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Performance Improvement of MIMO MC-CDMA system with multibeamforming

Chan Kyu Kim

Department of Electronics and Control Engineering, Hanbat University, Korea
ckkim@hanbat.ac.kr

Abstract

In this paper, we propose the beamforming algorithm for the performance improvement of MIMO MC-CDMA system. The proposed multibeamforming of MIMO MC-CDMA structure having the same number of beamformer as the number of transmit antenna is derived by calculating the error signals between the coded pilot symbols and the corresponding received signals from the multiple transmitters of the desired user in the frequency domain, transforming the frequency-domain error signals into time-domain error signals, and updating the weights of the multibeamformer in the time-domain in the direction minimizing the mean squared error (MSE). The proposed approach can track each direction of arrival (DOA) of the signals from multi-antennas of a desired user. The performance improvement is investigated through computer simulation by applying the proposed approach to MIMO MC-CDMA system in a multipath fading channel with multiusers.

Keywords: *MC-CDMA, beamforming, MIMO, MIMO MC-CDMA.*

1. Introduction

Since MC-CDMA technique is based on a combination of OFDM signaling and CDMA technique, it has the properties desirable such as insensitivity to frequency-selective channel with a simple one-tap equalizer, frequency diversity. Multi-Input Multi-Out (MIMO) antenna technology that makes MIMO channels with multiple independent paths can greatly improve data rate by employing multiple antennas at both transmitter and receiver.[1][2] MC-CDMA 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 next generation wireless communication [3][4][5]. In the wireless environment with multiuser, the performance of MIMO MC-CDMA system very decreased because the orthogonality among the received signals is distorted by CCI and IAI during the space time decoding[6][7]. To overcomes this limitation and improves the performance of system, we propose the new beamforming algorithm for MIMO MC-CDMA system in this paper. The proposed multibeamforming of MIMO MC-CDMA structure having the same

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Corresponding Author: ckkim@hanbat.ac.kr
Tel: +82-42-821-1138, Fax: +82-42-821-1129
Department of Electronics and Control Engineering, Hanbat University, Korea

number of beamformer as the number of transmit antenna is derived by calculating the error signals between the coded pilot symbols and the corresponding received signals from the multiple transmitters of the desired user in the frequency domain, transforming the frequency-domain error signals into time-domain error signals, and updating the weights of the multibeamformer in the time-domain in the direction minimizing the mean squared error (MSE).The proposed approach can track each direction of arrival (DOA) of the signals from multi-antennas of a desired user. Therefore, multi-beams are aimed toward multi-antennas of a desired user while null beams are formed toward the interference signal. When the proposed adaptive multi-beamforming scheme is applied to a MIMO MC-CDMA system, the performance improvement effect is confirmed through computer simulation in a multi-user environment with multipath fading.

2. MIMO-MC-CDMA systems with adaptive multibeamfomer

After Alamouti encoding the symbols in the frequency-domain, the spread signals by Walsh Hadamard for the m-th user are transformed into the time-domain signal by the IFFT, which can be expressed in a matrix form as follow

$$\begin{aligned} &\mathbf{T\_Y}^m(n) = \mathbf{F}^H(\mathbf{T\_X}^m(n)), \\ &\mathbf{T\_Y}^m(n+1) = \mathbf{F}^H(\mathbf{T\_X}^m(n+1)) \end{aligned} \tag{1}$$

where

$$\mathbf{T\_X}^m(n) = \left[\mathbf{T}_0\_\mathbf{X}^m(n) \quad \mathbf{T}_1\_\mathbf{X}^m(n)\right] \qquad \mathbf{T\_X}^m(n+1) = \left[\mathbf{T}_0\_\mathbf{X}^m(n+1) \quad \mathbf{T}_1\_\mathbf{X}^m(n+1)\right]$$

$$= \begin{bmatrix} d^m(n)c_0^m & d^m(n+1)c_0^m \\ d^m(n)c_1^m & d^m(n+1)c_1^m \\ \vdots & \vdots \\ d^m(n)c_{K-1}^m & d^m(n+1)c_{K-1}^m \end{bmatrix} \qquad = \begin{bmatrix} -d^{m*}(n+1)c_0^m & d^{m*}(n)c_0^m \\ -d^{m*}(n+1)c_1^m & d^{m*}(n)c_1^m \\ \vdots & \vdots \\ -d^{m*}(n+1)c_{K-1}^m & d^{m*}(n)c_{K-1}^m \end{bmatrix}$$

F and H are represented the FFT operation matrix and Hermitian transpose, respectively.

Figure 1 shows a block diagram of the proposed MIMO MC-CDMA system with adaptive multibeamformer.

The *L* multipath signals from M users arrive at each antenna with the corresponding DOA. The signal matrix, **R**(*n*), received at the antennas is written by

$$\mathbf{R}(n) = \sum_{l=0}^{L-1}\sum_{m=0}^{M-1} \mathbf{A}^m(\theta)^l\, \mathbf{T\_Y}^{mT}(n - \tau_{m,l}) + \Gamma_b(n) \tag{2}$$

where

$$\mathbf{A}^m(\theta)^l = \left[\mathbf{a}_0^m(\theta^l) \quad \mathbf{a}_1^m(\theta^l)\right] = \begin{bmatrix} a^m{}_0(\theta_0^l) & a^m{}_1(\theta_0^l) \\ a^m{}_0(\theta_1^l) & a^m{}_1(\theta_1^l) \\ \vdots & \vdots \\ a^m{}_0(\theta_{Nr-1}^l) & a^m{}_1(\theta_{Nr-1}^l) \end{bmatrix}$$

Here, $\mathbf{A}^m(\theta)^l$ represent the array response vector of the *l*-th path for the *m*-th user with argument of DOA. $\tau_{m,l}$ is the normalized time delay of the *l*-th path for *m*-th user. $\Gamma_b(n)$ is the matrix for the background noise. The signal matrix multiplied by the weight matrix of multibeamformers is given by

$$\mathbf{R\_Y}(n) = \mathbf{W}^H(n)\mathbf{R}(n) \tag{3}$$

where $\mathbf{W}(n) = [\mathbf{W}_0 \quad \mathbf{W}_1] = \begin{bmatrix} w_{00} & w_{01} \\ w_{10} & w_{11} \\ \vdots & \vdots \\ w_{Nr,0} & w_{Nr-1,1} \end{bmatrix}$

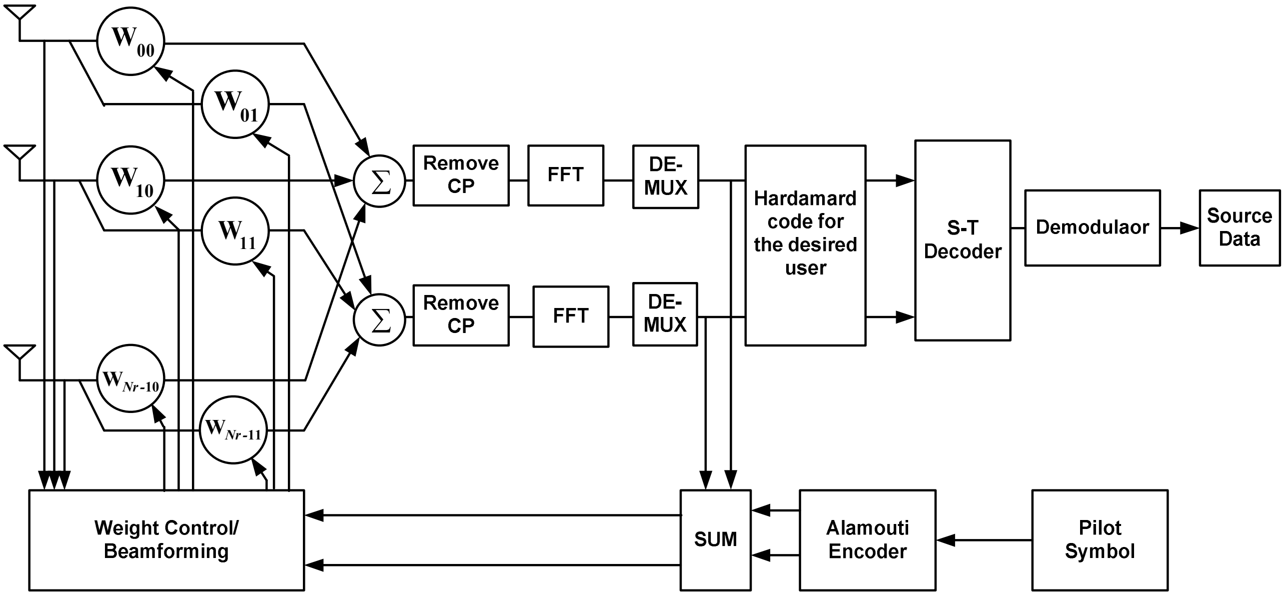

Figure 1. Block diagram of MIMO MC-CDMA system with adaptive multibeamforming

The received signal matrix in the frequency domain after FFT operation is given by

$$\tilde{\mathbf{Y}}(n) = \sum_{l=0}^{L-1} \mathbf{W}^H(n)\mathbf{A}^0(\theta^l)\mathbf{T\_X}^0(n)e^{-j2\pi\tau_{l,0}k/N} + \sum_{l=0}^{L-1}\sum_{m=1}^{M-1} \mathbf{W}^H(n)\mathbf{A}^m(\theta^l)\mathbf{T\_X}^m(n)e^{-j2\pi\tau_{l,m}k/N} + \mathbf{F}(\mathbf{W}^H\Gamma_b(n)) \tag{4}$$

where $\tilde{\mathbf{Y}}(n) = \begin{bmatrix} \tilde{y}_0(n) & \tilde{y}_1(n) \end{bmatrix}$ and $\tilde{y}_0(n), \tilde{y}_1(n)$ is the 0-th, 1-th signal of multibeamfomers respectively.

By walsh code for 0-th user, the despread signal vector over two consecutive symbol periods is given by

$$\begin{bmatrix} \hat{Y}_0(n) \\ \hat{Y}_1(n) \\ \hat{Y}_0^*(n+1) \\ \hat{Y}_1^*(n+1) \end{bmatrix} = \mathbf{H}^0(n)\begin{bmatrix} d^0(n) \\ d^0(n+1) \end{bmatrix} + \sum_{m=1}^{M-1} \mathbf{H}^m(n)\begin{bmatrix} d^m(n) \\ d^m(n+1) \end{bmatrix}\Psi_m + \zeta \tag{5}$$

where

$$\Psi_m = \begin{bmatrix} c_0^{0} & c_1^{0} & \cdots & c_{K-1}^{0} \end{bmatrix} \begin{bmatrix} c_0^{m} \\ c_1^{m} \\ \vdots \\ c_{K-1}^{m} \end{bmatrix}, \quad \zeta = \begin{bmatrix} \zeta_0^*(n) \\ \zeta_1^*(n) \\ \zeta_0(n+1) \\ \zeta_1(n+1) \end{bmatrix}$$

$$\mathbf{H}^m(n) = \begin{bmatrix} {}^0\alpha^m{}_{00} + {}^1\alpha^m{}_{00} e^{j2\pi\tau_{l,m} i/K} & {}^0\alpha^m{}_{10} + {}^1\alpha^m{}_{10} e^{j2\pi\tau_{l,m}(i+1)/K} \\ {}^0\alpha^m{}_{01} + {}^1\alpha^m{}_{01} e^{j2\pi\tau_{l,m} i/K} & {}^0\alpha^m{}_{11} + {}^1\alpha^m{}_{11} e^{j2\pi\tau_{l,m}(i+1)/K} \\ {}^0\alpha^{m*}{}_{10} + {}^1\alpha^{m*}{}_{10} e^{-j2\pi\tau_{l,m}(i+1)/K} & -({}^0\alpha^{m*}{}_{00} + {}^1\alpha^{m*}{}_{00} e^{-j2\pi\tau_{l,m} i/K}) \\ {}^0\alpha^{m*}{}_{11} + {}^1\alpha^{m*}{}_{11} e^{j2\pi\tau_{l,m}(i+1)/K} & -({}^0\alpha^{m*}{}_{01} + {}^1\alpha^{m*}{}_{01} e^{-j2\pi\tau_{l,m} i/K}) \end{bmatrix}$$

$$\begin{aligned} {}^l\alpha^m{}_{00} &= w_{00}^* a^m{}_0(\theta_0^l) + w_{10}^* a^m{}_0(\theta_1^l) + \ldots + w_{Nr-10}^* a^m{}_0(\theta_{Nr-1}^l), \\ {}^l\alpha^m{}_{01} &= w_{01}^* a^m{}_0(\theta_0^l) + w_{11}^* a^m{}_0(\theta_1^l) + \ldots + w_{Nr-11}^* a^m{}_0(\theta_{Nr-1}^l), \\ {}^l\alpha^m{}_{10} &= w_{00}^* a^m{}_1(\theta_0^l) + w_{10}^* a^m{}_1(\theta_1^l) + \ldots + w_{Nr-10}^* a^m{}_1(\theta_{Nr-1}^l), \\ {}^l\alpha^m{}_{11} &= w_{01}^* a^m{}_1(\theta_0^l) + w_{11}^* a^m{}_1(\theta_1^l) + \ldots + w_{Nr-11}^* a^m{}_1(\theta_{Nr-1}^l) \end{aligned}$$

The detected signal vector after decoding is calculated by

$$\mathbf{y} = \mathbf{H}^{0H}(n)\hat{\mathbf{X}} = \|\mathbf{H}^0(n)\|^2 \mathbf{I}_2 \begin{bmatrix} d^0(n) \\ d^0(n+1) \end{bmatrix} + \sum_{m=1}^{M-1} \mathbf{H}^{0H}(n)\mathbf{H}^m(n) \begin{bmatrix} d^m(n) \\ d^m(n+1) \end{bmatrix} \Psi_m + \tilde{\zeta} \tag{6}$$

where $\|\mathbf{H}^0(n)\|^2 = \mathbf{H}^{0H}(n)\mathbf{H}^0(n)$, $\tilde{\zeta} = \mathbf{H}^0(n)\zeta$

Finally, the detected signal is given by

$$y(n) = (|\beta^0{}_{00}|^2 + |\beta^0{}_{10}|^2 + |\beta^0{}_{01}|^2 + |\beta^0{}_{11}|^2) d^0(n) + I_{\inf}(n) + \tilde{\eta}_0 \tag{7}$$

where

$$\beta^0{}_{00} = {}^0\alpha^m{}_{00} + {}^1\alpha^m{}_{00} e^{j2\pi\tau_{l,m} i/K}, \quad \beta^0{}_{10} = {}^0\alpha^m{}_{10} + {}^1\alpha^m{}_{10} e^{j2\pi\tau_{l,m}(i+1)/K}$$

$$\beta^0{}_{01} = {}^0\alpha^m{}_{01} + {}^1\alpha^m{}_{01} e^{j2\pi\tau_{l,m} i/K}, \quad \beta^0{}_{11} = {}^0\alpha^m{}_{11} + {}^1\alpha^m{}_{11} e^{j2\pi\tau_{l,m}(i+1)/K}$$

and $I_{\inf}$ is the interference signal from the other user.

The proposed adaptive algorithm can be derived by employing the complex least means square (LMS) algorithm[8][9]. The complex LMS for updating the coefficient vector of multibeamformer in the time domain is given by

$$\mathbf{W}_0(n+1) = \mathbf{W}_0(n) - 2\mu_0 \frac{\partial \mathbf{T}_0\_\boldsymbol{e}^*(n)}{\partial \mathbf{W}_0^*} \mathbf{T}_0\_\boldsymbol{e}(n) \tag{8}$$

$$\mathbf{W}_1(n+1) = \mathbf{W}_1(n) - 2\mu_1 \frac{\partial \mathbf{T}_1\_\boldsymbol{e}^*(n)}{\partial \mathbf{W}_1^*} \mathbf{T}_1\_\boldsymbol{e}(n) \tag{9}$$

where μ_0, μ_1 is step size.

The error vector for the 0-th beamformer and the 1-st beamformer is given respectively by

$$\mathbf{T}_0\_\boldsymbol{e}(n) = \mathbf{F}^H(\mathbf{T}_0\_\mathbf{X}^m(n) - \tilde{\boldsymbol{y}}_0(n)) \tag{10}$$

$$\mathbf{T}_1\_\boldsymbol{e}(n) = \mathbf{F}^H(\mathbf{T}_1\_\mathbf{X}^m(n) - \tilde{\boldsymbol{y}}_1(n)) \tag{11}$$

And differential error vector is is expressed respectively as follows

$$\frac{\partial \mathbf{T}_0\_\boldsymbol{e}^*(n)}{\partial \mathbf{W}_0^*} = -\mathbf{R}(n) \tag{12}$$

$$\frac{\partial \mathbf{T}_1\_\boldsymbol{e}^*(n)}{\partial \mathbf{W}_1^*} = -\mathbf{R}(n) \tag{13}$$

The equations (10), (11), (12) and (13) are substituted into the equations (8) and (9) and the following equations for adaptively updating the coefficients of the multibeamformer in the MIMO MC-CDMA is derived as follows

$$\mathbf{W}_0(n+1) = \mathbf{W}_0(n) + 2\mu_0\mathbf{R}(n)\mathbf{F}^H(\mathbf{T}_0\_\mathbf{X}^m(n) - \tilde{\boldsymbol{y}}_0(n)) \tag{14}$$

$$\mathbf{W}_1(n+1) = \mathbf{W}_1(n) + 2\mu_1\mathbf{R}(n)\mathbf{F}^H(\mathbf{T}_1\_\mathbf{X}^m(n) - \tilde{\boldsymbol{y}}_1(n)) \tag{15}$$

3. Simulation and numerical results

In this section, the performances of the proposed technique for the MIMO MC-CDMA system are investigated by computer simulations. The radio channel for simulation is multipath Jacke's model with maximum time delay which is smaller than the cyclic prefix. The modulation scheme is BPSK and the size (N) of subcarrier is 32. Figure 2 shows the BER of MIMO MC-CDMA with *Nr*=4 when the number of user is 1 and 32. From figure 2, we can see that the performance of MIMO MC-CDMA system greatly degrade when the number of user is 32 because the orthogonality among the received signals is distorted by the increasing interference. Figure 3 shows the comparison on the bit error rate(BER) performance of the proposed multibeamforming at the 32 users when the number of the receiver antenna is varied. The BER performance of the MC MIMO-MC-CDMA system with adaptive multibeamforming is improved significantly as the number of the receiving antenna is increased. Also, we compare the performance of the proposed adaptive multibeamforming with that of no beamforming in the MIMO MC-CDMA system. This figure shows that the BER performance of the proposed approach is better than that of the no beamforming in the MIMO MC-CDMA system. At the BER of 10^{-3}, about 3 dB gain(*Nr*=4, *M*=32) can be achieved with the adaptive multibeamforming, compared to the case with no beamforming for MIMO MC-CDMA system. Figure 5 shows the beam pattern when the DOAs (DOA1 and DOA2) from two transmitter antennas for the desired user are -25° and -5°, and the DOAs of interference and multipath signals are random, respectively. 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.

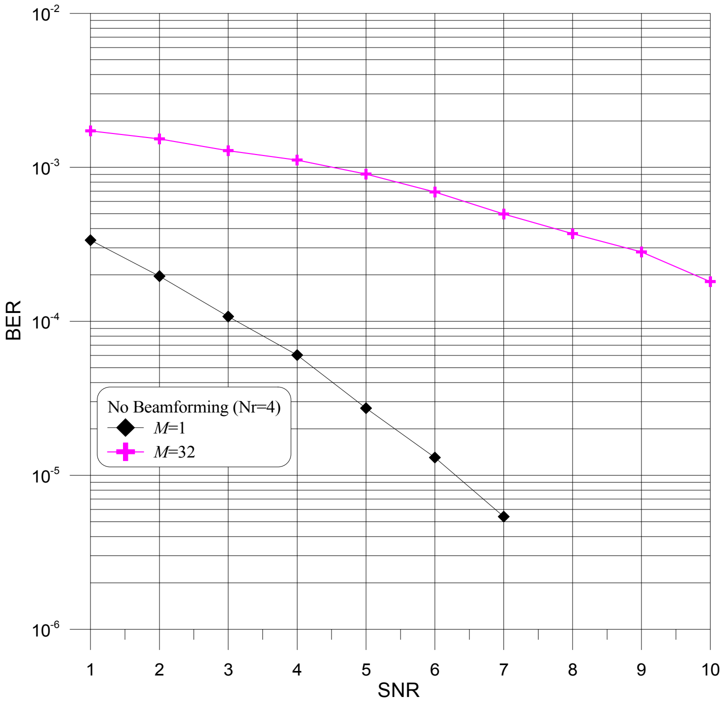

Figure 2. The performance of MIMO MC-CDMA system when the number of user is 1 and 32

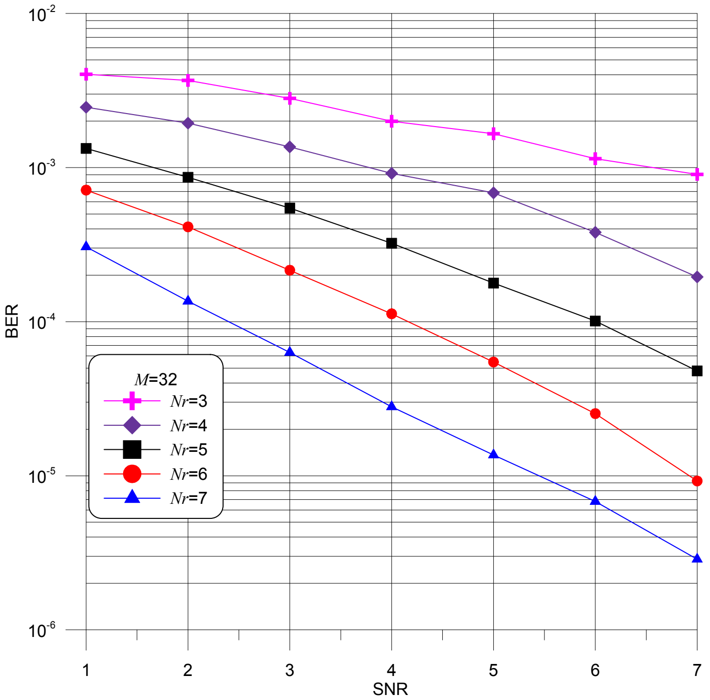

Figure 3. BER comparison of MIMO MC-CDMA system with proposed algorithm for various number of receiver antennas

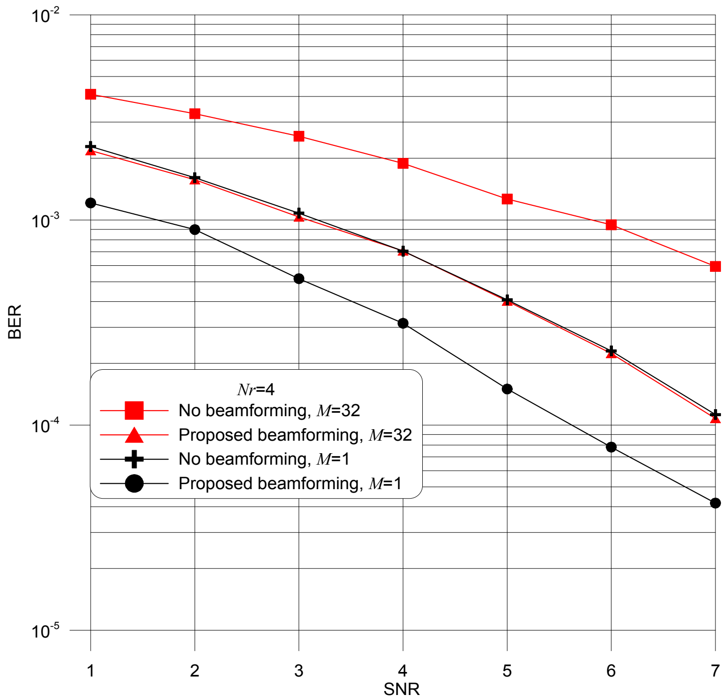

Figure 4. BER comparison between the proposed adaptive beamfoming and no beamforming in the MIMO MC-CDMA system

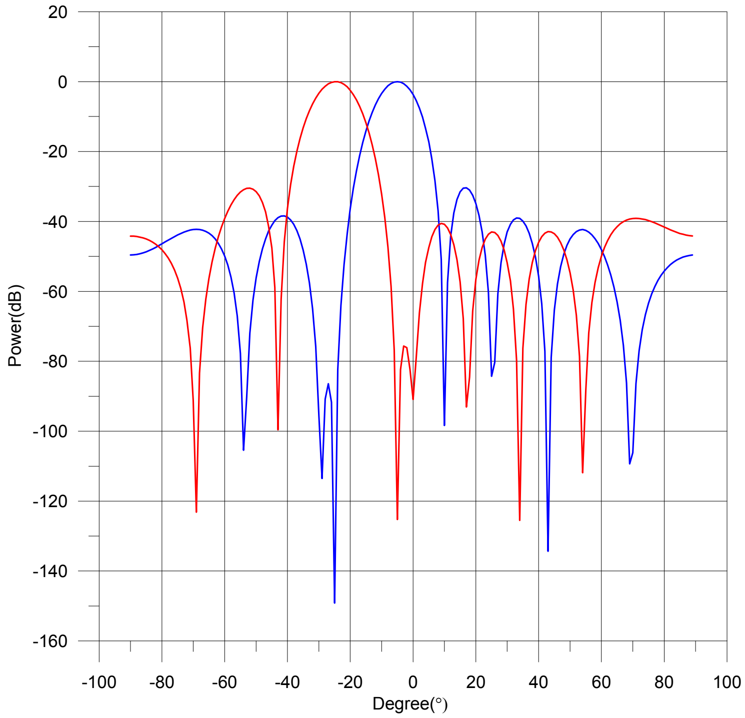

Figure 5. Beam pattern of MIMO MC-CDMA system when the proposed beamforming scheme is applied. (DOA1=-25°, DOA2=-5°, DOA_p1=-55°, DOA_p2=10°,*Nr*=8)

4. Conclusion

In this paper, we proposed an adaptive multibeamforming technique for MIMO MC-CDMA system. The proposed algorithm effectively eliminated CCI and IAI while preserving STC (space time code) diversity. To verify the performance of the proposed approach for MIMO MC-CDMA system, a computer simulation was performing. As a result of the simulation, the proposed approach could track each direction of arrival (DOA) of the signals from multi-antennas of a desired user and then a beam was formed to each transmit antenna of the desired user by the proposed approach while a null beam was forming toward the other interference signal. The BER performance of the MC MIMO-MC-CDMA system with adaptive multibeamforming was improved significantly and was better than that of the no beamforming in the MIMO MC-CDMA system. Therefore, we concluded that the proposed approach could significantly increase the performance of MIMO MC-CDMA system in the multipath fading channel with CCI.

Acknowledgements

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References

[1] M. I. Kadir, S. Sugiura, Sheng Chen, and Lajos Hanzo, "Unified MIMO-Multicarrier Designs: A Space-Time Shift Keying Approach," IEEE communication surveys & tutorial, vol. 17, no.2, pp. 550-579, April 2015.

[2] J.M.Luna-Rivera, D.Campos-Delgado, C. Gutirrez etc, "Performance analysis of closed-loop pre-equalisation for multiuser multiple-input multiple-output with multicarrier code division multiple access systems," IET Comm., vol. 10, pp. 271-350, Mar. 2016

[3] J. Kirubakaran1, G.K.D Prasanna ,"Performance Analysis of MIMO MC-CDMA System Using Multi Equalizers, "ICEICE2017, pp.1-5, 2017.

[4] R .Yuvaraj; L.Nithyanandan; J. Emmanuel, "Capacity enhancement with reduced complex receiver antenna selection algorithm for MIMO MC-CDMA system in mobile WiMAX networks," PCCCTSG15, pp.257-272, 2015

[5] Frederick W. Vook, A. Ghosh, Timothy A. Thomas, “MIMO and Beamforming Solutions for 5G Technology,” IMS2014, pp.1~5, 2014.

[6] G. Asadullah M.M. and G.orodon L. Stuber, "Joint Iterative channel estimation and soft-chip combing for a MIMO MC-CDMA anti-jam system," IEEE tran. On commun., vol. 57 No. 4, pp1068-1078, April 2009.

[7] H. Sheng-Wei and K. Chi Chung, "Multiple-access interference suppression for interleaved OFDMA system uplink," IEEE Tran. On vehicular technology, Vo. 57, No. 1, pp. 194-205, January 2008

[8] Simon Haykin, Adaptive filter theory, Prentice-Hall Inc., 1996.

[9] C. K. Kim and Y. S. Cho, "Pre-FFT adaptive bemaforming algorithm for OFDM systems with array antenna," IEICE Trans. Commun., vol. E86-B, no.3, pp. 1144-1148, Mar. 2003.