Performance Analysis of Novel Interference Mitigation Schemes in Heterogeneous Networks over Rayleigh and Rician Fading Channels

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Abstract — **Recently, Femtocell has been deployed as a part of Long Term Evolution (LTE) for indoor coverage extension. Heterogeneous networks in which femto and pico-cells are overlaid onto macro-cells are extensively discussed. In order to maintain reliable service of macro-cells, it is important to mitigate destructive femto-femto (co-channel) and femto-macro (adjacent or cross channel) cell interferences respectively. This paper presents the performance analysis of two novel schemes in order to mitigate interference issues in femto-cells. The significant advantage of the proposed femto cooperative (Fe-COPE) scheme is to mitigate co-channel interference that needs no back-haul connection. However, the another proposed Femto Adjacent (FE-ADJ) scheme helps to mitigate adjacent-channel interference and works with coordination of femto and macro base stations by using wired back-haul. The performance is analyzed over independent and identical ($i.i.d$) Rayleigh and Rician-K fading environments. The closed form expressions for the moment generating function (MGF) of the received signal-to-noise-ratio (SNR) are derived in order to evaluate the average symbol error rate (SER) analysis and then compute the bit error rate (BER) expressions under the *M*-QAM modulation scheme. Our simulation demonstrates considerable improvement in the curves of BER as a function of SNR. Monte-Carlo simulations are conducted to verify the correctness of the analytical expressions that are derived for the two proposed schemes.**

Keywords– **Femto Cooperative (Fe-COPE), Femto Adjacent (Fe-ADJ), Bit Error Rate (BER), Probability Distribution Function (pdf), Interference, and Moment Generating Function (MGF).**

I. INTRODUCTION

Femtocell systems consist of conventional macro cells deployment and overlaying femtocells, that form a hierarchical cell infrastructure [1]. This design constitutes an attractive solution to improve the macrocell capacity, as well as coverage for both macro and femto users respectively. However, the co-channel and adjacent channel interferences in such systems significantly reduce the performance, capacity and cause an unacceptably high level of outage. Such standardization are defined in [2] for various applications that provides an basic introduction about femto-cell system, basic architecture, and it's various components. This technique exploits for the wireless or radio access characteristics. Moreover, it provides a better solution to many of the next generation challenges with low-power transmission. Thus, becomes a very hot issue currently for many of the researchers. Since the distance between transmitter and receiver is so minimized that interference is a big issue to be addressed. To mitigate such interferences in femto-cell is of utmost interest and a big challenge for many of the researchers. Femto-cell locations are configured like an ad hoc topology, so the techniques to suppress such interferences alone cannot provide a better solution for femto-cell networks. The successive interference cancellation technique helps the system to subtract the strongest user's signal on the basis of its signal strength preferred on all other neighboring interferer signals. The technique seems to be very promising and efficient but in reality it affects the quality and degrades the over-all performance [3].

In [4], researchers have analyzed a system in which in a two-tier networks, a network is overlaid comprises with a conventional wireless network works as a hot spot, distributed antennas technique, femto-cell or can be a wired systems. This is a basic challenge for each era to have better and better indoor coverage. That makes a continuous pursuit to increase and have better indoor coverage by various mobile operators (Mo's).

In the past few years, many researchers discussed user cooperation diversity in single input and single output (SISO) or multiple input multiple output (MIMO) scenarios with different fading distributions in order to analyze the performance of the proposed techniques in terms of bit error rate (BER) or symbol error rate (SER), outage capacity analysis, and different power allocation techniques [5]-[9]. In literature, many researchers considered two users cooperative system in which mobile users are acting as a relay exploiting a user cooperation approach and different algorithmic approach are utilized in order to analyze the efficiency of the system in terms of outage,

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system throughput and power control adaptation techniques [10]-[12]. Despite the fact that femto networks exploit the promising solution for the next generation technology and the higher releases Rel. 8-10+ in Heterogeneous Networks (HetNets), interference is the major issue that needs to be addressed before the deployment of HetNets commercially. Due to minimum distance between transmitter and receiver, and low cost of infrastructure, the system becomes highly dense and saturated. Many researchers are putting their efforts to come-up with some solution to mitigate the interference issue in femto networks. Some of the related work can be presented as the source of inspiration:

Interference issues are addressed by many researchers and many mitigation techniques are intensively studied in the literature to combat interference and come up with the better system in terms of efficiency and coverage for indoor as well as out door users. Gollakota *et al* [13] proposes a new mitigation technique as Interference alignment and cancellation technique (IAC) that helps to mitigate interference for MIMO users. Interference alignment technique allows each user to achieve at least half its interference-free ergodic capacity at any SNR [14]. Interference in femto-cell with co-channel and adjacent-channel interferences for up-link are addressed and performance is analyzed in different terms of parameters such as BER, ergodic capacity, outage, and throughput of the system using Cumulative Distribution Function (CDF)-base approach in LTE femto cells. Various techniques are presented to smartly utilize the resources from macro to femto cell. Handover issues are also addressed with addition to mitigate macro-femto interference as cross-channel interference [15]-[17].

The idea of cooperative network coding (CNC) to exploit spatial diversity is proposed in [18], based on COPE, which is a technique introduced by Katti *et al* [19] for wireless mesh networks. Different scenarios and examples have been considered to elucidate the advantages of the COPE system in terms of increased throughput and performance analysis over fading channels for relay networks (two-way, dual-hop, multi-hop, and multi-cast). Femto-cell scenarios and the measurement of performance by BER analysis using a moment generation function (MGF)-based approach has not been considered [20].

Arunachalam *et al* [21] focused on analyzing the performance of the spatial channel separation method to mitigate the interference that is experienced by macro user equipment (MUE), trapped inside a closed access femto cell for a LTE system. They provided no mathematical derivation and analytical expressions of BER. They considered the path-loss model effect and conducted a simulation to verify their proposed scheme in terms of BER. The authors presented advanced interference mitigation schemes for user equipment (UE), including received-power dependent interference cancellation (IC), decision-directed channel estimation, and IC-assisted channel estimation [22]. They provided no mathematical expression for BER but performed a simulation to determine the BER of the proposed scheme. They have investigated the minimum power allocation in down-link communication for the open subscriber group (OSG) femto cell networks over Rayleigh fading environment. The power at the down-link is constrained by ergodic capacity and average bit error rate (BER) in different digital modulation schemes, such as BPSK, QPSK, and DPSK. Finally, the numerical results provide guidelines for designing future femto cell networks [23].

To the best of our knowledge, no one has yet investigated the COPE system with femto cells. We can divide the prior related research into two main categories. First category deals with the introduction of COPE. We have proposed a novel femto cooperative (Fe-COPE) technique for mitigating the co-channel interference without using back-haul connection in femto cell communications. The method is better than the conventional COPE system. Second category presents the mitigation of cross-channel interference in macro-femto cells exploiting back-haul (wired connection) between macro and femo base stations respectively. The performance of the two proposed Fe-COPE and Fe-ADJ schemes are analyzed in terms of BER versus SNR at the femto base station over Rayleigh and Rician fading channels. The MGF-based approach is investigated to derive the closed form expressions for the proposed schemes over various mentioned distributions using the M-QAM (quadrature amplitude modulation, M=16) digital modulation technique. The simulation results support the derived expressions for different fading distributions that are obtained using 16-QAM modulation technique. The remainder of the paper is organized as follows. Section 2 presents the model of the system and a comparison of the conventional COPE with the proposed Fe-COPE scheme. Section 3 discusses in detail the implementation of the Fe-COPE protocol in the Femto scenario in detail. Section 4 derives mathematical expressions in terms of MGF using the SNR equation. Demonstration of the Fe-ADJ protocol and the theoretical input-output relationship are evaluated in terms of MGF over Rayleigh and Rician-K Fading distributions, are discussed in section 5 and 6 respectively. Section 7 discusses the performance analysis of the two schemes in terms of famous performance parameter, such as BER. An expression for the average bit error rate (BER) is derived for both of the schemes under Rayleigh and Rician fading distributions using the 16-QAM modulation technique. The obtained simulation results are presented in Section 8 and are intensively discussed in detail for both of the schemes. Section 9 draws conclusions and suggest future directions for the extension of the proposed schemes.

II. System Model

This section defines the conventional COPE system and then discusses in detail the proposed Fe-COPE and Fe-ADJ systems to understand the concept in femto cell. The both schemes exploit diversity gain and mitigates the major interferences in femto cells, which are co-channel and adjacent-channel

A. Conventional COPE and Proposed COPE

In the COPE system, the basic scenario involves two sender nodes and two receiving nodes. In the three time slot protocol, with the aid of relay, both users transmit their information and, at the respective base stations (BS), the desired signal information is detected by a basic XOR operation or simply by subtraction. Fig. 1 clearly presents the concept of the conventional COPE system.

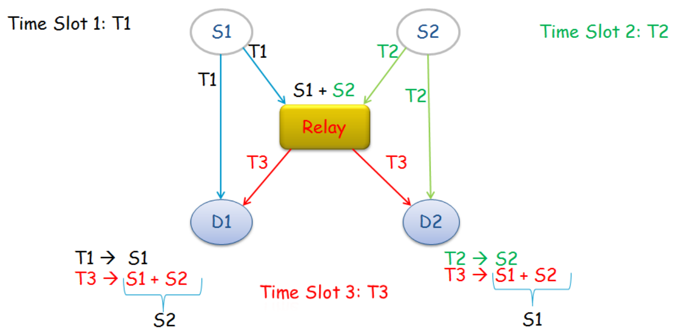

Figure. 1. Block diagram of conventional COPE system using Relay Node

In Fig. 1, destination one (D1) is to receive information from user two (S2) and the destination two (D2) is to receive information from user one (S1). Utilizing the three time slot protocol, S1 firstly transmits the signal to the relay node (R) and D1. Next, in the second time slot, S2 transmits its information to the relay node (R) and destination D2. The relay then combines both signals and forwards the combined signal by either the amplify-and-forward (AF) scheme or the decode-and-forward (DF) scheme, or it simply transmits the sum of the information from S1 and S2 in the third time slot. After the transmission has been successfully completed, the desired signal can be retrieved at the destinations.

Fig. 2 clearly depicts the idea that underlies the proposed scheme. The proposed COPE uses no Relay node (R). Rather, users work as a relay and assist each other to convey messages to the base station (destination). User cooperation technique exploits the diversity gain by an iterative method that is clearly explained in the following section.

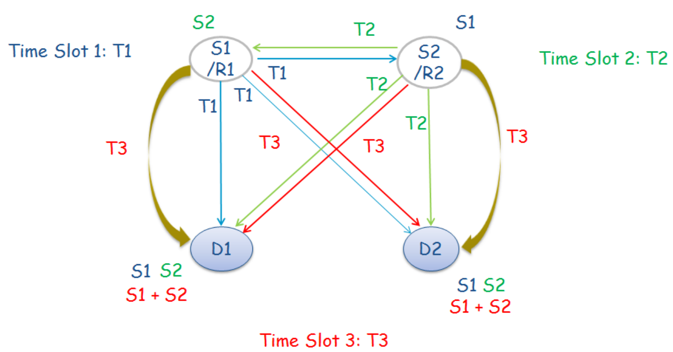

Figure. 2. Block diagram of the proposed COPE system with users as Relay Node

In the proposed COPE, user one (S1) broadcasts its information to user two (S2), destination one (D1), and destination two (D2). Similarly, in the next time slot, user two (S2) sends its information to user one (S1), destination one (D1), and destination two (D2). In the third time slot, both users S1 and S2, which have each other's signal information, forward this data to the destinations D1 and D2. Fig. 2 displays the overall process and acquires the diversity gain at the destinations after the desired signal has been retrieved.

Comparison of both techniques can be clearly made using tables that describe the main functionalities of the source nodes and relay nodes. Table 1 demonstrates that user 1 transmits in the first time slot whereas user 2 does so in the second time slot, and the relay combines the signal received in the third time slot by using the conventional COPE scheme.

TABLE I CONVENTIONAL COPE PROTOCOL

Nodes	S1	S2	R(S1+S2)
Slot1	×		
Slot2		×	
Slot3			×

In contrast to conventional scheme, in Table 2, the users work as a relay. Therefore, in the first time slot, user 1 broadcasts its signal. Next, in the second time slot, user 2 broadcasts its signal. Finally, in the third time slot, both users work as a relay and forward the information that they received in the first and second time slots, respectively.

TABLE II PROPOSED NEW COPE PROTOCOL

Nodes	S1	S2	S1/R1	S2/R2
Slot1	×			
Slot2		×		
Slot3			$\times(S2)$	$\times(S1)$

III. IMPLEMENTATION OF PROPOSED COPE WITH FEMTO CELLS: FE-COPE SCHEME

This section concerns the Fe-COPE system with basic femto scenario when several femto cells are deployed in macro cells. The two main forms of interference are the major obstacles to be addressed and overcome. The Fe-COPE scheme helps to mitigate the co-channel interference among multiple femto users and exploits the diversity gain. Consider a practical example: a building contains many offices, and two femto cells are deployed in two rooms. Next, the worst-case scenario for the proposed Fe-COPE system is investigated, in which the two users that are associated with their respective cells are located at the edge of the common boundaries of the both cells, such that both users, FU1 and FU2, interfere with both of the base stations F-BS1 and F-BS2, respectively. The femto cell scenario in which both users are located at the edges of cells, causing interference can be clearly understood with the aid of a block diagram which is presented in Fig. 3.

As clearly displayed in the Fig. 3, both femto users, FU-1 and FU-2, try to communicate with their respective base stations but interference with each other by mixing the desired

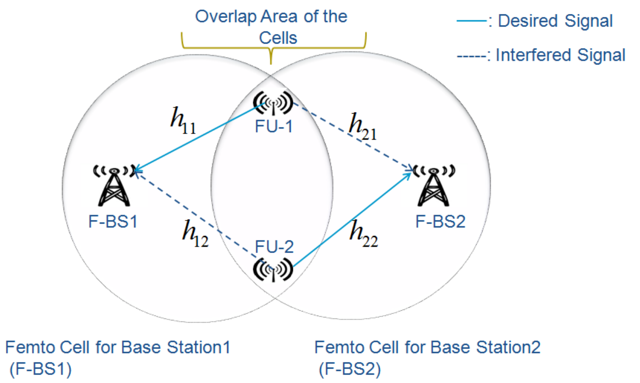

Figure. 3. Presentation of system model for two Femto cells scenario

signal with an unwanted signal. The Fe-COPE scheme helps to mitigate interference completely and exploits the diversity at both base stations.

Femto networks in which the proposed Fe-COPE scheme is utilized to mitigate co-channel interference between two femto users in Rayleigh and Rician-K fading channel environments. The communications between the source nodes and respective base stations take place in the three time slots. The energy at the respective source terminals is assumed to be normalized: the average signal power is normalized to unity with E = $\{\ |S_i{}^2|\ \}$. Assume that the additive white Gaussian noise (AWGN) variance is equal to N_o. Both users are equipped with a single antenna, while the base stations each have a single antenna. Perfect channel state information (CSI) is assumed to be known only at the respective receivers. The next section presents the mathematical expressions for input-output relationship, SNR, and moment generating function (MGF) for

IV. Input Output Relationship and Mathematical Closed-form Expressions

This section derives the equivalent end-to-end expressions for SNR for both users at the respective femto base stations and discusses the input-output relationship. The maximal ratio combining technique is applied at the receiver to combine and sum the desired signals. Finally, SNR equations are used to derive the MGFs for both users.

A. Input-Output Relationship

The signals that are received at the respective femto base station (F-BS1) from user 1 and user 2 in the three time slots can be mathematically expressed below.

$$y^{(1)}_{F-BS1} = \sqrt{E_{s_1}} h_{11} S_1 + n^{(1)}_{F-BS1} \tag{1}$$

$$y^{(2)}_{F-BS1} = \sqrt{E_{s_2}} h_{12} S_2 + n^{(2)}_{F-BS1} \tag{2}$$

$$y^{(3)}_{F-BS1} = \sqrt{E_{s_1}} h_{11} S_2 + \sqrt{E_{s_2}} h_{12} S_1 + n^{(3)}_{F-BS1} \tag{3}$$

where, $y^{(i)}_{F-BS1}$ are the received signals in the i-th ($i \in 1,2,3$) time slots from users 1 and 2. E_{s_i} is the signal power of the i-th user and $n^{(j)}_{F-BS1} \in \mathcal{CN}(0, N_o)$ is the complex Gaussian distribution noise in ($j \in 1,2,3$) time slots. Without loss of generality, assume that the signal energy level is normalized to unity. The channel co-efficient undergoes the different fading distributions such as Rayleigh and Rician-K fading environments respectively.

At F-BS1, the desired signal, S1, is that from user 1, but interference from user 2 causes interference of S1 with signal S2. The proposed scheme will be used herein to compare the channel gains to select the best channel gain, h_{11} or h_{12} as defined in Fig. 3. Depending on the channel conditions, one of two cases applies: $|h_{12}| > |h_{11}|$ leads to Case A and $|h_{11}| > |h_{12}|$ results in B.

1) Case A: A comparison of channel gains, considering the transceiver formulation at F-BS1 reveals that when $|h_{12}| > |h_{11}|$, Case A pertains. In this case, a high quality signal, $\widehat{S}_2$ received at F-BS1 in the form of $y^{(2)}_{F-BS1}$ in the second time slot, will be detected first. Hence, the interference of the signal can be mitigated using the following technique. Equations (1) and (3), can be expressed in matrix form as,

$$\begin{bmatrix} y^{(3)}_{F-BS1} \\ y^{(1)}_{F-BS1} \end{bmatrix} = \begin{bmatrix} h_{12} & h_{11} \\ h_{11} & 0 \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} n^{(3)}_{F-BS1} \\ n^{(1)}_{F-BS1} \end{bmatrix} \tag{4}$$

Now to obtain the desired signal $\widehat{S}_1$ at F-BS1 and to cancel the unwanted signal $\widehat{S}_2$, $\widehat{S}_1$ can be detected as follows.

$$\widehat{S}_1 = dec\left\{ \begin{bmatrix} h^*_{12} & h^*_{11} \end{bmatrix} \left\{ \begin{bmatrix} y^{(3)}_{F-BS1} \\ y^{(1)}_{F-BS1} \end{bmatrix} - \begin{bmatrix} h_{11} \\ 0 \end{bmatrix} \widehat{S}_2 \right\} \right\} \tag{5}$$

where, dec denotes the device for hard decision.

Some mathematical manipulation yields the instantaneous SNR for the user 1 at F-BS1 as,

$$\overline{\gamma}_{F-BS1} = (|h_{12}|^2 + |h_{11}|^2) S_1 + \widehat{n}_2 \tag{6}$$

where, $\widehat{n}_2 = h^*_{12} n^{(3)}_{F-BS1} + h^*_{11} n^{(1)}_{F-BS1}$.

Finally, for case A, the instantaneous SNR for user 1 at F-BS1 is computed as,

$$\overline{\gamma}_{F-BS1} = \frac{(|h_{12}|^2 + |h_{11}|^2)\sigma^2_{S_1}}{\sigma^2_n} \tag{7}$$

where, $\sigma^2_{S_1}$ (normalized to unity) and σ^2_n are the variances for the transmitted signal and the noise, respectively, and their ratio yields SNR.

2) Case B: Based on the second channel condition, when $|h_{11}| > |h_{12}|$, Case B applies. In this case, a high quality signal, $\widehat{S}_1$, received in the first time slot at F-BS1 in the form $y^{(1)}_{F-BS1}$, is detected first. To mitigate the interference of the signal and exploit the diversity in this case, the iterative procedure is utilized. Equations (2) and (3) can be expressed in matrix form as,

$$\begin{bmatrix} y^{(3)}_{F-BS1} \\ y^{(2)}_{F-BS1} \end{bmatrix} = \begin{bmatrix} h_{12} & h_{11} \\ 0 & h_{12} \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} n^{(3)}_{F-BS1} \\ n^{(2)}_{F-BS1} \end{bmatrix} \tag{8}$$

Use of the first detection signal $\widehat{S}_1$ with reliable performance, the interfering signal S_2 at F-BS1 can be detected by (8) and the cancellation scheme,

$$\widehat{S}_2 = dec\left\{ \begin{bmatrix} h_{11}^* & h_{12}^* \end{bmatrix} \left\{ \begin{bmatrix} y_{F-BS1}^{(3)} \\ y_{F-BS1}^{(2)} \end{bmatrix} - \begin{bmatrix} h_{12} \\ 0 \end{bmatrix} \widehat{S}_1 \right\} \right\} \tag{9}$$

After the interfering signal S_2 has been detected, the estimated signal $\widehat{S}_2$ is feedback into (5) to estimate the desired signal $\widehat{S}_1$ of higher quality than the first detected signal $\widehat{S}_1$ in the first time slot,

$$\widehat{S}_1 = dec\left\{ \begin{bmatrix} h_{12}^* & h_{11}^* \end{bmatrix} \left\{ \begin{bmatrix} y_{F-BS1}^{(3)} \\ y_{F-BS1}^{(1)} \end{bmatrix} - \begin{bmatrix} h_{11} \\ 0 \end{bmatrix} \widehat{S}_2 \right\} \right\} \tag{10}$$

After some mathematical manipulation, the instantaneous SNR for user 1 at F-BS1 in this case is given by,

$$\overline{\gamma}_{F-BS1} = (|h_{12}|^2 + |h_{11}|^2)S_1 + \widehat{n}_2 \tag{11}$$

Eventually, in case B, the instantaneous SNR for user 1 at F-BS1 can be computed as:

$$\overline{\gamma}_{F-BS1} = \frac{(|h_{12}|^2 + |h_{11}|^2)\sigma_{S_1}^2}{\sigma_n^2} \tag{12}$$

where, $\sigma_{S_1}^2$ and σ_n^2 are the variances of the source signal and the noise. Similarly, the proposed Fe-COPE scheme can be used at F-BS2 to detect the desired signal S_2 with diversity gain performance under both channel conditions.

Notably, the proposed Fe-COPE scheme can acquire diversity gain and ensure favorable performance under channel conditions A and B. Therefore, Fe-COPE system is reliable and better than the conventional COPE system. According to the authors' research, the proposed Fe-COPE scheme with cooperation and feedback cancellation techniques is novel and no such scheme has been proposed in any published paper.

B. MGF Expressions for Fe-COPE under Fading Environ-Ments

In this section, expressions for MGF is evaluated for Rayleigh and Rician-K fading distributions. The obtained SNR for user 1 at its base station F-BS1 yields the following MGF expressions.

1) Rayleigh Fading Distribution: The equation for an instantaneous SNR can be re-written as,

$$\overline{\gamma}_{F-BS1} = \frac{(|h_{12}|^2 + |h_{11}|^2)\sigma_{S_1}^2}{\sigma_n^2} \tag{13}$$

Assume $\beta = \frac{\sigma_{S_1}^2}{\sigma_n^2}$ and $\alpha = |h|^2$, such as $|h_{11}|^2$ or $|h_{12}|^2$. Then,

$$\overline{\gamma}_{F-BS1} = (\alpha_{12} + \alpha_{11})\beta \tag{14}$$

where β denotes the signal-to-noise ratio and α represents a fading amplitude, which is defined as a random variable (RV). The received carrier amplitude is modulated by the fading amplitude, α.

The probability density function (pdf) for the Rayleigh fading distribution can be found elsewhere in [24], and the expression for the pdf with respect to the RV herein is

$$p_\alpha(\alpha) = \frac{1}{\Omega} e^{-\left(\frac{\alpha}{\Omega}\right)} \qquad ;\alpha \geq 0 \tag{15}$$

where Ω is the scaling parameter and expresses as, $\Omega = E[|\alpha|^2]$ and E is the expectation. Moreover, the technique that was specified in [24] can be used to calculate MGF as,

$$M(s) = E[e^{-s\gamma}] \tag{16}$$

The conditional and unconditional expressions for MGF can be calculated using the above expression as,

$$\begin{aligned} M_\gamma(s) &= \int_0^\infty exp(-s\gamma) f_\gamma(\gamma) d\gamma \\ &= \int_0^\infty e^{-(\alpha_{12}+\alpha_{11})\beta s} p_\alpha(\alpha) d\alpha \end{aligned} \tag{17}$$

Using (15) to determine $p_\alpha(\alpha)$ and performing some algebraic manipulation yields the closed-form MGF expression for Rayleigh fading (Refer to Appendix A):

$$M_{\gamma R}(s) = \frac{1}{(\Omega_{11}\beta s + 1)(\Omega_{12}\beta s + 1)} \tag{18}$$

2) Rician-K Fading Distribution: The pdf of Rician fading distribution [24], is presented as,

$$\begin{aligned} p_\alpha(\alpha) = & \left(\frac{1+K}{\Omega}\right) e^{-K-\left(\frac{1+K}{\Omega}\right)\alpha} \\ & I_0\left(2\sqrt{\frac{K(1+K)}{\Omega}\alpha}\right) \qquad ;\alpha \geq 0 \end{aligned} \tag{19}$$

where Ω is the scaling parameter, which can be expressed as $\Omega = E[|\alpha|^2]$, where E is the expectation. $I_0(.)$ is the zeroth-order modified Bessel function of the first kind and K is the rice factor, which is defined as the ratio between the power in the direct path to the power in the other, scattered, paths. For $K = 0$, Rayleigh fading occurs and setting $K = \infty$ corresponds to the AWGN (no fading) scenario.

Next, the MGF is obtained in the same manner as described earlier, using the corresponding instantaneous SNR and the pdf of the Rician fading distribution. Then, the MGF in the Rician fading environment can be expressed as,

$$M(s) = E[e^{-\gamma s}] \tag{20}$$

$$M_{\gamma-Ric}(s) = \int_0^\infty e^{-(\alpha_{12}+\alpha_{11})\beta s} p_\alpha(\alpha) d\alpha \tag{21}$$

$$\begin{aligned} M_{\gamma-Ric}(s) = & \int_0^\infty e^{-(\alpha_{12}+\alpha_{11})\beta s} \left(\frac{1+K}{\Omega}\right) e^{-K-\left(\frac{1+K}{\Omega}\right)\alpha} \\ & I_0\left(2\sqrt{\frac{K(1+K)}{\Omega}\alpha}\right) d\alpha \end{aligned} \tag{22}$$

After some computation, the conditional MGF expression is (Refer to Appendix B.1),

$$M_{\gamma-Ric}(s)|_{\alpha_{12}} = e^{-\alpha_{12}\beta s-K}(1+K)\frac{e^{\frac{K(1+K)}{2(\beta s\Omega_{11}+1+K)}}}{\sqrt{(\beta s\Omega_{11}+1+K)(K(1+K))}} M_{-\frac{1}{2},0}\left(\frac{K(1+K)}{(\beta s\Omega_{11}+1+K)}\right) \quad (23)$$

where $M_{-\lambda,\nu}(z)$ is the Whittaker functions [25]. Moreover, to obtain the unconditional MGF, the average of the above Eq. (23) is taken w.r.t. α_{12}, and shown as,

$$M_{\gamma-Ric}(s) = \int_0^\infty M_{\gamma-Ric}(s)|_{\alpha_{12}} p_{\alpha_{12}}(\alpha_{12})d\alpha_{12} \quad (24)$$

Substituting the respective values, (21) and (23) yields,

$$M_{\gamma-Ric}(s) = \int_0^\infty e^{-\alpha_{12}\beta s-K}(1+K)\frac{e^{\frac{K(1+K)}{2(\beta s\Omega_{11}+1+K)}}}{\sqrt{(\beta s\Omega_{11}+1+K)(K(1+K))}} M_{-\frac{1}{2},0}\left(\frac{K(1+K)}{(\beta s\Omega_{11}+1+K)}\right)\left(\frac{1+K}{\Omega_{12}}\right)e^{-K-\left(\frac{1+K}{\Omega_{12}}\right)\alpha_{12}} I_0\left(2\sqrt{\frac{K(1+K)}{\Omega_{12}}\alpha_{12}}\right)d\alpha_{12} \quad (25)$$

Computation of some properties with reference to the work of [25] yields the final closed-form MGF for the Rician-K fading channel as (Refer to Appendix B.2),

$$M_{\gamma-Ric}(s) = \frac{e^{-K}(1+K)^2 e^{\left(\frac{K(K+1)}{\beta s\Omega_{11}+1+K}+\frac{K(K+1)}{\beta s\Omega_{12}+1+K}\right)}}{(\beta s\Omega_{11}+1+K)(\beta s\Omega_{12}+1+K)} \quad (26)$$

The final closed-form expressions of MGF for Fe-COPE scheme, $M_{\gamma-R}$, and $M_{\gamma-Ric}$ over Rayleigh, and Rician-K fading channels respectively can be computed as given in Table 3.

TABLE III CLOSED-FORM MGF EXPRESSIONS FOR FE-COPE

Channels	MGF Expressions
Rayleigh	$M_{\gamma-R}(s) = \frac{1}{(\Omega_{11}\beta s+1)(\Omega_{12}\beta s+1)}$
Rician-K	$M_{\gamma-Ric} = \frac{e^{-K}(1+K)^2 e^{\left(\frac{K(K+1)}{\beta s\Omega_{11}+1+K}+\frac{K(K+1)}{\beta s\Omega_{12}+1+K}\right)}}{(\beta s\Omega_{11}+1+K)(\beta s\Omega_{12}+1+K)}$

V. IMPLEMENTATION OF FEMTO ADJACENT (FE-ADJ) CHANNEL INTERFERENCE MITIGATION SCHEME

This section discusses the Fe-ADJ system with basic femto scenario when several femto cells are deployed in macro cells. The Fe-ADJ scheme helps to mitigate adjacent-channel interference between macro and femto users which causes degradation in the performance of the system and the resource blocks gets wasted. Considering a practical scenario when there are macro and femto cells consist of plural number of macro and femto users respectively. Next, the worst-case scenario for the proposed Fe-ADJ system is investigated, in which the two users that are associated with their respective cells are located at the edge of the common boundaries of the both cells, such that both users, FU1 and MU2, interfere with both of the base stations F-BS and M-BS, respectively. The scenario can be clearly depicted in Fig. 4 when macro-cell covers the distance of one Km radius and consists of several macro and femto cells.

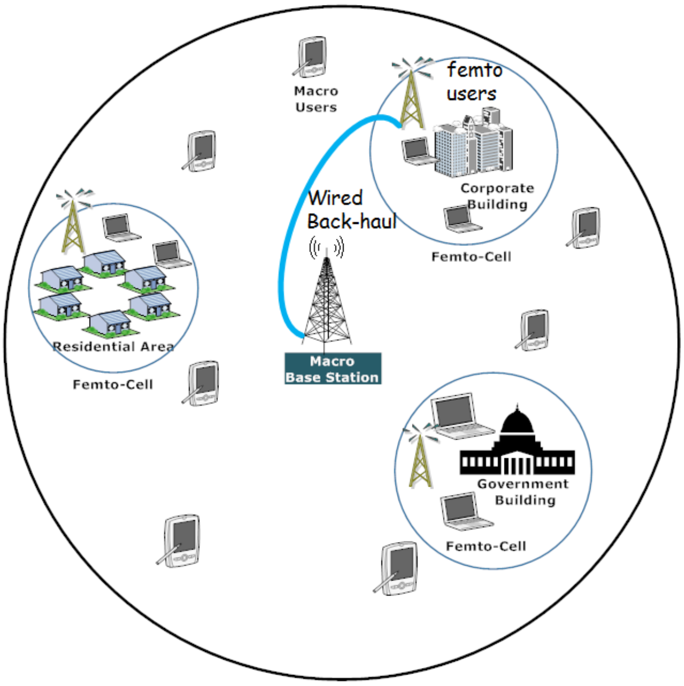

Figure. 4. Illustration of system model for the Fe-ADJ scheme

Fig. 4 presents the whole concept of adjacent-channel interference when femto and macro users cause interference to each other. Contrary to Fe-COPE scheme, implementation of Fe-ADJ scheme is done in two time slots. The system exploits the wired back-haul connection between macro and femto base stations.

In the proposed Fe-ADJ scheme, both femto and macro users broadcast the information at the respective base stations such as, macro and femto base stations in the firs time slot. In the second time slot, femto user transmits the signal however, macro user transmits negative of the signal information. Assuming, femto base station is turned-on for the second time slot whereas, macro base station is turned off and performs the other tasks. Both desired (wanted) and interfered (unwanted) signals are added at both of the base stations. Exploiting the two time slots, Fe-ADJ scheme performs the mitigation of adjacent-channel interference between both base stations using the back-haul connection, depicts in Fig. 5.

Femto networks with proposed Fe-ADJ scheme are con-

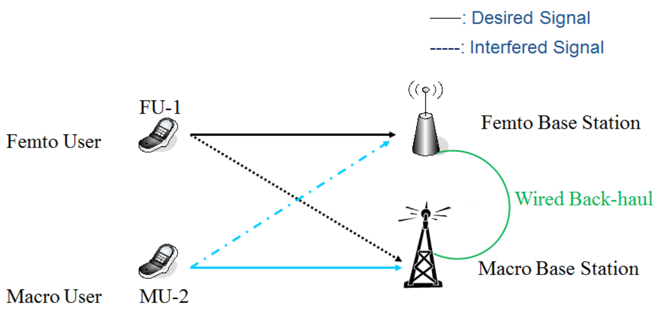

Figure. 5. Block diagram of the proposed Fe-ADJ system with femto and macro users

sidered to mitigate adjacent-channel interference between two femto and macro users in Rayleigh and Rician-K fading environments. The communication between the source nodes and respective base stations take place in two time slots using wired back-haul connection. The energy at the respective source terminals is assumed to be normalized: the average signal power is normalized to unity with E = { $|S_i{}^2|$ }. Assume that the additive white Gaussian noise (AWGN) variance is equal to N_o. Both users are equipped with a single antenna, while the base stations each have a single antenna. Perfect channel state information (CSI) is assumed to be known only at the respective receivers. Assuming flat-fading such that the channel conditions over two time frames are assumed to be same. The next section presents the mathematical expressions for input-output relationship, SNR, and moment generating function (MGF) for both fading environments.

VI. Input Output Relationship and Mathematical Closed-Form Expressions

This section derives the equivalent end-to-end expressions for SNR at the respective femto base stations and discusses the input-output relationship. The maximal ratio combining technique is applied at the receiver to combine and sum the desired signals. Finally, SNR equations are used to derive the MGFs for both users.

A. Input-output Relationship

The signals that are received at the respective femto base station (F-BS) from femto and macro users, will be termed as user 1 and user 2 for remaining of the paper, in the two time slots can be mathematically expressed below.

$$y^{(1)}_{F-BS} = \sqrt{E_{s_1}}h^{(1)}_{11}S_1 + \sqrt{E_{s_2}}h^{(1)}_{21}S_2 + n^{(1)}_{F-BS} \quad (27)$$

In the same time slot, the received signal at macro base station is shown as,

$$y^{(1)}_{M-BS} = \sqrt{E_{s_2}}h^{(1)}_{22}S_2 + \sqrt{E_{s_1}}h^{(1)}_{12}S_1 + n^{(1)}_{M-BS} \quad (28)$$

where $y^{(i)}_{F-BS}$ and $y^{(i)}_{M-BS}$ are the received signals in the i-th ($i \in 1,2$) time slots from user 1 and user 2 for Femto and Macro base stations respectively. $n^{(j)}_{F-BS}$ and $n^{(j)}_{M-BS} \in \mathcal{CN}(0, N_o)$ are the complex Gaussian distribution noises in ($j \in 1,2$) time slots. Without loss of generality, assuming the normalized signal energy level to unity. The channel co-efficients undergo the Rayleigh, and Rician-K fading environments respectively. At F-BS, the desired signal, S1, is that from user 1, but interference from user 2 causes interference of S1 with signal S2. Implementing the Fe-ADJ protocol, in the second time slot, user 1 sends the original signal and user 2 transmits the negative of the signal. The equation for the second time slot, at F-BS are shown as,

$$y^{(2)}_{F-BS} = \sqrt{E_{s_1}}h^{(2)}_{11}S_1 - \sqrt{E_{s_2}}h^{(2)}_{21}S_2 + n^{(2)}_{F-BS} \quad (29)$$

After the addition of the signals from two time slots at femto base station, assuming flat-fading channel, the desired signal is detected as,

$$Y_{F-BS} = 2\sqrt{E_{s_1}}h_{11}S_1 + N_{F-BS} \quad (30)$$

where $Y_{F-BS} = y^{(1)}_{F-BS} + y^{(2)}_{F-BS}$ and $N_{F-BS} = n^{(1)}_{F-BS} + n^{(2)}_{F-BS}$.

Finally the instantaneous SNR for user 1 at F-BS is expressed as,

$$\gamma_{F-BS} = \frac{2|h_{11}|^2\sigma^2_{S_1}}{\sigma^2_n} \quad (31)$$

where $\sigma^2_{S_1}$ and σ^2_n are the variances for the transmitted signal and the noise, respectively, and their ratio yields SNR and setting $\beta = \frac{\sigma^2_{S_1}}{\sigma^2_n}$ and $\alpha_{11} = |h_{11}|^2$.

After the desired signal is detected at femto base station (F-BS), it is feed-backed to the macro base station (M-BS) exploiting the wired back-haul. Inserting the detected strong signal from (30) into (28) and performing an XOR operation or simply subtract the in-coming strong signal, the desired signal (S2) at M-BS is easily detected.

B. MGF Expressions for Fe-ADJ over Fading Environments

In this section, MGF is evaluated for Rayleigh and Rician-K fading distributions. The obtained SNR for user 1 at its base station F-BS yields the following MGF expressions.

1) Rayleigh Fading Distribution: The equation for an instantaneous SNR can be re-written as,

$$\gamma_{F-BS} = 2\alpha_{11}\beta \quad (32)$$

where $\alpha = |h|^2$ and $\beta = \frac{\sigma^2_{S_1}}{\sigma^2_n}$. β denotes the value for SNR and α represents a fading amplitude, which is defined as a random variable (RV). The received carrier amplitude is modulated by the fading amplitude, α.

The pdf for Rayleigh fading distribution in [24], the expression is shown as:

$$p_\alpha(\alpha) = \frac{1}{\Omega}e^{-\left(\frac{\alpha}{\Omega}\right)} \qquad ; \alpha \geq 0 \quad (33)$$

where Ω is the scaling parameter and expresses as, $\Omega = E[|\alpha|^2]$ and E is the expectation.

Using the same technique in [24], is used to calculate MGF expression as,

$$M(s) = E[e^{-s\gamma}] \quad (34)$$

The MGF expression can be calculated using the above expression as,

$$\begin{aligned} M_\gamma(s) &= \int_0^\infty exp(-s\gamma) f_\gamma(\gamma) d\gamma \\ &= \int_0^\infty e^{-2\alpha_{11}\beta s} p_\alpha(\alpha) d\alpha \end{aligned} \tag{35}$$

Using Eq. (15) to determine and performing some algebraic manipulation yields the closed-form MGF expression for Rayleigh fading (Refer to Appendix A for similar approach):

$$M_{\gamma R}(s) = \frac{1}{(2\Omega_{11}\beta s + 1)} \tag{36}$$

2) Rician-K Fading Distribution: The pdf of Rician fading distribution in [24], is shown as:

$$\begin{aligned} p_\alpha(\alpha) = \left(\frac{1+K}{\Omega}\right) e^{-K-\left(\frac{1+K}{\Omega}\right)\alpha} \\ I_0 \left(2\sqrt{\frac{K(1+K)}{\Omega}\alpha} \right) \quad ; \alpha \geq 0 \end{aligned} \tag{37}$$

where Ω defines the scaling parameter and expresses as $\Omega = E[|\alpha|^2]$, where E is the expectation. $I_0(.)$ is the zeroth-order modified Bessel function of the first kind and K is the rice factor. Next, the MGF is obtained in the same manner as described earlier, using the corresponding instantaneous SNR and the pdf of the Rician fading distribution. Then, the MGF in the Rician fading environment can be expressed as,

$$M(s) = E[e^{-\gamma s}] \tag{38}$$

$$M_{\gamma-Ric}(s) = \int_0^\infty e^{-2\alpha_{11}\beta s} p_\alpha(\alpha) d\alpha \tag{39}$$

$$\begin{aligned} M_{\gamma-Ric}(s) = \int_0^\infty e^{-2\alpha_{11}\beta s} \left(\frac{1+K}{\Omega_{11}}\right) e^{-K-\left(\frac{1+K}{\Omega_{11}}\right)\alpha_{11}} \\ I_0 \left(2\sqrt{\frac{K(1+K)}{\Omega_{11}}\alpha_{11}} \right) d\alpha_{11} \end{aligned} \tag{40}$$

After some computation using [25], the the final MGF closed-form expression is expressed as (Refer to Appendix B.1 and B.2 for the similar approach),

$$M_{\gamma-Ric}(s) = \frac{e^{-K}(1+K)e^{\left(\frac{K(K+1)}{2\beta s\Omega_{11}+1+K}\right)}}{(2\beta s\Omega_{11}+1+K)} \tag{41}$$

The final closed-form expressions of MGF for Fe-ADJ scheme, $M_{\gamma-R}$ and $M_{\gamma-Ric}$ over Rayleigh and Rician-K fading channels respectively is presented in Table 4.

TABLE IV CLOSED-FORM MGF EXPRESSIONS FOR FE-ADJ

Channels	MGF Expressions
Rayleigh	$M_{\gamma R}(s) = \frac{1}{(2\Omega_{11}\beta s+1)}$
Rician-K	$M_{\gamma-Ric}(s) = \frac{e^{-K}(1+K)e^{\left(\frac{K(K+1)}{2\beta s\Omega_{11}+1+K}\right)}}{(2\beta s\Omega_{11}+1+K)}$

VII. PERFORMANCE ANALYSIS

In this section, the performance is analyzed in terms of average total bit error rate (BER). The derived mathematical equation for MGF can be used to simplify the expression for BER for the proposed Fe-COPE and Fe-ADJ schemes. The results in the form of closed form curves can be obtained using the well-known user-friendly MAPLE or MATHEMATICA software. The expressions are derived for Rayleigh and Rician-K fading channels over 16-QAM constellation modulation technique.

A. Fe-COPE Analysis

This section derives the SER expression for Fe-COPE system and obtains the curves for BER versus SNR over Rayleigh and Rician fading channels.

1) Rayleigh Fading Distribution: The average symbol error rate (SER) expression for M-QAM is shown in [24] as,

$$\begin{aligned} P_s = \frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)\int_0^{\frac{\pi}{2}} M_\gamma\left(\frac{g_{QAM}}{sin^2\theta}\right) d\theta \\ - \frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)^2 \int_0^{\frac{\pi}{4}} M_\gamma\left(\frac{g_{QAM}}{sin^2\theta}\right) d\theta \end{aligned} \tag{42}$$

where $g_{QAM} = \frac{3}{2(M-1)}$.
Setting $M = 16$, in the above equation yields,

$$P_s = \frac{3}{\pi}\int_0^{\frac{\pi}{2}} M_\gamma\left(\frac{1}{10sin^2\theta}\right) d\theta - \frac{9}{4\pi}\int_0^{\frac{\pi}{4}} M_\gamma\left(\frac{1}{10sin^2\theta}\right) d\theta \tag{43}$$

The expression for MGF obtained earlier for Rayleigh fading, and the evaluation and re-arrangement of parameters, can be used to rewrite the equation as:

$$\begin{aligned} P_{R_s} = & \frac{3}{\pi}\int_0^{\frac{\pi}{2}} \frac{(10sin^2\theta)^2 d\theta}{(\Omega_{11}\beta + 10sin^2\theta)(\Omega_{12}\beta + 10sin^2\theta)} \\ & - \frac{9}{4\pi}\int_0^{\frac{\pi}{4}} \frac{(10sin^2\theta)^2 d\theta}{(\Omega_{11}\beta + 10sin^2\theta)(\Omega_{12}\beta + 10sin^2\theta)} \end{aligned} \tag{44}$$

Integrating by parts and simplifying the integral by substitution yields the final equation as,

$$\begin{aligned} P_{R_s} = & \left[G_1 B\left(\frac{5}{2},\frac{1}{2}\right) {}_2F_1\left(2,\frac{5}{2};3,\frac{-10}{\beta\Omega}\right)\right] - \\ & \left[G_2 \int_0^{\frac{1}{2}} v^{\frac{3}{2}}(1-v)^{-\frac{1}{2}}\left(1+\frac{10v}{\Omega\beta}\right)^{-2} dv \right] \end{aligned} \tag{45}$$

Assume $\Omega_{11} = \Omega_{12} = \Omega$, where β is the SNR, $G_1 = \frac{150}{\beta^2\times\Omega^2\times\pi}$, and $G_2 = \frac{450}{4\times\beta^2\times\Omega^2\times\pi}$. $B(x,y)$ is the Beta function and ${}_2F_1(a,b;c,z)$ is the Gauss Hypergeometric function defined in [25]. The relationship between symbol error rate and bit error rate is defined as follows [26]:

$$P_b \approx \frac{P_s}{k} \tag{46}$$

where $k = log_2(M)$ bits/symbol. For the M = 16-QAM constellation, $k = 4$. Wolfram Mathematica software [27] is used to obtain the theoretical average BER in the Rayleigh fading environment, which is required to solve the complex integral.

2) Rician-K Fading Distribution: The average symbol error rate (SER) expression for M-QAM is given in [24],

$$\begin{aligned} P_s = &\frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)\int_0^{\frac{\pi}{2}} M_\gamma\left(\frac{g_{QAM}}{sin^2\theta}\right)d\theta \\ &-\frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)^2\int_0^{\frac{\pi}{4}} M_\gamma\left(\frac{g_{QAM}}{sin^2\theta}\right)d\theta \end{aligned} \tag{47}$$

where $g_{QAM} = \frac{3}{2(M-1)}$.

Next, to obtain the BER for Rician-K fading, (33) and MGF for the Rician-K channel are used and the complex integral thus obtained is simplified, yielding,

$$\begin{aligned} &P_{Ric_s} = \\ &\frac{3e^{-2K}(1+K)^2}{\pi}\int_0^{\frac{\pi}{2}}\frac{(10sin^2\theta)^2 e^{\left(\frac{20sin^2\theta K(K+1)}{\beta\Omega+10sin^2\theta(1+K)}\right)}}{(\beta\Omega+10sin^2\theta(1+K))^2}d\theta- \\ &\frac{9e^{-2K}(1+K)^2}{4\pi}\int_0^{\frac{\pi}{4}}\frac{(10sin^2\theta)^2 e^{\left(\frac{20sin^2\theta K(K+1)}{\beta\Omega+10sin^2\theta(1+K)}\right)}}{(\beta\Omega+10sin^2\theta(1+K))^2}d\theta \end{aligned} \tag{48}$$

Integration by substitution and simplifying the integral, yields,

$$\begin{aligned} P_{Ric_s} = &G_3\int_0^1 v^{\frac{3}{2}}(1-v)^{-\frac{1}{2}}\frac{e^{\frac{20K(1+K)v}{\beta\Omega+10v(1+K)}}}{(\beta\Omega+10v(1+K))^2}dv \\ &-G_4\int_0^{\frac{1}{2}} v^{\frac{3}{2}}(1-v)^{-\frac{1}{2}}\frac{e^{\frac{20K(1+K)v}{\beta\Omega+10v(1+K)}}}{(\beta\Omega+10v(1+K))^2}dv \end{aligned} \tag{49}$$

whereas, $G_3 = \frac{150e^{-2K}(1+K)^2}{\pi}$ and $G_4 = \frac{450e^{-2K}(1+K)^2}{4\pi}$ respectively. K defines the rice factor.

The software Mathematica [27] is used to obtain a theoretical solution to solve the complex integral for the average BER in a Rician-K fading environment.

B. Fe-ADJ Analysis

This section derives the SER expression for Fe-ADJ system and presents the obtained curves for BER versus SNR over Rayleigh and Rician fading channels.

1) Rayleigh Fading Distribution: Using the average symbol error rate (SER) expression for M = 16-QAM as given in [24], it can be re-written as,

$$P_s = \frac{3}{\pi}\int_0^{\frac{\pi}{2}} M_\gamma\left(\frac{1}{10sin^2\theta}\right)d\theta - \frac{9}{4\pi}\int_0^{\frac{\pi}{4}} M_\gamma\left(\frac{1}{10sin^2\theta}\right)d\theta \tag{50}$$

The expression for MGF obtained earlier for Rayleigh fading, and the evaluation and re-arrangement of parameters, can be used to rewrite the equation as:

$$\begin{aligned} P_{R_s} = &\frac{3}{\pi}\int_0^{\frac{\pi}{2}}\frac{(10sin^2\theta)^2 d\theta}{2\Omega_{11}\beta+10sin^2\theta} \\ &-\frac{9}{4\pi}\int_0^{\frac{\pi}{4}}\frac{(10sin^2\theta)^2 d\theta}{2\Omega_{11}\beta+10sin^2\theta} \end{aligned} \tag{51}$$

Integrating by parts and simplifying the integral by substitution yields the final equation as,

$$\begin{aligned} P_{R_s} = &\left[G_1 B\left(\frac{3}{2},\frac{1}{2}\right)\ {}_2F_1\left(1,\frac{3}{2};2,\frac{-10}{\beta\Omega}\right)\right] - \\ &\left[G_2\int_0^{\frac{1}{2}} v^{\frac{1}{2}}(1-v)^{-\frac{1}{2}}\left(1+\frac{10v}{\beta\Omega}\right)^{-1}dv\right] \end{aligned} \tag{52}$$

Assume $\Omega_{11} = \Omega_{12} = \Omega$, where β is the SNR, $G_1 = \frac{15}{\beta\times\Omega\times\pi}$, and $G_2 = \frac{45}{4\times\beta\times\Omega\times\pi}$. $B(x, y)$ represents the Beta function and ${}_2F_1(a, b; c, z)$ is the Gauss Hypergeometric function defined in [25].

2) Rician-K Fading Distribution: This section demonstrates the mathematical expression of SER for M=16-QAM under Rician-K fading distribution. Next, to obtain the BER for Rician-K fading, (43) and MGF for the Rician-K channel are used and the complex integral thus obtained is simplified, yielding,

$$\begin{aligned} P_{Ric_s} = &\frac{3e^{-K}(1+K)}{\pi}\int_0^{\frac{\pi}{2}}\frac{(10sin^2\theta)e^{\left(\frac{10sin^2\theta K(K+1)}{2\beta\Omega+10sin^2\theta(1+K)}\right)}}{(2\beta\Omega+10sin^2\theta(1+K))}d\theta \\ &-\frac{9e^{-K}(1+K)}{4\pi}\int_0^{\frac{\pi}{4}}\frac{(10sin^2\theta)e^{\left(\frac{10sin^2\theta K(K+1)}{2\beta\Omega+10sin^2\theta(1+K)}\right)}}{(2\beta\Omega+10sin^2\theta(1+K))}d\theta \end{aligned} \tag{53}$$

Using integration by substitution technique and simplifying the integral, the final expression is re-written as,

$$\begin{aligned} P_{Ric_s} = &G_3\int_0^1 v^{\frac{1}{2}}(1-v)^{-\frac{1}{2}}\frac{e^{\frac{10K(1+K)v}{2\beta\Omega+10v(1+K)}}}{(2\beta\Omega+10v(1+K))^2}dv \\ &-G_4\int_0^{\frac{1}{2}} v^{\frac{1}{2}}(1-v)^{-\frac{1}{2}}\frac{e^{\frac{10K(1+K)v}{2\beta\Omega+10v(1+K)}}}{(2\beta\Omega+10v(1+K))^2}dv \end{aligned} \tag{54}$$

whereas, $G_3 = \frac{15e^{-K}(1+K)}{\pi}$ and $G_4 = \frac{45e^{-K}(1+K)}{4\pi}$ respectively. K denotes the rice factor. Mathematica [27] is used to obtain a theoretical solution to solve the complex integral for the average BER in a Rician-K fading environment.

VIII. Simulation Results and Discussion

This section analyzes the performance of the Fe-COPE and Fe-ADJ systems by plotting analytical curves with the simulated results. Numerical results revealed the performance of the proposed Fe-COPE system and Fe-ADJ systems to mitigate co-channel and adjacent-channel interferences respectively. The exact BER performance was analytically derived in the Section 5 by taking into account MGFs that are derived in

Section 4 under Rayleigh and Rician-K fading distributions. For the systems that are displayed in Fig. 2, 3, 4, and 5, such results were obtained using Mathematica 8 software and compared with the results of Monte Carlo simulations using MATLAB in Rayleigh and Rician fading environments. All of the results for average BER are plotted w.r.t. the SNR in dB using the 16-QAM constellation technique.

Fig. 6 reveals good agreement between the analytical and simulated results over a Rayleigh fading channel. The figure plots the analysis of average BER versus SNR in dB and compares the curve with that for the conventional COPE with the decode-and-forward (DF) with different values of signal power. The proposed Fe-COPE scheme clearly performs better because of diversity gain. The Fe-COPE system helps to mitigate the co-channel interference in the femto scenario. Interestingly, the channel gain of the interfered signal is exploited and the cell is used as a relay. The proposed protocol performs robustly by taking into account diversity gains at respective femto base stations. It is noticed that at a value of BER = 10^{-2}, the performance of Fe-ADJ system degrades for about 4dB as compared to the Fe-COPE system. Considering the fact that the Fe-ADJ system utilizes two time slots and hence, enjoys higher capacity gains contrasts to the Fe-COPE system. The performance of Fe-COPE and Fe-ADJ is dramatically improved as compared to conventional COPE for about 8dB and 4dB respectively.

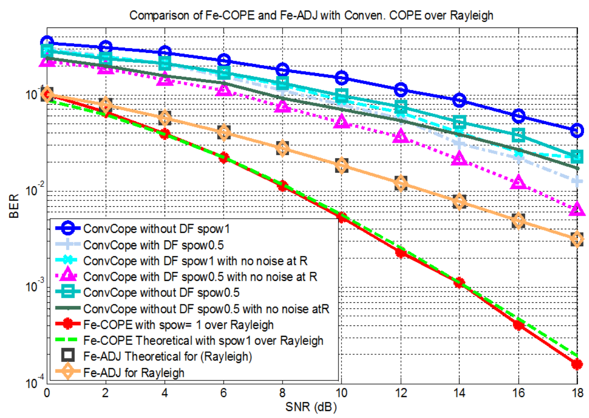

Figure. 6. Comparison of Fe-COPE and Fe-ADJ systems with Conv. COPE in terms of BER versus SNR over Rayleigh fading channel

The performance in terms of BER versus SNR of the Fe-COPE system over Rician-K fading distribution for different values of K is plotted in Fig. 7. The figure shows strong agreement between the simulated and theoretical results for $K = 0$, which is a special case of Rayleigh, $K = 5, \&10$ fading channels respectively. A negligible difference is seen in the upper bound of the numerical analysis. The Monte-Carlo simulation results for different values of K and high SNR values deviate, since the theoretical integration could not be computed, the crossing points does not exist anymore. At these points, the theoretical integration yields some degree of errors.

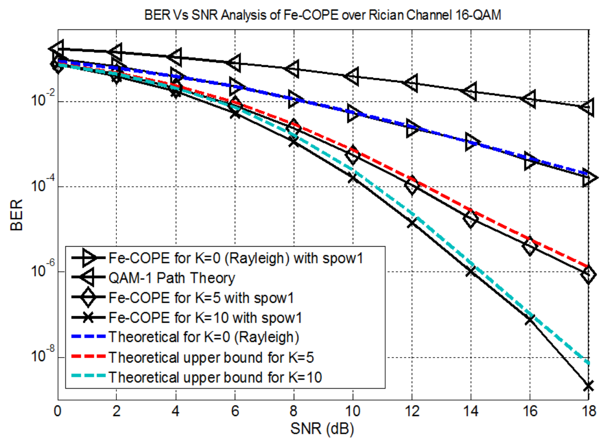

Figure. 7. Performance Evaluation of Fe-COPE system in terms of BER versus SNR curves over Rician fading channel

Fig. 8 reveals a good match between the analytical and simulated results for Fe-ADJ over Rician fading channel. The performance is analyzed in terms of BER versus SNR of the Fe-ADJ system over Rician-K fading distribution for different values of K depicted in Fig. 8. The figure shows a good agreement between the simulated and theoretical results for $K = 0$, which is a special case of Rayleigh, $K = 5, \&10$ fading channels respectively. Fe-ADJ system helps to mitigate the adjacent-channel interference in femto-cells. Considering the fact that the Fe-ADJ system uses two time slots and after implementing the protocol, the desired (wanted) signal is detected and separated easily with strong signal strength. The performance for the Fe-ADJ system gets better for the higher values of K and the effect is clearly seen in the curves.

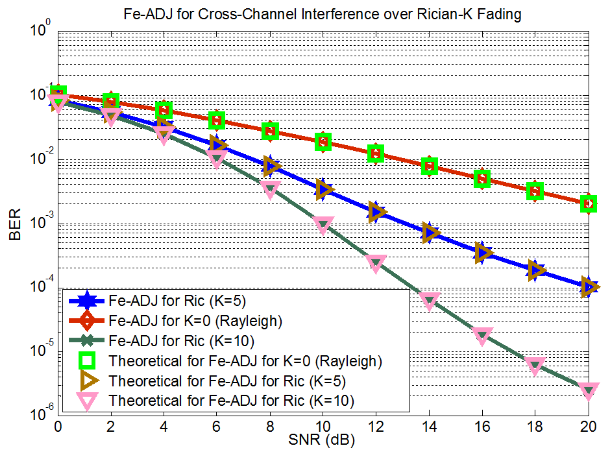

Figure. 8. Fe-ADJ performance analysis to mitigate cross-channel interference over Rician-K Fading for M=16-QAM modulation

Comparison of the Fe-COPE and Fe-ADJ systems over Rayleigh and Rician fading comprehensively elucidate the difference, displayed in Fig. 9. It is seen that the improvement in the performance of the Fe-COPE over that of the conventional COPE system for BER = 10^{-2}. An SNR gain of approximately more than 8 dB is achieved for Rayleigh fading channel. Sufficiently high SNR at high values of the Nakagami-m fading parameter ensures full diversity gain.

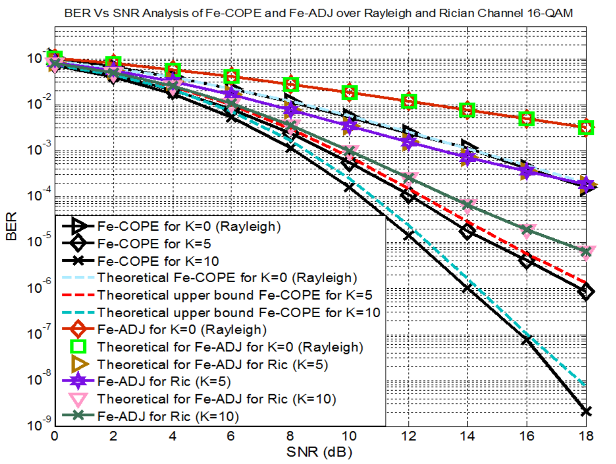

Figure. 9. Fe-COPE and Fe-ADJ systems in terms of BER versus SNR over Rayleigh and Rician fading channels for different values of $K = 0(Rayleigh), K = 5, \&10$

The main comparison among the slopes of BER against SNR values for different fading distributions is depicted in Fig. 9. It is clearly seen that how the performance gets dramatically better in terms of gain. The Fe-COPE helps to mitigate the co-channel interference essential in femto systems. The significant advantage of the proposed Fe-COPE scheme is the exploitation of the user as a relay network with feedback cancellation to acquire diversity gain from the interferer user, that results in no degradation in the performance of both users. Fe-ADJ system helps to mitigate the cross-channel interference between macro and femto users in two time slots. The performance degrades as compared to the Fe-COPE scheme but exploits the high capacity again due to less utilization of the resources. A negligible difference is seen and ignored for very high values of SNR in the analytical and Monte-Carlo simulations, since it is not possible to compute the integration, which results in some degree of error.

Simulated and theoretical results clearly comprehensively elucidate the femto cell scenario. These results help operators choose the best fading distribution according to the environment. Examining the slopes of the BER curves reveals that, in the femto case, owing to the line of sight factor (LoS), Rician-K fading yields greater gain for higher values of K and higher SNR regime, as depicted below in Fig. 9.

Fig. 10 plots the average BER analysis over a Rician fading channel for the 16-QAM modulation constellation. The slopes are analyzed for specific values of low and high SNR of between 0 and 20 dB. Monte-Carlo simulations demonstrate that as K and SNR increase, the BER curves fall dramatically and performance gets improved.

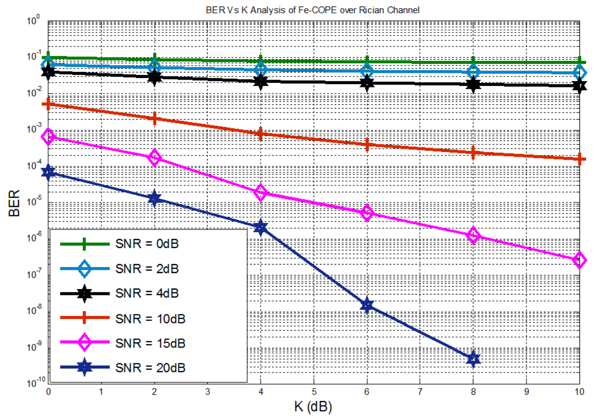

Figure. 10. Fe-COPE system for fixed value of SNR, depending on the values of K over Rician fading channel

IX. Conclusion and Future Recommendations

This section considers future directions and ongoing work,

A. Concluding Remarks

In this work, the COPE system is newly extended to femto systems. The co-channel and adjacent-channel interferences mitigation protocols are implemented on a system in which user works as a relay network and macro-femto back-haul connection under Rayleigh and Rician fading distributions respectively. The SER expressions of 16-QAM modulated signals are evaluated using the closed-form MGFs that were derived in different fading scenarios. The SER is then computed in Mathematica software to generate the curves of total average BER versus SNR.

The numerical results demonstrate that all of the derived approximate analytical expressions are very tight upper bounds. The simulated upper bounds and theoretical curves reveal the performance of the proposed schemes. The analysis indicates that the Fe-COPE and Fe-ADJ systems provide a significant performance improvement using diversity combining techniques. Fe-COPE mitigates co-channel interference in femto networks by exploiting the diversity gain that arises from the user that causes interference. Fe-ADJ helps to mitigate the cross-channel interference as well as exploits the higher capacity gain. The simulation results improve as the value of K increases over Rician fading distribution.

B. Future Research Plan

The proposed Fe-COPE and Fe-ADJ schemes provide novel solutions to the serious problems that are encountered in femto cellular networks. However, its potential improvements over the current scheme are currently under investigation. First, the proposed method is analyzed with two neighboring cells, considering two users that are associated with the different femto cells. Future research should develop a multi-user mitigation protocol with a higher data rate and an efficient algorithm that uses the MIMO diversity gain technique with the Fe-COPE system. Fe-ADJ system will be analyzed for the plural number of macro and femto case exploiting the use of MIMO techniques and the scenarios are under investigation. Finally, we believe that a joint-design of Fe-COPE and Fe-ADJ systems can mitigate both co-channel and cross-channel interference, improving the overall communication quality using resource allocation techniques in wireless relay networks.

APPENDIX A

By using (17), the MGF expression over Rayleigh fading is shown as,

$$M_{\gamma R}(s) = \int_0^{\infty} e^{-(\alpha_{12}+\alpha_{11})\beta s} p_\alpha(\alpha) d\alpha \tag{55}$$

Setting the pdf from (15), the conditional MGF is represented as,

$$M_{\gamma R}(s)|_{\alpha_{12}} = \int_0^{\infty} e^{-(\alpha_{12}+\alpha_{11})\beta s} \frac{1}{\Omega_{11}} e^{-\left(\frac{\alpha_{11}}{\Omega_{11}}\right)} d\alpha_{11} \tag{56}$$

The conditional MGF expression is written as,

$$M_{\gamma R}(s)|_{\alpha_{12}} = \frac{e^{-\alpha_{12}\beta s}}{1+\Omega_{11}\beta s} \tag{57}$$

Next, to obtain the un-conditional MGF expression, the average of the above Eq. w.r.t. α_{12} is taken as,

$$M_{\gamma R}(s) = \int_0^{\infty} M_{\gamma R}(s)|_{\alpha_{12}} p_{\alpha_{12}}(\alpha_{12}) d\alpha_{12} \tag{58}$$

After some mathematical derivation, the final MGF expression over Rayleigh fading is obtained as presented in (18).

APPENDIX B

B.1 DERIVATION OF *(23)*

As expressed in (22), the MGF for Rician fading environment is written as,

$$M_{\gamma-Ric}(s) = \int_0^{\infty} e^{-(\alpha_{12}+\alpha_{11})\beta s} \left(\frac{1+K}{\Omega}\right) e^{-K-\left(\frac{1+K}{\Omega}\right)\alpha} I_0 \quad 2\left(\sqrt{\frac{K(1+K)}{\Omega}\alpha}\right) d\alpha \tag{59}$$

Using [28, Eq (6.614.3), the integral gets simplified and the equation is re-written as follows, (60):

After simplifying the conditional MGF, the (60) reduces to (23).

B.2 DERIVATION OF *(26)*

Using (25), to solve the integral the complex terms need to be simplified. With the help of the identity presented in [28, Eq. (9.220.2)], $M_{-\frac{1}{2},0}(\cdot)$ is written as (61)

:

Using the property shown in [28, Eq. (9.215.1)], $\Phi(\alpha,\alpha;z) = e^z$. Thus, (61) is further simplified. Setting the values in (25), the equation is simplified and the closed-form expression of MGF over Rician-K distribution is obtained, as shown in (26).

$$M_{\gamma-Ric}(s)|_{\alpha_{12}} = e^{-\alpha_{12}\beta s-K}\left(\frac{1+K}{\Omega_{11}}\right)\frac{\Omega_{11}\times e^{\frac{K(1+K)}{2(\beta s\Omega_{11}+1+K)}}}{\sqrt{(\beta s\Omega_{11}+1+K)(K(1+K))}}\frac{\Gamma(1)}{\Gamma(1)}M_{-\frac{1}{2},0}\left(\frac{K(1+K)}{(\beta s\Omega_{11}+1+K)}\right) \tag{60}$$

$$M_{-\frac{1}{2},0}\left(\frac{K(K+1)}{\beta s\Omega_{11}+1+K}\right) = \left(\frac{K(K+1)}{\beta s\Omega_{11}+1+K}\right)^{\frac{1}{2}} e^{-\frac{K(1+K)}{2(\beta s\Omega_{11}+1+K)}}\Phi\left(1,1;\frac{K(1+K)}{\beta s\Omega_{11}+1+K}\right) \tag{61}$$

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