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Femtocell Subband Selection Method for Managing Cross- and Co-tier Interference in a Femtocell Overlaid Cellular Network

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Abstract—The femtocell overlaid cellular network (FOCN) has been used to enhance the capacity of existing cellular systems. To obtain the desired system performance, both cross-tier interference and co-tier interference in an FOCN need to be managed. This paper proposes an interference management scheme that adaptively constructs a femtocell cluster, which is a group of femtocell base stations that share the same frequency band. The performance evaluation shows that the proposed scheme can enhance the performance of the macrocell-tier and maintain a greater signal to interference-plus-noise ratio than the outage level can for about 99% of femtocell users.

Keywords—Clustering Method, Femtocell, Frequency Partition, Interference Management

1. INTRODUCTION

The femtocell base station (FBS) is a solution that can enhance the capacity of cellular systems for two reasons. First, since an FBS can share a frequency bandwidth with a macrocell base station (MBS), the spectral efficiency of the frequency bands is increased [1]. Next, an FBS can improve the available capacity of an MBS by reducing the load of incoming traffic for the MBS [2]. However, unlike the conventional cellular network, which only has a macrocell-tier, a femtocell overlaid cellular network (FOCN) induces a cross-tier interference between macrocell- and femtocell-tiers and co-tier interference between femtocell-tiers [1]. Thus, effective interference management schemes are needed to address both the cross- and co-tier interferences in the FOCN [3].

Several interference management schemes for the FOCN have been proposed [4-7]. These interference management schemes can be divided into power control (PC) and frequency partitioning (FP) based schemes. In the PC-based schemes, the FBS adjusts its transmission power based on the location of the user equipment (UE) that is attached to the MBS or other FBSs [4,5]. Since the PC-based schemes allow macrocell- and femtocell-tiers to reuse the

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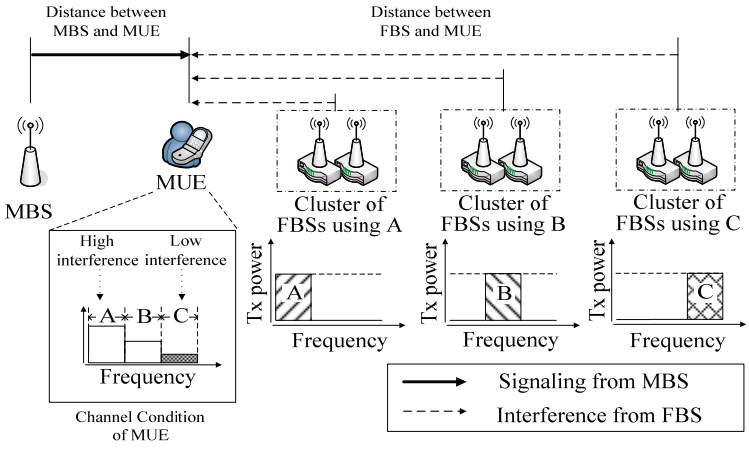

Fig. 1. Interference mitigation by partial spectrum sharing. FBS= femtocell base station, MBS= macrocell base station, MUE=macrocell user equipment.

overall system bandwidth, it has high spectral efficiency. Unfortunately, the PC-based schemes cannot obtain the desired performance gain due to the minimum transmission power constraint. The FP-based schemes allow each tier to orthogonally use frequency bands or share part of the frequency bands [6,7]. The orthogonal use of frequency bands between macrocell- and femtocell-tiers can eliminate cross-tier interference. However, this decreases the spectral efficiency of both macrocell- and femtocell-tiers, due to the unavailable frequency bands in each tier [1]. On the other hand, the partial sharing of frequency bands divides the overall frequency bands into dedicated and shared parts [7]. The frequency band in the dedicated part is assigned to the UE located in the dead zone in the macrocell-tier, while that of the shared part is allocated to all of the UEs in macrocell- and femtocell-tiers. In order to mitigate co-tier interference between femtocells, adjacent femtocells orthogonally utilize the frequency bands in the spectral shared part. However, the partial sharing of frequency bands decreases the average capacity of a femtocell-tier, because the tier is assigned a narrow frequency band.

This paper proposes an interference management scheme that is based on partial sharing to manage cross- and co-tier interferences. We designed a femtocell clustering method to decrease cross-tier interference. In this method, neighboring FBSs make a cluster and utilize the same subband, which is part of the overall frequency band. An MBS allocates the sub-band not used by the neighboring cluster to its serving macrocell user equipments (MUEs) to enhance the performance of the MUE. Fig. 1 shows the channel condition of the MUE when FBSs operate under the proposed clustering scheme. Under this condition, the allocation of subband C to the MUE reduces cross-tier interference. Moreover, co-tier interference can be controlled at a specific level by regulating the sizes of the clusters. Performance evaluation shows that the proposed scheme can increase the performance of the macrocell-tier because it mitigates cross-tier interference and preserves a certain level of the femtocell-tier performance according to the number of FBSs deployed in a macrocell-tier.

2. SYSTEM MODEL OF FOCN

A FOCN includes a large number of femtocells sharing radio resources with a macrocell. Since FBSs are installed at arbitrary locations by the end-consumer, it is difficult to estimate cross- and co-tier interferences in an FOCN by using the mathematical analysis model that is applied to the conventional cellular networks that are regularly deployed by mobile operators.

To analyze the performance of an FOCN using partial spectrum sharing, we consider the homogeneous Poisson point process (HPPP) model, where the BSs in macrocell-tier (m) and femtocell-tier (f) are independently distributed with constant intensities of λ_m and λ_f, respectively [8,9]. In this system model, the signal to interference-plus-noise ratio (SINR) of an MUE i from an MBS located at point x_i becomes:

$$SINR(x_i) = \frac{P_m h_{x_i} \| x_i \|^{-\alpha}}{\sum_{k\in\{m,f\}} \sum_{x\in\Phi_k \setminus x_i} l_k P_k h_x \| x \|^{-\alpha} + \sigma^2}, \tag{1}$$

where P_k is the transmit powers of BSs in k-tier, h is the fading factor of the transmit power between the transmitter and the receiver, Φ_k is a set of positions of BSs sharing the same channel as the MUE i, l_k ($\{1,l_f\}$) is wall_loss, α is the path_loss exponent, and σ^2 is the thermal noise power. In the case of the dense deployment of FBSs, since the interference from the FBSs is larger than the thermal noise, the thermal noise can be ignored. Thus, SINR(x_i) of the MUE located at x_i is simplified to SIR(x_i).

We assume that the quality of service (QoS) requirement of an MUE is defined as the required SIR (v_m) and the outage probability (ε). If all FBSs operate at the closed subscriber group (CSG) mode (i.e., closed access mode), no MUEs are allowed to connect to any FBSs. According to [9], the probability that an MBS will satisfy a certain QoS requirement to its serving MUEs can be estimated as:

$$\mathbf{P}(SIR(x_i) > v_m) = \frac{\pi\lambda_m v_m^{-2/\alpha}}{C(\alpha)(\lambda_m + \gamma\lambda_f)}, \quad C(\alpha) = 2\pi^2 \csc\frac{2\pi}{\alpha}\alpha^{-1}, \quad \gamma = \left(lP_f / P_m\right)^{2/\alpha}. \tag{2}$$

The outage probability is:

$$\mathbf{P}^o(\{\lambda_m\},\{\lambda_f\}) = 1 - \frac{\pi\lambda_m v_m^{-2/\alpha}}{C(\alpha)(\lambda_m + \gamma\lambda_f)} = \varepsilon. \tag{3}$$

Eq. (3) shows that the outage probability can be determined by the intensities of MBS and FBS sharing the same frequency band (i.e., λ_m and λ_f). When the intensity of MBS is fixed, an MBS can provide a performance greater than the outage constraint $\varepsilon(\in[0,1])$ by adjusting the intensity of FBS, λ_f.

3. PROPOSED SCHEME

The proposed scheme consists of two steps, one to determine the total number of clusters and another to select the cluster of FBSs. In the first step, the MBS determines the number of FBS clusters based on the QoS constraints of the MUEs and the number of FBSs within its coverage. It then notifies all FBSs of the number of FBS clusters and the FBSs in the macrocell-tier via the broadcasting channel. In the second step, each FBS obtaining the number of clusters selects one cluster based on the received signal strength (RSS) from its neighboring FBSs.

The number of FBSs and clusters mainly affects the performances of the macrocell- and femtocell-tiers in an FOCN. Under a dense deployment of FBSs, the use of many clusters may be an efficient way to increase the performance of the macrocell-tier since the clusters mitigate the cross-tier interference from the femtocell-tier to the macrocell-tier. However, under the sparse deployment of FBSs, the use of many clusters may be inefficient since they would reduce the width of the available frequency band in the femtocell-tier. Thus, we consider a methodology by which the minimum number of clusters could be obtained to guarantee the QoS requirement of MUEs according to the number of FBSs.

The number of clusters required to guarantee the QoS requirement of MUEs is related to the intensity of interfering FBSs. In the proposed scheme, we assume that all FBSs are still deployed by the HPPP, even though the FBSs are clustered. Since the condition where all FBSs are distributed by the HPPP (i.e., all FBS locations are i.i.d.) is the 'worst-case,' MBS can estimate the lower bound of performance in the macrocell-tier [10]. Under this assumption, the average number of FBSs included in each cluster is similar, since the intensity of FBSs in each cluster is the same. Thus, the intensity of interfering FBSs is determined by the number of clusters, N_c, that is, $\lambda`_f = \lambda_f / N_c$. Through Eq. (3) and the relationship between the intensity of FBSs and the number of clusters, the number of clusters can be estimated as:

$$N_c = \frac{\gamma \lambda_f C(\alpha)(1-\varepsilon)}{\lambda_m \{\pi \nu_m^{-2/\alpha} - C(\alpha)(1-\varepsilon)\}}. \tag{4}$$

Eq. (4) shows that the MBS can estimate the desired number of FBS clusters when it knows the intensity of the FBSs and the QoS requirements of the MUEs. After the number of FBS clusters is determined, the MBS informs all FBSs located within its coverage of the number of clusters by using broadcast messages.

The performances of MUEs and femtocell user equipments (FUEs) also vary according to the clustering method of FBSs. When many FBSs select the same cluster as their neighboring FBSs, cross-tier interference from FBSs to MUE in the unused subbands decreases. On the other hand, co-tier interference between FBSs in the selected cluster increases. However, the channel condition of the femtocell-tier is generally better than that of the macrocell-tier due to the relatively short distance between the transmitter and the receiver. Thus, we propose a clustering method to mitigate cross-tier interference with MUE by applying a constraint on the co-tier interference between FBSs.

The clustering method assigns FBSs to the same cluster to mitigate cross-tier interference if the co-tier interference between femtocell-tiers is lower than a predefined constraint. If not, the FBSs are assigned to different clusters to mitigate the co-tier inference. As shown in Fig. 2, the constraint on the co-tier interference is estimated by the ratio of the orthogonal area (ROA) [11].

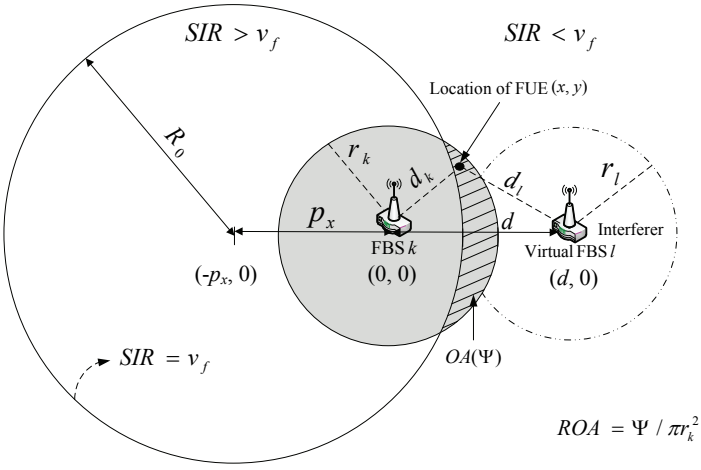

Fig. 2. Estimation of ratio of the orthogonal area (ROA). FBS= femtocell base station, SIR= signal-to-interference ratio, MUE=macrocell user equipment.

In Fig. 2, when an FUE connected to FBS k is located outside an area where the origin is ($-p_x$, 0) and the radius is R_0, the FUE has lower SIR value than the predefined SIR threshold. If FUEs only exist in the coverage area of FBS k with radius r_k, the orthogonal area (OA) refers to the region where the SIR value of an FUE is lower than the predefined SIR threshold. The ROA can be determined as the ratio of OA to the coverage area of FBS k. In [11], the ROA of each FBS is calculated using the geographical distance between neighboring FBSs and managed in the centralized gateway. However, it is difficult to measure the exact distance between two FBSs. In addition, the existing method to estimate ROA may be incorrect since it does not consider signal attenuation because of the walls between the FBSs. Thus, we considered the RSS based ROA estimation method, where the FBS assumes that the received signal in a subband is transmitted from a virtual FBS.

An FBS k estimates the distance from a virtual FBS l from the outdoor path_loss model using the following equation [12]:

$$d = (RSS_{k,l}/\beta P_l)^{1/\alpha}, \alpha = 3.76, \beta = 10^{-1.53} \tag{5}$$

where $RSS_{k,l}$ is the signal strength measured in FBS k and P_l is the transmission power of a virtual FBS l. In the proposed clustering method, the FBSs estimate the ROA values of N_c subbands, and then select one cluster based on the ROA values. When the ROA value of a subband is zero, the SIR requirement v_f of the subband is satisfied within the coverage of FBS. Thus, an FBS can include the cluster in a set of available cluster candidates. When the set includes at least one cluster (i.e., available cluster exists), FBS selects the cluster that has a subband with the highest RSS in the set of cluster candidates. If the set is null, FBS randomly selects one cluster.

4. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the proposed scheme by performing a system-level simulation based on C language. Table 1 shows the parameters of the FOCN simulation based on 3rd Generation Partnership Project (3GPP) long-term evolution (LTE) [13]. The FOCN consists of 19 hexagonal macrocells. The average number of femtocells overlaid with each macrocell is M. The location of an FBS is determined as HPPP with the constant intensity of FBSs, λ_f. The number of UEs served by an MBS and an FBS are 30 and 1, respectively. MUEs and FUEs are uniformly located in the coverage of their serving BS. Because all FBSs operate in the CSG mode, MUEs located within coverage of an FBS cannot connect to the FBS. Since the MBS utilizes the universal reuse, it can utilize the 9 MHz bandwidth without the guard band. Since FBSs are classified into N_c clusters, each FBS can utilize one subband with $9/N_c$ MHz bandwidth from among N_c subbands. Both MBS and FBS allocate radio resources within the available bandwidth to their UEs by the proportional fair algorithm.

Table 1. Parameters for femtocell overlaid cellular network

Parameter		Assumption	
		MBS	FBS
Intensity		$\lambda_m = 2$	$\lambda_f \in$ [50,250]
Number of UEs		30 per macrocell	1 per femtocell
Total transmission power		20 W (43 dBm)	0.2 W (23 dBm)
QoS constraints	SINR	$\nu_m = -4$ dB	$\nu_f = -10$ dB
	Outage probability	$\varepsilon = 0.4$	N/A
Carrier frequency (bandwidth)		2 GHz (9 MHz)	
Thermal noise power		–174 dBm/Hz	
Scheduling scheme		Proportional fair algorithm	

MBS=macrocell base station, FBS=femtocell base station, UEs=user equipments, QoS=quality of service, SINR=signal to interference-plus-noise ratio.

Table 2. Pass_Loss models for femtocell overlaid cellular network

Case	Location of UE	Path_loss (dB) Note: R (m), wall-loss l_f is 10 dB
MBS to UE	Outside	$15.3 + 37.6 \log_{10} R$
	Inside a house	$15.3 + 37.6 \log_{10} R + l_f$
FBS to UE	Inside the same house as FBS	$38.46 + 20 \log_{10} R$
	Outside the house	$max\ (15.3 + 37.6 \log_{10} R\ ,\ 38.46 + 20 \log_{10} R) + l_f$
	Inside the different house from FBS	$max\ (15.3 + 37.6 \log_{10} R\ ,\ 38.46 + 20 \log_{10} R) + 2\ l_f$

UE=user equipment, MBS=macrocell base station, FBS=femtocell base station.

Table 2 presents the channel models referred to in [12]. Under these models, the RSS from BS to UE can be estimated by using the path loss model corresponding to the location of the UE. In

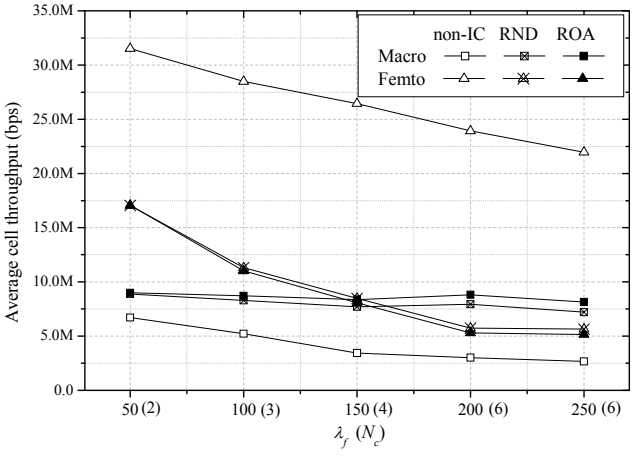

Fig. 3. Average cell throughput according to the intensity of femtocell base station in a macrocell. RND=random selection, ROA=ratio of the orthogonal area, non-IC=non-interference coordination.

each path loss model, R is the distance between a BS and an UE. l_f is the penetration loss due to an outdoor wall, which is 10 dB.

The performance of the proposed selection (ROA) scheme is compared with that of non-interference coordination (non-IC) and the random selection (RND) scheme. Under the non-IC condition, all MBSs and FBSs share the same overall frequency bandwidth. In the RND scheme, an MBS determines the number of clusters (N_c) based on the intensity of FBSs in its coverage, and an FBS randomly chooses one cluster from the N_c clusters with uniform distribution. Through a system-level simulation, we estimate the average cell throughput, which is the sum of the UE throughputs served by a BS. UE throughput is obtained by multiplying the bandwidth allocated to the UE and the spectral efficiency associated with the SINR of the UE in the modulation and coding scheme (MCS) as show in table [13].

Fig. 3 shows the average cell throughput according to the intensity of FBSs. Under the non-IC condition, the average macrocell throughput is less than 7 Mbps and decreases when the intensity of FBSs increases from 50 to 250. In both RND and ROA schemes, the average macrocell throughput can be enhanced to about 5 Mbps. In addition, since the intensity of interfering FBSs that share the same frequency band as a MUE is constantly adjusted, the average throughput of a macrocell slightly decreases even when the number of FBSs increases from 50 to 250. When FBSs are clustered using the ROA scheme, the macrocell throughput increases from 7.2 to 8 Mbps, while the femtocell throughput decreases from 5.6 to 5.2 Mbps. Thus, the ROA scheme can provide a gain in the macrocell throughput that is greater than the loss of the femtocell throughput.

Fig. 4 shows the cumulative distribution function (CDF) for SINR of MUE and FUE when λ_f = 250. In Fig. 4, we compare the results obtained from Eq. (3) and the statistical results obtained from the simulation. The SIR distribution under the non-IC condition and RND scheme is calculated by applying λ_f and λ_f/N_c, respectively. The analysis from Eq. (3) corresponds to the simulation result at more than –4 dB. This implies that the number of clusters for guaranteeing the QoS requirements (i.e., the required SIR and outage probability) can be found by using Eq.

(4) when the QoS requirements of the MUE are pre-determined. When the FBSs are clustered by using the ROA scheme, the performance of the MUE is always higher than that of the RND scheme. This implies that the performance of the RND scheme is the lower bound of the ROA scheme.

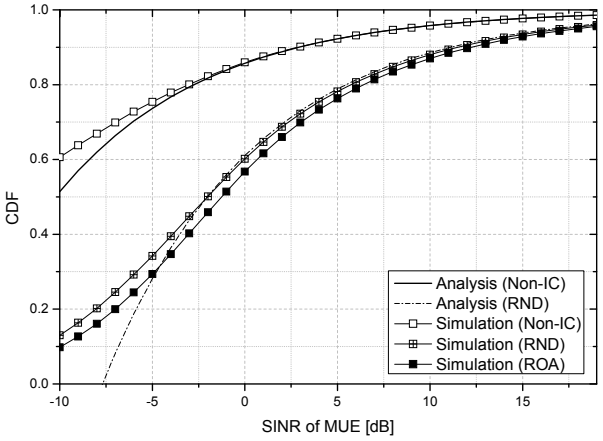

Fig. 4. Cumulative distribution function (CDF) for signal to interference-plus-noise ratio (SINR) of macrocell user equipment (MUE). non-IC=non-interference coordination, RND=random selection, ROA=ratio of the orthogonal area.

Fig. 5 shows the impact on the performance of the FUE with clustered FBSs. In both RND and ROA, since the FBSs included in each cluster orthogonally use different frequency bandwidths, the co-tier interference between FBSs reduces. If the SINR of a FUE is less than -10 dB, the spectral efficiency of the FUE is zero in the MCS table [13]. Thus, the FUE

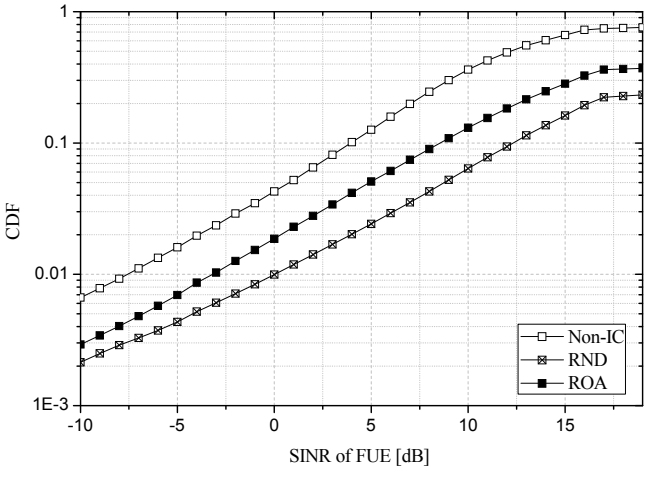

Fig. 5. Cumulative distribution function (CDF) for signal to interference-plus-noise ratio (SINR) of femtocell user equipment (FUE). non-IC=non-interference coordination, RND=random selection, ROA=ratio of the orthogonal area.

cannot receive any data from its serving FBS, that is outage. Under the RND scheme, outage probability of FUEs is about 0.2% of all FUEs. Even though the outage probability of FUEs under the ROA scheme increases about 0.1%, this increment of outage probability might be tolerable in the FOCN. In addition, the minimum SIR requirement of FUE can be adjusted in order to provide the improved performance for the FUE.

5. CONCLUSION

In this paper, we have proposed an interference management scheme by the clustering of FBSs. The proposed scheme can reduce the cross-tier interference in the downlink as long as the FBSs provide a larger SINR than the SIR requirement to their FUEs. The analysis and simulation results showed that the proposed scheme is able to find the number of clusters that can guarantee the pre-defined QoS requirement. In addition, FBSs clustered using the ROA scheme can further increase the performance of the MUE. Even though the performance of FUEs decreased, due to clustered FBSs, the loss of FUE's performance was tolerable.

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