

FRACTIONAL FREQUENCY REUSE BASED INTERFERENCE MITIGATION IN IRREGULAR GEOMETRY MULTICELLULAR NETWORKS

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FRACTIONAL FREQUENCY REUSE BASED INTERFERENCE MITIGATION
IN IRREGULAR GEOMETRY MULTICELLULAR NETWORKS

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To My Beloved Parents

(Abai & Baba)

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ABSTRACT

Recent drastic growth in the mobile broadband services specifically with the proliferation of smart phones demands for higher spectrum capacity of wireless cellular systems. Due to the scarcity of the frequency spectrum, cellular systems are seeking aggressive frequency reuse, which improve the network capacity, however, at the expense of increased Inter Cell Interference (ICI). Fractional Frequency Reuse (FFR) scheme has been acknowledged as an effective ICI mitigation scheme, however, in literature FFR has been used mostly in perfect geometry network. In realistic deployment, the cellular geometry is irregular and each cell experiences varying ICI. The main objective of this thesis is to develop ICI mitigation scheme that improves spectrum efficiency and throughput for irregular geometry multicellular network. Irregular Geometry Sectored-Fractional Frequency Reuse (IGS-FFR) scheme is developed that comprises of cell partitioning and sectoring, and dynamic spectrum partitioning. The cell-partitioning and sectoring allows full frequency reuse within an irregular geometry cell. Nevertheless, the sub-regions in an irregular cell have varying coverage areas and thus demands diverse spectrum requirements. The IGS-FFR scheme is designed to dynamically allocate the spectrum resources according to the traffic demands of each sub-region. An enhanced IGS-FFR has been developed to optimally allocate the spectrum resources to individual users of each sub-region. Enhanced IGS-FFR has been realized using two different approaches, Auction based Optimized IGS-FFR (AO-IGS-FFR) and Hungarian based Optimized IGS-FFR (HO-IGS-FFR). The results show that IGS-FFR has significantly improved the cell throughput by 89%, 45% and 18% and users' satisfaction by 112%, 65.8% and 38% compared to Reuse-1, Strict-FFR and FFR-3 schemes, respectively. The findings show that the ICI mitigation in IGS-FFR is reinforced by users' satisfaction. As the number of sectors in IGS-FFR increases from 3 to 4 and 6, the cell throughput increase by 21% and 33% because of spatial diversity exploitation along with orthogonal sub-band allocation. AO-IGS-FFR and HO-IGS-FFR have further improved the cell throughput of the basic FFR-3 by 65% and 72.2%, respectively. HO-IGS-FFR performs 7% better than the AO-IGS-FFR at the expense of 26.7% decrease in the users' satisfaction and excessive complexity. Although, AO-IGS-FFR compromises sub-optimal bandwidth allocation, it is a low complexity scheme and can mitigate ICI with high users' satisfaction. The enhanced IGS-FFR can be deployed in future heterogeneous irregular geometry multicellular OFDMA networks.

ABSTRAK

Pertumbuhan drastik dalam perkhidmatan terkini jalur lebar mudah alih terutamanya dengan percambahan telefon pintar memerlukan kapasiti spektrum sistem selular tanpa wayar yang lebih tinggi. Oleh kerana kekurangan spektrum frekuensi, sistem selular sedang mencari frekuensi guna semula yang agresif, yang mana meningkatkan keupayaan rangkaian, bagaimanapun dengan mengorbankan gangguan antara sel (ICI) yang meningkat. Skim frekuensi guna semula berperingkat (FFR) telah diiktiraf sebagai skim pencegahan ICI yang berkesan, namun begitu, dalam kajian FFR kebanyakan telah digunakan di dalam rangkaian geometri sempurna. Dalam penggunaan sebenar geometri selular adalah tidak teratur dan setiap sel mengalami ICI yang berbeza-beza. Objektif utama tesis ini adalah untuk membangunkan skim pengurangan ICI yang meningkatkan kecekapan spektrum dan daya pemprosesan untuk geometri tidak teratur bagi rangkaian multisel. Skim geometri tidak teratur bersektor-frekuensi guna semula berperingkat (IGS-FFR) dibangunkan yang terdiri daripada pembahagian dan persektoran sel, dan pembahagian spektrum dinamik. Pembahagian dan persektoran sel membolehkan penggunaan semula frekuensi penuh dalam sel geometri tidak teratur. Walau bagaimanapun, sub-kawasan dalam sel yang tidak teratur mempunyai pelbagai kawasan liputan dan dengan itu memerlukan keperluan spektrum yang pelbagai. Skim IGS-FFR direka untuk secara dinamik memperuntukkan sumber spektrum, mengikut permintaan trafik setiap sub-kawasan. IGS-FFR yang dipertingkatkan telah dibangunkan untuk berfungsi secara optimum dalam memperuntukkan sumber spektrum kepada pengguna individu bagi setiap sub-kawasan. IGS-FFR yang dipertingkatkan telah direalisasikan dengan menggunakan dua pendekatan yang berbeza, IGS-FFR yang dioptimum berdasarkan lelong (AO-IGS-FFR) dan IGS-FFR yang dioptimum berdasarkan Hungarian (HO-IGS-FFR). Keputusan menunjukkan bahawa IGS-FFR telah meningkatkan daya pemprosesan sel dengan ketara dengan pada 89%, 45% dan 18% dan kepuasan pengguna masing-masing pada 112%, 65.8% dan 38% berbanding dengan skim-skim Reuse-1, Strict-FFR dan FFR-3. Hasil kajian menunjukkan bahawa pengurangan ICI di IGS-FFR dikuatkan oleh kepuasan pengguna. Dengan kenaikan bilangan sektor di IGS-FFR dari 3 ke 4 dan 6, daya pemprosesan sel juga meningkat masing-masing sebanyak 21% dan 33% kerana eksploitasi kepelbagaian spatial bersama-sama dengan peruntukan sub-band ortogon. AO-IGS-FFR dan HO-IGS-FFR telah dipertingkatkan lagi pemprosesan sel daripada asas FFR-3 sehingga 65% dan 72.2%, masing-masing. HO-IGS-FFR berfungsi 7.1% lebih baik daripada AO-IGS-FFR dengan 26.7% penurunan dalam kepuasan pengguna dan kerumitan yang berlebihan. Walaupun, AO-IGS-FFR kompromi peruntukan jalur lebar sub-optimum, ianya merupakan skim kerumitan yang rendah dan boleh mengurangkan ICI dengan kepuasan pengguna yang tinggi. IGS-FFR teroptimum boleh digunakan dalam rangkaian OFDMA multisel geometri tidak teratur berbagai-bagai di masa depan.

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LIST OF ABBREVIATIONS

EB	-	ExaByte
CAGR	-	Compound Annual Growth Rate
IMT-A	-	International Mobile Telecommunication-Advanced
ITU	-	International Telecommunication Union
3GPP	-	3rd Generation Partnership Project
4G	-	4th Generation
5G	-	5th Generation
LTE	-	Long Term Evolution
LTE-A	-	Long Term Evolution-Advanced
VNI	-	Visual Networking Index
OFDMA	-	Orthogonal Frequency Division Multiple Access
ICI	-	Inter Cell Interference
CCI	-	Co-Channel Interference
ICIC	-	Inter Cell Interference Coordination
FFR	-	Fractional Frequency Reuse
BS	-	Base Station
SINR	-	Signal to Interference plus Noise Ratio
SON	-	Self Organization Network
QoS	-	Quality of Service
HGM	-	Hexagon Geometry Model
IGS-FFR	-	Irregular Geometry Sectored-Fractional Frequency Reuse
AO-IGS-FFR	-	Auction based Optimized IGS-FFR
HO-IGS-FFR	-	Hungarian based Optimized IGS-FFR
FDD	-	Frequency Division Duplexing
HetNet	-	Heterogeneous Network
FBS	-	Femto Base Station
D2D	-	Device 2 Device

M2M	-	Machine 2 Machine
H2H	-	Human 2 Human
IoT	-	Internet of Things
WiMAX	-	Worldwide Interoperability for Microwave Access
ISI	-	Inter Symbol Interference
OFDM	-	Orthogonal Frequency Division Multiplexing
BER	-	Bit Error Rate
OPEX	-	Operational Expenditures
CAPEX	-	Capital Expenditures
PPP	-	Poisson Point Process
PHCP	-	Poisson Hard Core Process
MUD	-	Multi-user Detection
SIC	-	Successive Interference Cancellation
PIC	-	Parallel Interference Cancellation
AWGN	-	Additive White Gaussian Noise
FH	-	Frequency Hoppping
CDMA	-	Code Division Multiple Access
IDMA	-	Interleave Division Multiple Access
MIMO	-	Multiple Input and Multiple Output
FRF	-	Frequency Reuse Factor
FFR	-	Fractional Frequency Reuse
VCG	-	Vickrey-Clarke-Groves
GFFR	-	Generalized Fractional Frequency Reuse
SSI	-	Spectrum Satisfaction Index
US	-	User Satisfaction
SORA	-	Self-Organized Resource Allocation
CDF	-	Commulative Density Function

LIST OF SYMBOLS

T_s	-	SINR threshold
S	-	Number of sectors
P^t	-	Transmit power
Φ	-	PHCP
R^2	-	Euclidean plane
d	-	Distance between BS and user
X	-	set of BSs
x	-	BS
$C(x)$	-	Coverage of the BS x
n	-	user
k	-	sub-carrier
N	-	Total number of users
K	-	Total number of sub-carriers
N^T	-	Total users in cell
B^T	-	Total bandwidth
$R_{n,k}^t$	-	Recieved power on k for n
$G_{n,k}^i$	-	Channel gain of i on k for n
$H_{n,k}^i$	-	Small scale fading gain
$PL(D_n^i)$	-	large scale path loss
D_n^i	-	Distan between BS i and user n
X_σ	-	log-normal shadowing
σ	-	standard deviation
X^i	-	Location of the BS i
X^n	-	Location of the user n
J	-	Set of interfering BS
$I_{n,k}$	-	interference received by a user n on sub-carrier k

$P_{n,k}^j$	-	Transmit power of the BS j for n on sub-carrier k
$G_{n,k}^j$	-	Channel gain of the BS j for n on sub-carrier k
$SINR_{(n,k)}$	-	Received SINR of user n on sub-carrier k
N_o	-	Power spectral density of additive noise
Δf	-	Sub-carrier spacing
US	-	User satisfaction
R_n	-	Throughput of the user n
R_{max}	-	Maximum user throughput
B^T	-	Total system bandwidth
$SE_{(n,k)}$	-	Spectral efficiency of user n on sub-carrier k
B_n^a	-	Bandwidth allocated to user n
R_n	-	Achievable throughput of user n
$x_{(n,k)}$	-	Sub-carrier allocation indicator
R_n^i	-	Throughput of a serving cell i
T_S	-	Threshold SINR
N^C	-	Number of users in cell-center region
N^E	-	Number of users in cell-edge region
N^s	-	Number of users in sector s
B_{req}^n	-	Bandwidth required by user n
K_{req}^n	-	Sub-carriers required by user n
R_d^n	-	Traffic demand of user n
B_{req}^c	-	Bandwidth required by cell-center region
B_{req}^e	-	Bandwidth required by cell-edge region
B_{req}^s	-	Bandwidth required by sector S
Γ^C	-	Cell-center region satisfaction index
Γ^E	-	Cell-edge region satisfaction index
Γ^T	-	Threshold satisfaction index
Γ_s^t	-	Sector satisfaction index
$B^{1,2,3}$	-	Sub-band for sector 1,2,3
B^o	-	Open sub-band
B_s^o	-	Part of open sub-band B^o for sector S

B_a^s	-	bandwidth allocated to sector S
$B_{(s,i)}^o$	-	Portion/part of the B^o initially allocated to setor S
$B_{(s,f)}^o$	-	Final portion of the open sub-band for sector s
$B^{o'}$	-	Remainig part of the open sub-band
B_t^S	-	Tatal bandwidth for sector S
K^S	-	Total number of sub-carriers in the sub-band for sector S
R_{max}^d	-	Maximum throughput demand
R_{max}	-	Maximum throughput
R^{mean}	-	Mean throughput
R_{max}^{mean}	-	Maximum mean throughput
R_{total}^{cell}	-	Cell throughput
K^c	-	Number of sub-carriers in cell-center sub-band
K^1	-	Number of sub-carriers in sector 1 sub-band
K^2	-	Number of sub-carriers in sector 2 sub-band
K^3	-	Number of sub-carriers in sector 3 sub-band
C_n	-	bundle of sub-carriers requested by user n
Γ	-	Game
B_n	-	Bid of user n
U_n	-	Utility function of user n
V_n	-	Valuation of the user n
P_n	-	Payment by user n or price for user n
$R_n^{t,c}$	-	Target date rate of cell-center user n
B_{NC}^C	-	Set of bids for cell center region
$B_{N^1}^1$	-	Set of bids for sector 1
$a(n)$	-	Approximate value of user n
$A(N)$	-	List of approximate values for N users
$u_i(s_i)$	-	Utility of user i for strategi s_i
G_n	-	Bundle of sub-carriers granted to user n
$H_{(N,K)}$	-	Channel matrix for normalized SINR values of N users and K sub-carriers

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CHAPTER 1

INTRODUCTION

1.1 Background

Future cellular systems are changing rapidly because of the proliferation of smart phones, tablets and other media hungry devices. Specifically with the advancement of the smart gadgets, the demand for broadband application services has dramatically increased over the past few years [1]. Recent Ericsson Mobility Report indicates that the exponential growth in the mobile data traffic will reach a nine-fold escalation by the year 2020 [2]. Global mobile data traffic was 1.5 Exabyte's (EB) per month by the end of 2013, raises up to 2.5 EB per month at the end of 2014, which translates to 66.6 percent growth in the global mobile data traffic recorded in the year 2014. Moreover, updated Cisco industry report for this year forecasts that the mobile data traffic is expected to grow up to 24.3 EB per month by 2019 [3]. Statistically, mobile data traffic will grow at a compound annual growth rate (CAGR) of 57 percent between 2014 and 2019, as shown in Figure 1.1.

Next generation wireless communication systems aim to meet the high data rates, increased capacity, extended coverage, low complexity and low latency requirements defined by International Mobile Telecommunications-Advanced (IMT-A) of the International Telecommunication Union (ITU). The formulation of the Long Term Evolution (LTE) into LTE-Advanced (LTE-A), make it possible to meet the IMT-A requirements (peak data rates of 1Gbit/s for the downlink and 500Mbits/s for the uplink, and extended bandwidth support up to 100MHz) for the fourth generation (4G) mobile communication [4]. According to the recent Cisco Visual Networking Index (VNI) report [5], 4G connection has generated 10 times more traffic than a non-4G connection in 2014 and is responsible for 40 percent of the total mobile data traffic. These statistics show that the 4G technology is going to be the most preferable choice for the mobile traffic in the near future.

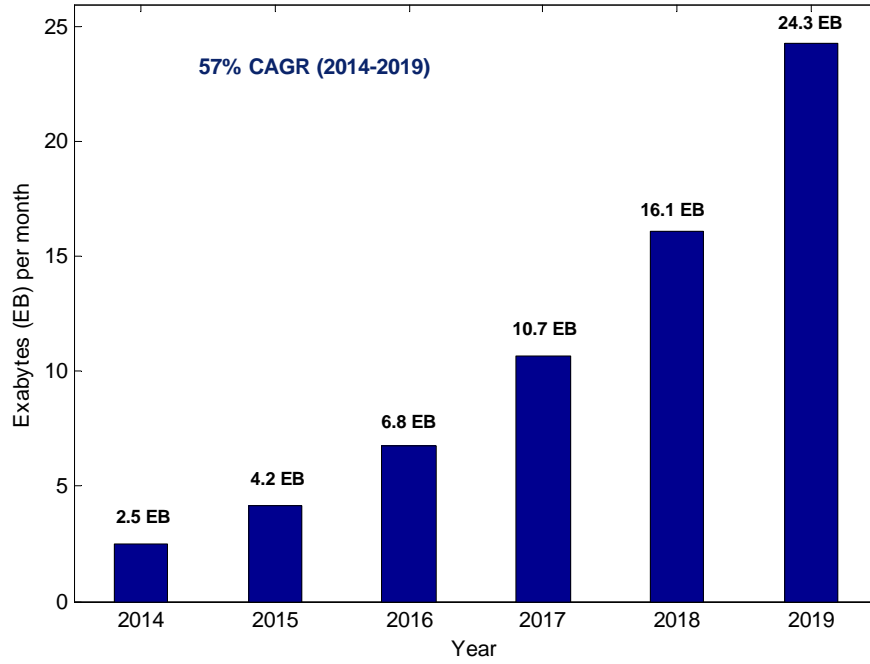


Figure 1.1: CISCO mobile data traffic growth forecast by 2019 [3]

The exponential growth in the mobile data traffic is forcing network operators to significantly enhance their system capacity and coverage. Therefore, efficient radio resource management is gaining more attention in the wireless communication as it could open up new prospects for the capacity and coverage enhancement [6]. These trends have triggered the development of new cellular standards, which incorporates the OFDMA as a radio access technique because of its capacity gain via frequency domain diversity as well as multi-user diversity [7].

Due to the scarcity of the frequency spectrum, spatial reuse is a promising technique to enhance network capacity by allowing spectrum reuse in the OFDMA based cellular network. However, the aggressive frequency reuse results in the inter cell interference (ICI) or co-channel interference (CCI), because of the co-channel deployment in neighboring cells. Therefore, there is always a trade-off between the support for improved network capacity offered by spatial reuse and the interference it introduced. Fractional Frequency Reuse (FFR) has been acknowledged as an effective interference mitigation technique in the OFDMA based cellular systems [8]. The basic mechanism of FFR corresponds to the partitioning of the cell coverage area in spatial sub-regions and the frequency spectrum in sub-bands. In addition, the spectrum sub-bands are then allocated to each sub-region in way that avoids the ICI.

In the wireless networks, signal power and interference received at a typical user depends mainly on the distance between transmitter and receiver [9]. On the other hand, the position of the typical user with respect to other Base Stations (BSs) which are simultaneously using the same channel, highly affects the interference experience by that user. The Signal to Noise plus Interference Ratio (SINR) experienced by each user depends on its location, the positions of the interference sources as well as the instantaneous channel gains. Consequently, the network geometry has a significant impact on the received SINR and hence the performance of wireless cellular system crucially depends on the spatial configuration of BSs and network topology [10]. Therefore, it is important to consider the network topology while designing any interference mitigation scheme.

Finally, to realize the requirement of both cellular operators and users in a cost effective way, recent development has triggered the induction of intelligence and autonomous adaptivity (i.e. called self-organization) into the future cellular networks. Self-organization has been extensively explored and applied in wireless ad-hoc networks, wireless sensor networks and autonomic computer networks. However, from the perspective of wireless cellular networks, this concept has gained significant interest in the recent past [11]. Self-Organizing Networks (SON) concept appears as an efficient solution, where in the network is capable to autonomously observe and adjust to different conditions with minimal human intervention [12] and therefore, results in reduce operational cost [13].

1.2 Problem Statement

In order to meet the ever increasing capacity demand for the mobile broadband applications and services, next generation cellular systems are targeting aggressive frequency reuse due to the scarcity of frequency spectrum, [14]. The frequency reuse of one (Reuse-1) is the example of such aggressive frequency reuse, where in, all the available radio resources are allocated at every cell of the network. Such frequent frequency reuse increase the spatial spectrum efficiency and the network capacity, at the expense of increased ICI [8]. Therefore, ICI is the prominent limiting factors which affect the users' ability to achieve the desired quality-of-service (QoS) [13]. Furthermore, the ICI problem is more severe at the cell edges [15].

Due to the above mentioned challenge, interference mitigation is the primary

interest of both the academic and industry communities [16]. Review on the present interference management approaches for OFDMA based cellular networks are presented in Chapter 2, section 2.5. It is found that, to enhance the performance of the cellular network, FFR is an effective ICI mitigation approach [8, 17]. FFR is attractive due to its low complexity and significant coverage improvement for cell edge users [18]. The main objective of FFR is to improve the SINR and system throughput by avoiding the ICI through orthogonal sub-band allocation specifically at the cell edge region. In FFR, each cell is allocating its resources in a way such that to minimize the overall interference experienced in the network and to maximize the spatial reuse [19].

In literature FFR has been used mostly with perfect cellular geometry models such as a hexagonal grid model (HGM), where each cell has a symmetrical coverage region [20]. However, in the realistic deployment of the cellular systems it is impractical to achieve an exact degree of symmetry [21]. In realistic deployment, where the cellular layout is irregular, not only propagation conditions vary significantly from cell to cell, but also, azimuths are not aligned and hence, cells experience vast difference of ICI [22]. As a consequence, the cell edge region may differ in terms of size and interference levels. Therefore, the performance of basic FFR techniques is poor in the irregular geometry cellular deployment [23].

Thus, network topology considered for any interference mitigation scheme plays an important role in the performance. The network topology consideration has triggered recent research on FFR with irregular geometry cellular networks [19, 24, 25]. However, almost all of the previous work on FFR on irregular geometry model only accounts for simplistic FFR with only two regions (cell-center and cell-edge) and the cell sectoring has not been taken into account [26]. Moreover, dynamic spectrum partitioning has not been adopted in the FFR configuration for irregular geometry multicellular networks in order to support the diverse users' traffic demands. Thus, there is a need to develop an ICI mitigation using FFR, which considers sectoring and dynamic spectrum partitioning for irregular cellular geometry based OFDMA multicellular networks while realizing full frequency reuse.

1.3 Research Objectives

The main goal of this research is to mitigate ICI in the irregular geometry OFDMA multicellular system through improving the system spectrum efficiency and

enhancing the system throughput. The specific objectives of the research are;

- To develop FFR scheme which considers sectoring and dynamic spectrum partitioning for irregular geometry OFDMA multicellular network.
- To develop an enhanced FFR scheme for the irregular geometry multicellular network to optimize the system performance in terms of achievable throughput.

The proposed FFR scheme is defined as Irregular Geometry based Sectored- Fractional Frequency Reuse (IGS-FFR). The IGS-FFR scheme has been optimized by adopting two different techniques and defined as Enhanced-IGS-FFR (eIGS-FFR). In the first optimization approach auction mechanism is adopted to optimize IGS-FFR and is named as AO-IGS-FFR. Then in the second optimization approach, Hungarian method is adopted to optimize IGS-FFR and is named as HO-IGS-FFR scheme. The performance of the proposed FFR schemes is evaluated in terms of cell achievable throughput, user satisfaction, and throughput with respect to different load conditions.

1.4 Scope of the Research

In the multicellular OFDMA network, the ICI occurs when the overlapping cells are utilizing the same frequency spectrum. This research mainly focuses on the ICI issue in the OFDMA based multicellular network operating in the downlink. The OFDMA is selected as a multiple access technique in the downlink as it offers the flexibility while allocating the frequency spectrum resources based on the channel quality, through its inherent feature of multi-user diversity. Specifically, the Frequency Division Duplexing (FDD) [27] access mode of the OFDMA downlink transmission is assumed in this thesis.

This research focuses on mitigating ICI in the irregular geometry based OFDMA multicellular network. Stochastic geometry based model is used to abstract the position of the BSs, which enables the realistic interference computation by considering the random distances between the neighboring cells. The users are assumed to be connected to the nearest BSs. Consequently, the coverage region of each cell is irregular or Voronoi tessellation. Self-organized ICI mitigation schemes are developed for the irregular geometry based OFDMA multicellular network. The proposed schemes are self-organized in the scope that each cell of the network autonomously decides its spectrum partition based on the load condition, spectrum

requirement and channel conditions. Therefore, the proposed interference mitigation schemes are aware of the diverse user traffic demands and the channel quality.

First, the IGS-FFR scheme is developed to mitigate the ICI in the irregular geometry based OFDMA multicellular network. The objective of this scheme is to achieve the full frequency reuse (Reuse-1) to meet the capacity demand. To achieve the full frequency reuse, the proposed scheme divides the cell into cell-center and cell-edge region, where the cell-edge region is further divided into a number of sectors. The resultant cell-center and sectors are defined as sub-region of the cell, and will be used throughout this thesis. Due to the irregular geometry, the resultant sub-regions are different in terms of coverage area and hence, in load distribution. The IGS-FFR scheme dynamically allocates the frequency spectrum (sub-band) to each sub-region of the cell, according to the traffic demand of each sub-region. Moreover, to mitigate the ICI, the proposed scheme maintains the orthogonality in the spectrum sub-band allocation.

The eIGS-FFR schemes is the enhancement of the IGS-FFR scheme in terms of optimal bandwidth allocation to the individual users of each sub-region of the cell. First, AO-IGS-FFR scheme is developed based on the game theoretic auction mechanism for optimal sub-carrier allocation in the irregular geometry OFDMA multicellular network. The AO-GOS-FFR is distributive in nature, where users are allowed to request for multiple sub-carriers, according to their traffic demand and channel condition. However, in order to avoid the complexity issue, the users are restricted to request for only one combination of the sub-carriers of their choice in one allocation time. On the other hand in the second approach, HO-IGS-FFR is developed based on Hungarian method to optimally allocate the sub-carriers to users in each sub-region based Channel Quality Information (CQI).

In this research, the BSs are considered to be equipped with an omni-directional transmission antenna configuration for the cell-center region, and a directional antenna transmission configuration for the cell-edge region. The directional antenna pattern depends on the number of sectors in the cell-edge region, for example, for the a three sectors cell, the BS is equipped with 120° directional antenna. Moreover, the antenna configurations are considered without any power control ability. This is due to the fact that the total transmission power of the BS is considered to be uniformly distributed across the amount of spectrum. Furthermore, this research considered the network users with heterogeneous traffic demand. The proposed schemes are evaluated by MATLAB simulation, considering the 3GPP model for the parameter settings.

1.5 Research Contribution

The major contributions of the thesis are listed as follows;

- **Development of Sectored-FFR for the Irregular Geometry Multicellular Network**

FFR has been acknowledged as an efficient scheme to avoid the ICI in OFDMA multicellular systems. The basic mechanism of FFR corresponds to the partitioning of the cell coverage area in spatial regions, where each sub-region is assigned with different frequency sub-bands in order to avoid the interference. However, in case of irregular geometry cellular network, partitioning of the cell resultants in sub-regions of varying coverage, number of users and load conditions. Therefore, each sub-region has a different spectrum requirement. In literature, almost all of the previous works on FFR with irregular geometry network models account for two sub-regions, cell-center and cell-edge. Cell sectoring has not been included in the FFR for irregular geometry networks. In this thesis, the sectored FFR scheme is developed for irregular geometry network, where the cell coverage area is partitioned into cell-center and cell-edge region, the cell edge is further divided into a number of sectors. The frequency spectrum is accordingly partitioned into a number of sub-bands, for each sub-region of the cell. The sectoring of the cell-edge region makes it possible to fully utilize the frequency spectrum, by orthogonally allocating the spectrum sub-band to each cell-edge region sector in the neighboring cells, in order to mitigate ICI in multicellular network.

- **Dynamic Spectrum Allocation**

The developed IGS-FFR and eIGS-FFR scheme are designed to dynamically allocate the spectrum resource to each sub-region, according to the spectrum requirement and traffic demand.

- **Optimized bandwidth allocation**

The IGS-FFR is optimized in terms of optimal bandwidth allocation to the individual users of each sub-region of the cell. In the IGS-FFR scheme the sub-bands are specified for each sub-region of the cell. However, the optimized bandwidth resources for the individual users are not specified. The eIGS-FFR is developed to optimally allocate the bandwidth resources to the users using two different approaches. AO-IGS-FFR is developed based on game theoretic auction mechanism whereas, HO-IGS-FFR is developed based on Hungarian method. In both, AO-IGS-FFR and HO-IGS-FFR, the sub-carriers are optimally

allocated to maximize the throughput of every users in the cell, and hence the overall throughput is maximized.

1.6 Significance of the Research

The proposed FFR schemes for the irregular geometry based OFDMA cellular system can contribute towards realizing self-organizing networks (SON). This is because the proposed IGS-FFR scheme is able to adapt to the network variations and automatically implement the proposed spectrum allocation according to the requirement when the current spectrum partition is no longer valid. Note that the deployment of the proposed self-organized spectrum assignment schemes are not limited for single tier macro-cell network. The proposed scheme can be an excellent fit to the successful deployment of the Heterogeneous Network (HetNet).

In the femtocell network, Femto Base Stations (FBSs) are randomly deployed by end users within the macrocell coverage area. The number and locations of FBSs can continuously vary. Classical network planning tools would not be able to configure and optimize a femtocell network. Therefore, the FBSs need to be self-organized in order to autonomously integrate into the radio access network [28]. Moreover, to efficiently utilize the available resources in the femtocell network, frequency spectrum is shared by macrocell and femtocell. However, this type of deployment results in cross-tier interference because of the co-channel deployment. The proposed interference mitigation scheme can be applied to avoid the interference by allocating orthogonal spectrum band to macro and femto users. Therefore, the proposed scheme is feasible in the successful deployment of the HetNets.

The proposed interference mitigation scheme can also be applied to Device-to-Device (D2D) communications [29], where the co-channel deployment will cause interference that would limit the performance gain of this technology. In D2D communication, the implementation of the proposed self-organized spectrum allocation schemes is feasible by ensuring the orthogonal sub-band allocation in the multi-tier devices. Similarly, in the Machine-to-machine (M2M) communication [30], which has been acknowledged to provide ubiquitous connectivity among communication-enabled devices in an unprecedented way, thus enabling in parts the Internet of Things (IoT) [31]. To improve the spectral efficiency, the same spectrum utilized for H2H (Human-to-human) communications can be reused for

M2M communications. This will increase the spatial spectrum efficiency and network capacity at the expense of increased interference. The proposed IGS-FFR scheme can be utilized to mitigate the interference in the M2M communication and 5G technology [32], by dynamically allocate the spectrum resources in the self-organized fashion.

1.7 Thesis Outlines

This thesis is organized as follows. Chapter 2 can be mainly composed of two main discussions, the theoretical background and the literature review. The theoretical background elaborates the technical aspects and fundamental features of OFDMA based systems, cellular network modeling, auction theory and Hungarian method. The literature review part of the chapter 2 covers the discussions on the existing interference mitigation approaches available in the literature, both for regular and irregular cell geometry OFDMA networks. The prior ICI approaches are analyzed based on their potentials and shortcomings which eventually leads towards the research motivations of this thesis.

Chapter 3 presents the design approach of the proposed ICI mitigation scheme for irregular geometry based OFDMA multicellular network. The basic design concept of IGS-FFR and eIGS-FFR schemes are presented in detail. The algorithmic flow charts for the proposed schemes are provided and discuss in detail. Moreover, chapter 3 also provides the specific detail of the system model, network topology and channel model. System performance metrics used to evaluate the network performance of the proposed schemes are provided and described. Furthermore, the chapter includes the description of the numerical and simulation tool using MATLAB, whereas its implementation concept is elaborated using functional blocks.

The formulation of the IGS-FFR for the ICI mitigation in the irregular geometry multicellular network is presented in the Chapter 4. The formulation is followed by the detail description of the IGS-FFR scheme. Then, the performance analysis of IGS-FFR scheme in comparison to the basic FFR schemes, when applied to irregular geometry networks, is presented.

Chapter 5 presents the formulation of the eIGS-FFR scheme. The formulation is followed by the detail description of AO-IGS-FFR and HO-IGS-FFR. Then, the

performance analysis of the AO-IGS-FFR and HO-IGS-FFR schemes in comparison to the basic FFR-3 scheme is provided.

Finally, Chapter 6 summarizes the significant achievements of IGS-FFR and eIGS-FFR schemes along with the recommendations for the future works.

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