Opportunistic Open-Access Macro-Femto Networks with Femto Base Station Selection

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***Abstract*—We consider an open-access macrocell-femtocell spectrum-sharing network with multiple femto base stations (FBSs) that are available to opportunistically handle the nearby macro users (MUs) traffic in order to manage the amount of co-channel interference to/from macro and femto systems. In fact, we believe that the co-channel interference can be managed by allowing strong macro interferers to communicate with nearby femtos. In this context, while multiple femtos are available in the area, one important question is: Which femto must be selected to serve the strong MU in order to more efficiently control the co-channel interference? In this regard, we assume that the MU of interest is located near a given number of femtos. Making use of this availability, we investigate a framework for establishing communication between the macro base station (MBS) and the MU of interest via the femto network while considering an appropriate constraint on the interference received at the neighboring MU. Then, we propose utilizing two major selection schemes, namely, *partial* and *reactive* selections, to find the appropriate FBS that can better match the femto capacity limitations. We also investigate the average bit error probability of the proposed system for both mentioned selection strategies. Finally, illustrative numerical results are shown and the benefits of using cooperative transmission with different selection strategies are discussed.**

I. Introduction

The mobile operators find the femtocell technology appealing because it leads to improvements in both coverage and capacity, especially in indoor environments [1]. It can also lead to better quality of service (QoS) and prolonged battery life [2]. Femtocell technology known as the user that acts as an *access point base station*, is a small cellular base station which is installed in a home or small business area and it connects to the service provider's network, e.g., a macrocell base station, via a broadband link such as a digital subscriber line (DSL) [3]. Although there is a huge potential in femtocell technology, there are still some important issues that need to be addressed to let this technology move forward and be fully utilized. One of the most critical problems with femtocell systems is the interference management between femtocell and macrocell nodes and this has a crucial importance for mobile operators acceptance [4].

In general, depending on whether the femtos allow access and hence usage of the backhaul DSL link to all femto users (FUs) or to a restricted set of users only, femtos are classified as open or closed [5]. In this context, in an open-access femto network with co-channel configuration (spectrum-sharing scenario), femtos are configured as open access subscriber groups and are deployed on the same channel as the macro network. Consequently, in such configuration, a nearby macro user (MU) transmitting at maximum power causes a significant interference to the adjacent femtos, also known as "Dead Zone" problem [6]. However, from a network provider's perspective, deploying co-channel femtos is of great interest [2], [7]. Accordingly, to enable efficient support of co-channel deployment of macro-femto networks, a sophisticated interference management scheme should be used to adapt to different numbers of femto nodes at various geographical conditions [8].

On the other hand, though cooperative transmission has shown significant potential in interference mitigation [9], there are a few studies in the context of using cooperative transmission in macro-femto networks. The advantage of using cooperative transmission in open-access macro-femto co-channel networks arises from the fact that serving a loud MU by the adjacent FBSs, reduces the amount of co-channel interference to/from macro and femto systems [6], [10]. In this context, a cooperative game theory method has been proposed in [11] for interference management in femto networks in which the femtos can cooperatively suppress the mutual interference through interference draining, while adhering to a Quality of Service (QoS) constraint. In [12], making use of the benefit of co-channel deployment and forming a coalitional game between macro and femto users, a framework for macro-femto cooperation has been proposed based on which a FU may act as a relay for loud MUs and this allows to mitigate the interference at the FBSs and reduce the transmission delay at the MUs.

In this paper, we consider an open-access cooperative macro-femto network with co-channel deployment (spectrum-sharing) and propose utilizing the available femtos in the area to opportunistically serve the nearby MUs' traffic in order to manage the amount of co-channel interference to/from macro and femto systems. In fact, in the system under consideration, we believe that the co-channel interference can be alleviated by allowing strong MUs to use the neighboring femtos. Our system model is also characterized by appropriate constraints on the average received-interference power at the adjacent MUs operating within the shared-spectrum band. In this context, assuming the availability of multiple femtos in the area, our aim is to find an optimal way to select the FBS that can better handle the nearby MU so as to more effectively control the co-channel interference and also the traffic of the network. To reach our goal, we assume that the MU of interest

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has a poor connection to its associated MBS (loud MU), but eventually, it is placed near a given number of available FBSs operating on the same spectrum as macros. Now, utilizing the availability of FBSs and considering the system constraint, we first investigate a framework for establishing connection between the MBS and the MU of interest through the available femtos. We then propose adopting two selection techniques, i.e., *partial* and *reactive* selections, to find the appropriate FBS that better satisfies the capacity limits of the femto network while adhering to the aforementioned interference constraints at the neighboring MUs. For the system under consideration, we obtain closed-form expressions for the end-to-end average bit error probability (BEP) performance of the proposed macro-femto cooperative system for both mentioned selection schemes. Moreover, through numerical results and comparisons, it is shown that the proposed cooperation scheme in macro-femto networks not only can provide a service to the MU whose direct access is limited or unavailable, but also allows the FUs of the shared-spectrum band to operate at a lower power which can lessen the generated interference in the femtocell network.

II. System and Channel Models

We consider a downlink scenario in an open-access macrocell-femtocell cooperative spectrum-sharing system where the available FBSs in a cluster[1] area are employed opportunistically to handle the nearby MUs traffic in order to manage the amount of co-channel interference to/from macro and femto systems. The considered system model is shown in Fig. 1. The macrocell is underlaid with L co-channel FBSs, named by $F_l \; \forall \; l = 1, 2, ..., L$, as shown in the figure. The femto users (FUs) are located in the transmission area of the FBSs and have access to the network through their corresponding FBSs. There is also a MBS with a number of MUs operating on the same shared-spectrum band as femtos. The MBS is connected to the FBSs via a dedicated wired DSL backhaul link which supports a limited bandwidth[2]. As shown in Fig. 1, we assume that a MU is located within the transmission area of femtos and the direct link between the MU of interest and the MBS is very weak[3]. Hence, the MU communication can be established only through the nearby femtocell networks. In this system, we utilize the available femtos in the area to establish communication between the mentioned MU and the MBS while considering appropriate interference constraints at the neighboring MUs. In this regard, we investigate two selection schemes, namely, *partial* and *reactive* selections, to find the appropriate FBS that can better match to the femto capacity limitations and also satisfy the received interference constraints at the neighboring MUs.

Considering the partial selection (PS) scheme, the best FBS is selected only by comparing the bandwidth availability at the FBSs who decided to participate in the cooperation process. In this case, we assume that the MBS monitors its connectivity with the FBSs and calculates the probability of occupancy associated with each transmission link. Then, the MBS selects the FBS with the maximum of the current probability of unoccupancy, i.e., $P_{\mathrm{UC}_{\max}} = \max_{\forall \; l \in L} \{P_{\mathrm{UC},l}\}$, where $P_{\mathrm{UC},l}$ is the probability of unoccupancy for the link between the MBS and the l-th FBS. Finally, the chosen FBS decodes the received signal and forwards it to the MU node. On the other hand, considering the reactive selection (RS) scheme, the best FBS is selected based on not only the FBSs' bandwidth availability, but also considers the quality of transmission channel between the FBSs and the MU of interest while controlling the amount of generated co-channel interference at the neighboring MUs. Specifically, we assume that at first, all FBSs check their link availabilities with the MBS and only those with probability of unoccupancy values higher than a certain threshold, denoted by $P_{\mathrm{UC}_{\min}}$, will decode the received signal. Then, the single FBS with the maximum received SNR at the MU node is chosen to forward the MBS's signal to the MU.

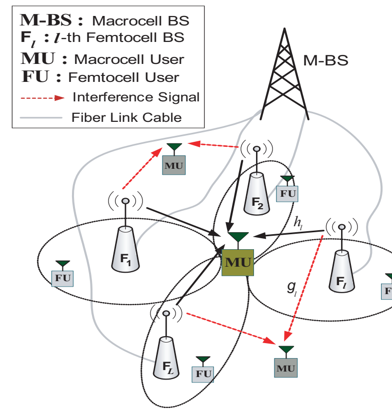

Fig. 1: The proposed macrocell-femtocell cooperative system with partial and reactive selection schemes.

We consider a discrete-time flat-fading channel with perfect channel state information (CSI) at the FBSs and the MU. As shown in Fig. 1, we assume that the channel power gain between the l-th FBS and the MU is given by h_l with mean τ and the one between the l-th FBS and the adjacent MU by g_l with unit mean. We also assume that, to enable efficient support of co-channel deployment of macro and femto networks, a sophisticated interference constraint should be used to control the amount of co-channel interference between femto and macro users. Hence, we consider that the selected FBS listens to the interference channel g_l and adaptively adjusts its transmit power to control the received interference at the adjacent MU. In particular, we consider a constraint on the interference power resulting from the FBS-MU transmission on the adjacent MU that is operating within the same spectrum. We define the average received-interference power constraint for the FBS-MU transmission as:

$$\mathcal{E}_{h_l, g_l} \left[S_l \left(h_l, g_l \right) g_l \right] \leq W, \tag{1}$$

where $S_l \left(h_l, g_l \right)$ represents the instantaneous transmit power at the l-th FBS. Furthermore, W is the maximum average received-interference power that can be tolerated by an MU

[1]Note that the available FBSs in a cluster area are selected by a long-term routing process, which guarantees the same average received SNR at the MU of interest (optimal clustering) [13].

[2]Note that this connection can be provided through the service gateway unit (SGU) which mandates the use of femto and macro network infrastructures to appropriately route and serve the traffic to and from these networks [14]. Herein, only for the sake of simplicity and tractability of the derivations, we assume that each FBS is connected directly to the MBS through a dedicated DSL link which supports a limited bandwidth.

[3]Note that this is feasible specially when the MU is located indoors.

during the second-hop transmission. We consider that the interference received at the MU of interest from the unselected neighboring FBSs and the MBS, can be modeled as an additive zero-mean Gaussian noise[4] with variance σ^2.

In the following, our aim is to obtain the statistical characteristics of the first- and second-hop transmissions while considering the above-mentioned interference constraint.

III. Statistical Analysis

As mentioned earlier, both selection strategies involve first choosing the appropriate FBSs based on the link probability of unoccupancy values $P_{\mathrm{UC}_{\min}}$ and $P_{\mathrm{UC}_{\max}}$. Let $P_{\mathrm{OC},l}$ be the probability of occupancy for the l-th FBS. Assuming that time division (TD) multiple access is utilized at the FBSs, occupancy is the portion of time used by the l-th FBS to serve the FUs in a specific period of time [6]. Accordingly, the probability of unoccupancy for the l-th FBS can be defined as $P_{\mathrm{UC},l} \triangleq 1 - P_{\mathrm{OC},l}$. Now, to deploy the RS scheme explained in Sec. II, our aim is to calculate the probability that K FBSs ($K \leq L$) have the probability of unoccupancy values higher than $P_{\mathrm{UC}_{\min}}$. In order to calculate the mentioned probability, we use the Binomial theorem and consequently, we need to first define the probability of success for this trial [15]. In this context, the probability of success can be considered as the probability that each FBS pass the threshold condition, i.e., $\Pr(P_{\mathrm{UC},l} \geq P_{\mathrm{UC}_{\min}})$. Herein, for the sake of tractability in our formulations, we assume that the variations of the probability of unoccupancy for available FBSs follow the standard Uniform probability distribution, i.e., $\Pr(P_{\mathrm{UC},l} < x) = x,\ \forall\ 0 \leq x \leq 1$, where $P_{\mathrm{UC},l}$ is the probability of unoccupancy for the l-th FBS with $l = 1, ..., L$[5]. Consequently, the probability of success for the above event can be calculated as $\Pr(P_{\mathrm{UC},l} \geq P_{\mathrm{UC}_{\min}}) = 1 - P_{\mathrm{UC}_{\min}}$. This means as the minimum threshold on the probability of unoccupancy decreases, the probability of success, $\Pr(P_{\mathrm{UC},l} \geq P_{\mathrm{UC}_{\min}})$, increases. Now, making use of the Binomial theorem [15], the probability that a number K of FBSs pass the minimum threshold condition $P_{\mathrm{UC},l} \geq P_{\mathrm{UC}_{\min}}$ can be calculated according to

$$P_{\mathrm{UC}_{\min},K} = \binom{L}{K} \left(1 - P_{\mathrm{UC}_{\min}}\right)^K \left(P_{\mathrm{UC}_{\min}}\right)^{L-K}. \quad (2)$$

Let us assume that K FBS candidates are selected during the first-hop transmission. For the second-hop transmission, considering the average interference power constraint in (1) and making use of the Lagrangian optimization technique, the optimal power transmission policy that maximizes the ergodic capacity of the link between the k-th FBS and the MU of interest can be obtained as [9]

$$S_k\left(h_k, g_k\right) = \left(\frac{\lambda}{g_k} - \frac{\sigma^2}{h_k}\right),\ \ \forall\ \frac{\sigma^2}{\lambda} \leq \frac{h_k}{g_k}, \quad (3)$$

[4]Validity of this assumption is sustained by the fact of employing the interference mitigation techniques, e.g., "interference cancelation" and "interference suppression", in macro-femto spectrum sharing systems as explained in [2]. Moreover, as for the interference generated by the MBS, we assume that the direct link between the MBS and the MU of interest is very weak, e.g., the MU is located indoors and there is an indoor penetration loss.

[5]Note that the L available FBSs may still have different probability of unoccupancy values.

where λ is the Lagrangian optimization parameter that must be calculated such that the interference constraint in (1) is satisfied with equality. Then, using the power allocation policy in (3), we can express the instantaneous received SNR at the MU as

$$\gamma_k = \frac{S_k\left(h_k, g_k\right) h_k}{\sigma^2} = \left(\frac{\lambda}{\sigma^2} Z - 1\right)^+, \quad (4)$$

where $(X)^+ \triangleq \max(X, 0)$ and the random variable Z is defined as $Z \triangleq h_k/g_k$. Considering that fading follows the Rayleigh distribution, i.e., h_k and g_k are exponentially distributed random variables, it can be shown that the probability distribution function (PDF) of Z is given by $f_Z\left(z\right) = \tau / \left(\tau + z\right)^2$ [15]. Now, using the fundamental theorem [15, P. 130], the PDF statistic of γ_k can be obtained according to

$$f_{\gamma_k}\left(\gamma\right) = \frac{\sigma^2}{\lambda} f_Z\left(z\right)\Bigg|_{z = \frac{\sigma^2}{\lambda}(\gamma+1)}, \quad (5)$$

which after some mathematical manipulations, we have

$$f_{\gamma_k}\left(\gamma\right) = \frac{\sigma^2 \lambda \tau}{\left(\lambda\tau + \sigma^2\gamma\right)^2}. \quad (6)$$

To obtain the CDF of γ_k, using $F_\gamma\left(\gamma\right) = \int_0^\gamma f_\gamma\left(\gamma\right) d\gamma$, we have

$$F_{\gamma_k}\left(\gamma\right) = \frac{\sigma^2\gamma}{\lambda\tau + \sigma^2\gamma}. \quad (7)$$

In the following, making use of the CDF expressions, we investigate the performance analysis of the macro-femto cooperative system in both cases of partial and reactive selections.

IV. Average Bit Error Probability Analysis

A. Partial Selection Scheme

Based on the PS scheme, the FBS that provides the maximum of the current probability of unoccupancy, $P_{\mathrm{UC}_{\max}}$, during the first-hop transmission is selected to participate in the communication between the MBS and MU. Then, the chosen FBS shares the received signal with the MU node. It is worth noting that in this selection technique, the FBS is selected only based on the unoccupancy rate of the first-hop transmission.

Now, considering the Binomial theorem, the probability of choosing a FBS that provides $P_{\mathrm{UC}_{\max}}$ can be obtained as $L\left(1 - P_{\mathrm{UC}_{\max}}\right)\left(P_{\mathrm{UC}_{\max}}\right)^{L-1}$. Accordingly, the average BEP of the cooperative system under consideration for the phase-shift keying modulation is given by [9]

$$P_E = \frac{L\left(1 - P_{\mathrm{UC}_{\max}}\right)\left(P_{\mathrm{UC}_{\max}}\right)^{L-1}}{\sqrt{2\pi}} \int_0^\infty e^{-\frac{\xi^2}{2}} F_{\gamma_1}\left(\frac{\xi^2}{2}\right) d\xi. \quad (8)$$

where $F_{\gamma_1}\left(\gamma\right)$ is the CDF of the second-hop transmission given in (7). Then, making the change of variable $x = \xi^2/2$ and after substituting (7) in (8), the expression for P_E can be simplified to

$$P_E = \frac{L\sigma^2\left(1 - P_{\mathrm{UC}_{\max}}\right)\left(P_{\mathrm{UC}_{\max}}\right)^{L-1}}{2\sqrt{\pi}} \int_0^\infty \frac{e^{-x}\sqrt{x}}{\lambda\tau + \sigma^2 x} dx. \quad (9)$$

The integral in (9) can be solved in terms of the complementary error function as follows [16]

$$P_E = \frac{L\left(1-P_{\mathrm{UC}_{\max}}\right)\left(P_{\mathrm{UC}_{\max}}\right)^{L-1}}{2\sqrt{\pi}} \times\left(\sqrt{\pi}-\pi\sqrt{\frac{\lambda\tau}{\sigma^2}}e^{\frac{\lambda\tau}{\sigma^2}}\mathrm{erfc}\left(\sqrt{\frac{\lambda\tau}{\sigma^2}}\right)\right), \quad (10)$$

where $\mathrm{erfc}(.)$ denotes the complementary error function defined as $\mathrm{erfc}(x) \triangleq 2/\sqrt{\pi}\int_x^\infty e^{-z^2}dz$ [17]. Finally, considering the alternative expression for the complementary error function in terms of the incomplete Gamma function [17], namely, using $\mathrm{erfc}\,(z) = \Gamma\left(0.5, z^2\right)/\sqrt{\pi}$, the average BEP of the macro-femto cooperative system using the PS technique can be obtained as

$$P_E = \frac{L}{2}\left(1-P_{\mathrm{UC}_{\max}}\right)\left(P_{\mathrm{UC}_{\max}}\right)^{L-1} \times\left(1-\sqrt{\frac{\lambda\tau}{\sigma^2}}\;e^{\frac{\lambda\tau}{\sigma^2}}\;\Gamma\left(0.5,\frac{\lambda\tau}{\sigma^2}\right)\right). \quad (11)$$

B. Reactive Selection Scheme

In this scheme, the selection is performed during the second-hop transmission. This means that between those FBS candidates that satisfy the minimum probability of unoccupancy constraint in the first-hop transmission, only the best FBS node with the maximum received SNR at the MU node, denoted by γ_{FD}, is selected among the FBS candidates to transmit the MBS signal to the MU node. Now assume that k^* is the best FBS selected among the K FBS candidates. Since $\gamma_{k^*} = \max\limits_{k=1,\cdots,K}\{\gamma_k\}$ and making use of the order statistics theorem [15], the CDF of γ_{k^*} pertaining to the second-hop transmission can be obtained as

$$F_{\gamma_{k^*}}(\gamma) = \left(\frac{\sigma^2\gamma}{\lambda\tau+\sigma^2\gamma}\right)^K. \quad (12)$$

Accordingly, we can obtain the PDF of γ_{k^*} by performing the derivative of the CDF expression in (12) as $f_{\gamma_{k^*}}(\gamma) = \partial F_{\gamma_{k^*}}(\gamma)/\partial\gamma$, which can be expressed as

$$f_{\gamma_{k^*}}(\gamma) = \frac{K\lambda\tau\left(\sigma^2\right)^K\gamma^{K-1}}{\left(\lambda\tau+\sigma^2\gamma\right)^{K+1}}. \quad (13)$$

Considering the RS strategy, the end-to-end instantaneous SNR at the MU node is defined as the minimum of the channel powers among the first and second transmission links. Since we assume that the first-hop communication is via a reliable cable with a good link quality, the average BEP of the system under study can be represented as [15]

$$P_E = \frac{1}{\sqrt{2\pi}}\sum_{K=1}^{L}P_{\mathrm{UC}_{\min},K}\int_0^\infty F_{\gamma_{k^*}}\left(\frac{\xi^2}{2}\right)e^{-\frac{\xi^2}{2}}d\xi, \quad (14)$$

where $P_{\mathrm{UC}_{\min},K}$ is the probability that K FBSs pass the selection criterion as calculated by the expression in (2). Then, substituting (2) and (12) into (14) and after some mathematical manipulations (change of variable $x = \xi^2/2$), P_E can be expressed as

$$P_E = \frac{\left(P_{\mathrm{UC}_{\min}}\right)^L}{2\sqrt{\pi}}\int_0^\infty\frac{e^{-x}}{\sqrt{x}} \times\sum_{K=1}^{L}\binom{L}{K}\left(\frac{\sigma^2\left(1-P_{\mathrm{UC}_{\min}}\right)x}{P_{\mathrm{UC}_{\min}}\left(\lambda\tau+\sigma^2x\right)}\right)^K dx. \quad (15)$$

It can be shown that the summation in (15) can be solved by considering the sum of Binomial coefficients rule [16, Eq. 0.155.3], namely, using $\sum_{K=1}^{L}\binom{L}{K}A^K = (A+1)^L-1$, which yields

$$P_E = \frac{\left(P_{\mathrm{UC}_{\min}}\right)^L}{2\sqrt{\pi}}\left(I_1-I_2\right), \quad (16)$$

where

$$I_1 \triangleq \int_0^\infty\frac{e^{-x}}{\sqrt{x}}\left(\frac{\lambda\tau P_{\mathrm{UC}_{\min}}+\sigma^2x}{P_{\mathrm{UC}_{\min}}\left(\lambda\tau+\sigma^2x\right)}\right)^L dx, \quad (17)$$

and

$$I_2 \triangleq \int_0^\infty\frac{e^{-x}}{\sqrt{x}}dx. \quad (18)$$

Using the expression in [16, Eq. 3.321.3], we can solve the integral in (18) according to $I_2 = \sqrt{\pi}$. To solve the integral in (17), after some algebraic manipulations, we can rewrite I_1 as

$$I_1 = \int_0^\infty\frac{e^{-x}}{x^{\frac{1}{2}}}\left(1+\frac{\sigma^2x}{P_{\mathrm{UC}_{\min}}\lambda\tau}\right)^L\left(1+\frac{\sigma^2x}{\lambda\tau}\right)^{-L}dx, \quad (19)$$

which after a careful observation, (19) can be expressed in terms of the second-kind confluent hypergeometric function given by [18]

$$\Phi_2\left(a,b_1,...,b_L;z;x_1,...,x_L,y\right) = \frac{1}{\Gamma(a)} \int_0^\infty \mathrm{e}^{-yt}t^{a-1}\left(1+t\right)^{z-a-1}\prod_{i=1}^{L}\left(1+x_it\right)^{-b_i}dt. \quad (20)$$

Therefore, a closed-form expression for I_1 is obtained as

$$I_1 = \sqrt{\pi}\Phi_2\left(0.5,-L,L;1.5;\frac{\sigma^2}{P_{\mathrm{UC}_{\min}}\lambda\tau},\frac{\sigma^2}{\lambda\tau},1\right), \quad (21)$$

where the hypergeometric function can be implemented in most popular numerical softwares, such as Mathematica.

Finally, substituting I_1 and I_2 into (16), we have a closed-form expression for the average BEP performance of the MU.

V. Illustrative Numerical Results

In this section, considering the partial and reactive FBS selection schemes, we provide numerical results and comparisons for the performance analysis of the macro-femto cooperative system for different values of the interference power and probability of unoccupancy constraint limits.

Figs. 2 and 3 depict the average BEP versus the average interference limit W and the number of FBSs used for selection L, respectively. In Fig. 2, we set $L = 5$ and plot the end-to-end average BEP as a function of the interference constraint

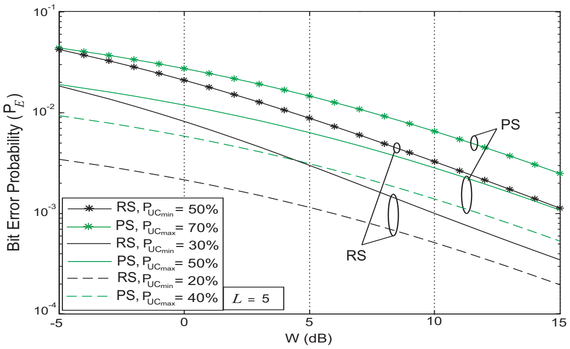

Fig. 2: Average BEP performance of the macro-femto cooperative system versus the interference limit (W) for different values of $P_{\mathrm{UC}_{\min}}$ and $P_{\mathrm{UC}_{\max}}$ with $L = 5$ ($\tau = 0$ dB and $\sigma^2 = 0$ dB).

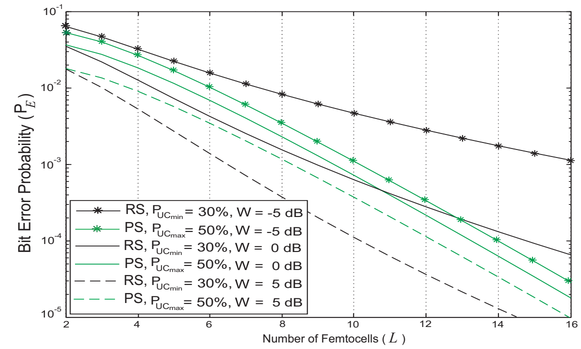

Fig. 3: Average BEP performance of the macro-femto cooperative system versus the number of femtocells (L) for different values of W ($P_{\mathrm{UC}_{\max}} = 50\%$, $P_{\mathrm{UC}_{\min}} = 30\%$, $\tau = 0$ dB and $\sigma^2 = 0$ dB).

limit on the second-hop transmission and for different unoccupancy probability values on the first-hop communication. For both selection schemes, this figure shows that the system performance improves when the interference constraint limit W increases or when the unoccupancy probability thresholds, $P_{\mathrm{UC}_{\min}}$ or $P_{\mathrm{UC}_{\max}}$, relax (decrease). Furthermore, we observe that the RS scheme shows considerably better performance than PS especially when the unoccupancy thresholds on the first link are more restricted, i.e., with lower values of $P_{\mathrm{UC}_{\min}}$ and $P_{\mathrm{UC}_{\max}}$. Indeed, in the selection process when there are limited resources, the RS scheme is taking advantage of considering not only the probability of unoccupancy on the first link, but also, the second-hop transmission condition. As observed from the numerical results in this section, this advantage improves the system performance with the RS scheme versus PS. On the other hand, Fig. 3 illustrates the average BEP performance for different numbers of FBSs while we set $P_{\mathrm{UC}_{\max}} = 50\%$, $P_{\mathrm{UC}_{\min}} = 30\%$ and $\tau = 0$ dB. Analysis of the number of FBSs for both selection schemes shows substantial improvements in performance as L increases, particularly when the transmission of the second link is less restricted, i.e., higher W. In fact, it is observed that for lower values of W, the PS scheme shows a better performance than the RS scheme, as the number of available FBSs, L, increases.

VI. Concluding Remarks

We considered an open-access cooperative macro-femto network with co-channel deployment where L FBSs are available to opportunistically assist the communication between the MBS and MU nodes while ensuring that no harmful interference is caused to the other adjacent MUs. In this context, making use of the availability of the femtocell network, we first investigated a framework for establishing communication between the MBS and the MU of interest. Then, we studied the performance of the proposed system under two major selection schemes, i.e., *partial* and *reactive* selections, in order to find the most appropriate FBS that better matches to the femto capacity limitations and also satisfies the preset interference constraint. To evaluate the performance of the system under consideration, we utilized the statistics of the received SNR at the MU node and investigated the average BEP of the proposed cooperative system for both selection strategies. Numerical results and comparisons have shown that the proposed cooperation schemes in macro-femto networks not only mitigates the amount of co-channel interference in the macro-femto network, but also allows the MBS to provide service to the MUs when the direct access would be limited or unavailable, e.g., indoors.

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