks to numerous newly-introduced devices in different forms such as sensors and relays and the integration of multiple antennas, spectral efficiency and reliability of wireless transmission could be significantly improved. Nevertheless, it also becomes much more challenging to control the devices and allocate the limited resources in an optimal fashion in order to approach capacity gains.

This dissertation is concerned with mixed-binary or combinatorial optimization problems to improve various service goals for a variety of interesting yet difficult wireless communication applications. These problems are highly prized for academic significance but remained open due to their mathematical challenges. We shall explore the hidden d.c. (difference of convex (or concave) functions) structure of the objective functions as well as the binary constraints. Further, we will prove such general d.c. programs can be equivalently converted into canonical d.c. programs with d.c. objective functions that are subject to convex and/or affine constraints only. Although global optimal algorithms are generally possible for such d.c. programs, they are normally very computation-intensive. Instead, we propose tailored path-following local-optimal d.c. algorithms with significantly reduced computational complexity. Through extensive simulation results, the designed d.c. decompositions of the problems are proven effective. The proposed algorithms are efficient and computationally affordable while locating outstanding solutions in comparison with other existing algorithms. In those more sophisticated problem scenarios, the d.c. algorithm appears to be the only suitable option thanks to the superior flexibility.

In the first part of the thesis, we will consider a sensor network for spectrum sensing in the context of cognitive radios. To improve sensing quality and prolong the battery life of sensors, the least correlated subset of sensors needs to be selected. A new Bregman matrix deviation-based framework is shown applicable to all the concerned correlation measure functions.

The second research investigates a relay-assisted multi-user wireless network. Besides the relay beamforming variables, we add into consideration a set of binary link variables which represent on/off operations of individual relays in relation to transmitter-receiver links. To achieve the maximin SNR or SINR capacity, certain relays may be optimally deactivated. This leads to reduced power consumption and complexity/ overhead of management. The relay assignment and beamforming design is a joint mixed combinatorial nonlinear program which is non-convex and non-smooth. Nonetheless, we show the it can be fit into a canonical d.c. optimization framework. Simulation results demonstrate the benefits of relay selection and beamforming.

The last research stems from the study of conventional coordinated transmission design with respect to transmit covariance and precoding matrix/vector variables. Inspired by the well-known Han-Kobayashi message splitting method in 2-user SISO interference channels, we further extend the idea of message splitting to the MIMO interference networks. An innovative non-smooth rate formula is discovered which builds the foundation of the work. The design in common and private covariance matrices or beamforming vectors, as well as the pairing variables, is formulated as a joint combinatorial nonlinear program which is non-convex and non-smooth. Due to the great difficulty, it is not imminently possible to jointly handle both variables. Therefore, we first propose an intuitive heuristic pairing algorithm to find excellent pairing choices. Then, the non-convex optimization problems in covariance matrices or beamforming vector variables are dealt with in the d.c. optimization framework. Finally, simulation results reveal the great potential of the novel message splitting scheme in approaching rate capacity.

CERTIFICATE OF ORIGINAL AUTHORSHIP

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I, Enlong CHE, certify that this thesis titled, 'Optimized Transmission and Selection Designs in Wireless Systems', has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

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

Signature of Student:

Date:

Signed: ______________________________

Date: ______________________________

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Abbreviations

MIMO	Multiple-Input-Multiple-Output
MISO	Multiple-Input-Single-Output
SIMO	Single-Input-Multiple-Output
SISO	Single-Input-Single-Output
(W)MMSE	(Weighted) Minimum Mean Squared Error
SDP	Semi-definite Programming
LMI	Linear Matrix Inequality
SINR	Signal to Interference plus Noise Ratio
SNR	Signal to Noise Ratio
INR	Interference to Noise Ratio
s.t.	Subject to
d.c.	Difference of Convex (Concave) Functions
DCI	D.C. Iterative Algorithm
NP-hard	Non-deterministic Polynomial-time hard
CM	Correlation Measure
DoF	Degrees of Freedom
MRC	Maximal Ratio Combining
DSP	Digital Signal Processing
BS	Base Station
MT	Mobile Terminal
CSI	Channel State Information
MIP	Mixed Integer Optimization Problem
COP	Combinatorial Optimization Problem
PSD	Power Spectral Density
TDM/ FDM	Time/Frequence Division Multiplexing

Notations

1. Matrices and vector are denoted by uppercase and lowercase characters, respectively. Variables are denoted by boldface letters.
2. $\langle \boldsymbol{X} \rangle = \mathsf{trace}(\boldsymbol{X})$ for matrix $\boldsymbol{X}$.
3. $|\boldsymbol{X}|$: the determinant of matrix $\boldsymbol{X}$.
4. $\langle \boldsymbol{X}, \boldsymbol{Y} \rangle = \mathsf{trace}(\boldsymbol{X}^H \boldsymbol{Y})$ for matrices $\boldsymbol{X}, \boldsymbol{Y}$.
5. $\langle \boldsymbol{x}, \boldsymbol{y} \rangle = \boldsymbol{x}^H \boldsymbol{y}$ for vectors $\boldsymbol{x}, \boldsymbol{y}$.
6. $\boldsymbol{X} \succ 0$ ($\boldsymbol{X} \succeq 0$, resp.): $\boldsymbol{X}$ is a (Hermitian) positive definite (semi-definite, resp.) matrix.
7. $\mathcal{S}_+^{N_t}$ denotes the cone of Hermitian symmetric positive semi-definite matrices of size $N_t \times N_t$.
8. $\vee$ is logical or operation, so $\alpha = \beta \vee \gamma$ means α is either β or γ.
9. $\log(.)$ is understood as base-2 logarithm, i.e., $\log_2(.)$.
10. $1 : N$ stands for $1, 2, \cdots, N$.
11. $\boldsymbol{x} \sim \mathcal{CN}(\bar{\boldsymbol{x}}, \boldsymbol{R}_{\boldsymbol{x}})$ means $\boldsymbol{x}$ is a vector of Gaussian random variables with. means $\bar{\boldsymbol{x}}$ and covariance $\boldsymbol{R}_{\boldsymbol{x}}$.
12. $\lambda_{max}(\boldsymbol{X})$: the maximum eigenvalue of $\boldsymbol{X}$.
13. $\boldsymbol{X} \geq 0$ and $\sqrt{\boldsymbol{X}}$ are entry-wise understood.
14. For $\boldsymbol{X} \succeq 0$, $\boldsymbol{X}^{1/2}$ is a symmetric matrix such that $\boldsymbol{X}^{1/2}\boldsymbol{X}^{1/2} = \boldsymbol{X}$.
15. $\mathbf{1}_N$: the N-dimensional vector with unity components.
16. $e_i \in R^N$ has zero components except i-th component equal 1.
17. $\odot$: the Hadamard product operator.
18. $\binom{M}{N}$: binomial coefficient.
19. $\mathsf{Re}(\boldsymbol{x})$: real-part function.
20. $[x]_b$: rounded binary value from $x \in [0, 1]$.

Dedicated to

my dearest parents, grandpas and grandmas …