CAPACITY AND COVERAGE ENHANCEMENT FOR MULTI-HOP RELAY IN LONG TERM EVOLUTION-ADVANCED NETWORK

By

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A thesis submitted in fulfillment of the requirements for the degree of
Doctor of Philosophy

School of Computer and Communication Engineering
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Acknowledgements

Praise and thanks to Allah (SWT) who gave me the strength and courage to complete this project. I would like to express my sincere thanks to all those who have contributed to the success of my study. First of all, I would particularly like to thank my supervisor, Prof. Dr. R. Badlishah Ahmad, who is not a supervisor of words. He is quiet and understanding, his continuous guidance and support in many aspects including, but not limited to, strengthening the scientific research capabilities, encouraging technical discussions with him at any time. He set an example for me to think and follow. He gave me professional guidance with critical comments. He was also kind to provide me with an invaluable source of materials and spiritual encouragement. It was the way he helped me finish my work. In other words, the more I worked with him, the more I admired him.

I am also indebted to last my supervisor Dr. Abid Yahya, who is young but talented. He is also smart and thoughtful to give an excellent explanation to me. He supported me throughout the long academic PhD, pursuing journey. His guidance, ideas, encouragement, affable nature, valuable advice, kindness and support were greatly helpful.

My deep appreciation and special thanks go to the Universiti Malaysia Perlis (UniMAP) and to the staff of the UniMAP; especially the staff members' of the School of Computer and Communication Engineering for their support and eagerness to provide the ideal research environment.

More specifically, my deepest gratitude goes to my mother, who devoted her life to me and to my wife, my brothers and my sisters for their daily prayers, giving me the motivation and strength, and for encouraging me to achieve my goals. I am really

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indebted to them all and words are not sufficed to express the gratitude I owe to them. Special thanks go to all my friends for their motivation, help and support during my academic period. I am indebted to all those namely mentioned above for their friendship and spiritual support that kept me going ahead. Last, but not least, I offer to my family the sincerest words of gratitude for their patience and unshakable faith in me.

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LIST OF ABBREVIATIONS

1G	1^{st} Generation
2G	2^{nd} generation
3G	3^{rd} Generation
3GPP	3^{rd} Generation Partnership Project
3GPP- LTE	3^{rd} Generation Partnership Project- Long Term Evaluation
4G	4^{th} Generation
16-QAM	16- Quadrature Amplitude Modulation.
AF	Amplify and Foreword.
AMC	Adaptive Modulation and Coding
AMPS	Advanced Mobile Phone Systems
AWGN	Additive white Gaussian Noise
BPA	Balance Power Algorithm.
BPSK	Binary Phase-Shift Keying
BS	Base Station
CA	Carrier Aggregation
CDMA	Code Division Multiple Access
CoMP	Coordinated Multi-Point transmission and reception
CQI	Channel Quality Indicator
DA	Directional Antenna
DAS	Distributed Antenna System
DF	Decode and Foreword
DL	Downlink
ERLC	Enhance Relay Link Capacity

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EPs	Extension Points
EVM	Error Vector Magnitude
FD	Full-Duplex
GSM	Global System for Mobile Communications
HD	Half-Duplex
ICI	Inter-Cell Interference
IMT-A	International Mobile Telecommunications -Advanced
IMT-2000	International Mobile Telecommunications
IP	Internet Protocol
ITU	International Telecommunication Union's
LOS	Line-Of-Sight
LTE	Long Term Evaluation
LTE-A	Long Term Evaluation –Advanced
MANETs	Mobile Ad Hoc Networks
MCS	Modulation and Coding Scheme
MIMO	Multiple-Input Multiple-Output
MR	Moving Relay
NLOS	Non-Line-Of-Sight
OA	Omni-Directional Antenna
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA-TDD	Orthogonal Frequency Division Multiple Access-Time Division Duplexing
ORND	Optimum Relay Node Deployment
QoS	Quality of Service
QPSK	Quadrature –Phase Shift Keying

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RN	Relay Node
RSS	Received Signal Strength
SER	Sample Error Rate
SNR	Signal to Noise Ratio
SINR	Signal to Interference Plus Noise Ratio
TDMA	Time Division Multiple Access
UEs	User Equipment
UMTS	Universal Mobile Telecommunications System
UL	Uplink
VPL	Vehicle Penetration Loss
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

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LIST OF SYMBOLS

$\mathrm{BW_{eff}}$	Adjustment for Bandwidth Efficiency
$BW_{\phi az}$	Beam Width Pattern at Azimuth Angle
$BW_{\theta el}$	Beam Width Pattern at Elevation Angle
C_{max}	Upper Limit Spectral Efficiency for BS
C_{Rmax}	Upper Limit Spectral Efficiency for RN
$C_{RN,2}$	Upper Limit Spectral Efficiency for RN at location 2
$C_{RN,3}$	Upper Limit Spectral Efficiency for RN at location 3
C_{sim}	Spectral Efficiency for BS through Simulator
C_i	Estimated Spectral Efficiency for BS
d	Distance Between BS And UE
d_{nr}	Distance between Neighboring RNs
$d_{nr,j}$	Distance between RNs in Neighboring Cell
d_A	Distance between BS and MR above Vehicle
$d_{c,q}$	Distance between BS and UE Inside Vehicle
$d_{i,k}$	Distances between UE and BS_j
D_{RN}	Location of RN from BS
$D_{i,k}$	Distances between UE to BS_i
E [.]	Expectation Function
G_t	Antenna Gains for Transmitter
G_{re}	Antenna Gain of Receiver
G_{tr}	Antenna Gain of Transmitter
G_d	Gain of DA for RN

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G_{ue}	Antenna Gain for UE
G_{BS}	Antenna Gain for BS
G_r	Antenna Gains for Receiver
$H_{i,k}$	Fading Channel Gain form Donor to User
$H_{j,k}$	Fading Channel Gain from Neighboring Cell to User
$H_{i,xs}$	Fading Channel Gain form Donor BS to User at X_s Location
$H_{i,2}$	Fading Channel Gain form Donor BS to User at Location 2
$H_{i,3}$	Fading Channel Gain form Donor BS to User at Location 3
$H_{i,xo}$	Fading Channel Gain form Donor BS to User at X_o Location
$H_{RN,xo}$	Fading Channel Gain form RN to User at X_o Location
$H_{j,xs}$	Fading Channel Gain from Neighboring Cell to User at X_s Location
H_A	Fading Channel at Relay Link
H_B	Fading Channel at Access Link
H_C	Fading Channel at Direct Link
$H_{k,q}$	Matrix Fading Channel between k^{th}-RN and q^{th}-User
L_r	RN Characteristics
L_{re}	Feeder Losses at Receiver
L_t	Feeder Losses at Transmitter
L_{prop}	Propagation Loss
L_{fsd}	Free Space Distance Loss
L_d	Diffraction Loss
L_{sp}	Sub-Path Loss
L_{gas}	Attenuation Caused by Atmospheric Gas
L_{rain}	Attenuation Caused by Hydrometeor Scatter

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L_{clut}	Clutter Attenuation
N_k	Background Noise at User
N_{Xo}	Background Noise for User at X_o
N_{xs}	Background Noise for User at X_s
N_2	Background Noise at User in Location 2
N_3	Background Noise at User in Location 3
N_{relays}	Optimum Number of Relay
N_{cell}	Number of Neighboring Cell
P_i	Transmitted Power from BS
P_{UE}	Transmitted Power from UE
P_{RN}	Transmitted Power from RN
P_{rj}	Received power to UE from Neighboring BS
P_j	Transmitted Power from Neighboring BS
$P_{o,RL}$	Outage Probability of Relay Link
$P_{o,MH}$	Outage Probability of Multi-Hop Link
$P_{o,access}$	Outage Probability of Access Link
$\rho_{RN,Xo}$	SINR for User at Xo via RN
$\rho_{i,k}$	SINR at k- User via BS_i
ρ_i	SINR for Each User in The Cell
ρ_{ideal}	Ideal SINR for User at X_s Location
ρ_{max}	Maximum Limitation on Received SINR by Using EVM
$\rho_{i,xs}$	SINR from BS to User at X_s Location
$\rho_{RN,2}$	SINR from RN to user at Location 2
$\rho_{RN,3}$	SINR from RN to user at Location 3

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$\rho_{UE,q}$	Downlink SNR at user via direct and Relay Links
ρ_{BS}	Uplink SNR at BS via Direct and Relay Links
$\rho_{UE,q}^{gm}$	SNR at UE inside Vehicle (Group Mobility) via MR
$\rho_{UE,q}^{Direct}$	SNR at UE inside vehicle (group mobility) via Direct Link
ρ^{max}	Maximum Required of SNR at UE inside Vehicle
ρ_{th}	Threshold of SNR at UE inside Vehicle
ρ_{eff}	Adjustment for SINR Spectral Efficiency
p_t	Transmitted Power From Source
p_r	Received Power From Destination
$p_{multi-hop}^{r}$	Received Power Via Multi-Hop Link
$p_{\mathrm{traditional}}^{r}$	Received Power Via Traditional Link
$R_{UE,q}^{gm}$	Bit Rate at UE Inside Vehicle (Group Mobility) via MR
$R_{UE,q}$	Downlink Bit Rate at User via Direct and Relay Links
R	Cell Radius
$SINR_{sim}$	SINR through Simulator
T_{MR}	Time of Approaching of Vehicle
V_{MR}	Velocity of vehicle
$X_{i,k}$	Received Signal from BS for User
$X_{j,k}$	Received Signal from Neighboring BS for User
$X_{i,xs}$	Received Signal from BS for User at X_s Location
$X_{i,2}$	Received Signal from BS for User at Location 2
$X_{i,3}$	Received Signal from BS for User at Location 3
$X_{RN,2}$	Received Signal from RN for User at Location 2
$X_{RN,3}$	Received Signal from RN for User at Location 3

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$X_{j,xs}$	Received Signal from Neighboring BS at User at LocationX_s
$X_{RN}[t_2]$	Transmitted Signal form RN at Second Time slot $[t_2]$
X_s	Distance of Estimated Saturation Capacity
X_{s2}	Distance of Estimated Saturation Capacity for RN at Location 2
X_{s3}	Distance of Estimated Saturation Capacity for RN at Location3
$Y_{i,k}$	Received Signal for k- User from BS_i
$Y_{RN,Xo}$	Received Signal for User from RN at Xo location
$Y_{RN,2}$	Received Signal for User from RN at Location 2
$Y_{RN,3}$	Received Signal for User from RN at Location 3
Y_{RL}	Received Signal for User via Relay Link
Y_{AL}	Received Signal for User via Access Link
$y_{UE,q}[t_1]$	Received Signal for User at first Time Slot $[t_1]$
$y_{UE,q}[t_2]$	Uplink Received Signal by UE_q at Second Time slot $[\mathrm{t}_2]$
$y_{RN}[t_1]$	Received Signal for RN at First Time Slot $[t_1]$
$y_{BS}[t_2]$	Downlink Received Signal by BS at Second Time Slot $[\mathrm{t}_2]$
$\hat{y}_{\mathrm{BS}}[t_2]$	Downlink Received Signal by BS at Second Time Slot $[\mathrm{t}_2]$ after Cancelation the Self-Interface
$\hat{y}_{\mathrm{UEq}}[t_2]$	Uplink Received Signal by UE_q at Second Time Slot $[\mathrm{t}_2]$ after Cancelation the Self-Interface
γ_{th}	Certain threshold of SINR
γ_{RL}	SINR at the Relay Link
γ_{access}	SINR at the Access Link
α	Path Loss Exponent
λ	Wavelength Of The Carrier Frequency
θ_{el}	Elevation Angle of Antenna

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θ_{az}	Azimuth Angle of Antenna
X_o	Handover Distance from BS
σ_o	Variance
Ψ	Amplification Factor for AF relay

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Pendekatan Baru Penambah Baikan Kapasity dan Liputan Bagi Rangkaian LTE-A Pelbagai

ABSTRAK

Rangkaian selular yang sedia ada mempunyai kesukaran untuk menyediakan tahap SINR yang memuaskan kepada pengguna terutamanya di sempadan sel rangkaian. Oleh itu, kaedah multi-hop dianggap sebagai salah satu kunci utama untuk memperbaiki teknologi rangkaian sel melalui teknologi Long Term Evaluation-Advanced (LTE -A) bagi memenuhi permintaan yang semakin meningkat dan memperluaskan liputan dan peningkatan kapasiti sistem. Walau bagaimanapun sistem multi-hop ini bergantung kepada lokasi Nod Relay (RN) bagi mengurangkan gangguan isyarat di antara sel. Penyelidikan ini mencadangkan tiga pendekatan asli bagi tujuan meningkatkan keupayaan dan memperluaskan kawasan liputan bagi LTE-A rangkaian selular. Pertama, yang dipanggil Kedudukan Optimum RN (ORND) yang berdasarkan kepada permodelan matematik menggunakan formula teori agihan kapasiti Shannon. Di dalam pendekatan ORND ini penentuan lokasi yang paling optimum untuk RN (D_{RN}) diperolehi melalui rumusan matematik yang memaksimumkan kapasiti untuk pengguna-pengguna di dalam kawasan tepian sel. Bilangan RN yang optimum (N_{relays}) diperolehi ditentukan bagi memastikan liputan keluasan yang optimum dan juga dapat mengurangkan kos. Berdasarkan kepada dapatan pengiraan D_{RN} dan N_{relays}, kuasa penghantaran untuk setiap RN ditentukan bagi mengelakkan pertindihan dan gangguan antara RNs yang berdekatan. Penggunaan semula frekuensi digunakan untuk memastikan tiada ganggunan antara RN dan Stesen Pangkalan (BS) dan untuk memelihara spektrum di dalam sel yang sama. Melalui permodelan persamaan matematik dan pengesahan melalui simulasi yang dibuat, keputuan menunjukkan bagi peringkat pertama sel (iaitu 6 sel-sel mengelilingi sel tertentu) menunjukkan 40% peningkatan kapasiti berbanding dengan rangkaian selular konvensional. Pendekatan kedua, dipanggil Peningkatan Kapasiti Pautan Relay (ERLC), memberi tumpuan kepada peningkatan kapasiti pautan untuk mengatasi gangguan dalam perkhidmatan mudah alih kerana saluran yang tidak tetap. ERLC berdasarkan kepada implementasi penggunaan dua jenis antena, Antena Banyak Arah (OA) dan Antara Satu Arah (DA) yang beroperasi secara Half Duplex (HD). Penghantaran kuasa setiap antena ditetapkan disamping memelihara penggunaan kuasa yang sama bagi perantara untuk RN. Kaedah ERLC berjaya meningkat kapasiti pautan relay kepada 46% berbanding dengan relay pautan konvensional. Akhir sekali, Relay Bergerak (MR) dicadangkan bagi menyediakan sambungan yang boleh diharap bagi rangkaian selular untuk menyediakan sambungan di sepanjang laluan kenderaan. Penggunaan MR menunjukkan prestasi yang baik bagi pengguna sel. Satu algoritma baru dipanggil Algoritma Samarataan Kuasa(BPA) dihasilkan dan dianalisa. Keputusan yang diperolehi menunjukkan bahawa BPA dapat mengurangkan 75% kuasa penghantaran dan meningkatkan keseluruhan bilangan pengguna aktif dan apabila digabungkan dengan menggunakan MR sekitar 88% celusan berbanding dengan pautan langsung tanpa menggunakan MR.

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Capacity and Coverage Enhancement for Multi-Hop Relay in LTE-A Network

ABSTRACT

Cellular networks known have difficulty to provide satisfactory SINR level to users at the cell boundaries. Therefore, multi-hop relay is considered as one of the main keys for Long Term Evaluation - Advanced (LTE-A) to meet the growing demand for coverage extension and capacity enhancement. However these benefits of multi-hop depend on location of Relay Node (RN) which mitigates interference among the cells. In this work three novel models to enhance the capacity and expand the coverage area for LTE-A cellular networks are proposed. The first model called Optimum RN Deployment (ORND) and based on mathematical modelling of modified Shannon formula of capacity distribution. In ORND the determination of optimal location for RN (D_{RN}) is formulated to maximize capacity for users at cell edge region. Optimum number of relays (N_{relays}) is derived to ensure the best coverage with low cost implementation. Based on both D_{RN} and N_{relays}, transmission power for each RN is allocated to avoid overlapping among neighbouring RNs and optimize the power consumption. Frequency reuse of multi-hop relay is applied to avoid interference between the RN and Base Station (BS) while preserving the same available spectrum for the cell. Mathematical results are validated by multi-cell simulation through using first tier of cells (i.e. six cells surround a particular cell) and showed 40% of capacity enhancement for cell size with interference- limited compared to conventional cellular network. The second model is called Enhance Relay Link Capacity (ERLC) and aims to enhance capacity for the relay link to overcome outages in mobile services due to channel fluctuations. ERLC is based on the usage of two antennas types, Omni directional Antenna (OA) and Directional Antenna (DA). The transmission power of each antenna is allocated while preserving the same consumption of the feeder power to the RN. ERLC increased capacity of the relay link to 46% in comparison with conventional relay link. Finally, Moving Relay (MR) is proposed to improve throughput for passengers on public transportation and provide reliable connection with cellular networks along the route, especially at the cell boundaries. A new algorithm called Balance Power Algorithm (BPA) is proposed to minimize the transmission power consumption for MR. The results shows that BPA substantially reduced 75% the transmission power consumption for MR and increased throughput for active users linked with the MR around 88% compared to direct link.

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