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Femtocell Networks in Indoor Environments

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ABSTRACT

This study investigates the channel correlation of a multiple-input multiple-output (MIMO) system tiered with a femtocellular network─specifically, a MIMO- femtocell (MIMO- FT) system, Channel correlation degrades the overall system performance of a wireless communication systems. Furthermore, this study argues that the coverage area of a MIMO-FT deployment will be reduced in size by channel correlation occurring in propagation channel. This study utilizes some derived analytical closed-form formulas to discuss the phenomenon of channel correlation occurring in MIMO-FT systems. In addition, an algorithm with precoding is explored for the purpose of mitigating the effects of channel correlation.

***Key Words*:** correlation channel, MIMO-femtocell, precoding, coverage area.

豪微微蜂巢於室內環境之研究

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摘　要

本文研究毫微微蜂巢部署於多輸入多輸出(multiple-input multiple-output, MIMO)系統所引起的通道相關因素，也就是 MIMO-femtocell 系統。據了解，通道相關性的現象肯定會降低無線通訊的整體性能。此外，我們主張 MIMO-femtocell 部署的覆蓋區域會下降的原因是因爲，在傳輸通道裡通道相關性的發生。文中利用一些推導到的解析性封閉公式，進行對存在於 MIMO-femtocell 系統中之通道相關現象進行討論。爲了克服通道相關的效應，前置編碼之演算法亦於文中進行探討；此外，利用一些數值結果的舉例來驗證說明所推得之結果。值得一提的是，如果考慮通道相關現象在 MIMO-femtocell 系統中，於基地站(base station, BS)覆蓋區域範圍內，並且以這篇文章之結果和之前發布過的文獻比較，其覆蓋區域範圍大約有 3-5 倍差異。

關鍵詞：通道相關，MIMO-femtocell，預編碼，覆蓋區域

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I. INTRODUCTION

The various channel correlation becomes very small, and can be assumed as equal to zero, when the angular spreading of the energy and/or the antenna separation at both terminals of the transmission elements are large enough. The aforementioned rules are hardly obeyed while the working area is indoor and/or a constrained place. In this investigation our contributions aim in exploring the correlation existing in the spatial diversity environments. In addition, the condition of spatial channel correlation which is taken into account the coverage area calculation for TTFN (two-tiered femtocell networks) adopts with MIMO (multiple-input multiple-output) channel environments. It is well-known that the correlation phenomenon caused between antennas and degrades system performance. Consequently, aforementioned reason leads the TTFN is always applied in constructing indoor building and inside room. The calculation of coverage area for f-AP (femtocell access point) hotspot within a TTFN has been gone through via the outage probability evaluation for a user communicating to a m-BS (macrocell base station) [1].

Recently, the application of MIMO signaling in wireless communications has spread widely [5, 11]. Especially, in combining with OFDM (orthogonal frequency division multiplexing) techniques, called MIMO-OFDM system, such form of technology gradually plays most important role becomes the candidate of 4G (4^{th} generation) communication systems [12]. In reviewing works addressed in MIMO system, the authors in [9] has validated a stochastic MIMO radio channel model with experimental research and has derived a lot of analytically useful results for analyzing system performance. System performance in channel capacity and capacity-range of beamforming in MIMO wireless systems are evaluated in [8] where considered the conditions of correlated fading channel phenomena with covariance feedback. Furthermore, an adaptive MIMO transmission was proposed in [3] to exploit the capacity performance in the scenario of spatially correlated channels. The publication [13] in which authors evaluated the system capacity for MIMO system operating in Rayleigh fading channels over the presence of interference and receive correlation. However, the channel capacity of MIMI environments was questionable in many aspects, such as the limitation in capacity of MIMO channel was studied in [4]. The issue of increasing linear throughput with multiple receives was addressed in [7] where the authors evaluated the throughput for MIMO wireless network in advanced.

On the other hand, it's worthy to look deeply into the background of femtocell for the development of last mile technologies. It's known that, the architecture of femtocell can provide with some advantages, such as low-power, short-coverage, high-throughput. Such a cellular base station is generally deployed indoors hotspot setting, such as enterprise or residential, and it offers excellent access to specialized femto-area applications and user experience at indoor to customers. In words, it reduces the costs of maintenance and infrastructure by using of self-organizing for operators. In reviewing the research reports, outage probability analysis accounting for shadowing effects, cellular geometry and cross-tier CCI (co-channel interference) was presented in [6]. In addition, same authors of [6] proposed a robust interference avoidance scheme to enable two-tier networks with universal frequency reuse to obtain higher channel capacity. Related issues to improve coverage by regulating femtocell transmit power were researched in [11]. Moreover, a tractable approach exploring in coverage and rate in cellular networks was investigated in [5].

In this report the scenario with indoor environment are assumed for exploring the system performance in channel capacity of MIMO-FT system. This report is organized as follows. In Section 2, the system environments of two-tier MIMO-FT network are constructed first. The analysis of coverage area for a f-AP (femtocell access point) over spatial correlated channel is derived in Section 3. The analytical results are reported in Section 4 and a brief conclusion is drawn in Section 5.

II. SYSTEM MODELS

On the view point of MIMO systems, it's known that the femtocell receiver with T_f dimensions can generally either cancel the interference comes from certain transmitters, enlarge the power intensity of the desired signal, or some combination of the aforementioned system with a two-tier network architecture.

Refer to the fact validated by [2] in which the use of Poisson point process to characterize the base station location and to take over a general lattice for two-tier architecture has tractable model and obtainable accuracy. A two-tier network equipped with multiple antenna shown in Fig. 1 is considered in this article, a set of randomly deployed f-APs, Ψ_f, $f=0,\cdots,F$, as following a homogeneous PPP with intensity,

ι_f . Each femtocell over second tier is with constant transmit power, P_f , and consists of clusters which can serve maximum T_f users. All users are considered distributed independently and uniformly in its designated f-AP. For adapting the MIMO model to the two-tier femtocell environments, the application of linear ZF (zero-forcing) precoding transmission with directional antenna is necessary. Thus, each f-AP is designated individually with channel direction antenna denoted as $\mathbf{F_f} = \| f_{f,T_f} \|^{-1} [f_{f,0}, f_{f,1}, \cdots, f_{f,U_f-1}]^{\dagger} \in C^{U_f \times T_f}, 1 \le U_f \le T_f$, for subscribers within its cover area, where f_{f,T_f} is modeled as $CN(0,1)$, $\| \cdot \|$ is Euclidean norm, and † denotes the conjugate transpose. The precoding matrix with column matrix, $W_{\mathbf{f}} = \left[w_{f,i} \right] \in C^{T_f \times U_f}, 1 \le i \le U_f$, which is equivalent to the normalized column of $(\tilde{\mathbf{F}}_f \tilde{\mathbf{F}}_f^{\dagger})^{-1} \in C^{T_f \times U_f}$ for ZF beamforming scheme.

Surrounding the second tier a macrocell m-BS, Ω , is overlaying with femtocell designated to a homogeneous PPP with intensity, ι_m , that is, $\Omega \sim PPP(\iota_m)$, as shown in Fig. 1. The macrocell over the first tier is providing with constant transmit power, P_m , for maximum T_m users. The method of linkage for T_m users within the macrocell communicate to m-BS is decided by the femtocells, nevertheless, the open access is assumed in this discussion. When two-tier networks operate in open access, a user within macrocell can access to both m-BS and f-APs, as long as it is within the femtocell coverage area. In addition, it is considered distributed independently and uniformly for all f-APs and access users in its designated m-BS. Similarly, for employing MIMO model to the two-tier femtocell environments and the application of linear ZF. m-BS, is designated individually with channel direction antenna indicated as $\mathbf{M_m} = \| m_{m,T_m} \|^{-1} [m_0, m_1, \cdots, m_{U_m-1}]^{\dagger} \in C^{U_m \times T_m}, 1 \le U_m \le T_m$, for subscribers within its coverage area, where m_{m,T_m} modeled as $CN(0,1)$.

For the reason of obtaining analytical tractable results this investigation focuses on the discussion of channel correlation phenomenon occurs in an MIMO-FT system. Though the system performance becomes inferior without imperfect channel estimation, the ignoring CSI (channel state information) is considered at the base station of both f-AP and m-BS. By the way, it not only the interference comes from neighboring m-BSs is assumed able to be ignored because the fact that the separation between them is far enough, but the CCI (co-channel interference) is also declared avoidable by using suitable arrangement of channel spectrum. Such scenario can be solved by the scheme of restricted channelization with grouping successive fixed number of subcarrier to compose as subchannel with B_S *Hz* from the total available spectrum B_T *Hz* for signal propagation. Explaining briefly the aforementioned scheme can diminish system overhead with respect to the amount of feedback from CSI. The total available number of subchannels now are $b_i \in \{ \lfloor B_T / B_S \rfloor \}$, *i.e.*, $\{b_0, \cdots b_{N-1}\}$ expressing the first one to the last available subchannels for MIMO-FT system.

Once the scenario of a two-tier femtocell network is modeled completely, to establish the characteristics of correlated MIMO-FT channel is necessary. Hereafter, the MIMO-FT system is assumed as with spatially correlated fading channel. Fig. 1 shows the indoor scenario of deployment with two-tier MIMO-FT system, *e.g.*, 2 femcells are built up in room A and E (f-AP-A1, f-AP-A2, and f-AP-E1, f-AP-E2), and a single femtocell is distributed in the other rooms (f-AP-B1, f-AP-C1, f-AP-D1). In the article two cases with spatial correlated channel are assumed to be analyzed. One of the cases assumes that the spatial correlation happens between femtocells within the same room, and the other consideration is the spatial correlation caused between femtocell located in different rooms.

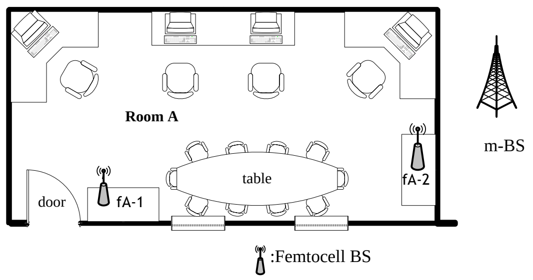

Fig. 1. Top view of the deployment of MIMO-FT in a living home

III. OUTAGE PROBABILITY EVALUATION

The outage probability is evaluated by preset a threshold value at the receiver, *i.e.*, it is considered as the cumulated distribution function of a effective SNR at a receiver terminal. Accordingly, after MIMO-FT signaling scheme is completed, the SNR (signal-to-noise ratio) at the receiver output over a spatially correlated channel can be given as

$$\gamma(\eta) = SNR / \log_2(M) = C\eta \|\mathbf{H}\|^2 \tag{1}$$

where $C = 1/R_s n_t \log_2 M$, and η is defined as SNR per channel, i.e., $\eta = P / \sigma^2$, where P is the total transmission power. In (1) $\mathbf{H} = \sqrt{R_r} \mathbf{H}_C \sqrt{R_t}$, denotes the spatially correlated MIMO-FT channel matrix, where $[R_r]_{n_r \times n_r}$ and $[R_t]_{n_t \times n_t}$ are represent as the matrix for determining the correlation between receiver and transmitter antennas, respectively. Accordingly, the MGF (moment generating function) is for applying in determining pdf (probability density function) of the SNR in (1) adopted in this paper. Consider $[\lambda_i,\ i=1,\cdots,L]$ are the nonzero eigenvalues of the Kronecker product of the matrix $[R_t]_{n_t\times n_t}$ and $[R_r]_{n_r\times n_r}$. Hence, by using the theory of stochastic process the pdf of instantaneous SNR over MIMO-FT correlated channel can be obtained as [10]

$$f_{\gamma(\eta)}(\gamma_c(\eta)) = \frac{1}{\Delta(\eta)}\sum_{n=0}^{N-1}\sum_{l=0}^{L-1}\Lambda_{n,l}(\eta)\cdot[\gamma_c(\eta)]^{l-1}\cdot\exp\left[-\left(\gamma_c(\eta)/C\eta\varphi_n\right)\right]\Big/(l-1)! \quad (2)$$

where $\Delta(\eta)=\prod_{n=1}^{N}(C\eta\varphi_n)^{u_n}$, $\varphi_n=\lambda_{1+\sum_{m=1}^{n-1}u_m}=\cdots=\lambda_{\sum_{m=1}^{n}u_m}$, for $n=0,\cdots,N-1$, where $\sum_{m=1}^{n}u_m=R$, and

$$\Lambda_{n,l}(\eta)=(-1)^{u_n-1}\sum\prod_{\substack{j=1\\ j\neq n}}^{N}\binom{u_j-1+i_j}{i_j}\left(\frac{1}{C\eta\varphi_j}-\frac{1}{C\eta\varphi_n}\right)^{-(u_j+i_j)} \quad (3)$$

Calculating SIR (signal-to-interference ratio) for a femtocell subscriber who is operating in one of the f-AP and at distance D_m from one of the m-BS, only the cross-tier interference is considered into the SIR. On the other hand, the intra-tier interference and background noise are assumed ignorable when some adjustment or applying suitable filters. Since each term in $\|f_\cdot T_f\|^2$ is equivalent to the squared modulus of complex normal distribution, $CN(0,1)$, the cross-tier interference is modeled as Chi-square distribution with U_C-1 degree of freedom, *i.e.*,

$$f_{I_{fc}}(x)=f_{\|f_0 V\|^2}(x)=\frac{x^{U_C-1}\cdot e^{-x/2}}{2^{U_C}\cdot\Gamma(U_C)} \quad (4)$$

Now, SIR, $Z=\gamma(\eta)/I_{fc}$, which is a random variable thought as the form of $Z=X/Y$. It is necessary to determine the pdf of Z for evaluating outage probability of MIMO-FT system over spatially correlated channel. Because X is independent of Y in SIR, by using of associating with pdf of corresponding to random variables X and Y, *i.e.*, multiplying (4) to (2) the jpdf (joint pdf) can be obtained as

$$f_{x,y}(x,y)=\frac{1}{\Delta(\eta)}\sum_{n=0}^{N-1}\sum_{l=0}^{L-1}\frac{\Lambda_{n,l}(\eta)}{(l-1)!}y^{l-1}\exp\left(-y/C\eta\varphi_n\right) \times x^{U_C-1}\cdot\exp\left(-\frac{x}{2}\right)\Big/2^{U_C}\cdot\Gamma(U_C) \quad (5)$$

Thus, the pdf of random variable Z can be easily gained with the formula given as

$$f_z(z)=\int_{y=0}^{\infty}y\cdot f_{xy}(yz,y)\,dy \quad (6)$$

By substituting (5) into the previously equation, the pdf of SIR now becomes as

$$f_z(z)=\frac{1}{\Delta(\eta)}\sum_{n=0}^{N-1}\sum_{l=0}^{L-1}\frac{\Lambda_{n,\ell}(\eta)}{(l-1)!}\cdot\frac{z^{U_C-1}}{2^{U_C}\cdot\Gamma(U_C)}\cdot\int_0^{\infty}y^{(l+U_C-1)}\cdot\exp(-y\kappa)\,dy \quad (7)$$

where $\kappa=1/C\eta\varphi_n+z/2$, and by means of special integral, $\int_0^{\infty}y^{a-1}\cdot\exp(-y\kappa)dy=\Gamma(a)/\kappa^a$, in last equation, and (7) is going to become as

$$f_z(Z)=\frac{1}{\Delta(\eta)}\sum_{n=0}^{N-1}\sum_{l=0}^{L-1}\frac{\Lambda_{n,l}(\eta)}{(l-1)!}\frac{z^{U_C-1}}{2^{U_C}\cdot\Gamma(U_C)}\cdot\frac{1}{\kappa^{(l+U_C-1)}}\Gamma(l+U_C-1) \quad (8)$$

The research focuses on the determination of coverage area of separation, D_f, which involves the spatial channel correlation in MIMO model embedded into a two-tier femtocell system. For the evaluation of results from the phenomenon of spatial correlated channels over the MIMO-FT networks.

Consequently, the outage probability for the user who is active in a f-AP constrained by the total power transmitted from femtocell, E_f, which is defined as [2]

$$E_f \overset{\Delta}{=} \frac{P_m/U_C}{P_f/U_f}\cdot\frac{A_{fm}}{A_{fc}}\frac{D^{-\alpha_m}}{R_f^{-\alpha_f}} \quad (9)$$

where P_m (resp. P_f), A_{fm} (resp. A_{fc}), and α_m (resp. α_f) represent transmitted power, fixed decibel path loss, and path loss exponent of m-BS (resp. femtocell), respectively. Since the spatial correlation fading channel for MIMO-FT system is considered in indoor cases in this article, the shadowing fading is basically ignored.

The outage probability is a minimum requirement to satisfy the QoS (quality of service) within the f-AP of MIMO-FT system. Thus, the outage probability can be estimated by substituting (8) into $P(Z\le E_f)=\int_0^{E_f}f_Z(z)dz$ which is determined as

$$P(Z\le E_f)=\frac{1}{\Delta(\eta)}\sum_{n=0}^{N-1}\sum_{l=0}^{L}\frac{\Lambda_{n,l}(\eta)}{(l-1)!}\frac{\Gamma(l+U_C-1)}{2^{U_C}\cdot\Gamma(U_C)}\cdot\frac{(E_f)^{U_C}(C\eta\varphi_n)^{(l+U_C-1)}}{U_C} \times {}_2F_1(l+U_C-1,U_C;U_C+1;-\frac{E_fC\eta\varphi_n}{2}) \quad (10)$$

where E_f has been defined in, and ${}_2F_1(\cdot,\cdot;\cdot;\cdot)$ is the confluent hypergeometric function. The nomenclature is shown in the Table I.

IV. NUMERICAL RESULTS

In this section the simulation results from scenario of the first case is illustrated. The encoding scheme is considering Almouti's coding. A scenario deployed with two antennas and four antennas corresponding to m-BS and femtocell receiver is adopted. By means of transmit and receive correlation coefficients matrices, the correlation coefficient can be obtained easily, and the correlation coefficient of the transmission terminal is fixed at $\rho_t = 0.9$. Arranging the $SNR = 20dB$ for the subscriber within a desired f-AP, the radius of m-BS is *500* meter, the path loss exponent are assigned as $\alpha_c = 3.8$ and $\alpha_f = 2.5$ for m-BS and f-AP, respectively. The reason of considering smaller value to f-AP path loss exponent is the femtocell located at indoor area. In Fig. 2 shows the results of system outage probability versus normalized femtocell radius, R_f / R_c, which means the radius of femtocell normalized that of the macrocell. The curves are simulated with that the correlation coefficients are from $\rho_r = 0.1$ to $\rho_r = 0.8$. It is easily to see that the plots shown in Fig. 2 where the outage probability is getting larger when the deeper correlation happened. On the other hand, it is valuable to present that the gap between the larger two correlations is much wide than that is between the smaller two. For example, the gap between $\rho_r = 0.7$ to $\rho_r = 0.8$ is double of that is between $\rho_r = 0.6$ to $\rho_r = 0.7$. Specifically, the reason of mentioned previously is caused by the indoor channels. Moreover, due to the correlation fading channel is considered to MIMO-FT, when compare to the outcome which was evaluated in [10] the system outage probability becomes inferior.

V. CONCLUSION

In this paper a case with spatial correlation fading channel which occurs in MIMO-FT system is explored. The indoor case of deploying 2 femtocells is considered in the larger same room. By adopting to calculate the outage probability of a desired user within the MIMO-FT coverage area, and validating the accuracy of the results. The results from the numerical evaluation are clearly shown accordance with the outcome of comparing to published work. In addition, the system performance will be suffering from degrade when take the correlation fading parameters into account.

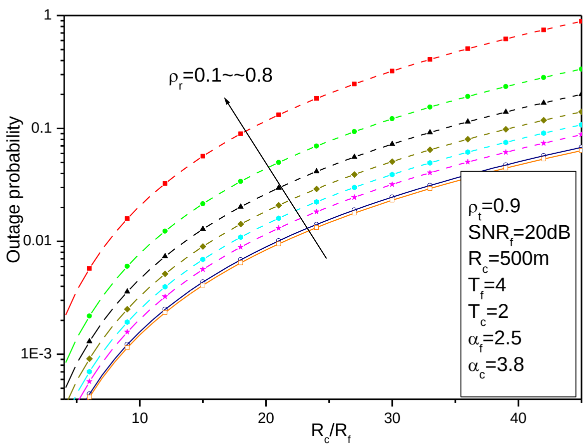

Fig. 2 Outage probability versus normalized f-AP Radius with different correlation coefficients

Table 1. Nomenclature

Symbols	Means
A_{fm}	Fixed f-AP decibel path loss
A_{fc}	Fixed m-BS decibel path loss
b_i	Available number of subchannels
$CN(0,1)$	Complex Normal distribution
D_m	Distance from f-AP to m-BS
$E[\cdot]$	Expectation operator
E_f	Total f-AP transmitted power
${}_2F_1(\cdot,\cdot;\cdot;\cdot)$	Confluent hypergeometric function
γ	The SNR at the receiver output
I_{fc}	
η	SNR per channel
ι_f	f-APs intensity
ι_m	m-BS intensity
L	Channel number
$\lambda_i,\ i = 1,\cdots,L$	Nonzero eigenvalues
$M_0,...,M_2$	Macro-cells
P	Total transmission power
P_f	f-APs transmit power
P_m	Transmit power
P	Outage probability
R_M, R_f	Macro/Femtocell Radius
$[R_r]_{n_r \times n_r}$ and $[R_t]_{n_t \times n_t}$	Matrix for determining the correlation between receiver and transmitter antennas
T_b	Bit interval
T_f	Receiver antenna dimensions
T_m	maximum users
U_f	Poisson mean user per femtocell
U_{M_0}	Macrocell active user's numbers
X , Y	Random variables
Z	Target SIR per tier
α_m and α_f	f-AP and m-BS path-loss exponent
$\overline{\Psi}_i$	Circular coverage area

W_f	Precoding matrix
Ω	a macrocell m-BS

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