UNIVERSITY OF TECHNOLOGY SYDNEY
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Achieving Quality of Service for LTE in Unlicensed Bands

by

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Certificate of Authorship/Originality

I, Weiwei Zhou declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Electrical and Data Engineering at the University of Technology Sydney.

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ABSTRACT

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Wireless networks aim to integrate different radio access networks, such as the WiFi and Long Term Evolution (LTE) heterogeneous systems, to provide seamless access and continuous service. The coexistence of different access techniques poses a challenge for admission control and resource allocation. Meanwhile, due to the limited licensed bandwidth, Licensed-Assisted-Access (LAA) is used to extend LTE links into the unlicensed band, and the coexistence of LTE and WiFi in the unlicensed bands has attracted considerable research interests. In this thesis, we investigate how to achieve Quality-of-Service (QoS) for the LTE system in unlicensed bands for LTE and WiFi heterogeneous wireless networks.

Firstly, we propose a resource denotation method in the WiFi and LTE heterogeneous networks based on a concept of spectral bandwidth mapping. This method simplifies the denotation of system resources and makes it possible to calculate residual system capacity. The network selection algorithm based on an economic model is designed in both under-loaded and over-loaded traffic scenarios in heterogeneous networks. The simulation results demonstrate that this algorithm achieves better performance than the existing scheme in terms of increasing system capacity, achieving load balancing, and reducing the new call blocking probability in heterogeneous networks.

Secondly, we extend our work to LTE unlicensed bands (LTE-U) to guarantee the QoS for LTE devices coexisting with WiFi. We quantitatively analyze the MAC delay for the tagged LTE evolved Node Base Station (eNB) under the saturated WiFi traffic condition. We propose a delay-guaranteed admission control scheme

that considers the freezing time of busy slots caused by collision or successful transmission. We introduce the exponential backoff mechanism for the delay analysis. Validated by simulation results, our method provides essential insights into the system admission performance and fairness of access.

Thirdly, we propose Deterministic Channel Aggregation (DCA) for LTE-U under the condition of unsaturated WiFi traffic, where the LTE eNB aggregates a predetermined number of channels in the unlicensed spectrum to achieve high data-rate communications. We introduce the MAC layer design and analyze the collision probability and channel occupation ratio for DCA. Simulation results validate the effectiveness of DCA and our analytical results when the eNB coexists with multiple WiFi systems under a wide range of traffic load conditions. DCA is particularly useful for applications requiring high bandwidth and enables efficient access control of mobile broadband applications in the LTE Unlicensed bands.

Dedication

To my parents, Yixiang Zhou and Qiufeng Ding, and to my husband Xingchao Zhu.

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Weiwei Zhou

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List of Publications

Journal Papers

1. **W. Zhou**, R. P. Liu, G. J. Sutton, J. A. Zhang, and S. Pan, "Deterministic Channel Aggregation for LTE in Unlicensed Spectrum," *IEEE Communications Letters*, vol. 25, no. 3, pp. 807-811, March 2021.
2. **W. Zhou**, G. J. Sutton, J. A. Zhang, R. P. Liu, and S. Pan, "Delay-Guaranteed Admission Control for LAA Coexisting with WiFi," *IEEE Wireless Communications Letters*, vol. 8, no. 4, pp. 1048–1051, Aug. 2019.

Other Relevant Publications

1. Y. Qin, S. Pan, **W. Zhou**, D. Pan, and Z. Li, "Consumer Wi-Fi device based action quality recognition: An illustrative example of seated dumbbell press action," *IET Communications*, vol. 15, no. 4, pp. 613-626, December 2020.
2. K. A. Bonsu, **W. Zhou,** S. Pan and Y. Yan, "Optimal power allocation with limited feedback of channel state information in multi-user MIMO systems," *China Communications*, vol. 17, no.2, pp. 163-175, Feb. 2020.
3. S. Pan, **W. Zhou**, Q. Gu, and Q. Ye, "Network Selection Algorithm Based on Spectral Bandwidth Mapping and an Economic Model in WLAN & LTE heterogeneous networks." *KSII Transactions on Internet and Information Systems*, vol. 9, no. 1, pp. 68-86, Jan. 2015.

Contents

List of Figures

Abbreviation

3GPP - 3rd Generation Partnership Project

4G - the fourth generation mobile communication technology

5G - the fifth generation mobile communication technology

AC - Access Control

AP - Access Point

ACK - Acknowledge

ABS - Almost Blank Subframe

BER - Bit Error Rate

CA - Carrier Aggregation/Channel Aggregation

CSAT - Carrier Sense Adaptive Transmission

CSMA/CA - Carrier Sensing Multiple Access/Collision Avoidance

COT - Channel Occupancy Time

COR - Channel Occupation Ratio

CCA - Clear Channel Assessment

CDF - Cumulative Density Function

DCA - Deterministic Channel Aggregation

DCF - Distributed Coordination Function

DIFS - Distributed InterFrame Space

DL - downlink

EMC - Embedded Markov Chain

ED - Energy Detection

eMBB - enhanced Mobile BroadBand

ETSI - European Telecommunications Standards Institute

eNB - Evolved Node Base station

FBE - Frame Based Equipment

LBT - Listen-Before-Talk

LBE - Load Based Equipment

LTE - Long Term Evolution

LTE-U - LTE-Unlicensed

MAC - medium access control

MCOT - Maximum Channel Occupancy Time

MT - mobile terminal

OCA - Opportunistic Channel Aggregation

OFDMA - Orthogonal Frequency Division Multiple Access

OFDM - Orthogonal Frequency Division Multiplexing

PD - Preamble Detection

PCH - Primary Channel

QCI - QoS Class Identifier

QoS - Quality-of-Service

RA-CSMA - Radar-Aware Carrier-Sense Multiple Access

RAT - Radio Access Technology

RTS/CTS - Request-To-Send/Clear-To-Send

RB - Resource Block

SCH - Secondary Channel

SIFS - Short Interframe Space

SDN - Software Defined Network

STA - Station

Tx - Transmission

UL - Uplink

UE - User Equipment

UFAS - Utility Function-based Access Selection

WMAN - Wireless Metropolitan Area Network

WT - Wireless/WLAN Termination