A Survey on Femtocells: Benefits Deployment Models and Proposed Solutions

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ABSTRACT
Femtocell networks are considered to be a viable option that can fulfill the demands of high speed voice and data traffic for the indoor users. It uses the services of the existing broadband connection to connect to the operator core network. The cellular network operators need to modify the existing single tier macrocell network in order to provide the services of femtocells to its users. In this paper, we present a survey on femtocell deployment. Various aspects of femtocell networks in a diverse domain are discussed. A detailed analysis of the previous approaches is given to highlight their pros and the cons.

Keywords: admission control, capacity estimation, mobile ad hoc networks, quality of service.

1. Introduction

Since mid-1990s, the mobile cellular communication industry has been enjoying its fastest growth. Today's wireless communication technology is the refined and mature version of what we called the new technology during the seventies. The worldwide success of wireless communication demonstrated that it is a workable medium for multimedia communication causing new wireless systems and standards being introduced for other types of telecommunication traffic besides voice and data service.

With the maturity in mobile communication technology, operators are deploying it both indoors and outdoors. Recent market surveys demonstrate that upto 80% wireless communication usage seems to occur indoors [1]. Out of that, 50% of the traffic is because of phone calls and 70% due to data services and the figure holds true especially for indoor environments [2]. There is a continuously increasing trend in the demands of high speed data services among end users. It has been estimated that between the year 2010 and 2013, there will be 10 to 30 times increase in mobile phone data traffic [3].

The demand of multimedia traffic is high and the existing cellular network system cannot meet the required demands as its coverage area and capacity is not sufficient. Providing these high speed data services to the dense urban areas is quite challenging. Especially in case of indoor environments, where penetration losses and high interferences makes the macrocell antenna's coverage very poor [4] and cellular users feel lot of difficulties in receiving high speed services in the indoor environment.

The problems faced by the indoor mobile users can be alleviated by employing femtocells. IEEE 802.16 SDD (system description document) initially introduced the concept of femtocells [5]. They are low power, short range, low cost small Base stations that operate in a licensed spectrum. Femtocells provide strengthened cellular signals for indoor users. It usually has coverage of 30-40 meters and is placed indoors for stationary or less mobile users. The femtocell communicates with the cellular operators' network over a broadband connection such as digital subscriber line (DSL), cable modem or a separate radio frequency backhaul channel [1]. Introduction of femtocells in the existing macrocell forms a two tier hierarchical cell network. Macrocell being the first tier primary user and femtocell, the second tier secondary user. Femtocells have attracted research interest as it is considered in the next generation wireless systems such as 3GPP long term evolution (LTE) and mobile WiMAX. Both the femtocell user and the operator can potentially benefit from deployment of femtocells. The users experience better signal quality while the operators achieve greater network capacity and spectral efficiency.

Like every other technology, femtocells also have some drawbacks that give rise to some major concern on part of the end users. In this paper, we presented a detailed survey on femtocells deployment. Various aspects of femtocells are studied along with a detailed analysis of the research done in past to figure out various cons and pros of femtocell deployment mechanisms in diverse environmental scenarios. This paper is structured as follows. In Section 2, we present various architectures proposed for femtocell networks. Section 3 provides the access control modes. In Section 4, different frequency reuse and resource allocation schemes are presented. Coverage quality is discussed in Section 5. Similarly in Section 6, various schemes for securing femtocells are given. Handover algorithms are introduced in Section 7, while different interference management schemes are presented in Section 8. Finally in Section 9, we conclude the paper.

2. Architecture

To provide services to the end users having a femtocell base station, it is necessary for the operators to define the architecture for a femtocell based on the type of cellular network. Generally, a mobile phone user can switch itself to the core network either by connecting itself to the femtocell or macrocell. Researchers have presented architectures for various femtocell networks. In this section, we discuss architectures for networks such as UMTS, Cognitive Networks, and CDMA etc.

As shown in Figure 1, the design of femtocell network is such that data traffic uses the public internet while the voice traffic goes through the IMS (IP Multimedia Subsystem) network [6]. The Figure shows the structure of IMS and SIP (Session Initiation Protocol) - based femtocells. IMS and SIP based structure is used because in interworking architecture, IMS protocols are converted through SIP gateway. After passing IMS through MGW (Media Gateway) and MGCF, it is taken for interworking with PSTN. The architecture presented in Figure 1 can guarantee end to end QoS call flow in the IMS and SIP type femtocells.

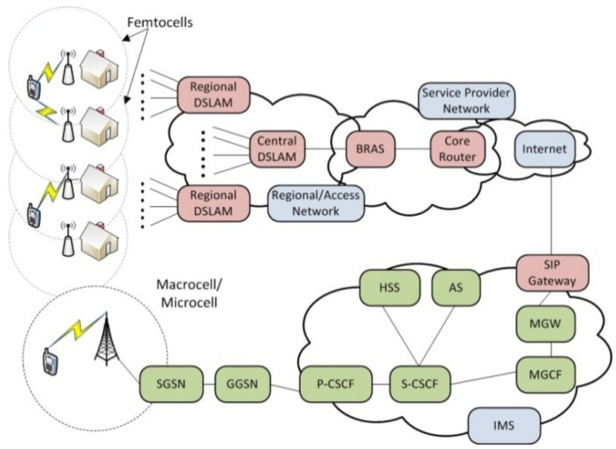

Figure 1. A general femtocell deployment architecture.

It must be kept in mind that IMS can handle only voice traffic; however it can be connected to several femtocells. Since data does not go through the IMS network, the subscribers can avail various services at lower cost.

There is also another architectural fact, in which conventional cellular deployment has been modified and IP-like architecture is proposed [7, 8], with mobility enhancement [9], and also paging mechanisms are introduced for distributed environments [10]. Initially femtocells were designed just for residential use, but by observing its competency and consistency, its self-optimization and coverage principles, can be extended further to include enterprises, campus, and even metropolitan zones. The standard architecture of CDMA 2000 1x is shown in the Figure 2 of femtocell integrated network defined in [11].

Figure 2 shows an insecure network, therefore Femto Security Gateway (FSG) and IPSec are enabled by default in it [12]. The IPSec tunnel based on IKEv2 (Internet Key Exchange Version 2) [13], algorithm is used for encryption between FAP (Femto Access Point) and the FGW.

The Femtocell integrated architecture can be divided into two modes [14].

- The legacy mode
- The flat mode

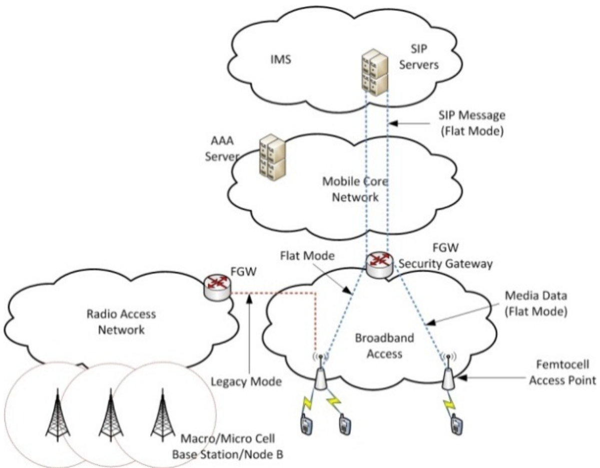

Figure 2. CDMA 2000 1x.

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In Figure 2, it is visible that in legacy mode the femtocell is connected to radio access network, while in the flat mode, the femtocell is directly connected to the mobile core network. The flat mode can reduce load on the radio access network. IMS is used on behalf of session management for voice communication. Through P-CSCF (Proxy-Cell Session Control Function), SIP registration is performed for S_CSCF (Serving – Call Session Control Function). SIP messages are managed by FAP for AT (Access Terminal) [14]. During the IMS session establishment process the SIP signaling delay can be analyzed as the performance indicator [15].

Three integrated architectures based on the coverage of macrocell network and on the availability of broadband connection are presented in [16]. The proposed configurations are single stand-alone femtocell, network-alone femtocell and femtocell network integrated with a macro-cellular infrastructure. The single stand-alone femtocell provides coverage to areas with no or poor macrocell signals and neighboring femtocells are avoided in such areas. While in network-alone femtocell, multiple neighboring femtocells are available. In a femtocell network integrated with a macrocell infrastructure there is an overlapping coverage of both the femtocell and the macrocell thus forming a two tier hierarchical network.

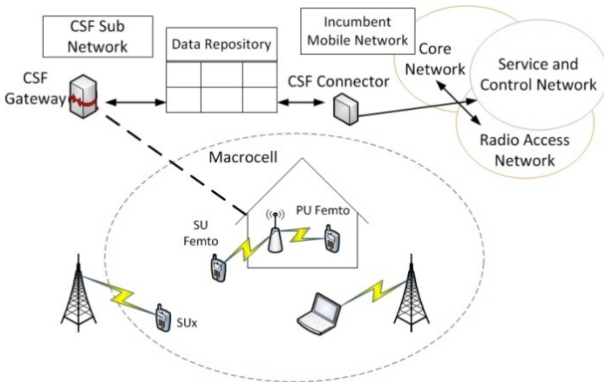

Figure 3. Cognitive femtocell network architecture.

In [17] and [18], the cognitive femtocell network architecture is presented. In [17], cognitive femtocell sub-network (CFS) provides services like profile management, user rights and services provision. CFBS controls interference between the femtocell and macrocell. The whole architecture is shown in Figure 3.

Architecture for femtocells in a UMTS network is presented in [19]. User equipment, core network and UTRAN are the three major domains. User equipment can access the services provided by the UMTS network. The UTRAN consists of several radio interfaces and handles mobility. The Uu interface connects user equipment with UTRAN while the core network is connected to UMTS via the Iu interface. Core network performs location management, handovers, and gateways to other networks. Figure 4 shows the proposed UMTS network. The features of GSM such as Mobile

Switching Center (MSC), Visitor Location Register (VLR) and gateway MSC (GMSC) etc are included. In the Figure Home Node-B is the femtocell, which is connected to the internet. Home Node-B Gateway (HNB-GW) connects femtocell with the UMTS network, while the Security Gateway (SeGW) provides security between the core network and the internet. A similar approach is described in [20] and [21] for LTE networks, to add more functionality to base station, E-UTRAN is added in LTE network.

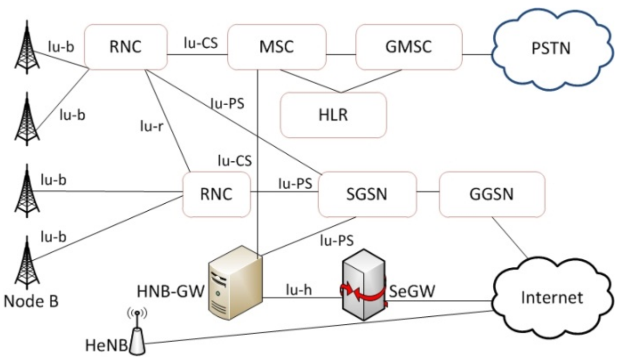

Figure 4. Proposed UMTS network architecture.

In some other researches, such as in [22], hierarchical overlay network in which femtocells deployed in a macrocell is presented. Similarly standardization of femtocells in 3GPP2 is presented in [23] and the CDMA2000 femtocell architecture for a legacy network is demonstrated.

3. Access Control Modes

Femtocell base stations have a list of its users in order to limit and prevent the usage of femtocells against illegal subscribers. Three types of access control methods in which femtocells can be configured to allow or block the users are thoroughly proposed.

There are three types of access control methods [24]:

- Open access
- Closed access
- Hybrid access

The open type access control is similar to a typical macrocell, i.e., every subscriber is allowed to communicate with the femtocell. It can be used for general public users in malls, restaurants, and airports etc. In case of closed access method, the femtocell services can be availed by limited number of subscribers subscribed to the given base station. This case can be used for private usage such as in homes and offices etc. There is also an adaptive femtocell access policy, called hybrid access method, which takes the specific accounts of the instantaneous loads on the network. It can lead to improved performance over the completely open, or completely closed approach suggested earlier [25]. In hybrid access mode, the subscribed users get the preferential charging in comparison with the non-subscribed users to the cell to avail the services [26]. The three different access control modes are illustrated in Figure 5.

There are security concerns regarding access control to block unauthorized users and allow authorized users. It is also important because without the knowledge of the owner its neighbors may use its services and can lead to the potential network intrusions and hacking.

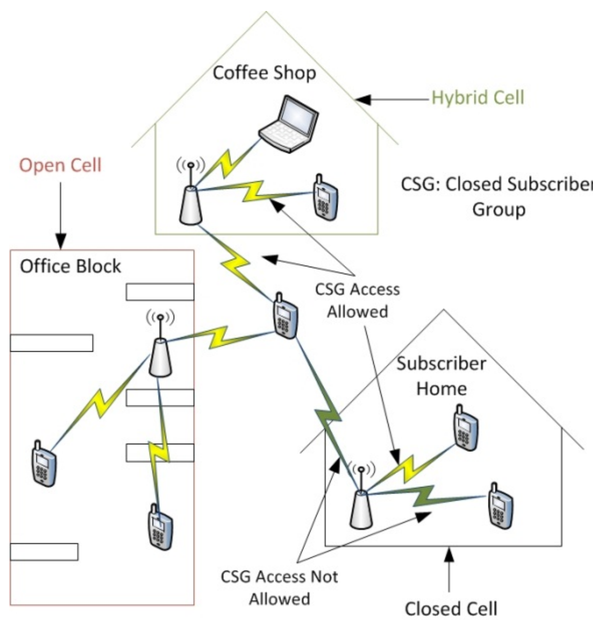

Figure 5. Different access modes.

Briefly, in open access the terminals/users are allowed to communicate without any authentication [27]. In closed access method only authorized subscribers can establish connection and communicate. While in hybrid access mode the non-subscribers have limited access of the femtocell resources. The CSG (Closed Subscriber Group) list can be managed by the femtocell owner through a protected web page, where the owner can login and add or remove users by entering their mobile numbers [28].

The network capacity can be improved by using the open access method [29] because, wherever the macrocell coverage decreases, the users can connect to the nearby femtocell. As in this method the outdoor users can connect to the indoor femtocells, therefore, it can also avoid femtocells behaving as interferers to their neighbors. The negative aspect of open access is the increase in number of handoff and signaling causing certain security issues. In addition a recent survey shows that open access is also exigent to the operators commercially as well, because the non-subscribers are able to avail the services as users of their own femtocells without any returns.

This issue of open access can be handled by the closed access method, in which only the subscribers can avail the femtocell services in a home or small enterprise. Power leakage through the doors and windows can be sensed as interference by the passing macrocell users, and consequently the signal quality attenuates, because if the distance between the subscriber and Femtocell Access Point (FAP) is more and if asked to increase their strength level will result in a very high level of interference not only with the neighboring femtocells but possibly with the macrocell. However, to some extent, this problem can be resolved by OFDMA sub-channel algorithm, which uses frequency sub channel allocation technique which utilizes the frequency reuse approach and consequently maximizes the cell throughput. In the Hybrid case they can also use the OFDMA sub channel technique which allows the non-subscribers to communicate through, but with certain restrictions.

4. Frequency Reuse and Resource Allocation

As femtocells are sometimes embedded inside a macrocell, both macro and femtocell should operate on a certain frequency. The operators need to specify the allotted frequency range for the macro and femtocells. This frequency allocation is a tedious job. A little mismanagement can lead to various levels of interference problems.

In order to improve the performance of cell, the conventional cellular networks apply strategies such as fractional frequency reuse (FFR) and soft frequency reuse (SFR). However, due to random behavior of femtocells in a network, such strategies need to be modified. Researchers have presented various resource allocation and frequency reuse methods. Approaches based on cognitive radio technology, shared spectrum usage, partitioned spectrum usage and modified FFR and SFR schemes have been presented. These schemes have been categorized as follows:

4.1 Fractional Frequency Reuse

Generally in mobile networks, the users at a cell center operate on all available sub-channels while only a fraction of all available sub-channels are allotted for the users at a cell edge. The sub-channels fraction allocation is done in such a way that the neighboring cells' edges operate on different sets of sub-channels. This phenomenon is termed as fractional frequency reuse. For a femtocell network, lots of researchers have proposed the same frequency reuse procedure with little modification. The literature proposing FFR for femtocell networks is as follows:

The work in [30] proposed fractional frequency reuse scheme in LTE femtocell systems for interference management. In the proposed scheme, macrocell coverage area is divided into two zones i.e. central zone and edge region. These two zones are further divided into three sectors. The frequency band is also divided into two parts, in which one part is further divided into three portions. The total frequency band is denoted by A, B, C and D in Figure 6. The macrocell’s center zone uses the frequency band A while the edge users uses the B, C and D sub-bands. The femtocell chooses the bands which are not used in the particular macrocell sub-area e.g. as shown in Figure 6. The center zone femtocells uses the B, C and D frequency bands while the edge region femtocells chooses the sub-bands which are not used by particular edge region macrocell. Due to small coverage of femtocell the sub-bands are reused as much as possible. The proposed scheme enhances the overall throughput, especially throughput of the edge users. It also reduces the interference problem.

In [34][31], fractional frequency reuse (FFR) strategy adopted by macrocell in two tier macro-femto network is presented. The macrocell located at the origin transmits its signals in a circular disc shape as shown in Figure 7. This coverage zone is divided into two sub-regions i.e. inner circle and outer circle.

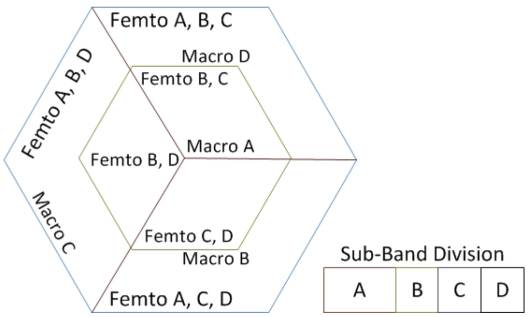

Figure 6. Sub-band division model.

By using FFR strategy, the allocated set of channels within the bandwidth is divided into two sub-bands i.e. one band for inner circle and other for outer circle. The femtocells are randomly distributed over the entire area. The macrocell and the femtocell schedule one sub-channel to one Mobile Station (MS) at a time. This scheduling is performed in a round robin fashion. The proposed strategy achieves a substantial gain in transmission capacity. However a drawback in the proposed approach is that in practical environment, the cell shape is hexagonal not circular shaped.

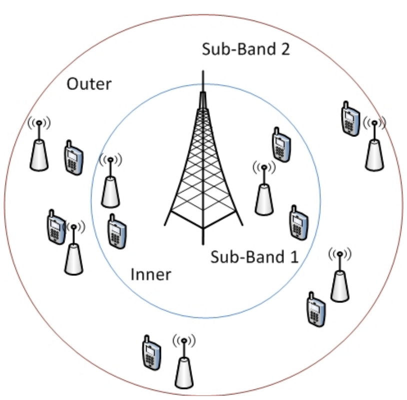

Figure 7. Network Model Based on Two Sub-Bands

Similarly in [40][32], FFR scheme is presented. The proposed scheme adjusts the frequency reuse according to the working environment. This technique helps in mitigation of inter femtocell interference. Based on the mutual interference information, the femtocell gateway classifies femtocells into number of groups. It then allocates minimum number of orthogonal subchannels for each group of femtocell. After allocation, the transmit power of each femtocell is adjusted to provide target performance. This scheme does not work properly in dense femtocell environment when each femtocell has different load.

4.2 Soft Frequency Reuse

In Soft frequency reuse, the UEs are divided into cell edge users and cell center users based on geometry factors. Similarly the available spectrum is also divided into two groups i.e. cell edge band width and cell center bandwidth. In this way cell center users are restricted to cell center bandwidth while edge users use cell edge bandwidth.

In [33], frequency planning scheme for femtocells in the existing macrocell environment is presented. The scheme presented is based on soft frequency reuse. In the proposed scheme, macro and femtocells are divided into two regions i.e. inner and outer region, shown in Figure 8. The inner macrocell and the outer femtocell use the same frequency band while the outer macrocell and inner femtocells uses the same frequency band. In this scheme the femtocells do not cause co-channel interference to nearby macrocell users and there is no use of signaling between the MS and femtocell for resource allocation. However, the inner femtocell throughput increases while the outer femtocell throughput decreases as power ratio and transmission power of femtocells increases.

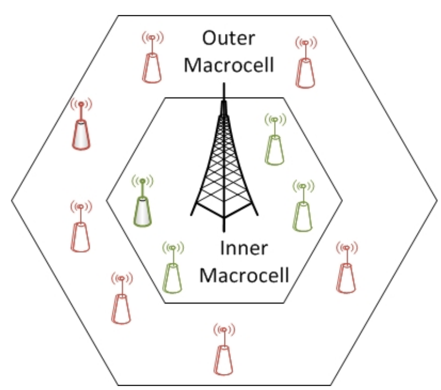

Figure 8. A Proposed frequency planning scheme.

4.3 Cluster Based Resource Allocation

In [34], a femtocell cluster based resource allocation (FCRA) algorithm is presented for OFDMA based femtocells. It involves three phases i.e. cluster formation, cluster head resource allocation and resource contention resolution. In cluster formation phase, each femtocell creates its one hop neighbor list. It is then shared with the corresponding one hop neighbors. In this way every femtocell can compute the number of interfering femtocells. Based on this information, a cluster head (CH) is elected while the rest of the femtocells are members of the cluster. The CH assigns the frequency resources to all the femtocells in its cluster, taking care of the required bandwidth. This stage is the cluster head resource allocation stage. Interfering femtocells, attached to different CHs might use same resources. This problem is tackled in resource contention resolution stage. Here the users suffering from the contention send a feedback to their associated femtocells. Bernoulli distribution is then implemented to resolve this contention. A cluster based network model is presented in Figure 9. Simulation results show that FCRA is an optimal solution for small sized networks as well as large sized networks. However, neighbor cell list formation/sharing needs time and maintaining/updating cluster members is a difficult process.

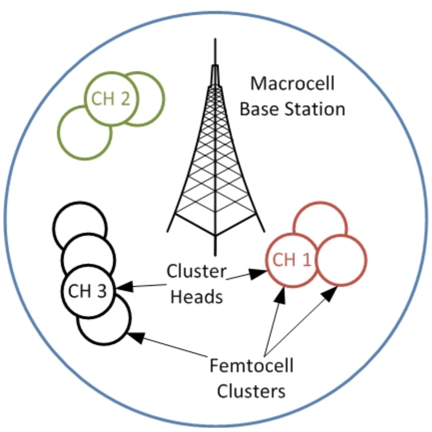

Figure 9. Clustered femtocell network.

4.4 Split Spectrum Reuse

In [35] spectrum allocation strategy for a Wireless Service Provider (WSP) on femtocell deployment is presented. It proposes a split spectrum strategy for WSP. In split spectrum strategy the spectrum is divided for dedicated use of femto and macrocells. Both femto and macrocell operate on different frequencies. All femtocells share the same frequency, utilizing an integrated channel strategy. To prevent femto-femto interference, fixed channel allocation (FCA) strategy is acquired by the femtocell. In FCA the whole spectrum is partitioned into equivalent sub-spectrums for exclusive usage in each cell. Any other femtocell that reuses the same sub-spectrum should be located far away to prevent femto-femto interference. However, any strategy for dealing with edge users is not presented.

4.5 Hybrid Spectrum Sharing

The work done in [36] proposed hybrid spectrum sharing for macrocells and femtocells to achieve higher capacity and lower cross tier interference. The femtocell selects whether to use shared spectrum or portioned spectrum. In a shared case, both the macro and femtocell operate in co-channel frequency reuse. While if partitioned, the spectrum is divided into separate portions; each tier uses a specific portion. The spectrum selection depends upon the position of femtocell i.e. inner femtocell or outer femtocell and also upon the distance of femtocell from a macrocell BS. When the femtocell is located very close to a macrocell Base Station (BS), it selects partitioned spectrum usage. When a femtocell is located at certain distance away from macrocell BS, it favors shared spectrum usage. In case of an outer femtocell, it makes use of a shared spectrum. The macrocell BS operates in partitioned spectrum.

4.6 Dynamic Spectrum Reuse

In [37], the Dynamic Spectrum Reuse (DSR) technique is presented. In DSR technique the femtocell dynamically decides not to reuse the spectrum of macrocell users. The femtocell is assumed to be capable of spectrum sensing and should use the DSR policy to make use of the overlap band at femtocell level whenever possible; depending upon the criteria such as maximum sum capacity, minimum macrocell loss and minimum effective interference. Simulation results give an indication that an improved capacity is achieved by not using the overlap band at femtocell under certain circumstances. Similarly interference can be avoided by using this technique.

4.7 Distributed Graphic Based Resource Allocation

In [38], a Distributed Graphic Resource Allocation (DGRA) scheme is presented. In this scheme the sub-channels are assigned to femtocells in a distributive way. The proposed scheme is carried out in three steps. First of all, based on the knowledge of the received power of reference signal, an interference graph is formed. Then each femtocell randomly selects initial sub-channels. Finally, each femtocell decides whether to choose other available sub-channels that have no conflict with its neighbors. This decision is made according to probability adjustment, in which throughput and fairness of the resource allocation are taken into account. Simulation results indicate that the fairness of resource allocation is greatly improved. However, the proposed work fails to provide the complete macro-femto resource allocation environment.

4.8 Adaptive sub-band Allocation

In [39], an adaptive sub band allocation scheme for dense LTE systems is presented. This scheme consists of three processes. Firstly the interference graph is created which is used to model the interference relationships between the femtocells and its users. The next process is orthogonal sub-band assignment (OSA). It is used to eliminate the inter cell interference by equally partitioning the total band into several orthogonal sub-bands. Round Robin scheduler is used for a fair resource management. The last process is adaptive sub-band reuse (ASR). It is actually borrowing of the neighboring femtocells sub-bands, in which based on interference level, a request is sent by a femtocell to its neighboring cells which then carries out SINR calculations and sends a reply. On receiving all the responding values the femtocell does logical calculations and decides whether to use the sub-band or not. Figure 10 shows that OSA and ASR algorithms operate alternatively. The simulation results shows that the proposed scheme obtain a fair throughput and effectively mitigates the interference in dense femtocell environment. However, the macro-femto interference is not taken into account.

4.9 Cognitive Radio based Resource Allocation

In [40], Cognitive Radio (CR) based resource allocation for femtocell is presented. The whole frequency band is divided into a number of frequency assignments, each of which is comprised of several sub-channels. The proposed scheme performs channel sensing and frequency resource scheduling. Through spectral sensing the available frequency assignment is determined by the femtocell. It then allocates the best spectrum resource (which is not occupied by the nearby macrocell users) to its serving users. The proposed scheme therefore intends to maximize the throughput while minimizing the interference to nearby macrocell users.

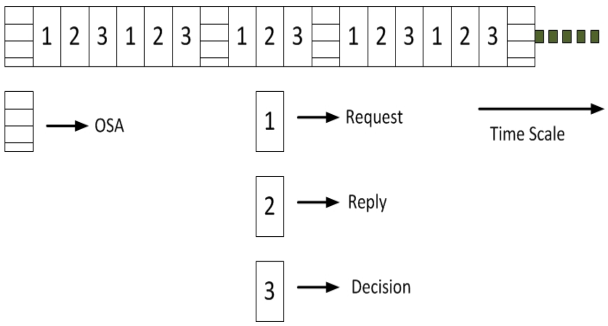

Figure 10. Two-phase time scale model.

4.10 Resource Allocation Based on user Traffic

In [41], a resource allocation scheme based on the type of users is presented. The mobile users' selfish characteristics and private traffic information is proposed. After getting the true traffic it leads to a Pareto efficient, weighted max-min and proportional fair resource allocation for a desirable resource allocation. The main aspects of the frequency reuse and resource allocation schemes are presented in Table 1.

5. Coverage Quality

One of the basic reasons behind the femtocell deployment is to get good coverage. The femtocells' coverage is short, 30-40 meters in range. Even though the Macrocell BS provides a good signal to the outdoor users, however, for indoor users, due to penetration losses, the macrocell signal is relatively poor. So femtocells are feasible for indoor environments. Since the network operator expects to increase the capacity of the network along with its coverage while reducing the cost, therefore femtocells can most likely fulfill the requirements of operator as well.

	Approach used	Positives	Negatives
[30]	Fractional frequency reuse	Better overall throughput. Reduces interference.	Complication occurs for a large macro/femto network.
[31]	Fractional frequency reuse	Improves transmission capacity	Circular cell shape is considered
[32]	Fractional frequency reuse	Minimizes femto-femto interference	Not suitable in dense femtocell environment
[33]	Soft frequency reuse	No co-channel interference b/w femto & macrocell users. No signaling b/w MS & Femtocell for resource allocation	As transmission power increases, through of inner femtocell increases while outer decreases
[34]	Cluster based resource allocation	Optimal for small and large sized networks	Maintaining/updating cluster members is difficult.
[35]	Split spectrum reuse Fixed channel allocation	Reduces macro-femto and femto-femto interference	No strategy for edge users is provided
[36]	Hybrid spectrum sharing	Improves spectrum utilization. Minimizes interference	For uplink throughput special care is needed.
[37]	Dynamic spectrum reuse	Improves capacity, minimizes interference.	Require sensitive femtocells
[38]	Distributive graphic resource allocation	Provides a fair resource allocation scheme.	Macro-femto environment is not considered.
[39]	Adaptive sub-band allocation scheme	Fair throughput. Minimizes interference in dense femtocell environment	Lot of data exchange. No information about macro-femto interference.
[40]	Cognitive radio based resource allocation	Maximizes throughput. Minimizes interference.	Require sensitive femtocells
[41]	User traffic based resource allocation	Provides fair resource allocation	---------

Table 1. Different frequency reuse and resource allocation schemes.

To have a better coverage that facilitates the users and the operators, different algorithms and techniques have been presented. For coverage, three different categories of techniques have been proposed. In the first type, the objective is to prevent the leakage of femtocell coverage into public places. This leakage causes interference problems as well as unnecessary handover requests, which can result in weak signals and a loaded network. The second type involves improvement of coverage quality in indoor environment and the main focus is to minimize the black spots in indoor environment. The third type is kind of hybrid and the objectives are to take care of both limiting the coverage and improving the coverage quality. [42] Presents a real environment simulated model in which macro and femtocells are deployed. Random channels are assigned to both macro and femtocells. Scenarios like frequency reuse and path loss models are configured. After simulations SINR values are calculated. The results show that femtocells can improve the indoor user's SINR in the 50-60 dB range. With the deployment of more femtocells, more indoor users use the femtocell services, making a macrocell less loaded hence improving the average SINR. However by deployment of more femtocells the co-interference between macrocell and femtocell also increases.

[43] Presents user assisted coverage and interference optimization. The goal is to maximize the coverage while minimizing the interference induced into the other cells by using lower pilot power that limits mobility related problems. An indoor site survey and an outdoor survey are presented. No geographical information is available for the indoor environment. So for indoor environment, the user provides all the way points inside his apartment/building by using the MS. These way points are continuously recorded. After

recording; the software performs measurements, configuration tests and gives the user information. It sets the transmission power to provide the maximum coverage and less interference. For outdoor sites, geographical position tracking (using GPS) is possible. So using the services of GPS the important waypoints are automatically recorded.

In [7], different auto-configuration and self-optimization techniques are discussed and the primary purpose is to enhance the femtocell's coverage. The optimization of coverage can decrease the load on core network. The pilot signal power is controlled so that there is no leakage outside the range of femtocell. The pilot power can be increased or decreased depending upon the mobility measurement. In the work done in [7], three mobility based self-optimization techniques are presented which are adaptive to minimize the mobility related events of passing users and to minimize total number of mobility related events. The simulation results indicate that using fixed pilot power results in highest number of mobility related events.

In [44], multi-element antennas are proposed to further refine femtocell's coverage using self-optimization as discussed in [7]. An appropriate antenna is selected to get the optimized coverage. Patched antenna and inverted F antenna is presented. To achieve self-optimization two solutions proposed in [44] are i.e. optimal solution and implementable solution. In optimal solution, two step optimization processes is performed. In first step, the pilot power for each antenna pattern is determined so that it results in minimum number of mobility events. After minimizing the total number of mobility events, an appropriate antenna pattern is selected to get the maximum indoor coverage. The optimal solution is just a conceptual solution and would result in slow convergence. To have better convergence properties the implementable solution is presented. It is performed in three steps. Firstly using auto-configuration the pilot power is initialized for all antenna patterns. Then the femtocell gathers information about wanted and unwanted mobility events. It also stores the coverage information by cycling through all available antenna patterns. Finally ongoing optimization is done to maximize the indoor coverage by increasing and decreasing pilot power for the appropriate antenna based on mobility events. Simulation results show that the proposed multi-element antenna is more flexible and can significantly reduce the mobility events compared to single element antenna.

In [45], the coverage optimization of a femtocell group is presented by using genetic programming (GP). The goals of the presented work are to minimize the black holes in the femtocell coverage areas, to balance the load among femtocells and to prevent leakage of femtocell power by minimizing the pilot transmission power. Algorithms are generated by the use of GP so that it optimizes the coverage according to the stated goals. In simulation, an algorithm is presented in which the load experienced by the femtocell, the coverage overlap and the femtocell coverage holes are computed together. A threshold value for each of the above three is also defined. The pilot power is either increased or decreased or remains same based on the values of the three parameters that have been mentioned. The simulation results show that the algorithm always increases the coverage whenever load is lower than the threshold load, at the same time it does not let the coverage to overlap with the other femtocells' coverage. In this way load is balanced among the femtocells while the overlap also remains as small as possible. Consequently the coverage holes also reduce.

In [46], coverage coordination scheme based on the value of signal and interference power is proposed. In this scheme, femtocell's pilot transmission power is controlled by self-configuration and self-optimization. Based on the measurements of interference from macrocell BSs, the femtocell initiates its transmitting power to achieve constant initial cell coverage. This is done in self-configuration. During self-optimization, the femtocell adjusts its coverage to prevent leakage of coverage into outdoor areas. The simulation results show that the proposed scheme minimizes outdoor coverage leakage while providing the sufficient indoor coverage.

In [47], a low cost six element antenna is proposed to achieve self-optimization and self-configuration of femtocells. Firstly, a user assisted method is presented so that the femtocell gains the information about the residence and the network environment. The user provides this information by mentioning the important points of residence to the femtocell. Based on the information provided by the user, the femtocell performs self-configuration and initializes its power to maximize the coverage for the residence while minimizing the interference with macrocell. This is done by setting the six element antenna, which utilizes a series of algorithms to get the desired coverage beam. For further refinement of coverage, self-optimization is performed. A threshold time is set to tackle the unwanted handovers. Simulation results show that the proposed method could reduce the call drop probability and also optimizes the coverage for indoor users.

[48] Presents the comparison between femtocell and macrocell coverage quality and data rates. After performing experimental tests it is concluded that by deploying femtocells the operator can expect five times improvement in the network. As the distance between the femtocell and MS is relatively less than that of macrocell and MS, so with the deployment of femtocells the shadowing effect, fading and overall propagation losses decrease. It is due to the fact that the distance between the femtocell and the MS is quite less; also femtocell is shared among few users.

Decentralized/distributed algorithms are focused on in [49]. These algorithms decide about the increase or decrease of pilot power periodically so that a better coverage and strong signal strength could be achieved. Simulation results show that minimum coverage holes could be achieved via these algorithms.

6. Femtocell Security

Despite the different access control mechanisms, security concerns are still there on the deployment of femtocells. A Femtocell is connected to the operator core network via broadband connection, which can be insecure. Wireless link and the broadband connection are susceptible to various forms of attacks because interception of data and eavesdropping on conversation are highly possible. There is still a need to tackle a number of attacks which includes eavesdropping and injecting attack, man in the middle attack, password guessing attack, Sybil and Denial of Service (DOS) attacks.

	Features	Positives	Negatives
[42]	Real environment simulated model	Less loaded femtocell	Increases co-channel interference.
[43]	User assisted coverage, way points tracking	Maximizes coverage Minimizes interference	Problems could arise when femtocell is used by multi-users.
[7]	Auto-configuration and self-optimization based on mobility measurements	Decreases load on core network. Enhances coverage	Signaling load.
[44]	Multi-element antennas. Auto-configuration and self-optimization based on mobility measurements	Decreases load on core network. Improves coverage. Reduce mobility events.	Signaling load and delays.
[45]	Optimizes coverage using generic programming	Minimizes coverage holes. Balances femtocell load. Prevent coverage leakage.	Requires a sensitive femtocell.
[46]	Provides self-configures and self-optimized coverage.	Minimizes outdoor coverage leakage. Provides sufficient indoor coverage.	Mobility of users for path loss calculation is not considered during simulation.
[47]	Uses multi element antennas, performs self-optimization and self-configuration.	Reduces call drop probability and optimizes coverage for indoor users.	Signaling load.

Table 2. Various coverage quality algorithms and their main features.

Researchers have presented different methods and techniques to make a femtocell network more secure. The security issue is discussed in [24] and proposes a need for more complicated registration and verification processes so that an attempt by a hacker to eavesdrop on conversation or to control the femtocell should fail. It also suggests the need for sufficient encryption of IP packets.

Work done in [50] suggests mutual authentication and access control process using a proxy signature method for femtocell security. The proposed scheme is completed in different phases in which several messages are exchanged. To use the services of femtocell, the MS should be registered to the femtocell. The registration is done in registration phase. Next is authentication phase. In this phase, there is a mutual authentication and key agreement between the MS and femtocell using the proxy signature method. After registration and authentication phase, the access control phase is executed. The MS provides its identity using a proxy signature. This novel security process can prevent the rogue femtocell attacks while the drawback includes signaling load and delays.

In [51], the authentication process for the security of femtocell and WiMAX is proposed. It proposes a six step scheme which includes *Key Encryption Key (KEK)* and *Traffic Encryption Key (TEK)* formation. The KEK is used to obtain transmission key information while TEK is used for data encryption. For a secure handover new KEK is sent to femtocell by the WiMaX base station. The proposed scheme is not vulnerable to security threats because KEK is generated on both sides of MS and BS without transferring it wirelessly. Also the proposed scheme securely protects the femtocell network from backhaul attacks. However, the security fails in case of fast handovers from the BS.

A mutual authentication protocol i.e. Rapid Deployment Authentication Protocol (RDAP) in [42] [52] is proposed that is used to make a secure connection between the femtocell and the MS. Authentication between the MS and the femtocell is provided by RDAP. Furthermore, to prevent eves dropping and injection attack, a session is created between MS and femtocell by RADP. RADP is completed in several phases and messages are shared between the MS and femtocell during those phases. The first phase of RDAP is scanning. In this phase the MS obtains the pre-shared secret keys i.e. encryption and authentication keys by scanning the femtocell's bar code. Different mobile devices generate different secret keys for the same femtocell. After scanning phase, mutual authentication phase starts. This phase starts with a request for identity from the femtocell for access control. In response, the MS sends its identity along with a base exponent, a modulus, an encrypted cipher of residue, a nonce and a message authentication code. On receiving data from the MS, the femtocell checks its Closed Subscriber Group (CSG) to see whether the MS is listed or not. If MS is not listed in the list then femtocell refuses to provide a connection. If the MS is listed then femtocell also creates the base exponent and a nonce. It also creates a session key which is then sent to the MS. After the completion of RDAP, a secure connection is established between the MS and the femtocell. With the help of RADP, one do not need to worry about security attacks like eves dropping, injection

	Features	Threats Solved
[24]	Complicated registration and verification process. Encryption of IP packets.	Eaves drop on conversation. Controlling of femtocell.
[50]	Mutual authentication and access control using proxy signature.	Prevents rogue femtocell attacks.
[51]	Authentication using key encryption key and traffic encryption key.	Secures femtocell from backhaul attacks.
[52]	Rapid Deployment Authentication Protocol	Prevents eaves dropping, injection of data, password guessing, man in the middle attack, Sybil and DoS attacks.=

Table 3. Femtocell’s security aspects and features.

of data, password guessing attacks, man in the middle attack, Sybil and Dos attacks. In table 3, the features and the threats solved by the mentioned schemes are presented.

7. Handover

With the introduction of femtocells in the macrocell environment, the mobile user is ensured to get a better and stronger signal. But due to the small range of femtocell's coverage, any motion of MS towards the premises of macrocell or another femtocell requires a handover. Similarly movement from a macrocell towards a femtocell also requires a handover.

The availability of thousands of femtocells in a particular macrocell increases the technological challenges for handover. The large number of neighboring femtocells can create a large neighbor cell list. Similarly, maintaining and updating this large neighbor cell list is also a problem as we can expect further addition/removal of femtocells any time. Selection of appropriate femtocell in the vicinity of thousands of femtocells is also a key problem for handover. Likewise, mitigation of unnecessary handovers is another challenge as in dense femtocell environment there is possibility of very frequent handovers.

With the availability of femtocells in the macrocell, a handover is done whenever

- An MS moves away from femtocell to the macrocell.
- An MS moves away from femtocell to another femtocell.
- An MS moves from macrocell to the femtocell.

Some researchers also provided the need for handover to offload either the macrocell or the femtocell. The handover techniques presented in different literatures are either MS controlled/ initiated or femtocell controlled/initiated. For the development of handover algorithms, substantial research work has been carried out. The main objective of these researches is to address the challenges faced during handover. In [53], the handover between macro and femtocell for UMTS based networks is presented. The proposed handover is an MS controlled handover. It is completed in two phases i.e. handover preparation phase and handover execution phase. The preparation phase consists of information gathering and decision making. During information gathering, the authentication and information about the handover candidates are collected. In decision making, the best candidate for handover is decided. Finally, in handover execution phase, the MS initiates a connection with a new access point. The macrocell to femtocell handover can be a little more complex. The large number of femtocells in the neighborhood of macrocell makes the selection of appropriate femtocell a challenging task for MS. Handover decisions are based on interference levels and also authorization is checked during handover preparation phase. After selecting the suitable candidate for handover, the handover execution phase is initiated. For femto to macrocell handover, there is no interference calculation and authorization checking. Furthermore, for the reduction of unnecessary handovers, it proposes a threshold time. It is the minimum time for which the MS must maintain the minimum required threshold level of the signal. The simulation results show that the number of handovers reduces with the increase in threshold time. So for high speed mobile stations, there is no need of short duration repeated handovers from macrocell to femtocell and back to macrocell.

Due to the continuous increase in the number of femtocells, a macrocell contains no information about its neighboring femtocells. This makes the macrocell BS incapable to hand over all the control to femtocell whenever an active user moves from macro to femtocell. For this reason the handover technique for femtocells is proposed in [54]. The handover is MS controlled. In this technique, the MS monitors the signal strength of neighboring cells, it handovers the control to the cell (femto/macro) with good signal strength. The handoff initialization occurs when the signal strength of the serving cell (femto/macro) is lower than the other cell (femto/macro) by a certain threshold. Simulation results show that the time taken by the overall handover process is approximately 0.1 second. However, in simulations, the authorization checking procedure was not taken into account without which, the femtocell cannot be termed fully secure.

In [55], a handover scheme for hybrid access mode of femtocell is presented. The main purpose of presenting this sort of handover is to reduce interference. In hybrid access mode an MS can access the femtocell whether it is subscribed to it or not, and can receive some level of its services. However, the priority of subscribed users is more than the unsubscribed users. Interference is caused whenever an unsubscribed MS enters the premises of the femtocell's coverage area. To overcome this problem, the femtocell allows the unsubscribed MS to access it and use its services. The handover introduced here is femtocell initiated. When an unsubscribed MS enters the femtocell premises, then the femtocell measures its signal strength. Based on the signal strength it decides whether to allow hybrid access or not. If the interference is above the threshold level, then a handover request is sent by the femtocell to the macrocell BS. On receiving the request, the macrocell BS informs the unsubscribed MS and starts the handover process. Meanwhile, for the security, (i.e. authentication and accountability), the femtocell follows a guest access procedure. For a small femtocell network, this technique can pose a significant overhead in the network.

In [56], a handover mechanism based on the MS's velocity and QoS along with the other aspects like authentication and signal strength is presented. Due to small coverage area of femtocell, a high speed MS (velocity>30kph) is assumed to be in proximity of a femtocell for a short duration. Similarly, for non-real time applications delay and packet loss can be tolerated. So by omitting the handover for high speed and non-real time application users, we can reduce unnecessary handovers. In the proposed scheme, whenever an MS is in the premises of a femtocell, then, first of all, authentication of the MS is checked. If it is authenticated to the femtocell, then it is eligible for handover. Signal strength is measured next. If signal strength is not below the threshold value then the handover is not processed. After this the speed of MS is calculated. Handover is not executed if MS is moving with velocity greater than 30kph. If it is moving with medium velocity (15 to 30kph), then the type of application it is using is checked. Handover takes place for an MS using real time applications. If the MS velocity is less than 15kph, then handover is executed for both real time and non-real time users.

In [57], the handover decision algorithm is presented. It uses the radio signal strength (RSS) in its analysis and calculates the handover probability from macro to femtocell or vice versa. The RSS values from both macro and target femtocell are combined. Later, the RSS from femtocell is compared with the scaled value of macrocell's RSS. The probability is calculated via a combination process. This process produces adaptive offsets according to the values of macrocell's RSS and a combination factor. The combination factor is introduced to compensate for the large asymmetry in the transmission power of macro and femtocells. In this method, no matter how greater the femtocell signal strength is, an MS is assigned to the macrocell as long as its probability is higher.

To detect the target femtocell in CDMA, [58] presented a reverse link sensing method. Among various femtocells, the MS detects the femtocell with the strongest signal. It then sends its PN code (pseudo noise) via a Pilot Signal Measurement Method (PSMM) to the serving macrocell BS. Since the available number of PN codes is very small, they are distributed and reused among all the femtocells. Due to this repetition, it is difficult for macrocell to decide the target femtocell whose code was send by the MS. On request from the macrocell, all the femtocells with the same PN code (the one sent by the MS) send their transmit power and its reverse link signal (PTx+S) power to the Macro-Femto Interface Function (MFIF). After receiving the transmit and the reverse link signal power from all the femtocells having the same PN code as that of target femtocell, the MSIF compares all the values and chooses the femtocell with highest (PTx+S) as the handover target.

In [59], handover procedure in LTE based femtocell networks is studied. Three scenarios for handover are proposed i.e. hand in, hand out and inter Femtocell Access Point (FAP). *Hand in* is the handover form macro to femtocell while the vice versa is *hand out* and handover from femto to femto is an inter FAP handover. Also to reduce unnecessary handovers the MS velocity, reactive and proactive handover schemes and mobility prediction strategy are also implemented. For handover decision, the MS regularly monitors parameters like Carrier to Interference and Noise Ratio (CINR), RSS (received signal strength) and QOS. For active handovers, mobility predictions of MS are also made .These predictions are made on the basis of the current position and velocity of MS.

In inter FAP handovers; reactive handover is preferred as it has the capacity to decrease unnecessary handovers. In reactive mode, the handover is made only when the MS almost loses the serving base station signal. In proactive handovers, the handover may occur any time before the signal level of serving base station reaches the threshold level.

The procedure for hand in is complex due to large number of target femtocells. The basic handover decision is made on the interference level parameter and authorization checking. Mobility prediction is also considered for handover decisions. For handout, the handover is made whenever the signal strength of macrocell is greater than that of femtocell. The inter FAP handover is similar to hand in procedure. Here mobility prediction accounts for handover decision. If the signal strength of femtocell is greater than that of macrocell then hand in is likely to occur. After that, the velocity of MS is calculated and no hand in is made if MS is moving with a velocity of more than 10kmph. If velocity is greater than 5kmph then mobility prediction is performed. If MS is using real time applications then proactive handover is made, and for non-real time applications, reactive handover is performed. If the velocity is less than 5kmph, there is no need for mobility prediction and for real time applications proactive handover while for non-real time applications reactive handover is carried out.

The work done in [60] proposed a neighboring list creation scheme for femto- femto handover in a dense femtocell network. The neighboring list contains small number of nearby femtocells. These nearby femtocells are selected on the basis of their signal level, the frequency and the location information.

To create a neighboring list, first of all, the serving femtocell receives the signals from all nearby femtocells. Those neighbors with good signal strength are temporary added in the neighboring list. To reduce the size of neighboring list, the serving femtocell removes those femtocells that use the same frequency as that of serving femtocell. The location information about the hidden femtocells is provided by those neighbors that were initially added in the temporary neighboring list. Hidden neighbors are the one that are physically nearer to the serving femtocell but there is some sort of barrier between them due to which the serving femtocell cannot receive their signal. After receiving the location information, if the distance of the hidden femtocell is less than or equal to some threshold value, then they are included in the neighboring list. Simulation results show that we can achieve reduced femto-femto handover failures and less power consumption for scanning the neighboring femtocells. However, maintaining and updating the neighboring list for such large random number of femtocells is a difficult process.

In [61] a new procedure for WiMAX macro and femtocell handover by taking QoS and load balancing into account is proposed. The handover process starts with a scanning process. In this process a request is sent by MS to the serving BS to search for available femto and macrocell BSs. An MS neither receives nor sends data during this interval. The scanning interval is minimized by scanning the macro or femtocell BS that are authorized, free and have satisfied the required QoS constraints. The MS synchronizes itself with target list and adds it to its old target list. To refine the handover, a QoS criterion is also introduced in target selection. For real time traffic, handover is given to macrocell BS while for non-real time traffic the femtocell is the first priority for handover. If a user (using real time traffic) is in the coverage area of a femtocell (to which it is subscribed) for a long time, then in such case handover is directly given to the femtocell for real time traffic. The simulation result shows that this procedure reduces the BS load, improves network load balancing and increases the BS bandwidth allowing more users to utilize it.

In [62], the handover algorithm based on MS's mobility state for LTE / LTE advanced based network is proposed. Only handover between macrocell and femtocell is considered in the proposed work. If the signal strength of target (macro/femto) is greater than the sum of hysteresis plus signal strength of serving station then mobility state will be considered for handover. If mobility state is greater than a specific value or in other words if the MS has high mobility then it will connect to the macrocell else it will connect to femtocell. The comparison between the traditional handover schemes (no mobility state consideration) and the proposed handover scheme shows that a better signaling overhead as well as reduction of unnecessary handovers is achieved in the proposed algorithm. In table 4, the mentioned algorithms for handover are summarized.

8. Interference Management

Femtocells are not only a good solution to overcome the indoor coverage problem but they can also deal with the growth of traffic within the network to some extent. However with the deployment of new femtocells, the performance of macrocell layer can be undesirably impacted. The challenges that can arise are the allocation of spectrum resources and avoidance of electromagnetic interferences. Additionally, the already deployed femtocells can also be disturbed with the deployment of new femtocells.

Minimizing macro-macro, macro-femto and femto-femto interference is one of the main concerns for femtocell deployment. How interference is minimized is already discussed in [30], [32-35], [39,40], [43] and [55]. In [55], whenever a femtocell senses interference from a nearby un-authorized user, it then performs handover and allows that unsubscribed user to use the femtocells' services. Similarly in [29], Fractional Frequency Reuse is introduced for interference management in an LTE femtocell system. If we consider the clocks of femtocells being synchronized with that of the macrocell [27], and thus considering them two different layers, the interference can be classified as:

- Co-Layer Interference
- Cross-Layer Interference

Co-layer is the interference of the same network, i.e. a FAP interfere with the neighboring femtocell user. Cross-layer refers to the interference between the users of two different network layers as the FAP and the macrocell. A cancellation technique is proposed to overcome this kind of interference; however this technique is disregarded because of errors in the cancellation process [63]. Another technique is proposed in [64] by using sectorial antennas at the FAP, which can decrease the number of interferers, resulting reduction in the interference. Similarly [45] has described the dynamic selection approach of predefined antenna patterns to reduce power leakage outdoors which causes interference to the macrocell users.

To mitigate interference usually power control algorithms and radio resource management schemes are preferred [27]. If these techniques are not used, then the users located far from a BS can be jammed by the closer positioned ones. Same techniques are used in FAPs, not only to handle this problem but also to deal with the cross-layer interference. For example, if a user located far from the FAP in a closed access femtocell, is asked to raise its power level, will cause high level of interference not only with the neighboring femtocells but also with the macrocell.

In [65] interference between two tier networks is addressed. Presence of macrocell and femtocell make the network, a two tier network in which one tier is governed by the macrocell while the other is covered by femtocells. The interference between the two tiers is known as cross-tier interference, which is shown in Figure 11. This type of interference results in poor signal quality. Whenever there is cross tier interference, then using inter-cell handover, a separate channel is reallocated to either the macrocell or the femtocell. Therefore, there is either separate channel or power allocation upon the detection of cross tier interference.

In [66], two techniques are introduced to reduce cross-tier interference; the open-loop control and closed-loop control technique. Both techniques operate on the basis of maximum transmit power. In open-loop technique the maximum transmit power is adjusted in the perspective of fixed interference threshold, while in the closed-loop control we consider adaptive interference threshold by considering noise and uplink interference (NI) level.

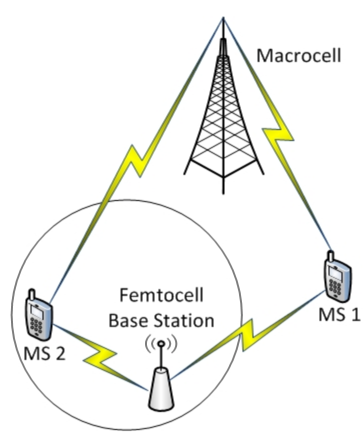

Figure 11. Cross Tier Interference.

	Handover approach	Features	Positives	Negatives
[53]	MS controlled	Two phases: Handover preparation phase Handover execution phase	Reduces number of handovers and minimizes mobility events.	Signaling load
[54]	MS controlled	MS compares signal strength of neighboring cells	Fast handover	No authorization checking procedure is provided.
[55]	Femtocell controlled	Hybrid access mode is initiated to offload the core network	Reduces interference and offload core network.	Signaling load, Not suitable for small femtocell network.
[56]	MS/femtocell controlled	Handover based on MSs' velocity and QOS	Reduces mobility events and unnecessary handovers.	Detection and judgment of real timing attribute is complicated and not cost effective.
[57]	MS/femtocell controlled	Handover decision based on probability and RSS.	Efficient handover in hierarchical macro/femto cell network.	Constant monitoring of traffic type and loading status of cells.
[58]	MS controlled	Reverse link sensing method to detect target femtocells.	Provides handover for CDMA femtocells.	Signaling load and delay
[59]	MS controlled	Handover decision based on RSS, CINR, QOS and mobility procedures.	Reduces mobility events, reduces unnecessary handovers and provides a secure handover.	Signaling load
[60]	Femtocell controlled	Neighboring list creation	Reduces femto-femto handover failures, less power consumption.	Managing/updating neighboring list is difficult.
[61]	MS controlled	Handover decision based on QOS and load balancing.	Reduces the base station load.	Mobility decision is not taken into account.
[62]	MS/femtocell controlled	Handover decision based on mobility.	Reduces unnecessary handovers.	Detection of real time scenario is a complicated process.

Table 4. Summary of various handover schemes.

Two performance metrics, used to evaluate the performance of the proposed algorithm, the Degradation Ratio of Macrocell Throughput (DRMT), L_T, and the Achievement Ratio of Femtocell Throughput (ARFT), A_T, are defined as

$$L_T = \frac{T_{m,0} - T_m}{T_{m,0}} \text{ and } A_T = \frac{T_f}{T_{f,0}} \quad (1)$$

In equation (1), T_m and $t_{m,0}$ are the throughput of uplink average sector in the macrocell with and without femtocell respectively. $T_{f,0}$ represents the uplink average throughput in the femtocell when the femtocell users employ a fixed maximum transmit power of 23 dBm, and T_f is the uplink average throughput in the femtocell using the proposed open-loop or closed-loop power control scheme. In the graph, we can see the DRMT versus the distance between the macrocell BS and the femtocell BS, *D*, for fixed power transmission with penetration loss PL of 10dB and 1dB, respectively. The simulation results suggest that by using these two techniques, uplink throughput degradation at macrocell BS occurs. However, the femtocells throughput of closed loop control is better as compared to open-loop control technique.

In [67] upload and download interferences are considered for UMTS/HSPA femtocells. To tackle download interference it proposes *femtocell base station autonomous carrier selection* and *inter-frequency handover* for macrocell users. To mitigate uplink interference it discusses two techniques that are adaptive uplink attenuation and limiting user equipment transmitting power. A distributive and fully scalable approach is proposed in [68]. In it, each cell selects the primary and secondary carriers so no use of a centralized network is needed. This method effectively minimizes interferences resulting due to femtocells deployed in local area environments for LTE-advanced.

In [69], the download interference between macro and femtocell is addressed. Using downlink power control, the interference is minimized. In the simulation model both centralized and distributed models are presented. The results show that the proposed model could effectively mitigate co-channel interference and provides QoS support for every type of user.

In [70], distributed dynamic spectrum access and power allocation algorithms are used for optimization of a femtocell network. An optimal solution is obtained by utilizing time sharing properties. Simulation results suggest that the proposed scheme increases network capacity and minimizes interference.

In [71], a *frequency scheduling* method is used to tackle the inter-carrier interference from macrocell uplink to femtocell uplink and co-channel interference in an OFDMA femtocell network. In frequency scheduling the femtocell avoids using macrocell's resource blocks. Spectrum sensing is performed to locate the free spectrum. Finally frequency scheduling is performed to get an interference free femtocell network.

Similarly spectrum splitting is performed to mitigate interference in OFDMA femtocell networks [72]. In [73], orthogonal FFR radio resource allocation patterns are presented for interference avoidance in macro-femto networks. The same fractional frequency reuse technique is also used in [74] to mitigate interference.

A recursive core approach is used in [75] to mitigate interference. First of all coalitions are formed in which each femtocell can make decisions independently to either join the coalition or not. Within each coalition in the resulting partition, the femtocell-to-femtocell interference can be minimized by cooperating femtocells, using a coalition-level scheduler.

In [76], an interference management scheme based on graph coloring algorithm is presented. Cognitive spectrum allocation results in interference mitigation. This is done in three steps. Interference is estimated first, then spectrum division threshold is calculated and finally, based on graph coloring, spectrum allocation is performed. In [77] *Successive Interference Cancellation* (SIC) technique is presented. SIC performs the channel estimation of the interfering signal, later it subtracts this interfering signal from the primary one, resulting in an almost interference free femtocell network.

9. Conclusions

The most important benefits of wide scale femtocell deployment are lower cost of deployment, better indoor signal reception for voice and data, and decreased burden on Macro/ Microcell base stations i.e. if the femtocell base station uses DSL as the means to backhaul the user traffic. Apart from the technical issues and their proposed solutions that are highlighted in this paper, effective development of attractive business models shall also facilitate the rapid deployment of femtocells. One of the main end user concerns related to femtocell deployment lie in the cost of femtocell base station and the packages offered to the user for data access. In case when the user has access to both DSL and WLAN services that provides the user with a much higher bandwidth than data access on a cellular network, the extra costs incurred while accessing data services via a femtocell can also be an important cause of reluctance on behalf of the end user to opt for a femtocell solution. However, with better indoor signal strength and higher bandwidths offered by LTE and LTE advanced (4G and beyond), along with offering cheaper packages to the end consumers for data access while addressing the technical issues highlighted in the paper, femtocell deployment on a much wider scale can be made a reality.

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