“A Study on Resource Allocation with Optimized Quality Class Interfaces and Challenges in OFDMA-Femtocell Networks”

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Abstract—Interference control and quality-of-service (QoS) awareness are the major challenges for resource management in orthogonal frequency-division multiple access femtocell networks now a days. Allocation of PRBs is of utmost importance for better utilization of network resources. Many techniques have been there which deals with it. This study investigates a self-organization strategy for physical resource block (PRB) allocation with QoS constraints to avoid the co-channel and co-tiered interference in the femtocell network. Femtocell self-organization including self-configuration and self-optimization is proposed to manage the network. We explain the optimization problems for PRBs assignments where multiple QoS classes for different services can be supported and interference between femtocells can be avoided. The proposed study pursues the maximization of PRB efficiency with avoiding interference in the network.

Index Terms—Femtocell, Interference Avoidance, Orthogonal frequency-division multiple access (OFDMA), Resource Allocation, Resource Reuse, Physical Resource Block (PRB), Home node (HN), Mobile node (MN), User equipment(UE).

1 Introduction

Today, mobile applications demands high-quality communications have tremendously increased in recent years. The femtocell network has widely been accepted as a promising concept in the next-generation wireless system to improve the radio resource reuse efficiency. The femtocell base stations can be deployed to cover dead zone areas or to share traffic loads from macrocells. With the large amount of traffic being properly handled by femtocells, the coverage and capacity of macrocells can be enhanced in cellular networks to more extent. Moreover, certain studies show that deployment of macrocells can be reduced since 70–80% of traffic can be off-loaded from macrocell. Instead of deploying more macrocells, the deployment of femtocells is an economical and beneficial option due to its low cost and low power consumption. Interference mitigation between neighboring femtocells and between the femtocell and macrocell is considered to be one of the major challenges in femtocell networks because Femtocells share the same licensed frequency spectrum with macrocell.

2 About OFDMA

2.1 Review

Orthogonal Frequency-Division Multiple Access (OFDMA) is a multiple-user version of the orthogonal frequency division multiplexing (OFDM) digital modulation scheme. Multiple accesses are achieved by assigning subsets of subcarriers to individual users in OFDMA.

2.2 Principle of Operation

About the channel conditions based on the feedback information, adaptive user-to-subcarrier assignment can be achieved. If the assignment is done fastly, this further improves the OFDM robustness to fast fading and narrow-band co-channel interference, and makes it possible to achieve the better system spectral efficiency. Different numbers of subcarriers can be assigned to different users, to support differentiated Quality of Service (QoS) to control the data rate and error probability individually for each user. OFDMA is similar to code division multiple access (CDMA) spread spectrum, where users can achieve different and better data rates by assigning a different code spreading or a different number of spreading codes individually to each user. OFDMA is regarded as a maximal solution for wireless broadband networks, due to advantages including scalability and MIMO friendliness and ability to take advantage of selectivity of channel frequency.

3 About Femtocells

As Femtocells are low power wireless base stations for cellular access in indoor areas with limited or no cellular provider or no signal.

- The Femtocell access point operates in a licensed spectrum and it is designed to route mobile traffic through a home or corporate IP network.
- A femtocell is connected to a network by a broadband by cable modem or Digital Subscriber Line and provides complete data and voice services to standard mobile devices such as cell phones or PDAs that are registered and within a limited range of the network.
- The main features of femtocell include authentication to the cellular core network, automatic registration, self-updation, location checking and power adjustment.
- Femtocell are not repeaters, which generally called signal boosters and are only used to improve existing macro cell coverage.
- It supports 2 to 4 active mobile phones in a residential setting and 8 to 16 active mobile phones in enterprise setting.
- Femtocell is compatible with any cellular technology and vendors are getting more focus on CDMA, 3G UMTS and the integration of the recent LTE standard.
- Femtocell is not limited to indoor use only and can be a best option for subway stations, tunnels, and other areas. It can also be used where callers usually lose signal from cell towers

while driving through tunnels or bridges.

4 Resource Allocation and Challanges in OFDMA Femtocell Network

Third- Generation Partnership Project (3GPP) specifies that femto architecture is composed of multiple sets of femtocell user equipment (FUEs), femtocells, and a femtocell management system (FMS). Mobile devices or laptops i.e. FUEs are connected to its associated femtocells through air interface. Femtocells can be deployed in indoor areas, houses, enterprise buildings, or in public places. Femtocells with geographical zones are logically grouped and connected to the Internet through the same FMS via broadband wire-line connections or through DSL. As, femtocells are designed to be installed by the end users with minimum interfere from the service providers view. The femtocell deployment is not controlled at its best when numerous femtocells may be randomly distributed in a surrounding area. The coverage area of neighboring femtocells overlapped and their FUEs may interfere with one another and hence, interference in femtocell occurs when radio resources with the same frequency and time slot are allocated to overlapping FUEs. There are two types of femtocell interference which are specified by the network tier on the basis of frequency. The category is specified firstly as a co-tiered and cross-tiered interference in the tiered network. As, in the co-tiered interference, the source node and the interfered node are in the same network. For example, a femtocell is interfered by unwanted signals sent from other femtocells. When a larger number of neighbors are heavily deployed, severe co-tiered interference arises and it is difficult to manage. The deployment of Femtocells in urban areas typically leads to overlapping coverage areas of multiple neighboring Femtocells in their tier. For example, the deployments of femtocell are likely to be in adjacent houses or nearby apartments and in cross-tiered interference, the source and the victim belong to different network tiers. There are many techniques which studied the problem of cross tiered interference through techniques of spectrum allocation, power adjustment, and open versus closed access operation. The both types of interference cross-tiered and co-tiered interference are independent of each other. Since the mitigation of co-tiered interference requires adaptive techniques, we will focus on the control of co-tiered interference. There is other category which is specified as co-channel and adjacent channel interference. In this co-channel interference, the same time–frequency resources are occupied by two different transmitters and in the adjacent-channel interference, the different but insufficiently separated resources are reused. With co-channel deployments, the femtocells are expected to reuse resources to improve the spectral utilizations and system capacities as the same resources may be reused by closely deployed femtocells that cause low communication quality. Since a flexible resource assignment technique eleminates co-channel interference the orthogonal frequency-division multiple access (OFDMA), intensely considered by 3GPP long-term evolution (LTE). The OFDMA exploits multiuser diversity by assigning resources according to the channel qualities of FUEs and based on OFDMA, the smallest unit of resource that can be assigned is called a physical resource block (PRB), which is a time–frequency block corresponding to 0.5 ms and 180-kHz frequency band having one resource frame of 20 time slots, where the frame length is 10 ms. And, this enable the femtocell technology, that aims to propose a resource allocation strategy to cope with interference and improve PRB efficiency in OFDMA femtocell networks. The quality of service (QoS) is also an important factor in resource management. There are different FUEs connections that can be classified into different QoS classes with their own QoS requirements. In 3GPP LTE specifications, there are nine different services specified by one to nine QoS class identifiers (QCIs). The QoS requirements for different QCIs of services are defined by L2 packet delay budget, L2 packet loss rate, and guarantee bit rate (GBR) criteria. Since different QoS services have different performance criterias so, the mechanism design to guarantee QoS services is one of the major issue for femtocell applications. To guarantee QoS without significant losses in PRB efficiency the QoS requirements for connections jointly with the resource allocation mechanism is introduced by LTE standards.

The FMS allocates usable resources for every femtocell in accordance with the number of clients/users, which is formed by the proper knowledge of neighboring femtocells. Many femtocells are connected to the FMS which serves as a controller and a gateway toward the cellular system and the relationships between FMSs and other network components where FUEs, femtocells and FMSs which constitute the entire femtocell networks. Interfernce may be caused when the neighboring femtocells operates on the same operator's network and hence, we can visualize this scenario of the femtocell deployment as several groups in a densely deployed area where the femtocells connected to one FMS are considered as a group. This grouping scheme validates that femtocells in different groups do not interfere with each other. And, to reduce the interference among neighboring femtocells, a femtocell must be able to organize itself automatically and in this deployment of femtocells with self-organization property is crucial hence resource allocation scheme automatically operates in a self-organizing network. The self-organization mechanism includes self configuration and self optimization in this after initialization of the femtocell will configure itself. Under this strategy the femtocell is assumed to transmit a neighbor-informing message with signal power twice as much as the regular information-bearing signal to overcome hidden terminal problem. And, then the femtocell waits for a period of time for feedbacks from neighboring femtocells during self-configuration process and the femtocell collects feedback messages and establishes the list of its neighbor femtocells. After the self-configuration is installed the femtocell will work in the operation mode and ready to provide services for FUEs. In the self-organization, the signals through FUE-to-femtocell, femtocell-to-FMS, and FMS-to- Internet connections can be used to facilitate the property of self-optimization. During the installation of self-optimization, neighboring information needs to be updated every fixed period of time to avoid stale neighbors. Since the femto management system allows numerous femtocells to be randomly deployed in a certain area, the radio resources, i.e., PRBs, may not be sufficient to fulfill the huge demand from the applications point of view. For this, the QoS constraint are measured by the required number of PRBs that are taken into account in allocating PRBs with the objective to improve PRB efficiency and each connection belongs to a single QCI in accordance with its application. For example, the services of QCI 1–4 are applicable to conventional voice, conventional video and for buffered streaming. QCI 5–6 are applied to IP multimedia signaling or for live streaming. QCI 7–9 apply to file sharing, email, P2P, or Web. In other words, the appropriate resources must be allocated to guarantee L2 packet delay budget, GBR limitation, and the required data rate in each QCI. Since GBR is required in QCI 1–4, the allocated number of PRBs should be equal to the requested PRBs. The remaining QCI 5–9 are non-GBR, which provides insufficient PRBs. So, the femtocells are assumed to operate with OFDMA technology in LTE and the requirements for the accomplishment of PRB numbers corresponding to data rates are predefined in 3GPP LTE specifications. Therefore, all the required resources are unique in different QCIs for various applications.

5 Technical Challenges in Femtocell Deployment

Femtocells give rise to several technical challenges. The major challenges are interference management between

- Neighboring Femtocells.
- Femtocell and Macrocell.

There are two types of interferences that occur in a two-tier femtocell network architecture is as follows:

Co-tier interference: In this type of interference happens among network elements that belong to the same tier in the network and in a femtocell network, co-tier interference occurs between neighboring femtocells. For example, a femtocell UE (aggressor) causes uplink co-tier interference to the neighboring femtocell base stations (victims). On the other hand, a femtocell base station acts as a source of downlink co-tier interference to the neighboring 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 as the 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 side, 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 in the network. 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 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 less 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 “Deadzones” 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 utmost important 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.

Other challenges in femtocell deployments include: Handoff and Mobility Management, Timing and Synchronization, Auto configuration and Security. An effective and efficient mobility management, handover schemes are necessary for deployment of femtocells in LTE network. The scheme should have low complexity and signaling 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.

6 Open Challenges

To enable mass deployment of femtocells, it is essential to develop distributed interference management schemes which primarily satisfy the QoS requirements of macrocell and femtocell UEs and at the same time enhances the capacity and coverage of the network. Such schemes should incur low overhead for coordination among macrocell BSs (i.e., MeNBs), and also should be able to integrate mobility management with different access modes and synchronization issues while keeping the complexity as minimal as possible. The interference management solution would strongly depend on the employed radio access technology (e.g., CDMA or OFDMA) and access mode (i.e., closed, open, or hybrid). In particular, adaptive admission control, power control, and advanced communication strategies such as interference cancellation and beamforming for multiple-antenna transceivers are important techniques to mitigate co-tier and cross-tier interferences. For example, one technique is by using beamforming techniques femtocells can form antenna beams toward their UEs while nulling interference caused to macrocell UEs. As macrocells have higher priority in accessing the spectrum; therefore, suitable admission control mechanisms should be activated when femtocells create intolerable interference for macrocell UEs. For OFDMA-based femtocell networks, if different sets of subchannels are assigned to macrocells and femtocells, cross-tier interference can be completely eliminated. However, to improve the spectrum utilization, a more efficient spectrum assignment method can be adopted. Also, hybrid interference management schemes which combine power control with resource partitioning are promising. Power control schemes are advantageous in that MN and HN can use the entire bandwidth with interference coordination for both control and data channels.

7 Conclusion

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 networks. With efficient interference management schemes, the network capacity and coverage can be increased that benefit both the subscribers and the operators. To mitigate the co-channel and co-tiered interference and the high demand for PRB efficiency in femtocell networks, in this paper, we have explored the usage of FMS to assist the allocations of OFDMA resources. To exploit the spectrum resource and increase the PRB efficiency in the femtocells, we focus on the design of the efficient resource management scheme, where the resource usages are not predefined but dynamically allocated with QoS considerations.

8 Acknowledgment

I Siddharth Rastogi (siddharthrastogi9696@gmail.com) acknowledged that this work has been done as a part of my thesis work in M.Tech, ECE from Lovely Professional University, Punjab, India and it is supported by my guide Mr. B. Arun Kumar, Asst. Prof, Lovely Professional University, Punjab, India .

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