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Performance of MIMO-OFDMA system combining power controlling algorithm with multi-beamformer

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Abstract

. In this paper, we propose the new technique adopting power control to MIMO(multi-input multi-output)-OFDMA(orthogonal frequency division multiplexing Access) system with multi-beamformer. The proposed power controlling algorithm for MIMO-OFDMA allocates the transmitting power of each subcarrier based on the CSI(channel state information) and the interference signal. CSI is feedback from base station to mobile station to decide the transmitting power of each subcarrier. Through the proposed technique, we can control iteratively the transmitting power and update the weight of beamformer simultaneously. Therefore, the SNIR of each subcarrier become to converge the target SNIR and the beam is formed toward the desired direction. And the performance of MIMO-OFDMA system with the proposed approach is very improved. The improvement in bit error rate is investigated through computer simulation of a MIMO-OFDMA system with the proposed approach.

Keywords: *OFDMA, beamforming, MIMO, power control, MIMO-OFDMA.*

1. Introduction

Orthogonal frequency division multiplexing Access (OFDMA) is multiple access technique that allocates the set of OFDM subcarrier into each user. Therefore, OFDMA can effectively overcome intersymbol interference(ISI) by exploiting a cyclic prefix (CP) in the multipath environments. Multiple-input multiple-output (MIMO) techniques can greatly improve the performance of wireless communications system by employing multiple antennas at both transmitter and receiver [1][2][3]. OFDMA technique with MIMO antennas can transmit high data rate multimedia services in the multipath fading channel and the limited frequency band. This approach has been widely researched in wireless mobile communication [4][5]. In the multi-user environment with the multipath fading channel, the performance of a MIMO-OFDMA system is greatly decreased as the received signals are considerably distorted by other user interference during space–time decoding and as the SNIR of partly subcarriers is very poor [6][7]. Power controlling

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algorithm for MIMO-OFDMA system has been widely researched to overcome this limitation in the wireless communication [7][8][9][10]. In this paper, we propose a new technique to overcome the degradation of performance. Our proposed technique combines power controlling algorithm with multi-beamforming for a MIMO-OFDMA system. The proposed power controlling algorithm for MIMO-OFDMA allocates the transmitting power of each subcarrier based on the CSI and the interference signal. And SNIR of each subcarrier becomes to converge on the target SNIR. Also, The beamforming technique is derived in the direction minimizing the mean squared error(the error between the coded pilot symbols and the corresponding received signals). And then, we can iteratively control the transmitting power and update the weight of beamformer, simultaneously.

2. MIMO-OFDMA system combining multi-beamformer with power control

Fig.1 shows a block diagram of the proposed MIMO-OFDMA system combining multi-beamformers with power controlling algorithm. After mapping subcarriers to one OFDMA block signal of the m-th user, each subcarrier of the signal is allocated the transmitting power by using CSI which is feedback from base station to mobile station. interference

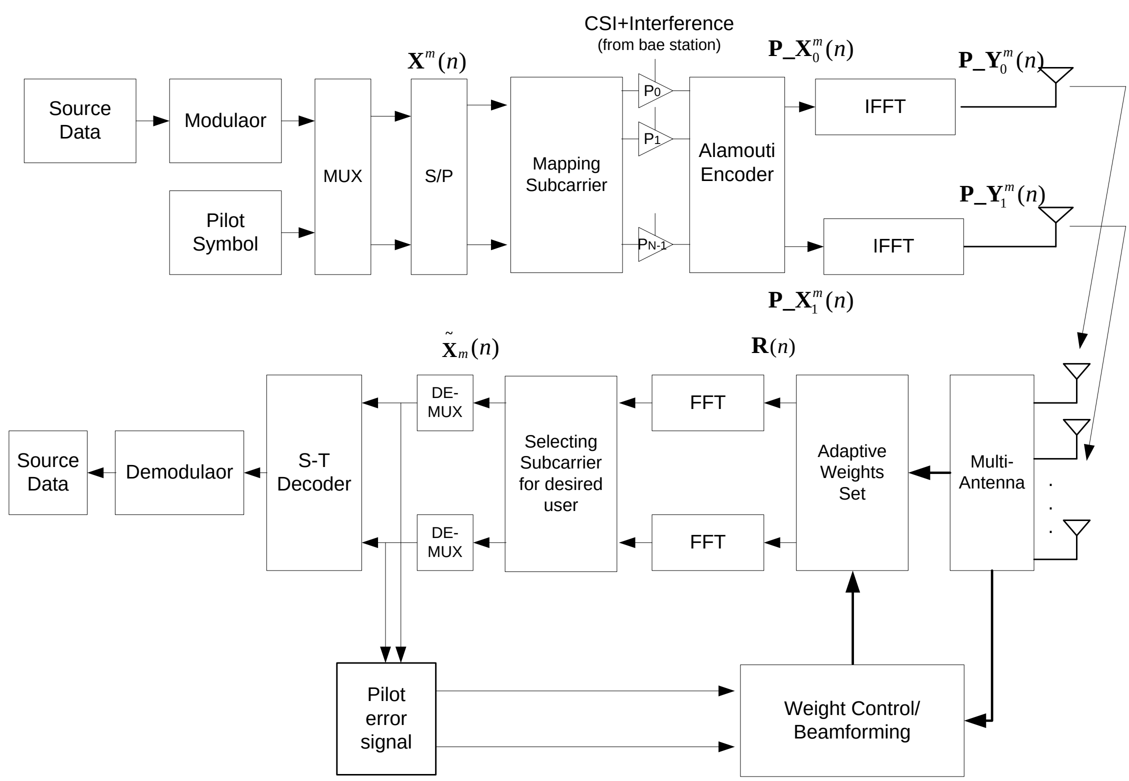


Figure 1. Block diagram of MIMO-OFDMA system combining multi-beamformer with power controlling algorithm.

When the signal vector of the m-th user with N mapping subcarriers is $\mathbf{X}^m(n) = \left[x_0^m(n) \quad x_1^m(n) \quad \dots \quad x_{N-1}^m \right]$ in the frequency domain, the Alamouti encoding symbol matrix allocated power by power control algorithm is given by

$$\mathbf{P\_X}^m(n) = \left[\mathbf{P}_0\mathbf{\_X}^m(n) \quad \mathbf{P}_1\mathbf{\_X}^m(n)\right] \tag{1}$$

where $\mathbf{P}_0\mathbf{\_X}^m(n) = \begin{bmatrix} x_0{}^m(n)\sqrt{P_0{}^m(n)} \\ -x_1^{m*}(n)\sqrt{P_1{}^m(n)} \\ x_2{}^m(n)\sqrt{P_2{}^m(n)} \\ -x_3^{m*}(n)\sqrt{P_2{}^m(n)} \\ x_4{}^m(n)\sqrt{P_4{}^m(n)} \\ \vdots \\ -x_{N-1}^{m*}(n)\sqrt{P_{N-1}{}^m(n)} \end{bmatrix}$, $\mathbf{P}_1\mathbf{\_X}^m(n) = \begin{bmatrix} x_1{}^m(n)\sqrt{P_1{}^m(n)} \\ x_0^{m*}(n)\sqrt{P_0{}^m(n)} \\ x_3{}^m(n)\sqrt{P_3{}^m(n)} \\ x_2^{m*}(n)\sqrt{P_2{}^m(n)} \\ x_5{}^m(n)\sqrt{P_5{}^m(n)} \\ \vdots \\ x_{N-1}^{m*}(n)\sqrt{P_{N-1}{}^m(n)} \end{bmatrix}$

Here $P_i{}^m(n)$ is the transmitting power of the i-th subcarrier.

The signal matrix transformed into the time domain by the inverse FFT (IFFT) is expressed as

$$\mathbf{P\_Y}^m(n) = \left[\mathbf{P}_0\mathbf{\_Y}^m(n) \quad \mathbf{P}_1\mathbf{\_Y}^m(n)\right] \tag{2}$$

Here, the transmitted signal vectors for the m-th user in the time domain for the 0-th and first antennas are defined, respectively, as

$$\mathbf{P}_0\mathbf{\_Y}^m(n) = \mathbf{F}^H(\mathbf{P}_0\mathbf{\_X}^m(n)) \tag{3}$$

$$\mathbf{P}_1\mathbf{\_Y}^m(n) = \mathbf{F}^H(\mathbf{P}_1\mathbf{\_X}^m(n)) \tag{4}$$

where $\mathbf{F}(n)$ and H are represented the FFT operation matrix and Hermitian transpose, respectively. The transmitted signals from the multi-antennas of M users arrive at Nr receiver antennas with the corresponding DOA. The i-th subcarrier signal matrix arrived at the antennas in the time domain is expressed as

$$\mathbf{p\_v}_i = \mathbf{a}^0(\theta_i)p\_y_i^0 + \sum_{m=1}^{M-1}\mathbf{a}^m(\theta_i)p\_y_i^m + \mathbf{n}_{th} \tag{5}$$

where $\mathbf{a}^m(\theta_i) = \left[a^m{}_0(\theta_i) \quad a^m{}_1(\theta_i)\right]$.

$\mathbf{a}^m(\theta_i)$ represent the array response matrix for the *m*-th user with argument of DOA(=θ) and $p\_y_i^0$ is the i-th subcarrier signal of the m-th user in the time domain and. $\mathbf{n}_{th}$ is the thermal noise vector. Therefore, the received signal matrix of the n-th OFDMA block in the time domain, $\mathbf{R}(n)$, is expressed as

$$\mathbf{R}(n) = \mathbf{A}^0(\theta)\mathbf{P\_Y}^0(n) + \sum_{m=1}^{M-1}\mathbf{A}^m(\theta)\mathbf{P\_Y}^m(n) + \mathbf{n}_b(n) \tag{6}$$

The signal matrix multiplied by the weights of beamformers are transformed into the frequency-domain signal by the FFT, which can be expressed in a matrix form as follow

$$\tilde{\mathbf{X}}(n) = \mathbf{F}(\mathbf{W}^H\mathbf{R}(n)) = \tilde{\mathbf{X}}^0(n) + \sum_{m=1}^{M-1}\tilde{\mathbf{X}}^m(n) + \mathbf{F}(\mathbf{W}^H\mathbf{n}_b(n)) \tag{7}$$

where $\tilde{\mathbf{X}}(n)=\left[\tilde{\boldsymbol{x}}_0(n) \quad \tilde{\boldsymbol{x}}_1(n)\right]=\begin{bmatrix} \tilde{x}_{00} & \tilde{x}_{01} \\ \tilde{x}_{10} & \tilde{x}_{11} \\ \vdots & \vdots \\ \tilde{x}_{N-10} & \tilde{x}_{N-11} \end{bmatrix}, \mathbf{W}(n)=\left[\mathbf{W}_0 \quad \mathbf{W}_1\right]=\begin{bmatrix} w_{00} & w_{01} \\ w_{10} & w_{11} \\ \vdots & \vdots \\ w_{Nr,0} & w_{Nr-1,1} \end{bmatrix}.$

Here, the signal matrix of m-th user, $\tilde{\mathbf{X}}_m(n)$, are defined as

$$\tilde{\mathbf{X}}_m(n)=\begin{bmatrix} \alpha^m{}_{00}x_0^m\sqrt{P_0{}^m}+\alpha^m{}_{10}x_1^m\sqrt{P_1{}^m} & \alpha^m{}_{01}x_0^m\sqrt{P_0{}^m}+\alpha^m{}_{11}x_1^m\sqrt{P_1{}^m} \\ -\alpha^m{}_{00}x_1^{m*}\sqrt{P_1{}^m}+\alpha^m{}_{10}x_0^{m*}\sqrt{P_0{}^m} & -\alpha^m{}_{01}x_1^*\sqrt{P_1{}^m}+\alpha^0{}_{11}x_0^{m*}\sqrt{P_0{}^m} \\ \alpha^m{}_{00}x_2^m\sqrt{P_2{}^m}+\alpha^m{}_{10}x_3^m\sqrt{P_3{}^m} & \alpha^m{}_{01}x_2^m\sqrt{P_2{}^m}+\alpha^m{}_{11}x_3^m\sqrt{P_3{}^m} \\ -\alpha^m{}_{00}x_3^{m*}\sqrt{P_3{}^m}+\alpha^m{}_{10}x_2^{m*}\sqrt{P_2{}^m} & -\alpha^m{}_{01}x_3^*\sqrt{P_3{}^m}+\alpha^m{}_{11}x_2^{m*}\sqrt{P_2{}^m} \\ \alpha^m{}_{00}x_4^m\sqrt{P_4{}^m}+\alpha^m{}_{10}x_5^m\sqrt{P_5{}^m} & \alpha^m{}_{01}x_4^m\sqrt{P_4{}^m}+\alpha^m{}_{11}x_5^m\sqrt{P_5{}^m} \\ \vdots & \vdots \\ -\alpha^m{}_{00}x_{N-1}^{m*}\sqrt{P_{N-1}{}^m}+\alpha^m{}_{10}x_{N-2}^*\sqrt{P_{N-2}{}^m} & -\alpha^m{}_{01}x_{N-1}^*\sqrt{P_{N-1}{}^m}+\alpha^m{}_{11}x_{N-2}^{m*}\sqrt{P_{N-2}{}^m} \end{bmatrix} \quad (8)$$

where

$$\alpha^m{}_{00}=a^{m*}{}_0(\theta_0)w_{00}+a^{m*}{}_0(\theta_1)w_{10}+\cdots+a^{m*}{}_0(\theta_{Nr-1})w_{Nr-10}$$
$$\alpha^m{}_{01}=a^{m*}{}_0(\theta_0)w_{01}+a^{m*}{}_0(\theta_0)w_{11}+\cdots+a^{m*}{}_0(\theta_{Nr-1})w_{Nr-11}$$
$$\alpha^m{}_{10}=a^{m*}{}_1(\theta_0)w_{00}+a^{m*}{}_1(\theta_1)w_{10}+\cdots+a^{m*}{}_1(\theta_{Nr-1})w_{Nr-10}$$
$$\alpha^m{}_{11}=a^{m*}{}_1(\theta_0)w_{01}+a^{m*}{}_1(\theta_1)w_{11}+\cdots+a^{m*}{}_1(\theta_{Nr-1})w_{Nr-11}$$

The detected signal after decoding is calculated by

$$\begin{aligned} z_{00} &= \alpha^{0*}{}_{00}\tilde{x}_{00}+\alpha^0{}_{10}\tilde{x}_{10}^* \\ &= \left|\alpha^0{}_{00}\right|^2 x_0^0\sqrt{P_0{}^0}+\left|\alpha^0{}_{10}\right|^2 x_0^0\sqrt{P_0{}^0}+\tilde{x}_{\inf 0}+n_0 \\ \tilde{x}_{\inf 0} &= \sum_{m=1}^{M-1}(\alpha^{0*}{}_{00}\alpha^m{}_{00}+\alpha^0{}_{10}\alpha^{m*}{}_{10})x_0^m\sqrt{P_0{}^m}+\sum_{m=1}^{M-1}(\alpha^{0*}{}_{00}\alpha^m{}_{10}-\alpha^0{}_{10}\alpha^{m*}{}_{00})x_1^m\sqrt{P_1{}^m} \\ n_0 &= \alpha^{0*}{}_{00}n_{00}+\alpha^0{}_{10}n_{10}^* \end{aligned} \quad (9)$$

$$\begin{aligned} z_{01} &= \alpha^{0*}{}_{01}\tilde{x}_{01}+\alpha^0{}_{11}\tilde{x}_{11}^* \\ &= \left|\alpha^0{}_{01}\right|^2 x_0^0\sqrt{P_0{}^0}+\left|\alpha^0{}_{11}\right|^2 x_0^0\sqrt{P_0{}^0}+\tilde{x}_{\inf 1}+n_1 \\ \tilde{x}_{\inf 1} &= \sum_{m=1}^{M-1}(\alpha^{0*}{}_{01}\alpha^m{}_{01}+\alpha^0{}_{11}\alpha^{m*}{}_{11})x_0^m\sqrt{P_0{}^m}+\sum_{m=1}^{M-1}(\alpha^{0*}{}_{01}\alpha^m{}_{11}-\alpha^0{}_{11}\alpha^{m*}{}_{01})x_1^m\sqrt{P_1{}^m} \\ n_1 &= \alpha^{0*}{}_{01}n_{01}+\alpha^0{}_{11}n_{11}^* \end{aligned} \quad (10)$$

$$z_{10} = \alpha^{0*}_{10}\tilde{x}_{00} - \alpha^{0}_{00}\tilde{x}^{*}_{10} = \left|\alpha^{0}_{00}\right|^2 x_1^0\sqrt{P_1^0} + \left|\alpha^{0}_{10}\right|^2 x_1^0\sqrt{P_1^0} + \tilde{x}_{\inf 2} + n_2 \tag{11}$$

$$\tilde{x}_{\inf 2} = \sum_{m=1}^{M-1}(\alpha^{0*}_{10}\alpha^{m}_{00} - \alpha^{0}_{00}\alpha^{m*}_{10})x_0^m\sqrt{P_0^m} + \sum_{m=1}^{M-1}(\alpha^{0*}_{10}\alpha^{m}_{10} + \alpha^{0}_{00}\alpha^{m*}_{00})x_1^m\sqrt{P_1^m}$$

$$n_2 = \alpha^{0*}_{10}n_{00} - \alpha^{0}_{00}n^{*}_{10}$$

$$z_{11} = \alpha^{0*}_{11}\tilde{x}_{01} - \alpha^{0}_{01}\tilde{x}^{*}_{11} = \left|\alpha^{0}_{01}\right|^2 x_0^0\sqrt{P_0^0} + \left|\alpha^{0}_{11}\right|^2 x_1^0\sqrt{P_1^0} + \tilde{x}_{\inf 3} + n_3 \tag{12}$$

$$\tilde{x}_{\inf 3} = \sum_{m=1}^{M-1}(\alpha^{0*}_{11}\alpha^{m}_{01} - \alpha^{0}_{01}\alpha^{m*}_{11})x_0^m\sqrt{P_0^m} + \sum_{m=1}^{M-1}(\alpha^{0*}_{11}\alpha^{m}_{11} + \alpha^{0}_{01}\alpha^{m*}_{01})x_1^{m*}\sqrt{P_1^m}$$

$$n_3 = \alpha^{0*}_{11}n_{01} - \alpha^{0}_{01}n^{*}_{11}$$

Finally, the signal detected is given by

$$z_0 = z_{00} + z_{01} = (\left|\alpha^{0}_{00}\right|^2 + \left|\alpha^{0}_{10}\right|^2 + \left|\alpha^{0}_{01}\right|^2 + \left|\alpha^{0}_{11}\right|^2)x_0^0\sqrt{P_0^0} + I_{0\_\inf} + n_0 + n_1 \tag{13}$$

$$z_1 = z_{10} + z_{11} = (\left|\alpha^{0}_{00}\right|^2 + \left|\alpha^{0}_{10}\right|^2 + \left|\alpha^{0}_{01}\right|^2 + \left|\alpha^{0}_{11}\right|^2)x_1^0\sqrt{P_1^0} + I_{1\_\inf} + n_2 + n_3 \tag{14}$$

where $I_{0\_\inf} = \sum_{m=1}^{M-1}(\zeta^{m}_{0})x_0^m\sqrt{P_0^m} + \sum_{m=1}^{M-1}(\zeta^{m}_{1})x_1^m\sqrt{P_1^m}$

$$I_{1\_\inf} = \sum_{m=1}^{M-1}(\zeta^{m*}_{0})x_1^m\sqrt{P_1^m} - \sum_{m=1}^{M-1}(\zeta^{m*}_{1})x_0^m\sqrt{P_0^m}$$

$$\zeta^{m}_{0} = \alpha^{0*}_{00}\alpha^{m}_{00} + \alpha^{0}_{10}\alpha^{m*}_{10} + \alpha^{0*}_{01}\alpha^{m}_{01} + \alpha^{0}_{11}\alpha^{m*}_{11}$$

$$\zeta^{m}_{1} = \alpha^{0*}_{00}\alpha^{m}_{10} + \alpha^{0*}_{01}\alpha^{m}_{11} - \alpha^{0}_{10}\alpha^{m*}_{00} - \alpha^{0}_{11}\alpha^{m*}_{01}$$

In Eq. (13), (14), we can get STC diversity gain and reduce interference signal by the proposed algorithm.

3. Power control algorithm for MIMO-OFDMA with multi-beamformer

The proposed algorithm for MIMO-OFDMA with multi-beamformer controls the transmitting power of each subcarrier based on the CSI and the interference signal. From the equation (13) and (14), $SINR_0^m(n)$ for the i-th subcarrier of the m-th user is represented as fellow

$$SNIR_0^m(n) = \frac{S_0^m(n)}{T\_N_{0\_\inf}(n)} \tag{15}$$

where $S_0^m(n) = \left|\left|\alpha^{0}_{00}\right|^2 + \left|\alpha^{0}_{10}\right|^2 + \left|\alpha^{0}_{01}\right|^2 + \left|\alpha^{0}_{11}\right|^2\right|^2 P_0^m(n)$,

$$T\_N_{0\_\inf}(n) = \sum_{m=1}^{M-1}(\left|\zeta^{m}_{0}{}^{0}\right|^2 P_0^m(n) - \left|\zeta^{m}_{1}{}^{0}\right|^2 P_1^m(n)) + \left|\left|\alpha^{0}_{00}\right|^2 + \left|\alpha^{0}_{10}\right|^2 + \left|\alpha^{0}_{01}\right|^2 + \left|\alpha^{0}_{11}\right|^2\right|^2 N_0 .$$

From the equation (15), the transmitting power of the 0-th subcarrier at the (n+1)-th OFDMA block for the target $SNIR_{target}$ is derived as fellow

$$P_0^{\,m}(n+1) = \frac{T\_N_{0\_\inf}(n)SNIR_{target}}{\left\| \left|\alpha^0{}_{00}\right|^2 + \left|\alpha^0{}_{10}\right|^2 + \left|\alpha^0{}_{01}\right|^2 + \left|\alpha^0{}_{11}\right|^2 \right|^2} + \Delta P_0^{CSI}(n) \tag{16}$$

Here, $\Delta P_0^{CSI}(n)$ is variable step power by following CSI.

Therefore, at the *i*-th subcarrier of the *m*-th user, the transmitting power is generally decided by

$$P_i^{\,m}(n+1) = \frac{T\_N_{i\_\inf}(n)SNIR_{target}}{\left\| \left|\alpha^0{}_{00}\right|^2 + \left|\alpha^0{}_{10}\right|^2 + \left|\alpha^0{}_{01}\right|^2 + \left|\alpha^0{}_{11}\right|^2 \right|^2} + \Delta P_i^{CSI}(n) \tag{17}$$

The proposed algorithm controlling the transmitting power for MIMO-OFDMA with multi-beamformer is described as follow

① The weights of beamformer are updated by[11][12]

$$\mathbf{W}_0(n+1) = \mathbf{W}_0(n) + 2\mu\mathbf{R}(n)\mathbf{F}^H(\mathbf{P}_0\_\mathbf{X}_p^m(n) - \tilde{\boldsymbol{x}}_{p0}(n))$$

$$\mathbf{W}_1(n+1) = \mathbf{W}_1(n) + 2\mu\mathbf{R}(n)\mathbf{F}^H(\mathbf{P}_1\_\mathbf{X}_p^m(n) - \tilde{\boldsymbol{x}}_{p1}(n)) .$$

Here, the beamforming technique for MIMO-OFDM is derived by calculating the error signals between the coded pilot symbols($\mathbf{P}_0\_\mathbf{X}_p^m(n)$) and the corresponding received($\tilde{\boldsymbol{x}}_{p0}(n)$) in the frequency domain, transforming($\mathbf{F}^H$) the frequency-domain error signals into time-domain error signals. Then, the weight of multi-beamformer are updated in the time domain using time domain error signal.

② CSI is feedback from base station to mobile station to decide the transmitting power of each subcarrier

③ The transmitting power of each subcarrier is controlled by using CSI and the equation that is given as follows

$$P_i^{\,m}(n+1) = \frac{T\_N_{i\_\inf}(n)SNIR_{target}}{\left\| \left|\alpha^0{}_{00}\right|^2 + \left|\alpha^0{}_{10}\right|^2 + \left|\alpha^0{}_{01}\right|^2 + \left|\alpha^0{}_{11}\right|^2 \right|^2} + \Delta P_i^{CSI}(n)$$

If $P_i^{\,m}(n+1) > P_{\max}$, $P_i^{\,0}(n+1) = P_{\max}$

④ Until converging each subcarrier to $SNIR_{target}$, repeat above processing

4. Simulation and numerical results

The performance of the proposed algorithm for the MIMO-OFDMA system is investigated by computer simulation. The radio channel for simulation was slowly the time-variant Jake's model. The doppler frequency is no more than 5. And it is assumed to estimate the CSI perfectly. The two transmitter antennas of mobile station are assumed to have different DOA. The modulation scheme is quadrature phase shift keying (QPSK) and the size(N) of one OFDMA block including pilot symbol is 32. Total number of subcarrier(for OFDMA system) is 256. Fig.2 shows the beam pattern when the DOAs from two transmitter antennas for the desired user are 25º and 15°and the DOAs of interference signals are random. From this figure, we can see that the beams with high gain are formed toward the two transmitter antennas of the desired user, whereas the beam with little gain is formed toward the interference signals. Figure 3 shows the SNIR at each subcarrier of an OFDMA block when the proposed approach applied to MIMO-OFDMA system with multi-beamformer. From this figure, we can see that the SNIR of each subcarrier converges on the desired target value(SNIR=4dB). In Fig. 4, we compare the performances of the MIMO-OFDMA system with and without the proposed multi-beamforming and power control when the number of antenna(Nr) is 3 and 5. At the BER of 10^{-4}, we can achieve about 2 dB gain(Nr=5) with the proposed approach, compared to the case with no power control. This figure shows that BER of MIMO-OFDMA system combining multi-beamforming with power control is significantly higher than that of the no power control as the proposed approach can effectively eliminate CCI and properly control the transmitting power of each subcarrier.

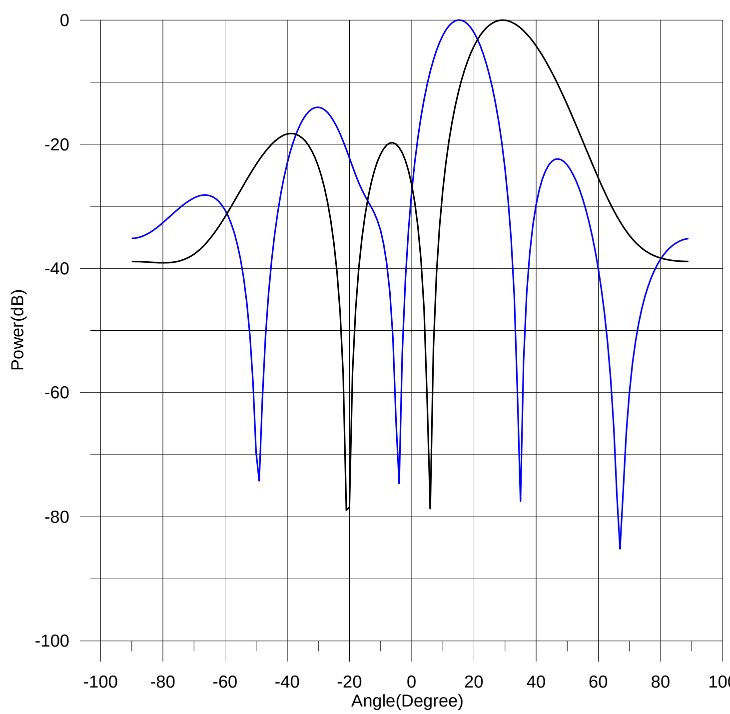


Figure 2. Beam pattern of MIMO-OFDMA system when the proposed approach is applied.

(DOA1=25°, DOA2=30°, DOAs of interferer = random, *Nr*=7, SNIR=10dB**)**

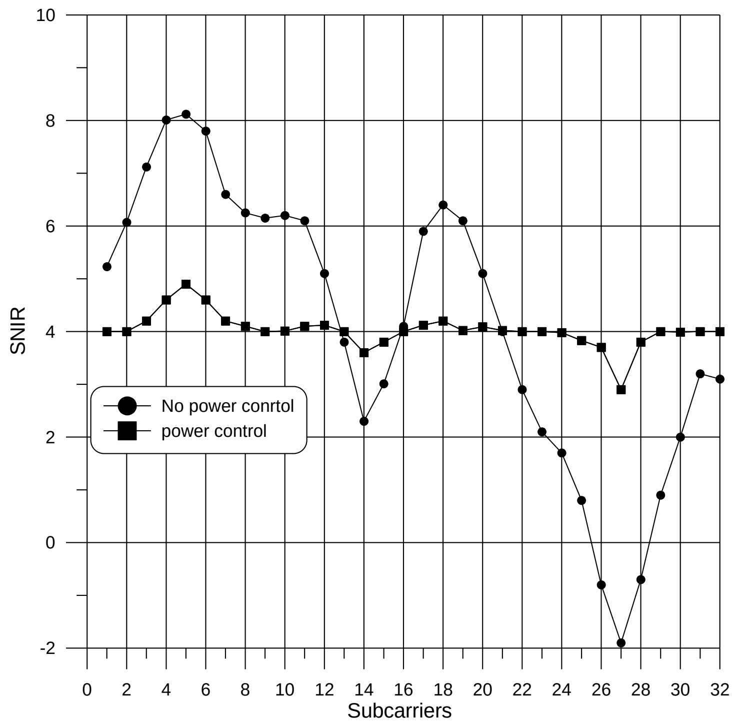
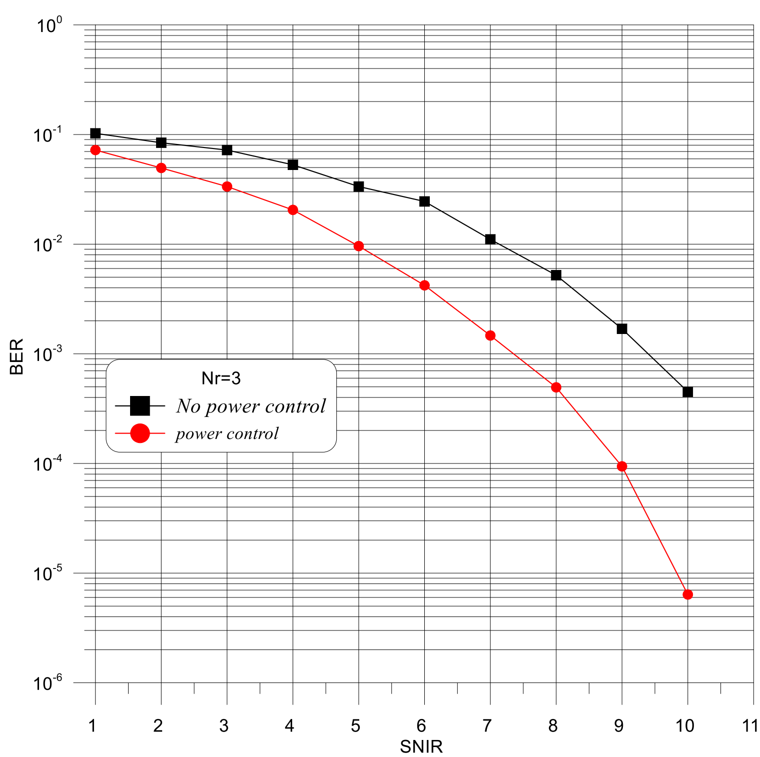
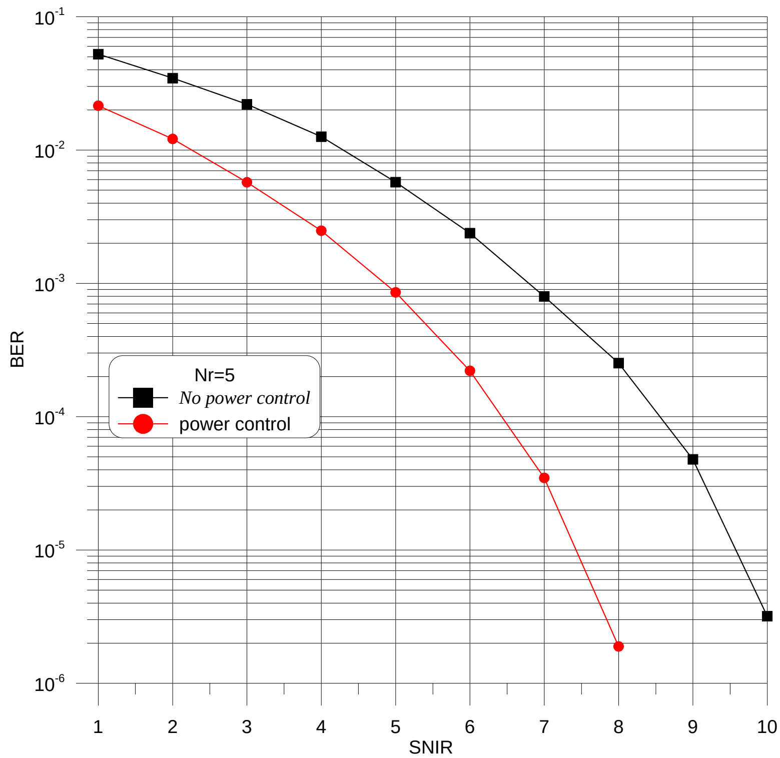


Figure 3. The SNIR of each subcarrier for MIMO-OFDMA with the proposed approach



(a) Nr=3



(a) Nr=5

Figure 4. BER comparison of MIMO-OFDMA system according to the power controlling algorithm.

4. Conclusion

In this paper, we proposed the new technique adopting power control algorithm to MIMO-OFDMA system with multi-beamformer. The proposed algorithm could be effectively controlling the transmitting power of each subcarrier based on the CSI and the interference signal and tracking desired user. Also, we could iteratively control the transmitting power and update the weight of beamformer simultaneously. Therefore, the beam is formed toward the desired direction and the SNIR of each subcarrier converged on the target SNIR. The performance of the proposed algorithm for the MIMO-OFDMA system was investigated by computer simulation. From the simulation results, we concluded that the SNIR of each subcarrier converged on the desired target value(SNIR=4dB) and other user interference was effectively removed. Also, the proposed approach could significantly increase the performance of MIMO-OFDMA system. We will further study the performance of MIMO-MC CDMA system combining the power controlling algorithm with muiti-beamformer.

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