A Generalized Cooperative and Cognitive Radio Resource Management Architecture for Future Wireless Networks

Eng Hwee Ong

B.E. (Elect.) Hons. I

A thesis submitted in partial fulfilment of
the requirements for the degree of

Doctor of Philosophy

School of Electrical Engineering
and Computer Science

THE UNIVERSITY OF
NEWCASTLE
AUSTRALIA

August 2010

STATEMENT OF ORIGINALITY

ACKNOWLEDGEMENT OF AUTHORSHIP

I hereby certify that the work embodied in this thesis is the result of original research and contains several published papers/scholarly work which have been co-authored with none other than my academic supervisors based on normal candidate-supervisor practice.

Eng Hwee Ong

To my parents,
Ong Chon Seng and Nyoe Ah Moi

ACKNOWLEDGMENTS

ABSTRACT

Heterogeneity and *convergence* are two distinctive connotations of future wireless networks. Multiple access networks are expected to converge in a manner where heterogeneity can be exploited as an enabler to realize the *Optimally Connected, Anywhere, Anytime* vision of the International Telecommunication Union (ITU). This stimulates current trends toward the convergence of complementary heterogeneous access networks in an all-internet protocol (IP) core network and raises the importance of *cooperation* in such a multiple radio access technology (multi-RAT) environment.

This thesis defines, develops, implements, and analyzes a novel generalized cooperative and cognitive RRM (CCRRM) architecture, anchored on the key principle of *technology agnostic approach*, to optimize radio resources usage, maximize system capacity, and improve quality of service (QoS) in future wireless networks. A novel measurement-based network selection technique, formulated based on mathematical framework, and terminal-oriented network-assisted (TONA) handover architecture are the main actors of this technology agnostic approach. In particular, QoS parameters estimation is a *cornerstone* of the generalized CCRRM architecture to facilitate technology abstraction and provide link layer cognition in an effort to realize seamless mobility in future wireless networks.

By leveraging on the cooperative exchange of QoS context information over the converged all-IP core and novel concept of *reactive QoS balancing (RQB)* to achieve the end-to-end goal of promoting a *QoS-balanced system*, three RQB algorithms augmented with multi-domain cooperation techniques are developed to exploit the heterogeneity of access networks and distribute load opportunistically. Additionally, the radio resource management (RRM) design of the generalized CCRRM architecture is based on a network-terminal

distributed decision making process, *similar and compliant* to the recent IEEE 1900.4 standard.

Performance evaluation is conducted with comprehensive discrete event based simulation studies to gain insights of the promising intrinsic benefits associated with RQB under realistic, pragmatic scenarios. Furthermore, an elegant unified analytical model is developed to obtain the key performance metrics for the IEEE 802.11 distributed coordination function (DCF) infrastructure basic service set (BSS), under *non-homogeneous* conditions, by integrating a Markov chain model in conjunction with a finite queueing model. These performance metrics serve as bounds for reliable capacity analysis from which a model-based predictive QoS balancing (PQB) algorithm is developed as a benchmark for comparative performance studies with the proposed measurement-based RQB algorithm.

The contributions of this thesis are not restricted to multiple access point (multi-AP) wireless local area network (WLAN), and the proof of concept is validated based on a heterogeneous multi-AP WLAN where appropriate. Moreover, conditions under which the generalized CCRRM architecture provides abstraction from underlying technologies and stays relevant to future IP-based multi-RAT environment have been established.

LIST OF ABBREVIATIONS AND ACRONYMS

i.i.d.	independent and identically distributed
w.r.t.	with respect to
3GPP	Third Generation Partnership Project
4G	fourth generation
ABC	always best connected
ACS	ambient control space
ACK	acknowledgment
AIFS	arbitration interframe space
AIFSN	arbitration interframe space number
ANI	ambient network interface
AP	access point
APC	access point controller
ARI	ambient resource interface
ASI	ambient service interface
AWGN	additive white Gaussian noise
B3G	beyond third generation
BER	bit error rate
BPSK	binary phase shift keying
BSS	basic service set
CBR	constant bit rate
CCRRM	cooperative and cognitive RRM
CDF	cumulative distribution function
CLM	cooperative load metric
COGNITION	cognition incorporating cooperation
CoRe	COGNITION relationships
CSMA/CA	carrier sense multiple access with collision avoidance
CTS	clear to send
CU	channel utilization
CUSUM	cumulative sum
CW	contention window

CWN	composite wireless network
DANS	dynamic access network selection
DAPU	data acquisition and processing unit
DCF	distributed coordination function
DIFS	distributed (coordination function) interframe space
DL	downlink
DSSS	direct sequence spread spectrum
EDCA	enhanced distributed channel access
EDCAF	enhanced distributed channel access function
ERP	extended rate PHY
ERP-OFDM	extended rate PHY using orthogonal frequency division multiplexing modulation
EWMA	exponential weighted moving average
FER	frame error rate
FIFO	first in first out
FTP	file transfer protocol
GSM	global system for mobile communications
HCUFO	highest channel utilization first out
HHO	horizontal handover
HOL	head-of-line
HR/DSSS	high rate direct sequence spread spectrum using the long preamble and header
IBSS	independent basic service set
iLB	integrated load balancing
IMT	International Mobile Telecommunications
IP	internet protocol
ITU	International Telecommunication Union
KPI	key performance indicator
LAP	load adaptation policy
LAS	load adaptation strategy
LBI	load balance index
LBM	load balancing mechanism
LTE	long term evolution
MAC	medium access control
MACK	missed acknowledgment
MADM	multi-attribute decision making
MAHO	mobile-assisted handover
MCHO	mobile-controlled handover

MIH	media independent handover
MIP	mobile IP
MIRAI	multimedia integrated network by radio access innovation
MPEG	motion picture experts group
MSDU	MAC service data unit
multi-AP	multiple access point
multi-RAT	multiple radio access technology
NACK	negative acknowledgment
NAHO	network-assisted handover
NCHO	network-controlled handover
NLOS	non-line-of-sight
NP	non-deterministic polynomial-time
NRM	network reconfiguration manager
NRT	non-real-time
OFDM	orthogonal frequency division multiplexing
OSM	operator spectrum manager
PD	packet delay
PER	packet error rate
PHY	physical layer
PLB	predictive load balancing
PLCP	physical layer convergence procedure
PLR	packet loss rate
PQB	predictive QoS balancing
QAM	quadrature amplitude modulation
QBI	QoS balance index
QLO	QoS-inspired load optimization
QoS	quality of service
QPSK	quadrature phase shift keying
QSF	QoS satisfaction factor
QSTA	QoS station
RAN	radio access network
RATs	radio access technologies
RE	radio enabler
RMC	RAN measurement collector
RQB	reactive QoS balancing
RRC	RAN reconfiguration controller
RRM	radio resource management
RSSI	received signal strength indicator

RT	real-time
RTP	real-time transport protocol
RTS	request to send
SAW	simple additive weighting
SDR	software defined radio
SIFS	short interframe space
SINR	signal-to-interference and noise ratio
SNR	signal-to-noise ratio
STA	station
TCP	transmission control protocol
TFI	throughput fairness index
TONA	terminal-oriented network-assisted
TOPSIS	technique for order preference by similarity to ideal solution
TMC	terminal measurement collector
TRC	terminal reconfiguration controller
TRM	terminal reconfiguration manager
TXOP	transmission opportunity
UDP	user datagram protocol
UL	uplink
UMTS	universal mobile telecommunications system
VBR	variable bit rate
VHO	vertical handover
VoIP	voice over internet protocol
VoWLAN	voice over WLAN
WiMAX	worldwide interoperability for microwave access
WLAN	wireless local area network

Table of Contents