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DEPLOYMENT OF FEMTOCELL AND ITS INTERFERENCE MANAGEMENT APPROACHES IN LTE HETEROGENEOUS NETWORKS

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ABSTRACT

With a vast number of wireless devices being connected to the system, the need for very high data rates and extremely low latency with ultra-high reliability is becoming more and more challenging. And with such density of network nodes, it is a huge challenge to provide wide coverage and high quality service in indoor environments. Femtocell, a new add-on in the small cell technology, acts as an extension to the existing outdoor macrocell with the aim of providing quality indoor coverage. However, vast deployment of femtocell network in the absence of proper network planning and coverage strategy makes it difficult to maintain the desired quality of service. Additionally, the service of femtocell in densely deployed heterogeneous network is challenged by interference, unwanted handover and signaling overhead in the system. Given the huge potential of the femtocell technology, extensive research has been carried out by companies, service providers and operators to mitigate the interference and to ensure the highest benefit of femtocell deployment. Against this backdrop, a rigorous review has been attempted in this paper with a brief analysis on femtocell technology and its deployment in LTE Heterogeneous Networks. Challenges of vast femtocell deployment and different interference management techniques have been studied with a quantitative comparison. Graphical and tabular analysis on the interference management techniques is also presented along with their advantages and limitations.

Keywords: *Femtocell, Interference Management, Hetnet, LTE, Small Cell*

1. INTRODUCTION

Due to the advances in modern cellular technology, wireless devices have become an essential indispensable element in our daily life. The rapid growth and proliferation of wireless devices and gadgets have turned the cellular networks from being basically voice networks to become mostly data networks. To provide this higher rate of data, operators across the world have switched to higher frequency to increase the bandwidth. However, increasing number of wireless nodes in sub-urban and urban areas has created a bigger challenge for the outdoor base station to provide quality coverage in indoor environments. According to recent studies, roughly 66% of the phone calls and 90% of the data services take place in indoor environments (e.g. home, office, enterprises)[1-3]. However, more and more users complain of poor connectivity as the received signal strength from outdoor Base Station (BS) weakens and deceases in performance due to the high penetration loss in the walls [4]. As stated in article [5], 45% of the residential subscribers and 30% of the corporate subscribers complain of poor indoor coverage. The existing outdoor base station cannot increase the transmission power in an infinite level to ensure the coverage in outage areas. The growing demand for broadband wireless access inside residential (indoors) environment along with the shortage of capacity in the existing outdoor base stations have motivated wireless service providers to look for possible solutions to improve indoor coverage with high data rates and enhanced Quality of Service (QoS). To handle these challenges, different deployment strategies have been proposed earlier including installation of extra macrocell, Distributed Antennas (DAs), hot spots, In-Building Solution (IBS), picocells, and multi-hop relays. The infrastructure for doing so, nonetheless, is expensive and cannot guarantee high quality indoor coverage. The concept of femtocells has recently

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been introduced as the cheapest solution for indoor wireless broadband [6-9].

Femto Base Station (FBS) or Femotcell Access Point (FBS), is a small base station typically designed for indoor use in a Small Office Home Office (SOHO) environment to provide voice and broadband services. FBS is a cost competitive, low power, short-range wireless device operating in the licensed spectrum. The term femtocell itself was first coined in 2006. FBS is not a new concept as it was first studied in 1999 by Bell Labs, while GSM based home base station were brought to the market by Alcatel in 2000. The first 3G-based home base station was introduced by Motorola in 2002[10]. In the metric measurement system, "Femto" means one-quadrillionth (10^{-15}). FBS is installed by the users to ensure seamless indoor coverage with better voice and data reception [11, 12]. FBS, on the air interface, provides radio coverage to a given cellular standard [13], such as Global System Mobile (GSM) communication, Wideband Code Division Multiple Access (WCDMA), Universal Mobile Telecommunications System (UMTS), Worldwide Interoperability for Microwave Access (WiMAX), and Long Term Evolution (LTE. The 3rd Generation Partnership Project (3GPP) refers to this FBS as Home Node Base station (HNBs). The LTE femtocell is referred to as Home evolved Node Base station (HeNB) [14]. FBSs are connected to the Internet via broadband backhaul connection such as, cable modem, digital subscriber line (DSL), on premise fiber optic link, separate Radio Frequency (RF) backhaul channel, satellite, or a similar IP backhaul technology. The wired connection is used to integrate the FBS with the mobile operator's core network. FBSs were introduced in the 3GPP release 8 in 2008 [15]. Given the continuous evolving of technologies of cellular networks, several femtocell specifications and standards are being included in the technical reports of 3GPP and 3GPP2 [16, 17].

Triggered by its highly spectral efficiency and low implementation cost, OFDMA has been utilized in many high-speed wireless transmission standards (e.g. LTE, WiMAX, and Wi-Fi). Long Term Evolution (LTE) is a broadband wireless access technology designed to support mobile Internet access via cell phones or handheld devices. As LTE exhibits significant performance improvements over previous cellular communication standards, it is commonly referred to as fourth generation (4G) technology [18]. This paper treats LTE as a standard to investigate the interference problem in OFDMA-based femtocell networks. The standard was developed by the 3GPP and was specified and enhanced in Release 8 and Release 9 of its document series respectively [19]. Besides LTE, LTE-Advanced has been developed as successor standard of LTE. There are many solutions which have been specified in release 10 and release 11 (LTE- Advanced) of LTE, and more solutions are studied and developed in the next release (Rel-12 and beyond). A number of worldwide mobile operators showed interest in LTE HeNB technologies as a promising solution to increase system capacity in the near future [20]. This paper is intended to focus on the role of femtocell in LTE heterogeneous network and the challenges of femtocell deployment in the existing network. The paper also explores the different interference management techniques and their performance in OFDMA based femtocell network to support the vast deployment of femtocell. The remainder of the paper moves as per the following roadmap: Section 2 provides short background information about LTE femtocell technology, Heterogeneous Networks, femtocell evolution compared to other wireless technologies, and finally discusses the pros and cons of femtocell deployments. Section 3 discusses in details the interference issue and provide different interference scenarios in OFDMA two-tier macro-femtocell heterogeneous networks based LTE. Section 4 reviews previous research on interference management techniques in femtocell networks. Section 5 provides qualitative comparison with various interference approaches and finally Section 6 provides concluding remarks.

2. LTE FEMTOCELL

The LTE femtocells are referred to as Home evolved Node base station (HeNBs) [14]. HeNBs operates in licensed spectrum owned by mobile operators to improve indoor wireless coverage, as well as, to increase the system capacity, and to enable the service of Fixed Mobile Convergence (FMC). HeNB is installed in homes, offices and other places by the user himself to ensure seamless coverage with better voice and data reception where macrocell coverage cannot reach. HeNB enables FMC service by connecting to the cellular core network via a wired or wireless backhaul connection. This connection is used to integrate the HeNB with the mobile operator's core network. Figure 1 shows the connection diagrams between various indoor User Equipment (UE) and the HeNB. Femtocell can support four to ten active users simultaneously [11, 12, 21].

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Figure 1. A Typical Indoor OFDMA Femtocell Architecture In LTE.

2.1. Heterogeneous Networks Serving Cells

The traditional cellular network deployment approaches are mainly macro-centric cell architecture where the macrocell base station corresponds to the main network layout. Such macrocell based cellular network is referred as homogeneous network. In homogeneous network, all base stations have similar transmission power levels, antenna heights, and antenna patterns [22]. A network, incorporating the hierarchical layering of cells with macro base stations coexisting with low-power and short-range small cells (such as femtocells, picocells, Remote Radio Heads (RRH) and/or Distributed Antenna Systems (DASs), and relays) in the same service area, is referred to as a Heterogeneous Network (HetNet) or a multi-tier network as illustrated in figure 2. HetNet or a multi-tier network is considered an efficient solution to enhance the spectral-efficiency per unit area of the network. It provides significant improvement in the coverage of the indoor and cell-edge users and assures better quality-of-service (QoS) to the users. In recent years, HetNet-based deployment model is adopted by the mobile operators all over the world. On the contrary, HetNet or multi-tiered cellular network is overlaid with additional infrastructure in the form of smaller, low-power, low-complexity and short-ranged base stations (referred as small cells) [23].

Figure 2. Layout Of A Heterogeneous Cellular Wireless Network

Before the femtocell, Picocell was the ultimate solution for indoor coverage. The coverage area of picocells usually ranges between 75 meter and 150 meter. The picocells consist of Omni-directional low-transmission antennas providing significant indoor coverage to the UEs in the public places such as airports, railway stations, stadiums, and shopping malls [23]. DASs comprise of several separate Antenna Elements (AEs) and /or Remote Radio head connecting to Macro Base Stations (MBSs) via dedicated Radio frequency (RF) links or fiber optics cables to extend the macro coverage. Similarly to picocells, relay nodes are also used to improve coverage in indoor areas (e.g., events, exhibitions, tunnels, and high-speed trains, etc.). However, relay nodes backhaul their data traffic via wireless link to a donor cell. There are two types of relay nodes: Inbound relays and Outbound relay. In the case of inbound relay nodes, the same frequency spectrum is used for relay link and backhaul link. A comparison of the different technologies for indoor coverage is summarized in Table 1 below.

Table1. *Comparison of Various Indoor Wireless Access Technologies*

Wi-Fi in a Wireless Local Area Networks (WLAN) is a plug and play broadband wireless access point technology. Wi-Fi access point is similar to femtocell base station (FBS) in terms of size. Both FBS and WiFi are backhauled to the internet via a broadband connection. Their performance is, therefore, affected by IP network conditions. The FBS implements cellular technology which can initiate a call in a real time using a licensed spectrum, while WiFi WLAN is mainly used for data services and voice over IP (VoIP) through unlicensed Spectrum. Table 2 provides a brief comparison that clearly illustrates the similarities and differences between femtocell and WiFi technologies [24].

Table 2 Femtocell Versus Wi-Fi

2.2. Femtocells Deployment

Femtocells can bring benefits to both operators and users. From the operator's viewpoint, the femtocell helps manage the exponential growth of traffic and increase the reliability of macrocell network. The growing number of towers and other elements of cellular network infrastructure increase the operating expenditure (OPEX) and capital expenditure (CAPEX). Femtocells use the licensed electromagnetic spectrum that is allocated to cellular service providers. It also allows the same security protocols as macrocell cellular service. Another advantage is that traffic served by femtocell is carried over wired broadband connections. This offloads the traffic load of Radio Access Network (RAN) and saves the backhaul cost for mobile operators. From the subscriber point of view, femtocell provides better indoor signal strength, high data rates, and improved Quality-of-Service (QoS) in indoor environments. Femtocell technology is also of benefit to the extension of battery lifetime of user equipment (UE) since the reduced communication link between UE and HeNB is smaller than that between UE and Macro base station [11]. In addition to that, femtocell can interact with smart homes technology. User can remotely control and connect to any electronic device at home and the interaction between all smart home devices can be done through HeNB

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[25].The benefits achieved from femtocell deployment are highlighted in Table 3[11]. Aside from the significant benefits femtocell technologies provide, they still face several technical challenges. Electromagnetic interference management, for instance, is considered as the prime issue above all. For successful femtocell deployment, mobile network operators and researchers worldwide are experimenting different techniques to counter this interference issue.

Table 3. Benefits Of Femtocells For Operator And Users

2.3. Technical Challenges Of Femtocell Deployment

The deployment of femtocell in the existing LTE HetNet brings several technical challenges to the operators. The key technical challenges associated with the dense deployment of femtocell, most specifically in urban and sub-urban areas are briefly described below:

Interference management*:* The major technical issues associated with the mass deployment of femtocells are the interference management between femtocell and other serving cells in the same spectrum. Since femtocells use same frequency spectrum as macrocells, it is important to develop an efficient interference management technique that increases the capacity and throughput of the network along with improved QoS to the UEs. Various methods are being proposed in the recent literature and these methods are presented in section 4 of this paper.

Handover and mobility management: When a huge number of femtocells are deployed under the coverage of macrocell in a typical HetNet as shown in Figure 2. It is very challenging to implement an effective mobility management and handover scheme. The problem gets more complicated especially for the unplanned deployment of femtocells in LTE networks.

Timing and synchronization: Femtocell synchronization over IP backhaul is quite complex due to a huge number of femtocells serving next to each other and inconsistent delays triggered by varying traffic congestion [26]. In OFDMA-based femtocell network, errors in timing and synchronization can cause inter symbol interference (ISI) and hence efficient algorithms should be developed to solve this problem [27].

Security: Since femtocells could be vulnerable to malicious attacks, security of femtocell is considered as a key issue. Network access security for authentication and authorization procedures are required to protect subscribers and femtocell network against fraud and unwanted risks.

Self-organization: Given the fact that it is installed by the end user, femtocell needs to support an auto initialization and configuration [28].

Moreover, QoS in femtocell depends largely on the broadband internet connection backhaul. Failure of backhaul internet will result in failure of femtocell. Prior to mass deployment of femtocell, the aforementioned technical challenges still need further investigation to guarantee interoperability with existing macrocell [29].

3. INTERFERENCE ISSUE IN OFDMA MACRO-FEMTO LTE HETNET

The major technical issue associated with the mass deployment of femtocells is the interference management between femtocell and macrocell and among neighboring femtocells. Generally, interference in OFDMA-based macro-femto tier network can be classified into two major types; co-tier interference and cross-tier interference as shown in figure 3.

Figure 3. Types Of Interference In Ofdma-Based Two-Tier Hetnet

Co-Tier Interference: Co-tier interference takes place between network elements of same tier. In terms of femtocell, co-tier interference relates to the interference between neighboring femtocells. Co-tier interference occurs in two different forms; uplink co-tier interference and downlink co-tier interference. The uplink co-tier interference occurs when femtocell user equipment cause interference in the uplink to its neighboring femtocell base stations which is illustrated in index 5 of figure 4 and table 4. Downlink co-tier interference occurs when a FBS may cause downlink interferences to a nearby FUEs. The downlink co-tier interference is illustrated in index 6 in both figure 4 and table 4. In OFDMA femtocell network, the occurrence of co-tier uplink/downlink interferences takes place only when both the neighboring femtocell attempts to communicate using the same sub-channels. Thus, for interference mitigation in such networks, an intelligent and efficient radio resource allocation mechanism is required.

Cross-Tier Interference: It is resulting from the occurrence of interference between network elements which belong to dissimilar tiers of the network; for example, between elements of the macrocell tier and those of the femtocell tier and vice versa. In figure 4, the macrocell UEs and femtocell UEs are the sources of uplink cross-tier

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interferences towards the nearby Femtocell Base Stations (FBSs) as well as the serving Macrocell Base Station (MBS) as shown in indexes 1 and 3 of both figure 4 and table 4 respectively. Conversely, the serving MBS, together with the FBS results in forward link (downlink) cross-tier interferences to the FUEs as well as neighboring MUEs as illustrated with indexes 2 and 4, respectively. Figure 4 provides a summary of the various cross-tier scenarios. For OFDMA networks, cross-tier forward-link (downlink)/reverse-link (uplink) interferences occur only in cases where both the aggressor and the victim attempt to use the same sub-channels. Thus, efficient channel allocation is indeed crucial for interference avoidance is such systems. Figure 4, again, shows all the various possibilities of interferences scenarios in OFDMA-based femtocell networks. By adopting a suitable interference management technique, co-tier interferences can be effectively avoided, while cross-tier interferences can be considerably minimized in order to improve the overall system throughput [30].

Figure. 4. Interference Scenarios OFDMA-Based Femtocell Networks [30].

Table 4. All Interference Scenarios for OFDMA-Based Femtocell Networks [30]

Given the fact that the femtocells are designed for deployment under the coverage of existing macrocells, femotcells have to be designed to operate at the same frequency as the macrocells. In order to afford optimal Quality of Service (QoS), macrocell users and femtocells may occupy a limited fraction of the available bandwidth. However, the spectral efficiency may, in such cases, be seriously jeopardized. Furthermore, unplanned femtocell deployment may cause dead zones. A dead zone is a regular phenomenon which occurs either as a result of asymmetric transmission power levels across the network or when MUE is located faraway from MBS and in vicinity to the FBS. In the downlink transmission, a cell edge MUE may be exposed to co-channel interference from neighboring femtocells because of excessive path-loss and shadowing. For these reasons, it is vital to employ robust techniques for co-tier and cross-tier interference management, with the general aim of improving the overall network throughput. Various techniques have been developed by researchers for reducing both (co-tier and cross-tier) interferences. These Techniques may include cooperative communication between the MBS or (MeNBs) and FBSs or (HeNBs), FBs group formations with information exchange connection among neighboring FBs and intelligent access to the radio spectrum.

4. INTERFERENCE MANAGEMENT APPROACHES

Interference management has been identified as the most important issue associated with the mass deployment of femtocells. Intensive investigations and research are required for the development of efficient interference management technique that can reduce both co-tier and cross-tier interference in a femtocell network. In heterogeneous network, there is no specific classification standard criterion available for interference management techniques. Different management techniques are being adopted by different air interface technologies. For example, the CDMA and OFDMA systems use different kinds of interference mitigation techniques than each other [31]. Based on different criteria, the classification of interference management techniques is also different; e.g. System centric approach and user centric approach, Centralized control strategies and distributed control strategies [32].

System Centric Approach and User Centric Approach: The interference problem, in system centric approach, is modeled mathematically. After that, related parameters are marked and key parameters of the system are optimized. In such approach, total system performance is considered more vital than the individual user satisfaction. In fact, the user fairness is hardly guaranteed in the system centric approach. Almost all the system centric techniques use the margin adaptive (MA) and rate adaptive (RA) methods. The MA method focuses on maximizing the overall transmission power while the RA method concentrates on the overall data rate of the system [32]. While ***the user centric approach*** imitates the satisfaction of users through the service of the network. In user-centric approach, the focus is always on improving the utility function that characterizes the users' satisfaction in the system. The user fairness is always guaranteed by allocating a suitable number of resources to each user for any particular service. However, overshooting from different serving cells and uplink interference management are also considered in some cases [32].

The Centralized Control Strategy means that there will be a central control system that assigns the sub-channels to the users based on some predefined algorithm or techniques. These algorithms or techniques usually collect Channel

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State Information (CSI) from both the serving cells and the users' equipment and assign the channels based on the priority of service. For a proper central control strategy, a communication link between the central system and the femtocells is required. On the one hand, this leads to delay in response, extra cost, and maintenance complexity that appear as a burden for the mobile operators. On the other, it allows the femtocell to gather information about the existing interference scenarios in advance and reduces the signaling overhead required for detecting the interference.

Distributed and Self-Organizing Strategy: In this strategy, each femtocell allocates the sub channels in either a cooperative or a non-cooperative fashion. In the non-cooperative scheme, the femtocell (HeNB) allocates the sub-channels to each user based on their required throughput while maintaining a particular level of QoS. In the cooperative approach, the femtocell or HeNB collects the information about the neighboring femtocells and performs its sub channel allocation technique considering the effects it may cause to neighboring cells. Like this, the femtocell ensures a fair throughput and QoS that is also reflected in the global performance of the system. Such cooperative approach is very useful in terms of interference management and resource allocation. On the other hand, it drags additional signaling overhead and sensing mechanism to collect and extract information about neighboring serving cells that leads to system delay and degradation of performance. Overall, the distributed method provides extra options to the femtocell as they asses the resources based on channel state condition and can exchange information among the neighboring femtocells. However, the distributed schemes are quite complicated since it requires self-organization and optimization capacity. It needs to have the prior knowledge of the both tier of users who are being assigned by the same spectrum so that it can avoid causing interferences to the desired users. Many distributed schemes have already been proposed in recent literature but there is still lack of an effective and less complex technique.

In this paper, the classification of interference management techniques is presented in four categories. Resource allocation which includes resource partition, fractional frequency reuse (FFR) and power allocation control based approaches as well as cognitive based approaches, hardware based approaches and some other hybrid approaches. The hybrid techniques are sometimes much more effective than the regular technique in interference mitigation. Furthermore, hybrid access control mechanism with both joint power control and resource allocation has proven quite useful in some scenarios. This mechanism can be very effective in heterogeneous networks with vast number of small cells. All approaches in OFDMA femtocell network can be classified in different categories. Figure 5 shows the tabular categorization of the interference management techniques. The literature on the various interference management techniques developed by researchers has been reviewed. This literature focuses largely on the downlink and uplink transmissions and the related interferences, most specifically, the co-tier and cross-tier interferences.

Figure 5. : Interference Management Techniques HetNet Based- LTE

4.1. Radio Resource Allocation Based Approaches

Resource allocation can be achieved through spectrum (frequency) allocation, resource partitioning, fractional frequency reuse (FFR), and power allocation control. A two-tier HetNet based LTE comprises MeNBs in the first-tier, overlaid with small cells (e.g., HeNBs) in the second tiers. Spectrum resource allocation is considered a very important issue. "The possible spectrum allocation for femtocell deployment are orthogonal (dedicated-channel deployment), co-channel deployment, and partial-channel sharing deployment" [33].

Orthogonal-channel deployment: It is best known as a dedicated approach or Spectrum splitting. Under this deployment, a different dedicated carrier frequency is allocated for both macrocell and femtocells. From the spectrum reuse view, it is considered ineffective since the available spectrum is divided between macrocell and femtocell. The femtocells, in such a scheme, requires extra spectrum that is difficult to allocate as the licensed spectrum is limited.

Co-channel deployment: It is also known as shared deployment or co-channel deployment. Such deployment requires that macrocells and femtocells share the whole frequency bands. The co-channel approach is preferable by operators because it increases the efficiency of spectrum reuse. However, this approach suffers from co-channel interferences.

Partial-channel deployment: this is an example of a hybrid deployment. In this deployment, the whole frequency bandwidth is divided into two parts. The first part is only dedicated to macrocell users, and

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the second part is shared by both femtocells and macrocell. Partial channel sharing is more efficient than the dedicated channel deployment without causing much bandwidth loss. However, both femtocells and macrocell still face interference.

In the article [34], a spectrum allocation management scheme has been presented that splits the entire frequency channels based on a hierarchical cell agreement. The author demonstrates that the scheme ensures a superior data rate as compared to the conventional shared spectrum schemes achieved by side stepping the co-channel interference. However, spectrum splitting reduces the spectrum efficiency together with the available bandwidth. In article [35], a collective resource allocation scheme is presented for shared-spectrum two-tier OFDMA network. In this resource allocation scheme, the macrocell enjoys the whole bandwidth. On the other hand, femtocell gets access only to an arbitrary portion of the bandwidth. Like this, the system reduces the number of femtocells that are interfering with the macrocell users. As the number of femtocell increases under a particular macrocell, the available portion of the bandwidth is reduced for each femtocell. The co-tier interferences among the macrocell users are handled using orthogonal sub-channel assignment. The weakness of this spectrum scheduling approach lies on the poor quality of service for the femtocell users. In the case of vast femtocell deployment, the femtocell users will suffer very badly due to lack of available spectrum.

In article [36], a full spectrum reuse approach has been implemented on OFDMA-based macro–femtocell network. Results show that, in the absence of any kind of interference control mechanism, the performance of the system reduces drastically due to co-tier and cross-tier interferences. A self-organized resource allocation technique for femtocell has been proposed in article [37]. The authors concluded that a proper exchange of information between the femtocell and the connected femtocell users regarding the channel state condition can lead to a better allocation of sub-channels and thus increasing the throughput and capacity of the system. However, the hypothesis is limited to assigning one sub-channel to each user which is quite impractical. In order to maximize the network capacity, a joint frequency and power control mechanism has been proposed in article [38]. The proposed technique uses both centralized and distributed approaches. A performance analysis attempted in [39] shows that the system, with the help of optimization algorithm such as the genetic algorithm, performs comparatively better and can ensure a better QoS in an OFDMA wireless communication system. A resource allocation technique for OFDMA macro-femtocell networks has been proposed in [40]. The proposed model assumes a hybrid-access femtocell to grant access to public users in their vicinity and to reduce interference perceived by femtocell users. Full spectrum sharing as a means to increase system capacity is investigated. The proposed system has been modeled to maximize the network throughput for a specified interference threshold. To achieve that end, the proposed model determines the best serving base station based on link conditions. Genetic Algorithm (GA) is employed to tackle the resource optimization problem by locating the suitable bandwidth and power assignments for every user. Simulations were carried out along with an evaluation and contrast with a modified version of the Weighted Water Filling algorithm. However, GA is getting popular in benchmark optimization operation and it is still a new approach for live network optimization application. Random convergence of solutions in QoS problems with respect to a fitness function is the major limitation of the genetic algorithm. Besides, the time consumed by the optimization algorithm is also high, making it unsuitable for the real time execution [1].An extensive study has been carried out in [41] for OFDMA based femtocell networks with partially co-channel deployment. At the outset, they have launched an inter-tier interference mitigation technique unaccompanied by the femtocell user's power management that forces the femto-interfering macro cell users to employ only certain dedicated subcarriers. The non-interfering macro cell users, in turn, are competent to employ either in the dedicated subcarriers, or in the shared subcarriers. Subsequently, they have brought to spotlight the subcarrier allocation techniques which are based on the auction algorithm for macro cell users and femtocell users, and correspondingly, to separately mitigate the intra-tier interference. The proposed interference mitigation technique for femtocell networks has a clear and unsurpassable edge over some techniques in terms of performance improvement by substantially scaling down the inter- and intra-tier inferences in the network. However, partial co-channel deployment limits it down over the spectral efficiency scale.

The study in [42] presents a full frequency reuse Resource Allocation technique-based Cuckoo Search Algorithm (RACSA) for cross-tier interference mitigation in Orthogonal Frequency Division Multiple Access based Long Term

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Evolution (OFDMA-LTE) system. The innovative RACSA technique takes upon itself the task of maximizing the throughput of network according to a specified interference threshold. The initial stage of proposed techniques is devoted to obtaining the best serving BS (either MBS or FBS) for every user. In the latter stage, a Cuckoo search Algorithm is extensively employed to successfully address the problem of resource optimization by finding and allocating the suitable power and bandwidth for all the users and this ultimately, leads to mitigating the cross-tier interference for two-tier OFDMA macro-femtocell networks. The Proposed RACSA was implemented using Vienna LTE system level simulation. The simulation results revealed that RACSA reduce the cross-tier interference and improve the system performance. The performance evaluation showed that, RACSA gives (38%) and (21%) higher in system throughput, (14%) and (35%) increase in spectral efficiency, (55%) and (33%) reduction for the outage probability when assessment and contrasted are done with the results produced by previous mentioned resource allocation based genetic algorithms and auction algorithm respectively. RACSA is consider moderate time complexity when compare it with genetic algorithms based interference mitigation technique, that is because the optimization using CSA is less time consuming which more suitable for real time systems.

In [43], a mathematical model has been proposed. This model offers the solution for joint resource allocation and optimal admission control. It enhances the Quality of Service (QOS) in two-tier femtocell networks by implementing the concept of Semi Markov Decision Process (SMDP). In the proposed model, game theory is used to promote a distributed femtocell power adaptive algorithm to achieve energy efficiency in femtocell networks. The model has proved to be capable of reducing cross-tier and co-tier interference while achieving a significant power saving in OFDMA femtocell networks.

The authors in [44] have proposed a Femtocell Network Controller (FNC) which allocates resources with a different femtocell access mode to avoid co-tier interference. The proposed scheme seeks to avoid the co-tier interference for closed access femtocells. The open access femtocell coverage area is divided into inner and outer coverage areas. The inner region uses the resource used by the nearby closed access femtocells and the outer coverage uses the resource which is used by the far away closed access femtocells. However, the FNC has both time and computational complexity to apply the resource allocation in such a way for all the femtocells deployed under the macrocell coverage zones. An easy decentralized frequency-domain resource allocation technique combined with uplink power optimization for LTE femtocell base stations. Femtocells are considered as an overlaying network that reuses spectral bands of the existing macro cell. The proposed technique seeks to maximize the uplink throughput of FUEs and yet without causing performance degradation to MUEs. System-level simulations were performed to examine the power optimization problem. This problem was further explored by delving deep into the Power Control (PC) parameter space. In accordance with the parameter selection, the FUEs uplink throughput is assessed by the means of the resource allocation technique. This technique is meant to separate the macro- and femtocell users in frequency by imposing different allocation probabilities on various parts of the spectrum.

4.1.1. Resource partitioning and fractional frequency reuse

In the resource-partitioning algorithm, the whole resource is divided into sub-bands, which are in turn allocated to different sub-areas of the macrocells and femtocells given the fact that the MeNB and HeNB do not overlap. The work in [45], proposed a frequency-sharing scheme that employs frequency reuse along with pilot sensing in order to minimize interferences. In this scheme, frequency reuse factor more than 2 or above is applied in macrocell. HeNB senses the band and discards the allocated bands while using the rest of the frequency sub-bands. By employing high order modulation techniques, the throughput of the system is also improved substantially. The authors in [46] also developed another interference control mechanism for LTE-based femtocells using FFR. The mechanism allocates sub-bands to the HeNBs from the overall available frequencies that are occupied by the macrocells in other areas. The macrocell is segmented into centre zone and edge region, which includes a trio of sectors per region. The scheme employs a reuse factor of one for the center zone, while a reuse factor of three is employed in the edge regions. Figure 6 (a) shows the cellular network with static FFR deployment. Figure 6 (b) shows the frequency assignment to the macrocell's sub-bands. Here, the sub-band A is assigned to the center zones (Cl, C2, and C3), while the sub-bands B, C, and D are assigned to the regions X1, X2, and X3, respectively. The neighboring MeNB signals are sensed and

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compared with the sub-band's Received Signal Strength Indication (RSSI); which uses the unutilized sub-bands. The result analysis shows that the model offers up to 27% and 47% improvement in throughput compared to the other models that does not use FFR.

Figure 6. Interference Management Scheme Using FFR [46]

In [46], a dynamic FFR model is proposed for minimizing the interference on the downlink. Using the density and location of HeNBs, the scheme employs the FFR wireless resource hopping and orthogonal FFR. Information on the node locations is attained through the HeNB internet protocol addresses. For HeNBs located in dense inner regions, the orthogonal sub-channels must be assigned by the HeNBs. Otherwise, the HeNB uses arbitrary sub-channel. In this way, the downlink cross-tier interference is minimized.

4.1.2. Power control approach

Power control mechanisms control the transmission power of HeNBs to counter the interference in the system. An important advantage of such mechanisms is that both the MeNBs and HeNBs can utilize the whole bandwidth in a coordinated fashion. The power settings of the model may be either open loop power setting (OLPS) or closed-loop power setting (CLPS). For OLPS, the HeNBs' transmission power is adjusted using measurements or predetermined values. In CLPS, however, the HeNB transmission power adjustment is afforded in coordination with MeNB. A hybrid model is also deployed in which the HeNB switches between the pair of nodes in accordance with the operating scenarios. Another important concept is the power control on a cluster by cluster basis, where the initial power level is determined using an opportunistic mechanism depending mainly on the quantity of active femtocells within a cluster (Figure 7) [47]. The centralized sensing technique (Figure 7(a)) is deployed where the MeNB projects the quantity of active femtocells for each cluster. Another method that can be employed is distributed sensing shown in Figure 7(b). Such a method is suitable where the individual cells sense the channel to detect if the other cells are active within the same cluster. If others are found active, cell regulates its transmitted power level in accordance with the volume of the detected power.

Figure 7. Sensing –Based Opportunistic Power Control [47]

Distributed power control mechanisms is developed using the game theory for heterogeneous network architectures. There are two main types of the game theory. These are non-cooperative and cooperative game theoretical models. The study in [48] used the non-cooperative game theory to develop a distributed power assignment model transmission in the downlink. The optimization problem is modeled to maximizing system throughput under the constraint of transmission power with the MUEs and femtocell UEs identified as the leaders and followers respectively. A diverse power control techniques for femtocell networks were discussed and compared in [49].The focus was placed on the distributed power control techniques. It is substantially proved from the review that the distributed power control techniques using pilot power control schemes are a simple and yet efficient method for optimizing the coverage of femtocell together with paving the way for a considerable dip in power utilization for FBS. Another power control mechanism has been studied for closed-access femtocell network in [50]. In this proposed scheme, the maximum transmitted power is determined by the femtocell so that the macrocell mobile users do not interfere in the same spectrum. Whenever the remote mobile users reach their threshold SINR regardless of the cross-tier interference, a price is applied on the FBS. A Link budget investigation is executed in [50] to regulate the distributed power based on SINR computations. Another article [51] focuses on minimizing the coverage hole at the macrocell edge by optimizing the femtocell coverage.

In macro–femtocell networks, cross-tier interference can be minimized substantially by altering the highest tolerable transmitted power in the BSs, [52-54]. A power control approach is presented in [52]. This proposed approach reduces the interference of the macrocell users that is created by the femtocell. When the macrocell user senses high interference from nearby femtocell, it informs the control system by sending messages. Based on the macrocell users report, the femtocell reduces the power to an optimum level. This algorithm ensures less interference for the macrocell users, while in such process, the femtocell users' gets less service that sometimes may lead to call-drop. Several research findings have addressed the challenges of resource allocation in heterogeneous networks. The main limitations of the previous research are mainly the selection of base stations that decides the best

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serving station for each user once the femtocells are operated in hybrid access mechanism. Particle swarm optimization, a popular optimization technique, is introduced in [55] to increase the capacity as well as the overall performance of the femtocells. The authors used both power control and channel allotment in the proposed technique. A joint bandwidth and power allocation using the Hungarian algorithm was carried out in [56] that aim to minimize the consumed power and improve QoS provided for each user. A combined bandwidth and power control approach was investigated in the article [57]. The highest transmitted power and operating frequency band for per femtocell user have been determined by formulating a mixed integer-programming problem. However, the complication of the algorithm makes it impractical for applications

4.2. Cognitive Based Approaches

Another important model for mitigating interference in femtocell networks is cognitive radio approach. The technique of cognitive network utilizes the distributed radio resource sensing for mitigating interference in femtocell network. In [58], an efficient downlink co-tier interference control mechanism is proposed for OFDMA-based LTE systems. The proposed mechanism deploys path-loss information sharing technique among the neighboring HeNBs. Moreover, there is also sharing of information on LTE Component Carriers (CC) between adjacent HeNBs, which is afforded using the carrier aggregation techniques. This information sharing is achieved through the femtocell gateway (HeNB GW) or over-the-air (OTA) technique. The HeNB GW is regarded as the intermediary between HeNBs and the core of the mobile network, which assumes the management of the inter-HeNB coordination messaging through S1 connection. Conversely, the OTA technique comprises of a direct HeNB-MeNB link. The particular HeNB detects its adjacent neighbors to attain information regarding the CCs assigned by the neighbors. Each HeNB estimates the co-tier interferences using path-loss information, and use such knowledge in order to ensure access to the spectrum to minimize interference. By selecting the CCs, each HeNB selects the CCs that are not being used by any of the neighboring cell. The simulation results indicates that the proposed model reduced the co-tier interferences and signaling cost significantly, compared to other interferences management schemes. Figure 8 shows a schematic illustration of a typical downlink co-tier interference management scenario of HeNBs. This scenario makes use of the cognitive radio mechanism. Let's consider that the available CCs for HeNBs are CC1, CC2, CC3, and CC4. In Figure 8(a), HeNB1 and HeNB3 select different CCs as they are close to each other. On the contrary, HeNB2, not close to HeNB1 or HeNB3, selects the available CCs (e.g., CC1 and CC2). When HeNB4 is switched on, it senses its adjacent neighbors. HeNB4 collects the information of CCs from its neighboring CCs, and in order to avoid tie interference, HeNB4 selects CC3 and CC4 for the downlink transmission and these are typically different from those used by HeNB1 and HeNB2. Moreover, in Figure 8(b), when it is turned on, HeNB5 identifies the nearby femtocells and collects the information of CCs. In such case, HeNB5 selects the CCs used by the furthest neighbor, i.e., HeNB1. , Therefore, it reduces the chance of co-tier interference.

Figure 8 Interference Management Using Cognitive Approach

4.2.1. Femto-aware spectrum arrangement scheme

The author in [59], developed a femto-aware spectrum arrangement technique that prevents macrocell-femtocell uplink cross-tier interference. In this approach, the available radio resources are divided into two portions: one portion is solely dedicated for macrocell while the other is shared jointly between the macrocell and femtocells. The MBSs that have prior information about the nature of the radio resource sharing, establish a pool of interference-capable MUEs comprising those UEs that may interfere with the neighboring HeNBs. This UE pool is then allocated as a segment of the dedicated bandwidth. In this way, the cross-tier interference is solved. Figure 9 shows a schematic diagram of a femto-aware spectrum allocation scheme, in which the macrocell UE4, macrocell UE5, as well as macrocell UE6 pose cross-tier interference threats to their neighboring HeNBs. With the proposed model, the MeNB includes macrocell UEs as part of the femtocell-interference pool and allocates a dedicated segment of the available radio resources. Conversely, given the fact that the rest of the macrocell UEs are located away from the interference zone of the HeNB, they are allowed to use the remaining frequency together with the femtocell UEs. The only limitation of this scheme, however, is that it does not account for the co-tier interferences among the HeNB. The scheme may also be inefficient for cases where the quantity

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of macrocell UEs within close proximity to the HeNB rises.

Figure 9 Femto-Aware Spectrum Arrangement Scheme [59].

4.2.2. Femtocells grouping and/or clustering Approach

The study in [60] developed a framework for the reduction of downlink interference of OFDMA-based closed access femtocell networks. The authors developed a Femtocell System Controller (FSC), which collects the information of interference scenarios and utilizes that for the required computation. After the computation, the scheme then combines dynamic channel allocation for HeNBs and MeNBs. This scheme also allocates a segment of the available bandwidth to the MeNB users, while the remaining bandwidth is shared and reused among the MeNBs and HeNBs. A significant merit of this technique is that it reduces the coverage of dead zones and ensures QoS for users. However, the frequency segment shared among the MeNBs and HeNBs depends on the quantity of available HeNB clusters generated by a clustering scheme. Using the clustering scheme, the HeNBs are grouped into clusters representing different frequency reuse zones. The clustering range is computed using the location of each HeNB and the predetermined distance threshold. Through simulation, the authors reported a high spectral efficiency for cases where the probability of spectrum reuse is above 97.4%. The probability of a single macrocell UE located in a dead zone was also quite low (2.4%). The authors also reported a significant enhancement in capacity as well as in the number of femtocell users. The work in [40] proposes energy efficient interference cancellation mechanism for closed access HeNB. The scheme proposes the minimization of the redundant available intervals (AI) in low duty operation (LDO) mode for HeNBs, as a means for minimizing inter-femtocell and co-tier interferences among neighboring HeNBs. In the LDO state, a HeNB alternatively changes state from available interval (AI) to unavailable interval (UAI). In the UAI state, a HeNB turns to active at the physical layer through the transmission of preambles incoming UEs in order to synchronize with them. The length of AI and UAI corresponds to the pattern of the low duty cycle (LDC), which aids the LDO state of the HeNB. If there is no UE to access the HeNB, the HeNB in the LDO state continues to have AIs. These unnecessary AIs may result in co-tier interference. To minimize this co-tier interference, the scheme decreases the AIs among the neighboring HeNBs. The fundamental reason for the reduction of such interferences is to group these neighboring HeNBs using their respective locations where each HeNB is assigned as the leader and the adjacent HeNBs becomes the follower. A "3-ON-3 Femtocell Clustering Architecture" concept is build-up in [61] where 3 Femto base stations (FBS) forms a cluster which transmits 3 levels of power to serve three kinds of users according to their priority. Based on Adaptive Hard Reuse Scheme (AHRS), the entire bandwidth is utilized by each femtocell.

4.2.3. Q-learning schemes

Q-learning is a corroboration learning framework that draws on the concept of the existing environment by using an action-value function. It gives the expected utility of taking a given action in a given state and following a fixed policy thereafter [62]. The main feature of Q-learning relates comparing the predictable efficiency of the obtainable actions without any reference model of the surrounding environment. Q-learning can be mentioned under the subcategories of the cognitive radio. However, it has a better efficiency than the typical cognitive radio approaches. A distributed reinforcement-learning framework is analyzed in [63, 64] where a macrocell network is supported by femtocells sharing the same spectrum. Each FBS interacts with the surrounding environment and gradually learns about the system through trails and error process. After understanding the system very well, it adapts intelligent channel selection process to minimize the interference problem due to spectrum sharing. This process also mitigates the interference of the macrocell network. Authors in [65] discuss the decentralized Q-learning algorithm by estimating the behavior and the intelligence level of the femtocell based on intelligent and self-organizing network concept. Here, newly activated femtocells share the updated expertness of the femtocell that they measure and store after a certain time. In Q-learning based approaches, it may take more time and iterations to realize the environment. Therefore, this dynamic learning method speeds up the process by knowledge exchange. In normal femtocell network, the cell is selected without much information about its behaviors. In [63], authors demonstrate the modern trade-off model where cell selection is done through predicting their future state based on Q-learning algorithm. A user capacity based handover model was discussed in [66]. User hand equipment determines the level of service it can handle at a time. At first, the authors studied the case with only one user performing a

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handover in single-agent multiple-state RL with adaptive action selection (SAMSRL-AAS). After that, they studied the multiple user performing handover named as MAMSRL-SS (Multiple-Agent Multiple-state RL with Soft-max Selection). In [67], authors tried to solve the interference problem with power management technique based on the decentralized Q-learning. The model engages each femtocell as an agent in the multi-agent network (femtocell network) which is in-charge of managing the radio resources to their users. Another model [68] shows the same concept but it is extended to share some of the experience during the next learning session in order to speed up their performance. In general, Q-learning represents a form of cognitive approach but it focuses mainly on the machine learning process. The femtocell learns from the previous performances by analyzing the network parameters. This approach is more effective than a general cognitive approach since it utilizes the previous experiences of the femtocell. However, it comes along with a complicated network architect in a dense femtocell network.

4.2.4. Access control mechanism

Access control limits the users to get access to personal femtocells. The performance of femtocell depends largely on a mechanism that decides whether the user can connect to the femtocell or not. The selection of access control has a vast effect on network performance. Closed access, open access, and hybrid access are the three different types of access control mechanism used in femtocell network. The third generation partnership project (3GPP) involves three groups which are referred to as Closed Subscriber Group (CSG), Open Subscriber Group (OSG), and Hybrid Subscriber Group (HSG) [69]. The closed access mode allows only particular users to get access into the femtocell. This mode is normally applied in residential environments. The close access does not have that much congestion of users as the femtocell denies the access of subscribers who are not registered in CSG even if it provides best signal quality. This induces a new set of signals overhead that makes the interference problem even more. The open access technique, on the other hand, allows users within the femtocell coverage to establish connections. In open access, femtocell allows all subscriber to get connection with the network. However, the number of handover and congestion of signaling increases as the femtocell allows all the users to get connected through it. It also has a sharing and security concern. In addition, the commercial deployment of open access is faced with a number of challenges. When a particular customer pays for a femtocell, he/she does not want any subscribers to gain access to the network unless they have specific benefits from the deal. For this reason, the technique is mainly deployed in coffee shops, shopping malls, airports, and other public places [64]. In the case of hybrid access, the nonsubscribers have a limited access to the femtocell service and only the CSG possesses the privilege to use full resources [69]. Since the access mode has a direct impact on the interference, the hybrid access is found to be a viable solution since it allows a limited number of outside macro users to access the resource of the nearby FBS. The number of outside users allowed to access the FBS in hybrid access mode needs to be selected carefully; otherwise, it reduces the service of the authorized FBS users [70, 71]. More details on femtocell access control strategies and their impacts are given in [69, 72]. In Figure10 illustrates the basic mechanism of the three access control in femtocell network.

Figure 10. Different Access Control Mechanism In Femtocell Network

A closed user group access control is proposed in [73]. This type of control allows a particular femtocells' user group like CGS to get access to the service. Under such a scheme, two-tier interference is minimized and unwanted interference is lessened, allowing it to be more energy efficient. In [74], the authors studied access control mechanism under the timing misalignment of uplink and showed that the average performance of closed access OFDMA femtocell depends on its distance to the connecting FBS as well as the number of users. If the timing misalignment among the users is greater than the cyclic prefix duration, inter-symbol interference and inter-carrier interference occurs at the femtocell end.

4.3. Hardware Based Approaches

Integration of different antenna arrangement along with the existing interference management approaches has proven to be quite impressive in recent studies. Therefore, researchers are trying to explore the hardware-based approaches to counter the interferences in the femtocell network. The hardware approaches are mainly the intelligent selection of antenna pattern to shape up the beam of the serving cells so that it does not overshoot the neighboring users. Moreover, coverage optimization and users performance enhancement is also possible by the selection of proper antenna

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pattern and phase angle selection. Some effective hardware based interference mitigation approaches are given below.

4.3.1. Beam subset selection strategy

Beam forming is a hardware-based technique that increases the response of the serving cells in a particular direction and minimizes response in other directions to avoid noise, interference, or jamming. The proposed technique, in [75], designed an orthogonal beam forming technique to mitigate the cross-tier interference in femtocell networks. The strategy of beam forming is achieved by selecting a subset of the antenna. It is selected based on the number of MUEs, the intensity of the HeNBs and SNR of the users. The idea is to improve the system throughput through the trade-off between the gain in multiplexing and multiuser interference (cross-tier). This mode of beam selection significantly reduces cross-tier interferences and ensures radio resources to the HeNBs in an opportunistic fashion. The scheme further minimizes cross-tier interference through the deployment of a distributed power control mechanism for HeNBs.

4.3.2. Sectorized and/or directional antennas

Using sectorial antennas at the FBS enhances the capacity and avoids uplink interference for the network as suggested in [76]. This approach, most closely linked with the downlink cellular capacity of a two-tier network, is derived in [77]. By using both methods, the number of the interferers will be decreased, so the interference will be reduced. The result shows that using sectorized antenna allows about a 7x higher femtocell density compared to Omni-directional femtocell antennas. However, using this method, mobile operators have to pay a lot for the hardware. The study in [78] proposed a cost-effective multi-element antenna solution through dynamic Antenna gain patterns aiming to reduce interference in femtocell network. The author(s) in [80] have adopted the E-plane horns based reconfigurable antenna. This type of antennas is meant to reduce the interference and enhance the link reliability as well as the capacity of OFDMA based femtocell systems. The findings show that E-plane horns based reconfigurable antenna is better in performance since it has 58% higher femtocell capacity than the Omni-directional antenna, and 13.5% higher capacity than the IEEE 802.16m sector antenna. The effects of access control methods and directional antenna for femtocell were presented in [81]. The authors attempted a comparison between switched-beam directional antenna and Omni-directional antenna. As demonstrated by the findings, the interference is reduced by using switched-beam directional antenna. Likewise, better performance is achieved.

4.3.3. Interference cancellation techniques

One of the recent schemes for interference mitigation is interference cancellation. The interference cancellation technique basically seeks to reduce the interference at the receiver. The interference is technically cancelled once the signal is received. In such a process, the interfering signals are regenerated and subsequently subtracted from the desired signal. The received signal is typically stored in a sample buffer. From the technical point of view, it is simple to cancel signals with known modulation symbols at the base station since the interference cancellation process can avoid data demodulation and decoding. According to [82], there are two classical techniques for interference cancelation and these techniques are the Successive Interference Cancellation (SIC) and the Parallel Interference Cancellation (PIC). SIC works by detecting one user in each stage. The strongest signal received is detected first, then the second strongest is detected next, and so on [79], whereas, the PIC detects all users in a parallel fashion. The PIC is also referred to as a multistage interference cancellation [80]. The Multistage SIC, is a finer and more sophisticated proposed technique. This scheme overcomes the weaknesses of the two aforementioned techniques [81]. In this technique, a group of users is detected in parallel, then their aggregate interference subtracted from the composite received signal, and then another group is detected in parallel. The majority of interference cancellation techniques require prior knowledge of the characteristics of the interfering signal. It also requires antenna arrays at the other end, the receiver system, to cancel any interference. Such challenges make these techniques less suitable for UEs but more suitable for implementation in base stations [31, 82, 83].

4.3.4. Techniques based recent receiver decoding algorithms

Interference management techniques adopting newer decoding approaches such as sphere decoding and dirty paper coding are markedly promising since they can allow achieving significant gains; however, the processing complexity of these approaches will likely make them less appealing and therefore limit their use to the UL in the near future [84].

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5. QUALITATIVE COMPARISON AMONG DIFFERENT INTERFERENCE MITIGATION APPROACHES

Table 4 compares and contrasts the various interference mitigation techniques proposed by the different researchers whose works were reviewed in this paper. It can be said that the "efficiency" of any particular technique is dependent on the strength of attributes each technique has. The efficiency of a technique is evaluated according to the following attributes : (i) capability to significantly mitigate both co-tier and cross-tier interferences; (ii) is applicability for both the forward link and reverse link; (iii) ability to put into consideration the coordination between the HeNBs and MeNB, or the use of limited available knowledge about the neighboring HeNBs, among HeNBs and MeNB; (iv) can utilize ICI (such as employing frequency scheduling); (v) ability to employ dynamic power control techniques; (vi) ability to use the opportunistic method of spectrum access among the HeNBs using RSSI from the MeNB signals; (vii) ability to minimize the redundant AIs of LDO mode for HeNBs; (viii) scalability and robustness; and (ix) applicability on all 3 types of access scenarios (i.e. closed, open, and hybrid). With these important attributes in mind, the model that achieves the majority of these attributes can be considered to have high efficiency, while those that attain 3 out of 5 of these attributes can be regarded as being moderate in efficiency. For example, the cognitive model, that can effectively handle the co-tier and cross-tier interferences, is considered to have a moderate efficiency. Similarly, the collaborative frequency scheduling model exhibits a highly efficient model in that it mitigates cross-tier and co-tier interferences even for large deployments of HeNBs for both the forward and reverse links, addresses the ICI problem, thus enabling opportunistic spectrum access for the HeNBs using only scheduling knowledge of the MUEs. The computational "complexity" of each model rises according to the following attributes: (i) the level of network information exchange that occurs among neighboring HeNBs, (ii) the degree of information exchange among HeNBs and MeNB, (iii) cluster establishment among the HeNBs, (iv) the execution of algorithm for HeNBs and MeNB for enabling the HeNBs to opportunistically access the radio resource. The higher in the level of information exchange among the HeNBs and MeNB, the higher in the signaling cost, and the higher the processing space for both the HeNBs and MeNB; all of which increase the computational complexity of the model.

Table 4. Qualitative Comparison for Different Interference Management Approaches

In terms of control strategy, the interference management approach will be either centralized or distributed. The centralized approaches require a communication link between the central entity and femtocells, and this will increase the time complexity. In contrary, the centralized approaches can save the processing time that needed by femtocells for sensing the environment to collect the information that will be used later to avoid the interference.

The distributed and/or cognitive approaches are more flexible, where the femtocell can take a decision depending on the sensing environment and information exchange between femtocells and macrocell BS. In contrast, distributed approaches are considered more complex because they required self-organization, optimization. Moreover, distributed schemes need to have some knowledge about macro UE locations utilized from the same frequency. A lot of distributed techniques proposed in the literature still need more investigation in terms of efficiency and complexity. Thus in the future work, a low complexity and high efficiency are required for interference management techniques. Selection of an interference management model is largely dependent on the required trade-off between efficiency and computational complexity. Based on the merits and demerits of each interference management techniques, the FFR model is found to be the best interference mitigation system for femtocell network architectures. This is because it enables opportunistic radio resource access using the RSSI from the MeNB. It further suppresses cross-tier and co-tier interferences in both the forward link and reverse link of the various access modes of HeNBs. Ultimately, this scheme can lead to improvement of the system throughput even for networks with a higher number of network nodes and serving cell.

6. CONCLUSIONS & OPEN FUTURE RESEARCH DIRECTIONS

As a next step to future cellular communication system, researchers focus more on higher frequency with larger number of serving cells. In this regard, femtocells are considered as the most effective

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promising small cell technology that can provide a high quality coverage for indoor environments, as well as, to increase data rates, capacity, and efficiency for the 5G wireless communication cells that will be deployed as close as 10 meter away from each other and by 2020 the number of wireless devices will reach up to 50 billion. However, competition is too high, femtocells face a strong competition from some other already exist wireless technology such as Wi-Fi. Thus, for a successful femtocell deployment, several challenges must be addressed. The interference mitigation is considered as the most important issue in two-tier HetNet. In reality, femtocell is deployed and installed randomly by users without any prior planning from the operator. However, femtocell deployment are assumed either normal distribution or specific location in most of previous studies. Therefore, the future is supposed to consider the most realistic or the worst scenario for femtocell deployment. Moreover, large scale femtocell deployment, especially when femtocell density increases dramatically still need more research efforts to investigate the impact of unplanned (random) femtocell deployment density on downlink performance of MUE in OFDMA based macro cellular LTE system. This paper presents an overview of femtocell technology deployment and some interference management techniques for OFDMA based two-tier HetNet. Resource allocation for either frequency or power is plying an essential role in wireless communication. In orthogonal resource allocation approaches, different dedicated sub bands are allocated to macrocell and femtocells. So cross-tier interference between macrocell and femtocell can be completely eliminated whereas co-tier interference between neighboring femtocells still need more investigation. However, in orthogonal spectrum allocation more frequency band are needed and in contrast, the available spectrum for operators are limited. Therefore, more optimal and efficient resource allocation algorithms are required to improve the utilization of the available spectrum. There is no perfect and finalized management technique that can completely avoid or mitigate interference without any drawbacks as a side effects. Most of proposed techniques in the literature are largely depend on the trade of between efficiency and time -computational complexity. To make balancing between efficiency and complexity, the recent research trends developed a hybrid approach for interference management. Hybrid approaches combine or mix two or more different interference management techniques to integrate together and utilize the strength of each. Such as hybrid technique that join both power control and resource allocation techniques, will be very helpful for both macro and femtocell and improve the overall network system performance. The hybrid techniques are considered as an interesting issue in the future work. As well as, the selection of the suitable interference management techniques that will be joint or combined together is considered critical for future studies. Given the constraints highlighted in this paper, the only agenda that can sustain the potential of femtocell is proper interference mitigation scheme. With proper implementation of an interference management scheme, the femtocell will play a key role in supporting the ever-increasing data demand in indoor environments. However, cost effectiveness is very instrumental for Operators throughout the world to decide on the best technique with the most potential to lead the infrastructure of future wireless communication system.

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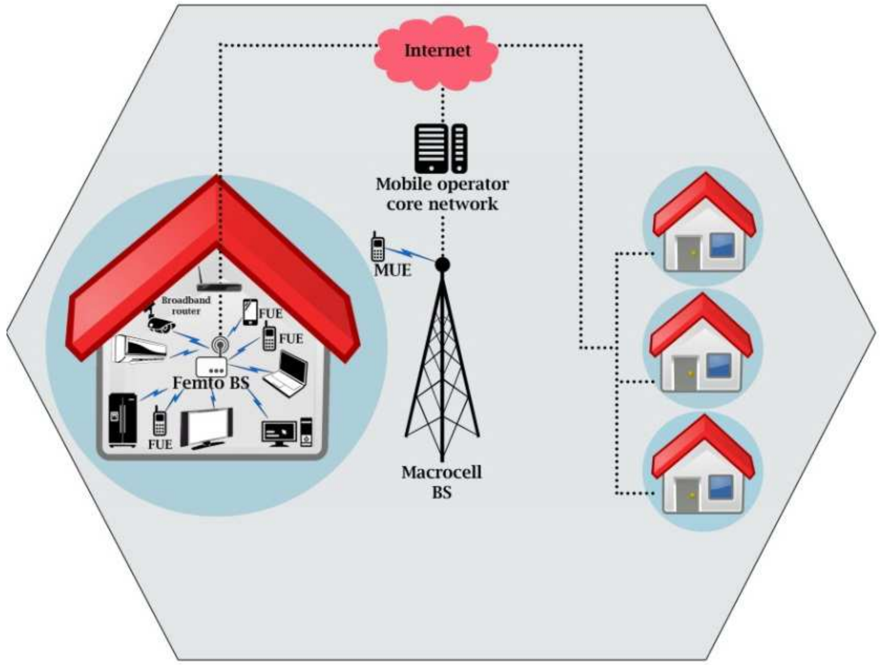

Figure 1. A typical indoor OFDMA femtocell architecture in LTE.

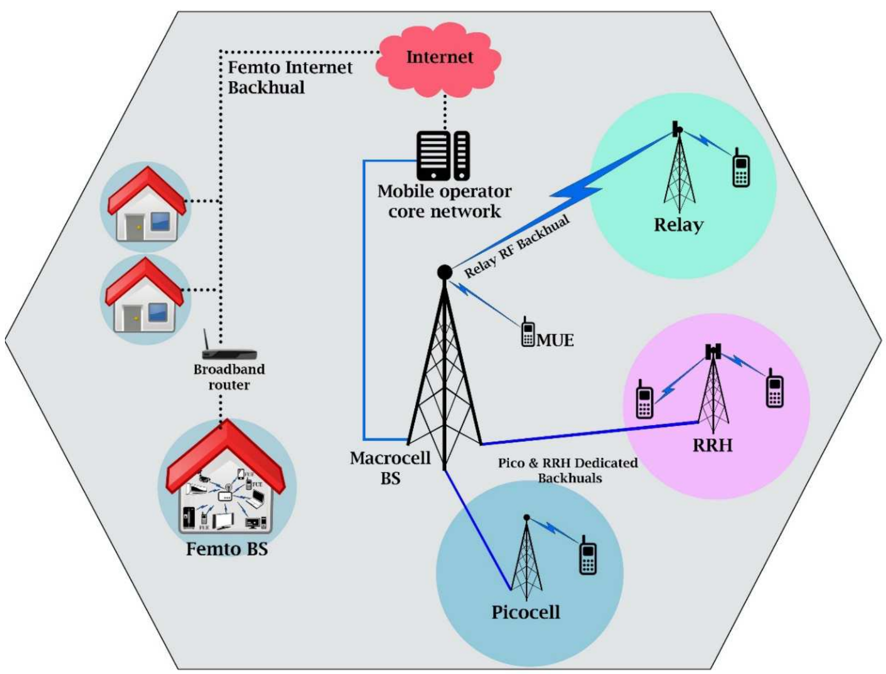

Figure 2. Layout of a heterogeneous cellular wireless network

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Table1. Comparison of Various Indoor Wireless Access Technologies

Specifications	Femtocell	Picocell	DAS	Relay	Wi-Fi
Spectrum type	Licensed	licensed	licensed	Licensed	Unlicensed
Typical power	10–100 mW	250mW–2W (out) < 100 mW (indoor)		250mW–2W (out), < 100 mW (indoor)	100–200 mW
Power control	Support	Support	Support	Support	Not support
Coverage range	20–50 m	150 m	Macro coverage extension	Macro coverage extension	100–200 m
Services	Voice and data	Voice and data	Voice and data	Voice and data	Data and VOIP
Handset device	All ordinary devices	All ordinary devices	All ordinary devices	All ordinary devices	Dual mode devices
Working environment	Indoor (home/office)	Outdoor/indoor (hot spot/office)	Indoor extension	Hot spot/office /tunnel, high speed train	Indoor/outdoor home/ hot spot
Backhaul	DSL/cable/ Optical fiber	X2 interface	Optical fiber or RF links to macrocell	Wireless in-band or out-of-band	DSL/cable/ optical fiber
Access methods	Closed/open/hybrid	Open access	Open access	Open access	Closed/open
Security	Robust	Robust	Robust	Medium	Fades
Installation	By consumer	Operator	Operator	Operator	Consumer
Data rate peak	LTE-Advanced (3GPP R10): 1G b/s (DL) 300M b/s(UL)				600 Mb/s (802.11n)

Table 2 Femtocell versus Wi-Fi

Specifications	Femtocell	Wi-Fi
Standard	3GPP, 3GPP2 femtocell standard	IEEE.802.11 a/b/g/n
Operating frequency	1.9-2.6 GHz (licensed)	2.4- 5 GHz (unlicensed)
Power	10-100mW	100-200 mW
Coverage range	20–50 m	100-200m
Data rates	7.2,14.4,100Mbps	11,54, 500Mbps
Services	Voice, and data	Data, and voice
Handset	All ordinary phone devices	Dual mode devices
Complexity of Service	Relatively Low	High
Signal Robustness	Robust	Fades

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Table 3. Benefits of femtocells for operator and users

Operator Benefits	User Benefits
Increased network capacity	Increase indoor coverage (BS in home)
Reduce capital/operational expenditure	Fast/higher performance data services
Lower backhaul costs	Higher quality of voice
Expand revenue opportunities	Improved multimedia experience
Reduce subscriber turnover (stickiness)	Lower cost home zone calling
Improved macro reliability	Continue using current handset
Offload (reduce) of macro base station traffic	Reduce battery drain (Prolong battery life)

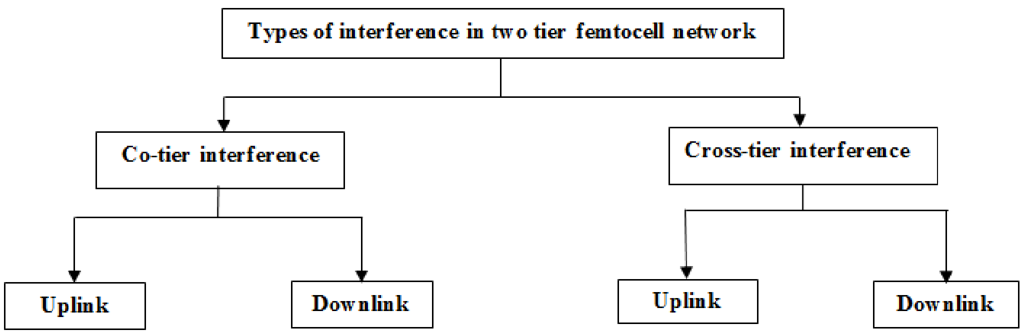

Figure 3. Types of Interference in OFDMA-Based Two-tier HetNet

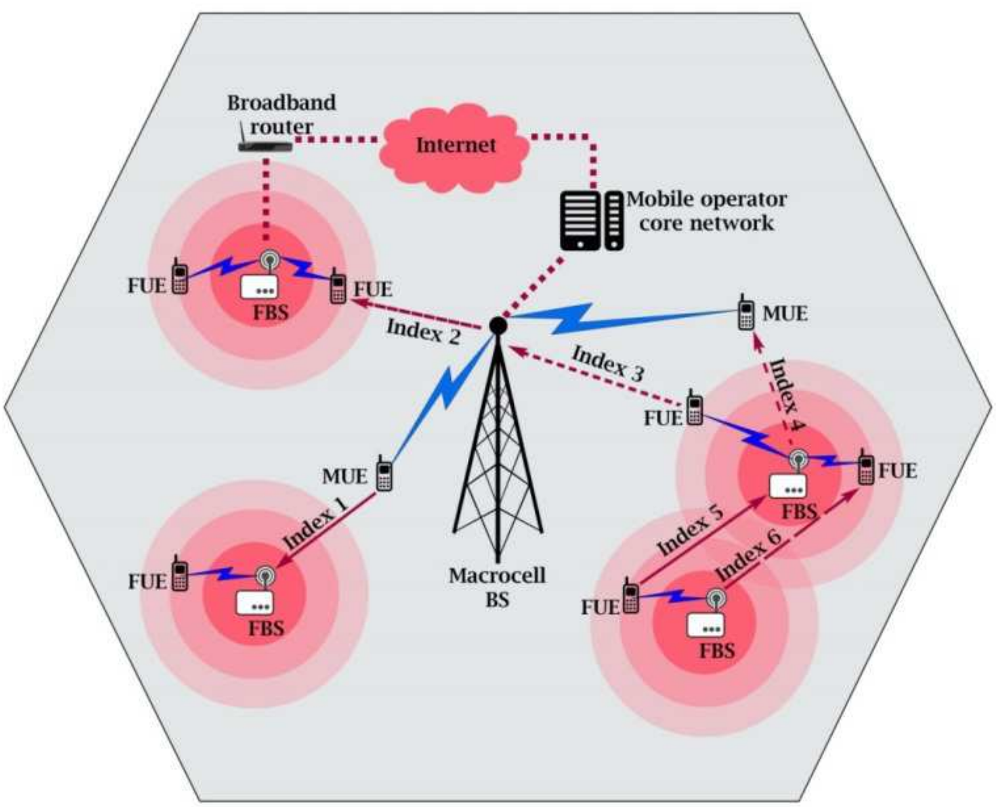

Figure. 4. Interference Scenarios OFDMA-Based Femtocell Networks [30].

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Table 4. All Interference Scenarios for OFDMA-Based Femtocell Networks [30]

Index	Interference type	Aggressor	Victim	Transmission mode
1	Cross-tier	MUE	FBS	Uplink
2	Cross-tier	MBS	FUE	Downlink
3	Cross-tier	FUE	MBS	Uplink
4	Cross-tier	FBS	MUE	Downlink
5	Co-tier	FUE	FBS	Uplink
6	Co-tier	FBS	FBS	Downlink

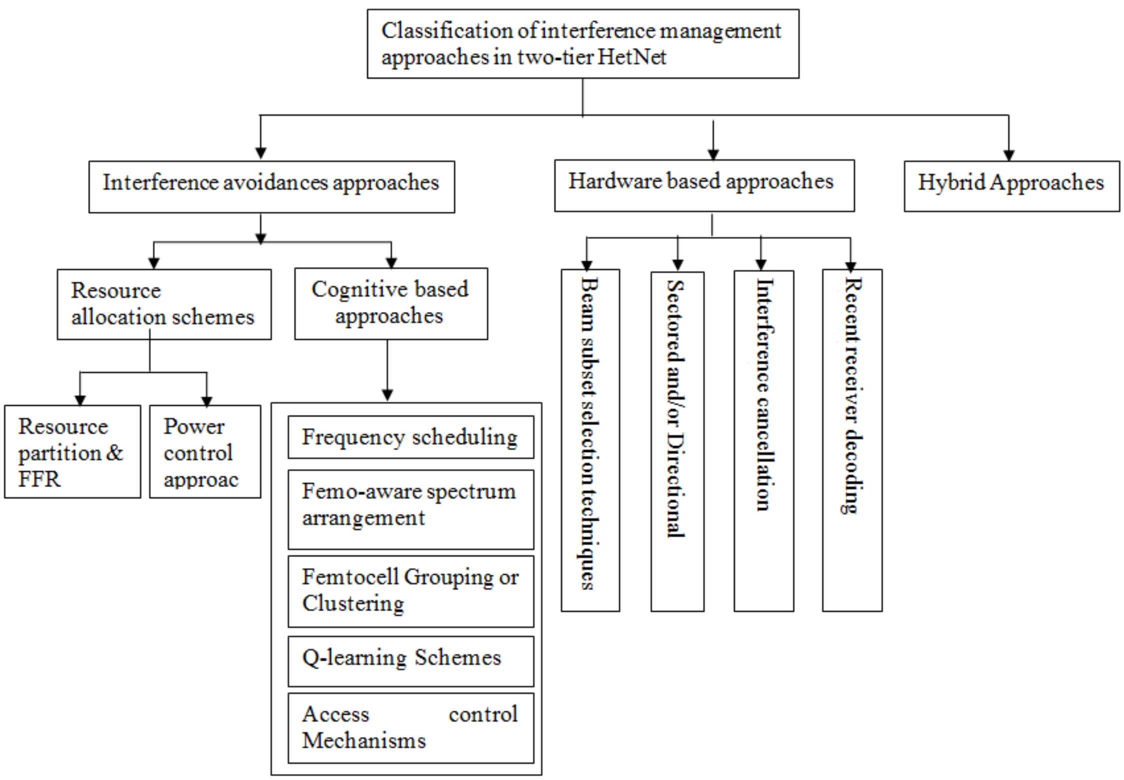

Figure 5. : Interference Management Techniques for HetNet Based- LTE

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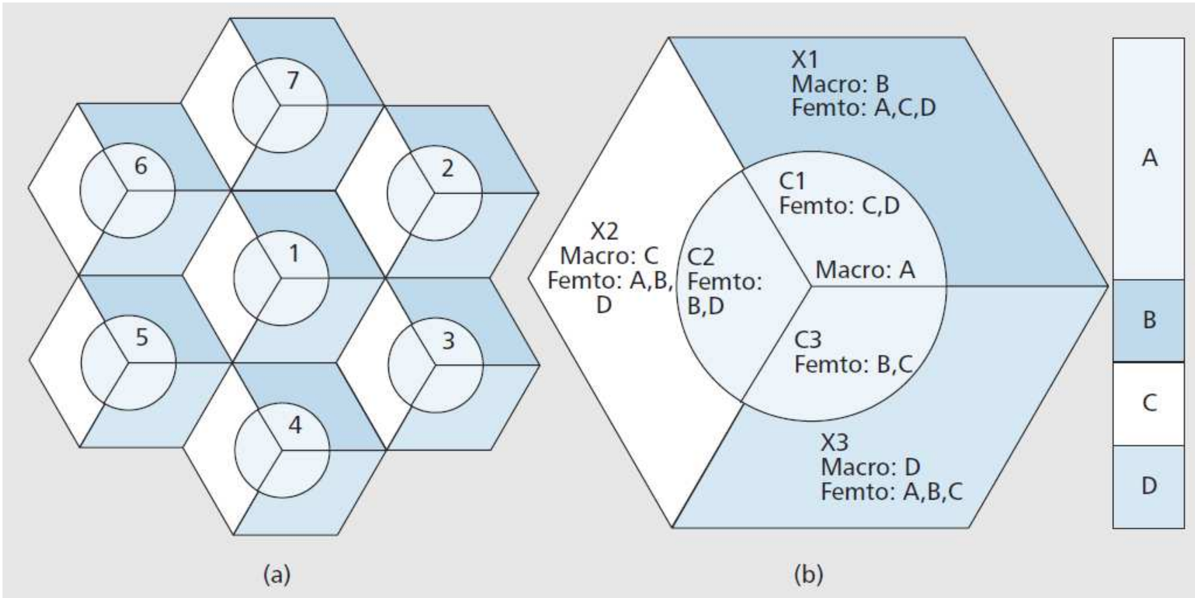

Figure 6. Interference Management Scheme Using FFR [46]

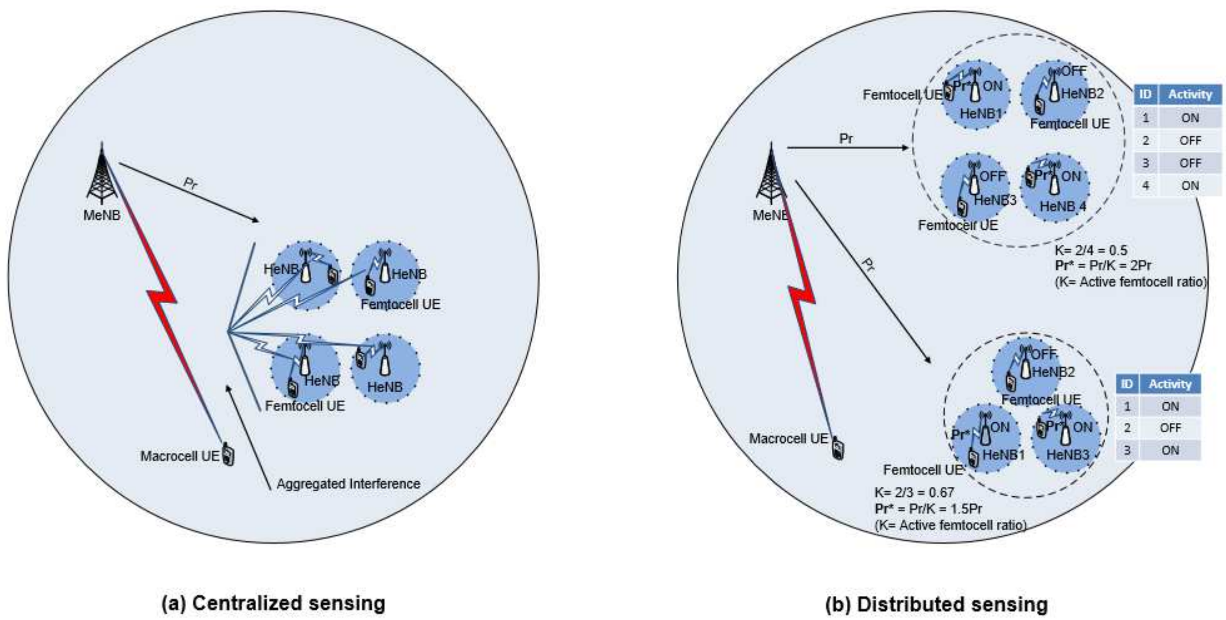

Figure 7. Sensing –Based Opportunistic Power Control [47]

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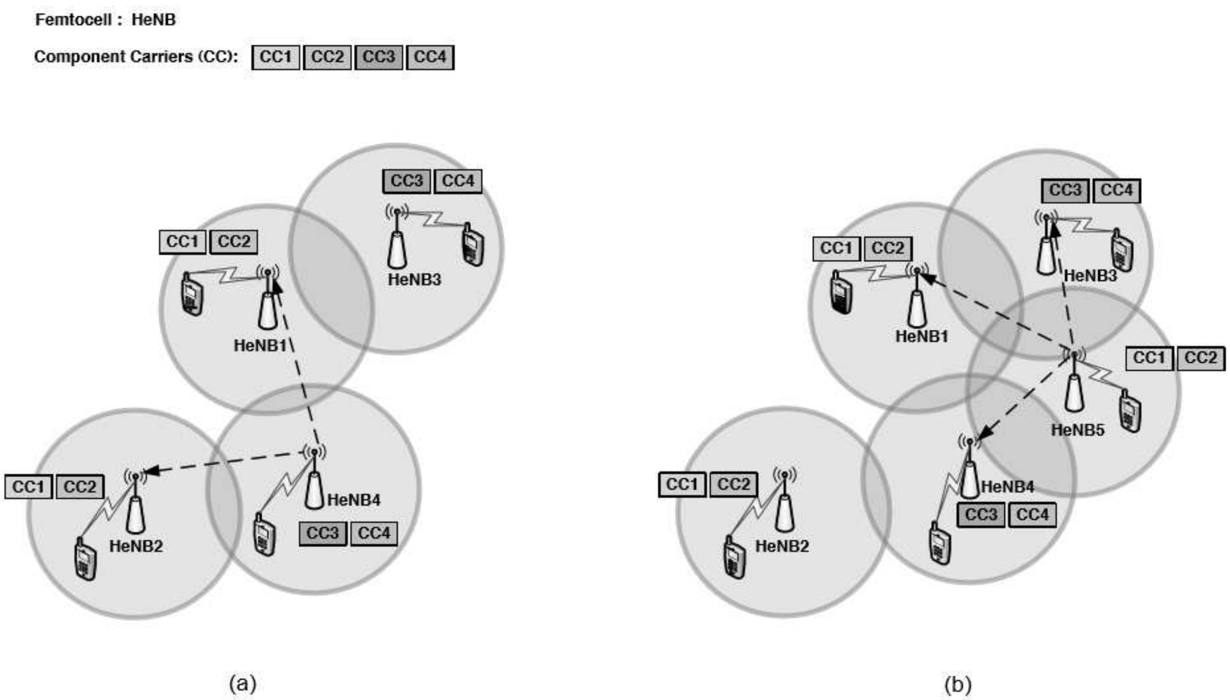

Figure 8 Interference Management Using Cognitive Approach

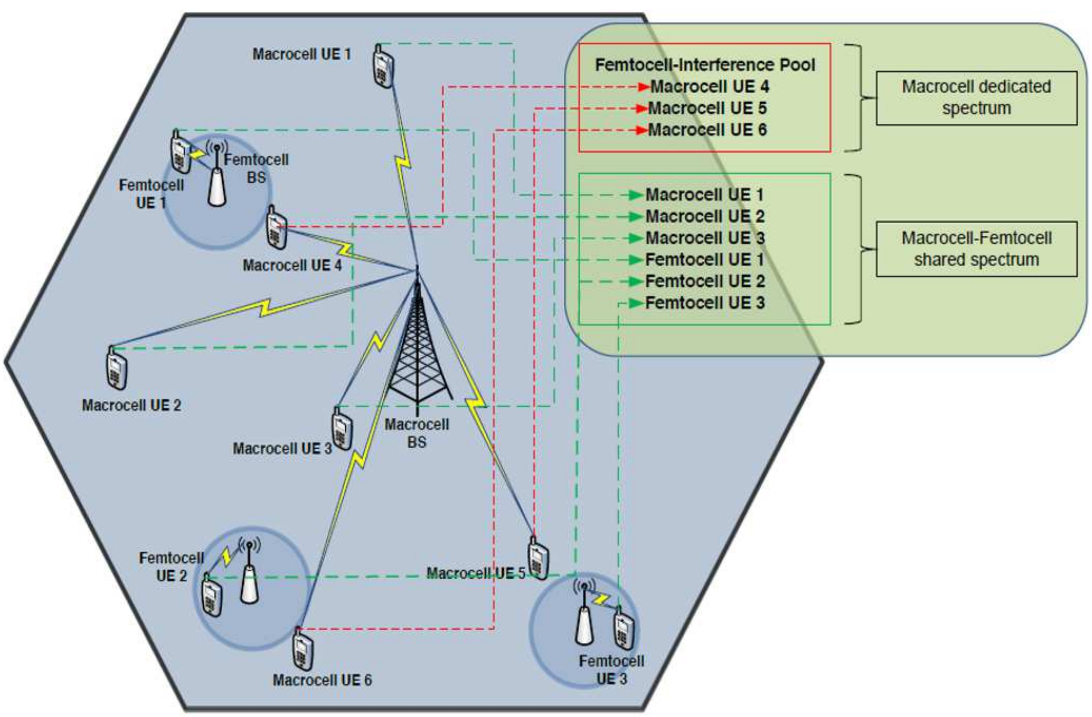

Figure 9 Femto-Aware Spectrum Arrangement Scheme [59].

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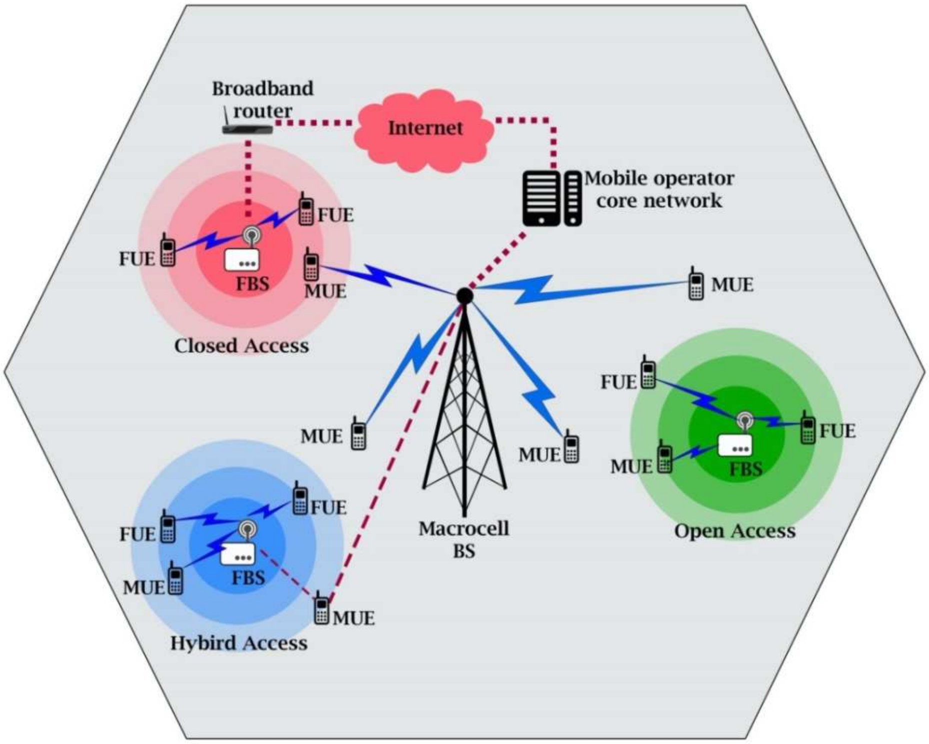

Figure 10. Different Access Control Mechanism In Femtocell Network

Table 4. Qualitative Comparison for Different Interference Management Approaches in HetNet.

Approach based on	Interference Management Scheme and /or Technique	Type of Interference	Transmission Mode	Cooperation among BSs	Control Approach	Access Mode	Spectrum Efficiency	Complexity
Resource Allocation	Fractional frequency reuse	Cross- & Co-tier	Downlink	Not required	Distributed	All	High	Low
	Power control	Cross-tier	Downlink	Not required	All	CSG & OSG	High	Moderate
	Genetic Algorithm	Cross-tier	Downlink	Not required	Distributed	Hybrid	Moderate	High
	Auction algorithm	Cross- & Co-tier	Uplink	Not required	Distributed	Closed	Moderate	Low
	RACSA	Cross-tier	Downlink	Not required	Distributed	Hybrid	High	Moderate
	Femtocells Grouping / Clustering	Co & cross tier	Downlink	Required	Centeralized	CSG	Moderate	Moderate
Cognitive	Frequency scheduling	Cross- & Co-tier	Up/downlink	Not required	Distributed	CSG	High	Moderate
	Femto-aware Spectrum manage	Cross- tier	Uplink	Required	Distributed	CSG	Low	Moderate
	Q-learning schemes	Cross- & Co-tier	Downlink	Not required	Centeralized	CSG & OSG	High	Moderate
	Access control mechanism	Cross- & Co-tier	Up/downlink	Required	Centeralized	All	Moderate	Low
Hardware	Beam Subset Selection	Cross- tier	Downlink/DL	Not required	Distributed	CSG	Moderate	High
	Directional antenna	Cross- & Co-tier	Downlink	Not required	Distributed	All	Moderate	Moderate
	Interference cancellation	Cross- tier	Uplink	Required	Distributed	CSG	Moderate	High
	Receiver decode Algorithms	Cross- tier	Uplink	Not required	Distributed	CSG	Low	High