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Adaptive Femtocell Design Scheme in Mobile Communication Systems

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Abstract Mobile communication technologies have been evolving very rapidly and providing many advantages with mobile users. However, the amount of data traffic has increased significantly due to rapid expansion of mobile market. Recently, femtocell which is known as indoor base station is considered as the key solution to combat the data traffic. Femtocell provides mobile users with better quality of service. However, deployment of femtocell is not so easy due to inter-cell-interference (ICI) with existing macrocell. Signals from base stations are transmitted by a form of electronic magnetic waves. So, these waves undergo interference each other. Thus, this paper proposes the design scheme for femtocell which can reduce the influence of ICI. And also, proposed femtocell operates adaptively in accordance with reliability of system. With this proposed scheme, free and easy deployment of femtocell is expected.

Keywords Femtocell · Macrocell · OFDM · Spatial diversity · Spatial multiplexing

1 Introduction

In rapidly growing mobile communication systems, the demand for high data rate and reliable services has been increased. The studies on wireless communications usage show that over 70% of data traffic occurs indoors [1]. In this situation, femtocell is developed to achieve these goals. Femtocell is known as indoor base station which has short cell range (15–30 m), low-power and low-cost device compared to existing macrocell. So, femtocell is very prospective research area for the next-generation mobile communication. Generally, transmitted signals which are transmitted by a form of electronic magnetic wave

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undergo fading channels. Received signals are composed of line-of-sight (LOS) signals and non-line-of-sight (NLOS) signals due to reflection from obstacles or buildings. Due to NLOS signals, inter-symbol-interference (ISI) occurs and it brings poor quality of service (QoS) to the mobile users. So, ISI leads receiver to need complex equalizer. Femtocell based on orthogonal frequency division multiplexing (OFDM) uses parallel multi-carrier transmission scheme which has orthogonal relationship each other for robustness to ISI. Because the rate of each subcarrier is low, OFDM is robust to multi-path fading because each subcarrier undergoes frequency flat fading channels. However, a few subcarriers may undergo deep fading channel. This problem is easily solved by channel coding scheme. So, unlike single carrier transmission system, OFDM receiver does not need complex equalizer. In fact, femtocell based on OFDM is applied to the mobile communication systems such as Long Term Evolution (LTE) [2] and will be expected to 5-Generation systems. Thus, mobile users will deploy femtocell increasingly in their homes or offices demanding for better QoS. However, the deployment of femtocell is not so easy because femtocell undergoes inter-cell-interference (ICI) with existing macrocell. Interference between femtocell and macrocell is one of the major issues in multi-cellular femtocell communication and also provides mobile users with poor QoS [3]. So, this paper proposes femtocell design scheme to deploy the femtocell freely and easily. Proposed femtocell can solve the degradation of reliability derived from ICI and also operate adaptively in accordance with reliability of system to satisfy the requirement of mobile users efficiently.

2 System Model

The system consists of two transmitters which have a single antenna respectively and one mobile station which has two antennas as shown in Fig. 1. The channel coefficient from transmitter to receiver is $h_{ij},\ i,j = 1,2$. i means receiving antenna index and j means transmission antenna index. Each channel distribution is assumed to Rayleigh fading channel and spacing of macrocell antenna and femtocell antenna is at least 10λ where λ denotes the wavelength. So, all channels are independent each other. Also there are no other macrocell, femtocell and mobile station within cell coverage area to simplify the system model. So, there is only one type of interference between macrocell and femtocell. Finally, the received signals based on OFDM in this system model are as follows,

$$\mathbf{Y} = \sum_{i=1}^{2}\sum_{j=1}^{2} h_{i,j}s_j + n_i = \mathbf{HX} + \mathbf{N} \tag{1}$$

where s_j means transmission wave from the j-th transmission antenna and n_i means additive white Gaussian noise (AWGN) in the i-th receiving antenna. However, in this system model, electromagnetic interference which may have large or small scale occurs due to transmitted wave from existing macrocell. Thus, femtocell needs any other transmission and receiving schemes to overcome the influence of ICI.

3 Proposed Scheme

To solve the degradation of reliability due to influence of ICI, femtocell which has two modes based on OFDM is proposed. One of these modes is spatial diversity mode and another mode is spatial multiplexing mode. And the proposed femtocell can convert its

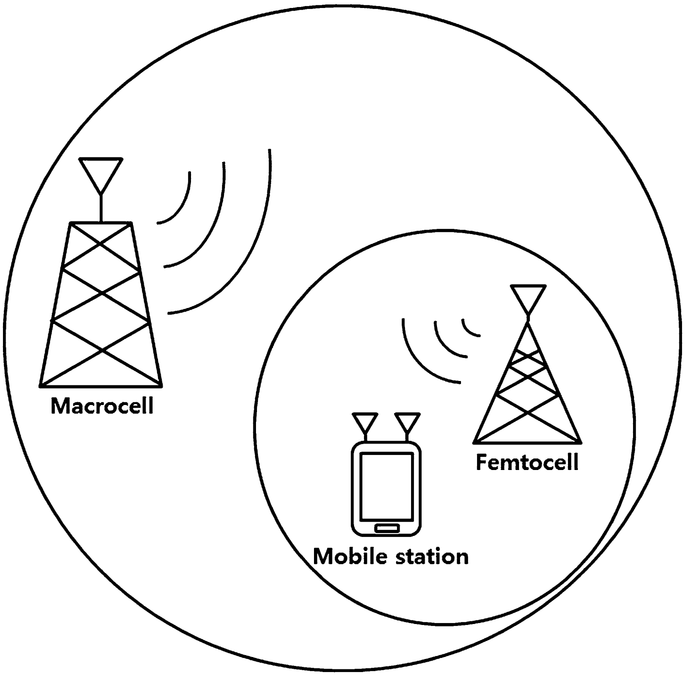

Fig. 1 System model of femtocell and existing macrocell in multi-cellular mobile communication

mode adaptively in accordance with reliability of system which is known to femtocell from uplink channel. Figure 2 shows an overview of proposed adaptive femtocell. As shown in Fig. 2, the femtocell mode is selected by reliability of system and these modes can be changed adaptively in accordance with reliability of the system. When reliability of system is low, femtocell converts its mode into spatial diversity mode. On the other hand, when reliability of system is high, femtocell converts its mode into spatial multiplexing mode.

3.1 Spatial Diversity Mode

In the proposed femtocell, the used spatial diversity scheme is cyclic delay diversity (CDD). The system which uses CDD scheme transmits cyclically delayed signals in the time domain. The purpose of CDD scheme increases frequency selectivity of channel. So, receiver can get high quality signal, i.e. high signal-to-noise (SNR) when channel coding scheme is used [4]. In Fig. 1, macrocell transmits non-shifted signal and femtocell transmits δ_{cyc}-shifted signal.

3.1.1 Transmission Signals from Each Cell

There are two transmission signals in the system model. Transmission signal $x_{\mathrm{c,MC}}(l)$ from macrocell after N-point inverse fast Fourier transform (IFFT) process is as follows,

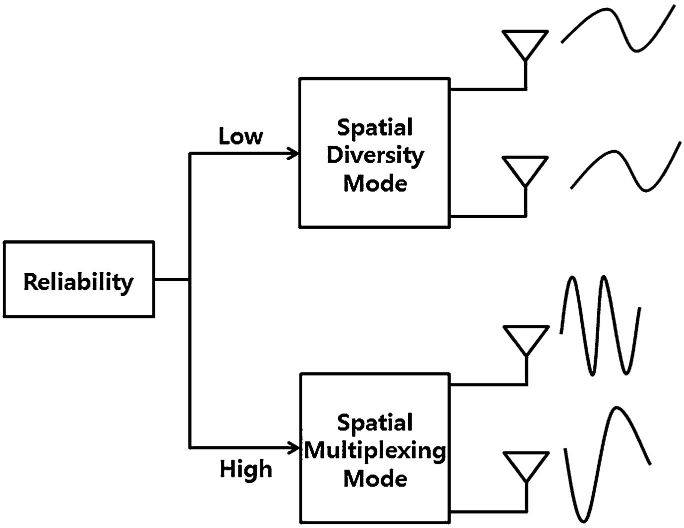

Fig. 2 Block diagram of proposed femtocell scheme

$$x_{\mathrm{c,MC}}(l) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_{\mathrm{c,MC}}(k) e^{j\frac{2\pi kl}{N}}, \tag{2}$$

where l denotes the time index, $e^{j\frac{2\pi kl}{N}}$ denotes the k-th subcarrier and $X_{\mathrm{c,MC}}(k)$ denotes the digitally modulated symbol at the k-th subcarrier.

And also, transmission signal $x_{\mathrm{c,FC}}(l)$ from femtocell after IFFT process is as follows,

$$x_{\mathrm{c,FC}}(l) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_{\mathrm{c,MC}}(k) e^{-j\frac{2\pi k\delta_{cyc}}{N}} e^{j\frac{2\pi kl}{N}}, \tag{3}$$

where $e^{-j\frac{2\pi k\delta_{cyc}}{N}}$ denotes the phase diversity due to δ_{cyc}-cyclic shift.

3.1.2 Received Signals in Mobile Station

Received signals $\mathbf{Y}_{\mathrm{c,MS}}(k)$ which undergo Rayleigh fading channels after N-point fast Fourier transform (FFT) process are as follows,

$$\mathbf{Y}_{\mathrm{c,MS}}(k) = \begin{bmatrix} H_{11}(k) & H_{12}(k) \\ H_{21}(k) & H_{22}(k) \end{bmatrix} \begin{bmatrix} X_{\mathrm{c,MC}}(k) \\ X_{\mathrm{c,FC}}(k) \end{bmatrix} + \begin{bmatrix} W_{\mathrm{c,MC}}(k) \\ W_{\mathrm{c,FC}}(k) \end{bmatrix} \tag{4}$$

where $W(k)$ denotes the AWGN. Transmission signals from femtocell and macrocell are different from phase in frequency domain due to cyclic shift. So, received signals are equalized by estimated composite channel. The transfer function of composite channel $H_{c,i}(k)$ is as follows,

$$H_{c,i}(k) = \frac{1}{\sqrt{2}} \sum_{j=1}^{2} H_{ij}(k) e^{-j\frac{2\pi l\delta_{cyc,j}}{N}}, \tag{5}$$

where $H_{ij}(k)$ denotes the transfer function of $h_{ij}(l)$.

The received signals can be equalized by transfer function of composite channel. For higher error performance, maximum ratio combining is used. So, spatial diversity mode of proposed femtocell using CDD scheme removes the influence of ICI and makes the reliability of system very high. Thus, mobile users can deploy femtocell easily and freely. On the other hand, when reliability of system is high, femtocell converts its mode into spatial multiplexing mode for higher data rate.

3.2 Spatial Multiplexing Mode

Multiple-input multiple-output (MIMO) system gets spatial multiplexing gain by transmitting different data to be transmitted simultaneously from the different transmission antenna [5, 6]. In the proposed femtocell, the used spatial multiplexing scheme is minimum mean square error (MMSE)-decision feedback equalizer (MMSE–DFE) because MMSE–DFE has great error performance with low complexity compared to many nonlinear spatial multiplexing schemes or many successive interference cancellation (SIC) spatial multiplexing schemes [7, 8].

3.2.1 Transmission Signals from Each Cell

There are two transmission signals in the proposed system model like spatial diversity mode. Transmission signals from macrocell and femtocell which are notated by $x_{s,\mathrm{MC}}(l)$ and $x_{s,\mathrm{FC}}(l)$ respectively after N-point IFFT process are as follows,

$$x_{s,\mathrm{MC}}(l) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_{s,\mathrm{MC}}(k) e^{j\frac{2\pi kl}{N}}, \tag{6}$$

$$x_{s,\mathrm{FC}}(l) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_{s,\mathrm{FC}}(k) e^{j\frac{2\pi kl}{N}}. \tag{7}$$

3.2.2 Received Signals in Mobile Station

Received signals $\mathbf{Y}_{s,\mathrm{MS}}(k)$ which undergo Rayleigh fading channels after N-point FFT process are as follows,

$$\mathbf{Y}_{s,\mathrm{MS}}(k) = \begin{bmatrix} H_{11}(k) & H_{12}(k) \\ H_{21}(k) & H_{22}(k) \end{bmatrix} \begin{bmatrix} X_{s,\mathrm{MC}}(k) \\ X_{s,\mathrm{FC}}(k) \end{bmatrix} + \begin{bmatrix} W_{s,\mathrm{MC}}(k) \\ W_{s,\mathrm{FC}}(k) \end{bmatrix}. \tag{8}$$

To simplify the mathematical notation, the subcarrier index k is dropped. At first, pseudo-inverse matrix $\mathbf{G}_{\mathrm{MMSE}}$ is calculated.

$$\mathbf{G}_{\mathrm{MMSE}} = \left(\mathbf{H}^H\mathbf{H} + \sigma^2\mathbf{I}\right)^{-1}\mathbf{H}^H. \tag{9}$$

Then, norm of each row of $\mathbf{G}_{\mathrm{MMSE}}$ is calculated to decide the interference cancelling order for higher reliability. So, new matrix which is sorted in descending order is defined as $\mathbf{G}_{\mathrm{sort}}$. Likewise, column of channel matrix $\mathbf{H}$ is also sorted like $\mathbf{G}_{\mathrm{sort}}$ and it is defined as $\mathbf{H}_{\mathrm{sort}}$. After sorting process, QR decomposition of $\mathbf{H}_{\mathrm{sort}}$ is proceeded. In the QR decomposition, $\mathbf{Q}$ means quadrature matrix which is satisfied with $\mathbf{Q}^H\mathbf{Q} = \mathbf{I}$ and $\mathbf{R}$ means upper triangular matrix. Then, QR decomposed matrix of $\mathbf{H}_{\mathrm{sort}}$ is as follows,

$$\mathbf{H}_{\text{sort}} = \mathbf{Q}\mathbf{R} = [\mathbf{q_1}\ \mathbf{q_2}]\begin{bmatrix} r_{11} & r_{12} \\ 0 & r_{22} \end{bmatrix}, \tag{10}$$

where $\mathbf{q_i}$, $i = 1, 2$ denotes the i-th column of $\mathbf{Q}$. So, modified received signal $\mathbf{Y}$ is as follows,

$$\mathbf{Y} = \mathbf{H}_{\text{sort}}\mathbf{X} + \mathbf{W} = \mathbf{QRX} + \mathbf{W}. \tag{11}$$

To remove the influence of $\mathbf{Q}$, the hermitian of $\mathbf{Q}$ is multiplied by the left side of $\mathbf{Y}$.

$$\mathbf{V} = \mathbf{Q}^H\mathbf{Y} = \mathbf{RX} + \mathbf{Q}^H\mathbf{W}, \tag{12}$$

where $\mathbf{V}$ denotes $[v_1 \quad v_2]^T$ and $\mathbf{Q}^H\mathbf{W}$ is modified noise which has same statistical property with existing $\mathbf{W}$.

Finally, estimated transmission signals from macrocell and femtocell are obtained successively with the process of decision feedback. It is assumed that transmission signal from femtocell is estimated at first.

$$\hat{X}_{\text{s,FC}} = Q(v_2/r_{22}), \tag{13}$$

$$\hat{X}_{\text{s,MC}} = Q\big((v_1 - r_{12}\hat{X}_{\text{s,FC}})/r_{11}\big), \tag{14}$$

where Q(·) means quantization function. The detection performance of $\hat{X}_{\text{s,MC}}$ is dependent on how well $\hat{X}_{\text{s,FC}}$ is estimated. So, the ordering is very important process.

So, spatial multiplexing mode of proposed femtocell using DFE scheme not only removes the influence of ICI but also makes the reliability and data rate of system high. Thus, mobile users can deploy femtocell easily and freely. Proposed femtocell converts its modes adaptively in accordance with reliability of system for mobile users to get both high reliability and data rate.

4 Simulation Results

This section shows bit error rate (BER) performance and throughput performance. The used simulation parameters are expresesed in Table 1. Figure 3 shows BER performance of conventional femtocell, existing macrocell, and proposed femtocell. For conventional femtocell, interference occurs due to the transmission signal of existing macrocell. So, despite of high SNR, very poor BER performance is shown. And for existing macrocell which is in the absence of femtocell, the used receive diversity scheme is MRC [9].

Table 1 The used simulation parameters

Parameters	
Modulation order	16-quadrature amplitude modulation (QAM)
Total subcarrier	256
Guard interval size	64
Data size	1024
Cyclic shift	[0 64]
Code rate	1/2
Constraint length	3

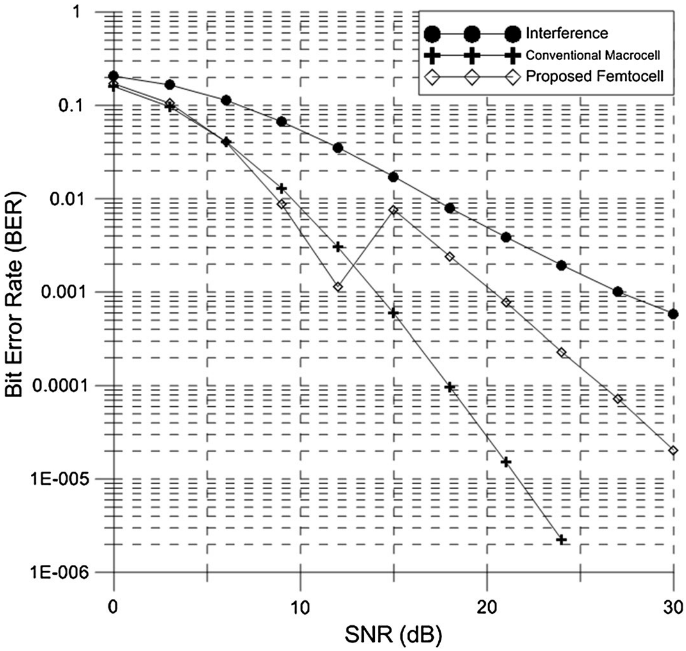

Fig. 3 BER performance of adaptive femtocell compared to existing systems

Finally, for the proposed femtocell, indicator of feedback system is simply noise power due to the property of flat fading channel in the OFDM. And the criterion of mode conversion is estimated noise power of 0.0315 which is equal to 12 dB for 10^{-3} BER performance. In detail, CDD scheme is used at high noise power and spatial multiplexing scheme is used at low noise power. For CDD scheme, optimal cyclic shift was studied according to modulation order in [10]. The proposed femtocell has better BER performance than existing macrocell when CDD scheme is used. And also, proposed femtocell has better BER performance than conventional femtocell when DFE scheme is used. However, despite of the fact that proposed femtocell has lower BER performance than existing macrocell when DFE scheme is used, the large amount of data is transmitted in the system compared to existing macrocell and conventional femtocell as shown in Fig. 4. That is, although proposed femtocell has trade-off relationship in view of reliability and data rate, proposed femtocell satisfies the mobile users with both reliability and data rate adaptively. Figure 4 shows throughput performance of conventional femtocell, existing macrocell, and proposed femtocell. The proposed femtocell has higher throughput performance than existing and conventional systems. Particularly, throughput performance of proposed femtocell is about two times than existing macrocell when proposed femtocell uses spatial multiplexing mode.

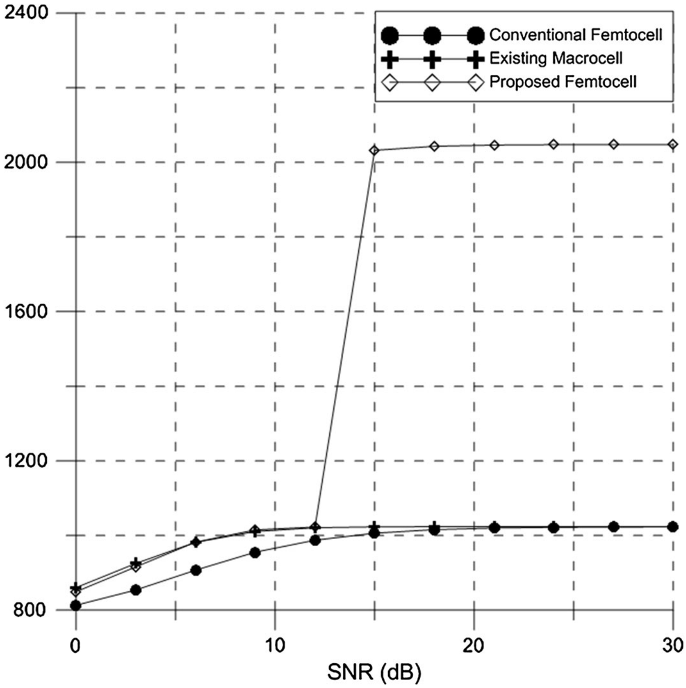

Fig. 4 Throughput performance of adaptive femtocell compared to existing systems

5 Conclusion

In existing mobile communication systems, the deployment of femotocell is very hard due to ICI. To solve the influence of ICI, femtocell which has spatial mode and spatial multiplexing mode in accordance with reliability of system is proposed. The proposed femtocell can convert its mode adpatively. So, the difficulty of deploying femtocell due to ICI can be solved by proposed femtocell scheme. Thus, with this proposed scheme, mobile users who want to receive better QoS can deploy femtocell more easily.

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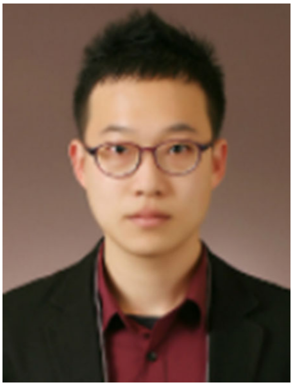

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