Intercell Interference Mitigation in Long Term Evolution (LTE) and LTE-Advanced

A Thesis
submitted to
University of Technology, Sydney
by

Ameneh Daeinabi

In accordance with
the requirements for the Degree of

Doctor of Philosophy

Faculty of Engineering and Information Technology
University of Technology, Sydney
New South Wales, Australia

February 2015

CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Ameneh Daeinabi

Date: 17.02.2015

ACKNOWLEDGMENT

I would like to express my special appreciation and thanks to my supervisor, A/Prof. Dr. Kumbesan Sandrasegaran, who has been a tremendous mentor for me with his priceless advice on both research and on my career. Also I would like to thank him for encouraging my research and for allowing me to grow as a researcher.

I would also like to thank to my close friends and all CRIN members for their friendly support and caring.

A special thanks to my mother, father, mother-in law and father-in-law. They were always supporting and encouraging me with their best wishes.

At the end I would like to express appreciation to my beloved husband Pejman Hashemi was my support in all times. He was always there cheering me up and stood by me through the good times and bad. Without his encouragement, it would have been impossible for me to complete this research work.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

4G	Fourth Generation
ABCS	Adaptive Offset Configuration Strategy
ABS	Almost Blank Subframe
ACK	Acknowledgement
AWGN	Additive White Gaussian Noise
BLER	Block Error Rate
BW	Bandwidth
CA	Carrier Aggregation
CC	Component Carriers
CCE	Control Channel Element
CCU	Cell Centre UE
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CEU	Cell Edge UE
CFI	Control Format Indicator
CG	Correlative Group
Ch	Chromosome
CINR	Channel to Interference and Noise Ratio
CoMP	Coordinated Multi-Point
CQI	Channel Quality Indicator
CRE	Cell Range Expansion
C-RNTI	Cell Radio Network Temporary Identifier
CRS	Common Reference Signal
CS	Common Subband
CSB	Common Subband
DFFR	Dynamic Fractional Frequency Reuse
DL	Downlink
DwPTS	Downlink Pilot Time Slot
EESM	Exponential Effective Signal to interference and noise ratio Mapping
eICIC	Enhanced Intercell Interference Coordination
eNB	Evolved NodeB
EPDCCH	Enhanced-PDCCH

EPS	Evolved Packet System
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FB	Full Buffer
FDD	Frequency-Division Duplex
FFR	Fractional Frequency Reuse
FLS	Fuzzy Logic System
FQL	Fuzzy Q-Learning
GBR	Guaranteed Bit Rate
GP	Guard Period
HARQ	Hybrid Automatic Repeat Request
HeNB	Home eNBs
HetNet	Heterogeneous Network
HII	High Interference Indication
HoL	Head-of-Line
HS	High Subband
HSPA	High-Speed Packet Access
IAF	Interference Avoidance Factor
IAR	Interference Avoidance Request
IASB	Interference Avoidance Subband
ICI	Intercell Interference
ICIC	Intercell Interference Coordination
IMT	International Mobile Telephony
ISI	Inter-Symbol Interference
ITU	International Telecommunication Union
IZ	Interference Zone
LLCS	Lightly Loaded Control Channel Transmission Subframe
LP-ABS	Low Power ABS
LS	Low Subband
LTE	Long Term Evolution
MCS	Modulation and Coding Scheme
MIB	Master Information Block
MIMO	Multiple –Input Multiple-Output
MME/GW	Mobility Management Entity/Gateway
NACK	Non-Acknowledgement
NCL	Neighbouring Cell List
NEFFR	Novel Enhanced Fractional Frequency Reuse

NP	Nondeterministic Polynomial
NRT	Neighbour Relation Table
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OI	Overhead Indication
PAPR	Peak-to-Average Power Ratio
PBCH	Physical Broadcast Channel
PCFICH	Physical Control Format Indicator Channel
PDCCH	Physical Downlink Control Channel
PDF	Probability Density Functions
PDN	Packet Data Networks
PDSCH	Physical Downlink Shared Channel
PFR	Partial Frequency Reuse
PGW	PDN Gateway
PHICH	Physical Indicator Channel
PLR	Packet Loss Rate
PPP	Poisson Point Process
PRB	Physical Resource Block
PSB	Priority Subband
PSF	Protected Subframes
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifier
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RB	Resource Block
RE	Resource Element
RE UE	Range Expanded UEs
REG	RE Groups
RF1	Reuse Factor 1
RF3	Reuse Factor 3
RNC	Radio Network Controller
RNTP	Relative Narrowband Transmit Power
RR	Round Robin
RRC	Radio Resource Control

RSRP	Reference Signal Received Power
RSS	Received Signal Strength
SAE	System Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SDF	Service Data Flow
SerFR	Softer Frequency Reuse
SFFR	Soft Fractional Frequency Reuse
SFR	Soft Frequency Reuse
SGW	Serving Gateway
SINR	Signal to Interference plus Noise Ratio
TB	Transport Block
TDD	Time-Division Duplex
TDM	Time Division Multiplexing
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
UpPTS	Uplink Pilot Time Slot
VoIP	Voice over Internet Protocol
VS	Video Streaming
WCDMA	Wideband Code Division Multiple Access
ZP-ABS	Zero Power ABS

LIST OF SYMBOLS

$\rho_{m,n}$	Indicator of RB allocation to UE_m
$C_{m,n}$	Maximal bits supported by PRB_n for UE_m
o_{κ_0}	Variance
P_n^i	Transmission power from the serving eNB_i
P_n^j	Transmission power from the interfering picocell j
P_n^k	Transmission power from the interfering macrocell k
$H_{n,m}^i$	Channel gain from the serving eNB i
$H_{n,m}^j$	Channel gain from the interfering picocell j
$H_{n,m}^k$	Channel gain from the interfering macrocell k
ς_{eff}	Effective SINR
Λ	Calibration by means of link level simulations to fit the compression function to the AWGN BLER result
$Hol_m^{'}$	Normalized value of HoL
$I_m^{'}$	Normalized value of the interference level
$Q_m^{'}$	Normalized value of QCI
$\mu_{L_i^n}$	Membership function for the n^{th} FLS input and the rule i
χ	Learning rate
ϑ	Discount factor
$O_P^{\max}$	Maximum outage probability for picocell
$O_P^{\min}$	Minimum outage probability for picocell
θ_m	Minimum required data rate for macro UE
θ_p	Minimum required data rate for UEs located in picocell basic coverage area
θ_{RE}	Minimum required data rate for RE UE
a	Scalar parameter
a_i	Fuzzy action
b	Scalar parameter
BW_c	Bandwidth allocated to cell centre
BW_e	Bandwidth allocated to cell edge

c	Scalar parameter
$c_{i,n}$	Doppler coefficient of process i of the n^{th} sinusoid
d	Gaussian central value
D	Delay
D^*	The maximum allowed delay for sending data
d_0	Shadow fading correlation distance
D_c	Encoding delay
dir_i	Direction of UE_i
$d_{p,k}$	Delay of the p^{th} packet of UE_k
f_i	The desired objective functions
$f_{i,n}$	Discrete Doppler frequency of process i of the n^{th} sinusoid
f_{max}	Maximum Doppler frequency
$G(t)$	Gaussian random variable
h	Fast fading power gain from the serving eNB
I_M	Interference from neighbouring macro eNBs
I_m	Interference level of UE_m from neighbouring eNBs
I_{max}	Maximum interference
I_p	Interference from neighbouring pico eNBs
K	Vector of actions
L	Offset value
L_i	Modal vector of rule i
L_i^n	Fuzzy label corresponding to a distinct fuzzy set defined in the domain of the n^{th} component S^n
L_m	Pathloss between a macro eNB and UE
loc_i	Location of UE_i
L_p	Pathloss between a pico eNB and UE
M	Transmission power reduction
m	Next state
mc	Number of interfering macrocells
m_{ch}	Number of chromosomes
N	Number of FLS inputs
N_a	Number of ABSs
N_i	Number of sinusoids of process i
N_m	Number of UEs located in macrocell
N_p	Number of UEs located in picocell basic coverage area
N_{packet}	Fixed number of packets

N_{PRB}	Total number of PRBs
N_{RB}	Number of RB allocated to each UE
N_{RE}	Number of UEs located in cell range expanded area
N_s	Number of subframes in each frame
N_U	Total number of UEs in macrocell and its picocells
N_{UE}	Ratio of RE UEs to macro UEs
o_i^k	k^{th} output action for rule i
o_j	Fuzzy output value
O_T	Acceptable outage probability
P	Set of rules
P^*	Maximum packet loss tolerance for video streaming traffic
P_C	Transmission power of *CS*
pc	Number of interfering picocells
P_H	Transmission power of *HS*
P_L	Transmission power of *LS*
P_m	Transmission power of macro eNB
P_N	Noise power
Pos_k	Locations of neighbouring eNB_k
Pos_l	Locations of serving eNB_l
P_p	Transmission power of pico eNB
P_{rf}	Power reduction factor
p_s	Total size of all packets (in bits) arrived into the eNB buffer of UE_k
P_T	Maximum transmission power of each eNB
q	Q-value function
Q	Q-value for the input state vector
Q_m	QCI priority
R	Distance of UE from its serving eNB
r	Distance from serving eNB
r_m	Minimum required data rate
R_m^*	The required transmission rate of macro UEs
R_p^*	The required transmission rate of pico UEs
s	Set of fuzzy rules
S	State vector
$SINR_{RE}$	5 % of CDF of SINR of pico UEs
S_n	n^{th} Subframe
S_p	Size of a packet

t	Time
T	Regular time interval
T^*	The required throughput of macro UEs
$T_{arrival}$	Time that the packet arrives to the buffer
Thr_m	Average throughput of macro UEs
T_{max}	Maximum allowable packet delay
T_{oj}	Output fuzzy set
T_s	Total simulation time
T_{xi}	Input fuzzy set
v_i	Speed of UE_i
w_i	Weighting coefficients
X	Vector
x_i	Fuzzy input value
z	SFR parameter
α	Pathloss
α_i	Degree of truth of rule i
α_m	Macrocell pathloss
α_p	Picocell pathloss
B	Offset value
γ_0	Outage threshold
Δ_{ABS_value}	Output of ABS value module
Δ_{offset_value}	Output of CRE offset value module
ΔP	Additional transmission power
ΔQ	Difference between the old and new values of Q
ε	Greedy parameter
η	Ratio of UEs schedules on ABS
$\theta_{i,n}$	Doppler phase of process i of the n^{th} sinusoid
κ_n	Correlated filtered white Gaussian noise with zero mean of the n^{th} sinusoid
λ_m	Density of macro eNBs
λ_p	Density of pico eNBs
λ_u	Density of UEs
μ	Membership degree
μ_ap_i	Approximated uncorrelated filtered white Gaussian noise
σ	Gaussian standard deviation
ς_i	Vector of the per-RB SINR values
φ	Shadow fading

ψ_i	Shadow fading autocorrelation function
ω	Shadow fading standard deviation

ABSTRACT

Bandwidth is one of the limited resources in Long Term Evolution (LTE) and LTE-Advanced (LTE-A) networks. Therefore, new resource allocation techniques such as the frequency reuse are needed to increase the capacity in LTE and LTE-A. However, the system performance is severely degraded using the same frequency in adjacent cells due to increase of intercell interference. Therefore, the intercell interference management is a critical point to improve the performance of the cellular mobile networks. This thesis aims to mitigate intercell interference in the downlink LTE and LTE-A networks.

The first part of this thesis introduces a new intercell interference coordination scheme to mitigate downlink intercell interference in macrocell-macrocell scenario based on user priority and using fuzzy logic system (FLS). A FLS is an expert system which maps the inputs to outputs using "IF...THEN" rules and an aggregation method. Then, the final output is obtained through a deffuzifaction approach. Since this thesis aims to mitigate interference in downlink LTE networks, the inputs of FLS are selected from important metrics such as throughput, signal to interference plus noise ratio and so on. Simulation results demonstrate the efficacy of the proposed scheme to improve the system performance in terms of cell throughput, cell edge throughput and delay when compared with reuse factor one.

Thereafter, heterogeneous networks (HetNets) are studied which are used to increase the coverage and capacity of system. The focus of the next part of this thesis is picocell because it is one of the important low power nodes in HetNets which can efficiently improve the overall system capacity and coverage. However, new challenges arise to intercell interference management in macrocell-picocell scenario. Three enhanced intercell interference coordination (eICIC) schemes are proposed in this thesis to mitigate the interference problem. In the first scheme, a dynamic cell range expansion (CRE) approach is combined with a dynamic almost blank subframe (ABS) using fuzzy logic system. In the second scheme, a fuzzy q-learning (FQL) approach is used to find the optimum ABS and CRE offset values for both full buffer traffic and video streaming traffic. In FQL, FLS is combined by q-learning approach to optimally select the best consequent part of each FLS rule. In the third proposed eICIC scheme, the best location of ABSs in each frame is determined using Genetic Algorithm such that the requirements of video streaming traffic can be met. Simulation results show that the system performance can be improved through the proposed schemes.

Finally, the optimum CRE offset value and the required number of ABSs will be mathematically formulated based on the outage probability, ergodic rate and minimum required throughput of users using stochastic geometry tool. The results are an analytical formula that leads to a good initial estimate through a simple approach to analyse the impact of system parameters on CRE offset value and number of ABSs.