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Spatial Phase Coding With CoMP for Performance Enhancement Based on MIMO-OFDM in HetNet System

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ABSTRACT This paper proposes a performance enhancement scheme using a coordinated multi-point (CoMP) with spatial phase coding (SPC) based on multiple-input-multiple-output orthogonal frequency-division multiplexing (MIMO-OFDM) in a heterogeneous network (HetNet) system. In the conventional system, the performance of the mobile terminal (MT) is degraded due to the inter-cell interference (ICI). When the MT is located on the cell edge, the performance and quality of service (QoS) of the MT are attenuated due to the interference caused by the signal transmitted from the adjacent base station (BS) or the signal broadcasted by other MTs. In order to increase the reliability of the MT, the proposed scheme uses a pre-coding and the CoMP scheme in HetNet. The proposed scheme can increase the signal-to-noise ratio (SNR) of the MT through the SPC scheme in the transmitter. Therefore, the proposed scheme can mitigate the performance degradation caused by the ICI and can enhance the reliability of the MT. The simulation results show that the proposed scheme has better bit error rate (BER) performance and has higher throughput than the conventional scheme. Therefore, the proposed scheme enhances the performance of the MT by using SPC with CoMP.

INDEX TERMS HetNet, cell edge, ICI, pre-coding, SPC, CoMP, MIMO-OFDM, performance enhancement.

I. INTRODUCTION

Recently, wireless communication technology has been evolved rapidly in order to satisfy the needs of users and to handle the increasing data traffic [1]. In this environment, a rapidly changing wireless communication system requires high frequency efficiency and high reliability. To satisfy such demands of the next generation mobile communication, current mobile communication system adopts an orthogonal frequency division multiplexing (OFDM) [2]. The OFDM scheme has many advantages such as high-speed data transmission capability based on high bandwidth efficiency and robustness against the frequency selective fading due to the multi-path fading [3]. OFDM is also easy to simulate digital signal processing in the transmitter and receiver using an inverse fast Fourier transform & fast Fourier transform (IFFT & FFT) algorithm [4]. For these reasons, OFDM is widely regarded as a powerful transmission method for wireless communication system. However, if the orthogonality between orthogonal signals is not achieved due to the various factors such as multi-path fading and delay spreading, an arbitrary frequency offset occurs between the signals and the frequency offset causes an inter symbol interference, so the performance of the mobile terminal (MT) is degraded [5]. Furthermore, when the MT is located on the cell edge, the performance of the MT is attenuated due to the inter cell interference (ICI) caused by the signal transmitted from the adjacent base station (BS) or the signal broadcasted by other MTs.

To enhance the performance of the MT and satisfy the needs of users, a small cell technology has emerged as a new technology for mitigating the interference and handling the

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explosive data traffic demands. By increasing the number of cells, the traffic per unit area can be increased without increasing the amount of traffic that must be supported per cell. However, as the number of the small cells increases, the ICI is increased due to the decrease of distance between adjacent small cells in user equipment of the cell boundary [6]. So, it is important to reduce the ICI in small cell technology.

Small cell technology is divided into the homogeneous and heterogeneous network (HetNet). Small cells in homogeneous network have a cell densification effect serving the service area divided into the multiple cells [7]. However, in the populated area, very large traffic is generated partially. Therefore, it is hard to limit and reduce the size of the macro cell to cope with the hot spot area. To overcome the disadvantages of the homogeneous network, HetNet has emerged. Small cells in HetNet are placed in the macro cell to increase the network capacity economically. However, it is important to synchronize the multi-cell system in practice since it is difficult to achieve a synchronization in HetNet. If the synchronization is not matched in multi-cell system, the performance of the MT is seriously degraded. Therefore, the offset of the received signals from BSs should be correctly estimated and corrected. So, the offset estimation of the transmitted signal is important. To solve the synchronization problem, many offset estimation schemes for MIMO-OFDM based multi-cell system exist [8]–[11].

A variety of small cell deployment scenarios were proposed in the HetNet and the small cell deployment scenarios considered at the 3^{rd} generation partnership project (3GPP) can be roughly divided into four types [12]. Among four types, this paper considers the first scenario. In the first scenario, the small cells are placed so as to overlap the macro cell network. At this time, it is assumed that the macro cell and the small cells use the same frequency band, so the interference that the small cell experiences from the macro cell in downlink is very large. Such interference can cause the communication problems for the cell edge user. When the MT is located on the cell center which does not sensitive to the interference, highly reliable communication is possible. However, when the MT is located on the cell edge, a signal transmitted from the adjacent BS or other MTs acts as an interference signal to the MT. So, the communication reliability is reduced [13], [14]. Therefore, it is important to satisfy the quality of service (QoS) of users. In order to increase the communication quality, 3GPP standardized coordinated multi-point (CoMP) in release 11.

CoMP is one of the technologies that enable inter cell communication between different BSs in HetNet so that other cells can communicate with the same MT [15]–[17]. The CoMP scheme can increase the signal-to-noise ratio (SNR) of the MT, reduce the interference and enhance the throughput. In CoMP scheme, the MT can transmit the feedback information (including the position of MT, channel state information (CSI) and etc.) to all BSs in adjacent cells. Then, the BSs can apply the pre-coding scheme to the signals to be transmitted by using the feedback information. As a result, the proposed scheme can enhance the performance of the MT.

The pre-coding scheme used in this paper is spatial phase coding (SPC). The SPC scheme changes the channel relationship between the BS and MT by using the CSI. Then, the channel coefficient is increased by constructive superposition. In addition, the SPC scheme can change the relationship of the channel to destructive superposition. In other words, SPC scheme can increase the reliability of the desired signal by increasing the channel coefficient of the desired signal constructively and reduce the influence of the interference signal by decreasing the channel coefficient of the interference signal destructively. So, the performance of the MT is enhanced.

Actually, it is difficult to obtain the CSI in a practical system. Therefore, many papers have been proposed in the assumption that the CSI can be perfectly known [18]–[21]. However, in simulation results, this paper additionally simulates in a practical environment that the CSI is not perfectly known.

In multi-cell environment, when the MT is located on the cell edge in each adjacent cells connected with the backhaul network, it can be regarded as a virtual MIMO system [22]. MIMO system uses multiple antennas in both transmitter and receiver and offers tremendous performance gains without additional bandwidth or transmit power. The MIMO system has two important MIMO gains. First one is a diversity gain which increases the transmission reliability and the other one is a multiplexing gain which increases the data rate. It is important to achieve these gains in the design of the transmitter and receiver. In MIMO-OFDM system, the desired signal can be detected by using the MIMO technique in HetNet system. Detection algorithms for MIMO-OFDM are such as zero-forcing (ZF), minimum mean square error (MMSE), successive interference cancelation (SIC), maximum likelihood (ML), decision feedback equalizer (DFE), depth-first sphere decoding (DFSD), QR-decomposition with M-algorithm (QRDM) and etc. [23]–[26]. Among these detection algorithms, this paper uses MMSE detection scheme.

This paper uses SPC with CoMP based on MIMO-OFDM in HetNet and has novelty in three major aspects. First, multi-cell communication system in HetNet for performance enhancement of the MT is proposed. Conventional SPC scheme is usually based on the cooperative communication. Typically, Seung-Jun's method used the SPC scheme with the space-time block code (STBC) in the cooperative wireless relaying system [27]. Also, many other papers are used in cooperative communication [28], [29]. However, the SPC scheme based on this cooperative communication has a great disadvantage. In the case of the interference mitigation technique using a relay, an error propagation phenomenon is occurred. Errors occurring in the signal processing process of the relay are transmitted to the MT. The error propagation degrades the reliability and throughput of the wireless communication system. Furthermore, there is a problem

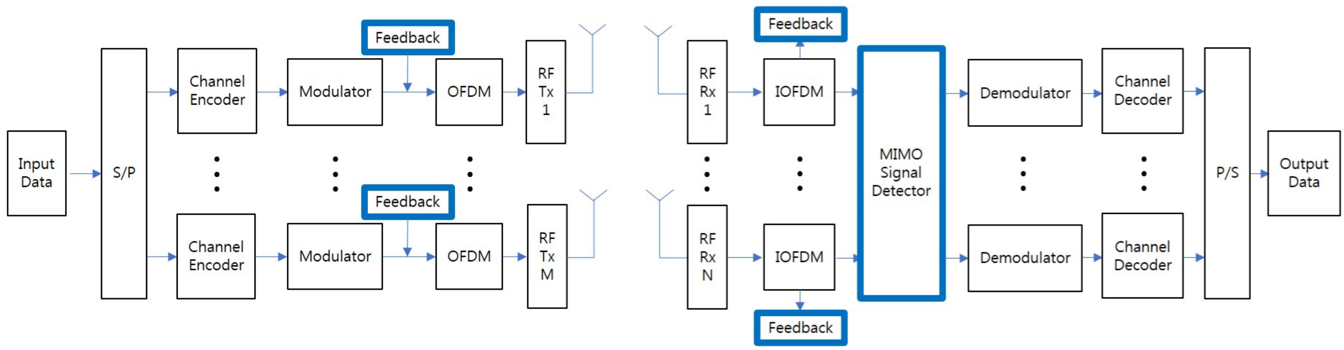

FIGURE 1. $N_t \times N_r$ **MIMO-OFDM block diagram of the proposed scheme.**

of reliability reduction which occurs when an appropriate relay is not selected. That is, a very complex relay selection technique is indispensable for selecting suitable relay. Second, this paper proposes SPC scheme for MIMO-OFDM that conventional papers did not deal with. Conventional papers apply SPC scheme based on multiple-input single-output OFDM (MISO-OFDM) [13], [30]. In these schemes, the influence of the interference is increased by the signal transmitted from the other BS and the performance of the MT is degraded. That is, a large capacity and high data rate can be achieved without increasing frequency bandwidth and transmission power by obtaining a multiplexing gain that cannot be obtained by MISO-OFDM. Finally, this paper considers not only the signal that the MT wishes to receive but also the interference signal sent from the adjacent BS. Shin proposed a constructive SPC scheme to improve the desired signal only [31]. However, this paper also considers the signals sent from adjacent BS using the destructive SPC to mitigate the interference. Therefore, this paper is more innovative than the conventional paper.

As a result, the proposed scheme uses the SPC and CoMP scheme to enhance the performance of the MT based on MIMO-OFDM in HetNet System.

This paper is organized as follows. Section 2 explains the MIMO-OFDM system model. Section 3 shows the system model of the conventional scheme. Section 4 describes the system model of the proposed scheme. Section 5 shows the simulation results. Finally, section 6 concludes this paper.

II. SYSTEM MODEL

Fig. 1 shows the $N_t \times N_r$ MIMO-OFDM block diagram of the proposed scheme. This figure shows how the signal of the proposed scheme is transmitted. In the transmitter, the input data is first switched from serial to parallel conversion and is converted to a symbol through a modulation. Then, the symbol is pre-coded with the pre-coding vector which is a feedback information obtained by the CSI in the receiver to modify the channel coefficient of the signal. In other words, the feedback information is calculated by the CSI and transmitted into the transmitter. After this process, the revised symbols are inserted into the each sub-carriers of the OFDM symbols through IFFT and the OFDM symbols are transmitted with added CP. The transmitted OFDM symbols are passed through a multi-path fading channel. In the receiver, the noise is added in the OFDM symbols. After the interleaved OFDM (IOFDM) process, the signal is detected. In the IOFDM process, the feedback information obtained by the CSI is transmitted to the transmitter. Finally, after the demodulation process, output data can be obtained.

The received signal of $N_t \times N_r$ MIMO-OFDM system is as follows,

$$\mathrm{Y} = \mathrm{HX} + \mathrm{N}, \tag{1}$$

$$\mathrm{H} = \begin{bmatrix} H_{11} & H_{12} & \cdots & H_{1N_t} \\ H_{21} & H_{22} & \cdots & H_{2N_t} \\ \vdots & \vdots & \ddots & \vdots \\ H_{N_r1} & H_{N_r2} & \cdots & H_{N_rN_t} \end{bmatrix}, \tag{2}$$

where the $\mathrm{Y} = \begin{bmatrix} Y_1 & Y_2 & \cdots & Y_{N_r} \end{bmatrix}^T$ denotes $N_r \times 1$ received symbols vector. $\mathrm{X} = \begin{bmatrix} X_1 & X_2 & \cdots & X_{N_t} \end{bmatrix}^T$ denotes $N_t \times 1$ transmit symbols vector which is normalized the power to 1. $\mathrm{N} = \begin{bmatrix} N_1 & N_2 & \cdots & N_{N_r} \end{bmatrix}^T$ denotes $N_r \times 1$ zero-mean complex additive white Gaussian noise (AWGN) vector. H denotes $N_t \times N_r$ complex channel matrix. The element $H_{ij}(i = 1, 2, \ldots, N_r, j = 1, 2, \ldots, N_t)$ denotes channel coefficient from the j-th transmit antenna to the i-th receive antenna. The channel coefficient H_{ij} is independent and identically distributed (i.i.d) random variables.

When the ZF scheme is used to detect the desired signal, the received symbol vector Y is multiplied with the filter matrix G_{ZF}. G_{ZF} is a Moore-Penrose pseudo-inverse of the channel matrix H. The filter matrix G_{ZF} and estimated transmit symbol vector $\hat{X}_{ZF}$ are as follows,

$$G_{ZF} = \mathrm{H}^{+} = \left(\mathrm{H}^H\mathrm{H}\right)^{-1}\mathrm{H}^H, \tag{3}$$

$$\begin{aligned} \hat{X}_{ZF} &= G_{ZF}\mathrm{Y} = (\mathrm{H}^H\mathrm{H})^{-1}\mathrm{H}^H(\mathrm{HX}+\mathrm{N}) \\ &= (\mathrm{H}^H\mathrm{H})^{-1}(\mathrm{H}^H\mathrm{H})\mathrm{X} + G_{ZF}\mathrm{N} \\ &= \mathrm{X} + G_{ZF}\mathrm{N}, \end{aligned} \tag{4}$$

where the $(\cdot)^{+}$ denotes a complex conjugate transpose and H denotes a Hermitian operator. ZF scheme is a technique

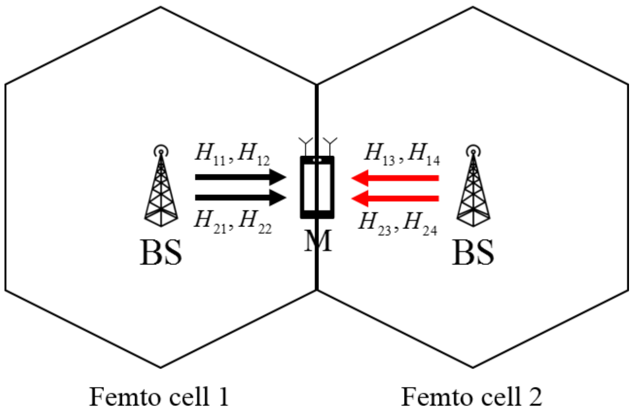

FIGURE 2. Conventional system model.

for estimating the transmitted symbol by multiplying the received symbol with the pseudo-inverse of the channel matrix [23]. In other words, ZF means that the mutual interference between the signals would be perfectly removed. However, ZF scheme amplifies the noise in the process of multiplying the filter matrix G_{ZF}. To solve this problem, MMSE scheme is used in this paper. In order to prevent the noise amplification, which is a disadvantage of ZF scheme, the MMSE scheme considering the deviation of the noise in the filter matrix G_{MMSE} is as follows,

$$\bar{\mathrm{H}} = \begin{bmatrix} \mathrm{H} \\ \sigma_n I_{N_t} \end{bmatrix}, \tag{5}$$

$$\bar{\mathrm{Y}} = \begin{bmatrix} \mathrm{Y} \\ 0_{N_t 1} \end{bmatrix}, \tag{6}$$

$$G_{MMSE} = \left(\bar{\mathrm{H}}^H \bar{\mathrm{H}}\right)^{-1} \bar{\mathrm{H}}^H, \tag{7}$$

$$\begin{aligned} \hat{X}_{MMSE} &= G_{MMSE}\bar{\mathrm{Y}} = (\bar{\mathrm{H}}^H\bar{\mathrm{H}})^{-1}\bar{\mathrm{H}}^H(\bar{\mathrm{H}}\mathrm{X}+\mathrm{N}) \\ &= (\bar{\mathrm{H}}^H\bar{\mathrm{H}})^{-1}(\bar{\mathrm{H}}^H\bar{\mathrm{H}})\mathrm{X} + G_{MMSE}\mathrm{N} \\ &= \mathrm{X} + G_{MMSE}\mathrm{N}, \end{aligned} \tag{8}$$

where the σ_n denotes a deviation of the AWGN, I_{N_t} denotes an identity matrix and 0 denotes the $N_t \times 1$ zero vector. The process of calculating the channel matrix and estimating the transmitted signal is similar to ZF. However, MMSE scheme prevents the amplification of the noise and has better performance than ZF. So, this paper uses the MMSE detection scheme.

III. CONVENTIONAL SCHEME

In this section, the conventional system model is described. Fig. 2 shows the system model of the conventional scheme. This system consists of two femto cells. The M denotes a MT which has two receiving antennas. H_{11}, H_{12}, H_{21} and H_{22} denote the channel coefficients of desired signal X_1 on the first and second transmit antennas of femto cell 1. H_{13}, H_{14}, H_{23} and H_{24} denote the channel coefficients of interference signal X_2 on the first and second transmit antennas of femto cell 2 and the signal X_2 is regarded as an interference to the MT. In Fig. 2, when the MT is located on the cell edge of the serving cell (femto cell 1), the performance of the MT is significantly degraded due to the path loss and the interference of the signal broadcasted by another BS in the adjacent cell (femto cell 2). A signal transmitted on the BS in femto cell 1 indicates a signal that the MT wants to receive. But, the signal transmitted on the femto cell 2 indicates an interference signal. In conventional system, the received signal Y_1 is as follows,

$$\mathrm{Y}_1 = \mathrm{H}_1\mathrm{X}_1 + \mathrm{N}_1, \tag{9}$$

$$\mathrm{H}_1 = \begin{bmatrix} H_{11}+H_{12} & H_{13}+H_{14} \\ H_{21}+H_{22} & H_{23}+H_{24} \end{bmatrix}, \tag{10}$$

where the $\mathrm{Y}_1 = [\,Y_1 \;\; Y_2\,]^T$ denotes a received symbols vector, $\mathrm{X}_1 = [\,X_1 \;\; X_2\,]^T$ denotes a transmit symbols vector and the noise $\mathrm{N}_1 = [\,N_1 \;\; N_2\,]^T$ denotes an AWGN. H_1 denotes a channel matrix of superimposed channel coefficient. When the MMSE detection scheme is used, the desired signal is detected by using the filter matrix G_{MMSE} of the channel matrix H_1 and received signal Y_1. The estimated transmit symbol vector is as follows,

$$\begin{aligned} \hat{X}_1 &= G_{MMSE}\bar{\mathrm{Y}}_1 = (\bar{\mathrm{H}}_1^H\bar{\mathrm{H}}_1)^{-1}\bar{\mathrm{H}}_1^H(\bar{\mathrm{H}}_1\mathrm{X}_1+\mathrm{N}_1) \\ &= (\bar{\mathrm{H}}_1^H\bar{\mathrm{H}}_1)^{-1}(\bar{\mathrm{H}}_1^H\bar{\mathrm{H}}_1)\mathrm{X}_1 + G_{MMSE}\mathrm{N}_1 \\ &= \mathrm{X}_1 + G_{MMSE}\mathrm{N}_1. \end{aligned} \tag{11}$$

IV. PROPOSED SCHEME

This section describes the proposed system model. Fig. 3 shows the system model of the proposed scheme. In the proposed system model, the CoMP scheme is additionally applied in the conventional system model to enhance the performance of the desired signal. So, the cooperative signal in the BS of the macro cell can be transmitted to the MT. H_{11}, H_{12}, H_{21} and H_{22} denote channel coefficients of the desired signal X_1. H_{13}, H_{14}, H_{23} and H_{24} denote channel coefficients of the cooperative signal X_1. H_{15}, H_{16}, H_{25} and H_{26} denote channel coefficients of the interference signal X_2.

In proposed system model, the proposed scheme can further enhance the performance of the MT by using SPC scheme.

A. SPATIAL PHASE CODING

The SPC scheme improves the SNR of the desired signal by modifying the channel coefficient using the pre-coding vector. A fundamental principle of the SPC is to obtain a constructive superposition of the same transmit signal from the different transmit antennas in the receiver, and it uses only one superimposed channel [30]. SPC can be divided into two types generally, depending on the relative angle of the channel. One is 1-bit SPC which adjusts the relative angle of two channels based on the 180 degrees, and the other one is 2-bit SPC which adjusts the relative angle based on 90 degrees. The pre-coding vectors of 1-bit constructive and destructive SPC are as follows,

$$P_1^c = \left\{ \begin{array}{lll} 1, & |\alpha^k| \le \pi/2 & (State\ 1) \\ e^{-j\pi}, & \pi/2 < |\alpha^k| \le \pi & (State\ 2) \end{array} \right\} \tag{12}$$

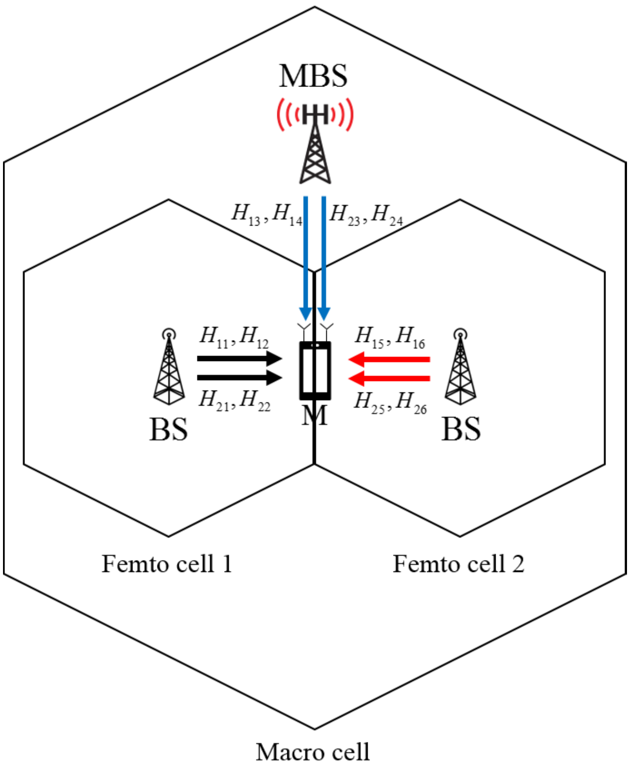

FIGURE 3. Proposed system model.

$$P_1^d = \begin{Bmatrix} e^{-j\pi}, & |\alpha^k| \leq \pi/2 & (State\ 1) \\ 1, & \pi/2 < |\alpha^k| \leq \pi & (State\ 2) \end{Bmatrix} \quad (13)$$

where the c and d denote the constructive and destructive SPC and the $(\cdot)_1$ denotes an 1-bit SPC. The α denotes a relative angle between two different signals and the k denotes a sub-carrier index and the P denotes a pre-coding vector. In 1-bit SPC, the states are divided into two parts according to the relative angle and the phase of the channel is flipped depending on the state. 1-bit constructive SPC can increase the SNR of the desired signal by increasing the magnitude of the superimposed channel coefficient through the pre-coding vector P_1^c. However, 1-bit destructive SPC can reduce the magnitude of the interference signal by decreasing the size of the superimposed channel coefficient through the pre-coding vector P_1^d [32]. The pre-coding vectors of 2-bit constructive and destructive SPC are as follows,

$$P_2^c = \begin{Bmatrix} 1, & |\alpha^k| \leq \pi/4 & (State\ 1) \\ e^{-j\pi}, & 3\pi/4 < |\alpha^k| \leq 5\pi/4 & (State\ 2) \\ e^{-j\frac{\pi}{2}}, & \pi/4 < |\alpha^k| \leq 3\pi/4 & (State\ 3) \\ e^{j\frac{\pi}{2}}, & 5\pi/4 < |\alpha^k| \leq 7\pi/4 & (State\ 4) \end{Bmatrix} \quad (14)$$

$$P_2^d = \begin{Bmatrix} e^{-j\pi}, & |\alpha^k| \leq \pi/4 & (State\ 1) \\ 1, & 3\pi/4 < |\alpha^k| \leq 5\pi/4 & (State\ 2) \\ e^{j\frac{\pi}{2}}, & \pi/4 < |\alpha^k| \leq 3\pi/4 & (State\ 3) \\ e^{-j\frac{\pi}{2}}, & 5\pi/4 < |\alpha^k| \leq 7\pi/4 & (State\ 4) \end{Bmatrix} \quad (15)$$

where the $(\cdot)_2$ denotes a 2-bit SPC and α, k and P are equal to 1-bit SPC. However, in 2-bit SPC, the states are divided into four parts according to the relative angle. Since the pre-coding vector can be obtained by subdividing the state more specifically, the performance of 2-bit SPC is better than 1-bit SPC.

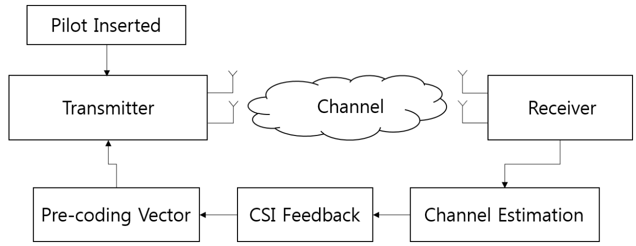

FIGURE 4. CSI feedback mechanism.

Fig. 4. describes the CSI feedback mechanism. When the first signal is transmitted from the BS to the MT, the MT does not know what signal is transmitted. Also, since there is no information on the signal, pre-coding can not be performed in the serving cell BS. Therefore, the BS of the serving cell first transmits a pilot signal to the MT and the receiver receives the pilot signal to perform channel estimation. After the channel estimation, the CSI is feedbacked to the BS and the pre-coding vector is multiplied with the transmission signal. Therefore, the CSI can be transmitted to the BS and pre-coding can be accurately performed in the transmitter.

Fig. 5 shows the process of the SPC. First, the MT transmits the CSI to the BSs which are transmitted the signal. Then, adjacent BSs share the CSI. And then, the phase relationship between two signals is observed and divided into several parts by comparing the relative angle α^k and the threshold degrees T_d. The T_d is determined by the number of the bits. Thereafter, the pre-coding vector is determined according to whether it is the desired signal or the interference signal. If the interference signal is an acute angle, the phase is flipped to reduce the magnitude of the superimposed channel coefficient of interference signal. Also, if the desired signal is an obtuse angle, the phase is flipped to increase the magnitude of the superimposed channel coefficient of desired signal. Finally, the transmit signal multiplied by the pre-coding vector is transmitted to the receiver.

Fig. 6 describes constructive and destructive SPC. H_1^k and H_2^k denote the channel coefficient of the desired and cooperative signal. $(\cdot)_1$ and $(\cdot)_2$ are the index of the channel coefficient. $(\cdot)_T$ denotes the superimposed channel coefficient of two channels. In Fig. 6-(a), the superimposed channel coefficient H_T^k is obtained by the desired signal H_1^k and the cooperative signal H_2^k. As a result, H_T^k is larger than the original channel coefficient H_1^k. On the other hand, the superimposed channel coefficient H_T^k is smaller than the original channel coefficient H_1^k in Fig. 6-(b).

Fig. 7 and 8 describe phase flipped 1-bit and 2-bit constructive and destructive SPC. If relative angle of the two channels are obtuse angle, the 1-bit constructive SPC modifies the angle by flipping the phase 180 degrees to increase the superimposed channel coefficient. However, if the relative angle is acute angle, the 1-bit destructive SPC modifies the angle

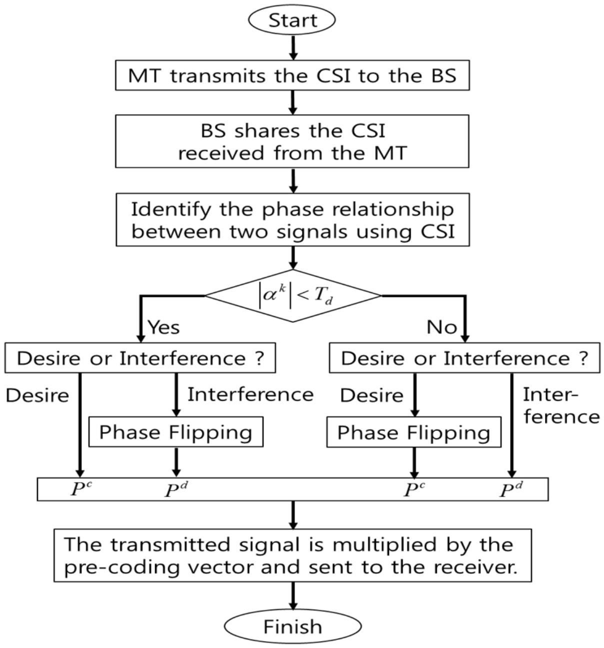

FIGURE 5. The flow chart of SPC.

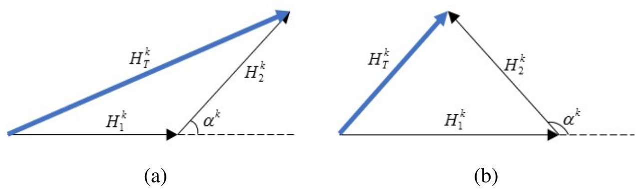

FIGURE 6. Constructive and destructive SPC. (a) Constructive SPC. (b) Destructive SPC.

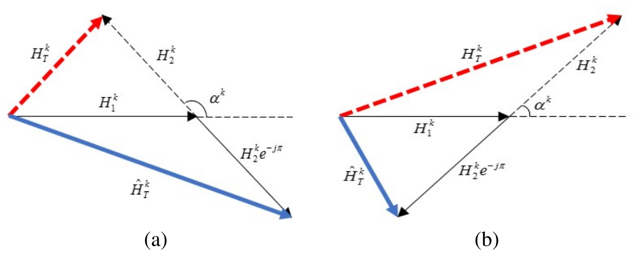

FIGURE 7. 1-bit constructive and destructive SPC (Phase flipping). (a) 1-bit constructive SPC. (b) 1-bit destructive SPC.

to make a small superimposed channel coefficient. Similarly, the 2-bit SPC adjusts the phase based on 90 degrees.

SPC scheme increases the reliability of the desired signal by increasing the channel coefficient of the desired signal and reduces the influence of the interference by reducing the channel coefficient of the interference signal. Therefore, the performance and throughput of the MT are enhanced.

In case of constructive 2-bit SPC, if the phase of desired and interference signal is different but the magnitude is same, the magnitude of the superimposed channel coefficient increases when the two signals are acute angle. However, when desired and interference signal are destructive, in order

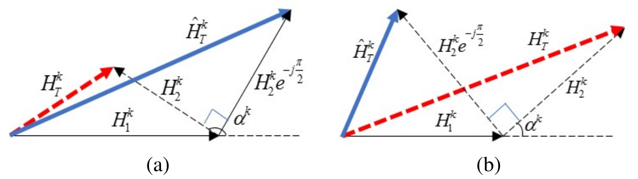

FIGURE 8. 2-bit constructive and destructive spc (Phase flipping). (a) 2-bit constructive SPC. (b) 2-bit destructive SPC.

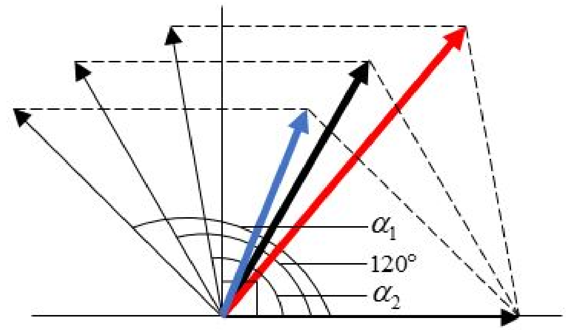

FIGURE 9. Increase of superimposed channel coefficient for 2-bit destructive SPC.

words, relative angle of the two signals is obtuse angle, the magnitude of the superimposed channel coefficient is decreased. However, as shown in Fig. 9, the relative angle from 90 degrees to 120 degrees increases the magnitude of the superimposed channel coefficient even if it is an obtuse angle. The α_1 denotes a relative angle of two different signals and the degrees is beyond 120. α_2 also denotes a relative angle and the degrees is higher than 90 and lower than 120. When all signals have the same magnitude, if the relative angle is 120 degrees, the superimposed channel coefficient is equal to original signal. In case of α_1, since the relative angle is larger than 120 degrees, the superimposed channel coefficient decreases. However, in case of α_2, since the relative angle exists between 90 and 120 degrees, superimposed channel coefficient is increased. This is because all signals are normalized to 1. To prevent this unwanted result and to increase the magnitude of the superimposed channel coefficient, the states can be divided specifically. As the number of bits and states increases, the relative angle α^k gradually decreases. Therefore, the magnitude of the superimposed channel coefficient is increased and the performance is enhanced. When the relative angle of two different channels are zero, the performance is maximized. It is called maximum ratio transmission (MRT) [33]. Since it uses all the number of bits, MRT is also called full-bit SPC. The pre-coding coefficient of MRT is as follows,

$$C_{MRT} = [\, H_1{}^{(k)*}\ H_2{}^{(k)*}\ \cdots\ H_{N_t \times N_r}{}^{(k)*}\,]^T, \tag{16}$$

where the k and $*$ denote the sub-carriers index and conjugate operator and $N_t \times N_r$ denotes the channel index. The full channel information about $H_{N_t \times N_r}{}^{(k)*}$ must be estimated at the receiver. Thus, the MRT requires the most complex estimation with highest overhead of all pre-coding schemes.

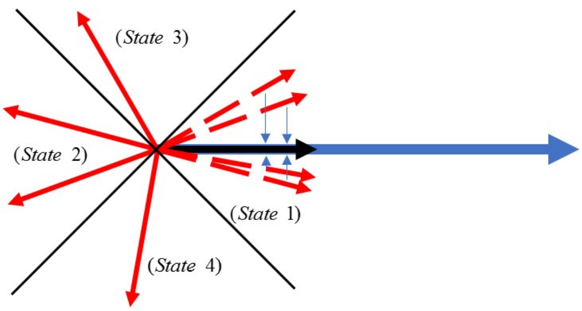

FIGURE 10. Superimposed channel coefficient of MRT.

Moreover, the MRT requires full feedback of amplitude and phase of each channel. Therefore, the MRT requires a large amount of feedback information.

Fig. 10 shows the process of modifying the channel coefficient of the MRT. The black and red line denote a channel coefficient of desired and cooperative signal respectively. All the black and red lines have the same magnitude. The dotted red lines denote the phase-flipped channel coefficient of cooperative signals and the blue line denotes a superimposed channel coefficient of desired signal. By using MRT, eventually, all the signals exist in the same direction as the desired signal and the channel coefficient of the desired signal is maximized. Therefore the SNR of the MT is increased. However, it is very difficult to adjust all the channels with the same direction and so the complexity of the implementation is increased accordingly. Furthermore, the performance of MRT is slightly improved compared to the 2-bit SPC, but the complexity increases greatly. Therefore, this paper uses 2-bit SPC with similar performance and low complexity to MRT.

B. PERFORMANCE ENHANCEMENT OF PROPOSED SYSTEM MODEL

In the proposed system model, in order to evaluate the performance of the proposed scheme, the following cases are proposed.

1) CONVENTIONAL & COMP SCHEME

Since the proposed system model is connected to the backhaul network, BS of the macro cell knows the signal that the serving cell sends. So, the macro cell signal can cooperate with the signal X_1 of the serving cell. The BS of the macro cell can transmit the same signal as serving cell to perform a cooperative communication. Then, the received signal is as follows,

$$Y_2 = H_2X_2 + N_2, \tag{17}$$

$$H_2 = \begin{bmatrix} H_{11}+H_{12}+H_{13}+H_{14} & H_{15}+H_{16} \\ H_{21}+H_{22}+H_{23}+H_{24} & H_{25}+H_{26} \end{bmatrix}, \tag{18}$$

where the $Y_2 = [\,Y_1\;\,Y_2\,]^T$ denotes the received symbols vector, $X_2 = [X_1\;\,X_2\,]^T$ denotes the transmit symbols vector and the noise $N_2 = [\,N_1\;\,N_2\,]^T$. H_2 denotes a channel matrix of superimposed channel coefficient. The desired signal is detected by using the filter matrix G_{MMSE} of the channel matrix H_2 and received signal Y_2. The estimated transmit symbol vector is as follows,

$$\begin{aligned}\hat{X}_2 &= G_{MMSE}\bar{Y}_2 = (\bar{H}_2^H\bar{H}_2)^{-1}\bar{H}_2^H(\bar{H}_2X_2+N_2)\\ &= (\bar{H}_2^H\bar{H}_2)^{-1}(\bar{H}_2^H\bar{H}_2)X_2 + G_{MMSE}N_2\\ &= X_2 + G_{MMSE}N_2, \end{aligned} \tag{19}$$

2) CONVENTIONAL & PRE-CODING SCHEME

In this case, the desired signal is pre-coded constructively and the interference signal is pre-coded destructively. In other words, the constructive SPC is used to increase the SNR of the received signal by increasing the superimposed channel coefficient of the desired signal. It also reduces the SNR of the interference signal by reducing the magnitude of the channel coefficient of the interference signal using the destructive SPC. As a result, the performance of the MT is improved. Then, the received signal is as follows,

$$\underbrace{\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix}}_{Y_3} = \underbrace{\begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix}}_{H_3} \underbrace{\begin{bmatrix} X_1 \\ X_2 \end{bmatrix}}_{X_3} + \underbrace{\begin{bmatrix} N_1 \\ N_2 \end{bmatrix}}_{N_3} \tag{20}$$

$$\begin{aligned} A_1 &= P_1H_{11}+P_2H_{12}, \quad B_1 = P_3H_{13}+P_4H_{14},\\ C_1 &= P_5H_{21}+P_6H_{22}, \quad D_1 = P_7H_{23}+P_8H_{24}, \end{aligned} \tag{21}$$

where the P_1,P_2,P_5 and P_6 are the constructive 2-bit SPC pre-coding vectors and P_3, P_4, P_7 and P_8 are the destructive 2-bit SPC pre-coding vectors. The $Y_3 = [\,Y_1\;\,Y_2\,]^T$ denotes the received symbols vector, $X_3 = [X_1\;\,X_2\,]^T$ denotes the transmit symbols vector and the noise $N_3 = [\,N_1\;\,N_2\,]^T$. H_3 denotes a channel matrix of superimposed channel coefficient. The desired signal is detected by using the filter matrix G_{MMSE} of the channel matrix H_3 and received signal Y_3. The estimated transmit symbol vector is as follows,

$$\begin{aligned}\hat{X}_3 &= G_{MMSE}\bar{Y}_3 = (\bar{H}_3^H\bar{H}_3)^{-1}\bar{H}_3^H(\bar{H}_3X_3+N_3)\\ &= (\bar{H}_3^H\bar{H}_3)^{-1}(\bar{H}_3^H\bar{H}_3)X_3 + G_{MMSE}N_3\\ &= X_3 + G_{MMSE}N_3, \end{aligned} \tag{22}$$

3) CONVENTIONAL & COMP WITH PRE-CODING SCHEME

In case 3, CoMP and pre-coding scheme are used together. Case 3 provides the constructive pre-coding to the desired signal with cooperative signal and destructive pre-coding to the interference signal. In addition, the CoMP scheme is applied, it can increase the SNR of the MT. Then, the received signal is as follows,

$$\underbrace{\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix}}_{Y_4} = \underbrace{\begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}}_{H_4} \underbrace{\begin{bmatrix} X_1 \\ X_2 \end{bmatrix}}_{X_4} + \underbrace{\begin{bmatrix} N_1 \\ N_2 \end{bmatrix}}_{N_4}, \tag{23}$$

$$\begin{aligned} A_2 &= P_5(P_3(P_1H_{11}+P_2H_{12})+P_4H_{13})+P_6H_{14},\\ B_2 &= P_7H_{15}+P_8H_{16},\\ C_2 &= P_{13}(P_{11}(P_9H_{21}+P_{10}H_{22})+P_{12}H_{23})+P_{14}H_{24},\\ D_2 &= P_{15}H_{25}+P_{16}H_{26} \end{aligned} \tag{24}$$

where the A_2 and C_2 are the superimposed pre-coding vector of constructive SPC. The B_2 and D_2 are the superimposed

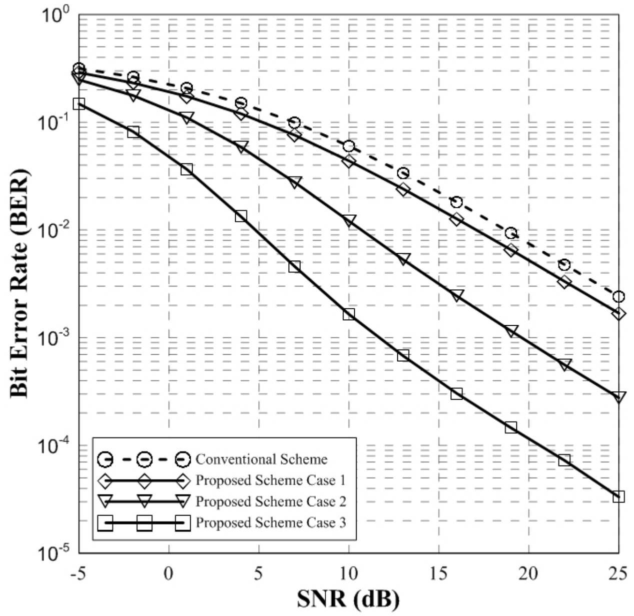

FIGURE 11. BER performance of conventional scheme and proposed scheme.

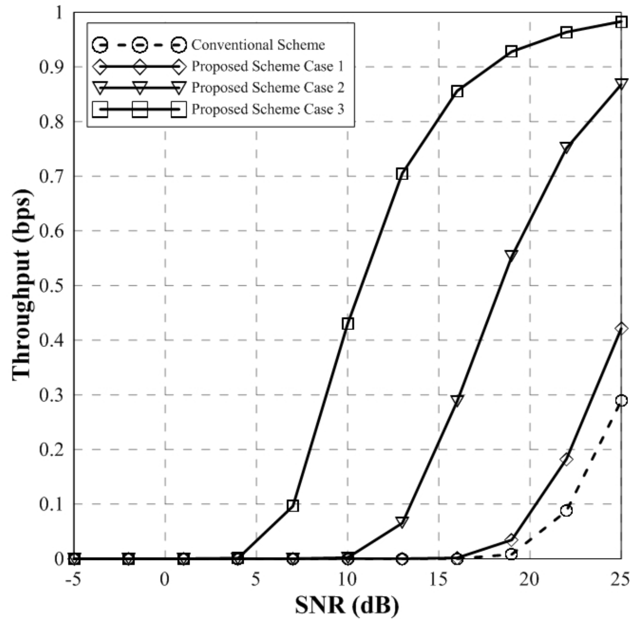

FIGURE 12. Throughput of conventional and proposed scheme.

pre-coding vector of destructive SPC. The $Y_4 = [\,Y_1\ Y_2\,]^T$ denotes the received symbols vector, $X_4 = [\,X_1\ X_2\,]^T$ denotes the transmit symbols vector and the noise $N_4 = [\,N_1\ N_2\,]^T$. H_4 denotes a channel matrix of superimposed channel coefficient. The desired signal is detected by using the filter matrix G_{MMSE} of the channel matrix H_4 and received signal Y_4. The estimated transmit symbol vector is as follows,

$$\begin{aligned}\hat{X}_4 &= G_{MMSE}\bar{Y}_4 = (\bar{H}_4^H\bar{H}_4)^{-1}\bar{H}_4^H(\bar{H}_4X_4 + N_4)\\ &= (\bar{H}_4^H\bar{H}_4)^{-1}(\bar{H}_4^H\bar{H}_4)X_4 + G_{MMSE}N_4\\ &= X_4 + G_{MMSE}N_4, \end{aligned} \tag{25}$$

V. SIMULATION RESULTS

In this section, the simulation results are shown. All simulation results are based on the MIMO-OFDM system and the simulation parameters are as follows: the number of the sub-carriers is 256 and the length of the CP is 64 to prevent the influence of the inter symbol interference. The modulation is a quadrature phase shift keying (QPSK). All channels are Rayleigh fading channels of 7-multi paths and the ideal backhaul network is used. The proposed scheme uses the 2-bit constructive and destructive SPC and CoMP scheme.

Fig. 11 shows that the BER performance of the conventional and the proposed scheme. It is shown that the BER performance of the MT is improved gradually. Since the effect of the interference is remained, conventional scheme has lowest performance at all SNR. In case 1, the CoMP scheme is applied and the performance improvement at the BER of 10^{-2} is 2dB gain compared to the conventional scheme. The SPC scheme is applied in case 2, 8dB gain is achieved at the same BER. Finally, in case 3, SPC and CoMP scheme are applied together and have highest performance at all SNR. Therefore, the proposed scheme can effectively enhance the performance.

Fig. 12 shows the throughput of the conventional and the proposed scheme. The throughput T is calculated as

$$T = (1 - P_e)^{N_b}, \tag{26}$$

where the P_e and N_b denote the BER and the number of the transmitted information bits. The conventional scheme has 0.28bps at the SNR of 25dB and has lowest throughput. In case 1, the throughput is improved approximately 0.14bps compare to the conventional scheme but still difficult to satisfy the QoS of the user. The throughput is increased more than twice in case 2 compared to the conventional scheme. Finally, in case 3, the throughput converges almost 1 and when the throughput is closer to 1, the QoS of the user can be satisfied. Since the SPC and CoMP scheme are used together, the case 3 outperforms other cases.

Fig. 13 shows the BER performance of non pre-coding, 1-bit, 2-bit and full-bit SPC. It is simulated in 2×2 MIMO-OFDM system for the performance comparison of the pre-coding scheme. The simulations are pre-coded as a constructive SPC. The BER performance of non pre-coded signal has lowest performance at all SNR. However, since the SPC scheme is used in 1-bit, 2-bit and MRT, the performance improvement is 5.5, 8 and 9.5dB at 10^{-2} BER, respectively, compared to the non pre-coded signal. MRT has the highest performance at all SNR and 2-bit SPC is next. In other words, the 2-bit SPC scheme can achieve the BER performance similar to the MRT scheme with only 2-bit feedback information. Therefore, the proposed pre-coding scheme can enhance the performance of the MT and reduce the complexity by using the 2-bit SPC.

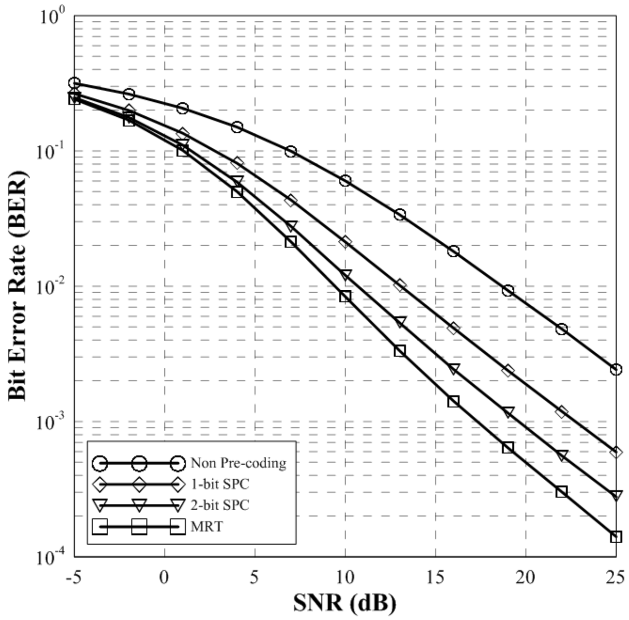

FIGURE 13. BER performance of non pre-coding, 1, 2 and full-bit SPC (MRT) in 2 × 2 MIMO-OFDM.

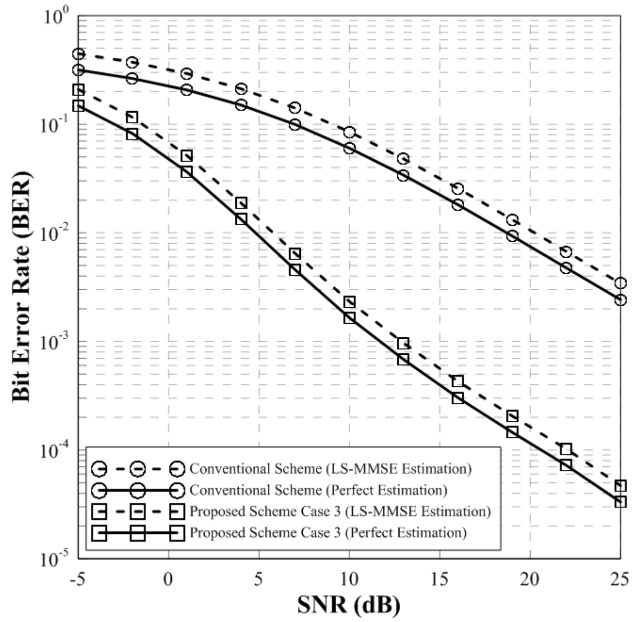

FIGURE 15. BER performance of LS-MMSE and perfect estimation.

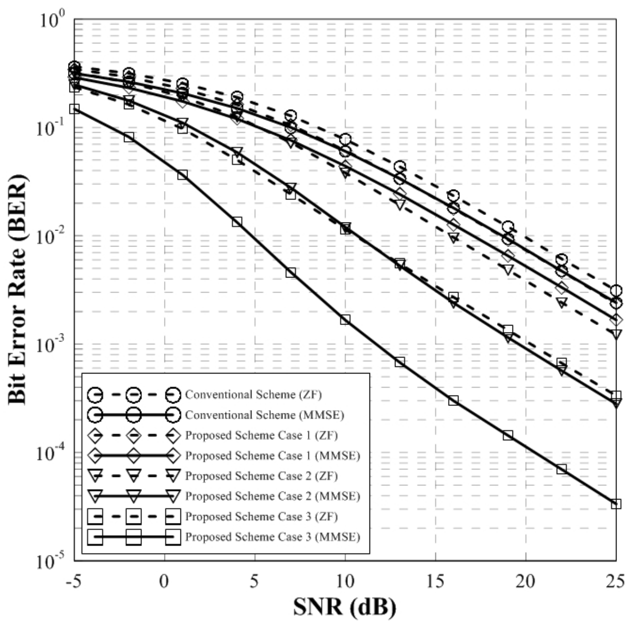

FIGURE 14. BER performance of ZF and MMSE in conventional scheme and proposed scheme.

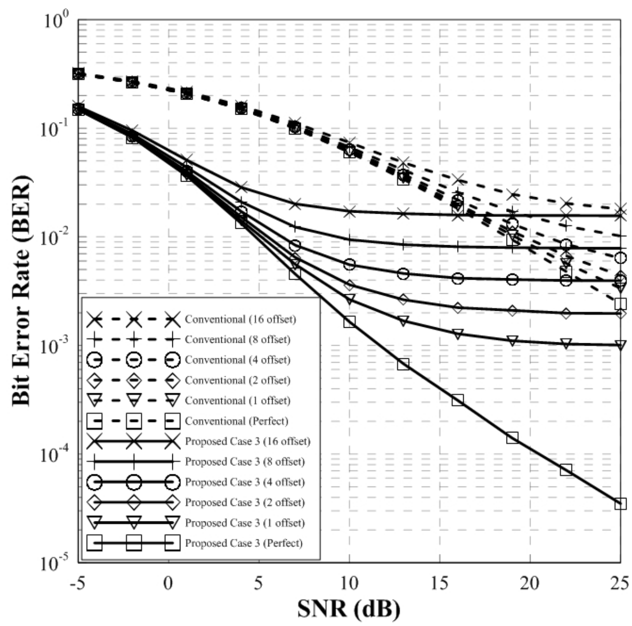

FIGURE 16. BER performance of non-synchronization and perfect synchronization.

Fig. 14 shows the BER performance of ZF and MMSE scheme. The simulation results compare the performance of ZF and MMSE scheme in conventional and proposed scheme. The MMSE scheme has better performance than the ZF scheme by preventing the amplification of the noise. In general, the performance gain between ZF and MMSE scheme is about 2dB at the same BER. However, since the pre-coding scheme is applied together, the proposed case 2 and 3 have 5 and 6dB gain. Therefore, the proposed scheme enhances the performance effectively.

In general, a perfect CSI is an ideal assumption that rarely occurs in practical system. So, this paper simulates in a practical environment that the CSI is not perfectly known. This paper uses the least square-minimum mean square error (LS-MMSE) channel estimation scheme in the environment that the CSI is imperfect [34], [35]. Fig. 15 shows the BER performance of LS-MMSE and perfect estimation in conventional and proposed scheme case 3. The BER performance of practical system using the LS-MMSE estimator in an environment that the CSI is not perfectly known is degraded about 2dB compared with the ideal system that the CSI can be perfectly known. Therefore, it is important to use the channel estimation in order to obtain the CSI in a practical system. Actually, interference from the adjacent BSs deteriorates the performance of the channel estimation when the channel estimation is performed in a practical environment, which causes degradation of BER performance. However, this paper reduces the magnitude of the interference by using the destructive SPC to cancel the interference at the adjacent BSs in channel estimation. Therefore, it is not correct to assume that there is no interference in channel estimation in a real system.

Fig. 16 shows the BER performance of non-synchronization and perfect synchronization in conventional and proposed scheme case 3 in case the offsets exist. According to the offset, the BER performance in multi-cell system is degraded due to the signal distortion. Finally, the offset increases significantly, the BER performance of the proposed scheme converges to the conventional scheme. Therefore, synchronization in multi-cell system might be a big issue in practice.

VI. CONCLUSION

This paper proposes the SPC with CoMP scheme in order to enhance the performance based on MIMO-OFDM in HetNet system. It is shown that the proposed schemes have better BER performance and higher throughput than the conventional scheme. The proposed scheme uses pre-coding and CoMP scheme and it can maximize the SNR of the MT by using a constructive SPC. It also minimizes the interference by using a destructive SPC. In conclusion, the SPC and CoMP scheme enhance the performance and reliability of the MT.

As a related works, the proposed scheme applied to the joint transmission (JT) technique and coordinated scheduling (CS). These are the CoMP schemes achieving a high throughput to satisfy the user's reliability and using a beam-forming for energy efficiency. Such a various studies are underway and better simulation result can be predicted.

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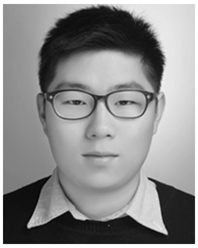

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