

Femtocell-Throughput Analysis in OFDMA-CR Networks

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Abstract

In OFDMA femtocell networks, the licensed spectrum of the macro users (MUs) are available to the femto users (FUs), on the condition that they do not spark off notable interference to the MUs. We contemplate wireless data for femto user (FU) / secondary user (SU) in cognitive radio (CR) networks where the frame structure split up into sensing and data transmission slots. Moreover, we review the frame success rate (FSR) by means of correct reception of frame at the receiver where FSR expressed as a function of signal to interference plus noise ratio (SINR). In this context, we conceptualize the cognitive femtocell in the uplink in which the femtocell access point (FAP) initially perceive by sensing to find out the availability of MU after that FAP revamps its action correspondingly. Appropriately, when the MU is sensed to be non-existent, the FU transmits at maximum power. In other respect, the FAP make the best use of the transmit power of the FU to optimize the cognitive femtocell network throughput concern to outage limitation of the MU. Finally, effectiveness of the scheme is verified by the extensive matlab simulation.

Keywords: *Spectrum Sensing; Frame Success Rate (FSR); Efficiency Function; Bit Error Rate (BER); Femtocell-Throughput*

1. Introduction

Radio frequency spectrums are treated as one of the substantial limited resources in wireless communications which should be used effectively. With such stimulation to decrease power consumption and the reuse of radio resources, there is an inescapable shift towards the deployment of femto cell networks by disintegrating traditional single-cell, single-layer network into multi-layer networks with large secondary network throughput [13]. But, it is crucial to emerge effective interference management scheme in order to make sure the coexistence of the two-tier networks [6, 7]. In [8], a spectrum dividing up technique is introduced to keep away from the inter-tier interference between primary and secondary networks known as fractional frequency reuse (FFR) technique. This is obtained by partitioning the total accessible_band into a number of sub-bands and put a limit on the femtocell network's access.

In a CR networks, the SUs are permitted to use the spectrum of PUs when these frequency bands are not been under utilization. To execute this frequency reuse mechanism, the SUs are required to sense the radio frequency scenario, and once the PUs are found to be active, the SUs are needed to evacuate the channel within a certain period of time. Thus, spectrum sensing is of notable importance in CR networks. The variables connected with spectrum sensing are probability of detection (P_d) and probability of false alarm (P_f) [10]. When high the P_d , the PUs are more protected from harmful interference. Moreover, from the SUs point of view, lower the P_f , more chances that the channel can be

reutilized when it is accessible, thus larger the secondary network throughput. In this paper, we review the issue of sensing period to optimize the femtocell throughput for the secondary network under the limitation that PUs are sufficiently protected. Consequently, a typical frame structure is contemplated for the SU which composed of the sensing and the data transmission periods [11]. The sensing period and the data transmission period are needed to be incorporated in a unit frame such that (i) the quantity of transmitted data packets become greater and (ii) the number of clashes with the PUs become less.

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

- In order to construct the sensing-throughput trade-off issue, the objective turns out to be reducing, P_f , under the limitation of P_d . We therefore construct the sensing-throughput trade-off issue from this viewpoint.
- We evaluate the efficiency function to have FSR more close to the actual. The possibility of bits in a frame being collected successfully without any error can be measured by FSR. The comprehensive numerical outcome of efficiency function and FSR also been vindicated by comparing it with BER.
- The performance metric of interest, we refer as femtocell-throughput, is a complete unit of data that is successfully transmitted in a particular amount of time.

This paper is organized as follows: The system model is defined in Section 2. Section 3 discusses the simulation model. Finally, results and discussions are provided in Section 4 before concluding remarks in Section 5.

2. System Model

In theoretical analysis, we assume that the OFDMA based dual tier network consists of N_M number of hexagonal grille 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 [4] [12]. A sub-band containing N_{sc} number of sub-channels that are available to provide service to the user's 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. Hence, link gain in dual-layer networks can be described as [1]-

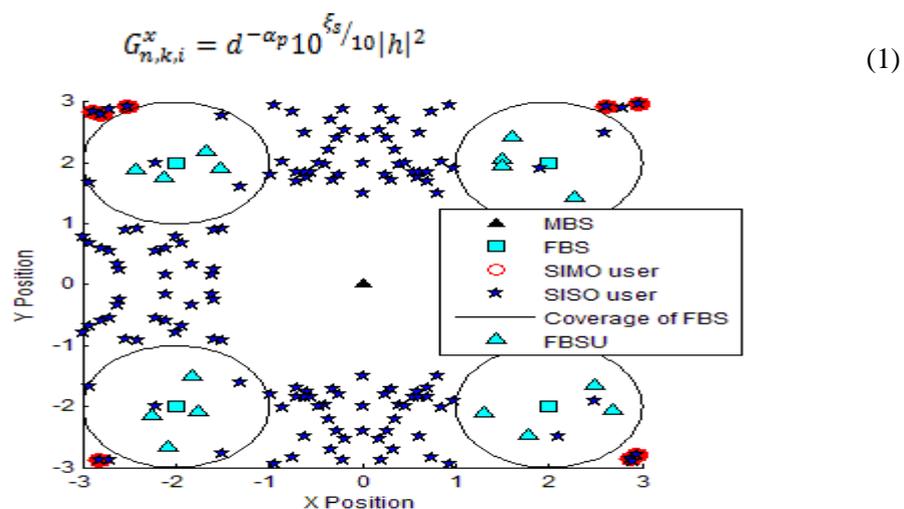


Figure 1. Co-existence Scenario of FAP and Macrocell in our Proposed Network

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 $d_{s2s,ji}$ is the distance between j -th FBS and i -th FBSU. ξ_s (in dB) is a Gaussian random parameter with 0 mean and σ^2 , variance, due to shadowing in the channel. Here $|h|^2$ denote the channel gain between k -th MBS and its associated i -th FBSU. 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, 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 [2]-

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

where $P_{n,k,i}^x$ 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 $h_{b_i} \sim \sqrt{X_{b_i}^2 + Y_{b_i}^2}$ and $h_{a_i} \sim \sqrt{X_{a_i}^2 + Y_{a_i}^2}$, respectively, where X_x, Y_x are indicated as 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).

The energy measuring device is composed of a square law device succeeded with an integrator for finite time. The outcome of the integrator at any instant of t is the energy of the input signal to the square law device on a particular interval $(0, T)$.

The detection is a measure of the following two hypotheses-

- i. \mathcal{H}_0 : The input $c(t)$ is noise alone-
 - a) $c(t) = n(t)$: $n(t)$ denote zero-mean AWGN with unit variance:
 - b) $E[n(t) n(t)] \cong \sigma(0,1)$ denotes sample index
 - c) noise spectral density = N_{02} (two sided)
 - d) noise bandwidth equals to w cycles per seconds
- ii. \mathcal{H}_1 : The input $c(t)$ is signal + noise -
 - a) $c(t) = s(t)h(t) + n(t)$
 - b) $E[s(t)h(t) + n(t)] = s(t)$

The tenancy of n -th sub-band is possible to detect with the help of a simple hypothesis test written as [4]

$$V' = \begin{cases} N_n ; & \mathcal{H}_{0,n} \\ S_n + N_n ; & \mathcal{H}_{1,n} \end{cases} \quad (3)$$

where $n = \{1, 2, \dots, N_{sc}\}$, S_n and N_n indicate the discrete frequency response of $s(t)$ and $n(t)$, respectively.

After proper filtering, sampling, squaring and integration, the test statistic of an energy detector is

$$T_v = \sum_{i=1}^{2r} |V'|^2 \quad (4)$$

where r is the number of complex signal samples. As described in [3] the probability density function (PDF) of T_v follows a central chi-square distribution with $2r$ degrees of freedom (DoF) under $\mathcal{H}_{0,n}$, or a noncentral chi-square distribution with $2r$ DoF and a noncentrality parameter 2γ under $\mathcal{H}_{1,n}$. The test statistic, T_v , is compared with a predefined threshold value λ . Hence, the probabilities of detection, and false alarm can be written as [5, 10]-

$$P_d(\gamma_{n,k,i}^x, \lambda) = Q_v\left(\sqrt{2\gamma_{n,k,i}^x}, \sqrt{\lambda}\right) \quad (5)$$

$$P_f(\lambda) = \frac{\Gamma(r, \frac{\lambda}{2})}{\Gamma(r)} \quad (6)$$

Where $Q_v(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty \exp(-t^2/2) dt$, $\Gamma(a, x) = \int_x^\infty t^{a-1} \exp(-t) dt$, and $\Gamma(a, 0) = \Gamma(a)$. Further, missed detection probability can be calculated as $P_m(\gamma_{n,k,i}^x, \lambda) = 1 - P_d(\gamma_{n,k,i}^x, \lambda)$ [10]. In general, a frame made up of a sensing period and a transmission period. The sensing period is represented by τ , while total time span of a frame is T . In the proposed network model, the sensing time is considered as zero from SUs point of view, as SU not an integral part of spectrum sensing. Additionally, typical value of τ differs from 0 to T as the introduced network senses the spectrum maximum to the frame duration. The achievable instantaneous data rate of k -th femto user can be calculated by considering two cases, when FAP finds that MU is absent which informs to FU by FAP to transmit at its maximum allowable power ($P_{n,k,i}^{max}$), and when FAP finds that the MU is present for that FAP optimizes ($P_{n,k,i}^*$) and then, inform femto user to transmit to the FAP. The data rates of FU under the above condition can be written as-

$$r_{00} = \log_2\left(1 + \frac{P_{n,k,i}^{max} G_{n,k,i}^x}{\sigma_{n,k,i}^2}\right) \quad (7)$$

when FAP accurately senses that the MU not exist.

$$r_{01} = \log_2\left(1 + \frac{P_{n,k,i}^{max} G_{n,k,i}^x}{I_{n,k,i}^{x*} + I_{n,k,i}^{x*} + \sigma_{n,k,i}^2}\right) \quad (8)$$

when the FAP inaccurately senses that the MU not exist

$$r_{11} = \log_2\left(1 + \frac{P_{n,k,i}^* G_{n,k,i}^x}{I_{n,k,i}^{x*} + I_{n,k,i}^{x*} + \sigma_{n,k,i}^2}\right) \quad (9)$$

when the FAP accurately senses that the MU exists

$$r_{10} = \log_2\left(1 + \frac{P_{n,k,i}^* G_{n,k,i}^x}{\sigma_{n,k,i}^2}\right) \quad (10)$$

when the FAP inaccurately finds that MU exists while MU not exist.

Hence, femtocell-throughput can be given by [11]

$$T_f = E \left\{ \left(\frac{T-T_s}{T} \right) \left[\begin{array}{l} r_{00} (1 - P_f(\lambda)) P(\mathcal{H}_{0,n}) + \\ r_{01} (1 - P_d(\lambda)) P(\mathcal{H}_{1,n}) \\ + r_{11} P_d(\lambda) P(\mathcal{H}_{1,n}) + r_{10} P_f(\lambda) P(\mathcal{H}_{0,n}) \end{array} \right] \right\} \quad (11)$$

where $E\{.\}$ is an expectation operator.

$$T_f = \left(\frac{T-T_s}{T} \right) \left[\begin{array}{l} R_{00} (1 - P_f(\lambda)) P(\mathcal{H}_{0,n}) + \\ R_{01} (1 - P_d(\lambda)) P(\mathcal{H}_{1,n}) \\ + R_{11} P_d(\lambda) P(\mathcal{H}_{1,n}) + R_{10} P_f(\lambda) P(\mathcal{H}_{0,n}) \end{array} \right] \quad (12)$$

where $R_{00} = E\{r_{00}\}$, $R_{01} = E\{r_{01}\}$, $R_{11} = E\{r_{11}\}$, $R_{10} = E\{r_{10}\}$. Here, we consider that the each user transmits L information bits in a frame which contains M number of bits at a R bits/second where $M > L$. Therefore, efficiency function can be written by,

$$f(\gamma_{n,k,i}^x) = \frac{T_f}{R} \quad (13)$$

Assuming coherent FSK modulation for data transmission and that SINR is unchanged over a frame (which means channel fading is constant over a frame), the FSR for the i -th user can be expressed as-

$$FSR_k = \left[1 - Q_v \left(\sqrt{\gamma_{n,k,i}^x} \right) \right]^M \quad (14)$$

The channel is time varying random process and SINR itself is a random process, thus frame outage probability (FOP) is an important concern from analytical point of view. The FOP (O_k^F) for the k -th user can be formulated as the possibility that the FSR for the k -th user drops below a lowest FSR acceptance level, FSR_{min} . Note also that $O_k^F=1$ when $P_{n,k,i}^*=0$.

3. Simulation Model

For better approximation of numerical results, Rayleigh fading is included with pathloss and shadowing. The simulation testbed model 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, $j \in N_F = \{1,2,\dots,N_F\}$; $k \in N_M = \{1,2,\dots,N_M\}$; $N_{MUE,ku} \forall \{1,2,3,\dots,u\} N_M$, $u \in$ any large integer value; $N_{FUE,ji} \forall \{1,2,3,\dots,i\} N_F$, $i \in$ any large integer value.
2. The interference on k -th user over the n -th sub-channel are executed as below [9], [14]-

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

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

$$I_{k,i}^m = \sum_{j=1}^{N_M \times N_F} \beta_j^n P_{i,j,n}^f G_{i,j,n}^f \quad \forall j \in \{1,2,3 \dots N_F\} \quad (17)$$

$$I_{k,i}^m = \sum_{l=1, l \neq i}^{N_M} P_{i,l,n}^m G_{i,l,n}^m \quad \forall l \in \{1,2,3 \dots N_M\} \quad (18)$$

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.
5. Assuming perfect error detection and no error correction, the bit error rate (BER) is been computed by $BER_k = 1 - \sqrt[M]{FSK_k}$.
6. Here, we include frame duration (T) as 1000 ms while sampling frequency (f_s) is set to 6 MHz. The probability that MU signal doesn't exist in the band, which is $P(\mathcal{H}_{0,n}) = 0.7$ and the probability that the MU signal present in the band, which is $P(\mathcal{H}_{1,n}) = 0.3$. Femtocell throughput is computed at the end.

4. Results and Discussions

The macro user's (MUs) transmission is assumed to be a QPSK modulated signal with a 6 MHz bandwidth. Now, the channel is assumed to follow the Rayleigh fading where the additive white gaussian noise (AWGN) is a zero mean.

Figure 1 shows the probability of detection vs. SINR for different values of P_f keeping number of sensor per unit location fixed at $\mathbf{k} = 3$. Now, for a given number of sensors per location, increasing the probability of false alarm increases the probability of detection (P_d), providing better performance of spectrum sensing that improves the femtocell throughput.

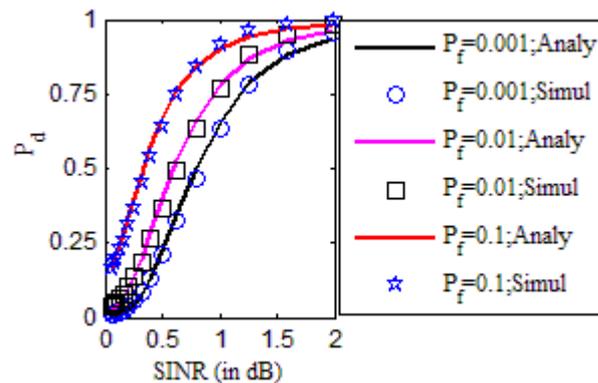


Figure 1. P_d vs. SINR for Different Values of P_f Keeping $\mathbf{k} = 3$ Fixed

In Figure 3, the FSR and efficiency parameter of the femto user (FU) are shown as an exponentially increasing function of SINR whereas BER is shown as an exponentially decreasing function of SINR. Three curves in Figure 3, tell us the variations of different effective parameters in which it has been observed that the unacceptably large BER for the SINR value less than equals to 6.

When the probability of false alarm is fixed at $P_f = 0.01$, the influence of number of sensors per unit location (\mathbf{k}) on the probability of detection is investigated in Figures 2. It

can be seen that, between the SINR and the number of sensors per unit location (k), the SINR is the dominant factor in determining the detection capability, particularly in the high-SINR region. We compare the probability of detection as a function of SINR for single and multiple sensors per unit location cases.

Figure 4 plots the femtocell throughput as a function of sensing time for different transmission probability (p) in imperfect sensing scenarios. However, there is $\left(\frac{T-T_s}{T}\right)$ in the femtocell-

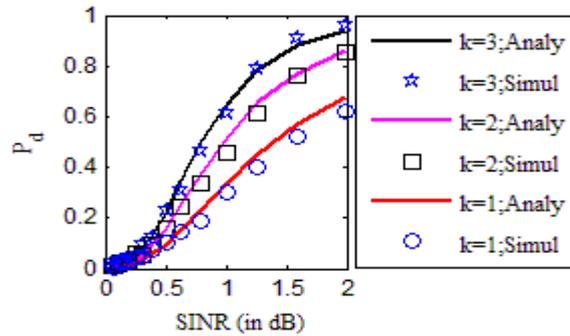


Figure 2. P_d vs. SINR for Different Values of k keeping $P_f = 0.01$ Fixed

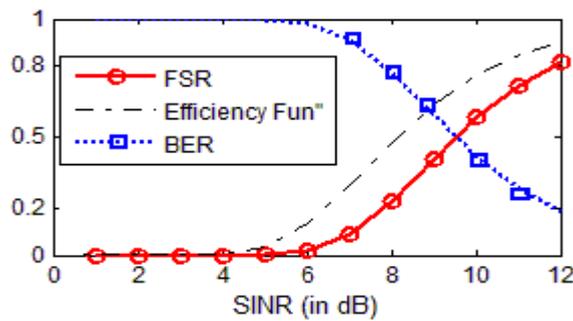


Figure 3. The Frame Success Rate (FSR), Efficiency and BER as a Function of SINR for Non-coherent FSK Modulation Schemes

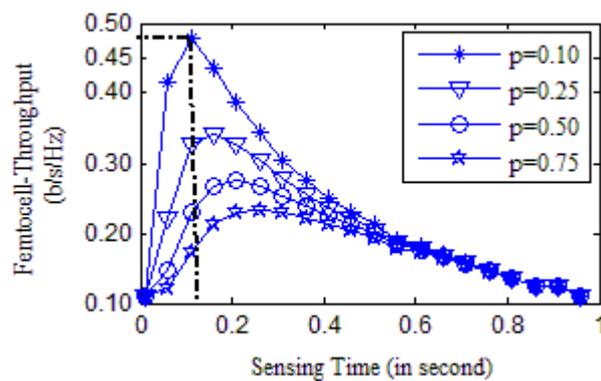


Figure 4. Femtocell-throughput vs. Sensing Time for Different Values of p

throughput expression in equation no. (12). which can rapidly reduce the femtocell throughput when the sensing time is too long. Hence, there is an optimal sensing time in order to achieve the optimal throughput of the femtocell. When the sensing time of primary

user less than 500 ms, then femtocell throughput is greater for lower transmission probability of MUs compare to the higher transmission probability of MUs.

5. Conclusions

In this paper, we develop a novel simulation testbed model to demonstrate various aspects in terms of substantial parameters in connection with imperfect spectrum sensing and femtocell throughput for dual-tier cognitive femtocell networks. The probability that a data packet received without errors is been analysed by a single univariate mathematical function referred to as FSR in which properties of layer1 and layer2 protocols are embodied. Using spectrum sensing, we investigated a lower probability of false alarm which ensures better utilization of licensed spectrum by FU.

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