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EFFICIENT RESOURCE ALLOCATION ALGORITHM FOR DENSE FEMTOCELL NETWORKS

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ALGORITHME EFFICACE D'ALLOCATION DE RESSOURCES POUR LES RÉSEAUX FEMTO-CELLULE DENSES

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I dedicate my thesis work to the four pillars of my life, my loving parents and my dear brother and sister. Without you, my life would fall apart. Mom, you have given me so much, thanks for your faith in me, and for teaching me that I should never surrender. Daddy, you always told me to "reach for the stars." I think I got my first one, thanks for inspiring my love for transportation. My Brother and sister, I might not know where the life's road will take me, but walking with you, through this journey has given me strength. A special feeling of gratitude to all of you, whose words of encouragement and push for tenacity ring in my ears.

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ABBREVIATIONS AND ACRONYMS

ADSL	Asymmetric digital subscriber line
BS	Base station
BW	Bandwidth
CR	Cognitive Radio
CSG	Closed Subscriber Group
EDGE	Enhanced Data Rates for GSM Evolution
EV-DO	Evolution-Data Optimized
FBS	Femtocell Base Station
FR	Frequency Reuse
FFR	Fractional Frequency Reuse
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HSDPA	High Speed Downlink Packet Access.
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access.
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced

MBS	Macrocell Base Station
M-LWDF	Maximum Largest Weighted Delay First
OFDMA	Orthogonal Frequency Division Multiple Access
OSG	Open Subscriber Group
PC	Power Control
PF	Proportional Fair
QoS	Quality of Service
RA	Resource Allocation
RB / PRB	Resource Block / Physical Resource Block
RNC	Radio Network Controller
RRM	Radio Resource Management
SFR	Soft Frequency Reuse
SINR	Signal to Interference and Noise Ratio
TTI	Transmission Time Interval
UE	User Equipment / Mobile Station
UMB	Ultra Mobile Broadband
UMTS	Universal Mobile Telecommunications System
WAP	Wi-Fi Access Point
WiMAX	Worldwide Interoperability for Microwave Access or 802.16e
WLAN	Wireless Local Area Network

RÉSUMÉ

La couverture d'intérieur pauvre et la basse capacité d'utilisateur représentent deux défis importants pour les opérateurs cellulaires. Plusieurs solutions (telles que les antennes distribuées) ont été proposées pour résoudre ces problèmes. Cependant, aucune de ces solutions ne fournit le niveau désiré de l'évolutivité et elles manquent l'aspect pratique. Pour ces raisons, une solution attrayante caractérisée par sa faible puissance et son prix faible connue sous le nom de femto-cellule a été introduite pour offrir une meilleure capacité et couverture d'utilisateur. Malgré tous les avantages provoqués par l'intégration de cette nouvelle technologie femto-cellule, plusieurs nouveaux défis ont émergé. Ces défis sont principalement présentés dans deux genres d'interférences ; connu comme interférence cross-tier et interférence co-tier. Tandis que l'impact d'interférence cross-tier (provoqué en partageant le spectre de fréquence) peut être réduit en mettant en application des algorithmes efficaces de réutilisation de fréquence, l'interférence co-tier continue à présenter un défi difficile pour les opérateurs et les chercheurs dans le domaine de réseaux cellulaires. Le déploiement non planifié et mal organisé des stations de base femto-cellule a comme conséquence une réduction radicale de la capacité d'utilisateur qui peut mener à une déconnexion des utilisateurs. L'impact de l'interférence co-tier devient plus provocant dans un déploiement dense des femto-cellule où les utilisateurs demandent des services en temps réel (par exemple, taux de données constant). Afin de réduire l'interférence co-tier, plusieurs solutions ont été proposées dans la littérature comprenant des algorithmes de contrôle de puissance, des techniques de détection avancées et des schémas d'allocation de ressources intelligentes. Dans ce projet, nous proposons une stratégie intelligente d'attribution des fréquences avec une stratégie avancée d'association de station de base femto-cellule pour les réseaux femto-cellule basés sur LTE. L'objectif des deux stratégies proposées est d'atténuer l'interférence co-tier et de réduire la probabilité de panne des utilisateurs en augmentant le nombre d'utilisateurs actifs par station de base femto-cellule. Nous montrons par simulations l'efficacité de notre solution proposée.

ABSTRACT

Poor indoor coverage and low end-user capacity represent two major challenges for cellular operators. Several solutions (such as Distributed Antennas) are proposed to alleviate these burdens. Yet, neither of them delivers the desired level of practicality and scalability. For these reasons, a low-cost low-power attractive solution known as femtocell is introduced to offer better end-user capacity and coverage. Despite all the benefits caused by the integration of femtocell technology, several new challenges come to light. These challenges are mainly presented in two kinds of interferences; known as cross-layer interference and co-layer interference. While cross-layer interference impact (caused by sharing the frequency spectrum) can be reduced through implementing effective frequency reuse algorithms, co-layer interference continues to present a difficult challenge for cellular operators and researchers. The unplanned and unorganized deployment of femtocell base stations results in a drastic reduction of the end-user capacity that may leads to an end-user disconnection. The impact of co-layer interference becomes more challenging in dense femtocell deployment scenario with users requesting real time services (e.g., constant data rate). In order to mitigate the co-layer interference, several solutions are proposed in the literature including power control algorithms, advanced sensing and reporting strategies and intelligent resource allocation schemes. In this project, we propose an intelligent frequency assignment strategy coupled with advanced femtocell base station assignment strategy for LTE based femtocell networks. The combined effort of the two strategies aims to mitigate the co-layer interference and to reduce the outage probability of end-users by increasing the number of active users per femtocell base station. Finally, we show through simulations the effectiveness of our proposed solution.

Key words: femtocell base station, interference management, resource block assignment, base station assignment, outage probability.

INTRODUCTION

In cellular networks, it is estimated that around 2/3 of calls and over 90% of data services occur indoors (Zhang and de la Roche, 2010). Other surveys reveal that 45% of households and 30% of businesses offices experience poor indoor coverage issues (Chambers, 2007). Therefore, cellular operators aim to provide decent indoor coverage for voice, video and high speed data services, which are becoming increasingly important.

Additionally, decent indoor coverage and good service quality help operators to generate additional revenues and to improve the subscriber loyalty. Therefore, providing good indoor coverage, especially, for high speed data services become a serious challenge for operators (Zhang and de la Roche, 2010). In order to efficiently deliver high-speed data services to an indoor mobile user, using base stations (BSs) located far away (a few kilometers) from the user is not the best method to follow (Boccuzzi and Ruggiero, 2011). This is inefficient because of the propagation path loss of the outer walls of the premises as well as the inter-floor loss (Boccuzzi and Ruggiero, 2011).

Furthermore, this increasing demand for higher data rates, higher speed, and higher accuracy in wireless communication systems lead the researchers and the industrials to develop and deploy new mobile communication standards such as WiMAX (Worldwide Interoperability for Microwave Access), HSDPA (High Speed Downlink Packet Access) / HSUPA (High Speed Uplink Packet Access), LTE (long term evolution), EV-DO (Evolution-Data Optimized) and UMB (Ultra Mobile Broadband). Another competitor, known as the Wi-Fi mesh networks, is designed to ensure high data rate services in a more distributed fashion (Claussen, 2007). Despite the fact that Wi-Fi networks are not able to offer high mobility and coverage similar to that supported by cellular systems, cellular systems need to offer services roughly comparable to those provided by Wi-Fi networks inside home and office environments in order to present a real competition (Ahson and Ilyas, 2011).

In order to enhance the capacity of mobile cellular networks, numerous attempts try to reduce cell sizes and transmit distances, reusing spectrum, and enhancing spectral efficiency (Alouini and Goldsmith, 1999). However, achieving these goals in micro networks necessitates installing added network infrastructure which requires more expenses (Ahson and Ilyas, 2011). The wireless capacity of cellular networks have been growing about one million times over the last 50 years, thanks to three different factors: better transmitter/receiver efficiency, larger spectrum, and larger number of cells (Moray, 2008). Besides, according to the same reference, the growth in term of capacity caused by transmitter/receiver efficiency and larger spectrum corresponds to 20 times and 25 times, respectively, comparing to the original state; whereas, the capacity growth resulted from using a larger number of cells corresponds to 2000 times. Furthermore, predictions for the year 2015 demonstrate that the growth in capacity will continue to be, mostly, the result of adopting small cell deployments strategy (Moray, 2008), where femtocell technology is expected to play an important role.

A femtocell unit represents a low-power base station communicating in a licensed spectrum and functioning with the operators' approval. It offers both improved indoor coverage and increased end-user capacity to mobile users within the home or office environment. Besides, it helps achieving improved voice and broadband services in a low-cost form factor (Boccuzzi and Ruggiero, 2011). Figure A shows an example of femtocell base station (FBS).

Figure A Femtocell base station device (Samsung, 2009)

The FBS is connected to the mobile operator's network through a standard consumer broadband connection, such as ADSL (asymmetric digital subscriber line), cable or optical fiber, as shown in Figure B. Data to and from the FBS is transmitted over the IP network (Saunders et al. 2009). By operating in an authorized frequency band, the operator can control the communications made within the licensed band. In addition, the operators can ensure a certain level of Quality of Service (QoS) to mobile users occupying the licensed band (Boccuzzi and Ruggiero, 2011). For scalability and security problems, numerous researches, such as (Lan Wang et al., 2009), suggest adding a new device known as femtocell Gateway (see Figure B) to improve the mobility management in dense femtocell deployment scenario.

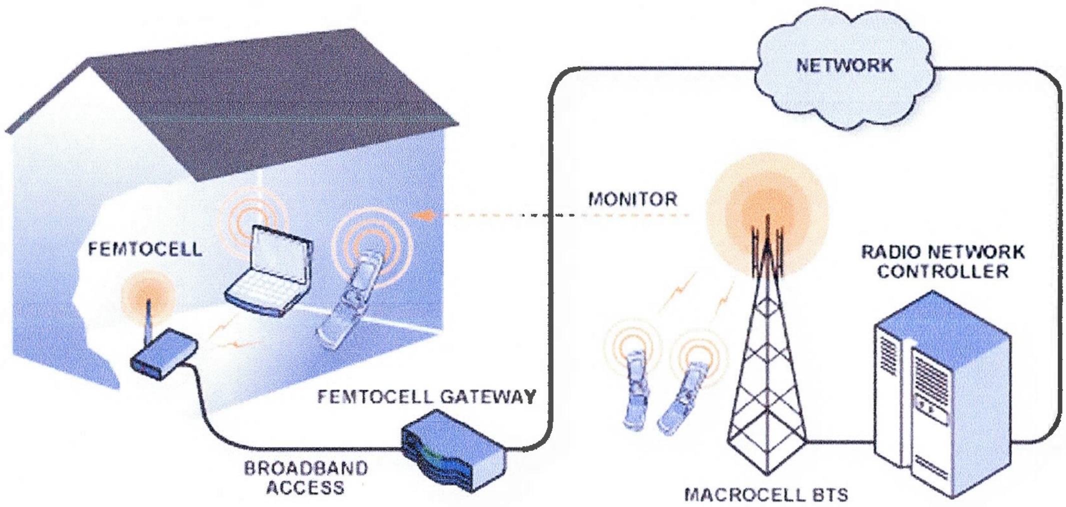


Figure B Comparison between FBS and M-BS (Forbes et al, 2008)

The FBS unit looks very similar to an ordinary Wi-Fi access point in terms of shape and size (as shown in Figure A). Yet, the FBS unit incorporates the functionality of the usual Macrocell Base Station (MBS). In other words, it integrates the Radio Network Controller (RNC) and all the core network elements (Zhang and de la Roche, 2010). As a result, the FBS does not need a cellular core network. It only needs to be connected to the mobile operator's core network via a data connection or a cable to the Internet network (Zhang and de la Roche, 2010).

The FBS implements cellular technologies such as GSM (Global System for Mobile Communications) / GPRS (General Packet Radio Service) / EDGE (Enhanced Data Rates for GSM Evolution), UMTS (Universal Mobile Telecommunications System) / HSPA (High Speed Packet Access) / LTE (Zhang and de la Roche, 2010).

Femtocell units can be classified into different categories (home FBS, operator FBS and enterprise FBS). Each category supports a maximum number of active User

Equipments (UE) connected at the same time (four active mobile users in a residential setting, and eight to 16 active users in enterprise settings). The FBS allocates the different sections of the bandwidth between active UEs. For instance, home mobile users need a high data rate services with short coverage while enterprises requires that FBSs support more simultaneous active users with larger coverage area and acceptable data rate services.

Since both FBS and MBS use the same spectrum to assign frequency resources to their users, UEs from both sides are going to experience severe mutual interference when they are located in an overlapping coverage area. The deployment configuration and parameters of FBSs are directly related to the severity of interferences that affect the system performance (outage ratio of UEs, system capacity, end-user capacity, etc.).

In (3GPP, 2008), three major FBS deployment's parameters are identified: channel allocation strategy (dedicated versus co-channel), femtocell access control (open access versus closed access) and transmit power adjustment (fixed power allocation versus adaptive power allocation).

Two different strategies can be followed by operators to assign the licensed spectrum between MBSs and FBSs. Each one has its benefits and drawbacks: A) First, in an orthogonal deployment (known also as dedicated channel deployment), a fraction of the spectrum is occupied by the macrocell mobile users and the other fraction is occupied by the femtocell mobile users. In an orthogonal deployment, cross-layer interferences (interferences between the two-tier macrocell and femtocell) are neglected, and FBSs only need to avoid interference from other FBSs. However, orthogonal deployment results in an inefficient usage of the radio spectrum. Hence, applying such strategy is expensive and undesirable for cellular network operators (Zhang and de la Roche, 2010). B) Secondly, in a co-channel deployment, both macrocell mobile users and femtocell mobile users reuse the same radio spectrum. Despite the increase of interferences among femtocell mobile users and macrocell mobile users, adopting this strategy can seriously improve the spectral efficiency (bit/s/Hz). Yet, it consequently necessitates the integration of more complex interference mitigation techniques. After all, thanks to the higher frequency reuse, co-channel deployment appears to be the favorite approach for the majority of operators (Zhang and de la Roche, 2010).

Furthermore, operators can choose between adopting CSG (closed subscriber group) or OSG (open subscriber group) access strategy. Likewise, each strategy has its own benefits and drawbacks: A) First, OSG represents the usual manner in which MBSs operate. In this strategy, all deployed FBSs are accessible to every neighboring subscriber registered with the cellular network operator (that offers the FBSs units). OSG allows any macrocell UE located in overlapping coverage area to perform a soft handover (access to the neighboring FBS), in order to avoid being affected by severe interferences, and to be served by the FBS instead of MBS. In other words, The FBS is offering services to any mobile user within its coverage area, such as nearby pedestrians. By having access to the FBS, visitors are allowed to access all the cellular services. However, the number of simultaneous UEs that can be serviced is limited by the broadband connection bandwidth, amount of interferences and the FBS unit configuration (Boccuzzi and Ruggiero, 2011). Therefore, the adoption of the open access method will decrease the existing interferences in overlapping coverage area as well as the outage probability of macrocell visitors. It will also increase the available bandwidth per macrocell user (visitor), achieves a better overall system throughput and coverage. Yet, OSG can decrease the available bandwidth per femtocell subscriber, increase the number of handoffs and increment signaling (Ang-Hsun et al., 2010).

The CSG strategy, can be considered as the most favorable solution to femtocell subscribers (owners of the FBS unit), in which a limited number of mobile users has access to the FBS. The remaining un-serviced mobile users are going to experience potential interferences once they combine two conditions: be close to femtocell and be positioned in poor macrocell's coverage areas. Besides, when an un-serviced UE is located near a FBS and transmits at high power to reach a far MBS, femtocell subscriber with weak signals may experience sever interferences (Saunders et al. 2009). That kind of interference is greater in CSG mode than in OSG mode (Ang-Hsun et al., 2010). In addition, CSG needs complex and precise power control algorithms that tunes the transmission power of FBSs dynamically (depending on the surrounding environment). These algorithms allow to avoid the leakage of power (excessive power) outside the premises of the home or the office and to reduce the interferences in overlapping coverage area. For simplicity reasons, we adopt OSG access strategy in this project.

Our work can be divided into several sections: a) First, we provide the readers with a set of definitions and background information that facilitate the comprehending task of our thesis. b) Second, we include a comprehensive review of the studied literature followed by our motivations. c) Third, we present a detailed description of our system model followed by the optimization problem and the performance metric. d) Fourth, we present our proposed solution that comprises the two assignment strategies. e) Fifth, we introduce the simulation parameters and discuss the obtained results. Finally, we wrap up our work with a conclusion that comprise our future work goals.

CHAPTER I

BACKGROUND INFORMATION AND DEFINITIONS

In this chapter, we provide the readers a general explanation of several technical terms that are going to be mentioned in the following chapters. These scientific terms belong mostly to the wireless communication dictionary.

1.1 LTE and LTE-A

Long-Term Evolution (LTE), known also as 4G, is a wireless communication standard that offers both higher capacity and better mobility to end-users compared to the previous cellular standards. It is built over previous standard network technologies. It takes advantage of different radio interfaces combined with core network enhancement to help the end-user achieving better capacity (3GPP, LTE, 2008). LTE Advanced (LTE-A) system is an upgraded version of LTE system. It concentrates mainly on further improving the end-user capacity (Wannstrom et al., 2012).

1.2 Backhaul link

The backhaul link is the portion of network that covers the intermediate links connecting the core network and the small sub-networks

1.3 Macrocell base station (MBS)

An MBS transmits/receives radio signals to/from UEs in order to establish connections between these UEs and the cellular network. The MBS allows mobile users to send/receive voice calls, video calls, texts, emails and pictures, to surf the web, and to stream TV shows. MBSs are linked to each other through backhaul link. The cell is the coverage area supported by the MBS. Whenever a mobile station moves from a cell to another, the new BS softly takes care of the current service with no connection breakage (Vodafone, 2013).

1.4 X2 Interface

X2 is a novel interface introduced in LTE network. It enables a peer to peer communication between adjacent BSs in order to support the execution of handover procedure and to ensure a swift coordination of radio resources. This interchange of information among BSs assists the execution of the following functions: handover, load management, coordinated multi-Point transmission and reception, network optimization, mobility optimization and general management (Cambridge, 2010).

1.5 Outage ratio or outage probability

It is the percentage of UEs whose service data rate is lower than the minimum rate requirement. It can be represented as the probability that the signal-to-interference plus noise ratio (SINR) of a received signal is under a certain predefined threshold.

1.6 Quality of Service (QoS)

QoS represents a bunch of methods used to manage and enhance the service quality offered to clients. It helps the monitoring of estimated bandwidth, the identification of network state variations (for instance congestion) as well as the prioritization of a specific type of traffic over another. It assists network resources to be shared more efficiently and improves the handling of mission-critical applications. For instance, it manages time-sensitive multimedia and voice application traffic in a way that guarantee for a specific type of traffic to receive higher priority, greater bandwidth, and less delay than best-effort data traffic.

1.7 Signal to interference plus noise ratio (SINR)

In communication systems, the received signal is weaker than the original transmitted signal. In addition it is added to the noise created by the circuit components at the receiver side. To measure the link quality, communication systems usually utilize the signal to noise ratio (SNR). This ratio represents the power of signal over the generated noise. In cellular networks, the background noise is weaker than the interferences created by neighboring mobile users. As a result, cellular systems use a modified link quality indicator ratio that includes the interference. It is known as SINR.

1.8 Spectral efficiency

Spectrum efficiency, or bandwidth efficiency, measures the efficiency of utilizing a limited frequency spectrum by the physical layer or media-access-control (MAC) layer. This performance metric represents the information rate that can be transmitted over a certain predefined bandwidth.

1.9 User satisfaction ratio

It is the percentage of QoS-satisfied users compared to the total number of users requesting services.

1.10 Base station cooperation

The base station cooperation technique is able to enhance the system performance through converting the destructive interferences into constructive signals. It can be performed in an architecture that consists of cellular communications and indoor wireless internet access at the same time. In order to exchange information and intelligence between the BS and the internet access points, a high-speed wired backbone is required (Hongyuan Zhang et al., 2004).

1.11 Cognitive radio (CR)

The cognitive radio represents a newly intelligent radio/network technology. It is capable of enhancing the radio operating behavior, automatically sensing and determining unoccupied channels within the wireless spectrum as well as changing the transmission parameters in order to allow interference-free alongside communications. Cognitive radio encloses both adaptive radio technology (which enable the automatic monitoring and calibration of system behavior) and Software Defined Radio (SDR) technology (wherein intelligent software replaces the conventional hardware components) (Steenkiste et al., 2009).

1.12 Frequency Reuse (FR)

In cellular network, adjacent cells must use different frequency bands to avoid interferences. Yet, this condition does not apply to far cells. This capability of reutilizing frequencies can improve both coverage and capacity. It is known as Frequency Reuse (FR) (Javvin, s. d). The Fractional Frequncy Reuse (FFR) represents an interference management technique in which cellular cells are split into inner regions and outer regions as shown in Figure 1.1. UEs at inner region, known also as cell center region, have access to all available frequency channels (Reuse-1) due to the fact of being so close to the BS. Whereas UEs at outer region, known also as cell edge region, have access only to a portion of all available frequency channels (Reuse-X), in which that portion must be different of adjacent cells (Ali et al., 2009).

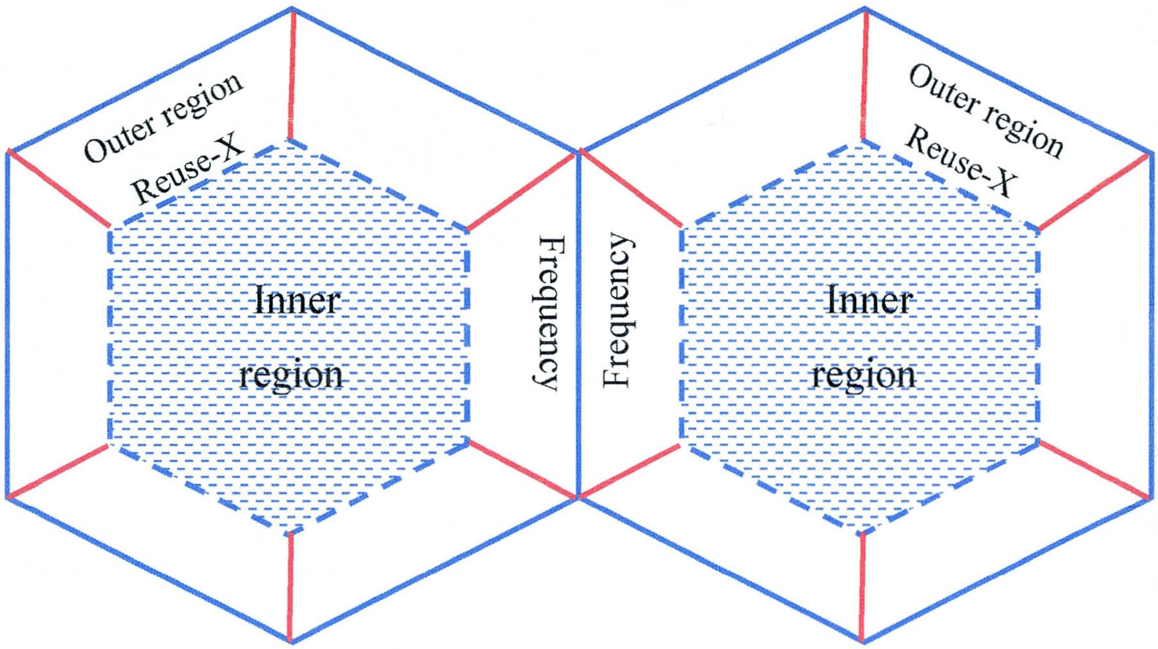


Figure 1.1 Fractional Frequency Reuse (FFR) concept

1.13 Handover

The inter-cell handover is the procedure responsible for transferring an ongoing communication from a frequency channel offered by a BS to another channel offered by another BS. However, when the user equipment keeps the same BS and switches between frequency channels the procedure is called intra-cell handover. The soft handover is a special handover where the transfer of ongoing communication from one BS to another is performed without interruption. Hence, the UE must be connected at least to two or more BSs at the same time.

1.14 Load balancing

The load balancing is a technique that distributes the total system workload among BSs in order to mainly avoid BS overload and to ensure optimal utilization, increased throughput, and reduced response time. In a WLAN network, one efficient way to reduce the network congestion is distributing users' sessions among neighboring Access Points (AP) with overlapping coverage. This task is achievable by integrating load balancing capability in each access point of the WLAN network (Juniper, 2013). By using AP equipped with load balancing ability, one can guarantee that the wireless load is divided among APs evenly which avoid overloading any AP.

1.15 Proportional Fair (PF)

Maximizing the total throughput and ensuring a minimum level of service to every user are the two concerns that a PF scheduler algorithm considers to determine the next user that is going to receive the service. It represents a compromise between maximum throughput and user fairness (Kushner and Whiting, 2004).

1.16 Radio Resource Management (RRM)

The aim of RRM technique is to efficiently utilize the limited radio frequency resources and radio network infrastructure by applying several techniques and algorithms that control the system parameters (Salem, 2011) (Cisco, 2010).

1.17 Coherence Time

The coherence time represents the duration in which the condition of communication channel is not varying.

1.18 Orthogonal Channels

Neighboring end-users that utilize orthogonal sub-channels do not interfere with each other.

1.19 Physical resource block (PRB) or resource block (RB)

In LTE OFDMA (Orthogonal Frequency Division Multiple Access) based system, the least amount of frequency resource that can be allocated to end-user is represented by the physical resource block (PRB)/resource block (RB) (TELETOPIX, n. d). Each RB consumes 180 KHz in frequency domain and a 0.5ms in time domain. The BS is the entity responsible of allocating these RBs to UEs requesting services. The LTE bandwidth corresponds to the total number of available RBs (for instance 20MHz of bandwidth supports 100 RBs) (TELETOPIX, n. d).

1.20 Sniffing capability

The sniffing capability mainly helps BSs to become self-configurable in a way that avoid using noisy channels. It enables BSs to perform handovers, cell planning and synchronization automatically (Picochip, 2008). In femtocell networks, this capability helps each FBS to detect neighboring FBSs.

1.21 Transmission Time Interval (TTI)

The TTI represents the duration of transmission on the radio link. It is relative to the size of data transferred from the network layer to the radio link layer (ATDI, 2008). In LTE network, the TTI duration is equal to 1ms (ATDI, 2008). It consists of two slots (of length T_{slot} each) known also as sub frames.

CHAPTER II

REVIEW OF THE LITERATURE AND MOTIVATION

Despite all the benefits that accompany the integration of femtocell technology, operators still struggle to overcome the challenges caused by unorganized and unplanned integration of FBSs into an existing organized cellular network. These challenges are mainly represented by severe interferences and unbalanced traffic load among FBSs and MBSs. Therefore, researchers are given the task of solving these challenges. In order to achieve such goal, femtocells' researchers mainly focus on mitigating occurring radio frequency interferences through load management algorithm, efficient resource allocation algorithms, FBSs cooperation and enhanced feedback reporting solutions, advanced sensing solutions, frequency reuse and power control schemes. These radio frequency interferences are divided into two main categories: cross layer interferences (that happen between the two tiers, in other words, between femtocell and macrocell) and co-layer interferences (known also as intra-femtocell interferences that happen between FBSs). Depending on how the proposed solutions are going to solve the occurring interferences, we classified the studied articles into several groups. Therefore, in this chapter, we revisit the published femtocell's research works and we show the uncompleted work. At the end of this chapter we briefly present the motivations of our work and we summarize our contributions.

2.1 Load management based approach

In order to ensure high system efficiency and reduced interferences, several researchers concentrate on creating load management algorithms. These algorithms take into account the current load of each BS to ensure an efficient scheduling of traffic load and UEs. These algorithms intend to improve the total system capacity and reduce the outage probability of UEs resulted from overloaded BSs.

In (Heng Zhang, et al., 2010), the authors achieve a distributed load balancing by adding new network entities defined as an automatic network management module (a function entity added in BS) and an autonomic load balancing control loop. The autonomic load balancing is responsible of calculating the expected cellular coverage patterns relative to the load conditions and geographic distribution of traffic load. According to the authors, previous researches tried to reduce the handover probability of UEs toward highly loaded cells while simultaneously increase the handover probability of UEs toward lightly loaded cells. Yet, they declare that their proposed solution outperforms previous works (in term of balancing the traffic load and minimizing overlapping areas) thanks to better use of LTE features, such as the adjustment of BS' antenna's beam coverage as well as the consideration of UE's handover triggering strategy that bases on the current load of BSs. However the proposed solution demands the addition of complexes modules as well as the change of beam radiation pattern to every deployed eNBs which does not represent a cost-effective solution.

In (Chung-Hsin, 2011) the authors propose a new scheme to balance the traffic load among FBSs while ensuring at the same time the requested QoS to the moving UEs. In other words, such method can increase the Call success probability of existing mobile station. In order to achieve these goals, the authors consider several factors such as UE mouvement's prediction, QoS satisfaction and load balancing between neighboring FBSs to make the best possible handover decisions. More precisely, the authors calculate the weight of each UE connected to an overloaded FBS using three different parameters: the remaining time index (measuring how long the UE is going to remain under the coverage area of its current serving FBS), mobile station satisfaction index (responsible of choosing the appropriate FBS for each UE), and FBS load balance indexes (selecting the future/target FBS with the best system balance). Finally, through simulations, the authors show that the consideration of traffic load balancing and mobile stations movement prediction can improve the average data throughput of mobile stations. However, the previous works, mentioned in the beginning of the article, such as power based and handover based solutions can be applied in fully distributed way; yet, the suggested proposition is clearly a centralized solution that lacks the scalability and the practicality of the two previous, mentioned, works.

In (Chang Soon et al., 2011) the authors propose a load control strategy with virtual coverage adjustments for downlink transmission. The coverage area of both serving macrocell and target cell can virtually change by tuning the handover thresholds. In other words, by reducing the handover's threshold values, the virtual coverage area of current/serving macrocell becomes smaller while, alternatively, the virtual coverage area of neighboring cells, macrocells and femtocells, becomes larger. Therefore, the transfer of macrocell' UEs to adjacent cells becomes more frequent and quicker, while the transfer of adjacent-cells' UEs to the current/serving cell becomes less frequent and slower. As a result, the addition of femtocells to the two-tier network helps macrocells to avoid being overloaded through lessening the traffic load handled by MBSs.

Regardless of all the benefits resulted from integrating load management algorithms to the system, the above mentioned solutions in most cases require a central coordinator or any kind of added hardware that organize the exchange of information between devices in a centralized way. However centralized solutions lack the level of practicality and scalability that current operators expect. For instance, the change of FBS antenna coverage range physically or virtually without informing the neighbors or reporting to central coordinator, in dense femtocell deployment, may lead to a reduction in system performance; for example a reduction in UEs SINR level for those situated between two FBSs without being able to establish a connection with any of them.

2.2 Power control based approach

Several researchers aim to reduce cross layer or co-layer interferences via proposing power control algorithm that adjust, for each FBS, the power allocated to the frequency channels that interfere with neighboring FBSs. Some researchers propose solutions that perform autonomously while others prefer to integrate intelligence/information sharing strategy among neighboring FBSs in order to further reduce the generated interferences.

In (Tian et al., 2010), the authors propose a fully distributed resource allocation algorithm. The proposed solution aims to optimize the resource allocation on both femtocell and macrocell tiers. In addition, the proposed algorithm aims to maintain a balance between two competing interests; improving the LTE network capacity while ensuring a certain level of fairness among UEs. The proposed solution dynamically allocates resources among UEs in a way that outperforms conventional round robin solution in term of capacity. By comparing the proposed algorithm to our work, we both proposed a fully distributed algorithm that does not require adding any new hardware components or changing the behavior of existing macrocell network, we both choose to simulate our solution using realistic parameters and a sophisticated path loss model in LTE based network (Dual strip model Versus WINNER 2). The authors choose to focus on improving system capacity while we choose to reduce the outage probability of UEs requesting real time services.

In (Bennis et al., 2011), the authors provide the readers of this article with an overview of the BeFEMTO project followed by an implementation of interferences mitigation techniques such as RRM and power control algorithm. Their proposed radio resource management algorithm starts by determining to each femtocell UE the appropriate transmission parameters (number of RBs, modulation/coding schemes and the transmission power). Afterward, the algorithm allocates to each served UE more available RBs. In addition, the authors suggest increasing the number of RBs allocated to each UE while decreasing their power level in order to reduce the generated interference on each RB. According to the authors, the proposed RRM (Ghost) performs better than the conventional RRM (that limits the number of assigned RBs for each UE) in term of decreasing the outage probability of UEs. Moreover, the authors propose a novel distributed learning method that could speed up the sharing process of acquired intelligence between neighboring F-BSs. Despite the fact that the proposed radio resource management algorithm succeeded to reduce the generated interference in each assigned RB by increasing the number of RBs assigned to each mobile user while reducing their power level, such strategy may increase the waiting time of new mobile users requesting services from neighboring busy F-BSs and lead to UEs starvation.

In (Stocchi et al., 2011), the authors propose a novel algorithm that focuses on mitigating co-layer interference at downlink transmission. The proposed algorithm offers self-configuration and self-optimization capabilities. It combines three different schemes; flexible spectrum usage, power control and initial spectrum selection. It aims to ensure for UEs with poor condition a high cells throughput and improved performance. In order to achieve these goals the authors divide their proposition into four main sections called priority chunk selection, additional spectrum selection, scheduling and transmission, and SINR estimation collection. First, they propose to split the total system bandwidth into orthogonal portions with identical number of RBs. Next, each portion is assigned to a single FBS that has the priority to transmit on it. Yet, each FBS can transmit on other portions of the bandwidth prioritized to other neighboring FBSs when it requires more bandwidth. However, a FBS is only allowed to use other FBSs' prioritized portions of bandwidth when all of its priority portion's RBs are already used. The usefulness of prioritizing portion of bandwidth to FBSs becomes clear when a new FBS is switched-on for the first time. It guarantees for that particular FBS a portion of bandwidth with low level of interference. In addition, in case of high traffic load, a power control scheme is utilized in order to avoid each FBS to generate high interferences to the others due to the fact of utilizing all the frequency spectrum's RBs. By comparing this article with our proposed solution; we assume better, more realistic and certified 3GPP path loss model know as dual strip with both indoor and outdoor mobile users.

In (Seokhyun and Joonyoung, 2011), the authors proposed a centralized-based coordinated scheduling strategy that concentrates on mitigating cross layer interferences between macrocell UEs and femtocell UEs in downlink transmission. To achieve that goal, the authors propose a multi-cell coordination scheme. This scheme benefits from using a list of dominant interferers and channel quality information (reported by UEs) combined with two separate power control mechanisms, namely, self-power control and user-requested power control. While the impact of cross-interference on the users is the main focus of this work, the authors decide to evaluate the performance of their proposed algorithm using average macrocell-user's throughput and 5% worst femtocell-user's throughput. Through simulation, the results prove that the coordinated scheduling can improve the 5% worst user throughput, especially for macrocell MSs by reporting few (or several) dominant interferer, which can be done periodically to the serving BS. Moreover, the user-requested power control shows superior results compared to the self-power control in term of improving the 5% worst macrocell user throughput at a slight loss in 5% worst femtocell user throughput while maintaining almost the same average throughput both in macrocell and femtocell.

In (Gen et al., 2012), the authors discuss a distributed algorithm that combines power control and scheduling for the downlink transmission. They concentrate on reducing the outage ratio of UEs as well as the average power consumption in densely deployed femtocells networks. Furthermore, it considers the variety of users' link qualities and exploits the multiuser diversity when scheduling users in the available resource blocks (RB) in LTE based systems. Their proposed algorithm performs in autonomous manner to provide the optimal solution that utilizes local information (UE's channel quality and the iterative power values). In brief, their proposed algorithm involves three stages: the pre-bandwidth allocation, scheduling policy of each FBS and power control based on the local link information. After categorizing all UEs into two separate groups: cell edge UEs and cell center UEs, the pre-allocation stage is executed. It is responsible for allocating an interference limited frequency spectrum to each FBS. Afterward, in order to reduce the power consumption at the FBS level, the authors apply a distributed power control algorithm. Through simulation, the authors demonstrate that their proposed distributed algorithm could improve the system performance in terms of outage ratio and scheduling fairness. Compared to our proposition, we both propose autonomous distributed systems that take advantage of the current channel quality of each UE in densely deployed femtocell environment and we both focus on reducing the outage ratio of UEs.

In (Nomikos et al., 2012), the authors propose a cooperation framework for LTE-A based Femtocells networks. It aims to reduce cross layer interferences, experienced by Femtocell UEs and caused by MBs, and to enhance the SINR level of macrocell UEs positioned close to FBSs. According to the authors, the proposed framework ensures an efficient cooperation strategy among FBSs and MBSs via wireless links by integrating a relaying capability into deployed FBSs. Besides, thanks to the exchanged context information of underutilized FBSs the proposed framework is capable of serving macrocell UEs located close to FBSs. The intervention of the authors in this article can be summarized into three stages; First, helping the unorganized FBSs deployment to mitigate cross layer interferences through decreasing MBSs' transmission power and enhancing the SINR level of macrocell UEs. Second, servicing macrocell UEs only over wireless relay links when a two-hop transmission is selected in order to avoid adding burden to the already constrained femtocell backhaul link. Third, taking advantage of opportunistic path selection procedure (that guarantees the best transmission quality to the macrocell UEs at the downlink) in order to enhance macrocell UE' data rate. In brief the proposed framework aims to reduce the average transmission power of M-BSs incurring less interference to femtocell mobile users and provide macrocell mobile users with better-quality links through hybrid-access underutilized F-BSs. Which will enhance their SINR and protect them from interference by other F-BSs that are currently serving their own mobile users. However, the cooperation among FBSs and MBSs comes with the cost of increased system overhead.

During our work different projects are investigated. The other researchers mostly aim to optimize UEs capacity, reduce the outage probability, maintain fairness among UEs or protect macrocell UEs from interferences. In order to reach their desired goals different architectures are proposed; centralized, distributed and cooperative. First, in power control solution, centralized architectures show impressive results thanks to the knowledge of the current power level allocated to each RB assigned to each UE instantly. Yet it lacks the level of practicality and scalability founded in autonomous / distributed solutions. Despite that fully distributed architectures deliver the desired level of practicality, scalability and self-tuning capability, they perform worse than centralized solutions due to performing the power control strategy locally. In order to fill the gap between the two architectures, other researchers propose cooperative solutions that perform in distributed way. In cooperative solutions, FBSs share their knowledge with each other. These solutions, such as (Nomikos et al., 2012), perform better than fully distributed solutions and deliver the desired level of practicality and scalability, yet they use complex algorithm and cause a considerable system overhead due to the instant exchange of intelligence (list of interferers, channel quality, etc.) between FBSs. Due to the fact of concentrating only on reducing co-layer interferences in our work, we decide not to add a power control algorithm at the time being. However, we propose in the future work to develop a power control mechanism that works in a distributed and cooperative manner with reduced system overhead by portioning the whole femtocell network within the macrocell into femtocell clusters. This solution will reduce the amount of information shared between FBSs by assigning a leader to each femtocell cluster and performing power control algorithm in centralized manner at each femtocell cluster.

2.3 Frequency reuse based approach

Other researchers aim to reduce the existing interferences through applying frequency reuse schemes. In these schemes, numerous projects choose to divide the cell coverage into inner region and outer region and make FBSs autonomously allocate orthogonal frequency channels to UEs.

In (Poongup et al., 2010), the authors propose an interference management scheme for LTE based femtocell network utilizing fractional frequency reuse. The main idea is to allocate to FBSs frequency channels different from those currently used in macrocell sub-region. The proposed solution benefits from utilizing fractional frequency reuse to evade the use of noisy channels and increase the frequency diversity.

In (Kan Zheng et al., 2010), the authors concentrate on reducing co-layer interferences by proposing an interference coordination scheme. Their interference coordination strategy is expressed in an optimization problem that attempts to enhance the cell throughput and the fairness among UEs. First, they assign to each FBS a frequency carrier different/orthogonal to those assigned to its neighboring FBSs or a frequency carrier experiencing the least level of interferences. Second, each FBS try to utilize more frequency carrier to improve the system spectrum efficiency. The measurement of co-layer interferences is calculated through FBSs and UEs combined effort.

In (Saha R.K, 2011), the authors propose a resource scheduling algorithm that aims to optimize the spectral efficiency in LTE-A based networks. Their proposed solution combines the implementation of an interference coordination strategy with a fairness optimized mechanism (that reserves a number RBs to be utilized only by macrocell UE in every TTL). In order to avoid cross layer interferences, RBs allocations among macrocell UEs and femtocell UEs are always orthogonal. Yet, when RBs are allocated to femtocell UEs via the PF scheduler they can be reutilized again. However, as soon as the RB is assigned to a macrocell UE, this RB becomes restricted to other UE.

In (Lin Yang, et al., 2011), first, the authors compare both orthogonal and shared assignment of RBs and prove the superiority of co-channel allocation over orthogonal allocation of RBs in term of spectral efficiency and achievable network capacity. Second, they comprehensively analyze possible cross layer interference scenarios. Next, the authors investigate an intelligent allocation strategy of frequency resources. As a result, the authors propose a semi-static allocation scheme that intends to reach the best compromise among interference cancellation and spectrum efficiency interests. This scheme takes advantage of applying a hybrid shared/partitioned spectrum usage that depends on FBS's location based measurement.

In (Zhen et al., 2011), the authors evaluate the downlink performance of three different systems (distributed antenna system, uncoordinated femtocells system and the proposed centralized joint scheduling system) in term of spectral efficiency. The distributed antenna system is proved to be inappropriate for in-building high-data-rate services. On the other hand, femtocell system reaches better overall throughput as well as a larger number of simultaneous services UEs than distributed antenna systems due to FBS capability of reusing the spectrum. Yet, because of high co-layer interferences, uncoordinated femtocell system experiences SINR deterioration. For these reasons, the authors propose a centralized joint scheduling solution. The proposed solution takes advantage of reducing the resource block consumption per each UEs in order to maximize the number of simultaneous services UEs under the predefined QoS requirement.

In (Gen et al., 2011), the authors propose a two-phase traffic aware adaptive resource allocation scheme under LTE context. It intends to mitigate the co-layer femtocell interferences while guaranteeing a minimum level of QoS to UEs located in highly dense femtocell deployment regions. Therefore, they propose an optimization problem that aims to guarantee the required QoS demanded by UEs' services and to minimize the power consumption. The authors choose to divide the UEs into two types (cell-center user and cell-edge users) by calculating their current SINR level. Next, they consider two resource allocation strategies; long period allocation strategy and short period allocation strategy. In order to eliminate severe interferences, a quasi-orthogonal bandwidth is assigned to FBSs during the long period allocation strategy. While, in order to balance the traffic load a short period allocation strategy is applied to coordinate the frequency resource allocation among neighboring FBSs.

In (Maqbool et al., 2011), the authors evaluate the performance of frequency reuse based interference avoidance strategy using dual stripes model and 5x5 Grid model to simulate urban environment within LTE networks. In this article, the authors propose an FFR based frequency planning strategy. The proposed strategy splits each cell area into two regions. Inner regions take advantage of frequency reuse 1 while outer regions are restricted only to frequency reuse 3. In this scheme, underlay FBSs autonomously allocate orthogonal channels to UEs in a way that inner and outer UEs are orthogonal to each other. Besides, a sniffing capability is integrated to each deployed FBS in order to identify the status of each deployed FBS, whether it belongs to inner region or outer region, in distributed way. Using this ability, every FBS becomes capable of measuring the signal power received over every frequency channel instead of depending on centralized reporting system. As a result, this capability allows each FBS during powering up procedure to sniff all the frequency channels and transmit over the frequency channel(s) with the least total received power.

In (Bouras et al., 2012), the authors investigate the interference mitigation techniques in femtocell/macrocell networks and propose a frequency reuse selection mechanism that aims to maximize end-user throughput and satisfaction ratio while reducing cross layer interferences at the same time. Every macrocell coverage area is divided into inner region with reuse factor 1 and outer region with reuse factor 3. The estimation of frequency needed by each region depends on inner cell radius and subcarrier allocation. The frequency allocation procedure for femtocell is performed according to FBS's positions. Each FBS selects a frequency band different/orthogonal to frequency channels already assigned to macrocell UEs positioned in the same coverage area. The proposed mechanism computes the total throughput of the cell as well as user satisfaction ratio for each pair of radius and frequency. Afterward, it selects the optimal frequency allocation scheme. Inner cell radius and the number of subcarriers to be allocated in each region are selected in a way to maximize the UE satisfaction ratio.

In (Selim et al., 2012), the authors propose a soft and partial frequency reuse strategy for interference management in LTE femtocell networks. It exploits a macrocell frequency allocation schemes to mitigate cross layer interferences through Soft Frequency Reuse (SFR) scheme. In addition, it requires no coordination between MBSs and FBSs to perform. Before integrating FBSs, the SFR splits the macrocell coverage area into center and edge regions and divides the entire frequency band of the system into three equal sub-bands. During the first time slot of LTE frame, the entire frequency band is accessed only by center macrocell UEs (Reuse-1). While, the second time slot is always reserved for edge macrocell UEs. At each sector, edge macrocell UEs have the capability to access only one of the three frequency sub-bands (Reuse-3). Compared to the center region, edge region transmission power is three times stronger. After integrating FBSs to network, FBSs are classified into center FBSs and edge FBSs. FBSs positioned at any sector are restricted to utilize sub-bands assigned to edge macrocell UEs of that sector. Similarly, by dividing the entire bandwidth into three sub-bands, the center FBSs of every sector have only access to a single sub-band different from what already assigned to center FBSs in neighboring sectors. While edge FBSs have access to the other two frequency sub-bands.

In (Wei et al., 2010), the authors propose a resource allocation scheme for two-tier OFDMA-based femtocell networks. Both energy efficiency and interference mitigation are considered in the proposed scheme. Macrocell UEs are considered prior to femtocell UEs. The proposed solution comprises three major stages; allocating sub-bands to UEs using cross layer interference coordination strategy, protecting edge macrocell UEs' performance and improving the energy efficiency under QoS requirements. The proposed solution starts by splitting cells' coverage into outer regions and inner regions. Next, sub-bands are allocated to macrocell UEs using SFR strategy. Then, the frequency band is divided into three portions. Then, only a single portion of the frequency band is allocated to FBSs and their UEs when they are positioned within inner regions, while the whole band is accessible to FBSs and their UEs when they are located in outer regions. Afterward, in order to maximize the energy efficiency of the whole networks under QoS requirement, the authors calculate the optimal frequency band allocation ratio, which guarantees for both macrocell UEs femtocell UEs to reach their demanded data rate.

The majority of the works mentioned in this section implement the same concept that aims to split UEs into classes based on their current location and whether they belong to macrocell or femtocell network. Next, they divide the whole frequency band into several portions and assign them to FBSs and MBSs with different probability in a way that reduces cross-layer interferences. These frequency reuse solutions represent an effective and simple way to eliminate cross layer interferences. Since our research focus mainly on reducing co-layer interferences and for simplicity reason, we decide not to integrate frequency reuse strategy.

2.4 Advanced sensing capability based approach

Other researchers choose to improve the sensing capability of FBSs' antenna by integrating cognitive radio features into deployed FBSs. Others prefer to focus on improving the interference recognition and coordination strategies that help BSs to share some sort of intelligence, such as a list of interferer or UEs' channel quality (to create local interference graphs), in order to avoid allocating noisy channels to UEs.

In (Gür et al., 2010) the authors propose a femtocell-based cognitive radio architecture that enables an opportunistic access to the broadband wireless systems. This architecture adds an infrastructure-based overlay cognitive network model to the existing femtocell networks in order to deliver additional efficient dynamic spectrum access and management. The UEs are divided into two classes of mobile users; primary users (macrocell UEs) and secondary users (femtocell UEs). The key advantage of using cognitive FBSs is to discover and detect spectrum opportunities more efficiently and allocates them to the secondary UEs.

In (Attar et al., 2011), the authors start by clarifying the advantages of incorporating cognitive radio capabilities into FBSs. Next, they discuss the ability of cognitive FBSs, with improved sensing capability, at exploiting their knowledge of the radio scene to cleverly allocate resources and reduce severe co-layer interference. In addition, the authors also discuss the important role of radio scene analysis and argue the expected benefits of integrating cognitive BSs to LTE network. Next, due to the distributed nature of femtocell networks, the authors formulate the Co-layer interference problem into either a coalition formation game or a game with correlated equilibrium. The main idea of this work is to prove the importance and the capability of incorporating a cognitive radio technology to the existing femtocell-based cellular network to reduce severe interferences.

In (Harjula et al., 2011) the authors consider a situation wherein macrocells' UEs are threatened by FBSs integration and their resulted interferences. Therefore, the authors demonstrate the capability of spectrum sensing strategy, based on Welch periodogram, to detect and discover neighboring radio frequency transmitters with an acceptable level of accuracy. Through simulations, the authors prove the effectiveness of the proposed Welch periodogram based spectrum sensing to detect the macrocell UE when it is positioned close to the house, or when the macrocell UE and the FBS are positioned at the same floor.

In (Sethom et al., 2012), the authors propose a scheduling algorithm that combine both; modified version of EXP-rule and maximum-largest weighted delay first (M-LWDF) algorithms to deliver the optimal data rate according to the number of UEs per FBS and their access priority. UEs are divided into two classes; real time service and non-real time service. The authors concentrate on how to perform scheduling at the BS level while providing the demanded QoS to UEs according to their needs and network access priority. The selection process of the appropriate scheduler to each UE takes into consideration both the UE's service and class. So, they apply the EXP-rule scheduler to UEs demanding real time service (delay sensitive) and the M-LWDF scheduler to UEs demanding non-real time service (throughput optimal).

In (Herranz et al., 2012), the authors focus on integrating cognitive radio features into femtocell network; such as the ability to efficiently exploit the limited spectrum frequency resources by implementing an opportunistic spectrum access strategy. This strategy allows an intelligent usage of unoccupied licensed frequency spectrum without resulting interferences to the licensee. In order to implement the proposed strategy, coordination mechanisms must be applied to avoid possible interferences among neighboring FBSs. Consequently, the authors study the capability of media independent handover signaling mechanism to feedback interference measurements (interference awareness). These interference measurements assist a central controller (centralized spectrum manager) to allow FBSs to exploit and share white spaces. As a result, whenever severe co-layer interference demands coordination, the proposed opportunistic spectrum access strategy is triggered to improve the spectrum efficiency and mitigate that interference.

In (Pantisano et al., 2010), the authors study the influence of scheduling information exchange within clustered femtocell network. Therefore, they implement a resource reuse strategy for femtocell networks, in which frequency resources are allocated to FBSs in time-division multiplexing of the macrocell uplink frequency band. In addition, they focus on optimizing the resource allocation (which UE to allocate in which time slot and which operation to perform; uplink/downlink). Therefore, the authors propose two solutions. First, by using list-coloring strategy (which is based on the overall conflict graph) a centralized scheduling is executed. Wherein the central coordinator collects all the local conflict graphs, created by FBSs, in order to create a global conflict graph. The second solution is distributed, by using local conflict graph (which contains local UEs and interfering UEs from neighboring cells) each FBS acts separately of the others in an autonomous way. Besides, the second distributed approach obliges conflicting UEs (belonging to other cells) to relay and feedback information on their own scheduling to the FBS that they are interfering with.

In (Kyuwhan et al., 2011), the authors propose a load balancing strategy that aims to ensure fairness among UEs. This strategy comprises two major steps. First, in interference recognition stage, the interference graph is created based on interference detection mechanisms (depending on UEs measurements and femtocell cooperation messages). Second, in femtocell load balancing stage, UEs are reallocated to FBSs based on the interference relationship. Consequently, the system chooses the allocation scheme with the smallest difference of UE's number allocated to each FBS.

In (Gen et al., 2011), the authors propose an adaptive sub-band allocation strategy. First in order to model the interference relationships between adjacent/neighboring FBSs and their UEs, an interference graph is created (based on the measurement reports sent from UEs). Second, in order to suppress severe interferences from adjacent cells, an orthogonal sub-band assignment algorithm is created to allocate sub-bands in an orthogonal way to adjacent/neighboring FBSs. Third, in order to improve the achievable system capacity, an adaptive sub-band reuse algorithm is created to help UE sharing some orthogonal sub-bands, belonging to the conjoint interfering femtocells, while respecting the constraints of the interference level.

In (Galindo-Serrano et al., 2011), the proposed learning approach permits each femtocell node (FBS agent) to react based on the instantaneous changes of the surrounding environment, in which femtocell to macrocell interferences (cross-layer) are properly controlled. However, using X2 interface to exchange information between MBSs and FBSs impose an additional delay. In order to decrease the added delays, the authors propose to transfer extra information over the X2 interface in a way that helps the MBS to inform the femtocell network about its intended future scheduling policies. In order to evade the severe femtocell to macrocell interferences, each femtocell node properly shares the intelligence and knowledge acquired in different RBs.

By studying the above mentioned articles (section 2.4), we recognize the importance of integrating sniffing capability to deployed FBSs. This feature helps each FBS to discover the surrounding coverage area and avoid assigning noisy and bad RBs to the current connected UEs. However the procedure of information exchange require a certain period of time to construct a local interference graph at each FBS which is not suitable for fast moving UEs and dense femtocell deployment. Therefore, we decide not to incorporate coordination scheme for the time being to minimize the system overhead. However, we assume that all deployed FBSs are equipped with sniffing capability that allow them to better estimate the channel condition between themself and their connected UEs' RBs.

2.5 Improved feedback reporting and FBS cooperation based approach

Other femtocell researchers concentrate on improving FBSs cooperation as well as enhancing feedback reporting strategies. These cooperative solutions represent a way of sharing intelligence gathered by each FBS in order to allocate available frequency resources more efficiently.

In (Hatoum et al., 2011) the authors propose a cluster based resource allocation strategy for femtocell networks. It aims to manage the available frequency resources more efficiently by applying an optimum centralized spectrum allocation within each cluster. The authors search for the optimal allocation strategy of frequency resources dedicated for each FBS to deliver the demanded UE's data/service while reducing the interferences between neighboring/adjacent FBSs and guaranteeing the demanded QoS. The selection procedure of the best suitable header of each cluster is performed as follows; first, each FBS creates its one-hop neighbor list that comprises the interfering FBSs identities. Second, each FBS shares its created list with its one-hop neighbors. Eventually, every FBS knows the number of interfering FBSs (interference degree) of each of its one-hop neighbors. Next, the FBS with the highest interference degree is selected as the cluster-header. Consequently all associated one-hop neighbors become cluster-members and attach to the selected cluster-header.

In (Garcia et al., 2009) the authors propose a fully distributed solution for femtocell based LTE-A network. The proposed solution aims to locally reduce interferences through minimal information exchange and negotiation among FBSs. In this solution, each FBS separately collects the needed knowledge about the surrounding area and selects the best suited frequency configuration without involving any centralized network control. In this solution; first, each cell selects only one primary component carrier for transmission. Second, the addition of secondary component carriers to the same cell is limited by its impact on neighboring cells (interference level).

In (Andrews et al., 2010), the authors propose a fully distributed solution with dynamic sharing level of spectrum between FBSs and MBSs. The assignment of RBs to UEs is based on proportional fair scheduling algorithm and each FBS evenly distributes the power among the assigned resources. The estimation process of the channel condition is performed thanks to UEs and FBSs combined efforts. Each FBS periodically estimates the average channel quality over all its RBs assigned to the connected UEs. The size of frequency band shared with MBS is decided by each FBS basing on the level of interferences caused to the shared frequency band.

In (Seung-Yeon Kim et al., 2011), the authors propose a cooperative transmission strategy in order to increase the system throughput of downlink transmissions. The UE is assumed to have the ability of receiving the main signal (from the current FBS) and other signals belonging to neighboring FBSs at the same time. As a result, the usage of two time synchronized signals helps improving UEs' SINR level. This achievement is reached through implementing a transmission timing control technique. This technique is utilized in order to obtain a diversity gain by synchronizing the inputs from a number of antennas and passing the sum into a standard receiver.

In (Bo et al., 2011), the authors propose a hybrid resource allocation solution that aims to improve the SINR level of both macrocell and femtocell UEs via mitigating the mutual interference between macrocell and femtocell to improve the system throughput. The proposed solution allows MBSs and FBSs to reallocate RBs, for several transmission time interval, based on received interference reports. These interference reports are created and sent by macrocell and femtocell UEs.

In (Mahapatra et al., 2011) the authors propose an interference aware radio resource management strategy for femtocell based network. This strategy allows FBSs to know the current position of their UEs. The main objective of the proposed solution is to allocate radio resources between femtocell UEs based on radio environment maps. The proposed solution combines the measured interference value on each RB with femtocell UE's position in order to create the interference cartography diagram for FBS coverage area using spatial interpolation algorithm. Based on interference cartography diagram, each FBS classifies the available RBs and utilizes them according to a dynamic fractional frequency reuse scheme at desired location. The RBs' transmission power are properly adjusted by the serving FBS in a way that mitigates interferences to neighboring macrocell and femtocell UEs.

In (Yi Wu et al., 2012), the authors propose a coordinated spectrum assignment strategy for highly dense FBSs deployment in LTE based enterprise networks. The proposed solution represents a self-organized solution that benefits from combining; first, the autonomous selection process of dedicated sub-band for basic connectivity, second, the cooperated allocation process of shared sub-band for high data capacity. In this work, the authors focus on spectrum assignment at femtocell level while they leave the multi UEs scheduling task to be handled by FBSs. More precisely, the authors propose to split the system spectrum into several sub-bands (pool of sub-bands) and effectively assign them to interfering FBSs for data channel usage. The selection strategy aims to find the cell that has the lowest probability of spectrum usage and suffers the least co-layer interference in order to reduce sub-bands overlapping effect. Since the available sub-bands per FBS is determined basing on its interference degree, the FBS with lower interference degree have more sub-bands under its control.

2.6 Motivation and contribution

Based on all the studied literature, we conclude that femtocell researchers focus on solving different challenges, such as mitigating occurred interferences, improving the system efficiency, improving the total system capacity or reducing the outage probability of UEs. However, the proposed solutions share some weaknesses such as: high level of signaling in centralized and cooperative solutions and lack of scalability especially in centralized solutions.

Some researchers choose the path of adopting a full scale cooperation between FBSs or centralized solution in order to share locally acquired intelligence and avoid allocating noisy frequency resource to their current users. However, no matter how small the shared information is going to be, the instant exchanging signaling system will increase the system overhead. As a result, they will sacrifice a precious data transmitting time and capacity. In order to avoid that all deployed FBSs must act autonomously in fully distributed manner. Besides, due to unorganized and unplanned deployment of FBSs (Garcia et al., 2009, 2010) combined with an exponential increase in the number of installed FBSs (Garcia et al., 2009, 2010) (Mavrakis and Dimitris, 2011), especially in urban regions, femtocell researcher's become more interested in solving co-layer interferences.

For these reasons, we focus on solving issues related to the intra-femtocell interferences in order to reduce the outage probability of UEs in highly dense femtocell environment.

Focusing on the reduction of outage probability of UEs, several works (such as (Bennis et al., 2011)) suggest adding more frequency resources (with low level of power) to mobile users having difficulties to maintain a certain minimum data rate (for real time service). Such solutions offer an efficient use of spectrum and an overexploitation of frequency resources which will eventually decrease the number of simultaneous serving users per FBS. Instead, we propose to adopt new allocation strategy, at every coherence time, to ensure not to give UEs more than the required number of RBs to support the requested service. Considering data traffic, just few articles from the femtocell literature, such as (Zhen et al., 2011), considers constant data rate or real time services, which encourage us to consider a real time service with constant data rate.

In this project, we achieve an efficient resource allocation solution by:

- avoiding the use of noisy channels;
- considering a full distributed and autonomous solution;
- allocating to each UE the best possible set of RBs in term of channel quality; and
- assigning to each UE the FBS that supports the requested service with the least number of frequency resources (RBs).

Our contribution can be summarized as two assignment strategies:

- frequency resources assignment; and
- base station assignment.

Our goal is to maximize the number of active UE per FBS, which will eventually lead to reducing the outage probability of UEs in the system. On the contrary of path loss based solution, we determine the least number of RBs and the best serving FBS based on the SINR level which comprises both the path loss and the interference level. Furthermore, we intentionally avoid adding any interference coordination scheme among FBSs in order to reduce the system overhead as well as improve the system practicality and scalability.

CHAPTER III

SYSTEM MODEL

In this chapter, we present the system model considered in our work. First, we clarify the composition of the simulation environment including FBSs, UEs, building structures, cellular technology and type of service. Next, we comprehensively describe our signal and propagation model including the dual strip path loss model followed by the way of calculating the channel gain, SINR level, UE capacity and UE outage probability. Afterward, we introduce our optimization problem that aims to increase the number of active UEs per FBS followed by the selected performance metric.

3.1 System modeling

We consider downlink frequency allocation for LTE based system (Nohrborg and Magdalena, 2013) where both components of the cellular wireless network, base stations and mobile terminals, implement an OFDMA air interface. In the context of LTE, the elementary time/frequency resource is represented by the RB. We assume that the system has frequency band W. The whole frequency band W is divided to X Resource Blocks. Each RB requires w band of frequency domain. In addition, we consider a network that contains N UE and M FBSs. Each FBS m has X' RBs under its control. The position of UEs follows a uniform distribution. The position of FBSs follows a dual-strip model (3GPP, TR 36.814, 2010) as described in Figure.3.1. N is largely higher than M. In order to model a realistic dense femtocell network, the dual strip model is considered. We assume a fixed transmit power. The N UEs are spread randomly inside and outside the two apartment complex. Only real time services with constant data rates are considered. The number of active UEs N' per FBS is only restricted by the number of available RBs X' per FBS such that $N' \leq X'$.

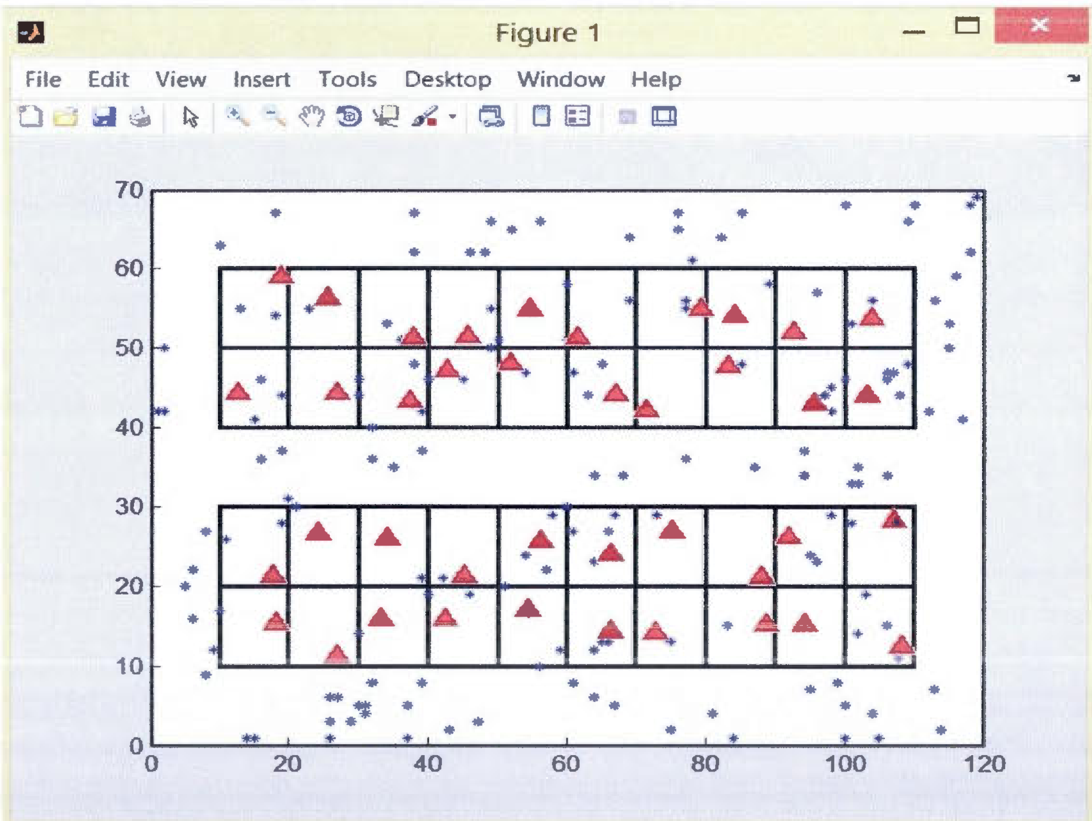


Figure 3.1 Dual strip path loss model

The considered dual strip path loss model simulates a dense urban scenario with crowded UEs. It consists of several office blocks or apartments assembled in two buildings separated by a street. Both of UEs and FBSs are randomly distributed inside and outside the two buildings. Each building has a rectangular shape. Each apartment is represented by a square and has a single active FBS. Each FBS is symbolized by a triangle while each UE is symbolized by a small star as shown in Figure 3.1. Several UEs can be placed inside the same apartment while a neighboring apartment can be empty. The inside walls and outside walls has different penetration loss. More details related to the dual strip path loss model are provided in section 5.1.

In general, integrating FBSs into an existing cellular network will eventually results into two major kinds of interferences:

- inter-cell interferences known also as cross-layer interferences; and
- intra-cell interferences known also as co-layer interferences.

Because of the low transmit power of FBS and the long distance separating the FBS and the MBS; the cross layer interferences are ignored and only intra-cell interferences are considered. We concentrate on simulating a dense femtocell deployment with open access FBSs. We assume that all deployed FBSs share the same frequency band.

3.2 Signal and radio propagation model

According to (Sklar, 1997) the received signal *r(t)* is represented as the transmitted signal s(t) multiplied by the gain as follows:

$$r(t) = s(t) \times G(t) \tag{3.1}$$

The overall channel gain is composed of dual strip path loss model (3GPP, TR 36.814, 2010) as well as Rayleigh fading (Proakis and Salehi, 2007). According to (Sklar, 1997) the gain formula is presented by:

$$G = [1/\sqrt{2} \times |h| \times \sqrt{PL}]^2 \tag{3.2}$$

where PL represents the path loss, while h is represented as follows:

$$h = (R + j \times I) \tag{3.3}$$

where R represents the real part and I represents the imaginary part of the channel coefficient. Both R and I follow a normal distribution.

According to 1 (3GPP, TR 36.814, 2010), the estimated path loss of each UE depends entirely on the UE current position in the simulated scenario. More precisely, it take into consideration: the separating indoor and outdoor distance to the serving FBS, the number of walls in between and the number of separating floors.

a) First, when both the UE and FBS are located inside the same apartment (same chamber) with no separating walls, the estimated path loss value depends entirely on the indoor distance ($d_{2D,indoor}$) that separates the UE from the BS. In this situation the separating total distance *(R)* and the indoor separating distance ($d_{2D,indoor}$) are equal. The estimated path loss value is calculated as shown in formula 3.4:

- UE is located inside the same apartment as the FBS (3GPP, TR 36.814, 2010):

$$PL_{dB} = 38.46 + 20 \times \log_{10}(R) + 0.7\, d_{2D,indoor} \tag{3.4}$$

b) Second, when both the UE and FBS are located inside the same building but not in the same apartment, a single or several indoor walls will be taken into consideration. Therefore, the estimated path loss value depends on the separating indoor distance ($d_{2D,indoor}$) that equals to the separating total distance *(R)*, the number of indoor walls (q) with penetration loss L_{iw}as well as the number of penetrated floors (n). The estimated path loss value is calculated as shown in formula 3.5:

- UE is located inside the same apartment's strip as the FBS (3GPP, TR 36.814, 2010):

$$PL_{dB} = 38.46 + 20 \times \log_{10}(R) + 0.7\, d_{2D,indoor} + 18.3 \times n^{((n+2)\times(n+1)-0.46)} + q \times L_{iw} \tag{3.5}$$

c) Third, when the UE is located outside the two buildings (on the street), the estimated path loss value depends on the separating indoor distance ($d_{2D,indoor}$), the separating total distance *(R)*, the number of indoor walls (q) with penetration loss L_{iw}, the single outside wall with penetration loss $L_{ow}$and the number of floors (n) separating the FBS from the ground. In this situation the outdoor and indoor walls have different penetration losses L_{iw} (indoor wall) and L_{ow} (outdoor wall) while the separating total distance *(R)* is greater than ($d_{2D,indoor}$). The estimated path loss value is calculated as shown in formula 3.6:

- UE is located outside the apartment's strip (3GPP, TR 36.814, 2010):

$$PL_{dB} = \max(15.3 + 37.6 \times \log_{10}(R), 20 \times \log_{10}(R) + 0.7\, d_{2D,indoor} + 18.3 \times n^{((n+2)\times(n+1)-0.46)} + q \times L_{iw} + L_{ow}) \tag{3.6}$$

d) Fourth, when the UE is located inside a building and the FBS is located inside the other parallel building, the estimated path loss value depends on the separating indoor distance ($d_{2D,indoor}$), the separating total distance *(R)*, the number of indoor walls (q) with penetration loss L_{iw}, the two outside walls of the two buildings (with penetration loss $L_{ow,1}$ and $L_{ow,2}$) and the number of level (n) differentiating the floors in which the FBS and UE are positioned . The estimated path loss value is calculated as shown in formula 3.7:

- UE is located inside a different apartment's strip (3GPP, TR 36.814, 2010):

$$PL_{dB} = \max(15.3 + 37.6 \times \log_{10}(R), 20 \times \log_{10}(R) + 0.7\, d_{2D,indoor} + 18.3 \times n^{((n+2)\times(n+1)-0.46)} + q \times L_{iw} + L_{ow,1} + L_{ow,2}) \tag{3.7}$$

The received SINR on RB i of user n connected to FBS m is expressed as follows:

$$SINR^{i}_{n,m} = \frac{P^{i}_{m} \times G^{i}_{n,m}}{N_0 \times \Delta s + \sum_{m'}^{M'} P^{i}_{m'} \times G^{i}_{n,m'}} \tag{3.8}$$

Each mobile user close to FBS m is being interfered with the set of adjacent FBSs M' such as $m \notin M'$. The *SINR* simply indicates the power of desired signal $P^{i}_{m} * G^{i}_{n,m}$ over the power of non-desired interfering signals $\sum_{m'}^{M'} P^{i}_{m'} \times G^{i}_{n,m'}$ plus the white noise N_0 multiplied by the subcarrier spacing Δs. In this equation the term P^{i}_{m} represents the transmitting power of the serving FBS m over the resource block i, while

$G^{i}_{n,m}$ denotes the channel gain between mobile user n and the serving FBS m. Likewise, $P^{i}_{m'}$ represents the transmitting power of neighboring interfering FBS over the RB i, while $G^{i}_{n,m'}$ denotes the channel gain between mobile user n and neighboring interfering FBS over the RB i. The capacity of mobile user n over the channel i provided by FBS m can be expressed as follows:

$$C^{i}_{n,m} = w \times \log_2(1 + SINR^{i}_{n,m}) \tag{3.9}$$

3.3 Optimization problem

In our work, we aim to increase the number of active UEs per FBS in order to reduce the outage ratio of UEs requesting real time services.

Our optimization problem is represented as follows:

- Maximize $| S |$ $\quad S = \sum_{n=1}^{N} b_n$ (3.10)

Such as:

$b_n = 1$ → User n is satisfied (achieved the requested data rate)

or

$b_n = 0$ → User n is unsatisfied (failed to achieve the requested data rate)

- Subjected to:

$$C^{current}_{n,m} \geq C^{threshold}_{n} \quad \text{for all} \quad 1 \leq n \leq N \tag{3.11}$$

$$\sum_{n=1}^{N'^m} X'^m_n \leq X' \qquad \text{for all} \qquad 1 \leq m \leq M \qquad (3.12)$$

In this optimization problem, $| S |$ represents the number of UEs having a current download data rate higher than the requested data rate. While $C_{n,m}^{current}$ denotes the current downlink data rate of user n connected to FBS m and $C_n^{threshold}$ signifies the minimum downlink data rate needed by the requested service. Although, X' represents the number of RBs under FBS m control and X'^m_n represents the number of RBs allocated to user n by FBS m. Finally, N'^m represents the number of UEs currently connected to FBS m.

3.4 Performance Metric

In our work, we measure the performance of our proposed solution through the outage ratio metric. This metric can be seen as the ratio of disconnected users over the total number of users demanding services.

$$P_d = \frac{number\ of\ unsatisfied\ users}{Total\ number\ of\ users\ requesting\ services} \qquad (3.13)$$

Or

$$P_d = \frac{\sum_{n=1}^{N}(1 - b_n)}{\sum_{n=1}^{N} b_n} \qquad (3.14)$$

In the equation 3.14, P_d represents the outage ratio of mobile users demanding the data rate d.

In this document, we decide to measure:

- the outage probability compared to the requested data rate; and
- the outage probability compared to the number of FBSs.

CHAPTER IV

PROPOSED SOLUTION

In this chapter, we present the two proposed assignment strategies; the base station assignment strategy and RBs assignment strategy. Both of the proposed strategies are comprehensively described with detailed flowcharts and pseudo codes. By combining the efforts of the two proposed strategy we aim to increase the number of UEs per FBS and reduce the UE outage probability.

4.1 Scenario

We make use of the following assumptions

- Each FBS m broadcasts periodically radio beacon bursts.
- Each user n, requiring real time service, evaluates the channel quality relative to neighboring FBSs.

- Each user n sends service request to the FBS that supports the service in demand with the least number of RBs.
- In case of receiving simultaneous requests from multiple UEs, each FBS assigns RB(s) to the user that requires the least number of RB(s).

4.2 Base station assignment strategy

As shown in Figure 4.1 each deployed FBS broadcasts periodically radio beacon bursts. Every neighboring UE listens to that radio burst and estimates the channel condition between itself and the FBS broadcasting that radio burst.

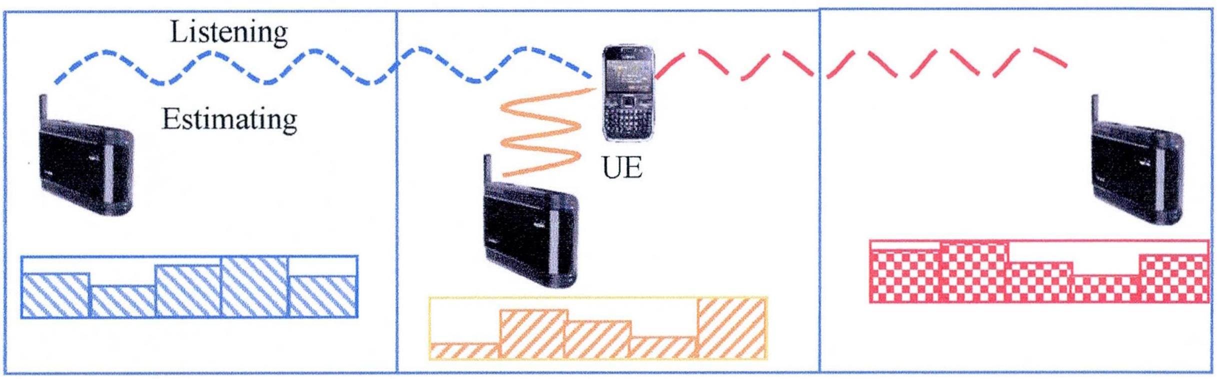


Figure 4.1 UE is estimating the SINR level of RBs belonging to neighboring FBSs

The estimation procedure is supposed to perform on the resource block level. Due to the fact of taking into consideration the Rayleigh fading, the Path-loss and interference level, the channel condition changes from one RB to another. This procedure of listening to the broadcasted radio bursts will be repeated until the UE requesting the service has a clear estimation of channels qualities between itself and every neighboring FBS.

4.2.1 FBS estimation procedure:

The goal of this procedure is to determine for each UE the FBS that supports the demanded service with least number of RBs. This strategy is applied at the UE level. First, the UE *n* listens to the broadcasted radio burst sent from neighboring FBSs. Then, the UE *n* analyzes the broadcasted radio bursts one by one. Let's assume that the first analyzed radio burst belongs to a FBS called *m*. Therefore, the UE *n* estimates the channel condition of available RB(s) belonging to FBS *m*. Afterward, the UE *n* sorts these RBs by SINR level from the highest to lowest in matrix called A as illustrated in table 4.1.

$BS\ index$	$RB\ index$	$SINR\ level$
1	3	$120\ dB$
1	6	$66\ dB$

Table 4.1 Example of matrix A or B

The UE *n* adds the highest RB *x* in term of SINR to a newly created matrix called B. Then, the UE *n* estimates the achievable Data Rate C^{cu} using RB(s) belonging to matrix B. Afterward; the UE *n* compares the achievable Data Rate C^{cu} with the requested service Data Rate C^{th}. If the achievable Data Rate C^{cu} appears to be lower than the requested service Data Rate C^{th}, the UE *n* removes the RB *x* from matrix A and adds the second highest RB in term of SINR to matrix B. Then, the UE *n* performs the comparison procedure again. Otherwise, the UE *n* adds the index of FBS *m* accompanied by the number of required RB(s) (to support the demanded service) to newly created matrix called BS_Estimation as shown in Table 4.2. After that, the estimation procedure of FBS *m* is considered done.

BS index	*Required number of RBs*	*Achievable Data rate in Mbps*
1	2	2.3
2	5	2.1

Table 4.2 Example of BS_Estimation matrix

The UE *n* repeats the same estimation procedure with every neighboring FBS. Finally, the UE *n* fills the BS_Estimation matrix with a number of rows equals to the number of sensed neighboring FBSs. Then, the UE *n* selects from BS_Estimation matrix the FBS that supports the requested service with the least number of RBs and sends to it a service request. The entire base station assignment strategy is demonstrated in Algorithm 4.1 while the FBS estimation procedure is shown in Figure 4.2.

```
for each UE do
    for each FBS do
        for each RB do
            SINR level estimation;
        end for
        UE n calculates the needed RBs for the service relative to the selected FBS
        UE n adds the estimated information to BS_Estimation matrix
    end for
    BS_Estimation matrix is completed
    The Best FBS requiring the least number of RB is decided for UE n
end for
The Best FBS to each UE is decided
```

Algorithm 4.1 FBS assignment strategy's pseudo code

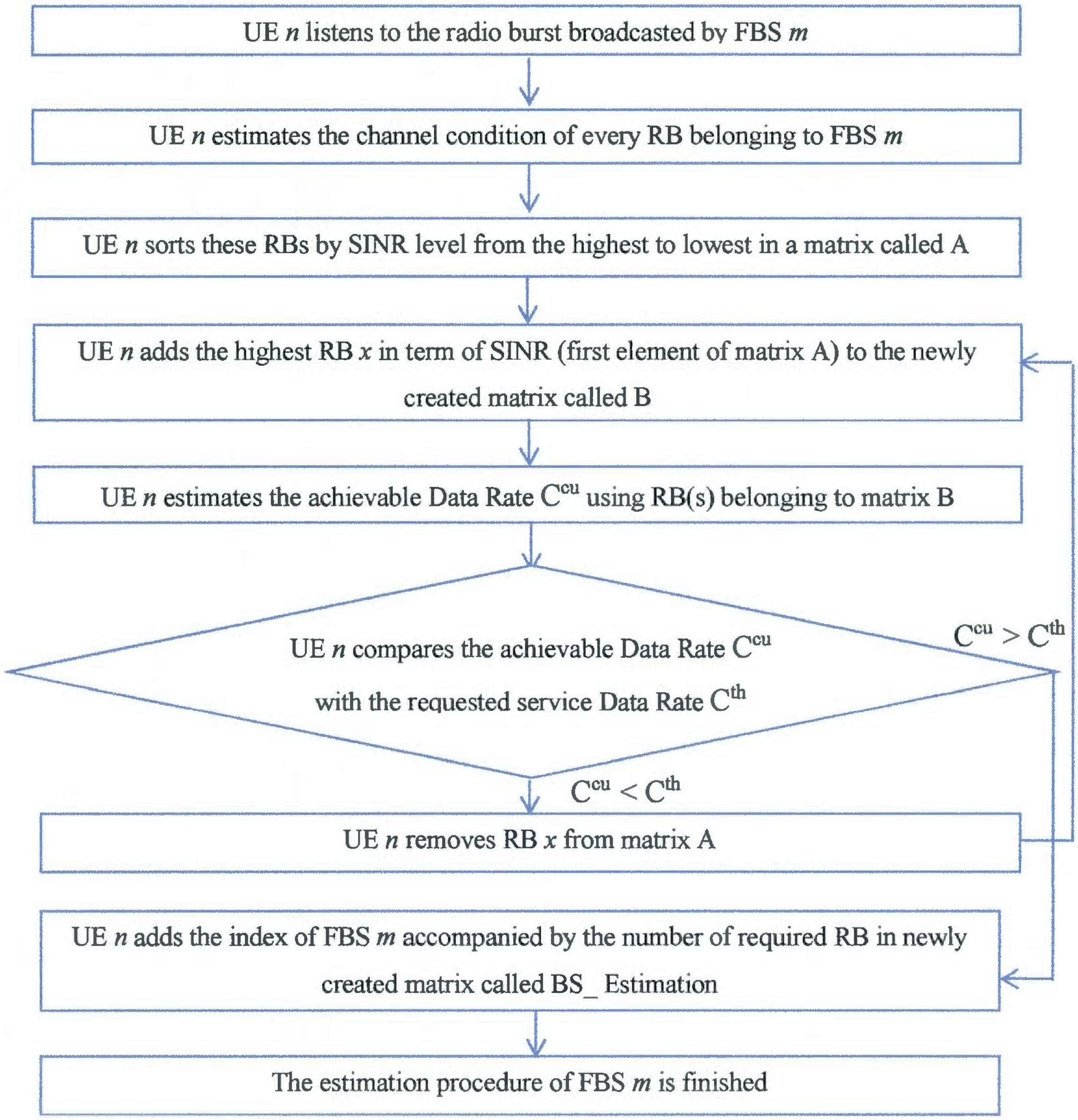


Figure 4.2 FBS estimation procedure

4.3 Resource Block assignment strategy

By proposing the Resource Blocks assignment strategy, we aim to further increase the number of active UEs per FBS. This strategy is applied at the FBS level.

As shown in Algorithm 4.2 and Figure 4.3, first, when a FBS *m* receives only a single service request message from one UE it simply allocates the demanded RB(s) to that UE. As a result, the RB assignment strategy of FBS *m* is completed and the algorithm jumps to treat the next UE. However, when a FBS *m* receives several service request messages from different UEs at the same time, it creates immediately a matrix called First_to_serve. This matrix comprises the requesting UEs index accompanied with the demanded RBs indexes. Afterward, the FBS *m* checks the capability of available, unoccupied, RBs to support the next UE's service. If these RBs are incapable of supporting the UE *n* requiring the least number of RBs among UEs belonging to First_to_serve matrix, the RB assignment strategy of FBS *m* is interrupted and the algorithm jumps to treat the next FBS. Otherwise, in the opposite case, the FBS *m* allocates the demanded RB(s) to UE *n* requiring the least number of RBs. Next, FBS *m* removes UE *n*'s entry from First_to_serve matrix (because it is just treated). Then, it updates the number of non-served UE(s). Afterward, FBS *m* checks the number of non-served UE(s). If there is no more UE(s) waiting to be served, the RB assignment strategy of FBS *m* is completed and the algorithm jumps to treat the next FBS. Otherwise, if there are at least a single UE waiting to be served, FBS *m* executes the RB estimation procedure to determine the next UE to treat. Following by updating the First_to_serve matrix. After that, the algorithm jumps to treat the next FBS. When unoccupied RBs of FBS *m* become incapable of supporting any more UE, the non-served UE(s) consider(s) FBS *m* unavailable or inaccessible and remove it from their BS_Estimation matrix. Afterward, each non-served UE selects from its BS_Estimation matrix the FBS that supports the demanded services with the least number of RB(s) and sends to it a service request.

```
for each FBS do
    if (FBS m receives a single service request)
        FBS m allocates RB to that UE
        The RB assignment strategy of FBS m is completed
    else if (FBS m receives multiple service request)
        FBS m creates First_to_serve matrix
        for each UE (in First_to_serve matrix)
            if (the number of unoccupied RB(s) is capable of supporting the next UE)
                FBS m selects the UE n requiring the least number of RBs
                FBS m allocates the demanded RB(s) to UE n
                FBS m Updates the number of non-served UE(s)
                if (the number of non-served UE(s) is equal to 0)
                    The RB assignment strategy of FBS m is completed
                else if (the number of non-served UE(s) is equal or superior to 1)
                    The FBS m starts the RB estimation procedure
                    The FBS m updates First_to_serve matrix
                end if
            else
                The RB assignment strategy of FBS m is interrupted
            end if
        end for
    end if
end for
```

Algorithm 4.2 RB assignment strategy's pseudo code

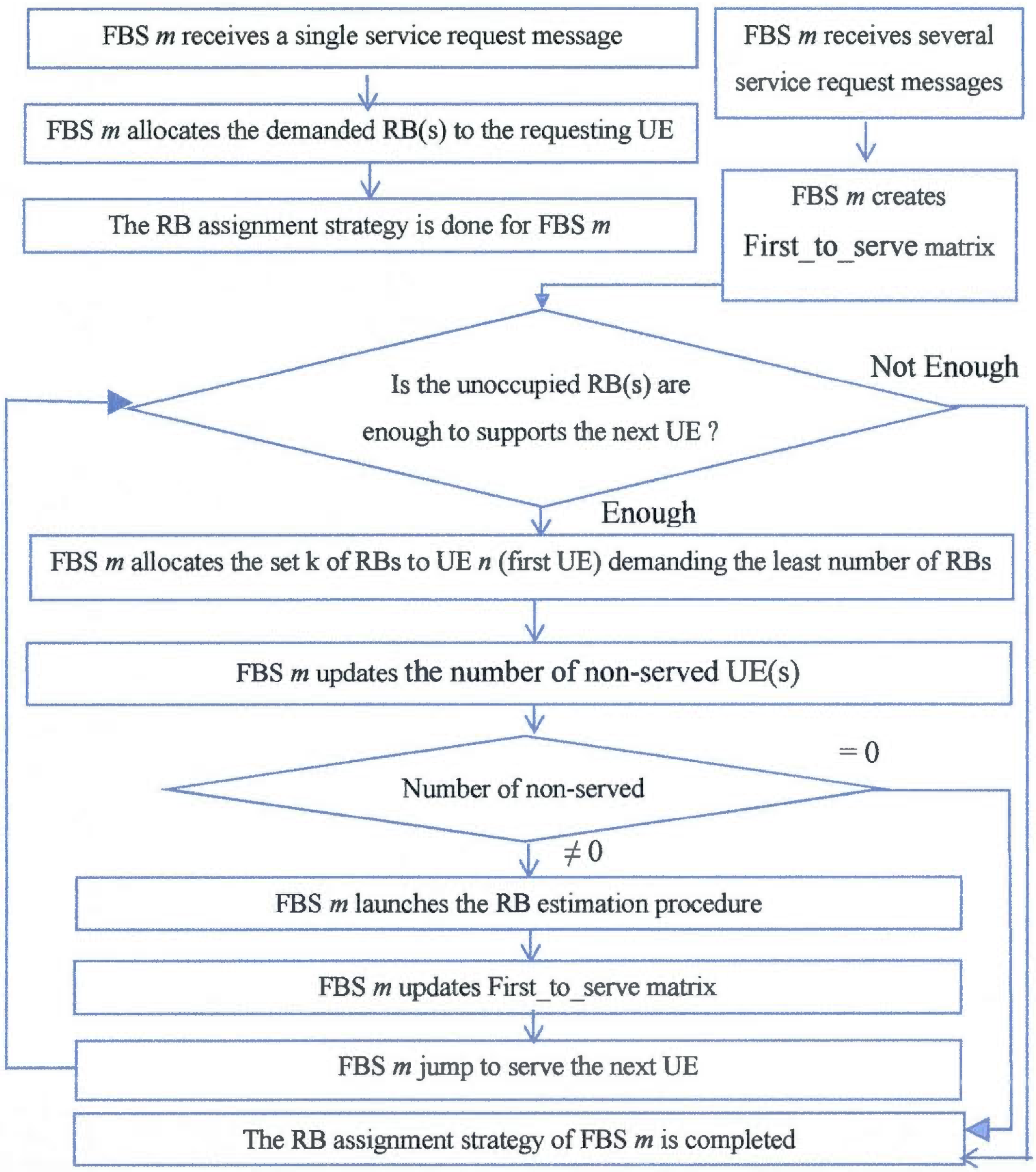


Figure 4.3 Resource Block Assignement

4.3.1 RB estimation procedure:

The aim of the RB estimation procedure is to determine the identity of the next UE to be served by FBS *m*. The RB estimation procedure is demonstrated in Figure 4.4.

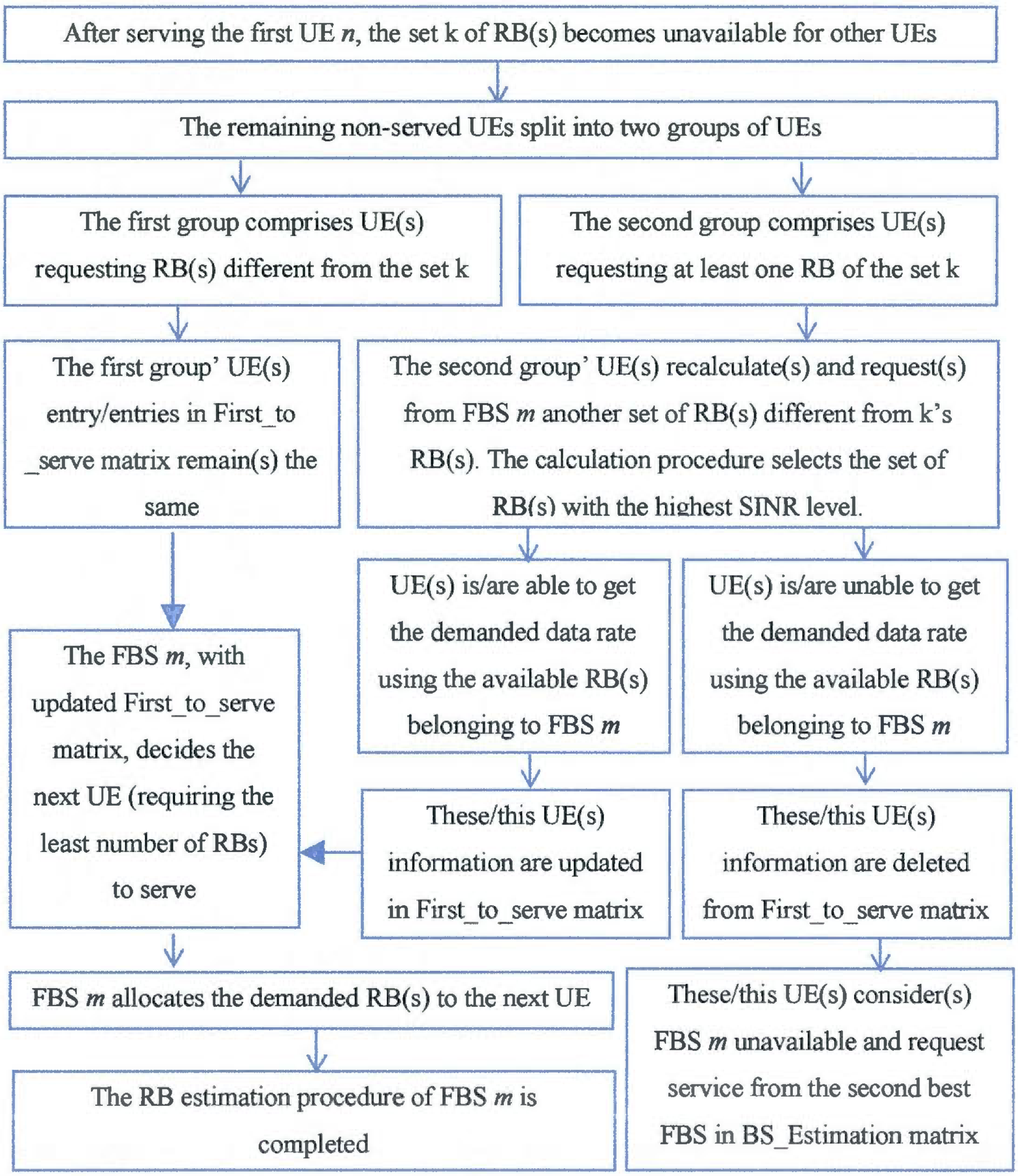
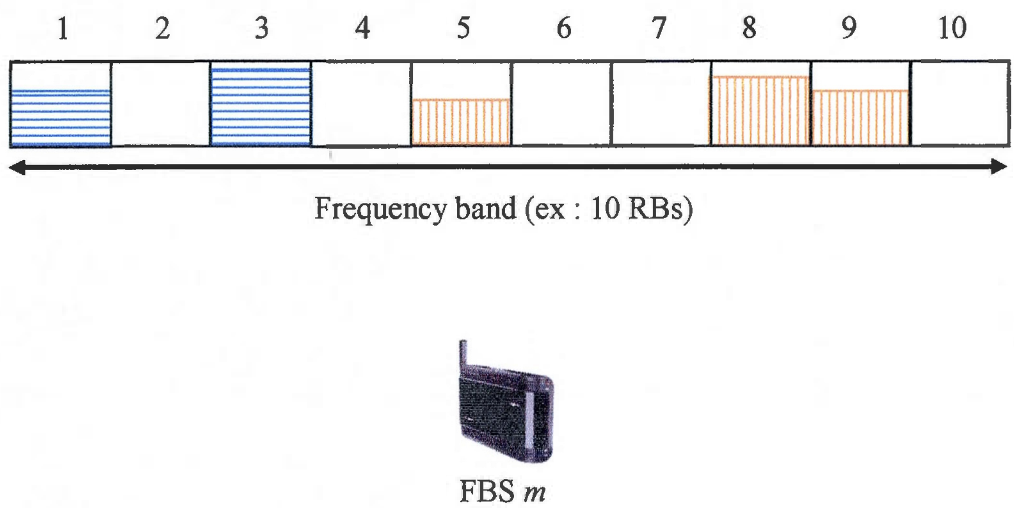


Figure 4.4 RB estimation procedure

After serving the first UE *n*, k's RB(s) become(s) unavailable to the other non-served UEs over the same FBS. However, the creation of First_to_serve matrix does not consider that particularity. In other words, the first assessment of FBSs done by UEs (BS_Estimation) does not consider the occupied set of RB(s) k allocated to, the first served, UE *n*. Therefore, the remaining UEs requesting services from FBS *m* split into two separate groups of UEs.

The first group comprises UE(s) requesting RB(s) different from the set k of occupied RB(s). The second group comprises UE(s) requesting at least one RB of the occupied set k of RB(s). The first group of UEs entries in First_to_serve matrix remains the same. While the second group of UEs re-estimates and requests from FBS *m* other RB(s) different from the set k. The re-estimation procedure is similar to that of FBS estimation procedure, where the RB with the highest SINR level is selected first until achieving the demanded data rate. Still, not every UE will be lucky enough to find new RB(s) that replaces RB(s) belonging to set k. UEs who can't achieve the requested data rate, using the available RBs (belonging to FBS *m*), are deleted from First_to_serve matrix. These UEs consider FBS *m* inaccessible. So, they send service request message to the second best FBS in BS_Estimation matrix. UEs who can achieve the requested data rate, using the available RBs (belonging to FBS *m*), are updated in First_to_serve matrix. Afterward, FBS *m*, with updated First_to_serve matrix, selects and serves the next UE (requiring the least number of RBs). As soon as the identity of next UE is decided, the RB estimation procedure is completed.

The Figure 4.5 clarifies the problem encountered by UEs requesting the same RB already allocated to the first served UE. In this example, UE 2 (grid pattern) is requesting four RBs. However, RB number 1 is already allocated to user 3 (horizontal lines pattern). In that case, UE 2 tries to replace RB number 1 with other available RB(s), belonging to FBS *m*, in order to achieve the demanded data rate for the requested service. In case of not achieving the demanded data rate, UE 2 must send a new service request message to the second best FBS in its BS_Estimation matrix.



UE index	Number of RB(s)	RB(s) indexes	Serving order
3	2	1,3	1
7	3	5,8,9	2
2	4	1,2,4,6	re-assessment

Table 4.3: Example of First_to_serve matrix

Figure 4.5 RB allocation example

CHAPTER V

SIMULATION PARAMETERS & RESULTS DISCUSSION

In this chapter, we first introduce the used simulation tool, known as MATLAB, then we clarify our simulation scenario and parameters. Finally, we compare our proposed solution to two other propositions through extensive simulations in which we vary the number of UEs and active FBSs. We choose to compare our proposed solution to gain based assignment strategy as well as to an average-SINR based assignment strategy. In this section we refer to our solution as selective-SINR based assignment strategy.

In order to evaluate the performance of our proposed solution, we use well-known numerical computing software namely MATLAB. In Brief, it is a numerical computing environment and fourth-generation programming language, developed by MathWorks. It allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran (MATLAB, n. d).

5.1 Simulation parameters

We study the benefits of implementing our intelligent base station assignment strategy and frequency resource assignment strategy in a dense femtocell based LTE network. For simplicity, we consider only downlink transmissions. Both Path loss and Rayleigh fading are considered. In the LTE context, the elementary time/frequency resource is called the resource block (RB). The RB is defined as a block of physical layer resources that spans over one slot (0.5ms) in time and over a fixed number of adjacent OFDM sub-carriers in the frequency domain (12 sub-carriers). The bandwidth of each RB is 180 KHz.

In this work we focus on simulating a dense femtocell scenario using a dual strip model. We consider a 70m x 120m space with two apartment's complex of whose building contains femtocell transmitters. The apartment complex consists of two rows of 20 apartments (2 by 10 apartments) separated by 10m width street. Each apartment measures 10m x 10m. FBSs are omnidirectional with 20 dBm transmit power. We consider a fixed power allocation strategy. We assume for this scenario a W band of 5 MHz that comprises 25 RBs. The 5 MHz band is shared among all FBs.

The UEs are uniformly distributed within the simulation environment, inside and outside the two buildings. Several UEs can be placed inside the same apartment while a neighboring apartment can be empty. We vary the number of placed UEs in each simulation between 40, 80 and 120. Similarly, FBSs are uniformly distributed inside the two buildings. However, each apartment can only have a single FBS. We vary the number of deployed FBSs between 20, 30 and 40. Furthermore, we consider that all deployed FBSs are active. We assume that the penetration loss of indoor walls (L_{iw}) is equal to 5 while the penetration loss of outdoor walls ($L_{ow,1}$ and $L_{ow,2}$) is equal to 20. The remaining simulation parameters are given in Table 5.1.

Description	Value
System Bandwidth	5 MHz
Number of RBs per FBs	25
RB Bandwidth	180 KHz
Subcarrier spacing	15 KHz
Channel model (Path loss)	Dual strip model
Channel model (fading)	Rayleigh fading
Simulation scenario size	70 X 120 meters
Number of FBSs	20, 30 and 40
Number of UEs	40, 80 and 120
Number of building	2
Number of floors	1
Number of apartments	40
Size of a single apartment	10 X 10 meters
Femtocell transmission power	20mW
Antenna technology	SISO
Cellular technology	LTE
Type of data traffic	Constant data rate
Transmission direction	Downlink
Penetration loss of indoor walls	5 dB
Penetration loss of outdoor walls	20 dB
White noise power	-174 dBm/Hz

Table 5.1 Simulation parameters

5.2 Results discussion

For comparison purposes, we propose two other base stations and frequency resource assignment strategies named *Gain-based assignment strategy* and *Average-SINR assignment strategy* while we refer to our solution as *Selective-SINR assignment strategy*. The major difference between the three strategies is the selection factor of the best serving FBS and frequencies resources (RBs).

In *Gain-based assignment strategy*, each UE listens to radio bursts and calculates the number of RBs needed for the requested service related to each FBS. The estimation procedure sorts the RBs of each FBS in term of gain (minimum path loss) and selects the set of RBs with the highest gain until achieving the requested data rate needed for the service. Similarly, the RB assignment strategy is based on the same selection factor (highest gain first). The previous estimated number of RBs needed for the requested service is used again to sort UEs from the one that needs the least number to the one that need the most number of RBs. The only difference between the two solutions is represented in the sorting parameter of RBs (gain instead of SINR).

In *Average-SINR-based assignment strategy*, each UE sends command to FBSs broadcasting radio burst and let them estimate the channel condition over all the available RBs. Afterward, each FBS that receives the command estimates the average SINR value of all unoccupied RBs and sends that value to the UE. Such strategy is capable of reducing the duration of estimating the radio channel quality due to superior sensing and calculation capability of FBSs. As soon as the UEs receives the average SINR value from different FBSs, it selects the FBS that offers the highest average SINR value and sends to it a service request. The RB assignment strategy is identical to the *Selective-SINR assignment* solution. In this simulation, we vary the number of UEs and FBSs in different simulations in order to see how our combined effort algorithm performs. In this section we calculate the outage ratio of UEs in the whole considered system. The outage ratio definition is explained in Section 3.4.

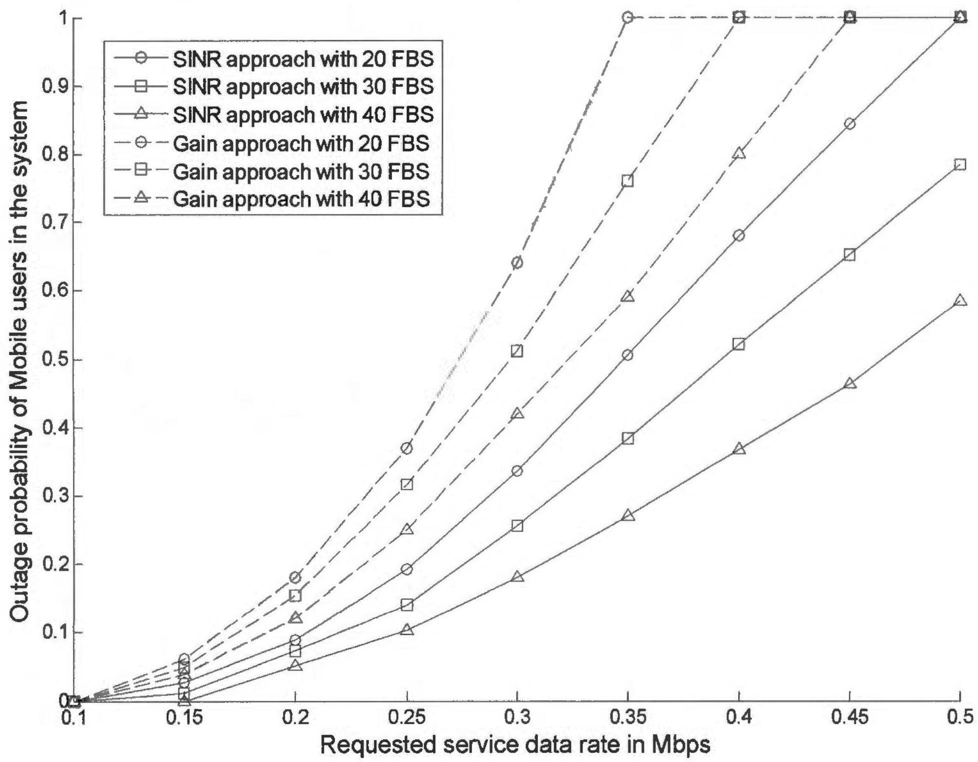


Figure 5.1 SINR approach versus gain approach with120 UEs

The Figure 5.1 shows the results of comparing the *Selective-SINR based strategy* to the *Gain-based strategy*. In this specific simulation we vary the number of FBSs from 20 to 40 and see how the two approaches react to the added number of FBSs. Due to the fact that both of these strategies are built upon the same framework, they showed a significant improvement in the number of simultaneous supported UEs as soon as we add more FBSs. By doubling the number of FBSs from 20 to 40, we almost reduce the outage ratio to the half with requested service of 450Kbps and higher. The reduction of the outage ratio resulting from adding more FBSs shows a high level of scalability. On the other hand, our proposed *SINR-based* solution shows superior results to the gain based solution due to taking into consideration the level of interference in the RBs selection and assignment procedures. For instance, with 40 FBSs, for a requested service of 450Kbps (as minimum constant data rate), the *Selective-SINR based approach* shows an outage ratio below the 0.5 while in *Gain-based approach* the outage ratio already achieves 1.

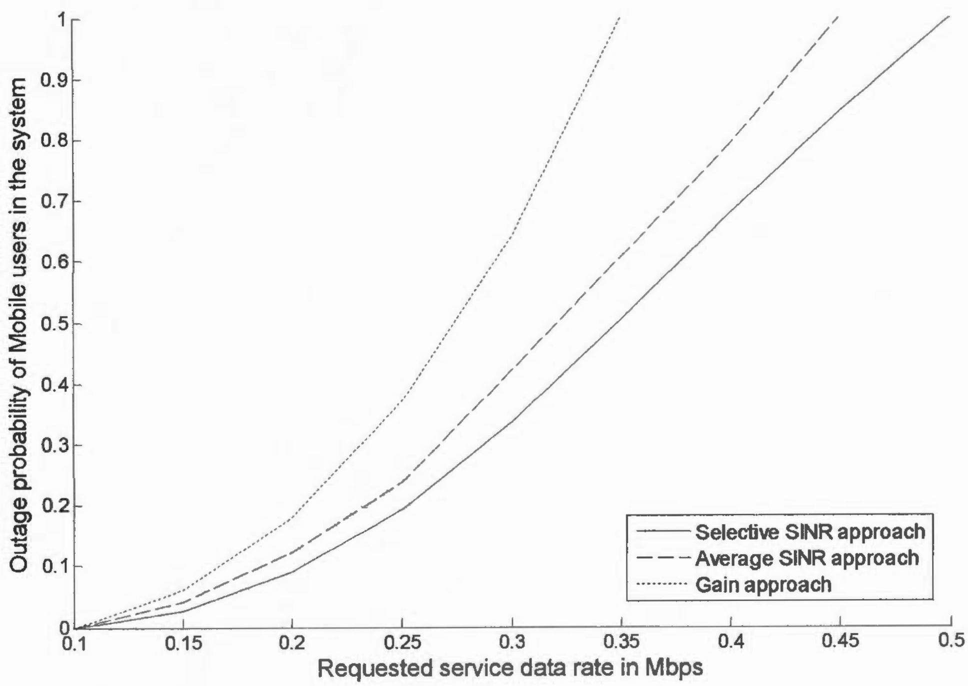


Figure 5.2 selective-SINR vs average-SINR vs gain approach

The Figure 5.2 shows the outage probability comparison between all the three approaches in a simulation scenario with 120 UEs and only a 20 FBs. The results show the superiority *of Selective-SINR based approach* over the two other approaches. These results are caused by the intelligent selection of RBs in the *Selective-SINR based approach* in way that ensure minimum interference and high gain in both the FBS assignment and RB assignment procedures. However, the *Average-SINR based approach* shows close results to *Selective-SINR-based approach* with reduced estimating duration of RBs channel quality.

CONCLUSION

In this work, we focused on improving the system performance of a dense femtocell scenario that simulates a realistic environment. First, we study the previous proposed solutions that aim to mitigate both cross-layer and co-layer interferences. Then, we formulate our optimization problem and we fix our aim to improve the maximum number of active mobile users per FBS. More precisely, we concentrate on mobile users requesting services that demand constant data rate in highly populated area. In order to achieve that goal, we proposed a femtocell base station assignment strategy coupled with a frequency resources assignment strategy. Our proposed solution assists each mobile user to synchronize with the FBS that offers the set of RBs with the highest SINR level which will minimize the number of RBs allocated to each UE. As a result, the efficient RBs allocation strategy will lead eventually to maximize the number of UEs per FBS and finally reduce the outage ratio of mobile users in the whole system.

Through simulations, our proposed solution namely *Selective-SINR assignment strategy* shows superior performance compared to the *Gain-based assignment strategy* by reducing more efficiently the outage ratio of UEs requesting real time services. By taking into consideration the level of interference, originated by neighboring FBSs, during the RBs selection and assignment procedures the *Selective-SINR assignment strategy* shows twice the performance of *Gain-based assignment strategy* for UEs requesting 450Kbps's services. Additionally, by increasing the number of deployed FBSs, in a highly populated environment, we experience a significant reduction in term of outage ratio of UEs in either strategies thanks to offering more FBSs choices to UEs requesting real time services.

Based on these results, our fully distributed solution shows a high level of practicality and scalability and proves itself in reducing the outage ratio of UEs in the system compared to both *Gain-based assignment strategy* and *Average-SINR-based assignment strategy* thanks to the intelligent selection of RBs that ensure minimum interference and high gain in both the FBS assignment and RB assignment procedures.

Yet, these results can be further improved by introducing a cluster based architecture that benefits from limited information exchange among FBSs members. These limited information exchanges assist FBSs to adjust their transmission power over each RB in a way that reduce the overall level of co-layer interferences. These further improvement suggestions represent our future work goals.

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