Network Optimization Using Femtocell Deployment at Macrocell Edge in Cognitive Environment

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Abstract— This research focuses on the problem of cell edge user's coverage in the context of femtocell networks operating within the locality of macrocell border where pathloss, shadowing, Rayleigh fading have been included into the environment. As macro cell edge users are located far-away from the macro base station (MBS), so that, the underprivileged users (cell edge users) get assisted by the cognitive-femto base station (FBS) to provide consistent quality of service (QoS). Considering various environment factors such as wall structure, number of walls, distance between MBS and users, interference effect (i.e., co-tier and cross-tier), we compute downlink (DL) throughput of femto user (FU) for single input single output (SISO) system over a particular sub-channel, but also based on spectrum allocation and power adaptation, performance of two tier network is analyzed considering network coverage as the performance metric. Finally, the effectiveness of the scheme is verified by extensive matlab simulation.

Keywords— Cognitive-Femtocell Networks, Okumura-Hata Propagation Model , DL Throughput, Network Coverage.

1 Introduction

In a double-layer heterogeneous network (HetNet), macrocell characterized by its high transmit power and bigger coverage area co-exist femtocells characterized by their small transmit power and limited coverage area. Femtocells are low power invention that comes up with better coverage to portable users through femto-cell access point (FAP) at the indoor scenario. The access node named as FAP, perform as the base station (BS) for the femtocell and take help of internet as backhaul network to get connected with MBS. Co-layer interference is a performance limiting parameter for the HetNet which can be reduced by introducing cognition into the femto access points (FAPs) [1]. The salient features and the potential of the Orthogonal Frequency Division Multiple Access (OFDMA) scheme makes it perfectly suitable for the CR based transmission system. The prime idea of OFDMA technology is that the available spectrum split into several orthogonal sub-channels and permits provision to multiple users to transmit data simultaneously on the different sub-channels. Combining cognitive radio and OFDMA is one of the best feature in the future mobile networks due to its flexibility in allocating resource among cognitive radio (CR) users. Here, we address quite a few

shortcomings still holding in the current stage of networking and emphasis on some design considerations of 5G embracing femtocells and cognitive radio technology. “Femto Cell” is a low power radio access point which operates in both licensed and unlicensed spectrum and it offers network coverage from 10 meters to several hundred meters. Fractional frequency reuse (FFR) has been developed as fruitful inter-cell interference coordination (ICIC) technique in OFDMA based wireless networks [5],[6]. The usage of FFR in cellular networks results in natural compromise between data rate and coverage in cell edge users and overall cell throughput and spectral efficiency. If the deployment of FBSs increases, the tendency of allocating the same frequency spectrum to two adjacent FAPs femtocells increases, and the inter-FAPs’ interference becomes more significant [9].

In this paper, we introduce Azimuth angle of sectorized sites which takes an important role in case of antennas with rather small horizontal beam width to optimize the network coverage. Note that antenna direction can be achieved by the azimuth angle. In practical downlink transmission most of the handsets can only accommodate one or at most two antennas. Here, Single input single output (SISO) system. In single input single output (SISO) system, the transmitter has a single antenna and the receiver also has single antenna. In contrast to Omnidirectional transmissions, beam forming reduces interference, allowing more concurrent transmissions in the network. The intention of considering beamforming is to improve signal to interference plus noise ratio (SINR). Additionally, by focusing the transmission energy in a particular direction, beamforming induces a signal that is in order of the magnitude stronger than that of the signals in undesired direction. This technique is utilized here to enhance the coverage of a specific zone or data rate or channel capacity of the system [8].

In particular, the major contributions of this paper are highlighted below-

- A simplified network model of resource allocation in CR based femtocell network has been introduced.
- The transmitting signal ($T_{x(MBS)}$) from MBS weakened and worsen quicker once the signal reaches indoors. Femtocells furnish way out to the difficulties present in macrocell edge area by means of reducing the number of outage. So that, FBS network coverage is one of the prime concerns in indoor environment to get good quality of service (QoS).
- We consider Azimuth angle as a degree of freedom for optimization of network coverage. Here, difference between antenna gains towards the main lobe and the half angle between adjacent sectors is relatively large and the cells associated to neighboring sites are so adjusted to obtain maximum network coverage.
- We present comprehensive numerical outcome to vindicate the developed simplified network model and to exhibit the effectiveness of our proposed scheme.

The remainder of this paper is organized as follows. In Section 2, we describe system model to define propose network. In Section 3, the assumptions considered for execution of exact scenario in the simulation model. In Section 4, we present

and analyse the numerical results. Ultimately, we finish this work in Section 5 with conclusion.

2. System Model

We consider a scenario where femtocells are deployed over the existing macrocell network and share the same frequency spectrum with macrocell. Here we focus only on downlink scenario. The downlink communications in a network with one macrocell and $N_F=4$ number of femtocells is as shown in Fig.1 in which 4 femtocells are located at $(2, 2)$, $(-2, 2)$, $(-2, -2)$, $(2, -2)$ within the macrocell coverage. In a macrocell, total N_{MUE} user equipments (UEs) are randomly distributed within its coverage area.

Fig.1 Co-existence scenario of FAP and Macrocell in our proposed network.

In theoretical analysis, we assume that the OFDMA based dual tier network consists of N_M number of hexagonal gride macrocell and N_F number of femto cells in each macrocell. Total bandwidth associated with the macrocell edge regions is split up into 3 sub-bands by applying FFR scheme. A sub-band containing N_{sc} number of sub-channels that are available to provide service to the users located at the cell-centre area and the corresponding cell edge area. Besides, we also consider that the channel is slowly time varying and follows the Rayleigh multipath fading distribution. Three kinds of possible links in dual-layer networks are as follows: MBS to outdoor user's link, FBS to indoor user's link, MBS to indoor user's link.

2.1 Propagation Path Loss Model (Empirical Model)-

As per our system model Okumura-Hata propagation path loss model for urban area is chosen to do the evaluation of network performance.

- **Macrocell Path Loss Model-**

Empirical model is nothing but an excessive computational effort. In Okumura-Hata propagation model the important parameter for us is to know how much overall area is covered. Okumura takes urban areas as a reference and applies correction factors [2]:

$$L_{dB} = A + B \log_{10}(d) - E \quad (1)$$

where $A = 69.55 + 26.16 \log_{10} f_c - 13.82 \log_{10} h_b$

$$B = 44.9 - 6.55 \log_{10} h_b$$

$$E = 3.2(\log_{10}(11.7554 h_m))^2 - 4.97 \text{ for large cities, } f_c \geq 300 \text{ Mhz}$$

TABLE-I
Some Values Related to Okumura-Hata model

Parameters	Symbol	Range
Carrier Frequency	f_c	$150 \leq f_c \leq 2000$ (MHz)
BS Antenna Height	h_b	$30 \leq h_b \leq 200$ (m)
MS Antenna Height	h_m	$1 \leq h_m \leq 10$ (m)
Distance Between BS and MS	d	$1 \leq d \leq 20$ (m)

- **Femtocell Path Loss Model-**

Two different path loss exponents and small breakpoint distance of 100 meters are used to characterize the femtocell path loss propagation model [4].

Path Loss:

$$\begin{aligned} L &= 10 * \alpha_{p1} \log_{10} r + L_1 \quad \text{for } r < r_b \\ &= 10 * \alpha_{p2} \log_{10}(r/r_b) + 10 * \alpha_{p1} \log_{10} r_b + L_1 \quad \text{for } r > r_b \end{aligned} \quad (2)$$

where L_1 = Reference Path Loss at $r=1$ m.

r_b = Breakpoint distance

α_{p1} = Pathloss exponent for $r \leq r_b$

α_{p2} = Pathloss exponent for $r > r_b$

To avoid sharp transition between the two path loss exponents, the following is:

$$L = L_1 + 10 * \alpha_{p1} \log_{10} r + 10 * (\alpha_{p2} - \alpha_{p1}) \log_{10}(1 + r/r_b) \quad (3)$$

2.2 Radio Channel Model-

Only MBS can cause interference for femto base station user (FBSU) receiver or FBS transmitter. The position of MBS, macro base station user (MBSU), FBS,

and FBSU are shown in Fig.1. The utilization of spectrum resources can be improved by cognitive radio (CR) technology. CR facilitates SU to access the spectrum bands licensed to PU as long as PUs QoS is not affected. Here, MBSU is treated as PU and FBSU is treated as SU. PU is power controlled by the BS. The link gain between MBS and u-th UE can be expressed as [2]:

$$G_{p2p,u}(r_u, \theta_u) = d_u^{-\alpha_p} 10^{\xi_s/10} |h_{p2p,u}|^2 \quad (4)$$

where $d_u(r_u, \theta_u)$ is denoted as the distance of a MBSU /PU at a location (r_u, θ_u) with respect to the MBS and let $|h_{p2p,u}|^2$ denote the channel gain between the MBS and its associated MUE. We have neglected the co-tier interference as FBSs are deployed in such a manner that it eliminates all the difficulties of overlapping of FBSs. The link gain between j-th FBS and i-th FBSU can be expressed as:

$$G_{s2s,ji} = d_{s2s,ji}^{-\alpha_p} 10^{\xi_s/10} |h_{s2s,ji}|^2 \quad (5)$$

where $d_{s2s,ji}$ is the distance between j-th FBS and i-th FBSU. ξ_s (in dB) is a Gaussian random variable with zero mean and variance, σ^2 , due to shadowing in the channel and let $|h_{s2s,ji}|^2$ denote the channel gain between j-th FBS and its associated i-th FBSU. A FBSU is assumed to be within a circle of radius, r_f around a FBS. If the position of a FBS is (r_j, θ_j) and the position of a FBSU is (r_i, θ_i) . Then,

$$d_{s2s,ji} = \sqrt{(r_j \cos \theta_j - r_i \cos \theta_i)^2 + (r_j \sin \theta_j - r_i \sin \theta_i)^2} \quad (6)$$

If the position of a MBS is (r_k, θ_k) then the distance of it from FBSU may be expressed as-

$$d_{p2s,ki} = \sqrt{(r_k \cos \theta_k - r_i \cos \theta_i)^2 + (r_k \sin \theta_k - r_i \sin \theta_i)^2} \quad (7)$$

The link gain from k-th MBS to i-th FBSU may be expressed as:

$$G_{p2s,ki} = d_{p2s,ki}^{-\alpha_p} 10^{\xi_s/10} |h_{p2s,ki}|^2 \quad (8)$$

where $d_{p2s,ki}$ is the distance between k-th MBS to i-th FBSU. All the channel gains are assumed to be independent and the channels have a coherence time greater

than or equal to a time slot. Here $|h_{p2s,ki}|^2$ denote the channel gain between k-th MBS and its associated i-th FBSU. For analysis, Rayleigh fading is included with pathloss and shadowing. Moreover, Rayleigh fading gives tractable results which assists understanding of the system response to a particular situation.

We use the notation x to denote the serving network entity for a generic user. That is, $x=a$ if the user is associated to a FAP and $x=b$ if the user is associated to a MBS. Without any loss of generic laws, the analysis is conducted on a typical user located at the origin. Therefore, the signal to interference plus noise ratio (SINR),

$\gamma_{n,k,i}^x$ at the typical user located at the origin (which also holds for any generic

user) served by an MBS or FAP (MBS/FAP) is given by [7]

$$\gamma_{n,k,i}^x = \frac{P_{n,k,i}^x G_{n,k,i}^x}{I_{n,k,i}^x + I'_{n,k,i}^x + \sigma_{n,k,i}^2} \quad (9)$$

where $G_{n,k,i}^x$ is the wireless link gain between the user to the serving network entity (i.e. an MBS or a FAP) over the n -th sub-channel. Here $P_{n,k,i}^x$ is designated as the proportion of total transmit power by an associated serving network entity over the particular sub-channel. Likewise, the channel gains from a generic location $x \in \mathbb{D}^2$ to the MBS, b_i and the FAP, a_i are denoted by

$$h_{a_i} \sim \sqrt{X_{a_i}^2 + Y_{a_i}^2} \quad \text{and} \quad h_{b_i} \sim \sqrt{X_{b_i}^2 + Y_{b_i}^2}, \quad \text{respectively, where } X_x, Y_x \text{ are independent gaussian random variables with zero mean and desired variance } \sigma_{n,k,i}^2$$

is the noise power of zero-mean complex valued additive white Gaussian noise (AWGN).

2.3 Outage Probability for Downlink Transmission of macro user-

A FUE experiences two kinds of outages. The first is due to the channel unavailability because of the opportunistic channel access, and the second is SINR outage. According to practical scenario, there is existence of SISO outage users and SIMO outage users. A user is said to be an outage if SINR of the user is less than a SINR threshold.

The outage probability of a SISO / SIMO may be expressed as:

$$P_{out,SISO} = Prob\{\gamma_{n,k,i}^x \leq SINR_{thd(SISO)}\} \quad (10)$$

$$P_{out,SIMO} = Prob\{\gamma_{n,k,i}^x \leq SINR_{thd(SIMO)}\} \quad (11)$$

2.4 Throughput of Macrocell Network-

The reachable throughput, T_p of an user can be calculated from Shannon's theorem. Considering a bandwidth W is assigned to a sub-channel. We have

$$T_p = W \log_2(1 + \gamma_{n,k,i}^x) \quad (12)$$

where γ_x -Signal to Interference plus Noise Ratio

3. Simulation Model

The simulation is developed in MATLAB. In our simulation, parameters mentioned in Table 1 have used. For simplicity of analysis we consider the pathloss only.

3.1 Implantation of Macrocell (Outdoor), and Femtocell (Indoor)

The following steps are followed to implant macrocell and femtocell successfully under indoor and outdoor scenario.

1. Each powerful MBS is located at the center of macrocell which is having the coverage of 3Km radius. The outdoor network incorporates of circular gride of 19 MBS. The transmitting signal ($T_{x(MBS)}$) from MBS attenuated while the signal reaches indoors. The network performance is under serious measure especially due to poor coverage and underutilize spectrum in border area.
2. The small coverage femto base stations (FBSs) are densely deployed in that area where macro base station (MBS) unable to provide QoS and spectrum also not been utilized efficiently. The location of implantation of low power FBS is strictly inside the indoor area. The indoor network incorporates of circular gride of 300 FBS.

3.2 Generation of Users' Location, and Interference

The generation of the users' locations and interference power is carried out considering the following steps.

1. A fixed number of outdoor users' ($N_{MUE,ku}$) and indoor users' ($N_{FUE,ji}$) is generated and they are randomly distributed within their own coverage area. N_{UE} includes all MBSUs /PUs ($N_{MUE,ku}$) and FBSUs/SUs ($N_{FUE,ji}$) which means $N_{UE} = N_{MUE,ku} + N_{FUE,ji}$. Here, $j \in N_F = \{1, 2, \dots, N_F\}$; $k \in N_M = \{1, 2, \dots, N_M\}$; $N_{MUE,ku} = \{1, 2, 3, \dots, u\}N_M$, $u \in$ any large integer value; $N_{FUE,ji} = \{1, 2, 3, \dots, i\}N_F$, $i \in$ any large integer value.
2. The interference on k -th user over the n -th sub-channel are executed as below [3]-

$$I_{k,i}^f = \sum_{l=1}^{N_M} P_{i,l,n}^m G_{i,l,n}^m \quad \forall l \in \{1, 2, 3 \dots N_M\} \quad (13)$$

$$I_{k,i}^f = \sum_{j=1, j \neq i}^{N_M} \beta_j^n P_{i,j,n}^f G_{i,j,n}^f \quad \forall j \in \{1, 2, 3 \dots N_F\} \quad (14)$$

$$I_{k,i}^m = \sum_{l=1, l \neq i}^{N_M} P_{i,l,n}^m G_{i,l,n}^m \quad \forall l \in \{1, 2, 3 \dots N_M\} \quad (15)$$

$$I_{k,i}^m = \sum_{j=1}^{N_M} \beta_j^n P_{i,j,n}^f G_{i,j,n}^f \quad \forall j \in \{1, 2, 3 \dots N_F\} \quad (16)$$

where $P_{i,l,n}^m$ and $P_{i,j,n}^f$ indicate the transmit signal powers over the n -th sub-channel of MBS l and FBS j , respectively; $G_{i,l,n}^m$ and $G_{i,j,n}^f$ indicate the corresponding path gains for MBS l and FBS j , respectively; β_j^n use as a indicator function for femtocell resource allocation. If $\beta_j^n = 1$ indicates n -th channel is assigned to femtocell j ; otherwise $\beta_j^n = 0$

3. The received signal strength (RSS) is evaluated from PU/MBSU or SU/FBSU at the reference MBS or FBS.
4. Next, the SINR for a PU/Macro user and/or a SU/Femto user are computed.

4. Results and discussions

The main parameters of the simulation framework are set as shown in Table 1 and separately simulated response of Rayleigh fading component is tested by comparing it with analytical results from Rayleigh fading equation [14] before including it into the networks

Fig.2 (a) Variation in PDF of Rayleigh fading with channel gain (h_x) (b) DL throughput of a FUE as a function of number of FBS with A^f

Fig.3 (a) DL throughput of a FUE as a function of number of FBS with number of FBSs simultaneously transmitting (b) DL throughput of FUE as a function of number of FBS with FUE

Fig.4 (a) DL throughput of a FUE as a function of number of FBS with BW of n -th sub-channel (b) Network coverage as a function of rotation angle with max. and min. dist. of coverage.

Fig. 2 (b) indicates that as more and more FBSs enter the system, DL throughput increases monotonically. The maximum is 38.2 kb/s in a system with $A^f = 4dB$. Fig. 3(a) & (b) depicts the same information as in Fig. 2 (b). It shows DL throughput as a function of number of FBS, when FBS (T_x) = 40 mW and FUE=10 for max. data rate, respectively. The four curves in Fig. 4(a) are segregated by different BW allotment to the n -th sub-channel. Fig. 2(b), 3(a) & (b), 4(a), tell us that beamforming parameter (antenna gain) is more effective variable next to BW of n -th sub-channel compare to other parameters. Fig. 4(b) shows the relationship of network coverage to rotation of angle for systems with max. dist. and min. dist. of coverage, when node distance=1km and azimuth angle= 30° . A FUE gets

the advantage of optimum network coverage by means of quality of service for the rotation angle more than 60° .

5. Conclusion

In this paper, we develop a novel simulation testbed model to demonstrate various aspects in terms of substantial parameters in connection with network coverage and DL throughput of a FUE for dual-tier cognitive femtocell networks. Beamforming mechanism with azimuth angle integrated at serving network entity (FBS) aims to reduce user effective interference. There is appreciable impact on network coverage in terms of max. and min. dist of coverage for a FUE. DL throughput is focused in this particular research work to improve network performance by improving instantaneous data rate of a FUE that are generally located at cell edges.

6. References

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