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Resource Allocation Methodologies with Fractional Reuse Partitioning in Cellular Networks

Hazar Aki
University of South Florida, haki@mail.usf.edu

Resource Allocation Methodologies with Fractional Reuse Partitioning in Cellular Networks

by

Hazar Akı

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Department of Electrical Engineering
College of Engineering
University of South Florida

Major Professor: Hüseyin Arslan, Ph.D.
Richard Gitlin, Sc.D.
Wilfrido Moreno, Ph.D.

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DEDICATION

To my Grandmother,

who watches me over all the time, from the sky...

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ABSTRACT

Conventional cellular systems have not taken full advantage of fractional frequency reuse and adaptive allocation due to the fixed cluster size and uniformed channel assignment procedures. This problem may cause more fatal consequences considering the cutting-edge 4G standards which have higher data rate requirements such as 3GPP-LTE and IEEE 802.16m (WiMAX). In this thesis, three different partitioning schemes for adaptive clustering with fractional frequency reuse were proposed and investigated. An overlaid cellular clustering scheme which uses adaptive fractional frequency reuse factors would provide a better end-user experience by exploiting the high level of signal to interference ratio (SIR). The proposed methods are studied via simulations and the results show that the adaptive clustering with different partitioning methods provide better capacity and grade of service (GoS) comparing to the conventional cellular architecture methodologies.

CHAPTER 1

INTRODUCTION

Cellular systems have been a well established solution for wireless communication over the last three decades. The architecture of the cellular system allows resource utilization in the power-space domain. Since the frequency spectrum is limited and expensive resource, efficiently make use of it to achieve optimum system capacity is extremely important.

1.1 The Necessity of Reusing the Resources

The main design objective of the early mobile radio systems was to place a single, high powered antenna on a tall building or a high mountain. Even though this approach offered a wide coverage area, let alone the huge amount of power requirements and health concerns, it was almost impossible to reuse the resource without creating severe interference to the other users. For instance, in 1970s, Bell Mobile Systems could only support twelve simultaneous calls in New York City. These facts changed the wireless communication concept entirely and single, high powered antennas became many, low powered transmitters and wide coverage areas became cells. Cells may have various radii in the ranges (1 km to 30 km), the boundaries of them can overlap between neighboring cells and also large cells can be partitioned into smaller cells.

Besides the inherent design characteristics of the cellular concept, the emerging technologies in wireless communication systems have also brought crucial setbacks to the network. Both end users and service providers desire cutting edge performance from their devices and technologies. Let alone high quality voice communication or multimedia messaging; rich web-based implementations, audio-video streaming and Internet browsing are the main applications that demand higher performance from the system. However, the law of nature is viable in the wireless domain and it surfaces the problem of scarcity in the most important resource: frequency spectrum. On the one hand, major licensed bands, which are mostly allocated for television-radio broadcasting or military applications. On the other hand, unlicensed bands are already overcrowded by the numerous devices and technologies from cordless phones, wireless LANs to microwave ovens and home entertainment products. Thus, reusing the limited resource within the designated band is a must to overcome the scarcity issues.

1.2 Channel Assignment Strategies

The conventional method of allocating channels is called fixed channel assignment (FCA), in which fixed number of channels are assigned to each cell according to a preset cluster size in order to satisfy the desired signal quality at the cell edge. Even though FCA schemes are simple and straightforward methods, they do not adapt to changing traffic conditions and user distributions. Moreover, in FCA, the overall average grade of service (GoS) of the system is the same as the GoS in a cell. Since traffic in cellular systems can be non-uniform with distributed users, a fixed allocation of channels in a cell may result high blocking in some cells, while others might have a large number of spare channels [1], [2]. This could result poor resource utilization.

Non-uniform channel allocation and channel borrowing methods are introduced in [3], [4] to solve the drawbacks of the FCA schemes and different channel borrowing algorithms are offered in [5]. However, under heavy traffic conditions, the channel borrowing methods could be inadequate as well by increasing the blocking probability which leads a reduction in channel utilization [6].

In order to overcome these deficiencies of FCA schemes, dynamic channel allocation (DCA) is offered. In DCA, all channels are placed in a pool and assigned to a new call when the signal to interference ratio (SIR) criterion is satisfied. Simulations in [7], [8] and analysis in [9] show that under heavy traffic intensity, DCA could perform worse. The performance analysis of the cellular mobile systems using dynamic channel allocation and their drawbacks are discussed in [10], [11], [12].

Hybrid channel allocation (HCA) schemes [7], [13], [14] are the combination of the both FCA and DCA methods. In HCA, channels are divided into fixed and dynamic groups. The dynamic channel allocation is done when the fixed channels are occupied. This improves the performance greatly by producing a significant increase in channel utilization. However; huge amount of computing and therefore high computational complexity is required for channel rearrangements in the large systems [2].

1.3 Frequency Reuse Concept

The fundamental idea in the cellular architecture is the capability of efficiently reusing the resource in a designated region. With the concept of smaller coverage area and reusing the same frequencies, a group of resource can be allocated to each base station and therefore to different cells.

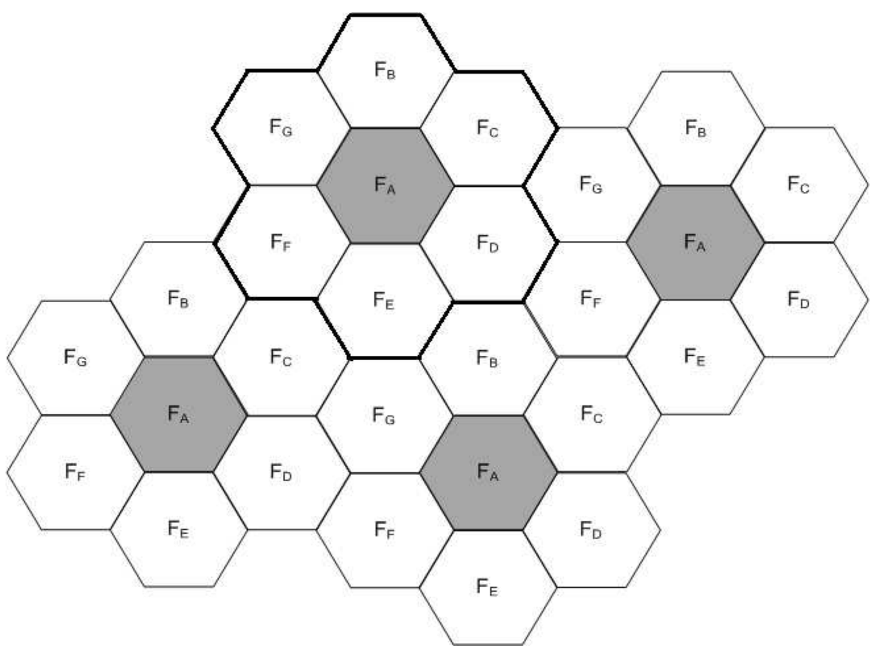

Figure 1.1 Frequency reuse concept with cluster size of 7.

Frequency reuse is a method of reusing the channels/frequencies in order to improve both capacity and spectral efficiency as it is shown in Fig. 1.1. Neighboring cells should have different frequencies but the cell next to the neighboring one could have same operating frequencies without suffering from interference. In other words, the same frequency should be used at least two cells apart from each other.

Frequency reuse concept also allows service providers to have more customers within a given license and limited resource. Since it was first introduced to the communication domain by Bell Laboratories at 1974, every generation and almost every standard has benefited from the frequency reuse methodologies. Several examples of generations with standards which use the concept as follows:

- 1G: AMPS, TACS,
- 2G: GSM, IS-95,
- 3G: WCDMA, CDMA2000, TD-SCDMA

On the other hand, it is important to keep in mind that, reusing frequencies by dividing the allocated band and then repeating the same assignment produces a trade-off between network capacity and reception quality as follows:

- Further away separated cells with same frequency allocations may offer a guarantee in solving the interference problems; however, higher number of divisions of the spectrum will decrease the total capacity of the system.
- If the division of the spectrum is limited with small numbers, capacity of the system will increase; but same frequencies which are allocated to the neighboring cells in close approximation will cause severe interference problems.

It is unquestionable that effective reuse of the resources as an overlaid manner can highly improve the effectiveness of the system. However, allocating a dedicated chunk of spectrum in each cell may not be sufficient for achieving the maximum capacity and spectral efficiency. Several other methodologies which are based on basic frequency reuse concept were introduced in literature. For example in GSM, world's most popular standard in 2G for mobile systems, Reuse Partitioning (RP) [15], [16] was used as a very useful technique for achieving higher spectrum efficiency by using regional cluster sizes in each individual cell.

In reuse partitioning, a cell is divided into several concentric SIR regions and each region has a different cluster size. A mobile close to its BS is assigned a channel with a smaller reuse distance, whereas a mobile far from its BS with low signal quality is assigned a channel with a larger reuse distance. This scheme allows less complex systems to perform efficiently without need for adaptive modulation schemes and power rearrangements. More available resource can be offered to the end user with having a smaller cluster size which leads to the ultimate goal in overlaid cellular systems is achieving the cluster size of 1 (N=1). However, with the uniform usage of N=1, the most cell edge users are suffered from inter-carrier interference and this will cause a degradation in the total system capacity and low data rate in transmission.

1.4 Fractional Frequency Reuse

Restrictions caused by the uniform reuse factor can be solved by Fractional Frequency Reuse (FFR) method [17]. The FFR scheme separates the cell area into two different geographical regions: the inner cell area close to the base station and outer cell area near to the cell edge. The global reuse factor is fractioned to the inner cell area therefore different cluster sizes or frequencies are used in two different regions as it is shown in Fig. 1.2. In its simplest form, FFR implements a reuse scheme-N (N>1) system in order to prevent unacceptable levels of interference that might be experienced by cell edge users.

The FFR scheme was firstly proposed for Global System for Mobile Communications (GSM) networks, however, it is also a very effective solution for the 4G standards such as 3GPP-LTE [18] and IEEE 802.16m (WiMAX) [19], [20] where aggressive spectrum reuse for achieving high data rate is necessary.

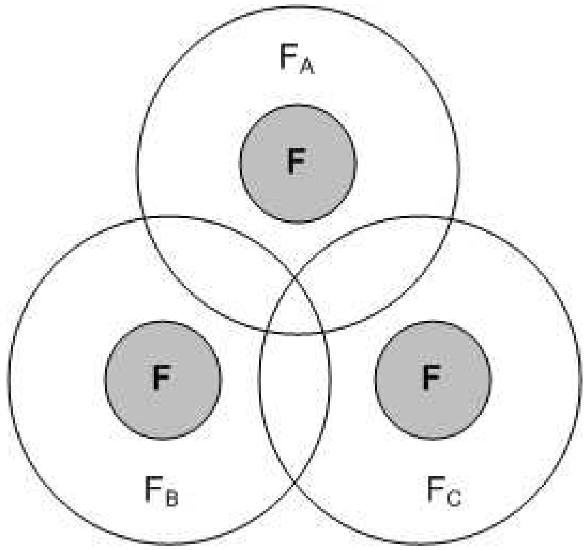

Figure 1.2 Conventional fractional frequency reuse concept.

In the conventional FFR scheme, both inner and outer region reuse factors are fixed for the every cell and they cannot be changed independently by an individual base stations. Several other methods have been proposed in the literature: Dynamic Fractional Frequency Reuse (DFFR), where both user regions are considered to be in the same total cell area, was offered in [21]. In [22], the authors offered Incremental Frequency Reuse (IFR) scheme. However; under overload scenarios, the IFR method could not perform better than the conventional FFR scheme [23].

In [24], [25] the Soft Frequency Reuse (SFR) schemes, which has been adopted in the 3GPP-LTE system [26], [27], were investigated. The basic idea of the SFR scheme is to apply N=1 to inner region and N=3 to the cell-edge users. The performance with the usage of the SFR scheme might be advanced, compared to the classical reuse of 1 system, but the resources are still underutilized since the FRF is fixed for both areas [23]. Aiming at the limitations of the SFR scheme, the Enhanced Fractional Frequency Reuse (EFFR) scheme was offered in [23], which intends to keep the advantages of the SFR method while avoiding its limitations especially in overload situations. The study in this thesis can be considered as a one step-forward of FFR schemes in terms of partitioning the cellular architecture in an overlaid manner for different SIR levels.

1.5 Resource Allocation Approaches in Macrocell-Femtocell Networks

Wireless operators have been trying to expand the limits of the cellular architecture in order to satisfy the end users' needs and applications' requirements. Besides partitioning the cell in the center of single base station and allocating the resources accordingly, several access points in the same cell and in the same coverage area can be established in order to achieve better capacity as well.

The cells with different power levels and therefore different coverage areas can be built as a multi-tiered manner in order to enhance the capacity of the wireless systems [28], [29] as it is shown in Fig. 1.3. Femtocells, which are low-power short-range home base stations, have a strong potential to improve the capacity of next generation wireless systems since they offer better link qualities and wider spectrum resources for connected subscribers [30].

Channel and resource allocation techniques have become more challenging when the architecture of the system is based on multi-tiered networks. Spectrum sharing approaches for macrocell-microcell networks have been investigated in terms of capacity, hand-off rates and velocity of the mobile users in [31], [32]. However, the architecture of a macrocell-

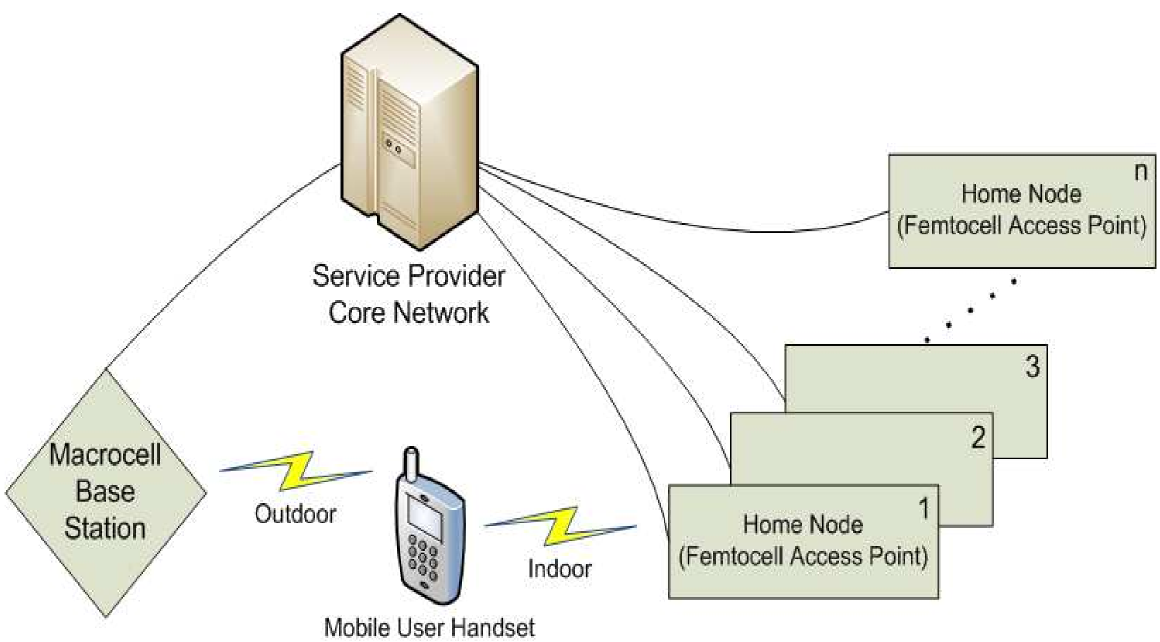

Figure 1.3 Basic structure of femtocell-macrocell network.

femtocell network is rather different. In macrocell-femtocell networks, since femtocell base stations are user deployed, wireless operators may not have fully control on the number of femtocells, number of users in each femtocell and interference conditions. Therefore, various scenarios should be investigated in order to optimize the macrocell-femtocell network.

In macrocell-femtocell two-tiered networks, the resource is allocated by using either shared or split spectrum methods. The former approach introduces the reuse of co-channel frequency for sharing the spectrum. In this method, cross-tier interference may cause crucial setbacks to the system. In the split spectrum approach, the allocated spectrum is partitioned between tiers. Each network can use its own segment of resource and therefore cross-tier interference is prevented [30].

In order to maximize the capactiy of a macrocell-femtocell network, adaptive access operation of femtocells [33], hybrid resource allocation [34] and adaptive transmit powers [35] have formerly proposed in the literature. Capacity maximization in split and shared spectrum methods are also investigated in different domains such as distributed antennas, macrocell-microcell networks, wired relay networks, multi-hop wireless networks, ad-hoc networks, and cognitive networks [36], [37].

Fractional frequency reuse methods are also beneficial for the two-tiered network structures. Interference management schemes based on FFR for macrocell-femtocell networks are investigated in [38] and [39] where a LTE based architecture is proposed. Also, a femtocell gateway server which has the location and throughput information of the femtocell base stations is offered as a part of the 3GPP technology in [40]. The server can manage the interference by using FFR [41]. Adjusting the cluster size according to the operating environment was offered in [42].

CHAPTER 2

OVERLAID CELLULAR ARCHITECTURES

Limiting the signal power of the transmitters to a certain level, frequency reuse concept is introduced, where the same chunk of frequencies is used over and over at tightly parceled cells. One way to increase the capacity of a cellular architecture is to reduce the channel reuse distance in the system while considering the receiver sensitivity for SIR.

2.1 Reuse Distance and Cluster Size

The co-channel (frequency) reuse ratio in cellular architecture which is defined as [43]:

$$\frac{D}{R} = \sqrt{3N} \quad , \tag{2.1}$$

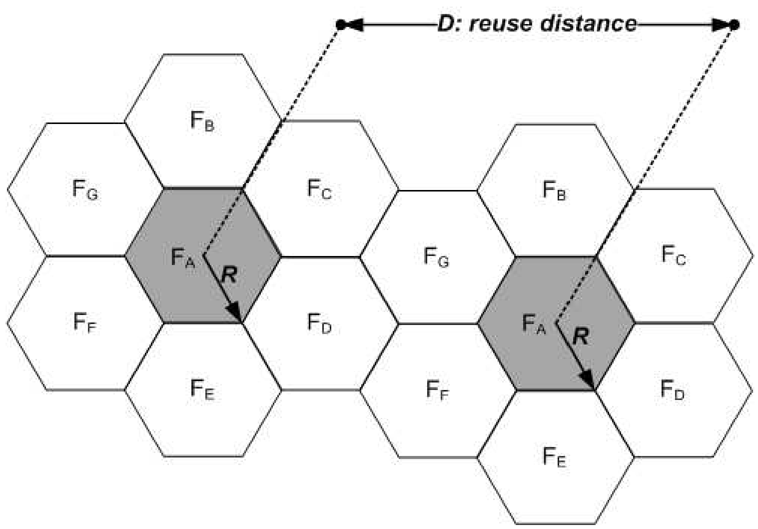

Figure 2.1 Reuse distance and cell radius.

where D is the minimum required distance (reuse distance) between any two co-channel cells in a cellular system, R is the radius of the hexagonal cell and N is the number of individual cells in a cell group, cluster size, as it is shown in Fig. 2.1. It is important to note that, N can assume only the integer values i.e., 1, 3, 4, 7, 9, 12, 13, 16, ... as generally presented by the series:

$$N = i^2 + j^2 + ij \quad , \tag{2.2}$$

while

$$i \geq 0 \quad \text{and} \quad j \geq i \quad . \tag{2.3}$$

Applying this equation and the required conditions for all possible values of $0 \leq i \leq 10$ and $i \leq j \leq 10$ gives the possible cluster size values as it is shown in Fig. 2.2.

Even though theory offers infinite number of cluster size values, in practical, it is usually selected as 3, 4, 7, or 12. Cluster size which are below 3 (only possible solution is N=1) will suffer from the unacceptable level of interference (unless other compansations are made like

		j										
		0	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
i	***0***	0	1	4	9	16	25	36	49	64	81	100
	1		3	7	13	21	31	43	57	73	91	111
	2			12	19	28	39	52	67	84	103	124
	3				27	37	49	63	79	97	117	139
	4					48	61	76	93	112	133	156
	5						75	91	109	129	151	175
	6							108	127	148	171	196
	7								147	169	193	219
	8									192	217	244
	9										243	271
	10											300

Figure 2.2 Possible cluster size values for $0 \leq i \leq 10$ and $i \leq j \leq 10$.

in CDMA and OFDMA-based systems) and above N=21 will waste the system resources by dividing the total frequency band into too many chunks.

2.2 Frequency Reuse Factor

The rate of reusing the resource defines the frequency reuse factor. It can be formed as 1/N where N is the number of cells which cannot use the same chunk of frequencies/channels for communication. Common values for the frequency reuse factor are 1/3, 1/4, 1/7, 1/9 and 1/12.

In the case of k directional sectoral antennas with different directions on the same access point or base station, communication can be available for k different regions in the same cell. k is usually defined as 3. Reuse ratio of k/N indicates a division in resource within k directional antennas per cell. Previously used frequency reuse factor and sector examples in the technologies as follows:

- North American AMPS: 3/7,
- Motorola NAMPS: 6/4,
- GSM: 3/4.

The ultimate goal of the wireless communication systems is to maintain cluster size of 1 in every cell. However, due to the interference issues, it is not possible to achieve the goal without making compensations in other domains. For example in code division multiple access (CDMA) based systems, frequency reuse factor of 1 is achieved. In CDMA-based architectures, neighboring cells use the exact same frequencies; however, users are separated by codes in transmission in each base station rather than frequencies.

CDMA-based systems are not the only ones which make different interpretations in achieving the cluster size of 1. Orthogonal frequency-division multiple access (OFDMA) based systems (for instance LTE) are also designed with a frequency reuse factor of 1. Because signal is not separated across the frequency band in these systems, inter-cell resource management is crucial to allocate the necessary resources and limit the interference.

Recently also orthogonal frequency-division multiple access based systems such as LTE are being deployed with a frequency reuse of 1. Since such systems do not spread the signal across the frequency band, inter-cell radio resource management is important to coordinates resource allocation between different cells and to limit the inter-cell interference [44].

2.3 Cell Radius Ratio

Conventional approach in cellular systems consider N as a fixed number and they design the architecture on the assumption of the worst case SIR for the neighboring clusters which is given in Fig. 2.3 is as follows [43]:

$$SIR_{min} \leq \frac{0.5}{\left(\frac{1}{\sqrt{3N}-1}\right)^{n} + \left(\frac{1}{\sqrt{3N}+1}\right)^{n} + \left(\frac{1}{\sqrt{3N}}\right)^{n}} \,, \tag{2.4}$$

where n is the environmental path loss exponent.

The main design criteria is to offer service even in the end users in the furthest place in the designated cell area. This is the reason why the SIR level of the users which are close to

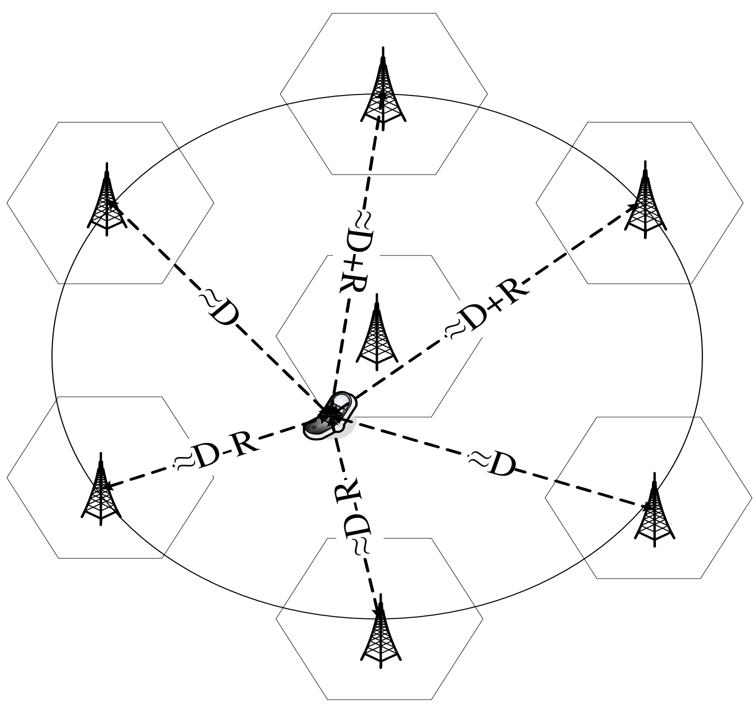

Figure 2.3 Co-channel interference for worst case cell edge assumption.

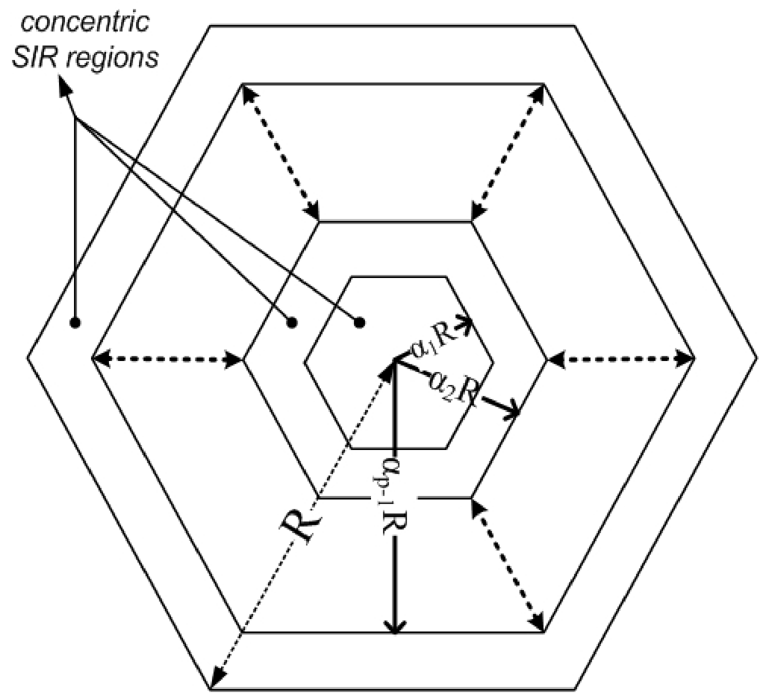

Figure 2.4 CRR for p^{th} order overlaid cellular system.

the base station (BS) is higher since (2.4) is calculated to the worst case cell-edge scenario in Fig. 2.3.

The ratio of the inner cell radius to the outer one is defined to be *cell radius ratio* (CRR) denoted by α as follows:

$$\alpha_m = \frac{R_m}{R} \tag{2.5}$$

where α_m is the CRR of m^{th} region. For instance, innermost concentric SIR region's CRR is calculated as $\alpha_1 = \frac{R_1}{R}$. An illustration of the proposed p^{th} order overlaid cellular system which uses p different clustering sizes is given in Fig. 2.4. It is important to define the new borders of the cell according to the cell radius ratio. Since $R_p = R$ at the cell edge and $R_0 = R$ at the base station, the borderline CRRs for the cell can be defined as follows:

$$\alpha_0 = 0 \text{ (base station), and } \alpha_p = 1 \text{ (cell edge).} \tag{2.6}$$

Analyzing the worst case scenario SIR given in (2.4) and Fig. 2.3, the derivation of (2.14) can be as follows:

$$P_D = \frac{P_T \cdot A}{R^n} \; , \tag{2.7}$$

where P_D received signal power of the desired BS, P_T is the transmit power, A is antenna gains, R is the radius of the hexagonal cell (cell edge). By calculating the received power from the interfering BSs as:

$$P_I = P_T \cdot A \left[\frac{2}{(D-R)^n} + \frac{2}{(D)^n} + \frac{2}{(D+R)^n} \right]. \tag{2.8}$$

Therefore SIR level of a cell edge user can be given as follows:

$$\frac{P_D}{P_I} = \frac{1/2}{\left(\frac{R}{D-R}\right)^n + \left(\frac{R}{D}\right)^n + \left(\frac{R}{D+R}\right)^n} \tag{2.9}$$

$$= \frac{1/2}{\left(\frac{1}{(D/R)-1}\right)^n + \left(\frac{1}{D/R}\right)^n + \left(\frac{1}{(D/R)+1}\right)^n}. \tag{2.10}$$

By replacing R with R_m in (2.10), we can obtain the worst case SIR for each concentric region as:

$$\left(\frac{P_D}{P_I}\right)_{\alpha_m} = \frac{1/2}{\left(\frac{1}{(D/R_m)-1}\right)^n + \left(\frac{1}{D/R_m}\right)^n + \left(\frac{1}{(D/R_m)+1}\right)^n}. \tag{2.11}$$

By using $\alpha_m = \frac{R_m}{R}$, we can rewrite (2.1) as

$$\frac{D}{R_m} = \frac{\sqrt{3N}}{\alpha_m}. \tag{2.12}$$

Therefore by using (2.12) in (2.11) we can derive (2.14) as:

$$\left(\frac{P_D}{P_I}\right)_{\alpha_m} = \frac{0.5}{\left(\frac{1}{\sqrt{3N}/\alpha_m - 1}\right)^n + \left(\frac{1}{\sqrt{3N}/\alpha_m + 1}\right)^n + \left(\frac{1}{\sqrt{3N}/\alpha_m}\right)^n}. \tag{2.13}$$

$$SIR(\alpha_m) \leq \frac{0.5}{\left(\frac{1}{\sqrt{3N}/\alpha_m - 1}\right)^n + \left(\frac{1}{\sqrt{3N}/\alpha_m + 1}\right)^n + \left(\frac{1}{\sqrt{3N}/\alpha_m}\right)^n}. \quad (2.14)$$

Fig. 2.5 presents the desired cluster size for different CRR values. It is important to note that the path loss exponent n is selected as 4 for the provided scenario and log-normal shadowing; small scale fading is not considered as we introduce a long-term average SIR for the concept demonstration. Assuming that the receiver could tolerate 18 dB of SIR, it is obvious that the cluster size will be chosen as 7 since lower cluster sizes could not satisfy cell edge ($\alpha_p = 1$) SIR. However, when users are closer to the BS, SIR is higher for the given receiver sensitivity. An adaptive clustering mechanism using fractional reuse partitioning would take advantage of it and decrease the cluster size as it is shown in the envelope in Fig. 2.5.

Various other path loss exponents and receiver tolerances are investigated in Fig. 2.6 and Fig. 2.7 in order to show the feasibility of the different fractional partitioning schemes. Environmental circumstances or receiver design specifications do not cause any drawback for fractioning the reuse ratio and it is still favorable for the system to adapt the cluster size according to the different radii and SIR values. In Fig. 2.6, path loss exponent is chosen as 6 (i.e. non-line of sight, very rich scatterers and diffractions are in the environment) for considering the highly populated urban areas. When the receiver sensitively is kept the same as 18 dB, N=1 can be used in almost half of the cell area. In Fig. 2.7, on the other hand, path loss exponent is selected as 2 for considering the free space model and receiver sensitivity is chosen as 8 dB for demonstration. In order to tolerate the interference (i.e. free space model acts like an empty, mirrored corridor with the high degree of reflectors), cluster size is needed to increase at the cell edge. Adapting the cluster sizes starting from N=12 to N=1 while approaching to the base station with slight differences in the radius, fractional reuse partitioning is still beneficial for the system.

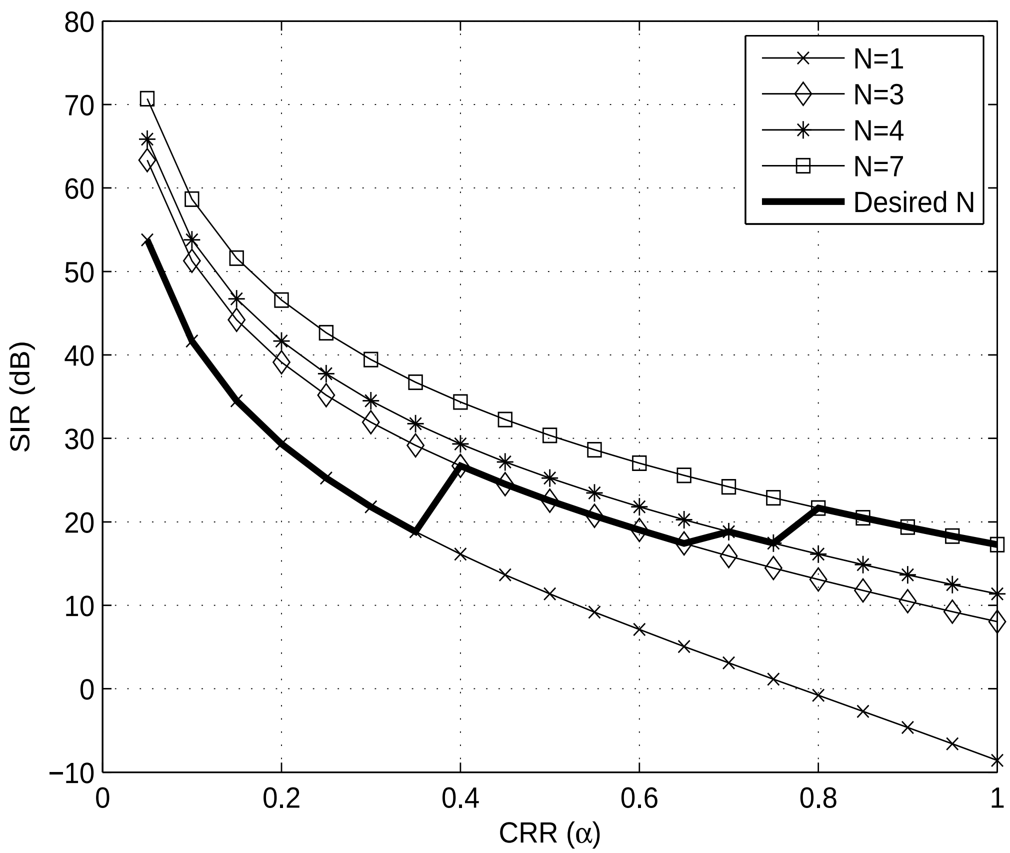

Figure 2.5 SIR vs. CRR for n and receiver sensitivity, $n = 4$ and sensitivity = 18 dB.

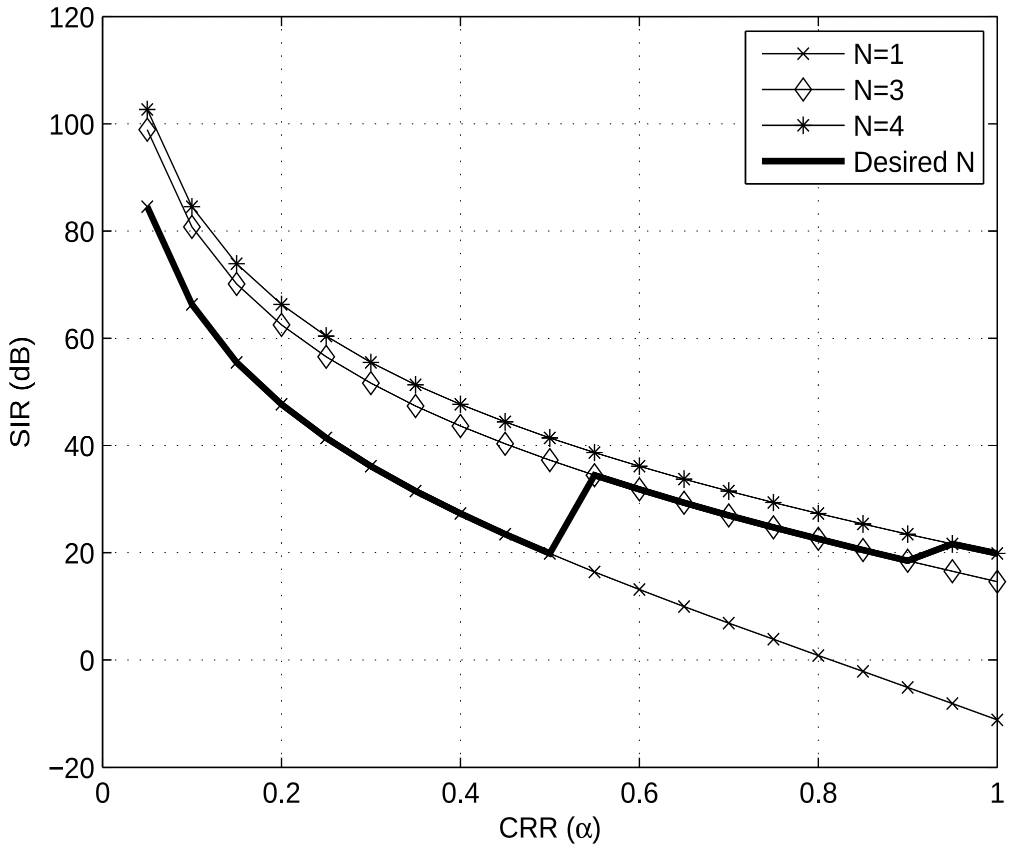

Figure 2.6 SIR vs. CRR for n and receiver sensitivity, $n = 6$ and sensitivity = 18 dB.

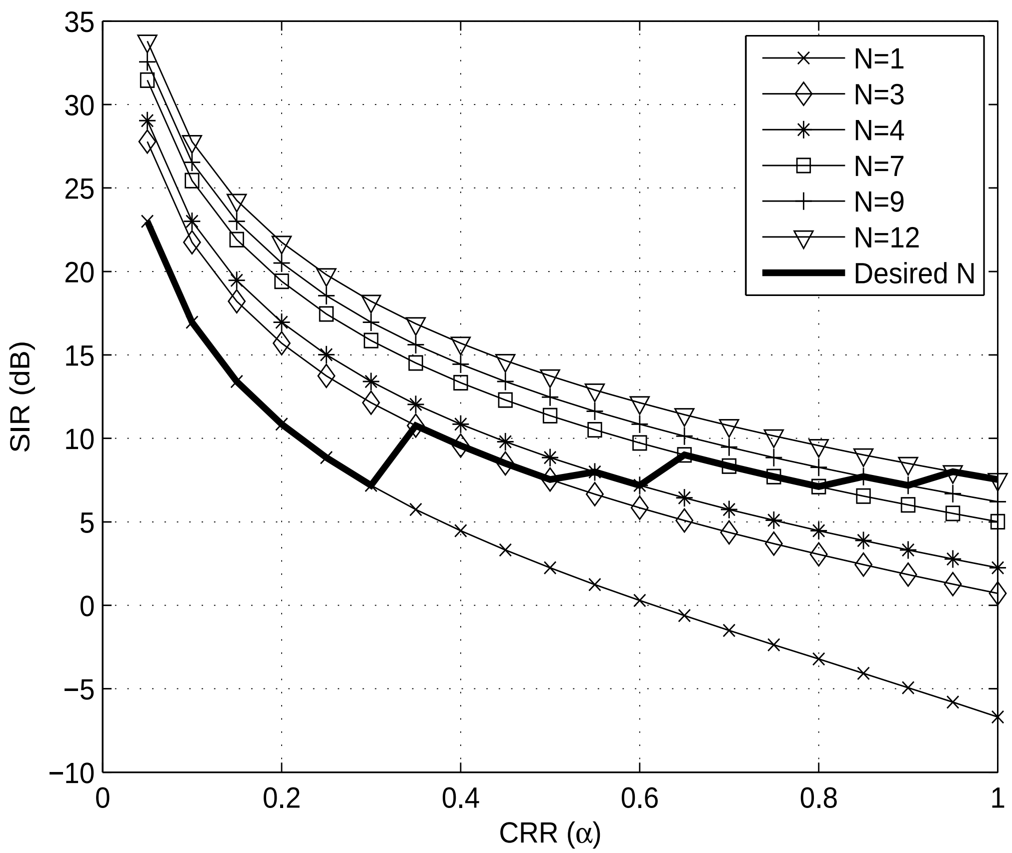

Figure 2.7 SIR vs. CRR for n and receiver sensitivity, $n = 2$ and sensitivity = 8 dB.

CHAPTER 3

FRACTIONAL REUSE PARTITIONING SCHEMES

In this chapter, two new reuse partitioning schemes were analyzed and investigated. The definitions of the parameters used for the capacity and grade of service derivations are given in Table 6.1.

3.1 Maximal Fractional Reuse Partitioning (MFRP)

Maximizing the total effective capacity is one of the most important criteria when the system is being designed. Especially with the current high-tech end-user devices, for instance smart phones and tablet PCs, the required data rate from the back haul is extremely high. Since the conventional systems were designed to offer a service for the worst case scenario (i.e. SIR is set in order to satisfy the users in the cell-edge), the users with a fairly better signal quality cannot take advantage of it.

Let $\tilde{C}_n$ be the effective number of channel in each concentric SIR region in the conventional clustering scheme where cluster size is not adaptive, can be calculated as follows:

$$\tilde{C}_n = \left\lfloor C_{\text{Conv}} \left(\alpha_n^2 - \alpha_{n-1}^2 \right) \right\rfloor, \text{where } n = 1, 2, ...p \ , \tag{3.1}$$

and

$$C_{\text{Conv}} = \frac{C_{\text{T}}}{\tilde{N}}, \tag{3.2}$$

Table 3.1 Description of parameters and notation for FRP schemes.

Parameter	Description
C_{T}	Total number of channels in the system.
$\tilde{N}$	Conventional system's fixed cluster size.
C_{Conv}	Conventional system's total number of channels in each cell.
α_m	Cell radius ratio of m^{th} concentric region, $m \in \{0, 1, \cdots p\}$.
$\tilde{C}_n$	Required number of channels in n^{th} concentric region.
N_n	Adaptive cluster size of n^{th} concentric region.
$C_n^{(1)}$	Effective number of channels in n^{th} concentric region for OFRP scheme.
$C_n^{(2)}$	Allocated number of channel according to the area of regions for OFRP scheme.
C_R	Remaining number of channels.
C_n^{t}	Fractional capacity of n^{th} concentric region for $\mathrm{t} \in \{\mathrm{MFRP}, \mathrm{OFRP}, \mathrm{GoS}\}$ schemes.
C_{t}	Total effective number of channels for $\mathrm{t} \in \{\mathrm{MFRP}, \mathrm{OFRP}, \mathrm{GoS}\}$ schemes.
P_n^{t}	Blocking probability of n^{th} concentric region for $\mathrm{t} \in \{\mathrm{MFRP}, \mathrm{OFRP}, \mathrm{GoS}\}$ schemes.
γ	Desired GoS level for GoS-oriented FRP scheme.

where C_{T} is the total number of channels in the cluster, $\tilde{N}$ is the conventional system's cluster size and C_{Conv} is the total number of channel in each individual cell for the conventional scheme. It is important to note that, C can always be considered as a designated frequency band, or some other resource which is wanted to maximize. However; capacity of the each region can be increased since SIR value corresponding to each CRR is different. Maximizing the capacity of p^{th} order overlaid cellular system could be achieved by allocating more channels to the *innermost* concentric SIR region which is defined by the smallest cluster size i.e., N=1, while the capacity of outermost p^{th} region is kept the same:

$$C_n = \tilde{C}_n \times N_n, \text{where } n = 2, 3...p \ , \tag{3.3}$$

while

$$C_1 = C_{\mathrm{T}} - \sum_{n=2}^{p} C_n \ , \tag{3.4}$$

where C_n is the channel number of each region in the adaptive clustering scheme, N_n is adaptive cluster size and C_1 is the capacity of the maximized innermost region. Therefore the total effective channel number in each cell for MFRP scheme can be calculated as follows:

$$C_{\mathrm{MFRP}} = \sum_{n=1}^{p} C_n^{\mathrm{MFRP}} \ , \tag{3.5}$$

where

$$C_1^{\mathrm{MFRP}} = C_1, \text{ and } C_n^{\mathrm{MFRP}} = \frac{C_n}{N_n} \text{ for } n = 2, 3..p, \tag{3.6}$$

C_n^{MFRP} is the fractional capacity of n^{th} concentric region for MFRP scheme and C_{MFRP} is the total effective capacity of each cell defined by a different clustering N_n. Thus by using this scheme, the effective capacity of the overlaid cellular system is greater than or in the worst case scenario (majority of users are cumulated at the cell edge i.e. at the outermost concentric SIR region), equal to the conventional clustering scheme. The detailed analysis and simulations results with the comparison of the other proposed methods are in Chapter 5.

3.2 Optimal Fractional Reuse Partitioning (OFRP)

Even though maximizing the limited resources has a crucial importance in the architecture design, sometimes it might not be the best both for the users and for the system. For instance, there may not be enough users in the close vicinity of the access point for physical reasons (i.e. base station is placed in a rocky mountain), in other words, adequate end users in the innermost concentric region cannot always be guaranteed. Moreover, extreme case scenarios such as disasters might make the aggressive resource allocation unnecessary and useless. This is the reason why optimization of the resources should always be under consideration.

Optimization in p^{th} order overlaid cellular system can be achieved by distributing the channels according to the regions while preserving the necessary capacity allocation in each region. Revisiting (3.3) in terms of optimization could be given as follows:

$$C_n^{(1)} = \tilde{C}_n \times N_n, \text{where } n = 1, 2...p \ , \tag{3.7}$$

where $C_n^{(1)}$ is the effective channel number of each region for satisfying the channel allocation for the conventional clustering scheme with adaptive cluster size. The remaining channels due to the usage of adaptive scheme can be calculated by subtracting the sum of the necessary capacity from the total capacity as follows:

$$C_{\mathrm{R}} = C_{\mathrm{T}} - \sum_{n=1}^{p} C_n^{(1)} \ , \tag{3.8}$$

and

$$C_n^{(2)} = \left\lfloor C_{\mathrm{R}} \left(\alpha_n^2 - \alpha_{n-1}^2 \right) \right\rfloor, \text{where } n = 1, 2, ...p \ , \tag{3.9}$$

where $C_n^{(2)}$ is the allocated channel number according to the area of regions. It is important to note that, in OFRP scheme, α can be thought as user distribution in each cell which is explained in Chapter 5 in more detail. The total effective number of channel in each cell, C_{OFRP}, can be calculated by adding the necessary number of channel in the conventional scheme with partitioning capacity according to the optimization method as follows:

$$C_{\mathrm{OFRP}} = \sum_{n=1}^{p} C_n^{\mathrm{OFRP}} \ , \tag{3.10}$$

where

$$C_n^{\mathrm{OFRP}} = \frac{C_n + C_n^{(2)}}{N_n}, \text{ for } n = 1, 2..p. \tag{3.11}$$

Note that C_n^{OFRP} is the fractional capacity of n^{th} concentric region for OFRP scheme. The total effective capacity of each cell will satisfy the following equation:

$$C_{\mathrm{MFRP}} \geq C_{\mathrm{OFRP}} \geq C_{\mathrm{Conv}}. \tag{3.12}$$

Thus, with this scheme, the effective capacity of the overlaid cellular system is greater than or equal to the conventional clustering scheme. In the worst case scenario, both MFRP and OFRP schemes will converge to the conventional method and therefore there will be no degradation in the effective channel number, total capacity and grade of service. The detailed analysis and simulations results with the comparison of the other proposed methods are in Chapter 5.

CHAPTER 4

GRADE OF SERVICE POINT OF VIEW IN FRACTIONAL FREQUENCY REUSE

In this chapter, partitioning schemes in terms of blocking probability performance was investigated and a GoS-oriented FRP scheme was provided. The GoS for corresponding concentric SIR regions are analyzed separately for overlaid architectures since the number of allocated channels for each region are different.

4.1 Grade of Service

Grade of Service is the blocking probability of a connection being incomplete for more than a defined time period with the reference of the busies hour where the traffic intensity is maximum. Access point or the routing equipment has the right to accept, direct or decline the incoming new connection request from the users in the cell vicinity. Rejections due to the heavy traffic load result in uncompleted requests, however, if the system is designed with the miscalculated blocking probability, already established connections in the cell will also be dropped.

It is the service provider's responsibility to make sure that sufficient number of resources are available for the specific demand level of the particular area. If unnecessary resource is allocated to the cell, there might be an excessive capacity which will never be used and therefore, limited resources would be wasted. On the other hand, the less than required amount would cause connection drops in very high numbers. This is the reason why it is extremely important to calculate the correct Grade of Service and implement it to the system.

In order to calculate the Grade of Service, the following set of assumptions can be made:

- All traffic through the network is equal chance traffic, (i.e. all call arrivals and terminations are independent random events)
- There is statistical equilibrium, (i.e. the average number of calls does not change)
- Any call that encounters congestion is immediately lost. [45]

From this assumption set, Erlang developed the Erlang-B formula for the blocking probability in a cell when the conventional scheme is considered [46], it is shown in the following:

$$P_{\text{Conv}} = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} , \tag{4.1}$$

and

$$A = A_u \cdot U , \tag{4.2}$$

where A is the total offered traffic, A_u is the call arrival rate, U is the total number of users, C is total number of channels in each cell according to the conventional scheme and P_{Conv} is the total blocking probability of the system.

4.2 GoS-oriented FRP

Using the previously defined fractional reuse partitioning schemes (MFRP and OFRP), GoS requirements can be redefined as follows:

$$P_n^t = \frac{\frac{A_n^{C_n^t}}{C_n^t!}}{\sum_{k=0}^{C_n^t} \frac{A_n^k}{k!}}, \text{ where } n = 1, 2..p, \text{ and t} = \{\text{MFRP}, \text{OFRP}\}, \tag{4.3}$$

and

$$A_n = A_u \cdot U_n \tag{4.4}$$

where U_n is the number of users in the n^{th} concentric region. It is important to note that, both MFRP and OFRP schemes have different GoS levels for each region, in other words, the subscribers who have paid the same amount of money for the same service are experiencing different service quality according to their physical locations in the cell. If every concentric region has lower GoS than conventional scheme, then it can be acceptable that some areas have relatively better blocking probability than others.

In order to supervise the system from the opposite site, a desired blocking probability can be defined at first, then the allocation of the resources is done accordingly. A more controlled scheme can be given with GoS-oriented FRP by defining a GoS level (i.e. γ) for each concentric region can be given as follows:

$$P_n^{\text{GoS}}(C_n^{\text{GoS}}) = \frac{\frac{A_n^{C_n^{\text{GoS}}}}{C_n^{\text{GoS}}!}}{\sum_{k=0}^{C_n^{\text{GoS}}} \frac{A_n^k}{k!}} \leq \gamma, \text{ where } n = 1, 2..p. \tag{4.5}$$

It is important to note that, fractional capacities, regional cluster sizes, and total number of channels should satisfy this inequality:

$$\sum_{n=1}^{p} N_n \cdot C_n^{\text{GoS}} \leq C_{\text{T}} \tag{4.6}$$

in order to guarantee that the resource is allocated to the regions with the limitation of C_{T}. By providing a desired level of GoS for each concentric region, the capacity maximizing partitioning can be given as follows:

$$C_n^{\text{GoS}} = P_n^{\text{GoS}^{-1}}(\gamma), \text{ where } n = 2, 3..p \ , \tag{4.7}$$

and

$$C_1^{\text{GoS}} = C_{\text{T}} - \sum_{n=2}^{p} C_n^{\text{GoS}} \cdot N_n. \tag{4.8}$$

Therefore, total capacity for the GoS-oriented FRP can be given as;

$$C_{\mathrm{GoS}} = \sum_{n=1}^{p} C_n^{\mathrm{GoS}}. \tag{4.9}$$

CHAPTER 5

COMPARISONS AND NUMERICAL RESULTS

In this chapter, three proposed methods are implemented in the basic simulation environment. Effective resources with the respect of the total resources are compared and GoS values of each concentric region are investigated. Moreover, the effect of the user distribution in the optimization method are explained and and example for a GoS-level selection is given.

5.1 Fundamental Differences Between the Proposed Methods

In order to avoid system failures and end-used dissatisfactions, choosing the correct fractional frequency reuse method is crucial for the service provider. Sometimes optimization may not be the perfect solution for the given architecture as well as aggressive capacity maximization could end up with unfair resource allocation.

The essential steps of the three proposed methods are summarized in the flowchart in Fig. 5.1. In order to calculate the total effective capacity of each individual cell, boundaries of the concentric regions (i.e. CRR values) according to the receiver sensitivities should be determined as a first step. After the mandatory resource allocation in each area is done, desired scheme is chosen between MFRP, OFRP or GoS-oriented FRP methods while considering the end user requirements and the system specifications.

In MFRP scheme, channel allocation is done according to the reuse partitioning except for the innermost region. Due to the smallest cluster size, the innermost concentric region's capacity is determined by subtracting the sum of the others from total capacity. By having this, with the smallest cluster size of the innermost concentric region, designated resources can be reused more often than any other regions. This method allows the service provider to acquire the maximum capacity while preserving the necessity resource allocation in each region. This scheme can be considered suitable in cases which the deployment area is flat and end-users are cumulated toward the center.

In OFRP scheme, where the optimization is the key point, instead of aggressive resource distribution, reallocation of the remaining channels are done by distributing them according to the concentric regions areas. While protecting the minimum amount of it in each region, more resources can be available and added to them regarding to the surface dimensions. Instead of region areas, user distributions in each region can also be considered as a decision point for the allocation. In this way, disaster situations or unevenly distributed surfaces/deployment areas can benefit from the system.

In GoS-oriented FRP scheme, desired minimum GoS level should be obtained and the capacity is calculated by using inverse function of blocking probability for outer regions. After finding the fractional capacities, innermost region's allocation is done by subtracting it from the total capacity. It is important to note that, when GoS-oriented scheme is considered, sum of the multiplication of fractional capacity and regional cluster sizes should always be equal or smaller than the total number of channels. After determining the important aspects of the system requirements, user specifications and comparing the total effective capacities, selected scheme can be implemented to the system.

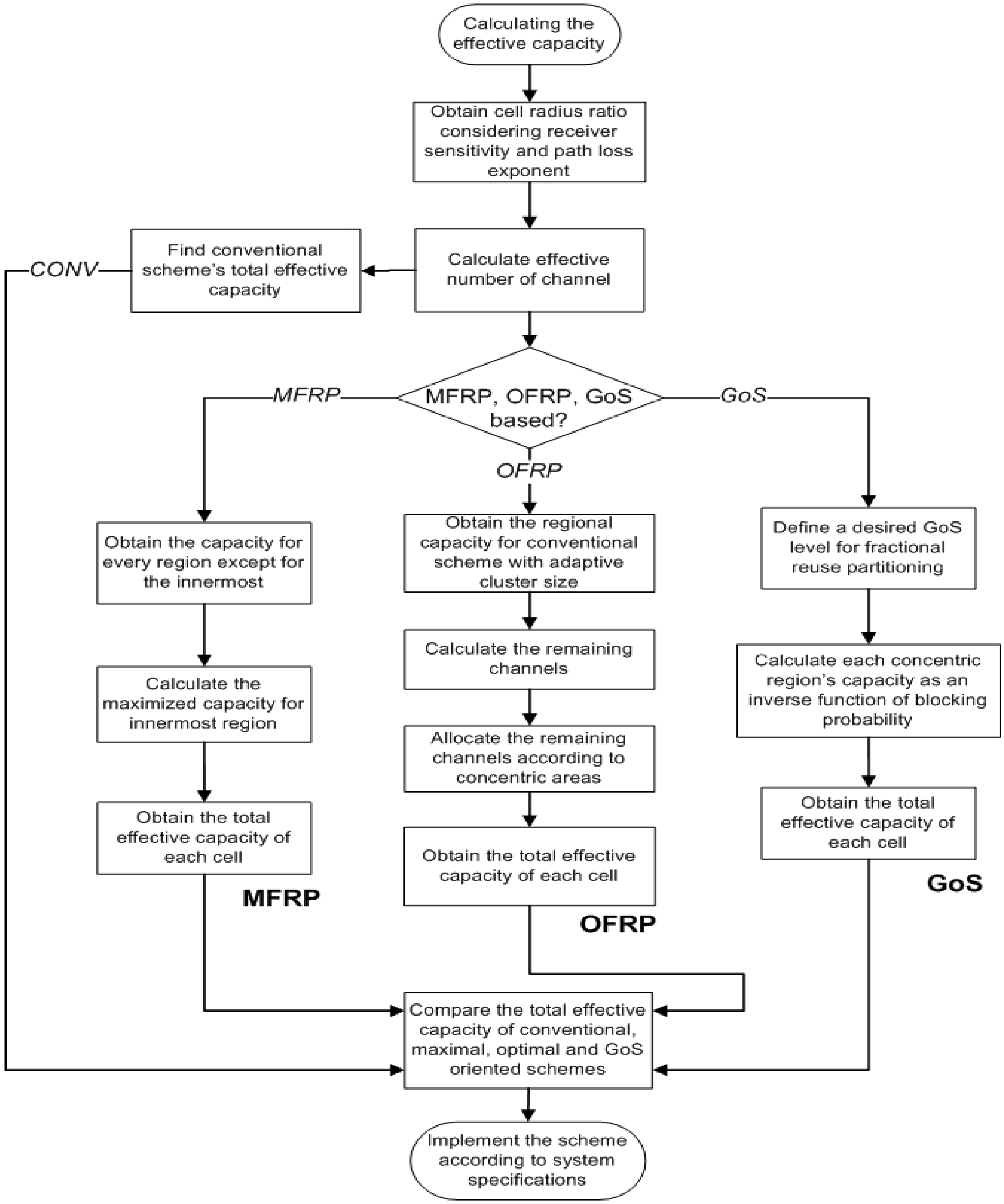

Figure 5.1 Partitioning flowcharts for various FRP schemes.

Table 5.1 Parameters and their values that are used in the numerical analysis.

Parameter	Value
p	4
$\tilde{N}$	7
C_{T}	1000
N_1	1
N_2	3
N_3	4
N_4	7
U	1000
A_u	0.1
α_0	0
α_1	0.35
α_2	0.65
α_3	0.8
α_4	1

5.2 Capacity Analysis

In this section, the numerical results for the proposed methods of adaptive clustering are proposed for MFRP and OFRP schemes and parameters are given in the Table 5.1. The p^{th} order overlaid system where p is chosen as 4 according to the model in Fig. 2.5 and four concentric SIR regions are considered for the simulations. Fig. 5.2 illustrates the capacity; in terms of effective number of channel in each cell according to the total number of channel in the cluster for the conventional method and MFRP, OFRP schemes. It is obvious that, the effective number of channel is increasing as the total number of channel is increasing, as described in Fig. 5.2.

MFRP allocates the redundant channels to the innermost region (i.e. smallest cluster size) and therefore this method has the largest capacity as it is shown in Fig. 5.2. On the other hand; OFRP distributes the channels according to the areas of concentric SIR regions assuming that users are uniformly distributed inside the cell. Even though OFRP scheme's capacity curve falls behind the MFRP scheme in Fig. 5.2, it still offers better results than conventional method. It is important to note that; cotangent of the angle between the curve and the x-axis yields the *cluster size* in Fig. 5.2. In the conventional scheme, the cotangent

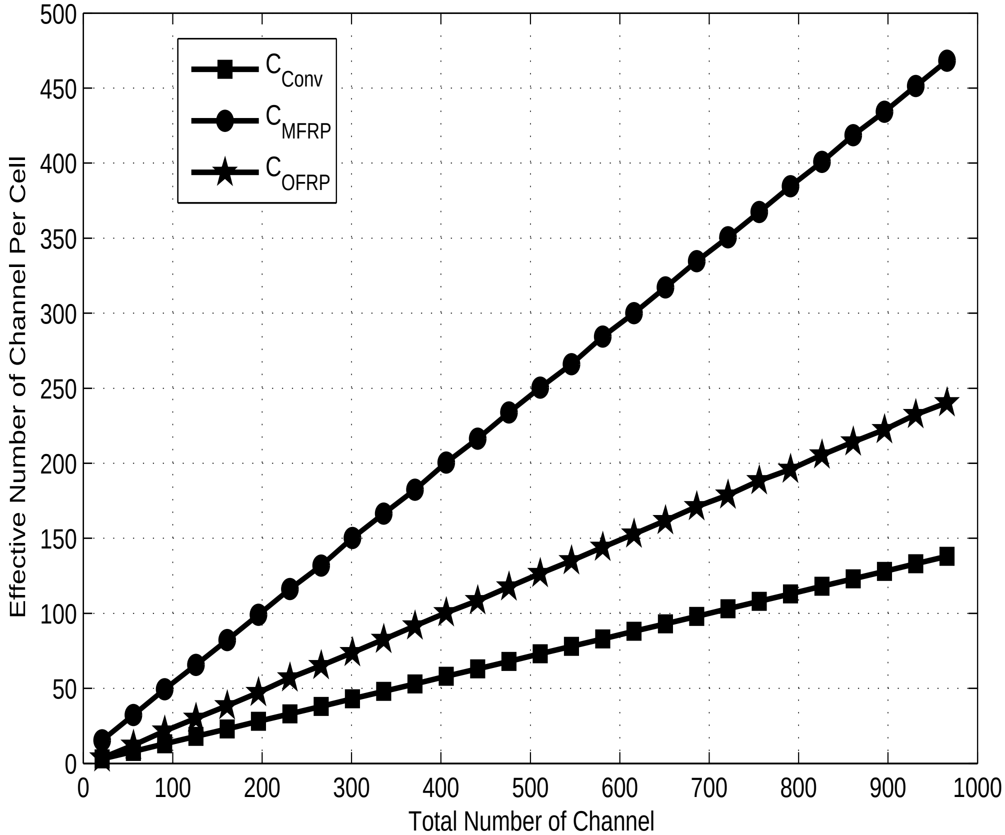

Figure 5.2 Effective number of channel vs. total number of channel.

of the angle is 7 (i.e. $\tilde{N}$=7) as expected. MFRP and OFRP scheme's cotangent of the angle yields the *average cluster size*, N_{ave}, of the designed systems. MFRP's average cluster size can be calculated from Fig. 5.2 as N_{ave}=2. Maximal approach offers the closest method for reaching the ultimate goal in overlaid cellular systems which is achieving the cluster size, $N = 1$.

5.3 Regional Grade of Service

Fig. 5.3 presents the GoS of each cell [resp. region] for conventional [resp. MFRP and OFRP] schemes. It is obvious that; with a fixed number of users, (i.e. $U = 1000$ and $A_u = 0.1$), while the total number of channel increases, the blocking probability decreases exponentially. MFRP scheme improves the innermost region's GoS (P_1^{MFRP}) excessively, on the other hand the GoS for outer regions (P_2^{MFRP}, P_3^{MFRP} and P_4^{MFRP}), which are using higher cluster sizes, are worse than the conventional scheme. Alternatively; using OFRP scheme, the GoS for each region is decreased since less aggressive capacity maximization is applied while preserving the GoS for each region. OFRP scheme's four region curves are fallen under the conventional scheme's curve and therefore, OFRP schemes offer better total GoS comparing to the conventional scheme.

5.4 Effect of the User Distribution

We also study the effect of the user distribution to the OFRP scheme. β_1 and β_2 are defined to be; inner boundary and outer boundary of the user distributions inside the

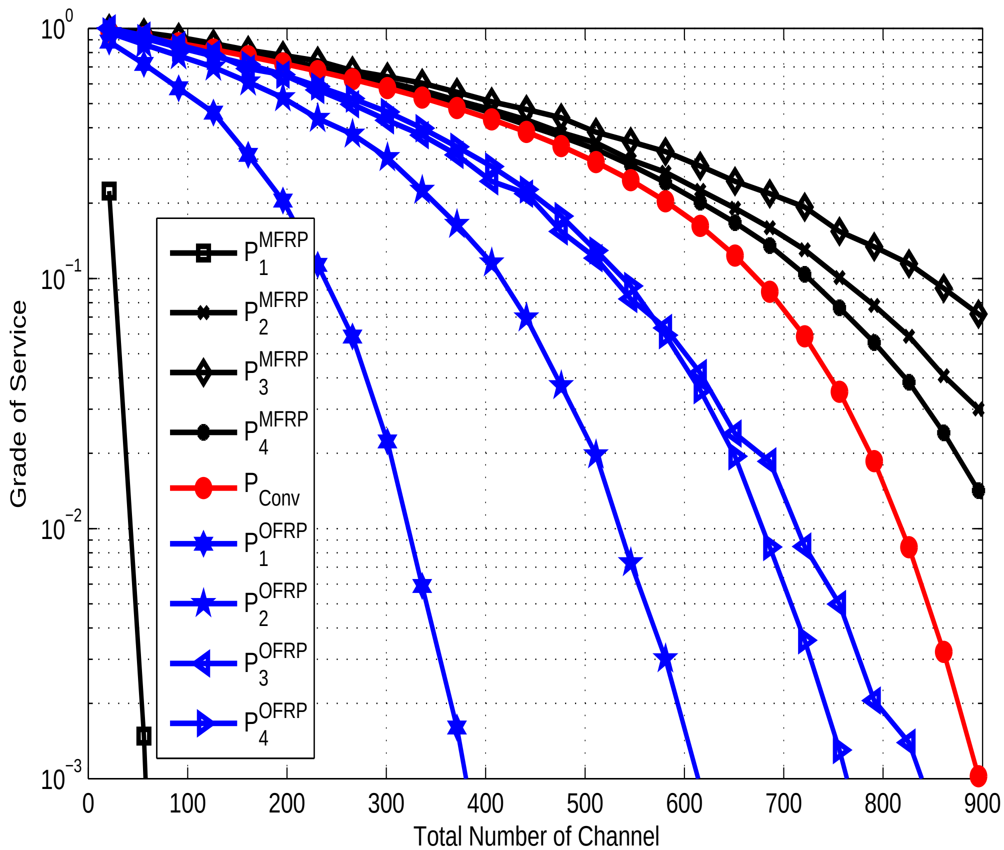

Figure 5.3 GoS vs. total number of channels of four concentric regions (R_1 through R_4) in three different schemes (Conventional, MFRP, OFRP).

concentric SIR regions. The parameter set $\{\beta_1,\ \beta_2\}$ i.e. $0 < \beta_1 < \beta_2 < 1$ in which the users are distributed inside the region defined by Ω, where $\Omega \in \{\beta_1 R,\ \beta_2 R\}$. Fig. 5.4 shows the percentage of effective channel allocation with respect to the inner and outer boundaries based on various users' distributions. While β_1 increases, the effective number of channels decreases, since the average SIR values of users distributed within the region Ω is decreasing. Moreover, while β_2 is increasing, the overall distance between BS and the users are increasing and therefore the effective capacity decreases. For instance, when β_1=0 and $0.1 < \beta_2 < 0.35$, percentage of effective channel usage in that area is calculated as 100% due to users' SIR levels are well enough to provide a cluster size of one to the entire system. This simulation shows that OFRP can also take advantage of the distribution of the users inside the concentric SIR regions and enhance the capacity accordingly.

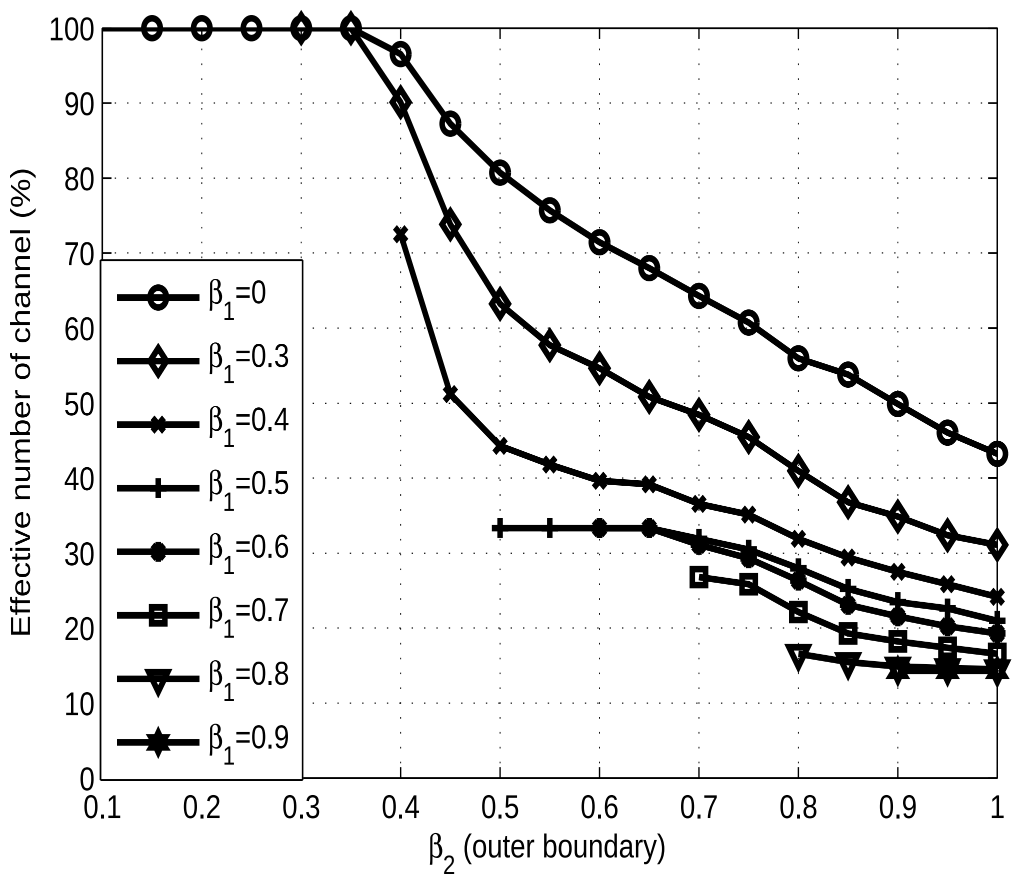

Figure 5.4 Effective number of channel vs. β_1 and β_2 in OFRP.

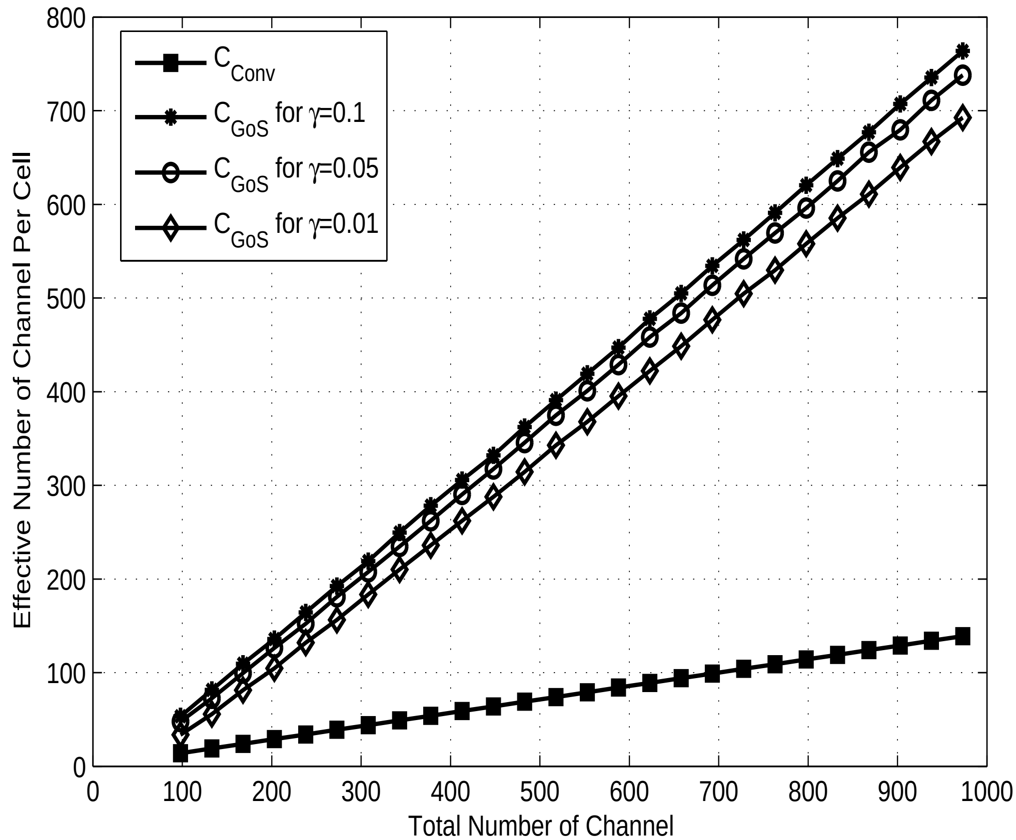

Figure 5.5 Effective number of channel vs. total number of channel for GoS-oriented FRP.

5.5 Grade of Service Level

In order to investigate the behavior of the GoS-oriented FRP scheme, a rather different simulation scenario is considered comparing to the simulations of MFRP and OFRP. Note that the total number of channels and the number of users in a cell should be chosen appropriately to analyze the GoS-oriented FRP scheme since there might be cases where the number of channels can not satisfy the GoS levels defined by γ values. In other words, there should be at least a minimum number of channels in which desired GoS levels are satisfied in the system. Therefore in this scenario the user number is defined as a function total number of channels, i.e., not fixed as it is in the case for the simulations of MFRP and OFRP.

Fig. 5.5 shows the effective number of channels versus total number of channels for various γ values in GoS-oriented FRP scheme with the reference of conventional capacity. Note that the capacity increase with the increase of γ, since less channels can be allocated to the outer concentric regions to satisfy their GoS requirement. Therefore more channels are assigned to the innermost concentric region, where N=1, which leads to increase in capacity.

GoS performance for various γ values are investigated in Fig. 5.6. Partitioning in Fig. 5.6 shows that, the outer regions' average blocking probabilities satisfy the desired GoS levels by being under the γ limits as it is shown in the subplot in Fig. 5.6. For the sake of brevity, we provide only the outer regions' GoS levels with the reference of the conventional method since the innermost regions' blocking probabilities already satisfy the desired GoS levels by reaching zero rapidly due to the aggressive resource allocation. As it can be seen in both Fig. 5.5 and Fig. 5.6, GoS-oriented FRP scheme offers better performance by increasing the total capacity while protecting the desired blocking probability values comparing to the conventional scheme. It is important to note that, while performing the simulations in Fig. 5.6, the number of users in a cell is considered as the half of the total number of channels in order to make sure that minimum number of channels are guaranteed in which desired GoS levels are satisfied. Note that blocking probabilities in Fig. 5.3 decreases exponentially since the number of users are fixed in a cell where as they are linear in Fig. 5.6 since the number of users are as the function of total number of the channels.

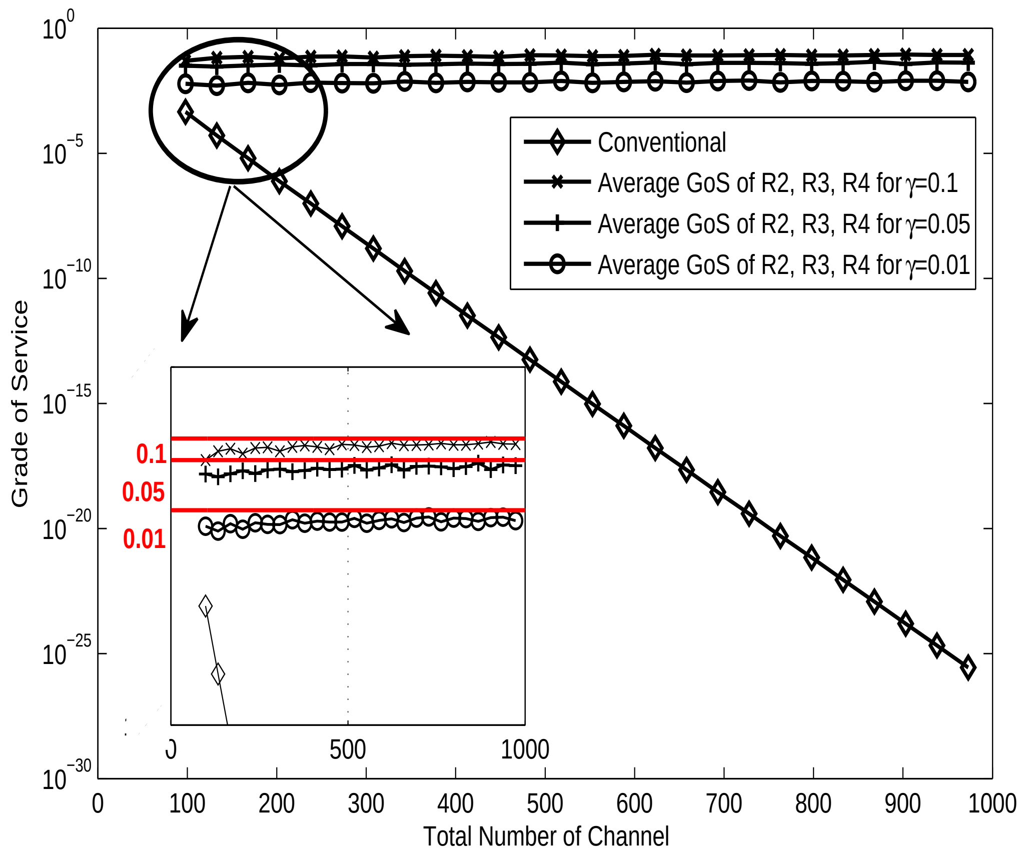

Figure 5.6 Average GoS for various γ vs. total number of channels for GoS-oriented FRP.

CHAPTER 6

RESOURCE ALLOCATION IN MACROCELL-FEMTOCELL NETWORKS

In this chapter, previously explained two resource assignment schemes called maximal fractional reuse partitioning (MFRP), optimal fractional reuse partitioning (OFRP) are proposed to make a bandwidth partitioning in macrocell.

The proposed partitioning schemes can be considered as a one step-forward of the previously proposed FFR schemes in the literature in terms of partitioning the cellular architecture in an overlaid manner for different SIR levels as it is given in Fig. 6.1. Once the partitioning for macrocell for each region is done with one of the above schemes, femtocells are allocated with the rest of the spectrum (i.e., spectrum which macrocell users are not using) within each concentric region. In both schemes, clustering size is changed according to the concentric SIR regions. In MFRP scheme, abundant bandwidth is assigned to the innermost region in order to acquire maximum effective capacity from the interested cell. OFRP scheme, on the other hand, allocates unused bandwidth according to the areas and the distribution of users in the concentric SIR regions. The flexible reuse of resource makes these schemes very attractive both in terms of capacity and the GoS [47].

An illustration of the proposed p^{th} order overlaid cellular system which uses p different clustering sizes is given in Fig. 6.1. It is important to note that the assumptions which were made in Chapter 3 are still valid. The path loss exponent n is selected as 4 for the provided scenario and log-normal shadowing; small scale fading is not considered as we introduce a long-term average SIR for the concept demonstration. Assuming that the receiver could tolerate 18 dB of SIR, it is obvious that the cluster size will be chosen as 7 since lower cluster sizes could not satisfy cell edge ($\alpha_p = 1$) SIR. However, when users are closer to the BS, SIR is higher for the given receiver sensitivity.

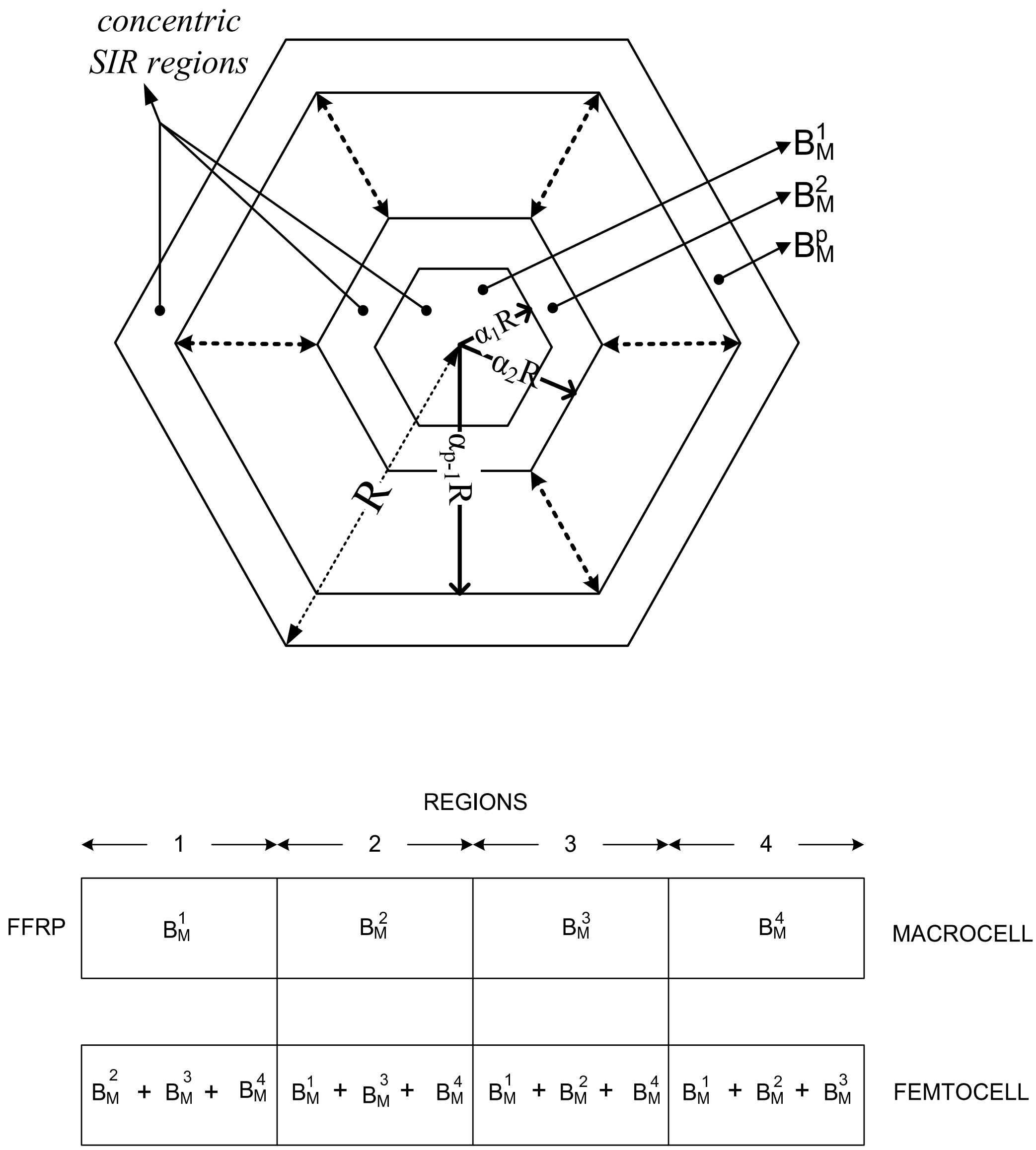

Figure 6.1 CRR for p^{th} order overlaid cellular system and bandwidth partitioning for FRP

6.1 Capacity of Macrocell with Fractional Reuse Partitioning

In this section, we analyze the MFRP, and OFRP schemes from capacity maximization and optimization point of views respectively. The definitions of the parameters used for the capacity are given in Table 6.1.

Table 6.1 Description of parameters and notation for macrocell-femtocell network scenario.

Parameter	Description
i, j, k	Indices for the tiers, networks in each tier and users in each network, respectively.
$C_{i,j,k}$	Capacity of the k^{th} user in the i^{th} tier and j^{th} network. Note that, there is only one macrocell ($j = 1$, for $i = 1$) and several femtocells ($j = 1, .., N_{\text{N},2}$, for $i = 2$).
$B_{i,j,k}$	Bandwidth of the k^{th} user in the i^{th} tier and j^{th} network.
$SINR_{i,j,k}$	Signal to interference plus noise ratio (SINR) of the k^{th} user in the i^{th} tier and j^{th} network.
$P_{i,j,k}$	Received power of the k^{th} user in the i^{th} tier and j^{th} network.
B	Total bandwidth of the system.
$\tilde{N}$	Conventional system's fixed cluster size.
${}_{\text{Conv}}B_{\text{M}}$	Conventional system's total bandwidth in each cell.
α_n	Cell radius ratio of concentric region, $m \in \{0, 1, \cdots p\}$.
$\tilde{B}_{\text{M}}^{n}$	Compulsory amount of bandwidth in n^{th} concentric SIR region.
N_n	Adaptive cluster size of n^{th} concentric region.
${}^{(1)}B_{\text{M}}^{n}$	Effective bandwidth in n^{th} concentric region for OFRP scheme.
${}^{(2)}B_{\text{M}}^{n}$	Allocated bandwidth according to the area of regions for OFRP scheme.
B_{R}	Remaining portion of bandwidth.
${}_{\text{t}}B_{l}^{n}$	Fractional bandwidth of n^{th} concentric region for $\text{t} \in \{\text{MFRP}, \text{OFRP}\}$ schemes, where $l \in$ {M,F}; M and F stands for macrocell and femtocell, respectively.
${}_{\text{t}}B_{\text{M}}$	Total bandwidth of macrocell for $\text{t} \in \{\text{MFRP}, \text{OFRP}\}$ schemes.

6.1.1 Maximal Fractional Reuse Partitioning (MFRP) in Macrocell-Femtocell Network

Let $\tilde{B}_M^n$ be the effective bandwidth in each concentric SIR region in the conventional clustering scheme where cluster size is not adaptive, can be calculated as follows:

$$\tilde{B}_{\mathrm{M}}^{n} = {}_{\mathrm{Conv}}B_{\mathrm{M}} \left(\alpha_n^2 - \alpha_{n-1}^2\right), \text{where } n = 1, 2, ...p \ , \tag{6.1}$$

and

$${}_{\mathrm{Conv}}B_{\mathrm{M}} = \frac{B}{\tilde{N}}, \tag{6.2}$$

where B is the total bandwidth in the cluster, $\tilde{N}$ is the conventional system's cluster size and ${}_{\mathrm{Conv}}B_M$ is the total bandwidth in each individual cell for the conventional scheme. However, capacity of the each region can be increased since SIR value corresponding to each CRR is different. Maximizing the capacity of p^{th} order overlaid cellular system could be achieved by allocating more bandwidth to the *innermost* concentric SIR region which is defined by the smallest cluster size i.e., N=1, while the capacity of outermost p^{th} region is kept the same:

$$B^n = \tilde{B}_{\mathrm{M}}^{n} \times N_n, \text{where } n = 2, 3...p \ , \tag{6.3}$$

while

$$B^1 = B - \sum_{n=2}^{p} B^n \ , \tag{6.4}$$

where B^n is the bandwidth of each region in the adaptive clustering scheme, N_n is adaptive cluster size and B^1 is the capacity of the maximized innermost region. Therefore the total effective bandwidth in each cell for MFRP scheme can be calculated as follows:

$${}_{\mathrm{MFRP}}B_{\mathrm{M}} = \sum_{n=1}^{p} {}_{\mathrm{MFRP}}B_{\mathrm{M}}^{n} \ , \tag{6.5}$$

where

$$ {}_{\text{MFRP}}B_{\text{M}}^{1} = B^{1}, \text{ and } {}_{\text{MFRP}}B_{\text{M}}^{n} = \frac{B^{n}}{N_{n}} \text{ for } n = 2, 3..p, \tag{6.6} $$

where ${}_{\text{MFRP}}B^{n}$ is the fractional bandwidth of n^{th} concentric region for MFRP scheme and ${}_{\text{MFRP}}B_{M}$ is the total effective bandwidth of each cell defined by a different clustering N_n. Thus by using this scheme, the effective bandwidth of the overlaid cellular system is greater than or in the worst case scenario (majority of users are cumulated at the cell edge i.e. at the outermost concentric SIR region), equal to the conventional clustering scheme.

6.1.2 Optimal Fractional Reuse Partitioning (OFRP) in Macrocell-Femtocell Network

Optimization in p^{th} order overlaid cellular system can be achieved by distributing the bandwidth according to the regions while preserving the necessary bandwidth allocation in each region. Revisiting (6.3) in terms of optimization could be given as follows:

$$ {}^{(1)}B^{n} = \tilde{B}_{\text{M}}^{n} \times N_{n}, \text{where } n = 1, 2...p \ , \tag{6.7} $$

where ${}^{(1)}B^{n}$ is the effective bandwidth of each region for satisfying the bandwidth allocation for the conventional clustering scheme with adaptive cluster size. The remaining bandwidth due to the usage of adaptive scheme can be calculated by subtracting the sum of the necessary bandwidth from the total bandwidth as follows:

$$ B_{\text{R}} = B - \sum_{n=1}^{p} {}^{(1)}B^{n}, \tag{6.8} $$

and

$$ {}^{(2)}B^{n} = B_{\text{R}} \left(\alpha_{n}^{2} - \alpha_{n-1}^{2} \right), \text{where } n = 1, 2, ...p \ , \tag{6.9} $$

where ${}^{(2)}B^{n}$ is the allocated bandwidth according to the area of regions. It is important to note that, in OFRP scheme, α can be thought as user distribution in each cell. The total effective bandwidth in each cell, ${}_{\text{OFRP}}B_M$, can be calculated by adding the necessary bandwidth in the conventional scheme with partitioning bandwidth according to the optimization method as follows:

$$ {}_{\text{OFRP}}B_{\text{M}} = \sum_{n=1}^{p} {}_{\text{OFRP}}B_{\text{M}}^{n} \ , \tag{6.10} $$

where

$$ {}_{\text{OFRP}}B_{\text{M}}^{n} = \frac{B^n +^{(2)} B^n}{N_n}, \text{ for } n = 1, 2..p. \tag{6.11} $$

Note that ${}_{\text{OFRP}}B_M^n$ is the fractional bandwidth of n^{th} concentric region for OFRP scheme. The total effective bandwidth of each cell will satisfy the following equation:

$$ {}_{\text{MFRP}}B_{\text{M}} \geq_{\text{OFRP}} B_{\text{M}} \geq_{\text{Conv}} B_{\text{M}}. \tag{6.12} $$

Thus, with this scheme, the effective bandwidth of the overlaid cellular system is greater than or equal to the conventional clustering scheme. In the worst case scenario, both MFRP and OFRP schemes will converge to the conventional method and therefore there will be no degradation in the effective bandwidth, and total capacity.

Using the notation given in Table 6.1 the capacity of a macrocell user within each region can be written as follows:

$$ {}_{t}C_{1,1,k}^{n} =_{t} B_{1,1,k}^{n} \log_2 \left(1 + \frac{P_{1,1,k}^{n}}{I_{1,1,k}^{n} + B_{1,1,k}^{n} N_0} \right) \quad . \tag{6.13} $$

Therefore total capacity of macrocell-tier becomes

$$ {}_{t}C_{\text{Mac}} = \sum_{n=1}^{P} {}_{t}C_{\text{Mac}}^{n} \quad . \tag{6.14} $$

where

$$ {}_{t}C_{\text{Mac}}^{n} = \sum_{k=1}^{N_{\text{U},1,1}^{n}} {}_{t}B_{1,1,k}^{n} \log_2 \left(1 + \frac{P_{1,1,k}^{n}}{I_{1,1,k}^{n} + B_{1,1,k}^{n} N_0} \right) \quad . \tag{6.15} $$

where $I^n_{1,1,k}$ denotes interference level for the k^{th} macrocell user in the n^{th} region. The following assumption set is considered for the macrocell network (ASM-1):

- Inter-macrocell interference is assumed to be negligible i.e., $I^n_{1,1,k} = 0, \forall k, n$.
- Received power of each user is assumed to be constant i.e., $P^n_{1,1,k} = P^n_{\text{M}}, \forall k,\ n = 1, 2 \ldots p$.
- Bandwidth in each macrocell is distributed in a round robin fashion i.e., $B^n_{1,1,k} = \frac{{}_tB^n_{\text{M}}}{N^n_{\text{U,M}}}, \forall k$ where $N^n_{\text{U},1,1} = N^n_{\text{U,M}}$, $t = \{\text{MFRP}, \text{OFRP}\}$, and $N^n_{\text{U,M}} = N_{\text{U,M}}\left(\alpha^2_n - \alpha^2_{n-1}\right)$.

Then, (6.15) can be expressed as follows:

$$ {}_tC_{\text{Mac}} = \sum_{n=1}^{P} \underbrace{{}_tB^n_{\text{M}}\log_2(1+\Gamma^n_1)}_{{}_tC^n_{Mac}} \quad . \tag{6.16}$$

where $\Gamma^n_1 = \frac{P^n_{\text{M}}N^n_{\text{U,M}}}{{}_tB^n_{\text{M}}N_0}$.

6.2 Capacity of Femtocells

Bandwidth of the each femtocell can be calculated as follows:

$$ {}_tB^n_{\text{F}} = B - {}_tB^n_{\text{M}} \tag{6.17}$$

$$ = B - \sum_{i=1, i\neq n}^{p} {}_tB^i_{\text{M}}, \tag{6.18}$$

$$\text{for } n = 1, 2..p. \text{ and t} = \{\text{MFRP}, \text{OFRP}\}.$$

Using the notation given in Table 6.1, the capacity of femtocell user-k with the j^{th} femtocell in the n^{th} region can be written as

$$ {}_tC^n_{2,j,k} = B^n_{2,j,k}\log_2\left(1 + SINR^n_{2,j,k}\right) \quad . \tag{6.19}$$

Signal to interference plus noise ratio (SINR) of the k^{th} user with the j^{th} femtocell in the n^{th} region can be given as

$$SINR^n_{2,j,k} = \frac{P^n_{2,j,k}}{I^n_{2,j,k} + {}_tB^n_{2,j,k}N_0} \quad , \tag{6.20}$$

where $I^n_{2,j,k}$ denotes interference power of the k^{th} user with the j^{th} femtocell in the n^{th} region and N_0 is the spectral density of noise. Therefore the total capacity for the femtocell-tier (tier-2) can be expressed as follows:

$$ {}_tC^n_{\text{Fem}} = \sum_{j=1}^{N^n_{\text{N},2}} \sum_{k=1}^{N^n_{\text{U},2,j}} {}_tC^n_{2,j,k} = \sum_{j=1}^{N^n_{\text{N},2}} \sum_{k=1}^{N^n_{\text{U},2,j}} {}_tB^n_{2,j,k} \log_2 \left(1 + \frac{P^n_{2,j,k}}{I^n_{2,j,k} + {}_tB^n_{2,j,k}N_0}\right) \quad . \tag{6.21}$$

For the sake of analytical tractability, we consider the following simplifying assumptions in assumption set (ASM-2):

- The number of the users in each femtocell is assumed to be fixed, i.e., $N^n_{\text{U},2,j} = N_{\text{U,F}}, \forall j$. Assuming that femtocells are uniformly distributed in a macrocell, $N^n_{\text{N},2} = N_{\text{N},2}(\alpha_n^2 - \alpha_{n-1}^2)$.
- Inter-femtocell interference is assumed to be negligible, and inter-tier interference is assumed to be constant in each region i.e., $I^n_{2,j,k} = I^n, \forall j, k$.
- Received power is assumed to be constant, i.e., $P^n_{2,j,k} = P_{\text{F}}, \forall j, k$.
- Bandwidth in each femtocell is distributed in a round robin fashion, i.e., ${}_tB_{2,j,k} = \frac{{}_tB^n_{\text{F}}}{N^n_{\text{U},2,j}} = \frac{{}_tB^n_{\text{F}}}{N_{\text{U,F}}}, \forall j, k$.

Then, (6.21) can be expressed as follows:

$$ {}_tC_{\text{Fem}} = \sum_{n=1}^{P} \underbrace{N_{\text{N},2}^{n} \ {}_tB_F^n \log_2(1+\Gamma_2^n)}_{{}_tC_{Fem}^n} \quad . \tag{6.22} $$

where $\Gamma_2^n = \frac{P_{\text{F}} N_{\text{U,F}}}{N_{\text{U,F}} I^n + {}_tB_{\text{F}}^n N_0}$.

Total capacity for each partitioning scheme can be given as:

$$ {}_tC_{\text{Tot}} = \sum_{n=1}^{P} {}_tB_{\text{M}}^n \log_2(1+\Gamma_1^n) + \sum_{n=1}^{P} {}_tB_{\text{F}}^n N_{N,2}^n \ \log_2(1+\Gamma_2^n). \tag{6.23} $$

CHAPTER 7

CONCLUSION AND FUTURE WORK

In this thesis, we present the idea of partitioning the resource with adaptive cluster size and fractional frequency reuse by exploiting the high SIR level and apply dynamic resource allocation methods according to the concentric SIR regions. Conventional method with fixed cluster size is used for comparing the proposed methods while relationships between different channel allocation methods and various fractional reuse schemes in the literature are given. The proposed methods show that the total effective capacity and GoS of the conventional scheme could be increased by using fractional frequency reuse with adaptive overlay clustering.

Three new resource assignment schemes called MFRP, OFRP, and GoS-oriented FRP are proposed. The proposed schemes are investigated in terms of fractional frequency reuse with adaptive cluster sizes, while the GoS requirements are considered. In all three schemes, cluster size is changed according to the concentric regions' receiver sensitivities. In MFRP scheme, abundant channels are assigned to the innermost region in order to acquire maximum effective capacity from the interested cell. OFRP scheme, on the other hand, allocates unused channels according to the area surfaces and user distributions to maintain fair and optimum resource distribution for the system. GoS-oriented FRP scheme offers capacity maximization similar to MFRP while resource allocation is done in order to protect the desired GoS-levels in every concentric region. The flexible allocation of the resource, adaptive cluster sizes and fractional frequency reuse make these schemes very attractive both in terms of capacity and the GoS.

This work can be considered as a part of next generation wireless network architecture such as 3GPP-LTE and IEEE 802.16m (WiMAX) in terms of intelligent FRP which will allow increasing capacity in a two-tiered network structure. The proposed schemes in this study are going to be used for designing tiered networks (e.g. femtocells, picocells, or wired relays) to solve the problem of dead-zones.

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