

**SECURE AND EFFICIENT DYNAMIC SPECTRUM ACCESS
SOLUTIONS FOR FUTURE WIRELESS NETWORKS**

by
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ABSTRACT

The future wireless communication network (5G and beyond) is expected to provide many advantages, such as an extremely high peak rate, ultralow latency and less energy consumption. However, since an extremely large number of connecting devices will be deployed, the demand for the spectrum will also be growing exponentially, causing a problem of spectrum shortage. To effectively address the spectrum crunch, dynamic spectrum access (DSA), including both sensing-based and database-driven DSA, has been proposed.

In this thesis, we investigate critical challenges in DSA, including the efficiency in sensing-based techniques and privacy in database-driven techniques. First, to improve the sensing performance of the sensing-based DSA in half-duplex (HD) systems, we propose two sensing approaches leveraging the property of deep learning networks. Our solutions are significantly superior in terms of the robustness to noise uncertainty, timing delay, and carrier frequency offset (CFO), compared to conventional sensing methods. Moreover, our work does not require any prior information of signals, which however is essential for the traditional sensing methods. Second, to improve the sensing performance of sensing-based DSA in full-duplex (FD) systems, we develop two novel sensing methods using the features of orthogonal frequency division multiplexing (OFDM) signals. The developed sensing approaches are robust to not only residual SI but also timing delay or CFO. We also obtain the closed-form expressions of the probability of detection and false alarm for our approaches. Third, to protect the users' privacy in

the database-driven DSA, we develop two schemes to protect the operational privacy of Incumbent Users (IUs) and honest/dishonest Secondary Users (SUs). To implement our proposed work, we introduce an interference calculation scheme that allows users to calculate an interference budget without revealing operational information. It also reduces the computing overhead of our developed approaches. Additionally, we propose a “punishment and forgiveness mechanism to encourage dishonest SUs to provide truthful information. Theoretical analysis and extensive simulations show that our proposed schemes can better protect all users’ operational privacy under various privacy attacks, yielding higher spectrum utilization with less online overhead, compared with state of the art approaches.

CERTIFICATE OF ORIGINAL AUTHORSHIP

I, QINGQING CHENG, 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 reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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

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Dedicated to My Beloved Husband, Parents and Grandparents

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List of Publications

Journal publications

- **Qingqing Cheng**, Zhenguo Shi, Diep N. Nguyen, Eryk Dutkiewicz, “Sensing OFDM Signal: A Deep Learning Approach”, *IEEE Transactions on Communications (TCOM)*, 2019, DOI: 10.1109/TCOMM.2019.2940013 (Corresponding to Chapter 3)
- **Qingqing Cheng**, Diep N. Nguyen, Eryk Dutkiewicz, Markus Mueck, “Preserving Honest/Dishonest Users’ Operational Privacy with Blind Interference Calculation in Spectrum Sharing System”, *IEEE Transactions on Mobile Computing (TMC)*, 2019, DOI: 10.1109/TMC.2019.2936377. (Corresponding to Chapter 5)
- **Qingqing Cheng**, Zhenguo Shi, Diep N. Nguyen, Eryk Dutkiewicz, “Sensing OFDM Signals in Full-duplex Systems with Residual Self-interference, Timing Delay and Carrier Frequency Offset”, to be submitted to *IEEE Transactions on Communications (IEEE TCOM)* (Corresponding to Chapter 4)

Conference publications

- **Qingqing Cheng**, Eryk Dutkiewicz, Gengfa Fang, Zhenguo Shi, Diep N. Nguyen, Huiyang Wang, “A Novel Full-Duplex Spectrum Sensing Algorithm

- for OFDM Signals in Cognitive Radio Networks”, in *IEEE Global Communications Conference (GLOBECOM)*, Dec 2017, pp. 1 – 6. (Corresponding to Chapter 4)
- **Qingqing Cheng**, Zhenguo Shi, Diep N. Nguyen, Eryk Dutkiewicz, “An OFDM Sensing Algorithm in Full-Duplex Systems with Self-Interference and Carrier Frequency Offset”, accepted to *IEEE Global Communications Conference (GLOBECOM)*, 2019. (Corresponding to Chapter 4)
 - **Qingqing Cheng**, Diep N. Nguyen, Eryk Dutkiewicz, Markus Mueck, “Preserving operational information in spectrum access system with dishonest users”, in *17th International Symposium on Communications and Information Technologies (ISCIT)*, Sep 2017, pp. 1 – 6. (Corresponding to Chapter 5)
 - **Qingqing Cheng**, Diep N. Nguyen, Eryk Dutkiewicz, Markus Mueck, “Protecting operational information of incumbent and secondary users in FCC spectrum access system”, in *IEEE International Conference on Communications (ICC)*, May 2018, pp. 1 – 6. (Corresponding to Chapter 5)
 - **Qingqing Cheng**, Zhenguo Shi, Diep N. Nguyen, Eryk Dutkiewicz, “Non-cooperative OFDM Spectrum Sensing Using Deep Learning”, accepted to appear at *International Conference on Computing, Networking and Communications (ICNC)*, 2020. (Corresponding to Chapter 3)

Other

- Zhenguo Shi, Andrew Zhang, Richard Xu, **Qingqing Cheng** “Deep learning networks for human activity recognition with CSI correlation feature extraction”, in *IEEE International Conference on Communications (ICC)*, May 2019, pp. 1 – 6.

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- Asanka Kekirigoda, Kin-Ping Hui, **Qingqing Cheng**, Zhipeng Lin, Andrew Zhang, Diep N. Nguyen, Xiaojing Huang, “Massive MIMO for Tactical Ad-hoc Networks in RF Contested Environments”, accepted to *IEEE Military Communications Conference (MILCOM)*, 2019.
 - Huiyang Wang, Diep N. Nguyen, Dinh T. Hoang, Eryk Dutkiewicz, **Qingqing Cheng**, “Real- Time Crowdsourcing Incentive for Radio Environment Maps: A Dynamic Pricing Approach”, in *IEEE Global Communications Conference (GLOBECOM)*, Dec, 2018, pp. 1 – 6.
 - Zhenguo Shi, Zhilu Wu, Zhendong Yin, Zhutian Yang, **Qingqing Cheng**, “Novel Markov channel predictors for interference alignment in cognitive radio network”, in *Wireless Networks*, Vol. 24, Iss. 6, 2018.

Abbreviations

AWGN	Additive white Gaussian noise
ANN	Artificial Neural Network
BPSK	Binary phase shift keying
BICS	Blind interference calculation scheme
CFO	Carrier frequency offset
CBSD	Citizens Broadband Radio Service Device
CDMA	Code Division Multiple Access
CRNs	Cognitive radio networks
CNN	Convolutional neural network
CSS	Cooperative spectrum sensing
CM	Covariance matrix
CP	Cyclic Prefix
CRC	Cyclic Redundancy Check
DL	Deep learning
DoS	Denial of service

DoD	Department of Defense
DSA	Dynamic spectrum access
ED	Energy detection
ETSI	European Telecommunications Standardization Institute
FFT	Fast Fourier transform
FCC	Federal Communications Commission
FSS	Fixed Satellite System
FD-AC	Frequency domain autocorrelation
FD	Full-duplex
GMM	Gaussian mixture model
GAA	General Authorized Access
HD	Half-duplex
HAAT	Height above average terrain
IDN	Identity number
IUs	Incumbent users
KNN	K-nearest-neighbor
LSA	Licensed Shared Access
LRT	Likelihood ratio test
LAT	Listen and talk
LBT	Listen before talk

ML	Machine learning
MCMC	Markov Chain Monte Carlo
Massive MIMO	Massive Multiple-input and multiple-output
MIMO	Multiple-input and multiple-output
NDE	Negative decision error
NDER	Negative decision error ratio
NOMA	Non-orthogonal multiple access
OFDM	Orthogonal frequency-division multiplexing
OFDMA	Orthogonal frequency-division multiple access
PT	Pilot Tone
PDE	Positive decision error
PDER	Positive decision error ratio
PU_s	Primary users
PA	Priority Access
PAL	Priority Access license
PSEO	Privacy-preserving scheme with encryption and obfuscation methods
PF	Punishment and forgiveness
RLS_s	Radio Location Services
ROC	Receiver operating characteristic
RNN	Recurrent neural network

RHs	Reputation histories
RSs	Reputation scores
SCM	Sampled covariance matrix
SUs	Secondary users
SINR	Signal-to-interference-plus-noise ratio
SNR	Signal-to-noise ratio
SAS	Spectrum Access System
SAE	Stacked autoencoder
SAE-SS	Stacked autoencoder based spectrum sensing method
SAE-SS-AF	SAE-SS with additional features
SAE-TF	Stacked autoencoder based spectrum sensing method with time-frequency domain signals
SAE-TF-AF	SAE-TF with additional features
SVM	Support vector machine
TDMA	Time Division Multiple Access
TDE	Total decision error
TDER	Total decision error ratio
TS-1	Training strategy 1
TS-2	Training strategy 2