Bandwidth Access And Interference Mitigation Techniques For Femtocells

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ABSTRACT-

With the continuously increasing the need of mobile users there is need for the cellular network operators to upgrade the networks by which they can meet the requirements of current users. Network operators cannot do this only by availing new spectrum but they have to improve their network architecture as well. In 4G networks the new standards LTE-Advanced are used to improve the network architecture. In LTE-Advanced the Femtocells are used to meet the requirements of indoor users. We cannot investigate the problem of interference in Femtocells using traditional cellular methods. We use the bandwidth flexibility, provided by OFDMA, to efficiently use the spectrum by Femtocells. In this paper we discuss the various methods by which the femtocells can access the bandwidth.

Keywords- OFDMA, LTE, Femtocells, 4G, Two-tier Architecture.

I. INTRODUCTION

The requirement of mobile users are growing exponentially in terms of devices (smartphones, tablets, etc.), multimedia (e-lectures, HD Movies, etc.). Cellular network operators trying their best to meet the requirements by additional spectrum as well as enhance their network architecture. From the architectural point of view, wireless networks are moving from homogenous network planning to heterogeneous network planning – i.e. a mix of large and small cells. The need for small cells introduced the concept of Femtocells (for indoor users). [1]

Femtocell is very important concept to enable the Next-Generation Wireless Technology i.e. LTE-Advanced. The deployment of Femtocell enables the optimization of network performance at relatively low cost [2]. With the help of Femtocells, low power base stations, network planners are able to provide mobile users better coverage and capacity at cell edges. Using the concept of Femtocells users can get higher data rates (compared to macro cells) at hot-spot areas i.e. in a particular of important building and also without any fibre connection [1]. Femtocells do not require any additional license of spectrum but it functions on
same licensed spectrum as the outdoor macro cells. Usually it is preferred to deploy the femtocell with same frequency bands as macro cell, i.e. Co-channel fashion. The purpose of co-channel implementation is to achieve the higher capacity. For the backhaul link to, Femto Gateway in the cellular network femtocell uses user's own broadband Internet connection.

Femtocells designed in a way that it works as a small indoor wireless access point with only one and two users active at a time. Femtocells that typically serve only few users at a time they are very spectral efficient as well as they can provide users much higher data rates as compared to the outdoor macro cells. In simple words, we can say that Femtocells are small, less expensive and low power base stations that are generally deployed according to the position and need of some specific consumers [3]. From the user equipment or mobile station point of view the femtocells are just same as traditional base station because it performs in-band handoffs and uses usual overhead channels which performs and done by normal base station. But on the other hand from the user point of view it resembles just as Wi-Fi access points because by using femtocells the are able to get their desired Quality of Service (QoS). For detailed description of femtocells see [3]. Heterogeneous network architecture can also be called as two layers or two tier network architecture. One tier of the network is usual macro cellular tier while the second tier of the network is of the femtocell network. The new layer of the network architecture, i.e. Femtocell layer is unplanned and behaves as ad-hoc in nature. Due to this new layer the network have number of advantages in the form of capacity, quality etc. But these advantages come with some design challenges. In these challenges the interference management is of the utmost importance.

The main performance limiter in the deployment of femtocells is the interference. We cannot say that only the interference degrades the performance of femtocells but from the study and research point of view of interference is the area of great research and practical interest because cellular network operator wants to make the architecture of the network which is very efficient in the terms of spectrum utilization. We should understand that interference techniques which used in traditional cellular network cannot be used in heterogeneous network architecture because this new architecture is the two tier architecture and ad-hoc in nature. The femtocells deployment is always according to the need of consumers and the quantity of femtocells in network can be increase and decrease as per the requirement of users. Hence we cannot rely on the static interference mitigation techniques, which are used in traditional cellular networks. We can think that the use of Orthogonal Frequency Division Multiple Access (OFDMA) can solve the problem because OFDMA can make the time and frequency resources mutual orthogonal with respect to the adjacent femtocells. There is two methods to counter the problem of interference in this case. First, the whole problem of interference is managed by a central node, but this type of solution is not feasible in the femtocell network because of ad-hoc nature of networks. Second, the problem is distributed to various nodes but this solution also not practical because of the dense deployment of femtocells (a lot of message passing between nodes).
In general there are two types of interference occur in two tier architecture. First one is Co-tier Interference which occurs between two femtocells. The main cause of Co-tier Interference is dense deployments of femtocells; sometimes they are so dense that there is separation of only one wall between two femtocells. The Co-tier Interference is much severs in closed access as compared to open access. The uplink interference is caused by user equipment (UE) to the neighbouring femtocells. Downlink interference is caused by Femtocell to the neighbouring UE. Now we can say that the power control is very important to avoid the Co-tier Interference because if the power level of UE is very high then it will disturb the neighbouring femtocell and also if the power level of femtocell is very high then it will disturb the neighbouring UE [4].Second one is Cross-tier Interference which occurs between femtocell and macrocell. Cross-tier interference in uplink takes place when femtocell user acts as a source of interference to the outdoor macrocell and the downlink of this interference take place when femtocell acts as source to the outdoor macrocell base station.

II. HISTORY OF FEMTOCELLS

The concept of small cells has been introduced nearly 3 decades ago. In the starting days of small cell concept small denotes the cell size in urban areas where the macrocell (large diameter) split into smaller cells. These new smaller cells having the diameter of less than kilometre and also the transmit power of these smaller cells are less as compared to the macrocell.

In the 1990s, a precursor to cellular picocells began to appear with cell sizes ranging from tens to about one hundred meters. These “traditional” small cells were used for capacity and coverage infill. These types of small cells were essentially a smaller version of the macro base station, and required comparable planning, management and network interfaces. More similar to the current femtocell concept was a little known industry project in the early 1990s led by Southwest Bell and Panasonic to develop an indoor femtocell- like solution that re-used the same spectrum as the macrocells. However, there was a lack at this time of ubiquitous IP backhaul, and the level of integration had not yet achieved the critical point whereas base station could be truly miniaturized. Like the other small cell technologies just mentioned, they were technically a step forward but economically unsuccessful, because the cost of deploying and operating a large number of small cells outweighed the advantage they provided.
New thinking on the deployment and configuration of cellular systems began to address the operational and cost aspects of small cell deployment. A femtocell is fundamentally different from the traditional small cells in their need to be more autonomous and self-adaptive. Additionally, the backhaul interface back to the cellular network – which is IP-based and likely supports a lower rate face connecting macro and Pico cells – mandates the use of femtocell gateways and other new network infrastructure to appropriately route and serve the traffic to and from what will soon be millions of new base stations. Small cells have recently become a hot topic for research as evidenced by a significant increase in publications in this area, and small cell technology has advanced a great deal from the simple cell splitting ideas. In addition, the European Union has started funding research on femtocells. Today, advanced auto-configuration and self-optimization capability has enabled small cells to be deployed by the end-user in a plug-and-play manner, and they are able to automatically integrate themselves into existing microcellular networks. This was a key step to enable large scale deployments of small cells.

The governing body with arguably most impact onto standardization bodies is the Femto Forum. It is a not-for-profit membership organization founded in 2007 to enable and promote femtocells and femto technology worldwide. Today, it counts on more than 70 providers of femtocell technology, including mobile operators, telecommunication hardware and software vendors, content providers and start-ups. It has had a major impact in various standardization bodies, such as ETSI and 3GPP. It caters, among others, for developing a policy framework that encourages and drives the standardization of key aspects of femtocell technologies worldwide. It is active in two main areas: 1) standardization, regulation & interoperability; and 2) marketing & promotion of femtocell solutions across the industry and to journalists, analysts, regulators, and special interest groups and standards bodies.
A key difference in OFDMA (both LTE and WiMAX) is the large quantity of dynamically allocated time and frequency slots. This considerable increase in the flexibility of resource allocation is both a blessing and a curse. Because femtocells can be allocated orthogonal resources to nearby Pico and macrocells, the possibility for fine-tuned interference management exists, whereas it did not in GSM or CDMA. That is, in theory, a complex network-wide optimization could be done whereby femtocells claim just as much resources as they “need”, with the macrocells then avoiding using those time and frequency slots. And therein lies the curse: potentially a large amount of coordination is necessary. A popular compromise is fractional frequency reuse, whereby frequency (or time) resources can be semi-statically allocated to interior, edge, or small cell users, with power control on top to lower the throughput disparities experienced in each of these scenarios. Alternatively, a semi-static partition could simply be made between femtocells and macrocells.

III. OVERVIEW OF KEY CHALLENGES

1). Interference Coordination:
Perhaps the most significant and widely-discussed challenge for femtocell deployments is the possibility of stronger, less predictable, and more varied interference. This occurs predominantly when femtocells are deployed in the same spectrum as the legacy (outdoor) wireless network, but can also occur even when femtocells are in a different but adjacent frequency band due to out-of-band radiation, particularly in dense deployments. The introduction of femtocells fundamentally alters the cellular topology by creating an underlay of small cells, with largely random placements and possible restrictions on access to certain BSs. Precise characterizations of the interference conditions in such heterogeneous and multi-tier networks have been the subject of extensive study. In principle, with open-access and strongest cell selection, heterogeneous, multi-tier deployments do not worsen the overall interference conditions or even change the SINR statistics. This “invariance property” has also been observed in real-world systems by Nokia Siemens and Qualcomm, and provides optimism that femtocell deployments need not compromise the integrity of the existing macrocell network. However, in practice, at least two aspects of femtocell networks can increase the interference significantly. First, under closed access, unregistered mobiles cannot connect to a femtocell even if they are close by; this can cause significant degradation to the femtocell (in the uplink) or the cell-edge macrocell user in the downlink, which is near to a femtocell. Second, the signalling for coordinating cross-tier interference may be logistically difficult in both open and closed access. Over-the-air control signalling for interference coordination can be difficult due to the large disparities in power. Also, backhaul-based signalling with femtocells is often not supported or comes with much higher delays since femtocells are typically not directly connected to the operator’s core network.

2). Cell Association and Biasing:
A key challenge in a heterogeneous network with a wide variety of cell sizes is to assign users to appropriate base stations. The most obvious way, which does in fact maximize the SINR of each user, is to simply as-
sign each user to the strongest base station signal it receives. However, simulations and field trials have shown that such an approach does not increase the overall throughput as much as hoped, because many of the small cells will typically have few active users. This motivates biasing, whereby users are actively pushed onto small cells. Despite a potentially significant SINR hit for that mobile station, this has the potential for a win-win because the mobile gains access to much larger fraction of the small cell time and frequency slots. Furthermore, the macrocell reclaims the time and frequency slots that user would have occupied. Biasing is particularly attractive in OFDMA networks since the biased user can be assigned orthogonal resources to the macrocell, so the interference is tolerable.

3). Mobility and Soft Handover:
Since the coverage area of an individual femtocell is small, it is essential to support seamless handovers to and from femtocells to provide continuous connectivity within any wide-area network. Handover scenarios include femto-to-macro (outbound mobility), macro-to-femto (inbound mobility) and possibly femto-to-femto; the latter occurring in enterprise deployments or dense femtocell coverage in larger public areas. In principle, femtocells act as other base stations and can therefore utilize existing mobility procedures. However, femtocell mobility presents a number of unique challenges that require special consideration. Standards bodies such as 3GPP have devoted considerable attention to these mobility issues. Procedures are also being developed for vertical handovers between femtocells and non-cellular access technologies such as Wi-Fi, under the Generic Access Network framework. Perhaps the most difficult aspect of femtocell mobility is that femtocells are not typically directly connected into the core network where mobility procedures are usually coordinated. The lack of a low delay connection to the core network can result in significant handover signalling delays. Moreover, for similar architectural reasons, CDMA femtocells suffer from a further limitation that they are typically unable to share a Radio Network Controller (RNC) with a macrocell or other femtocell for coordinating soft handovers. Several works have begun considering architectural changes in the core network and femtocell gateway functions to address these mobility issues, although the subject remains an active area of research. Femto and picocells also result in much more dense deployments, which complicates base station discovery—a key initial step in any handover. Considerable research, particularly in the standard bodies, have considered improved methods for cell identification and discovery signalling.

4). Security:
Providing efficient security to femtocell networks is one of the key challenges. In the case of open access mode, security is of much importance as the users private information needs to be protected. The femtocell network is prone to many security risks. For example, the private information of subscriber travels over the backhaul internet connection. This data can be hacked, which would breach privacy and confidentiality. The femtocells are also prone to Denial of Service (DoS) attacks. A hacker can overload the link between a FAP and mobile core network. This would prohibit a subscriber to connect to the core network and the femtocell service would not be available. Security is also required to prevent unwanted users to access a femtocell

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network and use the resources. This is mainly for the close access mode, where only specific users can access a femtocell. Due to these threats, operators and manufacturers provide some level of security. Mainly the Internet Protocol Security (IPsec) is used to provide security to the link between FAP and operators core network. There is a security gateway in the operator’s core network and when the FAP wants to connect to the core network, a secure tunnel is established between the FAP and the security gateway. All the data to and from the femtocell travels through the secure tunnel, hence making the data more secure. With the increasing number of femtocell deployments the security issue would become more and more serious. Therefore, there is a need of extensive research in this area.

5). Self-Organizing Networks:
Femtocell networks are unique in that they are largely installed by customers or private enterprises often in an ad hoc manner without traditional RF planning, site selection, deployment and maintenance by the operator. Moreover, as the number of femtocells is expected to be orders of magnitude greater than macrocells, manual network deployment and maintenance is simply not scalable in a cost-effective manner for large femtocell deployments. Femtocells must therefore support an essentially plug-and-play operation, with automatic configuration and network adaptation. Due to these features, femtocells are sometimes referred to as a self-organizing network (SON). One aspect of SON that has attracted considerable research attention is automatic channel selection, power adjustment and frequency assignment for autonomous interference coordination and coverage optimization. Such problems are often formulated as a mathematical optimization problem. This special issue, in particular, contains two articles on adaptive interference coordination – one on power control and a second on adaptive carrier selection. Also, although femtocells are often deployed in an unplanned manner, femtocell placement may be optimized for interference and coverage, particularly in enterprise settings. The adaptive and autonomous nature of interference management in SONs also bears some similarities to the cognitive radio concept, where spectrum is allocated in a distributed manner by devices operating with a significant degree of autonomy. Indeed, research has begun considering so-called cognitive femtocells that can dynamically sense spectrum usage by the macrocell and adapt their transmissions to optimize the overall usage of the spectrum. Currently several initiatives are focusing on reducing the energy consumption of networks. The most prominent one is “Green Touch”, a consortium founded by leading industry, academia, government and non profit research institutions around the world with the mission to deliver the architecture, specifications and roadmap to demonstrate the key components needed to increase network energy efficiency by a factor of 1000 from current levels by 2015.

IV. INTERFERENCE MANAGEMENT IN DETAIL
In general, two types of interferences that occur in a two-tier femtocell network architecture (i.e., a central macrocell is under-laid/overlaid with 3G/OFDMA femtocells, respectively) are as follows: Co-tier interference: This type of interference occurs among network elements that belong to the same tier in the network.
In case of a femto-cell network, co-tier interference occurs between neighbouring femtocells. For example, a femtocell UE (aggressor) causes uplink co-tier interference to the neighbouring femtocell base stations (victims). On the other hand, a femtocell base station acts as a source of downlink co-tier interference to the neighbouring femtocell UEs. However, in OFDMA systems, the co-tier uplink or downlink interference occurs only when the aggressor (or the source of interference) and the victim use the same sub-channels. Therefore, efficient allocation of sub-channels is required in OFDMA-based femtocell networks to mitigate co-tier interference. **Cross-tier interference:** This type of interference occurs among network elements that belong to the different tiers of the network, i.e., interference between femtocells and macrocells. For example, femtocell UEs and macrocell UEs (also referred to as MUEs) act as a source of uplink cross-tier interference to the serving macrocell base station and the nearby femtocells, respectively. On the other hand, the serving macrocell base station and femtocells cause downlink cross-tier interference to the femtocell UEs and nearby macrocell UEs, respectively. Again, in OFDMA-based femtocell networks, cross-tier uplink or downlink interference occurs only when the same sub-channels are used by the aggressor and the victim.

Femtocells are deployed over the existing macrocell network and share the same frequency spectrum with macrocells. Due to spectrum scarcity, the femtocells and macrocells have to reuse and/or share the total allocated frequency band partially or totally which leads to cross-tier or co-channel interference. At the same time, in order to guarantee the required QoS to the macrocell users, femtocells should occupy as little bandwidth as possible that leads to co-tier interference. As a result, the throughput of the network would decrease substantially due to such co-tier and cross-tier interference. In addition, severe interference may lead to “Dead-zones,” i.e., areas where the QoS degrades significantly. Deadzones are created due to asymmetric level of transmission power within the network and the distance between macrocell UE and macrocell base station. For example, a macrocell UE located at a cell edge and transmitting at a high power will create a deadzone to the nearby femtocell in uplink transmission due to co-channel interference. On the other hand, in the downlink transmission, due to high path-loss and shadowing effect, a cell edge macrocell UE may experience severe co-channel interference from the nearby femtocells. Thus, it is essential to adopt an effective and robust interference management scheme that would mitigate the co-tier interference and reduce the cross-tier interference considerably in order to enhance the throughput of the overall network. In OFDMA-based femtocell networks, due to the flexibility in spectrum allocation, orthogonal sub-carriers can be assigned to femtocells and macrocells. This gives OFDMA-based femtocells an edge over CDMA systems in terms of utilizing the frequency spectrum resources efficiently. If an effective interference management scheme can be adopted, then the co-tier interference can be mitigated and the cross-tier interference can be reduced which would enhance the throughput of the overall network. Other challenges in femtocell deployments include: handoff and mobility management, timing and synchronization, auto-configuration, and security. An effective and efficient mobility management and handover scheme (macrocell-to-femtocell, femtocell-to-macrocell and femtocell-to-femtocell) is necessary for mass deployment of femtocells in
UMTS and LTE networks. The scheme should have low complexity and signalling cost, deal with different access modes and perform proper resource management beforehand for efficient handover. Timing and synchronization is one of the major challenges for femtocells since synchronization over IP backhaul is difficult, and inconsistent delays may occur due to varying traffic congestion. Since the femtocells are required to operate on a “plug-and-play” basis, it is important that femtocells can organize and configure autonomously and access the radio network intelligently so that they only cause minimal impact on the existing macrocell network. Since femtocells could be vulnerable to malicious attacks (e.g., masquerading, eavesdropping, man-in-the-middle attack etc.), enhanced authentication and key agreement mechanisms are required to secure femtocell networks. In this article, we give an overview of the different interference management techniques for OFDMA-based femtocell networks presented in the recent literature.

Types of Interference in a Two Tier Network

The two-tier architecture enables us to divide the interference in to two main types. 1) Co-tier Interference: This type of interference refers to the interference caused by network elements that belong to the same tier or layer of network. In the case of femtocells, it is the interference caused to a femtocell by another femtocell as shown in

Fig.3. A scenario showing co-tier interference between neighboring femtocells

Usually the femtocells causing interference to each other are immediate neighbouring femtocells, as they are close to each other. The deployment of femtocell is random and they can be deployed very close to each other in apartments, where the wall separation might not be enough to avoid causing interference to each other. In the case of dense deployment, where there might be a number of neighbouring interferers, the overall interference observed at a femtocell can be higher than any of the individual interfering femtocells. To establish a communication link, the SINR value should be above a certain threshold. If the SINR at a certain femtocell location is lower than a defined threshold due to co-tier interference, it would be impossible to
create a communication link and thus a dead zone would be created. The SINR threshold level is usually defined by the air interface technology in use and can be different for different requirements of QoS. The access methods used in femtocells have a huge impact on the overall interference. The co-tier interference is more severe in closed access as compared to the open access. Due to this, the dead zones in closed access are larger as compared to open access. The dead zones also depend on the QoS requirement of each service. If a service requires higher SINR, it might not be possible to provide the service near the windows or edges of a femtocell. So the dead zone for such services would be larger as compared to other services that do not require comparatively high SINR. The uplink co-tier interference is caused by the femtocell user equipment (UE). The femtocell UE acts as a source of interference to the neighbouring FAPs. For example, in a CDMA system, the immediate neighbouring femtocell UEs are the main source of uplink interference. If a UE in the neighbouring femtocell transmits at a high power, it will affect the victim femtocell and the performance will be degraded. In this case, an FAP should impose power limits on its UEs in order to control the noise level at neighbouring FAPs. The 3G system like UMTS and High Speed Uplink Packet Access (HSUPA) applies intelligent power control techniques to limit the uplink interference. In these systems, the FAP is able to sense the surrounding radio environment and gather information about any nearby femtocell UEs. It then sets the transmit powers of its UEs based on the gathered information. In the case of OFDMA femtocells, the FAP should sense the surrounding radio environment for certain sub channels. A UE would require certain number of sub channels depending on the QoS, the FAP should then allocate sub channels that are subject to lower level of interference. As compared to the CDMA, the OFDMA system provides better chances of avoiding interference due to the division of spectrum into small sub channels.

Cross-tier Interference: This type of interference is caused by network elements that belong to different tier or layer of the network. For example, an FAP can cause interference to the downlink of a macrocell UE nearby as shown in

![Diagram of Cross-tier Interference](image_url)

**Fig. 4.** A scenario showing cross-tier interference between femtocell and macrocell.
Also a macrocell UE can cause interference at the uplink of a nearby FAP. Femtocells would cause large amount of interference to neighbours that are using macrocell services for indoor purpose. This problem becomes more severe in the case of closed access mode. The macro UEs would receive strong signals from the close by neighbour, to which access is denied and there would be huge dead zones around the femtocell. To cope with the cross-tier interference, spectrum splitting is also proposed. However, this is a less efficient technique, as spectrum is costly and scarce as well. In the case of having separate spectrum portion for the femtocell tier, there would be no cross-tier interference. However, if the bands are adjacent to each other in the frequency domain, there can be adjacent channel interference. Hence, effort is required to mitigate the adjacent channel interference as well. The cross-tier uplink interference can take place when a femtocell UE acts as a source of interference to the macrocell BS. In the case of a CDMA system, power control is used in order to prevent femtocell UE from causing interference to the macrocell BS. The FAP should sense the environment and not ask for higher powers from its UEs. The femtocell UEs are normally close to the FAP and do not transmit at enough high powers to cause interference to macrocell BS. In the case of open access mode, the users are allowed to connect to any layer, depending on the quality of the received signal at the time. This enables the use of minimum power by both femtocell and macrocell and hence the interference can be reduced. Another case of cross-tier uplink interference is when a macrocell UE transmits at high power near a femtocell. This will cause interference at the FAP. The femtocells are normally isolated, due to the wall penetration, but still in some cases the macrocell UE can cause sufficient interference to the femtocell. In the case of OFDMA, the same two types of uplink cross-tier interference can occur. The first type of interference as defined above for CDMA can also occur in OFDMA systems if the femtocells located near the macrocell BS. If a femtocell UE is transmitting with high power on certain sub channels near a macrocell BS, these sub channels become unusable for the macrocell BS and hence the overall efficiency is reduced. In this case, the power of the femtocell UE should be restricted and there should be bound on the upper limit of transmit power of a femtocell UE. In the second case of interference, where a macrocell UE is transmitting with high power because of being away from the macrocell base station, the femtocell should allocate different sub channels in order to avoid interference. The downlink cross-tier interference can be caused by an FAP to a close by macrocell UE. In the case of closed access mode, the area around the femtocell becomes dead zones for macrocell UE. There can be power leakage through windows and doors from an indoor located FAP to a nearby macrocell UE. In the case of CDMA co channel deployment; there is a need for adaptive power control, because of the changing circumstances. The adaptive power control can provide FAPs with a variety of options and hence mitigate interference. If the femtocell is located near to the macrocell BS, the femtocell size would shrink because of the interference from the macrocell BS. In this situation, the femtocell UEs can have coverage only when they are located very near to the FAP. In a scenario, where a femtocell UE is near the window of a house having FAP, it is more likely that the UE near the window will connect to the macrocell BS instead of the indoor FAP. The Femto forum investigated such a sce-
nario and deduced that a throughput of 14.4 Mbps can be achieved using HSDPA femtocells, when the femtocell UE is located 250 meters from a microcell and 1000 meters from a macrocell. In the case of OFDMA femtocells, the downlink interference management is mostly dependent on the allocation of subchannels. The FAP would not cause any interference to a macrocell UE, if the macrocell UE uses a different set of subchannels.

V. OFDMA-BASED RANDOM MULTIPLE ACCESS

Since OFDMA is often associated with planned cellular networks, random access MAC may seem of little relevance. So far, random access MAC has only been used for initial channel request and synchronization. For example, LTE sets aside few resource blocks in each radio frame with a set of random preamble sequences to be used exclusively for the Random Access Channel (RACH). The RACH procedure is essentially a form of Reservation-Aloha in which users contend to reserve a larger bandwidth or to be admitted into the system; i.e. no actual data is transported over the RACH. Once the user is successfully admitted, all subsequent downlink and uplink transmissions are scheduled by the Base Station. At the macrocell level, the BS can be considered active most of the time because a macrocell usually serves a large number of users. This implies that the randomness of the traffic at the user level needs not be taken into account in studying the inter-cell interference in a macro-cellular network. However, because a femtocell is designed to serve very few users with at most one or two users being active at any instant, the generated traffic load at the cell level is often bursty with low duty cycles. Furthermore, the number of femtocells operating in the same licensed spectrum in a given area is relatively small. We can view this as a cluster of interfering transmit-receive pairs (single-user femtocells) competing for channel access without a central arbitrator. In such situations, random multiple access is a viable choice if designed properly. In fact, we can exploit the flexibility of OFDMA and time synchronism to design more efficient random MAC algorithms for OFDMA-based femtocells. OFDMA provides an additional degree of freedom by allowing contention resolution over the frequency as well as over time dimension. The time-frequency resource grid in OFDMA (Fig. 2) can be thought of as a slotted multi-channel system. The grouping of sub-carriers into Resource Blocks (RB) divides the channel bandwidth into equally-sized subchannels which can be accessed on a slot-by-slot basis. We will use the terms “subchannel” and “channel” interchangeably to denote one RB in the frequency domain. Because these subchannels are orthogonal, the channel access problem translates into a Multi-Channel MAC problem. Numerous contention-based algorithms have been studied for Multi-channel MAC mostly in the context of ad-hoc and mesh wireless networks. In multi-channel ad-hoc networks, the user usually contends for a single channel and then transmits one packet over that channel. The advantage is that when the number of users is much greater than the number of channels, the multi-channel MAC can distribute the contention load and reduce collisions. Two unique features distinguish OFDMA from traditional multi-channel MAC proposed in the context of wireless ad-hoc and mesh networks. First, channel switching is in-
stantaneous, because by definition OFDMA allows control over which subchannels are accessible and which are not on a slot-by-slot basis. This type of channelization being entirely realized in the digital processing domain marks a big leap over traditional multi-channel wireless systems where the transmitting node has to switch its radio from one frequency carrier to another incurring a significant time penalty. The second feature is the ability to transmit and receive over a variable number of subchannelssimultaneously with a single radio. For example, a packet in LTE is segmented or concatenated with other packets to fit into a variable-size block that is mapped to the allocated (randomly accessed) subchannels. This enables the random MAC protocol to adapt dynamically to various network loads and traffic scenarios. Several random access algorithms have been proposed to exploit the multi-channel nature of OFDMA. Upper- tunistic multi-channel Aloha attempts to exploit the multi-user diversity by adapting the transmission probability in each subchannel to its corresponding channel quality. It proposed what we term OFDMA-Aloha - a fast retrial algorithm for frequency-domain back off. In OFDMA-Aloha, instead of waiting for a random back off period after a collision, the user tries another (randomly selected) subchannel immediately subject to a maximum retry limit. This basic idea was extended to OFDMA-based CSMA/CA systems. In OFDMA-CSMA/CA, the user first senses all subchannels and randomly selects one subchannel from the set of idle subchannels for transmission. Then, it backs off for a random Collision Avoidance (CA) interval whose length is proportional to the number of sensed idle subchannels in every slot. In the above algorithms, the user is not allowed to access more than one subchannel at a time because the target is to distribute the offered load (attempt rate) over the available subchannels. The implicit assumption here is that the numberof users is greater than the numberof subchannels. The MAC modelin this case is the traditionalmulti-channel MAC with single access where exactly one packet is transmitted over a single subchannel. This MAC model is not suitable for femtocells where the numberof subchannelsis significantly greaterthan the numberof active users. Hence, an important design criteria in this case is to allow the user access to as many subchannels as possible to maximize utilization. The MAC frame in OFDMA is a single coded block of bits that is mapped to multiple subchannels. Since the user can initiate transmissions over multiple parallel subchannels, we need to define the notion of collision for such parallel transmissions.

VI. CONCLUSIONS

Femtocell technology can provide many advantages to the mobile subscribers and the service providers. Thus, femtocells could be viewed as a promising option for next generation wireless communication networks such as OFDMA-based LTE-Advanced and WiMAX networks. We have provided a survey of different techniques to cope with the co-tier and cross-tier interference problem in OFDMA-based two-tier femtocell net- works. With efficient interference management schemes, the network capacity and coverage can be increased that benefit both the subscribers and the operators. The distributed ad-hoc nature of
femtocells renders centralized interference mitigation solutions impractical. OFDMA provides a high degree of bandwidth flexibility that can be exploited in a new way to address the interference problem in femtocell

REFERENCES


