

# JOINT RELAY SELECTION AND BANDWIDTH ALLOCATION FOR COOPERATIVE RELAY NETWORK

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*To my beloved parents; Ab Ghafar bin Ismail and Satariah binti Yong,  
brothers; Annas Asqalanee and Aizad Ayasyi  
and sisters; Husnul Hakimah, Amira Syazwani, Aina Saufi, and Alia Salwani ☺*

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## ABSTRACT

Cooperative communication that exploits multiple relay links offers significant performance improvement in terms of coverage and capacity for mobile data subscribers in hierarchical cellular network. Since cooperative communication utilizes multiple relay links, complexity of the network is increased due to the needs for efficient resource allocation. Besides, usage of multiple relay links leads to Inter-Cell Interference (ICI). The main objective of this thesis is to develop efficient resource allocation scheme minimizes the effect of ICI in cooperative relay network. The work proposed a joint relay selection and bandwidth allocation in cooperative relay network that ensures high achievable data rate with high user satisfaction and low outage percentage. Two types of network models are considered: single cell network and multicell network. Joint Relay Selection and Bandwidth Allocation with Spatial Reuse (JReSBA\_SR) and Optimized JReSBA\_SR (O\_JReSBA\_SR) are developed for single cell network. JReSBA\_SR considers link quality and user demand for resource allocation, and is equipped with spatial reuse to support higher network load. O\_JReSBA\_SR is an enhancement of JReSBA\_SR with decision strategy based on Markov optimization. In multicell network, JReSBA with Interference Mitigation (JReSBA\_IM) and Optimized JReSBA\_IM (O\_JReSBA\_IM) are developed. JReSBA\_IM deploys sectorized-Fractional Frequency Reuse (sectorized-FFR) partitioning concept in order to minimize the effect of ICI between adjacent cells. The performance is evaluated in terms of cell achievable rate, Outage Percentage (OP) and Satisfaction Index (SI). The result for single cell network shows that JReSBA\_SR has notably improved the cell achievable rate by 35.0%, with reduced OP by 17.7% compared to non-joint scheme at the expense of slight increase in complexity at Relay Node (RN). O\_JReSBA\_SR has further improved the cell achievable rate by 13.9% while maintaining the outage performance with reduced complexity compared to JReSBA\_SR due to the effect of optimization. The result for multicell network shows that JReSBA\_IM enhances the cell achievable rate up to 65.1% and reduces OP by 35.0% as compared to benchmark scheme. Similarly, O\_JReSBA\_IM has significantly reduced the RN complexity of JReSBA\_IM scheme, improved the cell achievable rate up to 9.3% and reduced OP by 1.3%. The proposed joint resource allocation has significantly enhanced the network performance through spatial frequency reuse, efficient, fair and optimized resource allocation. The proposed resource allocation is adaptable to variation of network load and can be used in any multihop cellular network such as Long Term Evolution-Advanced (LTE-A) network.

## ABSTRAK

Komunikasi koperasi yang mengeksplotasi pelbagai pautan pengulang memberi peningkatan prestasi ketara dari segi liputan dan kapasiti untuk pelanggan data mudah alih dalam rangkaian selular hierarki. Memandangkan komunikasi koperasi menggunakan pelbagai pautan pengulang, kerumitan rangkaian meningkat disebabkan oleh perlunya peruntukan sumber yang cekap. Selain itu, penggunaan pelbagai pautan pengulang menyebabkan Gangguan Antara Sel (ICI). Objektif utama tesis ini adalah untuk membangunkan skim peruntukan sumber efisien dan mengurangkan ICI dalam rangkaian pengulang koperasi. Kerja ini mencadangkan pemilihan pengulang dan peruntukan jalur lebar bersama dalam rangkaian pengulang koperasi yang memastikan kadar data boleh capai tinggi, kepuasan pengguna tinggi dan peratus gangguan rendah. Dua jenis model rangkaian telah diambil kira: rangkaian sel tunggal dan rangkaian multisel. Pemilihan Pengulang dan Peruntukan Jalur Lebar Bersama dengan Guna-semula Ruang (JReSBA\_SR) dan JReSBA\_SR Teroptimum (O\_JReSBA\_SR) dibangunkan untuk rangkaian sel tunggal. JReSBA\_SR mengambil kira kualiti pautan dan permintaan pengguna untuk peruntukan sumber, dan dilengkapi dengan penggunaan semula ruang untuk menyokong beban rangkaian lebih tinggi. O\_JReSBA\_SR merupakan pembaikan JReSBA\_SR dengan strategi berdasarkan pengoptimuman Markov. Dalam rangkaian multisel, JReSBA dengan Pengurangan Gangguan (JReSBA\_IM) dan JReSBA\_IM Teroptimum (O\_JReSBA\_IM) dibangunkan. JReSBA\_IM menggunakan pembahagian Penggunaan Semula Frekuensi Pecahan-tersektor (FFR-tersektor) bagi mengurangkan ICI antara sel-sel berdekatan. Prestasi dinilai daripada segi kadar data boleh capai sel, Peratus Gangguan (OP) dan Indeks Kepuasan (SI). Hasil kajian untuk jaringan sel tunggal menunjukkan bahawa JReSBA\_SR telah meningkatkan kadar data boleh capai sel sebanyak 35.0%, dengan OP berkurang sebanyak 17.7% berbanding dengan skim-tidak-bersama dengan sedikit peningkatan kerumitan di Nod Pengulang (RN). O\_JReSBA\_SR telah meningkatkan lagi kadar data boleh capai sel sebanyak 13.9% di samping mengekalkan prestasi gangguan dengan pengurangan kerumitan berbanding JReSBA\_SR disebabkan oleh kesan pengoptimuman. Hasil kajian untuk rangkaian multisel menunjukkan JReSBA\_IM meningkatkan kadar data boleh capai sel sehingga 65.1% dan mengurangkan OP sebanyak 35.0% berbanding dengan skim tanda aras. Begitu juga, O\_JReSBA\_IM telah mengurangkan kerumitan di pengulang dalam skim JReSBA\_IM dengan ketara, meningkatkan kadar data boleh capai sel sehingga 9.3% dan mengurangkan OP sebanyak 1.3%. Peruntukan sumber bersama yang dicadangkan telah meningkatkan prestasi rangkaian dengan ketara melalui penggunaan semula frekuensi berdasarkan ruang, dan peruntukan sumber teroptimum yang cekap dan adil. Peruntukan sumber yang dicadangkan dapat disesuaikan dengan perubahan beban rangkaian dan boleh digunakan dalam mana-mana rangkaian selular pelbagai langkauan seperti rangkaian Evolusi Jangka Panjang-Lanjutan (LTE-A).

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## LIST OF ABBREVIATIONS

3GPP	-	Third Generation Partnership Project
4G	-	Fourth Generation
AF	-	Amplify-and-Forward
AL	-	Access Link
B4G	-	Beyond 4G
BA	-	Bandwidth Allocation
BER	-	Bit Error Rate
BO	-	Bandwidth Occupancy
BRS	-	Best Relay Selection
BRS+DBA	-	Best Relay Selection and Demand-based Bandwidth Allocation
CA	-	Carrier Aggregation
CapEx	-	Capital Expenditure
CC	-	Component Carrier
CoMP	-	Coordinated Multi-Point Transmission
CQI	-	Channel Quality Indicator
CSI	-	Channel State Information
D2D	-	Device-to-Device
DBA	-	Demand-based Bandwidth Allocation
DCF	-	Decode-and-Forward
DL	-	Direct Link
eNB	-	Evolved Node B
FDD	-	Frequency Division Duplexing
FDX	-	Full-duplex
FFR	-	Fractional Frequency Reuse
HDX	-	Half-duplex
HetNets	-	Heterogeneous Networks



ICIC	-	Inter-Cell Interference Cancellation
ImpEx	-	Implementation Expenditure
IMT-A	-	International Mobile Telecommunications-Advanced
IP	-	Internet Protocol
ISD	-	Inter-Site Distance
JReSBA_IM	-	Joint Relay Selection and Bandwidth Allocation with Inter-cell Interference Mitigation
JReSBA_SR	-	Joint Relay Selection and Bandwidth Allocation with Spatial Reuse
L1	-	Layer 1
L2	-	Layer 2
L3	-	Layer 3
LTE	-	Long Term Evolution
LTE-A	-	Long Term Evolution-Advanced
MAC	-	Medium Access Control
MIMO	-	Multiple-Input Multiple-Output
MIMO-BC	-	Multiple-Input-Multiple-Output Broadcast Channel
MIMO-MAC	-	Multiple-Input-Multiple-Output Multiple Access Channel
MRC	-	Maximal Ratio Combining
MTC	-	Machine Type Communications
O&M	-	Operation and Maintenance
O_JReSBA_IM	-	Optimized Joint Relay Selection and Bandwidth Allocation with Inter-cell Interference Mitigation
O_JReSBA_SR	-	Optimized Joint Relay Selection and Bandwidth Allocation with Spatial Reuse
OFDMA	-	Orthogonal Frequency Division Multiple Access
OP	-	Outage Percentage
OpEx	-	Operational Expenditure
PA	-	Power Allocation
PDCCH	-	Physical Downlink Control Channel
PDSCH	-	Physical Downlink Shared Channel
PHY	-	Physical Layer

PL	-	Path Loss
PRBs	-	Physical Resource Blocks
QoS	-	Quality of Service
RL	-	Relay Link
RN	-	Relay Node
RRM	-	Radio Resource Management
RS	-	Relay Selection
SC-FDMA	-	Single Carrier Frequency-Division Multiple Access
SE	-	Spectral Efficiency
SI	-	Satisfaction Index
SINR	-	Signal-to-Interference-plus-Noise Ratio
SNR	-	Signal-to-Noise Ratio
SON	-	Self-Organizing Network
SUP	-	Symbol-Based Superposition
TCO	-	Total Cost of Ownership
TDD	-	Time Division Duplexing
TTI	-	Transmission Time Interval
UE	-	User Equipment
UJRSP	-	Utility-based Joint Relay Selection and Spectrum Partitioning
WiMAX	-	Worldwide Interoperability for Microwave Access

## LIST OF SYMBOLS

$T_{frame}$	-	Frame duration
$T_{subframe}$	-	Subframe duration
$T_{slot}$	-	Duration of LTE time slot
$T_u$	-	Useful symbol time
$T_s$	-	Symbol time
$T_{CP}$	-	Cyclic prefix length
$\ell_d^{AF}$	-	Downlink spectral efficiency of AF relay
$\ell_u^{AF}$	-	Uplink spectral efficiency of AF relay
$\ell_d^{DCF}$	-	Downlink spectral efficiency of DCF relay
$\ell_u^{DCF}$	-	Uplink spectral efficiency of DCF relay
$SNR_{R_{i,j}}$	-	Relay link SNR from terminal $i$ to terminal $j$
$SNR_{A_{i,j}}$	-	Access link SNR from terminal $i$ to terminal $j$
$\omega$	-	Power allocation coefficient for signals from eNB and UE for AF two-way relay
$h_{A_{i,j}}$	-	Access link channel gain from terminal $i$ to terminal $j$
$h_{R_{i,j}}$	-	Relay link channel gain from terminal $i$ to terminal $j$
$\ell_d^{DCF-XOR}$	-	Downlink spectral efficiency of DCF two-way relay with XOR signals combination
$\ell_u^{DCF-XOR}$	-	Uplink spectral efficiency of DCF two-way relay with XOR signals combination

$\ell_d^{DCF-SUP}$	-	Downlink spectral efficiency of DCF two-way relay with SUP combination
$\ell_u^{DCF-SUP}$	-	Uplink spectral efficiency of DCF two-way relay with SUP combination
$\varsigma$	-	Power allocation coefficient for signals from eNB and UE for DCF two-way relay
$E_{Dq,k}$	-	Average signal energy over one symbol period received at UE through the direct link (DL)
$E_{Rq,m}$	-	Average signal energy over one symbol period received at UE through the relay link (RL)
$E_{Aq,m,k}$	-	Average signal energy over one symbol period received at UE through the access link (AL)
$h_{Dq,k}$	-	Independent frequency flat fading with complex valued, unit power channel gains for DL
$h_{Rq,m}$	-	Independent frequency flat fading with complex valued, unit power channel gains for RL
$h_{Aq,m,k}$	-	Independent frequency flat fading with complex valued, unit power channel gains for AL
$\sigma^2$	-	Additive white Gaussian noise
$h_{mean_m}$	-	Harmonic mean channel magnitude
$\mathcal{M}_q$	-	Set of RNs in cell $q$
$\ \mathcal{M}_q\ $	-	Length of vector $\mathcal{M}_q$
$ \mathbf{h} $	-	Modulus of a vector $\mathbf{h}$
$\mathcal{M}_{q,j}$	-	Set of RNs in sector $j$ of cell $q$
$\mathcal{K}_q$	-	Set of UEs in cell $q$
$W_{tot}$	-	Total bandwidth
$\mathcal{N}$	-	Set of available subchannels
$\mathcal{Q}$	-	Set of cells
$\mathcal{N}_{Cj}$	-	Subchannel sets of inner regions sector $j$
$\mathcal{N}_{Ej}$	-	Subchannel sets of outer or edge regions sector $j$

$\gamma_{q,k}$	-	Data rate requirement of user $k$ in cell $q$
$\gamma_{\min}$	-	Minimum data rate value
$\gamma_{\max}$	-	Maximum data rate value
$R$	-	Cell radius
$P_{eNB}$	-	Maximum eNB transmit power
$P_{RN}$	-	Maximum RN transmit power
$C_{q,k}$	-	Achievable rate of UE $k$ in cell $q$
$C_q^T$	-	Total achievable rate of users in cell $q$
$\mathcal{K}_{out_q}$	-	Set of UEs which suffer outage in cell $q$
$\mathcal{N}_j$	-	Set of subchannels allocated for sector $j$
$\theta$	-	Angle for directional antenna coverage
$A(\theta)_{dB}$	-	Antenna gain in decibels at angle $\theta$
$\theta_{3dB}$	-	Angle of which the antenna gain is 3 dB lower than the antenna gain at the main beam direction
$A_m$	-	Maximum attenuation for the sidelobe
$d_{Dq,k}$	-	Distance (in km) between eNB $q$ to UE $k$ for DL
$d_{Rq,m}$	-	Distance (in km) between eNB $q$ to RN $m$ for RL
$d_{Aq,m,k}$	-	Distance (in km) between RN $m$ to UE $k$ for AL
$PL_{Dq,k}$	-	Path loss for DL between eNB $q$ and UE $k$
$PL_{Rq,m}$	-	Path loss for RL between eNB $q$ and RN $m$
$PL_{Aq,m,k}$	-	Path loss for AL between RN $m$ and UE $k$ in cell $q$
$P_{eNBq,k}$	-	Transmit power of eNB $q$ to UE $k$
$P_{eNBq,m}$	-	Transmit power of eNB $q$ to RN $m$
$P_{RNq,m,k}$	-	Transmit power of RN $m$ to UE $k$
$\tau$	-	Processing delay at relay node
$y_{r,q,m,k}$	-	Received signal at UE $k$ from relay node

$x_{q,k}$	-	Intended signal for UE $k$
$n_{R_{q,m}}$	-	Additive white Gaussian noise at RN with variance $\sigma^2$
$y_{u_{q,k}}$	-	Received signal at UE $k$ from both eNB and relay node
$\alpha_{q,m,k}$	-	Binary indicator for cooperation of RN $m$
$\mathbf{a}_{q,k}$	-	Node selection vector
$y_{I_{q,k}}$	-	Interference signals received by UE $k$ in cell $q$
$x_{q,k'}$	-	Transmitted signal for UE $k'$
$\psi_{q,m',k}$	-	Binary indicator showing that RN $m'$ is reusing same subchannel as UE $k$ to serve UE $k'$ in other sector
$\ell_{q,k}^d$	-	Spectral efficiency over DL for one-hop UE $k$
$\ell_{q,k}^{co}$	-	Maximum achievable SE for UE $k$ with multiple cooperating RNs
$\rho_{eff_{q,k}}$	-	Number of effective subchannels allocated to each UE $k$
$W_{eff_{q,k}}$	-	Size of effective bandwidth assigned to the UEs
$\varphi_{q,k}$	-	User binary indicator
$\mathcal{S}_{q,k}^n$	-	Indicator for subchannel $n$ reuse by UE $k$
$\ell_{q,m,k}^a$	-	Access links spectral efficiency values
$\mathcal{M}_{q,k}$	-	Candidate RNs matrix for UE $k$
$W_{q,k}$	-	Estimated size of bandwidth needed to meet UE $k$ demand
$\rho_{q,k}$	-	Number of requested subchannels $\rho_{q,k}$ needed to satisfy UE $k$ demand
$\rho_{th_{q,k}}$	-	Subchannel allocation threshold
$\rho_{q,sum}$	-	Summation of UEs required subchannels

$\beta_{q,k}$	-	Bandwidth weightage
$W_{th,q,k}$	-	Bandwidth allocation threshold
$\mathcal{K}_{q,j}$	-	Set of UEs in sector $j$ of cell $q$
$\eta_{q,k}^n$	-	Binary indicator for allocation of subchannel $n$ for UE $k$ in cell $q$
$\mathcal{R}_q$	-	List of ranked UEs based on their spectral efficiency
$r_{q,m,k}$	-	Relay subchannel reuse indicator
$\mathcal{R}_k$	-	Subchannel reuse vector UE $k$
$\mathcal{N}_{RN_m}$	-	Set of subchannels used by each RN $m$ to serve its UEs
$\mathcal{N}_{reuse_m}$	-	Candidate subchannels from RN $m$ for UE $k$ in sector $j$
$\mathcal{N}_{cand_{q,j,k}}$	-	Set of candidate subchannels for UE $k$
$\ \mathcal{K}_q^{\max}\ $	-	Highest number of UEs that is evaluated in the numerical evaluation
$Outage_q$	-	Outage percentage
$SI_q$	-	User satisfaction index
$\gamma_{mean}$	-	Mean of user demanded rate range
$\gamma_{mean}^{\max}$	-	Maximum mean of user demanded rate range
$S_{q,k}^s$	-	Markov state indicating cooperative structure
$\mathcal{S}$	-	State spaces defining set of cooperative structures
$Po(S_{q,k}^s)$	-	Payoff function
$\ell_{q,k}(S_{q,k}^s)$	-	Spectral efficiency for current state $S_{q,k}^s$
$\xi$	-	Cost of a relay
$W_{q,k}^s$	-	Requested bandwidth for each state
$\rho_{q,k}^s$	-	Number of requested subchannels needed to satisfy UE $k$ demand with current state $S_{q,k}^s$

$\mathbf{P}_{q,k}$	-	Transition probability matrix for the cooperative structure
$P_{S_{q,k}^s, S_{q,k}^{s'}}$	-	Transition probability from state $S_{q,k}^s$ to $S_{q,k}^{s'}$
$\delta_{q,k}$	-	Probability that eNB makes decision for joint relay selection and bandwidth allocation of a user $k$
$\hat{\theta}(S_{q,k}^{s'}   S_{q,k}^s)$	-	Best-reply rule for eNB decision for a user $k$
$\Theta$	-	Constant value representing the probability transition from state $S_{q,k}^s$ to $S_{q,k}^{s'}$
$\mathcal{B}_{q,k}^s$	-	Set of better states
$\pi_{q,k}$	-	Steady state distribution vector
$\pi_{S_{q,k}^s}$	-	Probability that eNB decides on cooperation structure $S_{q,k}^s$
$y_{I_{q,k}}^{adj}$	-	Interference signals received by UE $k$ from adjacent cells $q'$
$\mathcal{G}_{q',k}$	-	Binary indicator showing that eNB $q'$ has UEs to be served on same subchannel as UE $k$
$\psi_{q',m',k}$	-	Binary indicator of whether RN $m'$ of cell $q'$ is serving its UEs on the same subchannel as UE $k$ or not
$d_c$	-	Centre radius of cell
$\mathcal{N}_{RN_{m'}^{adj}}$	-	List of subchannels used by adjacent relay $m'$ to serve its UEs
$\mathcal{N}_{reuse_m^{adj}}$	-	Candidate subchannels from adjacent relay $m'$ for UE $k$ in sector $j$
$\mathcal{N}_{cand_{q,j,k}^{adj}}$	-	List of subchannels that can be used from all non-interfering relays of adjacent cells



**LIST OF APPENDIX**

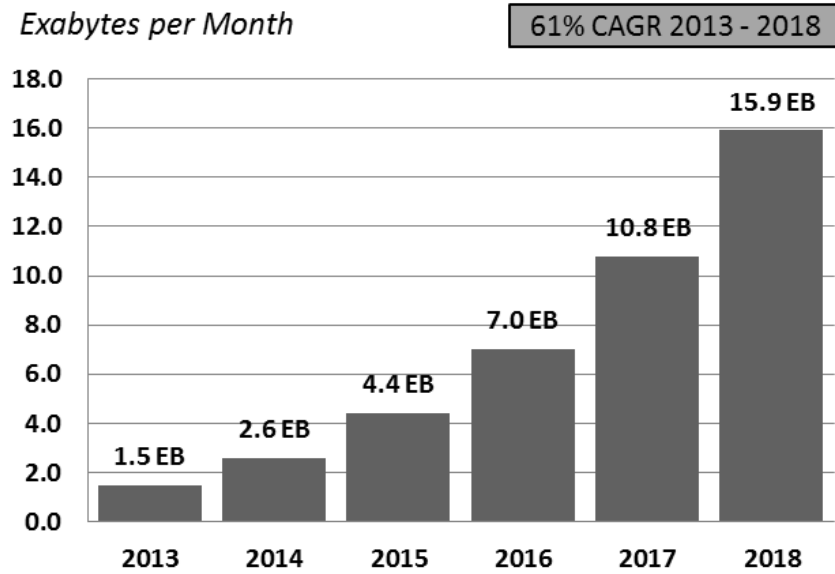
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## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Background**

Global mobile data traffic is growing rapidly over the past few years with the increasing number of smartphones and tablets around the world and has already overtaken the total monthly traffic of voice traffic since 2009. It is also observed that the growth of voice traffic is almost flat [1]. There is no doubt that increment on the number of mobile smartphones and mobile broadband subscription is the key factor for the rapid data traffic growth. In 2013 alone, according to Cisco Visual Networking Index for Global Mobile Data Traffic Forecast Update [2], over half a billion mobile devices and connections were added, where the number grew from 6.5 billion in 2012 to 7 billion in 2013. From that extensive growth, 77% of it is accounted from smartphones. Moreover, based on the forecast done by Cisco, mobile data traffic is expected to grow from 1.5 exabytes in 2013 to 15.9 exabytes per month by 2018. Statistically, mobile data traffic will grow at a compound annual growth rate (CAGR) of 61% from 2013 to 2018, as shown in Figure 1.1.



**Figure 1.1** Cisco forecasts for monthly growth of mobile data traffic by 2018 [2]

In response to the explosive demands for mobile data, the entire world is moving towards next generation wireless broadband network in order to meet the requirements of high throughput, extended coverage and low latencies which are defined in International Mobile Telecommunications-Advanced (IMT-A) requirements [3], [4]. As an enhancement to the formerly developed Long Term Evolution (LTE) Release 8 standard, the Third Generation Partnership Project (3GPP) working group has carried out studies for LTE-Advanced (or LTE Release 10). LTE-Advanced development should be backward compatible to LTE as to enable LTE terminal to work in LTE-Advanced network and vice versa. It also aims to fulfil or even exceed the IMT-A requirements including peak data rates of 1Gbit/s for the downlink and 500Mbits/s for the uplink, and extended bandwidth support up to 100MHz [5], [6]. Key technologies of LTE-Advanced are carrier aggregation, enhanced multiple-input multiple-output (MIMO) transmission (spatial multiplexing of eight layers for downlink and four layers for uplink), coordinated multi-point transmission (CoMP), relaying and heterogeneous networks.

Relay assisted cellular network is a form of multi-tier or hierarchical network that offers coverage extension and capacity enhancement. The usage of relaying is very useful in densely populated cellular network. Relay deployment is also a cost-efficient solution to improve network performance. This is because the installation of relay node does not require expensive cost for planning, construction, and maintenance. In practical network scenario, the usage of relaying can be applied to improve the performance of cell edge users, provide coverage to areas affected by shadowing, support temporary network deployments, and also to support group mobility [5], [7], [8]. In wireless networks, cooperative communication has been widely considered as an extension to relay networks to improve diversity gain [9]. Basically, virtual MIMO concept is applied where an Evolved Node B (eNB) exploits multiple relay nodes (RNs) to cooperatively transmit the data to the destination by taking advantage of multiple antennas that belongs to a pool of individual relay terminals. Cooperative relaying has been considered as an efficient solution because it offers dramatic performance gains by taking advantage of space or multiple antenna diversity techniques which can be readily combined with other diversity techniques such as time and frequency diversity.

Spatial reuse is a promising technique to enhance network capacity by means of allowing spectrum reusing among multiple nodes in the network. The nature of multi-tier network provides more rooms for simultaneous transmission on same spectrum band by taking the advantage of directional antenna of the transmitter [10], [11]. There is a trade-off between the support for high network capacity offered by spatial reuse and the interference it introduced. One of the eminent methods to mitigate interference is sectorized-Fractional Frequency Reuse (sectorized-FFR). Sectorized-FFR technique involves partitioning of the spectrum band according to cell sectors and proper planning of the spectrum reuse which efficiently mitigate interference leading to good network performance [12].

## 1.2 Problem Statement

The deployment of cooperative relay to enhance network performance poses technical challenges. The main challenge in hierarchical cooperative network is to provide efficient resource allocation to meet user demands in order to obtain high cell achievable rate and low outage percentage.

The problem with conventional transmission where the source is transmitting directly to its destination is that if link is broken, then the transmission will fail and retransmission is needed leading to longer delay. Therefore, cooperative relaying is introduced where multiple relay nodes are used to forward signals for the source-destination pair [9], [13]–[15]. The destination then combines the signals coming from source and multiple relays, which created spatial diversity by taking the advantage of sending redundant data through multipath transmission. Thus, cell throughput is improved significantly. However, it is not optimal to use all available RNs in the network in assisting the transmission to users because it incurs cost of additional resources and power [16], [17]. Besides, some relays may be far-away from a particular user which will result in waste of power resources if it assists the transmission to that user. Hence, there is a need for relay selection in the network.

Bandwidth sharing is also one of the challenges concerned throughout the literature [18]–[21]. In a network with large number of users with their own traffic demand, bandwidth allocation is crucial. Ineffective bandwidth allocation that is unaware of user traffic demand leads to user dissatisfaction. The service providers need to differentiate users based on their requirements in order to ensure fair resource allocation while maintaining high network performance. Thus, efficient bandwidth allocation technique is needed.

Explosive data rate demand of users and high network load due to large number of users leads to shortage of spectral resources. One of the ways to handle the problem is to provide more spectrum resources which are very expensive. In order to overcome this problem without the need for additional spectrum resources,

spatial reuse technique is introduced by means of exploiting the space dimension to enable concurrent transmissions on the same spectrum channel [10]. Following this, inter-cell interference (ICI) issue arises among adjacent cells as the effect of spectrum reusing by relay nodes [10], [22]. Therefore, the spatial reuse technique needs to be designed such that ICI is kept minimal while simultaneously provides high cell achievable rate.

Currently, few research works tackle the problem of spectrum resources shortage by considering spatial reuse technique to mitigate ICI in densely populated network. In contrary, most of the research works limit the number of users for each RN utilizing the same frequency band [23], [24]. In densely populated network, limiting the number of users entering the network may lead to inefficient usage of bandwidth utilization. Since the main goal of resource allocation is to maximize the achievable rate to cater for various users demand, there must be an optimal solution to ensure fair bandwidth allocation among participating users while taking advantage of spatial reuse.

As mentioned earlier, allowing concurrent transmissions of multiple relay nodes in the network may lead to interference problem. Therefore, in order to use the cooperative communication effectively, there is a need for efficient resource allocation which leverages the trade-off between achieving the diversity gain benefit and interference caused by the concurrent transmission.

### **1.3 Research Objectives**

The main objective of this research is to develop an optimal joint relay selection and bandwidth allocation strategy for cooperative relay network that provides high achievable rate and can efficiently allocate resources with high user satisfaction and very outage percentage. The specific objectives of the work are:

- i) to develop joint relay selection and bandwidth allocation scheme with spatial frequency reuse for single cell network.
- ii) to develop joint relay selection and bandwidth allocation scheme with interference mitigation for multicell network.
- iii) to optimize the joint relay selection and bandwidth allocation schemes in both single cell and multicell network.

In this thesis, the joint relay selection and bandwidth allocation scheme for single cell is developed to mitigate the interference that occurs among adjacent sectors within the cell. On the other hand, the joint relay selection and bandwidth allocation scheme for multicell is developed to mitigate the interference that occurs among adjacent cells. Optimization of the relay selection and bandwidth allocation decision aims to enhance the cell achievable rate and satisfy user traffic demand.

#### **1.4 Scope of Research**

This research mainly focuses on relay assisted hierarchical cooperative network based on LTE-Advanced system. Two network scenarios are considered. Firstly, single cell network scenario is considered where two strategies are proposed, namely JReSBA\_SR and O\_JReSBA\_SR. The first one is a heuristic algorithm, while the second one is equipped with optimization using Markov chain technique to reduce the complexity of the former. Both strategies are aware of diverse users traffic demand and link quality. In order to overcome the problem of spectrum resources shortage due to high network load, spatial reuse is implemented. For the second scenario, multicell scenario consisting of seven adjacent cells is considered. Similarly, another two strategies are proposed, namely JReSBA\_IM in heuristic manner, while the other is an optimized version of it, O\_JReSBA\_IM. Sectorized-FFR based spatial reuse technique is proposed to mitigate the effect of ICI, while at the same time maximizing network performance. In this research, equal power allocation

is adapted where the total transmit power is divided to all the served users of eNB and RN.

This research considers only two-hop cellular network with infrastructure mode. Centralized resource allocation mechanism is considered, where eNB is responsible in making all the allocation decisions. The performance evaluation is done for downlink transmission only. The RN is assumed to be Type 1 full-duplex relay and implementing Decode-and-Forward (DCF) operation. Apart from that, this research also considers multi-users scenario with asymmetric traffic demand. Performance evaluation is done in MATLAB, considering evaluation settings based on 3GPP case 1 urban macro scenario. Throughout the research, frequency division duplexing (FDD) mode is considered.

## 1.5 Research Contributions

The proposed joint resource allocation schemes aim to enhance the performance of relay network. The proposed joint relay selection and bandwidth allocation scheme is furnished with interference mitigation competency and is optimized to deliver high cell achievable rate with low probability of denying users demand. The major contributions of this thesis include:

### i) **Joint relay selection and bandwidth allocation for single cell and multicell cooperative relay network**

In this work, the proposed resource allocation schemes JReSBA\_SR for single cell network and JReSBA\_IM for multicell network will be able to select good quality cooperative links and allocate adequate bandwidth to meet user demands. The selected cooperative relay links in single and multicell network will ensure high cell achievable rate due to the cooperative diversity gain.



**ii) Optimized joint relay selection and bandwidth allocation for single cell and multicell cooperative relay network**

Both JReSBA\_SR and JReSBA\_IM allow as many users as possible to be served by a RN. Without the limitation on the number of participating users, the algorithm tends to burden RN which may lead to lower power allocation to participating users. The optimization based on Markov process in O\_JReSBA\_SR and O\_JReSBA\_IM generate optimal relay selection and bandwidth allocation that maximizes cell achievable rate by compromising spectral efficiency enhancement with the cost of cooperative relay links. Consequently, more efficient power can be allocated to reduced number of participating users.

**iii) Support for higher network load through spatial reuse**

In a densely populated network with limited resources, satisfying every user demand is competitive. In this work, spatial reuse technique is utilized along with O\_JReSBA\_SR and O\_JReSBA\_IM to further enhance network capacity in order to support higher network load by providing rooms for more concurrent transmissions on the limited spectrum band.

**iv) Interference mitigation by adopting sectored-FFR partitioning**

In practical network scenario, spectrum reuse leads to ICI problem which deeply affects the performance of cell edge users. The deployment of sectored-FFR spectrum partitioning along with the spatial reuse technique in O\_JReSBA\_SR and O\_JReSBA\_IM enable the network to maximize cell achievable rate and minimize the effect of ICI.

## **1.6 Significance of Research**

The proposed joint relay selection and bandwidth allocation is suitable for any multihop cellular network (MCN). MCN is a cutting edge technology which is heavily considered in next generation wireless broadband network such as LTE-Advanced and Worldwide Interoperability for Microwave Access (WiMAX) IEEE 802.16m that utilizes the advantage of relay to provide coverage extension and capacity enhancement. Cooperative communication utilizing multiple relay nodes is a cost-efficient solution to enhance the network performance because relay node does not incur expensive installation and operational costs. In addition, the proposed schemes are also suitable for implementation in ad-hoc network such as multi-tier Wireless Fidelity (WiFi) and clustered Wireless Sensor Network (WSN) that operates in centralized manner.

Furthermore, the proposed scheme will work efficiently in both urban and rural area. The proposed scheme is capable to support densely populated network with limited spectrum resources by means of using spatial reuse. On top of that, the proposed scheme will be able to meet user traffic demands which includes various types of application such as web browsing – Hyper Text Transfer Protocol (HTTP), File Transfer Protocol (FTP), online video streaming, and Voice over Internet Protocol (VoIP).

## **1.7 Thesis Outline**

The thesis elaborates the development of joint relay selection and bandwidth allocation for hierarchical relay network. Chapter 2 highlights the technology features of LTE-Advanced system, which includes relaying as one of its key technologies. The issues in cooperative relay network which includes relay selection, bandwidth allocation and power allocation are discussed, and the related approaches to solve the relay network problems are presented and analysed. Several loopholes are identified which become the driver for this research work.

Chapter 3 mainly focuses on the design framework of the proposed joint resource allocation schemes. It covers the basic design concept of all four schemes, namely JReSBA\_SR, O\_JReSBA\_SR, JReSBA\_IM and O\_JReSBA\_IM. The algorithms of the proposed schemes are described and differences between the schemes are highlighted by using flowcharts. In addition, the considered network model, which include single cell and multicell scenarios are described, along with the network parameters and assumptions for numerical simulation study. Performance metrics used to justify network performance are listed and described. Then, numerical simulation tool using MATLAB and its implementation concept is depicted by using functional blocks and the consistency of the numerical simulation result is validated.

Chapter 4 presents the formulation for JReSBA\_SR followed by its algorithm design which includes link quality and user traffic demand parameters in its decision making block. In addition, implementation of spatial reuse technique is also described. Then, performance analysis of the proposed JReSBA\_SR scheme in comparison to non-joint scheme and JReSBA\_B scheme without spatial reuse is presented. Following that, by identifying the drawback of JReSBA\_SR, development of O\_JReSBA\_SR with optimization based on Markov process and method to determine the optimization solution are also described. Then, the performance of O\_JReSBA\_SR is analysed in comparison to JReSBA\_SR.

Chapter 5 describes the detail algorithm design for JReSBA\_IM scheme. Formulation of JReSBA\_IM by incorporating sectorized-FFR spectrum partitioning concept is described, followed by the algorithm description which includes the joint relay selection and bandwidth allocation scheme with centre and edge regions spatial reuse technique. The performance of JReSBA\_IM is analysed in comparison to Soft Frequency Reuse (SFR) based scheme in the literature.

Chapter 6 presents the detail of O\_JReSBA\_IM algorithm. Markov process representation of joint relay selection and bandwidth allocation with sectorized-FFR is described. Similar to Chapter 4, stable cooperation structure for two-hop users are

determined. Performance analysis is done to compare O\_JReSBA\_IM performance with JReSBA\_IM and JReSBA\_SR schemes.

Finally, Chapter 7 concludes the thesis with summary of the research work, significant achievements, together with recommendations for future work.

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