

**ITERATIVE DETECTION ALGORITHMS FOR HIGH SPECTRAL
EFFICIENCY WIRELESS COMMUNICATION SYSTEMS**

by
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Dissertation submitted in fulfilment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

under the supervision of

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November 2020

CERTIFICATE OF ORIGINAL AUTHORSHIP

I, QIAOLIN SHI, declare that this thesis is submitted in fulfilment of the requirements for the award of DOCTOR OF PHILOSOPHY in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree at any other academic institution except as fully acknowledged within the text. This thesis is the result of a Collaborative Doctoral Research Degree program with Beijing Institute of Technology.

This research is supported by the Australian Government Research Training Program.

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ABSTRACT

With the ever-growing of the number of devices and new applications (e.g., in industry automation, intelligent transportation systems, healthcare) and given the severe bandwidth congestion observed at the sub-6GHz frequency bands, it is critical to develop high spectral efficiency transmission techniques. However, the detection of new transmission signalling becomes more challenging compared to that of its conventional counterpart. In this thesis, advanced iterative detection algorithms for index modulation-aided and faster-than-Nyquist (FTN) signalling-aided communication systems are investigated. First, factor graph-based message passing algorithms are proposed for the joint phase noise (PHN) estimation and signal detection in orthogonal frequency division multiplexing with index modulation (OFDM-IM) systems. The solutions are superior to conventional extended Kalman filter and variational approaches in terms of the robustness to severe PHN, as well as the realistic imperfect channel state information and residual carrier frequency offset. Second, amalgamated belief propagation and mean field message passing methods based iterative detection algorithms are developed for satellite communication systems relying on the dual mode-aided index modulation (Sat-DMIM) over nonlinear dispersive satellite channels. The computational complexity of the proposed detector is further reduced by approximating the nonlinear messages using a Taylor series expansion technique. The bit error rate performance of Sat-DMIM is improved compared with the conventional linear equalizer which directly linearizes the

nonlinear system model. Third, frequency-domain joint channel estimation and signal detection methods using the variational Bayesian framework for FTN systems over frequency-selective fading channels are designed. Taking into account the structured inter-symbol interference imposed by FTN signalling and dispersive channels, reliable estimates of channel coefficients and FTN symbols are obtained by minimizing the variational free energy without the aid of the cyclic prefix. Simulation results show that the FTN system relying on the proposed iterative detection algorithm can significantly improve the spectral efficiency compared to its conventional Nyquist counterpart.

ACKNOWLEDGMENTS

The accomplishment of my PhD thesis is owed to the contributions and supports of many people. First and foremost, I would like to express my appreciation and thanks to my supervisors Dr. Diep N. Nguyen and Prof. Xiaojing Huang for their tremendous encouragement, guidance, constructive comments and enduring patience. Dr. Nguyen not only taught me a lot in the research journey but also took good care of my life. Dr. Nguyen's kind support and valuable guidance go far beyond this thesis, and I feel greatly honoured to be supervised by him. I also want to thank my co-supervisor Prof. Huang for his kind care, as well as wonderful support and valuable advice for my research work. From them, I have learned to be patient and dedicated to the research work, which will undoubtedly influence my life.

I would like to thank Prof. Nan Wu and Prof. Hua Wang from Beijing Institute of Technology for their guidance in my early graduate years, from whom I have learned how to find latest studies that interest me and think rigorously. I am greatly thankful to Prof. Lajos Hanzo from University of Southampton for kindly inviting me to visit his group for one year and conducting collaborative research works. I also thank Prof. Xiaoli Ma from Georgia Institute of Technology and A/Prof. Qinghua Guo from the University of Wollongong for their precious guidance on doing research and paper writing. Collaborating with them has broadened my horizon and improved my research.

I would like to thank Dr. Peiyuan Qin, Dr. Forest Zhu and Dr. Negin Shariati for their kind help during my PhD study. Furthermore, many

thanks to all the staff from the School of Electrical and Data Engineering, University of Technology Sydney, for various forms of help they gave to me. I would like to thank all my colleagues and friends for their support and company.

Last but most importantly, my deepest gratitude and love to my family. My loving husband, Ruiheng Zhang, always puts up with me and holds my hand during this long journey. He always tells me funny jokes to make me laugh. We row upstream in the stormy winds and we also have a lot of happy water fights. My beloved daughter, Yuxi, your beautiful smile is always the sunshine in my life. My best friend, Qi Zhang, is always there with me. Finally, I would like to express my gratefulness to my parents Shengchun and Conghua for their unconditional love, patience and sacrifice.

Dedicated to My Beloved Husband, Daughter and Parents

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List of Publications

Journal publications

- **Qiaolin Shi**, Nan Wu, Hua Wang, Xiaoli Ma, Lajos Hanzo, “Factor Graph Based Message Passing Algorithms for Joint Phase-Noise Estimation and Decoding in OFDM-IM”, *IEEE Transactions on Communications (TCOM)*, 2020, 68(5), 2906 – 2921. (Corresponding to Chapter 2)
- **Qiaolin Shi**, Nan Wu, Diep N. Nguyen, Xiaojing Huang, Hua Wang, Lajos Hanzo, “Low-Complexity Iterative Detection for Dual-Mode-Aided Index Modulation in Nonlinear Dispersive Satellite Channels”, to be submitted to *IEEE Transactions on Communications (IEEE TCOM)*. (Corresponding to Chapter 3)
- **Qiaolin Shi**, Nan Wu, Xiaoli Ma, Hua Wang, “Frequency-Domain Joint Channel Estimation and Decoding for Faster-than-Nyquist signaling”, *IEEE Transactions on Communications*”, *IEEE Transactions on Communications (IEEE TCOM)*, 2018, 66(2), 781-795. (Corresponding to Chapter 4)
- **Qiaolin Shi**, Nan Wu, Hua Wang, Weijie Yuan, “Joint channel estimation and decoding in the presence of phase noise over time-selective flat-fading channels”, in *IET Communications*, 2016, 10(5): 577-585.

Conference publications

- **Qiaolin Shi**, Nan Wu, Hua Wang, Diep N. Nguyen, Xiaojing Huang, “Low-Complexity Message Passing Receiver for OFDM-IM in the Presence of Phase Noise”, in *IEEE Global Communications Conference (GLOBECOM)*, Dec 2020, pp. 1 – 6. (Corresponding to Chapter 2)
- **Qiaolin Shi**, Nan Wu, Hua Wang, “Joint Channel Estimation and Decoding for FTNS in Frequency-Selective Fading Channels”, in *IEEE Global Communications Conference (GLOBECOM)*, Dec 2016, pp. 1 – 6. (Corresponding to Chapter 4)
- **Qiaolin Shi**, Desheng Shi, Guibo Wang, Nan Wu, Hua Wang, “Joint channel response, phase noise estimation and decoding in time-selective flat Rayleigh fading channels”, in *IEEE International Conference on Wireless Communications and Signal Processing (WCSP)*, Oct 2015, pp. 1 – 5.

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- Nan Wu, Weijie Yuan, Hua Wang, **Qiaolin Shi**, Jingming Kuang, “Frequency-Domain Iterative Message Passing Receiver for Faster-than-Nyquist Signaling in Doubly Selective Channels”, in *IEEE Wireless Communications Letters*, 2016, 5(6): 584-587.
- Shaoang Li, Nan Wu, **Qiaolin Shi**, Qinghua Guo, “FTN Signaling-Aided Space-Time Multi-Mode Index Modulation Systems With a GMP-Based Receiver”, in *IEEE Access*, 2019, 7: 162898-162912.
- Ruiheng Zhang, Chengpo Mu, Min Xu, Lixin Xu, **Qiaolin Shi**, “Synthetic IR Image Refinement Using Adversarial Learning With Bidirectional Mappings”, in *IEEE Access*, 2019, 7: 153734-153750.

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- Weijie Yuan, **Qiaolin Shi**, Nan Wu, Qinghua Guo, Yonghui Li, “Gaussian Message Passing Based Passive Localization in the Presence of Receiver Detection Failures”, in *IEEE Vehicular Technology Conference (VTC Spring)*, 2018, pp. 1 – 5.

Abbreviations

1G	The First Generation
4G	The Fourth Generation
5G	The Fifth Generation
AMP	Approximate Message Passing
AWGN	Additive White Gaussian Noise
AR	Auto Regressive
BER	Bit Error Rate
BP	Belief Propagation
BPSK	Binary Phase Shift Keying
CFO	Carrier Frequency Offset
CIR	Channel Impulse Response
CP	Cyclic Prefix
CS	Compressed Sensing
CSI	Channel State Information
dB	Decibel

DCT	Discrete Cosine Transforms
DFT	Discrete Fourier Transform
EM	Expectation Maximization
EP	Expectation Propagation
EXIT	Extrinsic Information Transfer
FBMC	Filter Bank Multi Carrier
FFT	Fast Fourier Fransform
FTN	Faster-than-Nyquist
GAMP	Generalized Approximate Message Passing
GFDM	Generalized Frequency Division Multiplexing
GMP	Gaussian Message Passing
ICI	Inter-Carrier Interference
IM	Index Modulation
IMUX	Input Demultiplexer
IoT	Internet of Things
IRC	Iterative Residual Check
ISI	Inter Symbol Interference
KLD	Kullback-Leibler Divergence
LDPC	Low Density Check Code
LLR	Log Likelihood Ratio

LMMSE	Linear Minimum Mean Squared Error
LS	Least Square
LTE	Long Term Evolution
MAP	Maximum <i>A Posteriori</i>
MF	Mean Field
MIMO	Multiple-Input Multiple-Output
ML	Maximum Likelihood
MMSE	Minimum Mean Squared Error
mm-Wave	MillimeterWave
OFDM	Orthogonal Frequency Division Multiplexing
OFDM-IM	OFDM with Index Modulation
OMUX	Output Multiplexer Filter
PA	Power Amplifier
pdf	probability density function
PHN	Phase Noise
pmf	probability mass function
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RSC	Recursive Systematic Convolutional

SC-IM	Single-Carrier with Index Modulation
SIC	Successive Interference Cancellation
SISO	Soft-In Soft-Out
SM	Spatial Modulation
SNR	Signal-to-Noise Ratio
SPA	Sum Product Algorithm
VB	Variational Bayesian
VMP	Variational Message Passing

Notation

Boldface capital (small) letters denote matrices (vectors).

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

$\mathbf{A}_{i,:}$ denotes the i th row of matrix \mathbf{A} .

$\mathbf{A}_{i,k}$ denotes the i, k th element of matrix \mathbf{A} .

$\mathcal{D}(\mathbf{a})$ denotes the diagonal matrix constructed from the vector \mathbf{a} .

$\mathcal{D}(\mathbf{A})$ denotes the diagonal matrix with the diagonal elements of square matrix \mathbf{A} on its diagonal.

$E\{\cdot\}$ denotes the expectation operation.

$V\{\cdot\}$ denotes the (co)variance operation.

$\text{tr}(\cdot)$ denotes the trace operator.

\mathbb{R} denotes the field of reals.

\mathbb{C} denotes the field of complex.

\propto denotes proportionality.

\mathbf{F} denotes the unitary DFT matrix.

Φ denotes the unitary DCT matrix.

\mathbf{I} denotes the identity matrix.

$\mathbf{0}$ denotes the all-zeros matrix.

$\mathbf{1}$ denotes the all-one column-vector.

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

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

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

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

\star denotes the linear convolution.

\otimes denotes the cyclic convolution.

\odot denotes the element-wise product.

\hat{m}_x denotes the mean of the random variable x .

\hat{v}_x denotes the mean of the random variable x .

$p(\cdot)$ denotes the pdf of a continuous random variable.

$P(\cdot)$ denotes the pmf of a discrete random variable.