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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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, "P-reserving 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)

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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

PUs Primary users

PA Priority Access

PAL Priority Access license

PSEO Privacy-preserving scheme with encryption and obfuscation methods

PF Punishment and forgiveness

RLSs 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