UNIVERSITI PUTRA MALAYSIA

EFFICIENT BEAMFORMING AND SPECTRAL EFFICIENCY MAXIMIZATION IN A JOINT TRANSMISSION LTE-A SYSTEM

ALI RAED FAISAL

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By

ALI RAED FAISAL

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

June 2016

DEDICATIONS

In the Name of Allah, the Most Gracious, the Most Merciful
This thesis is dedicated to:

My caring and devoted parents for their unconditional love and substantial support

And

My beloved aunts, brother & nephew

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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June 2016

Chair: Fazirulhisyam Hashim, PhD
Faculty: Engineering

Next-generation cellular networks and beyond are expected to adopt a frequency reuse factor of one to support high spectral efficiency. Consequently, Inter-Cell Interference (ICI) represents a serious issue among neighboring cells, especially for cell-edge users. In addressing this, Joint Transmission (JT) represents one of the most sophisticated techniques for mitigating ICI stemming from implementing a frequency reuse factor of one. Moreover, JT also converts the interfering signals into useful signals to improve the spectral efficiency of the system. However, JT produces enormous overhead on both the feedback and backhaul interfaces; thus, partial JT was proposed as a trade off between signaling demand and increased spectral efficiency. Maintaining an equivalent Beamforming (BF) matrix based on a sparse aggregated channel matrix is a challenging issue with regard to linear BF schemes such as Zero-Forcing (ZF). This is mainly because ZF can only invert a well-conditioned matrix. Therefore, a Multi-Start Particle Swarm Optimization Algorithm (MSPSOA) is included in this thesis and used to present an efficient beamformer that achieves equivalent backhaul reduction and high spectral efficiency. Moreover, addressing the lack-of-diversity issue in Basic Particle Swarm Optimization Algorithm (BPSOA) is a primary concern of this work. As a contribution of this thesis, diversity loss can be solved by replacing the inactive particles adaptively based on the difference between local best and global best optimization criterion. In this study, the performance of ZF, BPSOA and the proposed MSPSOA BF are evaluated by using different metrics like acquired sum rate, level of actual interference and transmitting power along with total utility of three different internet applications. The beamformer obtained with the objective function of sum rate maximization achieves a spectral efficiency of **15.3%** compared to BPSO BF in some of the conducted scenarios.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBENTUK ALUR BERKESAN DAN PEMAKSIMUMAN KECEKAPAN SPEKTRUM DALAM PENHANTARAN BERSAMA SISTEM LTE-A

Oleh

ALI RAED FAISAL

Jun 2016

Pengerusi: Fazirulhisyam Hashim, PhD
Fakulti: Kejuruteraan

Rangkaian selular generasi akan datang dijangka akan menerima pakai faktor frekuensi guna semula yang bernilai satu untuk mewujudkan kecekapan spektrum yang tinggi. Oleh itu, Gangguan Inter-Sel (ICI) merupakan satu isu yang serius antara sel-sel berdekatan, terutamanya bagi pengguna telefon bimbit di pinggiran sel. Untuk menanganinya, Penghantaran Bersama (JT) merupakan salah satu teknik yang paling canggih untuk mengurangkan ICI yang berpunca daripada pelaksanaan faktor frekuensi guna semula yang bernilai satu. Tambahan pula, JT juga menukarkan isyarat pengganggu kepada isyarat yang berguna untuk meningkatkan kecekapan spektrum sistem. Walau bagaimanapun, JT menghasilkan overhed yang banyak pada kedua-dua antara muka maklum balas dan angkut balik; dengan itu, JT separa telah dicadangkan sebagai tukar ganti antara permintaan pengisyaratan dan peningkatan kecekapan spektrum. Mengekalkan matriks penbentuk alur (BF) setara berdasarkan matriks saluran agregat jarang adalah isu yang mencabarkan dengan mengambil kira skim BF linear seperti Sifar-Memaksa (ZF). Ini adalah kerana ZF hanya boleh terbalikkan matriks yang berkeadaan baik. Oleh itu, Algoritma Pengoptimuman Kerumunan Zakar Mula Berbilang (MSPSOA) telah dicadang dalam karya ini dan digunakan untuk mengemukakan penbentuk alur berkesan yang mencapai pengurangan angkut balik setara dan kecekapan spektrum yang tinggi. Selain itu, bagi menangani isu kekurangan kepelbagaian dalam Algoritma Pengoptimuman Kerumunan Zakar Asas (BPSPA) adalah perhatian utama kerja ini. Sebagai sumbangan tesis ini, kekurangan kepelbagaian boleh diselesaikan dengan menggantikan zarah tak aktif secara adaptif berdasarkan perbezaan di antara pengoptimuman kriteria terbaik tempatan dan terbaik global. Dalam kajian ini, prestasi ZF, BPSOA dan MSPSOA BF yang dicadangkan telah dinilai dengan menggunakan metrik yang berbeza seperti kadar jumlah yang diperolehi, tahap gangguan yang sebenar dan kuasa hantaran selaras dengan jumlah utiliti daripada tiga aplikasi internet

yang berbeza. Penbentuk alur diperolehi dengan objektif untuk memaksimumkan kadar jumlah dapat mencapai kecekapan spektrum **15.3%** berbanding BPSO BF dalam beberapa senario yang dijalankan.

ACKNOWLEDGEMENTS

I would like to dedicate my deepest gratitude to my supervisors, Dr. Fazirulhisyam Hashim, Prof. Dr. Nor Kamariah Noordin and Prof. Dr. Mahamod Ismail because of their long-time support and great motivation on my way of conducting this research as well as their precious comments to improve the excellence of the dissertation.

I certify that a Thesis Examination Committee has met on **June 17, 2016** to conduct the final examination of **ALI RAED FAISAL** on his thesis entitled **"EFFICIENT BEAMFORMING AND SPECTRAL EFFICIENCY MAXIMIZATION IN A JOINT TRANSMISSION LTE-A SYSTEM"** in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

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I certify that a Thesis Examination Committee has met on 17 June 2016 to conduct the final examination of Ali Raed Faisal on his thesis entitled "Efficient Beamforming and Spectral Efficiency Maximization in a Joint Transmission LTE-A System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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Declaration by graduate student

I hereby confirm that:

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This is to confirm that:

- the research conducted and the writing of the thesis was under our supervision;
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Name of Member of Supervisory Committee: Nor Kamariah Noordin, PhD

Signature: ______________________________

Name of Member of Supervisory Committee: Mahamod Ismail, PhD

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1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
3GPP	Third Generation Partnership Project
ACS	Array Coordinate System
AMC	Adaptive Modulation and Coding
AMPS	Advanced Mobile Phone System
ARQ	Automatic Retransmission Request
BEC	Backward Error Correction
BER	Bit Error Rate
BF	Beamforming
BPSOA	Basic Particle Swarm Optimization Algorithm
CCN	Central Coordination Node
CDMA	Code Division Multiple Access
CN	Core Network
CoMP	Coordinated Multipoint Transmission and Reception
CP	Cyclic Prefix
CS/CB	Coordinated Scheduling/Coordinated Beamforming
CSI	Channel State Information
CQI	Channel Quality Indicator
DFT	Discrete Fourier Transform
DL	Downlink
DMRS	Demodulation Reference Signal
DPC	Dirty Paper Coding
DPS	Dynamic Point Selection
ECS	Element Coordinate System
EDGE	Enhanced Data Rates for GSM Evolution
eNB	Evolved Node B
EPC	Evolved Packet Core
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FJT	Full Joint Transmission
FJP	Full Joint Processing
GCS	Global Coordinate System
GERAN	GSM EDGE Radio Access Network
GPS	Global Positioning System
GSM	Global System Mobile

HARQ	Hybrid Automatic Retransmission Request
HSPA	High Speed Packet Access
ICI	Inter-Cell Interference
ICIC	Inter-Cell Interference Coordination
IEEE	Institute of Electrical and Electronics Engineers
IFR	Intelligent Frequency Reuse
IMT	International Mobile Telecommunication
IP	Internet Protocol
JT	Joint Transmission
JP	Joint Processing
LO	Local Oscillator
LOS	Line of Sight
LTE	Long Term Evolution
MAC	Medium Access Control
MCP	Multi-Cell Cooperative Processing
MCS	Modulation Coding Scheme
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
MMSE	Minimum Mean Square Error
MSPSOA	Multi-Start Particle Swarm Optimization Algorithm
MU	Mobile User
MU-MIMO	Multi-User MIMO
NLOS	Non Line of Sight
NMT	Nordic Mobile Telephone System
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Multi-User Orthogonal Frequency Division Multiple Access
PDCCH	Physical Downlink Control Channel
PFR	Partial Frequency Reuse
PGW	Packet Gateway
PJT	Partial Joint Transmission
PJP	Partial Joint Processing
PMI	Precoding Matrix Indicator
PSO	Particle Swarm Optimization
PUCCH	Physical Uplink Control Channel
QAM	Multi-User Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift keying
RAN	Radio Access Network
RB	Resource Block
RI	Rank Indicator
RoF	Radio over Fiber
RRC	Radio Resource Control
RRH	Remote Radio Head
RRM	Radio Resource Management
RS	Reference Signal

RSRP	Reference Signal Received Power
SC-FDMA	Single Carrier Frequency Division Multiple Access
SFR	Soft Frequency Reuse
SGW	Serving Gateway
SINR	Signal to Interference plus Noise Ratio
SNR	Signal to Noise Ratio
SRS	Sounding Reference Signal
SU-MIMO	Single User MIMO
TACS	Total Access Communications System
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TR	Technical Report
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
ULA	Uniform Linear Array
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over IP
WCDMA	Wide band Code Division Multiple Access
Wi-Fi	Wireless Fidelity
WIM	WINNER
WiMAX	Worldwide Interoperability for Microwave Access
ZF	Zero-Forcing

CHAPTER 1

INTRODUCTION

1.1 Background

Cellular communication has emerged as a powerful platform for humans' daily use communications. Mobile networks technologies have passed through several generations as a result of evolution, started with first generation (1G) and all the way to 2G, 3G and 4G in which represented by LTE-A. Recently, several studies have been carried out on defining the framework and the specifications of 5G.

1.1.1 Mobile Cellular Communication Evolution

The first generation (1G) wireless hand-held communication mobile network was introduced in the early 1980s. There were different standards depending on the countries. For instance, in United States, the term Advanced Mobile Phone Service (AMPS) was deployed by using analog frequency modulation for transmission and each user equipment (UE) is given a specific frequency slot in a Frequency Division Multiple Access (FDMA) fashion. In the United Kingdom, Total Access Control/Communications System (TACS) had used frequency shift keying in FDMA [1]. Nordic Mobile Telephone (NMT) was the 1G form in Nordic countries. Allocated different frequency band to each user leads to low co-channel interference. This influences the use of frequency reuse, by dividing the whole frequency band among the adjacent cells and reusing a particular frequency after some distance in order to alleviate the co-channel interference. However, this comes on the account of insufficient frequency resources because the spectrum that assigned to a network is not fully utilized in each cell.

The first digital communication introduced in 1991 under the category of second generation (2G), namely, Global System for Mobile (GSM) communications [2]. At that time GSM was considered to be as a milestone mobile technology, since it introduces the idea of scheduling users in a given time-slot as Time Division Multiple Access (TDMA). Moreover, CDMA-One was introduced in the United States with a coding separation mechanism, in other words each user has a unique code to distinguish itself from others by implementing a Code Division Multiple Access (CDMA). The issue of insufficient spectrum in GSM is similar to 1G in a way that assigning a part of the frequency band to each cell in the cluster. The use of resources, time and frequency, in CDMA has to be implemented at the same time and unique codes are used to differentiate users. The effect of interference in CDMA is a serious issue and that is due to the non-orthogonal codes that can give rise to intra-cell interference, whereas inter-cell interference is still existed because the codes have been reused in other cells. An optimized code planning may reduces the effect of inter-cell and intra-cell interference.

In 2001, third generation (3G) cellular network was presented on the basis of Wideband Code Division Multiple Access (WCDMA). In that scenes, all the frequencies are utilized in every cell, likewise CDMA, and UEs are differentiated

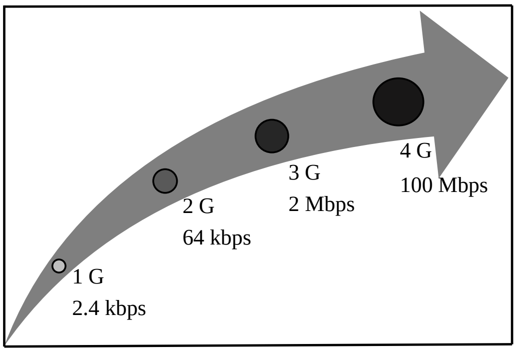

Figure 1.1: Data rate requirements of mobile cellular communications.

by codes. To reduce the inter-cell interference and non-orthogonality that causes intra-cell interference, gold codes are implemented as a scrambling code. The radio technology enhancement owes to using 5 MHz bandwidth and GSM/EDGE Radio Access Network (GERAN) [3]. Meanwhile, along with WCDMA development, High-Speed Packet Access (HSPA) was introduced by 3GPP in 2006 [4]. Multiple Input Multiple Output (MIMO) antenna technology as well as advanced coding and modulation schemes such as (16 QAM, and 64 QAM) collaborated with latest HSPA technology to produce HSPA+.

Long-Term Evolution (LTE) is the first step to emerge toward forth generation (4G) cellular network. In 2004, 3GPP revealed the specifications of LTE technology with a promising high spectral efficiency, high data rate and low latency [5]. LTE suppose to support various services and applications by its Internet Protocol (IP) and and flat architecture, such as Voice over IP (VoIP), data transfer and video calling. There are other broadband wireless mobile technologies besides LTE, like Wireless Microwave Access (WiMAX) and Wireless Fidelity (WiFi). Based on IEEE802.16e standards, WiMAX brings better performance, capacity and mobility. Moreover, WiMAX facilitates Orthogonal Frequency Division Multiple Access (OFDMA), and that enables high data rate by eliminating intra-cell interference and also supports the necessary features for vehicular mobile users [6]. The features of mobile WiMAX are listed as Hybrid Automatic Repeated Request (HARQ), Adaptive Modulation and Coding (AMC), efficient handover and fast scheduling. Figure 1.1 illustrates the evolution of mobile cellular communications in terms of provided data rate.

A key aspect of 4G is the frequency reuse of one as well as the employment of OFDMA and utilizing all the frequency-time resources in one cell. In this context, the neighboring cells may also reuse the same frequency, thus the spectrum resources is going to be used efficiently. Although the use of full frequency may relax the constraints on the available frequency band, a severe Inter-Cell Interference (ICI) comes up, especially for cell-edge users. To tackle this problem, Coordinated Multipoint (CoMP) Transmission and Reception is proposed in [7].

1.1.2 Coordinated Multipoint (CoMP) Transmission and Reception

CoMP is a major area of interest within the field of cooperative communications [8]. In the downlink, multiple collaborating eNBs transmit user's data simultaneously to the UEs, and thus the interfering signal is treated as a desired one. In [9], this technique was proposed as network coordination. CoMP may be divided into two main categories namely, Coordinated Scheduling/Coordinated Beamforming (CS/CB) and Joint Processing (JP) [7]. JP may also be classified into Joint Transmission and Dynamic Point Selection, (to be discussed in Section 2.3.2.2). CoMP may be classified on the basis of architecture into centralized and decentralized coordination [10]. In centralized coordination, the UE feeds back the Channel State Information (CSI) through the feedback overhead to the cooperative eNBs, and then the CSI is accumulated in the Central Coordination Node (CCN) to create an aggregated channel matrix [11, 12]. In decentralized coordination, the CSI is available at all the eNBs, but the Beamforming (BF) and the power allocation are performed on each eNB. Therefore, a special scheduling algorithm is necessary to assign an eNB to each UE [13]. Depending on the aggregated channel matrix, the CCN generates the BF matrix after power allocation. The CCN can be combined with one of the eNBs in the cluster. The BF matrix and the user data have to be available at the cooperative eNBs in order to eliminate ICI by sending exact user data to a specific UE [14]. CoMP network overhead can be classified into two types. The first is feedback overhead, which is the signaling of CSI from the UEs to eNBs, and the second is backhaul overhead, which represents the signaling of BF elements between the cooperative eNBs. Thus, the feedback and backhaul overhead give a tremendous load on both frequency resources as well as the interface between the cooperative eNBs [12, 15].

One of the greatest challenges of JP is reducing the complexity by arranging eNB into clusters. The clustering approach can be static, which means the collaborating eNBs have not changed with time, whereas dynamic clustering changes with time to deploy the fairness among UEs. Moreover, clustering topology may be classified according to whether the clustering decision is made into a user-centric or network-centric decision, taking into account the channel conditions [14]. Regardless the high performance of JP, it comes with high demand on both frequency resources and backhaul requirements. When a multiple collaborating eNBs transmitting user's data simultaneously that leads to burden the assigned frequency band and degrade the performance of UEs. JP, however, requires high backhauling speed and requirements in order to perform the cooperation and thus fiber optics is one of the possible solutions to provide high speed backhauling. Thereby, to cope with the current backhauling technologies a considerable amount of literature has been published on reducing the backhauling requirements such as in [13, 14, 16, 17, 18, 19, 20]. A variety of schemes were presented to relax the burdens on backhaul and frequency resources and presenting a trade off between the performance and required infrastructure. One such technique is a threshold-based window algorithm Partial Joint Processing (PJP), where a subset of eNBs is considered for cooperation on the basis of the channel conditions of UEs in a defined cluster, and form a sparse aggregated channel matrix [13, 16, 17]. Consequently, the load on both feedback and backhaul overload is reduced.

Returning to the subject of PJP, when linear Zero-Forcing (ZF) BF is performed by the CCN depending on the sparse aggregated channel matrix, that may not necessarily reflect on the BF matrix, in other words, it does not reduce the backhaul demand. In the case of ZF linear properties with respect to a sparse aggregated channel matrix, some of the inactive links may be mapped to active BF elements and that give rise to unnecessary load, since those links are already indicated as inactive. So far, equivalent backhaul reduction can not be done by using linear beamforming techniques on the basis of limited CSI feedback, unless special scheduling constraints are applied. Therefore, a stochastic Multi-Start Particle Swarm Optimization Algorithm is proposed in this thesis to achieve equivalent backhaul reduction based on the physical layer approach and without any scheduling constraints.

1.2 Problem Statement

The major drawback of JP approach is that it requires a massive frequency and backhaul resources. Therefore, PJP has been proposed in [13, 16, 17] to reduce the frequency and backhaul overhead. However, the main weakness of the PJP is the failure of the linear BF techniques, such as ZF BF and partial ZF BF, to achieve an equivalent backhaul reduction unless a special scheduling constraints are applied [18, 20]. Moreover, linear approaches can only invert well-conditioned matrices, such as diagonal or block-diagonal matrices.

Based on physical layer approach, the issues of backhaul equivalence, failure of inversion and lack of maintaining the scalability are still existed in [13, 16, 17] with the deployment of linear ZF BF. Therefore, a stochastic Basic Particle Swarm Optimization Algorithm (BPSOA) BF was presented in [14, 19] to address those issues. However, the main drawback of BPSOA is its lack-of-diversity, which means it does not guarantee global optimization [21, pp. 171–172]. Specifically, it is stuck to local optimization and shrinks searching space. Thus, a Multi-Start Particle Swarm Optimization Algorithm (MSPSOA) is proposed in this study to achieve equivalent backhaul reduction, maintaining the scalability and to overcome the lack-of-diversity in BPSOA by replacing the inactive particles adaptively based on the difference between local best and global best optimization criterion. Chapter 2 and 3 present an overview on swarm optimization to justify the proposed MSPSOA.

1.3 Aims and Objectives

The aim of this work is to design a stochastic MSPSOA BF that achieves equivalent backhaul reduction and high spectral efficiency by addressing the lack-of-diversity of BPSOA BF in a Joint Transmission (JT) system, as a main subcategory of JP. Maintaining the scalability compared to linear BF mechanisms is a primary concern of this study, where the main focus is on cell-edge users in a cooperative system. To achieve those aims, fulfillment of the following objectives are the crucial part of this thesis:

- To attain an equivalent backhaul reduction with a limited channel feedback in a Partial Joint Transmission (PJT) system.
- To propose a MSPSOA BF that achieves high spectral efficiency by addressing the lack-of-diversity in BPSOA BF along with maintaining the scalability of the system compared to linear ZF BF technique.
- To evaluate the performance of PJT and FJT schemes based on different metrics such as level of actual interference, transmitting power and total utility of three different internet applications such as hard real-time, adaptive real-time and elastic applications.

1.4 Scope of the Thesis

In this thesis, JT has been considered as a significant subcategory of JP. JT has been evaluated with respect to the level of cooperation, full cooperation with an intensive focus on partial cooperation. The system was implemented in a centralized architecture with a frequency selective channel utilizing WINNER II channel model. OFDM has been performed to exploit the frequency selectivity of the channel. In this model the users are scheduled in every Resource Block (RB), in order to represent the worst case scenario. The system model is implemented in a Frequency Division Duplex (FDD) manner for each RB.

The main focus of this thesis is on developing a diverse beamforming algorithm that can achieve equivalent backhaul reduction with respect to sparse aggregated channel matrix and can obtain the BF matrix even when the CSI matrix is not well-conditioned (not diagonal or block-diagonal). Moreover, the key aspect of the proposed MSPSOA BF is to ensure global optimization and maximize the spectral efficiency of the cell-edge users in LTE-A cellular network. In this context, two BF techniques, linear ZF and BPSOA have been modeled and compared to the proposed MSPSOA BF. The performance evaluation has been done on the basis of backhaul requirements, spectral efficiency and level of interference along with transmitting power and utility of three traffic type such as hard real-time, adaptive real-time and elastic applications.

1.5 Study Module

The summary of chosen approach in this thesis is presented in Figure 1.2, where the shaded boxes with solid lines denote the followed direction to attain determined goals and the white boxes with dashed lines show the other research areas within the interference mitigation domain which have not been investigated in this research.

1.6 Thesis Organization

The overall structure of the study takes the form of five chapters as follows:

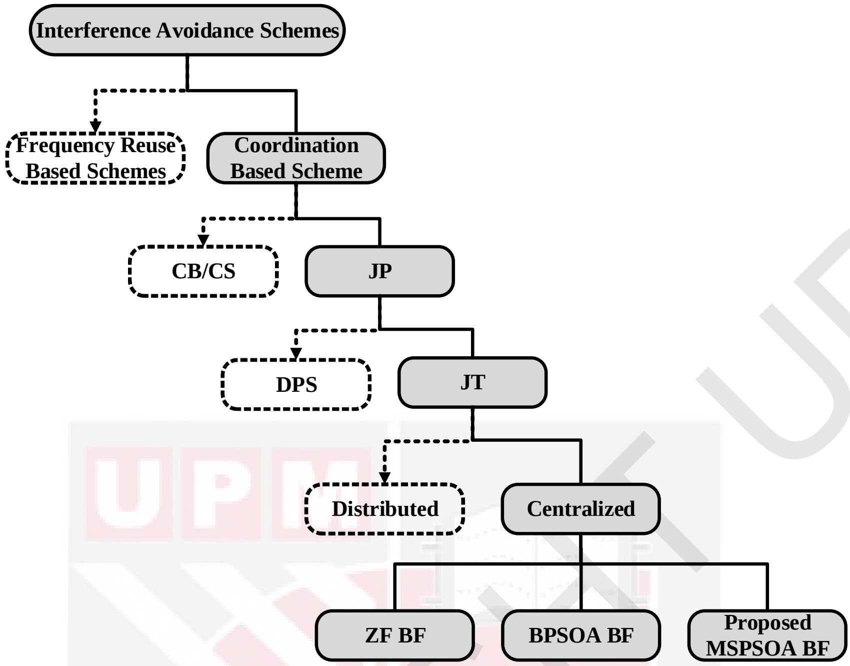

Figure 1.2: Study module.

In Chapter 1, the road-map of the research conducted is delineated in details. It consists of problem statement, research objectives, scope of research and study module.

Chapter 2 establishes the necessity of this research through its background and previous works.

In Chapter 3, the system model is defined in details. This chapter gives a description of different schemes under study, which primarily consist of the PJT and FJT algorithms being applied to the WINNER II channel model. The proposed stochastic beamforming algorithm is also defined. The layout of the assumed scenario, including the cluster area together with the generation of the channel matrix, antennas for both of eNBs and UEs are discussed under the section named WINNER II channel model.

Chapter 4 includes a brief explanation of simulation setup and presentation of results through comparison of different scenarios.

Finally, the conclusions, thesis contributions and recommended future research works are discussed in Chapter 5.

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