ADAPTIVE GEOLOCATION BASED INTERFERENCE CONTROL FOR HIERARCHICAL CELLULAR NETWORK WITH FEMTOCELLS

BY SHWETA SAGARI

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ABSTRACT OF THE THESIS

Adaptive Geolocation Based Interference Control for Hierarchical Cellular Network with Femtocells

by Shweta Sagari

Thesis Director: Professor Dipankar Raychaudhuri

This thesis presents adaptive interference control methods to mitigate undesirable interference effects from femtocells to macrocell users in hierarchical cellular networks. The study in this thesis begins by quantifying the deterioration in performance experienced by macrocell users on the downlink in a simulated 3G/CDMA environment. Our baseline results show that the median deterioration in signal-to-interference plus noise ratio (SINR) observed for the macrocell users may be up to 10dB and the outage probability increases by large extend.

In the next part of study, we propose interference mitigation schemes - ‘Proximity Based Iterative’ (**PBI**) scheme and ‘Adaptive Interference Scaling’ (**AIS**) scheme to adjust femtocell power to reduce femtocell interference effect on macrocell users. We show that previously studied mechanisms like the load-spillage, utility based power adaptation usually require relatively high system overhead due

to over-the-air signalling for estimation of interference. Proposed **PBI** and **AIS** schemes avoid such over-the-air signalling and make use of geo-location information and backhaul signalling for the femtocell interference estimation. These schemes achieve power re-distribution by scaling power uniformly across femto-cells, while allowing the network operators to set desired target data rates.

Results from simulations show that the **PBI** and **AIS** schemes are able to increase the number of macrocell users achieving chosen target data rates by up to 158% when compared with the value when femtocell transmission power is at maximum. However, in case of the **PBI** scheme, results shows that 25% of femtocell users may receive rates below the target rate. The **AIS** scheme provides an improvement over the **PBI** scheme by adjusting femtocell power according to the interference contribution by each femtocell. Thus, **AIS** achieves better performance and only up to 12.2% of femtocell users receive rates below the target rate.

This study concludes with parametric evaluation of system throughput as a function of both macrocell and femtocell user densities. Qualitative results are provided to support the conclusion.

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Chapter 1

Introduction

With advancement to 3G and 4G cellular networks, cellular operators are looking for low-cost network solution to support increasing demand for high data rate mobile applications, mainly targeted for indoor users. Femtocell or home base station is certainly a contending solution to achieve this target [3]. Femtocells are user-deployed small cellular base-stations which are typically designed for use in small office and home (SOHO) environment. Femtocells connect to cellular operator's core network using an IP based backhaul. Fig 1.1 shows a typical deployment of femtocells in existing cellular network using customer's broadband connection as a backhaul. 3G/CDMA femtocells are already being deployed by operators and mobile manufacturers [4, 5].

Femtocell deployment offers following advantages to cellular network:

1. *Improved cellular coverage and macrocell capacity:*

Due to short distance between femtocell base-station and femtocell user, femtcell can operate at lower transmission power but still achieve higher signal-to-interference-plus-noise ratio (SINR). This also leads to longer battery life of mobile handsets and availability of higher data rate at user. This achieves improvements in the area spectral efficiency of the cellular network.

2. *Increased reliability of macrocell:*

Femtocells are especially targeted for indoor cellular users as indoor users receives weak signal because of penetration losses. In the proximity of femto-cell, higher quality signal is available at macrocell users which also improves

Figure 1.1: Deployment of femtocell in existing macrocell structure.

overall service of the network operators.

3. *Cost Benefits:* Femtocell deployment is a cheaper solution to cellular operator rather than deploying cellular base-stations. As femtocell is user-installed unit at home/office, cellular operator can manage femtocells with no significant operating cost.

Femtocell can be operated in the macrocell by two frequency allocation methods: (1) Dedicated channel assignment to femtocell and macrocell (2) Co-channel operation of macrocell and femtocell. Co-channel operation of femtocell with existing macro-cellular network can significantly improve the spectral efficiency in comparison with dedicated channels assignment to each macrocell and femtocell users [6, 7, 8]. Open access femtocell, one of the operating mode of femtocell, allows cellular users to connect to near-by base-station (macrocell or femtocell base-station) with the best signal quality. Closed access femtocell, on the other hand, is accessible to only registered users to that femtocell which ensures privacy and advantage of constant high SINR/data rate. Closed access femtocell is likely to be deployed in home/small offices by large amount over open access femtocell because of the privacy issues. However, closed access femtocells pose

Figure 1.2: Operation of closed and open access femtocell in co-channel operation with macrocell. (MUE: Macrocell User, FUE: Femtocell user. Solid line for link: direct connection with base-station (Macrocell or femtocell), dotted line for link: interference link)

serious interference to near-by macrocell users which are not connected to femto-cell base-station, thus degrading the performance of the macrocell. Fig 1 shows operation of closed and open access femtocell in co-channel operation with macro-cell. Our work studies achievable performance of interference mitigation schemes in a co-channel deployment of closed access femtocells, primarily in downlink scenarios.

1.1 Motivation and Problem Definition

In most previous studies, the system infrastructure needs to exchange information (e.g. channel gain, load spillage, measurement reports etc.) between the macrocell and the femtocell to coordinate interference management between them. Primarily measurement of channel gain is done through explicit beaconing. For example, Rangan et. al [9] use an implementation of signal beaconing to calculate the channel gain between the femtocell base-station and the macrocell user. This scheme

Figure 1.3: Summary of a selected approach to study interference mitigation between macrocell and femtocell

requires the macrocell user to transmit a reference signal intermittently on the uplink and the femtocell base-station to stop their normal reception. Although such mechanisms are able to effectively mitigate interference for the macrocell users, they impose the following additional requirements on the system:

- Explicit channel for signalling and interference estimation
- synchronization across femtocell base-stations and macrocell users

An important aspect in this explicit signaling and interference estimation mechanism is that the overheads grow in direct proportion to the density of the femtocell users. For example, consider a 3G CDMA based system. In this case, if beacon messages (for estimation) are broadcasted by MUE to surrounding femtocells at the control data rate of 38.4kbps, the channel is occupied for a minimum time period of 26.66ms per femto basestation. These overheads can lead to a loss of up to 18Mbps of bandwidth with a femto deployment that has up to 30% overlap with the macrocell coverage.

The above mentioned overheads can be saved if information exchange and estimation over-the-air can be avoided. Hence, we propose the ‘Proximity Based Iterative’ (**PBI**) and ‘Adaptive Interference Scaling’ (**AIS**) interference mitigation schemes which take advantage of location information and the IP backhauling for interference mitigation. Fig 1.3 shows the scenario considered to study interference mitigation problem between femtocell and macrocell.

Our study mainly focuses on following aspects:

1. **Interference Characterization:** We present a detailed evaluation of the interference seen by macrocell users due to the presence of femtocells distributed in the network. This characterization serves to describe the upper bound of the performance that can be achieved by macrocell users in the absence of femtocells.
2. **Interference Mitigation Approach:** We present a heuristic based ‘Proximity Based Iterative’ (**PBI**) and ‘Approximated Interference Scaling’(**AIS**) power control schemes to satisfy the SINR requirements of the macrocell users. The **PBI AIS** schemes reduce femtocell transmission power without using over - the - air interference estimation schemes, thereby resulting in superior performance for the macrocell users while resulting in savings in the overall system capacity. We show that iterative correction, added to the **AIS** scheme, reduces approximation errors of the schemes and achieves significant improvement in performance at both macrocell and femtocell users.
3. **System Evaluation:** Through the use of a detailed network simulation model we show that the proposed schemes **PBI** and **AIS** are able to closely approximate the performance of a mechanism that would possibly use explicit over - the - air interference estimation techniques. We also show that our schemes (1) allow programmable interference control, and (2) performs

well even under the absence of accurate location information.

The rest of the thesis is organized as follows. In chapter 1.2, we present prior work in the area of interference mitigation in coexistence of macrocell and femtocell that is relevant to our work. Chapter 2 presents the network and interference models used in our study which is followed by baseline results of performance degradation of macrocell users in the presence of femtocell in Chapter 3. The **PBI** and **AIS** interference mitigation algorithms are discussed in Chapter 4. System evaluations are presented in Chapter 5. Finally, Chapter 6 discusses the conclusions and future directions.

1.2 Related Work

Since their introduction, hierarchical macrocell-femtocell deployments have been studied for interference impact on overall system performance. Reference [3] gives the overview of the technical and business aspects of femtocells and discusses the technical challenges facing femtocell networks. Reference [10] discusses the feasibility of deployment of femtocell in same frequency band as the macrocell. Another study [11] studies the call drop probability of mobile user in coexistence of the macrocell and femtocell when femtocell is operating in open access mode. This study shows that open access femtocell gives the opportunity to mobile user to connect to base-station with the best signal quality but at the expense of increased handovers between base-stations. References [12, 8] discusses femtocell interference problems to macrocell user when femtocell is operating in closed access mode. Co-channel operation of femtocell with existing macro-cellular network can significantly improve the spectral efficiency in comparison with dedicated channels assignment to each macrocell and femtocell users [6, 7, 8].

Interference management/coordination in coexistent scenarios of macrocell and femtocell is well studied problem and several approaches have been proposed.

References [10, 11] considers the femtocell power configuration based on received power from the macrocell base-station. This solution works well in case of open-access, low density femtocells with large wall separation. References [13] and [9] offer power control solutions based on the utility maximization in cellular system based on non-cooperative game theory and load-spillage algorithm respectively. Reference [13] also proposes concept of reducing power of femtocells which are in near-by region of the MBS in uplink. Reference [14] encounters interference mitigation with usage of frequency division duplexing (FDD) in WCDMA with carrier separation. We consider though whole CDMA spectrum to increase spectrum utilization [6]. Reference [15] provides interference analysis for OFDMA system by utilizing resource blocks of MUEs which are away the femtocell through spectrum sensing and MUE scheduling information. Reference [7] also studies interference avoidance in OFDMA through scheduling of sub-carriers by spectrum sensing and measurement reports given by femtocell users. As opposed to explicit interference measurements used in all the previous work, our approach exploits geolocation information available at macrocell users and base-stations for interference estimation and mitigation.

Chapter 2

System Setup

In this chapter, we present the network scenarios we considered for our study. Our network Setup consists of a 3G/CDMA 1xEV-DO (First generation evolution data only) network analyzed for downlink, considering variable data rate availability at both macrocell and femtocell [16, 17]. In our study, we have referred revision 0 of 1xEV-DO, in which thirteen data rates can be supported. The Table (2.1) gives the overview of key performance features of the 1xEV-DO System such as DRC (data rate control) index, available data rate, the number of timeslots needed (depending on data rate), bits/packet, channel coding rate, corresponding modulation scheme and corresponding SINR required respectively.

In our study, we assume a hexagonal macrocell structure of 19 adjacent cells, while evaluating the central cell C_0 with a macro base-station B_0 . M macrocell users (MUE) and F femtocell base-stations (FBS) are uniformly randomly distributed in C_0 . Each MUE $_i$ $i \in \{1, 2, \dots, M\}$, is associated with B_0 . Let's assume that only one femtocell user FUE $_j$ is associated with each FBS $_j$, $j \in \{1, 2, \dots, F\}$. Let η be the density of femtocells corresponding to the percentage of area overlapped between the macrocell and femtocell. Wall loss corresponding to each femtocell is chosen with equiprobability from a given set of values for different kinds of wall separations like outer wall, wooden doors, glass window etc. [11, 10]. Table (2.2) summarizes the notations which will be used in the rest of this thesis.

Table 2.1: Simulation Parameters Based on 3GPP [1]

DRC Index	Data Rate (kbps)	Slots Scheduled	Payload size (bits)	Code Rate	Modulation	SINR (dB)
1	38.4	16	1024	1/5	QPSK	-12
2	76.8	8	1024	1/5	QPSK	-9.6
3	153.6	4	1024	1/5	QPSK	-6.8
4	307.2	2	1024	1/5	QPSK	-3.9
5	307.2	4	2048	1/5	QPSK	-3.8
6	614.4	1	1024	1/3	QPSK	-0.6
7	614.4	2	2048	1/3	QPSK	-0.8
8	916.2	2	3072	1/3	8-PSK	1.8
9	1228.8	1	2048	2/3	QPSK	3.7
10	1228.8	2	4096	1/3	16-QAM	3.8
11	1843.2	1	3072	2/3	8-PSK	7.5
12	2457.6	1	4096	2/3	16-QAM	9.7

2.1 System Assumptions

We make following assumptions for our study:

1. We assume that all users (macrocell users) and (femtocell users) in the network are stationary. Channel is modeled considering path-loss and log-normal shadowing for sub-urban location. See Table (2.3).
2. For simplification purpose, the interference range of each FBS is defined at some constant value D_I meters. Thus, while selecting femtocells which are interfering to MUE, FBSs which are in range of D_I of MUE, are considered.
3. Every FBS provides location information using GPS capability. In a real cellular system, a GPS is available by default on all base-stations for synchronization, and can be used to further obtain location information. Location information of the MUE can be obtained through triangulation, and the errors in triangulation are low.

Table 2.2: Notations and definitions used throughout the thesis

Signal-to-interference plus noise ratio	SINR (γ)
Macrocell base-station	MBS
Femto base-station	FBS
Macrocell user	MUE
Femtocell user	FUE
Femto density	η
Wall loss	L_w
Transmission power of MBS(m) or FBS(f) x	Φ^x
Channel gain between base-station x and user y	h_{xy}
Interference from base-station x to user y	$I_{x,y}$
Outage probability	ψ
Interference Range	D_I

Table 2.3: Channel models suggested by 3GPP [2]

Path Loss	
MBS to MUE	$15.3 + 37.6\log(R)$
FBS to FUE (both belong to same femto)	$38.46 + 20\log(R) + 0.7R$
FBS to FUE (both belong to different femtos)	$15.3 + 37.6\log(R) + L_w$
FBS to MUE	$15.3 + 37.6\log(R) + L_w$
Log-Normal Shadowing	
Outdoor	$Std.dev = 8.9dB$
Indoor	$Std.dev = 4dB$

4. Channel conditions are considered to be static for duration of power control algorithm.

2.2 Interference Model

We use notations $i \in \{1, 2, \dots, M\}$ and $j \in \{1, 2, \dots, F\}$ for MUE and FUE respectively. We also use notations $p \in \{0, 1, 2, \dots, 18\}$ and $q \in \{1, 2, \dots, F\}$ for MBS and FBS respectively where $p = 0$ represents B_0 . Assume Φ_p^m and Φ_q^f as the transmitter power of MBS and FBS respectively. We use notation h_{xy} to

Figure 2.1: Downlink interference scenarios in coexistent operation of macrocell and femtocell users.

represent channel gain from base-station x (MBS or FBS) to user y (MUE or FUE). We define the downlink interference scenarios described in Figure 2.1 as following:

Interference to MUE _{i} :

1. The *co-layer interference* from adjacent MBSs is given as

$$I_{m,m} = \sum_{p \neq 0} \Phi_p^m h_{pi}.$$

2. The *cross-layer interference* from near-by FBSs which are in the interference range of D_I meters from MUE, is given as

$$I_{f,m} = \sum_q \Phi_q^f h_{qi}.$$

Interference to FUE _{j} :

1. The *co-layer interference* from adjacent FBSs which are in interference range of D_I meters from FUE, is given as

$$I_{f,f} = \sum_{q \neq j} \Phi_q^f h_{qj}.$$

2. The *cross-layer interference* from the near-by MBSs is given as

$$I_{m,f} = \sum_p \Phi_p^m h_{pj}.$$

2.3 Performance Evaluation Metrics

Using this network setup and interference model, let us define the metrics which will be used to evaluate the co-existence performance of macrocell-femtocell. We maintain same notations as defined in previous sections.

1. SINR (Signal to Interference-Noise Ratio) (γ):

The SINR received at MUE_{*i*}, $i \in \{1, 2, \dots, M\}$, which is associated to MBS B_0 is given as

$$\gamma_i = \frac{\Phi^m h_{0i}}{I_{m,m} + I_{f,m} + N_0} \quad (2.1)$$

The SINR received at FUE_{*j*}, $j \in \{1, 2, \dots, F\}$, which is connected to FBS_{*j*} is given as

$$\gamma_j = \frac{\Phi_j^f h_{jj}}{I_{f,f} + I_{m,f} + N_0}$$

where, N_0 is a noise in Additive White Gaussian Noise (AWGN) channel.

2. Outage Probability (ψ):

The user is said to be in outage, if SINR received at user is below the minimum SINR required to maintain connection with the base-station. With reference to Table (2.1), the SINR requirement for minimum data rate 38.4kbps is given as -12dB . The SINR value is also required to maintain connection with base-station. Thus if SINR $\gamma < 12\text{dB}$, then user (MUE or FUE) is considered to be in outage.

3. Bit-meter:

We measure the overall system capacity of macrocell in terms of maximum achievable data rate in bits per second which is normalized over distance between macrocell base-station and user [18].

Table 2.4: Simulation Parameters Based on 3GPP [1]

PARAMETER	VALUE
Operating Frequency	2 GHz
Bandwidth	1.25 MHz
Data Rate Availability	38.4 to 2457.6 kbps
SINR requirement	−12 to 9.7 dB
Macrocell Parameters	
Number of Macrocell Users (N_m)	20/km ²
Inter-Site Distance (ISD)	2 km
MBS Transmission Power (Φ_m^t)	42 dBm
Femtocell Parameters:	
femto density (η)	5% to 20%
Maximum Transmission Power ($(\Phi_f^t)_{max}$)	125 mW
Target Range	20 m
Wall Loss(L_w) for glass, door and light internal/ /internal/external walls resp.	[1, 3, 7, 10, 15] dB
Simulation Iterations	1000

2.4 Network Simulation Parameters

Table (2.4) lists important network simulation parameters which we have considered for our study. We have evaluated system performance in this thesis based on these parameters. The simulation parameters are based on 3GPP specifications [1] and the definition given in previous sections of this chapter.

Chapter 3

Baseline Performance

In a macrocell, femtocells are placed without any network planning. Thus, intuitively, as the number of femtocells increases in the network, performance of macrocell gets degraded due to interference from femtocells. Also, the femtocell network relies on the premise that the interference between macrocell and femtocells will be minimum on account of the attenuation provided by external walls of the house. However, this may not always be the case, e.g. in case of glass windows, wooden walls. Thus, we study the effect of varying femtocell density (η) and wall loss (L_w) on the performance of MUEs in downlink. In this chapter, transmission power of femtocell base-stations is set at constant maximum value (Φ_{max}^f) without any power control scheme.

3.1 Impact of Femtocell Density (η)

In our first experiment we will vary the femtocell density η (as defined in previous Chapter) of the femtocell deployment, and measure the corresponding deterioration in performance for macrocell users. Performance is evaluated for $\eta = 10\%$ and 30% while keeping femto transmission power at maximum $(\Phi_f^t)_{max}$. Here, the wall loss L_w is randomly generated from the set of wall loss values shown in Table (2.4). Fig. 3.1 shows the CDF of SINR distribution of macrocell users.

We observe that, in case of the absence of femtocells, median SINR at MUE is given as around 3.8dB. It means that 50% of the MUEs receives SINR below $\gamma_m = 3.8\text{dB}$ when no femtocell is present. At $\eta = 10\%$, though, 67.3% of the MUEs

Figure 3.1: Effect of femtocell density on the CDF of SINR distribution for macrocell users, with femto power = maximum and femto density = 10% and 30%

receives SINR lower than γ_m . This degradation further increases at $\eta = 30\%$ with 83% of users receiving lower SINR than γ_m . Thus we observe deterioration of 35% and 66% respectively at η 10% and 30% when compared to no femtocell case.

In the absence of femtocells, outage probability (ψ) for the macrocell user is 0.002. However, with $\eta = 10\%$ and 30%, outage probabilities values ψ increases to 0.14 and 0.34 respectively. Performance degradation in outage probability is observed up to 34% in comparison to no femtocell case when femtocell density is increased. Thus, we can conclude that, as femto density η increases, the performance of macrocell user decreases to a large extent.

Figure 3.2: Impact of wall loss (L_w) on the SINR distribution of macrocell users when femtocell density (η) is 10%

3.2 Impact of Varying Wall Loss

The femtocell network relies on the premise that the co-channel interference between macro and femtocells will be minimum on account of the attenuation provided by external walls of the house. Previous related studies [15, 14] have typically considered this parameter to be constant. However, this may not always be the case, since newer building architectures in urban areas rely on different materials for outside walls ranging from see through glass to concrete. Through this experiment we will show that this parameter plays an important role in determining the interference for macrocell users, further strengthening our case for effective interference management schemes. In this experiment, we will vary the amount of wall loss (L_w) from values [1, 3, 7, 10, 15]dB. The femtocell transmission power is considered at the maximum Φ_{max}^f . Results are represented as the CDF of SINR distribution of macrocell users and compared with the case when no

Figure 3.3: Impact of wall loss (L_w) on the SINR distribution of macrocell users when femtocell density (η) is 30%

femtocell is present.

Fig. 3.2 shows the impact of varying wall loss (L_w) impact when femtocell density (η) is 10%. Outage probability (ψ) of macrocell users is minimum at the value 0.04 when wall separation is the highest at value $L_w = 15$ dB. ψ value increases, though, as the wall separation reduces and reaches at value 0.23 when $L_w = 1$ dB. Also, at L_w 15 dB and 1 dB, 57% and 74% of macrocell users receives SINR below γ_m respectively. We repeated the experiment for femtocell density 30% to observe the impact of wall loss at higher femtocell density. Results are as shown in Fig. 3.3. We observe that the effects of varying wall loss increases significantly for higher density of femtocell deployment. Typically, ψ increases to 0.11 and to 0.50 for $L_w = 15$ dB and $L_w = 1$ dB respectively. Also, at this high femtocell density, 68% and 90% of macrocell receives SINR below γ_m . Thus, we observe deterioration of 80% the performance in comparison with no femtocell case.

Thus, at high femtocell densities, if enough attenuation is not provided by wall loss, it causes high interference to macrocell users and determines the performance of macrocell users.

Chapter 4

Interference Mitigation Strategies

Results in the previous chapter show that interference mitigation strategies are required for reducing interference on the near-by macrocell users. We propose following two mitigation strategies where femtocell interference mitigation is achieved through femtocell transmission power control:

1. Proximity Based Iterative (**PBI**) scheme
2. Adaptive Interference Scaling (**AIS**) scheme

Both of these schemes avoid interference estimation over-the-air by using approximate geolocation information available in the system. Position of every femtocell base-station is known because they are equipped with GPSs which are currently used only for synchronization. Approximate position of the macrocell user is known through triangulation method. Accordingly, power adjustment is initiated at macrocell base-station B_0 using communication of information/control messages through backhaul.

Both the **AIS** and **PBI** schemes are implemented in two sequential stages that are run iteratively at the macrocell base-station:

4.1 Stage 1: Femtocell Power Rate Adaptation

We apply modified Foschini-Miljanic (FM) algorithm [19] to adjust femtocell transmission power according to SINR corresponding to the required data rate. Consider γ_j and Γ_j to be the received and target SINR of the FUE _{j} which is

connected to the FBS_{*j*} with transmission power Φ_j^f , where $j \in \{1, 2, \dots, F\}$, and $\gamma_j \neq \Gamma_j$. Then, according to the FM algorithm, revised power of FBS_{*j*} is given as:

$$\Phi_j^f(t+1) = \min(\Phi_j^f(t) \cdot \frac{\Gamma_j}{\gamma_j}, \Phi_{max}^f)$$

Where, Φ_{max}^f is the maximum power constraint for the FBS. ‘t’ represents the current power iteration and ‘t+1’ represents the next iteration the algorithm. This function adjusts the power of FBS_{*j*} according to the needs of the FUE_{*j*}, thus, minimizes interference. This function specially beneficial in case when femtocell transmission power is higher than necessary for its target SINR.

However, this function alone is not sufficient to mitigate the interference to the macrocell users. So, we take a heuristic approach in *stage 2* to achieve the desired signal quality at macrocell users.

4.2 Stage 2: Femtocell-macrocell Interference Mitigation

The second stage of the interference mitigation strategies adjusts the transmission power of every femtocell base-station (Φ^f) which lies in the proximity of a macrocell user. We develop logic for this stage as follows:

For a MUE_{*i*}, $i \in \{1, 2, \dots, M\}$, and received SINR is given by as defined in Eq.(2.1),

$$\gamma_i = \frac{\Phi^m h_{0i}}{I_{m,m} + I_{f,m} + N_0} \quad (4.1)$$

We also define Γ_i which denotes the target SINR. If $\gamma_i < \Gamma_i$, then MUE_{*i*} is assumed to be at poor signal quality, and B_0 initiates power adjustment of femtocell base-station, in proximity of MUE_{*i*}.

Let us consider S_{Fi} as the set of l FBSs around the MUE_{*i*} in radius D_I . D_I is given as interference range of a femtocell base-station. Further $\forall F_q \in S_{Fi}$, where $q \in \{1, 2, \dots, l\}$, each F_q contributes to interference in $I_{f,m}$. Assuming $I_{f,m}$ as dominant interference to MUE_{*i*}, ($I_{m,m} + N_0 \ll I_{f,m}$), we ignore $I_{m,m} + N_0$ from

Algorithm 1: Proximity Iterative (PI) running at MBS B_0 for each MUE $_i$ where $i \in \{1, \dots, M\}$

```

repeat
  while  $\gamma_i < \Gamma_i$  do
    //Locate subset of FBS in proximity of MUE $_i$ 
     $S_{Fi} = \{F_1, \dots, F_l\}$ 
    Send ‘Power reduction’ messages from  $B_0$  to each  $F_j$ ,  $F_j \in S_{Fi}$ ,
    through backhaul signalling
    //Adjust transmission power  $\Phi_j^f$  of each  $F_j$ 
    if  $\Phi_j^f > 0$  then
       $(\Phi_j^f)^* = \Phi_j^f \cdot \Delta t$ .
      //Reduction factor,  $0 < \Delta t < 1$ 
    end
  end
until link between  $B_0$ -MUE $_i$  is active

```

Eq. (4.1) as

$$\gamma_i = \frac{\Phi^m h_{0i}}{I_{f,m}} = \frac{\Phi^m h_{0i}}{\sum^l \Phi_q^f h_{qi}}. \quad (4.2)$$

For each such MUE $_i$, power adjustment of FBSs, $F_j \in S_{Fi}$, is initiated by B_0 as suggested by following schemes **PBI** and **AIS**:

4.2.1 Proximity Based Iterative (PBI) Power Adjustment

The proximity based iterative (**PBI**) power control scheme targets the reduction of transmission power of all FBS (Φ^f), which are in proximity of MUE ($F_j \in S_{Fi}$), by a small step of Δt ($0 \leq \Delta t \leq 1$) in iteration until MUE achieves the target SINR. The logic for $F_j \in S_{Fi}$ is given as presented in Algorithm 1.

Advantage of the (PBI) scheme:

The advantage of this scheme is that it protects the desired QoS of macrocell users by giving full priority to them. Thus, the performance of the macrocell users improves and is close to that without any femtocells.

Drawbacks of the (PBI) scheme:

PI reduces transmission power (Φ^f) of all femtocell in the proximity of the MUE without considering interference contribution of each femtocell. This makes the scheme unfair, specially, to femtocells which are already operating at lower transmission power and not adding interference contribution to MUE. This scheme sometimes leads to switching off some of the femtocells and diminishing overall performance of femtocell by large extend.

4.2.2 Adaptive Interference Scaling (AIS) Power Adjustment

To overcome the drawbacks of the **PBI** scheme and improve performance of femtocell from previous scheme, we suggest the **AIS** scheme. The **AIS** scheme adjusts the transmission power of every femtocell base-station (Φ^f) which lies in the proximity of a macrocell user. It chooses the dominant femtocell base-station interferers for every macrocell user and assigns weights/reduction factors in proportion to the interference they are causing. The **AIS** scheme proposes to pass femtocell base-station information such as its unique femtocell id, transmission power (Φ^f) and geolocation coordinates to macrocell base-station using IP back-haul. ³ Using this information interference estimation for the macrocell user is done which is followed by power adjustment at femtocell base-stations, which is done as discussed below.

From Eq. (4.3), we have

$$\gamma_i = \frac{\Phi^m h_{0i}}{I_{f,m}} = \frac{\Phi^m h_{0i}}{\sum^l \Phi_q^f(t) h_{qi}}, \quad (4.3)$$

where $\Phi_q^f(t)$ presents transmission power of femtocell F_q at current time instant t . At B_0 , the channel gain h_{qi} from F_q to MUE _{i} is calculated using a static path-loss

³Power control using **AIS** is implemented at FBSs in correspondence to the nearest MBS B_0 .

model using distance measurements obtained from geolocation coordinates. This model depends on the terrain around B_0 .

We define the target *SINR margin* for MUE_i as

$$\Delta_i = \frac{\Gamma_i}{\gamma_i} \quad (4.4)$$

Assuming received power at MUE_i from B_0 remains constant, from Eq. (4.3), we get

$$\Delta_i = \frac{\sum \Phi_q^f(t) h_{qi}}{\sum \Phi_q^f(t+1) h_{qi}}, \quad (4.5)$$

where $\Phi_q^f(t+1)$ represents transmission power of F_q at time instance (t+1) after the power is adjusted to achieve target SINR margin.

Let us define contribution of interference by each F_q , $q \in \{1, \dots, l\}$, in total interference $I_{f,m}$ by factor k_q such that

$$\Phi_q^f(t) h_{qi} = k_q (\sum \Phi_q^f(t) h_{qi}), \quad (4.6)$$

where

$$\sum k_q = 1$$

We consider w_q as the scaling factor applied to $\Phi_q^f(t)$ to achieve desired transmit power as

$$\Phi_q^f(t+1) = w_q \Phi_q^f(t). \quad (4.7)$$

Hence, from Eq. (4.5), Eq. (4.7) and Eq. (4.6), we have the relation

$$\Delta_i = \frac{\sum \Phi_q^f(t) h_{qi}}{\sum w_q k_q (\sum \Phi_q^f(t) h_{qi})} = \frac{1}{\sum w_q k_q}. \quad (4.8)$$

Thus, larger the contribution of interference from F_q (large k_q) to MUE_i , **AIS** does a larger reduction in Φ_q^f , and corresponding smaller should be the w_q . Considering a linear relationship between k_q and w_q , we get

$$k_q \propto \frac{1}{w_q} \Rightarrow k_1 w_1 = k_2 w_2 = \dots = k_l w_l = \text{constant}. \quad (4.9)$$

Algorithm 2: The Adaptive Interference Scaling (**AIS**) scheme running at MBS B_0 for $MUE_i \forall i$

repeat

 Calculate received SINR $= \gamma_i$.

 Set target SINR $= \Gamma_i$.

 Set SINR margin $\Delta = \frac{\Gamma_i}{\gamma_i}$.

while $\gamma_i < \Gamma_i$ **do**

 At MBS B_0 , locate subset of l FBSs in proximity of MUE_i
 $S_{Fi} = \{F_1, F_2, \dots, F_l\}$.

 //Calculate interference contribution by each $F_q \in S_{Fi}$ using geola-
 tion information of MUE_i and all F_q as

$$k_q = \frac{\Phi_q^f(t)h_{qi}}{\sum \Phi_q^f(t)h_{qi}}.$$

 //Calculate power scaling factor as

$$w_q = (l.k_q.\Delta)^{-1}.$$

 Send ‘Power scaling factor’ from B_0 to each F_q , $F_q \in S_{Fi}$, through
 backhaul signalling.

 //Adjust Φ_q^f of each F_q for time instance $t + 1$

$$\Phi_j^f(t + 1) = w_q \Phi_j^f(t).$$

end

until link between B_0 - MUE_i is active

Thus, solving Eq. (4.8) using Eq. (4.9) for w_q , we get

$$w_q = (l.k_q.\Delta)^{-1}. \quad (4.10)$$

The **AIS** scheme will use Eq. (4.7) and Eq. (4.10) to adjust the transmission power of F_q . The logic for power adjustment is given as presented in Algorithm 2.

We note that the performance results by the **AIS** scheme are bound to be erroneous for reasons-

1. We assume that interference estimation is done at macrocell base-station by two parameters distance and transmission power of femtocell. Using these parameters, static pre-defined path-loss model is applied and interference is calculated. But this model does not represent the real channel gain along

Figure 4.1: Effect of femtocell density on the CDF of SINR distribution for macrocell users, with femto power = maximum and femto density = 10% and 30%

with shadowing and small-scale fading. Thus, results obtained with this scheme are noisy.

2. This scheme also assume that femtocells as the only reason for low SINR at macrocell users and reduces the femtocell power according to target SINR of macrocell user. But this may not hold true, specially in case of strong interference from near-by macrocell base-station (at the edge of macrocell) or strong shadowing at macrocell users.

Addition of iterative correction to the AIS scheme

To compensate these estimation errors, the **AIS** scheme operates in an iterative correction mode in which, after the power adjustment at F_q , B_0 checks SINR gain at MUE_i . Depending on the SINR gain after femtocell power adjustment, algorithm resets the target SINR margin of MUE_i and recalculates the $\Phi_q^f(t+1)$

Figure 4.2: Effect of femtocell density on the CDF of SINR distribution for macrocell users, with femto power = maximum and femto density = 10% and 30%

value. If the SINR gain is above predefined threshold value, then the (AIS) algorithm calculates the new target SINR margin and repeats the algorithm to achieve target SINR. But in a case, if SINR gain is below predefined threshold, then transmission power of femtocell fall backs to previous values which are set before recent power reduction.

Fig. 4.1 and Fig. 4.2 shows the SINR distribution performance of macrocell and femtocell users respectively when iterative correction is added. We observe 11% improvement in performance of macrocell users at femtocell density of 30%. This improvement is calculated with regards to number of macrocell users below SINR γ_m value of 3.8dB. As shown in Fig. 4.2, small degradation is observed in the performance of femtocell users even at high femtocell density of 30%.

Chapter 5

Evaluation

In this chapter, we present evaluation to compare and characterize the performance of macrocell users and femtocell users for the proposed schemes **PBI** and **AIS**. The evaluation is based on metrics- SINR, outage probability and bit-meter defined in Chapter 2. We also discuss the localization error related with geolocation information used in the **AIS** scheme. All results are averaged over 1000 runs of system simulations.

Performance of macrocell users based on the **PBI** and **AIS** schemes are compared with the following cases:

1. when no femtocell is present which signifies the ideal case for macrocell users with no femtocell interference,
2. when femtocell power is set at maximum (Φ_{max}^f) with maximum femtocell interference to macrocell users,
3. and when femtocell power is set based on the modified Foschini-Miljanic (FM) algorithm.

Performance of femtocell users based on **PBI** and **AIS** is compared with cases when FBS power is set:

1. at maximum femtocell power (Φ_{max}^f),
2. and based on the FM algorithm.

Figure 5.1: Performance of the CDF of SINRs for MUEs based on proposed schemes when femto density = 10% and 30%

5.1 SINR Performance

We compare the SINR distribution achieved in relation to the scenarios mentioned above. For both macrocell users and femtocell users, we assume that the minimum required satisfactory data rate (R_g) is 1200Kbps. This data rate is corresponding to the SINR 3.8dB which is median SINR value of macrocell users without any femtocell. We plot these results for two different femtocell densities (η) 10% and 30%. Femtocell density 10% is the average expected femtocell penetration in suburban areas. 30% is close to upper bound of femtocell density of any deployment.

5.1.1 SINR Performance of Macrocell User

Figure 5.1 shows CDF of SINR values for the macrocell users. Best macrocell user performance is achieved in the ideal case. Worst case performance is achieved

Figure 5.2: Performance of the CDF of SINRs for FUEs based on proposed schemes when femto density = 10% and 30%

at the maximum value of femtocell transmit power Φ_{max}^f . At lower femtocell density, the FM algorithm is able to improve performance of macrocell users up to 50% with regards to outage probability, but it is unable to provide significant interference reduction for $\eta = 30\%$. Both the **PBI** and **AIS** schemes achieve macrocell SINRs close to the ideal case for both values of η . The **PBI** and **AIS** schemes allow the network provider to decide and deploy the femtocells with target SINR pf macrocell users provisioned based on its service level agreements (SLA). Once the target SINR for the macrocell user is achieved, the **PBI** and **AIS** schemes do not reduce any further power for the femtocells surrounding the macrocell. Due to this feature we see that the **PBI** and **AIS** schemes match the ideal case up to the target SINR (which is set to 3.8dB in this case), and then gives a preference to femtocell users. At best, we observe that the **PBI** and **AIS** schemes are able to increase the number of macrocell users achieving target data

Figure 5.3: Distribution of SINR of MUE when target SINR parameter for MUE set at three different values -3.9dB, 3.8 dB, 9.7dB

rate by 158% over those supported by Φ_{max}^f .

5.1.2 SINR Performance of Femtocell User

Figure 5.2 shows the CDF of SINR values for femtocell users. The FM algorithm achieves the best femtocell user performance among all cases for both values of η , since it only tries to reduce inter-femtocell interference. Since both **PBI** and **AIS** reduce femtocell powers to improve SINR for macrocell users, SINR values of femtocell users are consequently lesser. Performance of the femtocell users is worse because of our system design parameter of providing a target SINR of 3.8dB for macrocell users. If this target is lowered, performance of the femtocell users would improve significantly. Similar performance trends are seen for $\eta = 30\%$. However, due to increased density, **PBI** and **AIS** reduce power of more femtocell base-stations to achieve SINR below target SINR. We observe that with the **PBI**,

Figure 5.4: Distribution of SINR of FUE when target SINR parameter for MUE set at three different values -3.9dB, 3.8 dB, 9.7dB

25% of femtocell users may receive SINR below the target SINR value. But **AIS** suggests improvement over **PBI**, offering reduction at dominant interference only rather at all femtocells in proximity of macrocell users. Thus, **AIS** results in up to 12.2% of users not being able to achieve the target rates.

5.1.3 Effect of Target SINR of Macrocell User

In the previous results, the target SINR of macrocell users was considered at 3.8dB which can be system design parameter. We aim to evaluate the performance of macrocell and femtocell under varying design parameter of target SINR for the **AIS** scheme. Fig. 5.3 and Fig. 5.4 shows the performance of macrocell and femtocell users when target SINR is set -3.9dB (SINR corresponding to data rate of 300kbps), 3.8dB and 9.7dB (SINR corresponding to highest available data rate which is 2.5Mbps) at femtocell densities 10% and 30%. At the target SINR

of 9.7dB and -3.9 dB, performance of macrocell users is closer to and way from the ideal case respectively. This is expected behavior of the **AIS** scheme as it can adjust the priority to the macrocell users according to their target SINR. This difference in performance is highlighted more at higher femtocell density of 30%. This effect is observed because of increased femtocell interference at this η value. Correspondingly, expected trend is observed in the performance of femtocell users. At the target SINR of -3.9 dB, best performance of femtocell users is achieved because of lesser power reduction at femtocells compared to other two target SINRs. When MUE target SINR is 9.7dB, more power is reduced at femtocells to achieve this target and the worst femtocell performance is observed.

5.2 Outage Probability

We aim at observing performance of macrocell user and femtocell users for the **PBI** and **AIS** schemes under varied femto density (η). Thus, we evaluate performance based on outage probability (ψ) when η is varied from 2% to 30%. In ideal case, outage probability of MUE is assumed to be 0.002.

5.2.1 Outage Probability of Macrocell User

Figure 5.5 plots the outage probabilities for macrocell users for all the described schemes. In case of macrocell users, both the **PBI** and **AIS** schemes maintains ψ values in the range of 0.002 to 0.004, which are close to the ideal case.

Thus, it is seen that MUE performance for the **PBI** and **AIS** schemes is robust even in case of addition of femtocells in network or change in femtocell topology. On the other hand, as η increases ψ of macrocell users increases both for the FM algorithm and Φ_{max}^f . In the worst case, it is seen that Φ_{max}^f can result in an outage probability of 35%.

Figure 5.5: Outage probability of MUEs with respect to varied femto density (η) based on proposed schemes

5.2.2 Outage Probability of Femtocell User

Figure 5.6 plots the outage probabilities for femtocell users for all the described schemes. In case of femtocell users, as in the earlier case, the FM scheme has the best performance with ψ values ranging from 0.006 to 0.072 over a given range of η . As expected the **PBI** reduces power at all femtocell base-stations in the proximity resulting in a worst case performance of up to 31% femtocell users in outage. The **AIS** scheme improves the performance of femtocell users over all femto densities in comparison with **PBI** with outage probability up to 20%.

Figure 5.6: Outage probability of FUEs with respect to varied femto density (η) based on proposed schemes

5.3 Localization Error

An important contribution of the **AIS** interference mitigation mechanism is the reduction in system overheads for interference estimation through the use of location information. However, in case of errors in location estimation, the performance of such a system could deteriorate.

In the **AIS** scheme, interference estimation at macrocell base-station is based on geolocation information of macrocell users and femtocell. We assumed that the geolocation information available at macrocell user and femtocell is accurate. But, in a real system, this may not be true as triangulation method or GPS system have localization error up to 50m. This error is very high in case of the **AIS** scheme. The **AIS** scheme does the mapping of femtocell based on interference contributed to macrocell user while taking interference range of 100m. Fig. 5.7 illustrates the effect of localization error on the **AIS** scheme. As shown

MUE M and its dominant interfering FBSs F1, F2 and F3 show the scenario without any localization error. M^* , $F1^*$ and $F2^*$ represent the new position of M, F1 and F2 with localization error respectively. FBS F4 gets located with interference range due to erroneous location of M^*

Figure 5.7: Scenario of localization error in the macrocell and femtocell

in Fig. 5.7, positional error can change femtocell interference mapping at macro-cell base-station completely with addition of non-interfering femtocells or removal of dominant femtocell interferes from the list. We suggest that iterative correction mode of the **AIS** scheme can compensate for these errors and maintain the performance of macrocell and femtocell users.

In this experiment, we describe the number of additional iterations (corrections) that would be required by the **AIS** scheme for compensating error in positional information. We assume that the localization error in the GPS position of the femtocell base-station/macrocell user can be up to $\pm 50\text{m}$, and we study the effect on performance with the error values at 10m, 20m and 50m. Figure 5.8 plots the distribution of convergence of **AIS** for femtocell densities (η) at 10% and 30%. As can be seen from the CDF results, the **AIS** scheme requires few additional iterations for convergence. This difference is accurately quantified by the KullbackLeibler divergence (KLD) with respect to no error. For femtocell densities η of 10%, we

Figure 5.8: Disribution of AIS convergence for femtocell densities at 10% and 30%

observe a maximum KLD of 39.4. As expected, the worst case KLD increases to 52.6 for $\eta = 30\%$. We see that for a 20% increase in η , the KLD increases by only 13.2. This small increase is because increase in η results in the requirements of more iterations for **AIS** convergence across a larger number of femtocell base-station.

5.4 Bit-meter

In this section, we study a system capacity of co-existent network of macrocell-femtocell. Our objective is to improve the system capacity but maintaining the required QoS (quality-of-service) at macrocell users. Thus, we plot the system capacity performance with respect to the outage probability of macrocell users.

Figure 5.9: Network capacity including both MUEs and FUEs with respect to outage probability of MUE

Outage probability of macrocell users is basically function of femtocell density. Thus, we considered outage probability for macrocell user over the femtocell densities (η) from 2% to 30%. Results are plotted in Figure 5.9 for all described approaches.

System capacity is noted at highest for schemes Φ_{max}^f and the FM algorithm. As shown in the previous results, these schemes achieves better femtocell performance than the **PBI** and **AIS**. Thus, high aggregate throughput is achieved because of dominant number of femtocells over macrocell users in the network. But this high capacity is achieved at the expense of high outage probability of macrocell user of the order of 10^{-1} . On the other hand, network capacity of **PBI** and **AIS** is degraded at the peak value by 14% and 5% only in comparison with the Φ_{max}^f . This degradation is mainly due to decrease in femtocell throughput due to femtocell interference mitigation for macrocell users. But this capacity is achieved at lower MUE outage probability in the order of 10^{-3} to 10^{-2} .

We observed a common trend among all described schemes that as femtocell density increases, network capacity also keep on increasing. But when femtocell density reaches certain value, system capacity decreases when more femtocells are added. The reason behind this situation can be explained as- at very high femto-cell density, inter-femtocell interference becomes dominant and it deteriorates the performance of femtocells itself, thus lower throughput is observed at femtocells.

Chapter 6

Conclusion and Future work

This study describes the **PBI** and **AIS** mechanisms for interference mitigation that relies on the estimation of femtocell interference for macrocell users based on geolocation information. Results based on simulations show that the **PBI** and **AIS** schemes are able to control femtocell power such that the number of macrocell users achieving target data rates increase by up to 158%, while resulting 25% of femtocell users receiving rates below target for the **PBI** scheme. With the **AIS** scheme, performance of femtocell users further improved resulting only 12.2% femtocell users receiving rates below the target. Further, the results show that the **AIS** scheme is able to work satisfactorily even with some level of inaccuracy in the location data. We also show that total capacity of the cellular system can be improved by deploying femtocells but is limited up to certain threshold of femtocell density for a given macrocell density.

Future work is planned on improved **AIS** algorithms to reduce convergence time, characterize the performance of **AIS** for the case of mobility of macrocell users and on extensions of the algorithm to OFDMA/4G systems.

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