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Low-complexity Iterative Receiver Design for High Spectral Efficiency Communication Systems

by

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Statement of Originality

I, Weijie Yuan, declare that this thesis, is submitted in fulfilment of the requirements for the award of PhD in Engineering, in the School of Electrical and Data Engineering at the University of Technology Sydney. This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

The document has not been submitted for qualifications at any other academic institution.

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ABSTRACT

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With the rapid development of the modern society, people have an increasing demand of higher data rate. Due to the limited available bandwidth, how to improve the spectral efficiency becomes a key issue in the next generation wireless systems. Recent researches show that, compared to the conventional orthogonal communication systems, the non-orthogonal system can transmit more information with the same resources by introducing non-orthogonality. The non-orthogonal communication systems can be achieved by using faster-than-Nyqusit (FTN) signaling to transmit more data symbols in the same time period. On the other hand, by designing appropriate codebook, the sparse code multiple access (SCMA) system can support more users while preserving the same resource elements. Utilisation of these new technologies leads to challenge in receiver design, which becomes severer in complex channel environments. This thesis studies the receiver design for high spectral efficiency communication systems. The main contributions are as follows:

1. A hybrid message passing algorithm is proposed for faster-than-Nyquist, which solves the problem of joint data detection and channel estimation when the channel coefficients are unknown. To fully exploit the known ISI imposed by FTN signaling, the interference induced by FTN signaling and channel fading are intentionally separated.

2. Gaussian message passing and variational inference based estimation algorithms are proposed for faster-than-Nyquist signaling detection in doubly selective channels. Iterative receivers using mean field and

Bethe approximations based on variational inference framework are proposed. Moreover, a novel Gaussian message passing based FTN signaling detection algorithm is proposed.

3. An energy minimisation based SCMA decoding algorithm is proposed and convergence analysis of the proposed algorithm is derived. Following optimisation theory and variational free energy framework, the posterior distribution of data symbol is derived in closed form. Then, the convergence property of the proposed algorithm is analysed.

4. A stretched factor graph is designed for MIMO-SCMA system in order to reduce the receiver complexity. Then, a convergence guaranteed message passing algorithm is proposed by convexifying the Bethe free energy. Finally, cooperative communication methods based on belief consensus and alternative direction method of multipliers are proposed.

5. A low complexity detection algorithm is proposed for faster-than-Nyquist SCMA system, which enables joint channel estimation, decoding and user activity detection in grant-free systems. The combination of FTN signaling with SCMA to further enhance the spectral efficiency is first considered. Then, a merging belief propagation and expectation propagation algorithm is proposed to estimate channel state and perform SCMA decoding.

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List of Publications

Published Journal Papers

J-1. **W. Yuan**, N. Wu, B. Etzlinger, H. Wang, and J. Kuang, "Cooperative Joint Localization and Clock Synchronization Based on Gaussian Message Passing in Asynchronous Wireless Networks," *IEEE Transactions on Vehicular Technology,* vol. 65, no. 9, pp. 7258-7273, Sep. 2016.

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Submitted Journal Papers

J-12. **W. Yuan**, N. Wu, Q. Guo, X. Huang, Y. Li, and L. Hanzo, "TOA Based Passive Localization Constructed over Factor Graphs: A Unified Framework," Submitted to *IEEE Transactions on Communications.*

J-13. **W. Yuan**, N. Wu, B. F. Fleury, X. Huang, and Y. Li, "A Merging Message Passing Algorithm for Cooperative Joint Localization and Synchronization," To be submitted to *IEEE Internet of Things Journal.*

J-14. **W. Yuan**, N. Wu, A. Zhang, X. Huang, Y. Li, and L. Hanzo, "Iterative Receiver Design for Faster than NqyuistSignaling-Spare Code Multiple Access System," Submitted to IEEE Transactions on Wirless Communications.

Contents

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Abbreviation

1G	The First Generation
2G	The Second Generation
3G	The Third Generation
4G	The Fourth Generation
5G	The Fifth Generation
ADMM	Alternating Direction Method of Multipliers
AMP	Approximate Message Passing
AR	Auto Regressive
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BP	Belief Propagation
BS	Base Station
CDMA	Code Division Multiple Access
CS	Compressive Sensing
CSI	Channel State Information
dB	Decibel
DFT	Discrete Fourier Transform
DSC	Doubly Selective Channel
EM	Expectation Maximisation
EP	Expectation Propagation
EXIT	Extrinsic Information Transfer
FBMC	Filter Bank Multi Carrier
FDMA	Frequency Shaped Sliding Mode Control

FDE	Frequency Domain Equalisation
FTN	Faster Than Nyquist
GMP	Gaussian Message Passing
GSM	Global System for Mobile Communication
IDMA	Interleave Division Multiple Access
IDFT	Inverse Discrete Fourier Transform
ISI	Inter Symbol Interference
KLD	Kullback-Leibler Divergence
LDPC	Low Density Check Code
LDS	Low Density Signature
LLR	Log Likelihood Ratio
LMMSE	Linear Minimum Mean Squared Error
LS	Least Square
MAP	Maximum *A Posteriori*
MIMO	Multiple Input Multiple Output
MF	Mean Field
MMSE	Minimum Mean Squared Error
MPA	Message Passing Algorithm
MPSK	M-ary Phase Shift Keying
MUSA	Multi-User Shared Access
NOMA	Non-Orthogonal Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OMA	Orthogonal Multiple Access
PDMA	Pattern Division Multiple Access
PMF	Probability Mass Function
p-NOMA	power domain NOMA

QAM	Quadrature Amplitude Modulation
SCM	Single-Carrier Modulation
SCMA	Sparse Code Multiple Access
SIC	Successive Interference Cancellation
SPA	Sum Product Algorithm
TDMA	Time Division Multiple Access
VMP	Variational Message Passing

Nomenclature and Notation

Capital boldface letters denote matrices.

$\mathbf{A}_{:,i}$ denotes the ith column of matrix $\mathbf{A}$.

Lower-case boldface alphabets denote column vectors.

$(.)^T$ denotes the transpose operation.

$(.)^*$ denotes the conjugate operation.

$(.)^H$ denotes the Hermitian operation.

$(.)^{-1}$ denotes the inverse operation.

I_n is the identity matrix of dimension $n \times n$.

$\propto$ represents equality up to a constant normalization factor.

$\mathbb{E}$ is the expectation operator.

C denotes a constant.

$\mathbb{B}^K$ denotes a K-dimensional binary space.

$\mathbb{C}^K$ denotes a K-dimensional complex space.

$\mathbb{R}^{K \times K}$ denotes a $K \times K$-dimensional complex space.

$*$ denotes the convolution operator.