The Analysis of System Performance of An MC-CDMA System over Two-Tier Femtocell Networks

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***Abstract*—The paper is analyzing the evaluation of system performance for an MC-CDMA (multi-carrier coded-division multiple-access) system operating over two-tier femtocell environment. The considered scenario is deployed with a macrocell site where is surrounding some femtocells, which are designed to serve a group of subscribers locate in a small coverage area such as small office, home office or a house. Mostly, the femtocell is applied to serve indoor subscribers, thus, the Rayleigh fading is adopted to characterize the propagation channel between transceiver. The technique of TH-CDMA (time-hopped coded-division multiple-access) is supposed to transmit each symbol alternatively with fair time slot for each user in the hotspots (the area around *0^{th}* femtocell). The contribution of the paper is not only to evaluate the system performance with both the BER (bit error rate) according to the most important parameters, for example, the activating user number, the hopping number provided by TH-CDMA system and the subcarrier number.**

***Index Terms*—Time-hopped CDMA (TH-CDMA); hotspot; femtocell; macrocell; MC-CDMA; Rayleigh fading.**

I. INTRODUCTION

Recently, the last mile transmission has been attracted by the fact that cell phones have become indispensable in people’s life, especially in indoor wireless transmission. In order to go through the full path that the enough intensity of signal can arrive at the mobile unit of a subscriber located at indoor site, which is small coverage such as a building, home office, small firm or even in a mobile vehicle, the femtocell with two-tier networks are being to installed for improving cellular capacity. The reason of significant interest works in licensed spectrum to link traditionally to a mobile operation network without modifying mobile terminals. In general, the co-sited users (i.e., the mobile users located under the same coverage of a femtocell) is limited due to the coverage is smaller has in recent focused on the supplication of femtocells are: it is defined widely in the telecommunications industry as easily installed, low-cost, and low power cellular BS (base station) that than other kinds of base station (BS), in contrast the less interference caused to others subscribes, and can serve higher reuse of spectrum.Moreover, decentralized strategies for interference management may be much suitable for femtocells, because femtocells are mainly costing in traffic, installation fee, and without any operator influence [1].

Specifically, it is known that there are two in turn technologies for femtocells coverage, *i.e.*, relay and WiFi (IEEE802.16j). The coverage of radius of femtocells are in the tens of meters which is much smaller than that is of the macrocells radius range about in the hundreds of meters. Except the advantages mentioned before, the others are including prolong handset battery life and obtain a higher SINR (signal-to-interference-plus-noise ratio) [2]. However, the more are the desired signal components, the less the interference plus noise components are in a wireless system usually. Up to this moment, since the microcell has a much larger communication radius than that of a femtocell, and the centralized deployment of microcell site is adopted generally, the methods of loading balance user were proposed in [3], in which the authors derived by load balancing metrics used to optimize the hierarchical wireless data networks. The research published in [4], has analyzed an operation planned underlay of a macrocell with single/multiple microcells. The focus of outage probability analysis accounting for shadowing effects, cellular geometry, and cross-tier CCI (co-channel interference) is presented in [5], in addition, an robust interference avoidance scheme is also proposed to enable two-tier networks with universal frequency reuse to obtain higher channel capacity. By proposing the related issues to improve coverage by regulating femtocell transmit posers is researched in [6] by same authors of previous second published paper. The maximum femtocell contention densities at a distance between macrocell BS and analytically to search the solution of coverage zones within the subscribers can arrive at the QoS (quality of service) requirement are proposed in [7]. It is known that the cell site plan is one of the impact factors for the system performance of a user under a two-tier femtocell environment. In [8] the authors studied in tiered networks have definitely assumed that an operator planned underlay of a macrocell with single/multiple microcells. The investigation in CR (cognitive radio) with the schemes of sensing-throughput tradeoffs for computing optimal sensing time by CR users and limit transmit power of CR users are presented in [9] and [10, 11], respectively. The analysis of channel capacities in an a*d hoc* network with spatial diversity is illustrated in [12]. Though the factor has been proof that nearly 25 multiplies improvement in overall spatial reuse and has been proposed in related researches in [12], in which the assumption is moving from a marcocell-only network to a two-tier underlay with 50 femtocells per cell-site with the outage probability (OP) criteria.

On the basis of inspecting the analysis results from the aforementioned published paper, in this paper the system performance with the expression of BER (bit error rate) is investigated by definitely considering some possibly caused interferences due to a referenced user suffering from the real world transmitting environments of a two-tier femtocell environment. Seriously speaking, in order to obtain the most completely analyzed results of the system performance for the mobile unit operating in such an deployed environment with Rayleigh fading, at least three of

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the RF (radio frequency) interferences, for instance, (A) Macrocell-to-femtocell interference, (B) Femtocell-to-femtocell interference, (C) Femtocell-to-macrocell interference, arising from a femtocell-based cellular are should be included in the analysis of system performance for an MC-CDMA (multi-carrier coded-division multiple-access) system. This report is organized as follows. In Sect. II, the channel environments of an two-tier femtocell network are analyzed first; then the statistical analysis of the MC-CDMA system is derived in Sect. III, following the analytical results reported in Sect. IV, a brief conclusion is drawn in Sect. V.

II. ANALYSIS OF SYSTEM AND CHANNEL ENVIRONMENTS

Since the MC-CDMA system is popular in the related searches, the system descriptions will be ignored in the letter. However, it can be obtained in the published paper worked by the present author [13]. Under the condition which assumes that a two-tier femtocell structure is shown in Fig. 1. There are *M* femtocells and each is with *K* users normally distributed in a single macrocell site. An MC-CDMA system is adopted as the transmission technique and TH-CDMA (time-hopped CDMA) schemes is applied to dominate the time-slot (multiplex) for all the *M* femtocells included in macrocell. For the purpose of calculating the BER (bit error rare) performance for a referenced subscriber operating in an two-tier femtocell system, the MRC (maximal ratio combining) diversity is assumed to implement the receive the signal for a referenced user located on a femtocell. Thus, to determine the SINR (signal-to-interference-plus-noise) at the output of the MRC for the referenced user is necessary, and it is given as

$$\Upsilon_{SINR} = \frac{(S_{FEM})^2}{\sigma^2_{I_{AWGN}} + \sigma^2_{I_{FEM}}} \tag{1}$$

where $S_{FEM} = E[s_{fem}]$ is the average value of the received signal for the referenced user, and it can be obtained as

$$S_{FEM} = \sqrt{\frac{P_{r,F}}{2N}} \cdot E\left[\sum_{n=0}^{N-1} (\beta_{n,0})^2\right] \tag{2}$$

where $P_{r,F}$ denotes the received power of a user within a femtocell, N is the number of subcarrier, $\beta_{n,0}$ indicates the channel fading fraction of the *0th* received path at a femtocell site. The first term of the denomination in (1) expresses the AWGN component with a double-sided power spectral density of $N_0/2$, which is able to be calculated as

$$\sigma^2_{I_{AWGN}} = \frac{N_0}{4T_b} \sum_{n=0}^{N-1} (\beta_{n,o})^2 \tag{3}$$

where T_b is bit interval which is assumed smaller than the CDMA period, that is, $\mathrm{T}_b << T = G \cdot T_c$, where G denotes the processing gain, and T_c is the chip-time of the PN (pseudo-noise) sequence for a CDMA system. The second term of the denomination in (1) designates as all of the interferences caused from the sources around the femtocell. All of the interferences can be explained by the diagram shown in Fig. 2 where there are 5 macrocells working in the first tier, $M_0,...,M_4$ in which M_0 is chosen as the referenced macrocell, and the active user's numbers for each macrocell is assumed as $U_{M_0},...,U_{M_4}$. On the other hand, the femtocells are overlapped within in the first tier and the referenced femtocell is considered as $F_{M_0,0}$, then the other femtocell belongs to the macrocell of the first tier is indexed as $F_{M_1},...,F_{M_4}$. Similarly, $U_{F_{M_1}},...,U_{F_{M_4}}$ are used to express the active subscribers number located on the second femtocell. The figure says that the subscriber, U_{M_0}, in macrocell occupies the first time slot is communicating with the macrocell M_0. The femtocell $F_{M_0,0}$ holds on the second time slot, and femtocell $F_{M_0,1}$ is within the third time slot, and so on.. Moreover, it is naturally known that the interferences are comprised by three most mainly parts, which are including the interference comes from the macrocell, the other is the interference comes from different femtocells, and the last part is caused by the interfering of the same coverage area. However, for the purpose of simplicity in analytically analyze. It is only the interference mentioned below will be adopted to include in this report: the interference comes from the different femtocell $I_{F,I}$; the interference comes from the same femtocell, $I_{F,F}$; the interference induces from the macro-cell, $I_{F,C}$; and the interference causes from CCI (co-channel interference), $I_{C,F}$, which is ignored with the condition that the distance between fetmocell and macrocell site is assumed as large enough.

III. STATISTICAL ANALYSIS

In order to compute the SINR for the signal at the output of the decision maker, some of the statistical values such as the first and second moments should be calculated first. Generally, small sized femtocell is considered since it is installed in indoor applications. Hence, the variance of $I_{F,F}$ is given as [12]

$$\sigma^2_{I_{F,F}} = (Q_F \cdot \overline{\Psi}_i) \big/ |\mathrm{X}_i|^\alpha \tag{4}$$

where

$$Q_F = P_{r,F} \cdot R_f^\beta \cdot (\frac{\lambda_M}{\lambda_F}) \frac{(d_{0,M})^\alpha}{(d_{0,F})^\beta} \tag{5}$$

and

$$\overline{\Psi}_i = \sum_{k=1}^{K} \frac{Q_{k,F_j}}{Q_{k,F_i}} \tag{6}$$

The same second moment of Q_{l,F_j} and Q_{l,F_i} is σ^2_{dB}, and $\overline{\Psi}_i$ is a log-normal distribution with variance $2\sigma^2_{dB}$. The λ_M and λ_F are two empirical parameters deigned as $\lambda_M = [C/4\pi f_c d_{0M}]^2$ and $\lambda_F = [C/4\pi f_c d_{0F}]^2$, respectively, where d_{0M} and d_{0F} are corresponding to the reference distance for indoor loss of femtocell and macrocell, and $C = 3\times10^8$ *m/s*, f_c is the Doppler frequency. By substituting (5) and (6) into (4), the variance of $I_{F,F}$ can be obtained easily as

(2)

$$\sigma^2_{I_{F,F}} = \left[P_{r,F} R_f^\beta (\frac{\lambda_M}{\lambda_F}) \frac{(d_{0,M})^\alpha}{(d_{0,F})^\beta}\right] \Big/ |\mathrm{X}_i|^\alpha \tag{7}$$

(3)

Next, consider there are U_f activating users are working in the femtocell, the variance of $I_{F,I}$ can be determined as

$$\sigma^2_{I_{F,I}} = (U_f - 1) P_{r,(m)} \tag{8}$$

Finally, the variance of $I_{F,C}$ is able to be evaluated as

$$\sigma^2_{I_{F,C}} = \sum_{i=\Pi_c} P_{r,c} \overline{\Psi}_i (|\mathrm{X}| / |Y|)^2 \tag{9}$$

where $\overline{\Psi}_i$ has been defined in (6), and $P_{r,(c)}$ is the received power of a macrocell user.

The SINR, γ_{SINR}, expression of the MC-CDMA system can be calculated by substituting all of the results from the statically evaluated above to the formula, and expressed as (see Appendix)

$$\gamma_{SINR} = \frac{s/2}{\sum\limits_{i=\Pi_M} 2\sigma^2_{dB} (\frac{|\mathrm{X}_i|}{|Y_i|})^\alpha + 0.2\sigma^2_{dB} R_f^\beta (\frac{\lambda_M}{\lambda_F})(\frac{{d_{0M}}^\alpha}{{d_{0F}}^\beta}) \cdot U_{FM_0} |\mathrm{X}_i|^{-\alpha} + 0.1(U_{FM_0} - 1)\sigma^2_{dB} + \frac{N_0}{4E_b}} \tag{10}$$

where $s = \sum_{n=0}^{N-1} ({\beta_{n,o}}^2)$.

Once the SINR has been obtained, keep on the evaluation of system performance with the BER (bit error probability). Consequently, with coherent technical demodulation, the BER conditioned on the instantaneous *SINR* for an MC-CDMA system working in two-tier femtocell cellular network is given as [14]

$$P_r(error\,|\,\beta_l,\ l=0,1,\cdots,L-1)=Q\left(\sqrt{SINR}\right) \tag{11}$$

where β_l, $l=0,1,\cdots,L-1$, present the mean value of the desired signal, and $Q(\cdot)$ is the well-known Macuamm *Q*-function, which can be alternate expressed as [14]

$$Q(t)=\frac{1}{\pi}\int_0^{\frac{\pi}{2}}\exp(\frac{-t^2}{2\sin^2\theta})d\theta \tag{12}$$

Once the desired signal and the total interference are determined, the average error probability for an MC-CDMA system in correlated-Nakagami-*m* fading channels can be accomplished by averaging $P_r(error\,|\,\beta_l,\ l=0,1,\cdots,L-1)$ over L variates with the jpdf shown in (29), and denoted as

$$P_{av}=\overbrace{\int_0^\infty\int_0^\infty\cdots\int_0^\infty}^{L} P_r(error\,|\,\beta_l,\ l=0,\ 1,\cdots,\ L-1) \times f_{\beta_0,\cdots,\beta_{(L-1)}}(\beta_0,\cdots,\beta_{(L-1)})\cdot d\beta_0 d\beta_1\cdots d\beta_{L-1} \tag{13}$$

The previous equation involving *L*-fold integration can be evaluated by the detailed means given in Reference [15].

IV. NUMERICAL RESULTS AND DISCUSSION

The hop numbers of a TH-CDMA system generated to serves different femtocells surrounding around a macrocell definitely dominates the performance of a two-tier femtocell networks. This is proved by the results from the Fig. 3, in which the hop number with $N_{hop}=1$, and $N_{hop}=2$ are compared with the different values of the radius of marcocell, $d_{oc}=500,\ 1000,\ 2000,\ 3000$ meters, the user number is set as $U_f=2$, and the subcarrier number is $N=16$. It is easy to understand that the more of the hop number, the better of the system performance. In other words, the more of the hop numbers provided to a femtocell user and the outage probability (OP) decreased. Certainly, the results show that the system performance becomes deterioration when the radius is growing gradually. With the parameter $d_{oc}=500$ meter, the comparison results from different hop number, $N_{hop}=1,\ 2$, and different subcarrier number, $N=8,\ 16,\ 32,\ 64$, are shown in Fig. 4, where illustrates that the system performance becomes superior once the number of subcarrier is increased. Especially, it is worth noting that the phenomenon is much significant during the larger SNR (E_b/N_0) values. This point is accordance with the general characteristics of multi-carrier systems. Assigning subcarrier number $N=16$ and distance between macrocell and femtocell $d_{oc}=2000$ meter in Fig. 6 where shows the BER curves of an MC-CDMA system in a femtocell environment, $U_f=1,\ 2,\ 3$ and $N_{hop}=1,\ 2,\ 3$ are adopted as different user numbers and different hopping numbers, respectively. It is obviously to discover that when the time-hopped CDMA system provides with fewer hopping number to an MC-CDMA system's user who is activating under one of the referenced femtocell, the inferior system performance is going to be obtained. This fact is supported again by the reason that the hopping number definitely dominates the system performance of a multi-subcarrier system operating within a two-tier femtocell networks. However, it exists one critical problem in Fig. 5 is that the curve of $U_f=1$ and $N_{hop}=1$ is going to be superior to the curve with conditions of $U_f=3$ and $N_{hop}=2$ after $E_b/N_0=15$ about. This describes that the system performance becomes degradation when the number of user increases within an femtocell, that is, the multiple access interference (MAI) is getting larger gradually.

V. CONCLUSION

In the paper the evaluation of system performance for an MC-CDMA (multi-carrier coded-division multiple-access) system operating over single-cell with two-tier femtocell environments is derived and analyzed with the numerical results. The scenario is assumed that there are several femtocells arbitrarily distributed around a macrocell, and the Rayleigh fading environment is considered. Under the consideration of TH-CDMA scheme in alternatively spreading the data to each user with fair opportunity, the results show that the system performance is definitely dominated by the parameter of the hopping number. In addition, the number of subcarrier is still one of the important factors to affect the system performance of the MC-CDMA system operating in multi-user transmission systems.

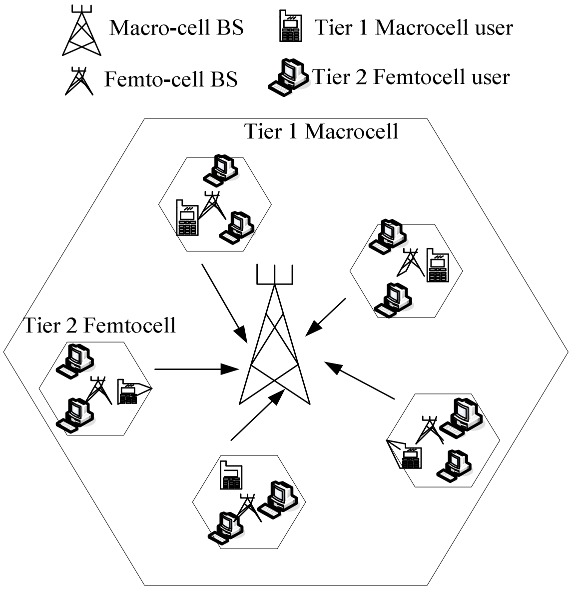

Fig. 1 The diagram of an two-tier femtocell application

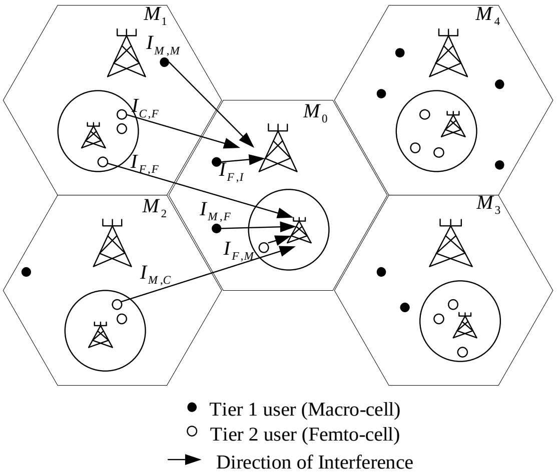

Fig. 2 The diagram shows different kind of interferences occur in a two-tier femtocell

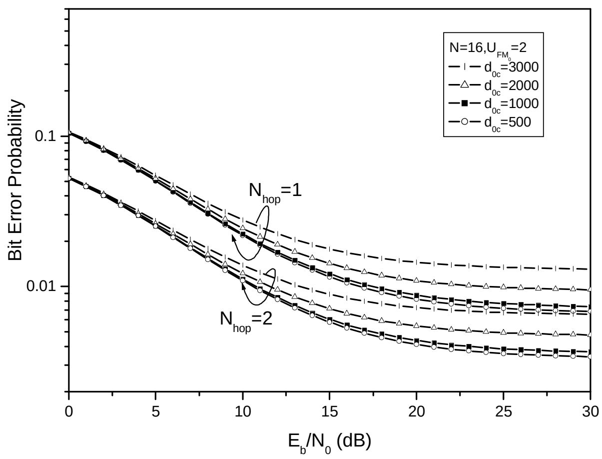

Fig. 3 The plots of SNR (E_b/N_0) vs BER under the assumption of different hopping numbers

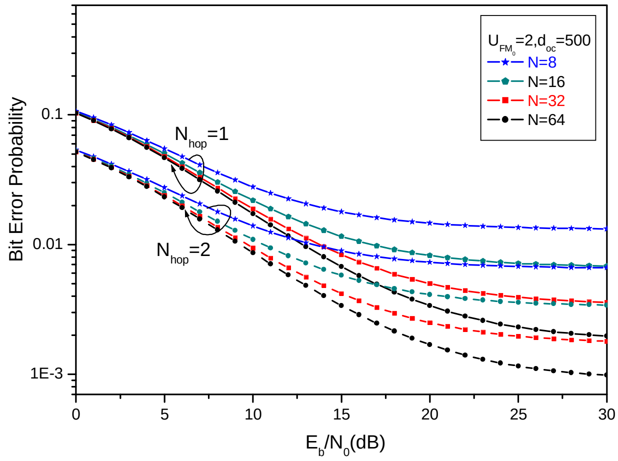

Fig. 4 The plots of SNR (E_b/N_0) vs BER under the assumption of different subcarrier numbers

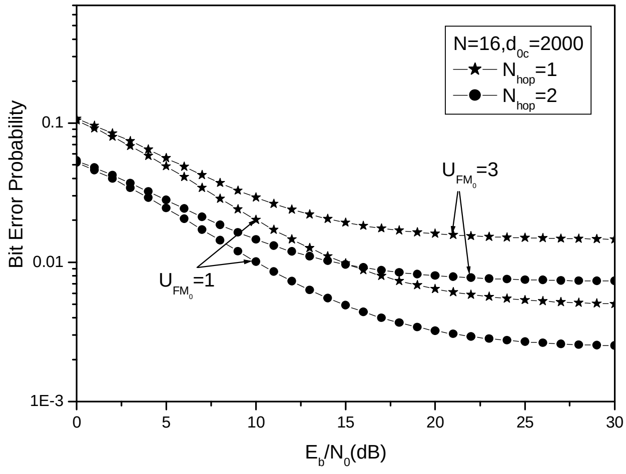

FIG. 5 THE PLOTS OF SNR (E_b/N_0) VS BER UNDER THE ASSUMPTION OF DIFFERENT SUBSCRIBER NUMBERS AND DIFFERENT HOPPING NUMBER

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