Strategies for Spectrum Allocation in OFDMA Cellular Networks

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Abstract. The use of orthogonal frequency division multiple access (OFDMA) in Long Term Evolution (LTE) and WiMax cellular systems mitigates downlink intra-cell interference by the use of sub-carriers that are orthogonal to each other. Intercell interference, however, limits the downlink performance of cellular systems. In order to mitigate inter-cell interference, various techniques have been proposed. These techniques are generally divided into static and dynamic techniques. In static techniques, resources allocated for base stations are fixed, while they are adaptively allocated in the dynamic techniques. Although static and dynamic frequency reuse techniques, address the issue of interference, they do not have any mechanism to sustain a disruption or to maintain a allocation in a distributed manner. Hence, the need for distributed frequency allocation. In this paper we briefly discuss the merits of distributed spectrum allocation algorithms for cellular networks and also present an assessment of static interference schemes, and evaluate overall performance of the system in terms of the SINR, and spectral efficiency by adjusting different input parameters. In addition, we study an adaptive frequency reuse algorithm presented by and compare it with the static techniques.

Keywords: OFDMA · Inter cell interference · FFR · SFR · Adaptive frequency reuse

1 Introduction

Emerging wireless mobile systems, such as the 3GPP Long Term Evolution (LTE) and Mobile WiMax aim at providing higher data rate and enhanced spectral efficiency. To achieve that goal, they use orthogonal frequency division multiple access (OFDMA) in their downlink air interfaces [1]. OFDMA offers a high spectral efficiency and a scalable bandwidth for cellular systems. It uses orthogonal frequency division multiplexing (OFDM), which is a multi-carrier modulation scheme that divides a frequency band into a group of mutually orthogonal narrow band subcarriers whose bandwidth is smaller than the coherence bandwidth of the channel.

P.M. Pardalos et al. (Eds.): LION 2014, LNCS 8426, pp. 378–382, 2014.
DOI: 10.1007/978-3-319-09584-4_32

The sub-carriers' orthogonality in OFDMA mitigates any inter-carrier interference among the sub-carriers. However, co-channel interference (ICI) or inter-cell interference (ICI) will be incurred in adjacent cells that share the same spectrum. The ICI decreases the signal to interference and noise ratio (SINR), which causes a decrease in the spectral efficiency and data rate of the system [2]. Hence, the need for interference mitigation schemes.

In this work, we consider inter-cell interference coordination/avoidance techniques. These techniques require some form of coordination between different cells to restrict/allow resources in order to improve SINR and coverage [3]. Various inter-cell avoidance techniques have been studied in the past. These techniques generally fall into two categories: static or dynamic techniques. In static inter-cell interference coordination/avoidance techniques, allocated resource and power levels of transmitter for base stations are fixed. In the dynamic schemes, on the other hand, the resources are dynamically or adaptively allocated and power levels adjustments are made depending on the channel condition and capacity demand of the cells. In this paper, we present an assessment of static interference schemes, and evaluate overall performance of the system in terms of the SINR, and spectral efficiency by adjusting different input parameters. In addition, we study an adaptive frequency reuse algorithm presented by [10] and compare it with the static techniques.

Although interference avoidance/coordination techniques, specifically static and dynamic frequency reuse techniques, address the issue of interference, they do not have any mechanism to sustain a disruption. This is due to the fact that there needs to be some type of coordination between the base stations. If a base station or a coordinator base station that coordinates the allocation of spectrum among the cells fails to function due to disruption, for example in case of a major disaster, there will not be a fair spectrum reuse among the cells. Distributed mechanisms solve this problem. In addition to addressing disruption, distributed schemes allocate resources at base station level with no coordination between cells. Base stations assign channels to its users independently. This approach is a work in progress, and we present the advantages of using this scheme and briefly compare it with the other techniques discussed above in Sect. 4.

2 Static Frequency Reuse Techniques

2.1 Reuse-1

In this approach the entire bandwidth is reused in multiple cells. Upon deployment of the cellular network, all base stations are allowed to use the same cellular spectrum. It targets higher system capacity and spectrum efficiency by reusing the scarce resource in all cells. However, it causes considerable inter-cell interference when adjacent cells allocate the same frequency. This interference greatly limits the capacity and spectral efficiency of users by significantly reducing the SINR of users, especially that are located at the edge of cells.

2.2 Reuse-n

In reuse-n the available bandwidth is split into n orthogonal sub-bands and each cell transmits on non interfering sub-bands. This ensures that the spectrum is reused at distant cells. One example of Reuse-n is the Reuse-3 where the whole frequency band is divided into three equal and orthogonal sub-bands. This scheme provides improved inter-cell interference by avoiding using the same frequency bands in adjacent cells. By increasing the reuse factor, interference can be further reduced. However, interference avoidance comes at the expense of bandwidth [4]. Each cell will have only a fraction of the available spectrum, resulting in a reduction in the number of resource blocks provided for users in each cell. This in turn will reduce the capacity and spectral efficiency of the system.

2.3 Fractional Frequency Reuse (FFR)

Fractional frequency reuse [5] partitions the whole spectrum into two parts; namely, one with reuse factor 1, and one with reuse factor n, usually $n = 3$. The key idea behind FFR is to employ a reuse factor of unity for cell-center regions and a reuse factor of 3 for cell-edge regions. As a result of splitting the spectrum for inner and outer regions of a cell so that interior users do not share any spectrum with exterior users, significant inter-cell interference reduction, particularly for cell-edge users, is achieved [6]. However, the spectrum is underutilized in FFR since the cell-edge user can only use part of the total spectrum [7]. In addition, the implementation of a reuse factor at a cell edge results in lower system throughput [8].

2.4 Soft Frequency Reuse (SFR)

Similarly to FFR, the basic idea of soft frequency reuse (SFR) is to apply Reuse-1 at the inner cell region and a higher frequency reuse (Reuse-n) at the outer or edge cell region. Unlike FFR, however, SFR reduces inter-cell interference without reducing spectrum efficiency [9]. SFR splits the available band two regions: cell-edge or outer band and cell-center or inner band. The cell is also divided into two zones; a center zone where all of the spectrum is available and a cell-edge zone where only a portion of the spectrum is available. The cell-edge band is transmitted with a higher power level whereas the cell-center band is transmitted with a reduced power level.

3 Adaptive Frequency Reuse (AFR)

Unlike the static techniques where allocation of spectrum is fixed, adaptive frequency reuse techniques adapts to its environment, such as traffic loads and interference. An example of these techniques is presented in [10]. In this technique, number of sub-carrier and transmit power for each base station is optimized based on traffic load to maximize the total system throughput. Similar to SFR, subcarriers are divided into two groups inner and outer subcarriers each having different transmit power levels. Therefore, AFR finds the number of outer and inner subcarriers as well as their transmit power for a given cell iteratively until it finds the number and power level that satisfies a certain data rate requirement. Each cell determines these parameters by exchanging information with neighboring cells.

4 Distributed Frequency Reuse

The techniques we have seen so far have limitations in that they are either fixed during deployment or they require some form of coordination between base stations. Therefore, if a base station or a coordinator base station that coordinates the allocation of spectrum among the cells fails to function due to disruption, for example disaster, the performance of the cellular system will be highly affected. Distributed allocation schemes tackle this problem by relying only on their local information without having coordination as an important requirement. By eliminating the need for a central coordinator between base stations, distributed schemes provide an independent, fast, and self organized frequency allocation for cellular network. Although their benefit is firmly understood, there is a very limited work done in distributed allocation for cellular networks so far. We have an ongoing research in applying this concept and plan to present it in the near future.

5 Results and Conclusion

An LTE based cellular system is simulated. We consider 19 cells in a hexagonal layout, where 608 users are randomly distributed, and evaluated the overall throughput and user SINR of the static schemes and they adaptive scheme that are described in Sects. 2 and 3. As seen from Table 1, the results obtained show that AFR provides a better overall system throughput while Reuse-1 provides the lowest system throughput. That is due to the high interference caused by reusing spectrum in adjacent cells in Reuse-1. On the other hand, Reuse-3 avoids interference by reusing spectrum far apart and has the highest SINR. However, the smaller number of available spectrum means lower throughput than FFR

Table 1. Results

Scheme	System throughput (Mbps)
Reuse-1	6.99
Reuse-3	10.33
FFR	11.03
SFR	12.78
AFR	13.1

and SFR. In sum, reducing interference, by avoiding frequency reuse in adjacent cells, and using the right number of inner cell and outer cell sub-carriers, system throughput is improved. To further decrease interference and increase capacity, future work will be focused on employing distributed frequency allocation. In addition to the benefits of increased capacity, distributed frequency allocation can sustain system disruption since it relies solely on cells' local information.

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