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Performance Improvement of MIMO-OFDMA system with beamformer

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Abstract

In this paper, we propose the adaptive beamforming algorithm for the MIMO (Multi-Input Multi-Out)-OFDMA(Orthogonal Frequency Division Multiplexing Access)system to improve the performance. The performance of MIMO-OFDMA systems is greatly decreased in the wireless channel environment with multiusers, because the received signals are much distorted by a cochannel interference (CCI) during the space-time decoding. The proposed approach can track the DOA of each signal from the multiple antennas of the desired user without being greatly dependent on the impinging angle. And beams are directed toward the multiple transmitters of the desired user while null beams are directed toward interference directions. Therefore, we can can effectively cancel CCI and mitigate the impairment of delay spread while preserving the STC(space time code) diversity. BER performance improvement is investigated through computer simulation by applying the proposed approach to MIMO-OFDMA system in a multipath fading channel with CCI.

Keywords: *OFDMA(OFDM), beamforming, MIMO, STC, MIMO-OFDMA.*

1. Introduction

Multiple-input multiple-output (MIMO) techniques can greatly improve system capacity by employing multiple antennas at both transmitter and receiver for wireless mobile communications in rich multipath environments[1][2]. Orthogonal frequency division multiplexing Access (OFDMA) is multiple access technique that allocates the set of OFDM subcarrier into each user. Therefore, OFDMA have the property of OFDM that can effectively overcome intersymbol interference (ISI) by inserting a cyclic prefix (CP) longer than the delay spread of the channel into the guard band[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][6]. In the multipath fading channel with CCI, the performance of MIMO-OFDMA systems is greatly decreased because the received signals are much distorted by CCI during the space-time decoding[7][8]. Adaptive beamforming are

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known to be effective in increasing system capacity by eliminating CCI for wireless mobile communication system with multiple antennas [9][10]. In this paper, we propose an effective CCI cancellation technique that improves the performance of system by combining MIMO-OFDMA with adaptive beamforming. The proposed approach can track the DOA of each signal from the multiple antennas of the desired user without being greatly dependent on the impinging angle. And beams are directed toward the multiple transmitters of the desired user while null beams are directed toward interference directions. It is demonstrated by computer simulation that the proposed approach can effectively eliminate CCI while preserving STC diversity, thereby, greatly improving the performance of MIMO-OFDMA systems.

2. MIMO-OFDMA systems with adaptive beamfomer

Figure 1 shows a block diagram of the proposed MIMO-OFDMA system with adaptive beamformer. The transmitted signals from the multi-antennas of M users arrive at receiver antennas with Nr through the multipath channel. The received signals with spatial phase for each receiver antenna are multiplied by the weights of beamformers, and then output signals of beamformer are transformed back into frequency domain signals by the FFT.

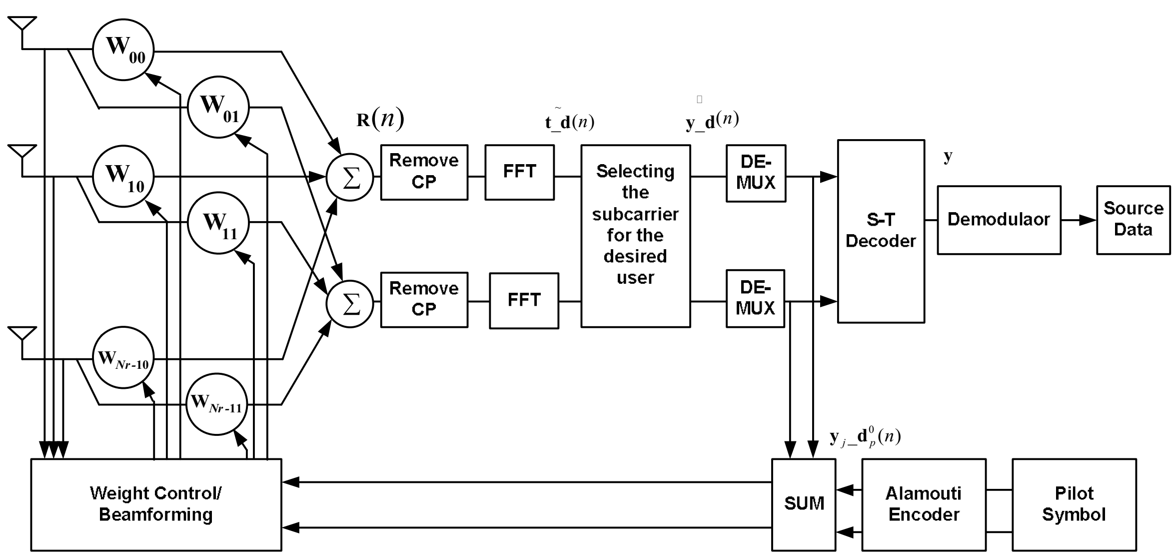

Figure 1. Block diagram of MIMO-OFDMA system with adaptive beamforming

After selecting the subcarrier for the m-th user, the signals are decoded by space-time decoder. When the weights are optimal, beams with maximum gain are formed toward each transmitter antennas of the desired user. Diversity gain can be obtained from the space–time decoding output signals that eliminated CCI and the multipath signal, resulting in an increase in the signal to interference and noise ratio (SNIR). When the signal vector of OFDMA block for the m-th user in the frequency domain is $\mathbf{d}^m(n) = \left[d_0{}^m \quad d_1^m \quad \cdots \quad d_{N-1}^m \right]$, the signal matrix by the Alamouti encoder is given by

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

where

$$\mathbf{y}_0\_\mathbf{d}^m(n)=\begin{bmatrix} d_0^{\ m} \\ -d_1^{m*} \\ \vdots \\ -d_{N-1}^{m*} \end{bmatrix}, \mathbf{y}_1\_\mathbf{d}^m(n)=\begin{bmatrix} d_1^{\ m} \\ d_0^{m*} \\ \vdots \\ d_{N-1}^{m*} \end{bmatrix}$$

and after allocating the subcarrier, the signal matrix is expressed as

$$\mathbf{t}\_\mathbf{d}^m(n)=\begin{bmatrix}\mathbf{t}_0\_\mathbf{d}^m(n) & \mathbf{t}_1\_\mathbf{d}^m(n)\end{bmatrix}$$

where

$$\mathbf{t}_0\_\mathbf{d}^m(n)=\begin{bmatrix} t_0\_d_0^{\ m} \\ t_0\_d_{Ns+m}^{\ m} \\ \vdots \\ t_0\_d_{(N-1)Ns+m}^{\ m} \end{bmatrix}=\mathbf{y}_0\_\mathbf{d}^m(n) \qquad \mathbf{t}_1\_\mathbf{d}^m(n)=\begin{bmatrix} t_1\_d_{Ns+m}^{\ m} \\ t_1\_d_m^{\ m} \\ \vdots \\ t_1\_d_{(N-1)Ns+m}^{\ m} \end{bmatrix}=\mathbf{y}_1\_\mathbf{d}^m(n)$$

$\mathbf{t}_0\_\mathbf{d}^m(n)$, $\mathbf{t}_1\_\mathbf{d}^m(n)$ are the signal vector which are allocated subcarrier for the 0-th and the 1st transmitter antenna of the m-th user, respectively and * is represented conjugate. Here, N and Ns represent the number of sample in an OFDM block and the number of subchannel, respectively. The signal matrix transformed into the time domain by the inverse FFT (IFFT) is expressed as

$$\mathbf{T}\_\mathbf{D}^m(n)=\begin{bmatrix}\mathbf{T}_0\_\mathbf{D}^m(n) & \mathbf{T}_1\_\mathbf{D}^m(n)\end{bmatrix} \tag{2}$$

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

$$\mathbf{T}_0\_\mathbf{D}^m(n)=\mathbf{F}^H(\mathbf{t}_0\_\mathbf{d}^m(n)), \quad \mathbf{T}_1\_\mathbf{D}^m(n)=\mathbf{F}^H(\mathbf{t}_1\_\mathbf{d}^m(n)) \tag{3}$$

where F and *H* are represented the FFT operation matrix and Hermitian transpose, respectively. The L multipath signals from *M* users arrive at each antenna with the corresponding DOA. The signal matrix, **V**(n), received at the antennas is written by

$$\mathbf{V}(n)=\sum_{l=0}^{L-1}\mathbf{A}^0(\theta^l)\mathbf{T}\_\mathbf{D}^{0T}(n-\tau_{0,l})+\sum_{l=0}^{L-1}\sum_{m=1}^{M-1}\mathbf{A}^m(\theta^l)\mathbf{T}\_\mathbf{D}^{mT}(n-\tau_{m,l})+\mathrm{N}_b(n) \tag{4}$$

where

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

$\mathbf{A}^m(\theta^l)$ represent the array response matrix for the *l*-th path of the *m*-th user with argument of DOA($=\theta^l$) and is the normalized time delay of the *l*-th path for *m*-th user. $\mathrm{N}_b(n)$ is the matrix for the background noise. The signal matrix multiplied by the weight matrix of beamformers is given by

$$\mathbf{R}(n) = \mathbf{W}^{H}(n)\,\mathbf{V}(n) \tag{5}$$

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

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

$$\begin{aligned} \tilde{\mathbf{t\_d}}(n) &= \mathbf{F}(\mathbf{R}(n)) \\ &= \sum_{l=0}^{L-1} \mathbf{W}^{H}(n)\mathbf{A}^{0}(\theta^{l})e^{-j2\pi\tau_{l,0}k/N}\mathbf{t\_d}^{0}(n) + \sum_{l=0}^{L-1}\sum_{m=1}^{M-1}\mathbf{W}^{H}(n)\mathbf{A}^{m}(\theta^{l})e^{-j2\pi\tau_{l,m}k/N}\mathbf{t\_d}^{m}(n) + \mathbf{F}(\mathbf{W}^{H}\mathrm{N}_b(n)) \end{aligned} \tag{6}$$

And then selecting the subcarrier for desired user, the received signal matrix is given by

$$\tilde{\mathbf{y\_d}}(n) = \begin{bmatrix} \tilde{\mathbf{y}_0\mathbf{\_d}} \\ \tilde{\mathbf{y}_1\mathbf{\_d}} \end{bmatrix} = \begin{bmatrix} \tilde{y_0\_d_0}(n) & \tilde{y_0\_d_1}(n) & \cdots & \tilde{y_0\_d_{N-1}}(n) \\ \tilde{y_1\_d_0}(n) & \tilde{y_1\_d_1}(n) & \cdots & \tilde{y_1\_d_{N-1}}(n) \end{bmatrix} \tag{7}$$

Here, $\tilde{y_j\_d_i}$ is the output signal of the j-th beamformer at the i-th subcarrier.

The proposed adaptive algorithm for the MIMO-OFDMA systems transforms the error signals between the coded pilot symbols of desired user and the received signals from each multi-antennas of other users, given in the frequency-domain, into the time-domain error signals so that the weights of the adaptive beamformers are updated in the time-domain in the direction of minimizing the MSE.

$$\mathbf{W}_0(n+1) = \mathbf{W}_0(n) + 2\mu\mathbf{R}(n)\mathbf{F}_p^{H}(\mathbf{y}_0\mathbf{\_d}_p^{0}(n) - \tilde{\mathbf{y}_0\mathbf{\_d}_p}(n)) \tag{8}$$

$$\mathbf{W}_1(n+1) = \mathbf{W}_1(n) + 2\mu\mathbf{R}(n)\mathbf{F}_p^{H}(\mathbf{y}_1\mathbf{\_d}_p^{0}(n) - \tilde{\mathbf{y}_1\mathbf{\_d}_p}(n)) \tag{9}$$

where

$$\mathbf{F}_p = \begin{bmatrix} \lambda_{0,0} & \lambda_{0,1} & \cdots & \lambda_{0,N-1} \\ \lambda_{1,0} & \lambda_{1,1}\varsigma_{1,1} & \cdots & \lambda_{1,N-1}\varsigma_{1,N-1} \\ \vdots & \vdots & \vdots & \vdots \\ \lambda_{N-1,0} & \lambda_{N-1,1}\varsigma_{N-1,1} & \cdots & \lambda_{N-1,N-1}\varsigma_{N-1,N-1} \end{bmatrix}$$

$$\varsigma_{i,l} = e^{-j2\pi(i)(l)/N}, \qquad \lambda_{i,l} = \begin{cases} 1 & \text{if } l = k\Delta p \text{ or } l = k\Delta p + 1 \\ 0 & \text{otherwise} \end{cases}$$

$$k = 0,1,2,\ldots,N_p - 1 \;\; for\; i = 0,1,2,\ldots,N-1$$

The notations, Δp and N_p, represent the frequency spacing between pilot symbols and the number of pilot symbols inserted in an OFDMA block of desired user, respectively. $\mathbf{y}_j\mathbf{\_d}_p^{0}(n)$, $\tilde{\mathbf{y}_j\mathbf{\_d}_p}(n)$ denote the coded pilot symbol vector of the desired user and the received pilot signal vector in the frequency domain for the j-th beamformer, respectively.

The detected signal vector after decoding is calculated by

$$\mathbf{y} = \| \tilde{\boldsymbol{a}}^{0} \|^{2} \begin{bmatrix} d_k^0 \\ d_{k+1}^0 \end{bmatrix} + \sum_{m=1}^{M-1} \tilde{\boldsymbol{a}}^{0H} \tilde{\boldsymbol{a}}^{m} \begin{bmatrix} d_k^m \\ d_{k+1}^m \end{bmatrix} + \tilde{\boldsymbol{\zeta}}(n) \tag{10}$$

where $\| \tilde{\boldsymbol{a}}^{0} \|^{2} = \tilde{\boldsymbol{a}}^{0H} \tilde{\boldsymbol{a}}^{0}$

$$\tilde{\boldsymbol{a}}^{m} = \begin{bmatrix} \beta_{00}^{m} & \beta_{10}^{m} \\ \beta_{01}^{m} & \beta_{11}^{m} \\ \beta_{10}^{m*} & -\beta_{00}^{m*} \\ \beta_{11}^{m*} & -\beta_{01}^{m*} \end{bmatrix}$$

$$\beta_{00}^{m} = {}^{0}\alpha_{00}^{m} + {}^{1}\alpha_{00}^{m} e^{-j2\pi\tau_{m,1}k/N}, \beta_{10}^{m} = {}^{0}\alpha_{10}^{m} + {}^{1}\alpha_{10}^{m} e^{-j2\pi\tau_{m,1}(k+1)/N},$$
$$\beta_{01}^{m} = {}^{0}\alpha_{01}^{m} + {}^{1}\alpha_{01}^{m} e^{-j2\pi\tau_{m,1}k/N}, \beta_{11}^{m} = {}^{0}\alpha_{11}^{m} + {}^{1}\alpha_{11}^{m} e^{-j2\pi\tau_{m,1}(k+1)/N}$$

$${}^{l}\alpha^{0}{}_{00} = w_{00}^{*} a^{0}(\theta_{00}^{l}) + w_{10}^{*} a^{0}(\theta_{10}^{l}) + \ldots + w_{Nr-10}^{*} a^{0}(\theta_{Nr-10}^{l}),$$
$${}^{l}\alpha^{0}{}_{01} = w_{01}^{*} a^{0}(\theta_{00}^{l}) + w_{11}^{*} a^{0}(\theta_{10}^{l}) + \ldots + w_{Nr-11}^{*} a^{0}(\theta_{Nr-10}^{l}),$$
$${}^{l}\alpha^{0}{}_{10} = w_{00}^{*} a^{0}(\theta_{01}^{l}) + w_{10}^{*} a^{0}(\theta_{11}^{l}) + \ldots + w_{Nr-10}^{*} a^{0}(\theta_{Nr-11}^{l}),$$
$${}^{l}\alpha^{1}{}_{11} = w_{01}^{*} a^{0}(\theta_{01}^{l}) + w_{11}^{*} a^{0}(\theta_{11}^{l}) + \ldots + w_{Nr-11}^{*} a^{0}(\theta_{Nr-11}^{l})$$

$$\tilde{\boldsymbol{\zeta}}(n) = \tilde{\boldsymbol{a}}^{0H} \boldsymbol{\zeta}(n) = \begin{bmatrix} \tilde{\boldsymbol{\zeta}}_k(n) \\ \tilde{\boldsymbol{\zeta}}_{k+1}(n) \end{bmatrix},$$

Finally, the signal detected at the i-th subcarrier is given by

$$y_0 = (\left|\beta^{0}{}_{00}\right|^2 + \left|\beta^{0}{}_{10}\right|^2 + \left|\beta^{0}{}_{01}\right|^2 + \left|\beta^{0}{}_{11}\right|^2) d_0^0 + I_{\inf 0} + \tilde{\zeta}_0(n) \tag{11}$$

$$y_1 = (\left|\beta^{0}{}_{00}\right|^2 + \left|\beta^{0}{}_{10}\right|^2 + \left|\beta^{0}{}_{01}\right|^2 + \left|\beta^{0}{}_{11}\right|^2) d_1^0 + I_{\inf 1} + \tilde{\zeta}_1(n) \tag{12}$$

$I_{\inf k}$ is the interference signal from the other user to the k-th detected signal. In Eq. (11),(12), we can get STC diversity gain and reduce CCI even though DOAs of the signals from multi-transmitter antennas of desired user are different.

3. Simulation and numerical results

The performances of the proposed technique for the MIMO-OFDMA 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 QPSK and the group(N) size of subcarrier(OFDM block per one transmitter) including pilot symbol is 32. The number of subchannel in a group are 8 and multipath(L) are 2. In addition, the receiver was equipped with a linear array antenna and the distance between adjacent arrays was assumed to be λ/2. Figure 2 shows the beam pattern when the DOAs (DOA1 and DOA2) from two transmitter antennas for the desired user are 20° and 30°, 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 3 shows BER performance in the multipath channel with CCI when the proposed approach applied to MIMO-OFDMA system. Also, we compare the performance of the proposed adaptive beamfoming with that of no beamforming in the MIMO-OFDMA system. This figure shows that the BER performance of the proposed approach is better than that of the no beamforming in the MIMO-OFDMA system. At the BER of 10^{-2}, about 4 dB gain(Nr=5) can be achieved with the adaptive beamforming, compared to the case with no beamforming. Figure 4 shows the comparison on the BER performance of the proposed beamforming algorithm when the number of the receiver antenna is varied. The BER performance of the MIMO-OFDMA system with adaptive beamforming is improved significantly as the number of the receiver antenna increases.

Figure 5 shows BER performance of MIMO-OFDMA system in the multipath channel with different time delays. From figure 5, we can see that the performance of the proposed scheme is not affected by the time delay due to removing the delayed path when the guard interval is larger than the time delay.

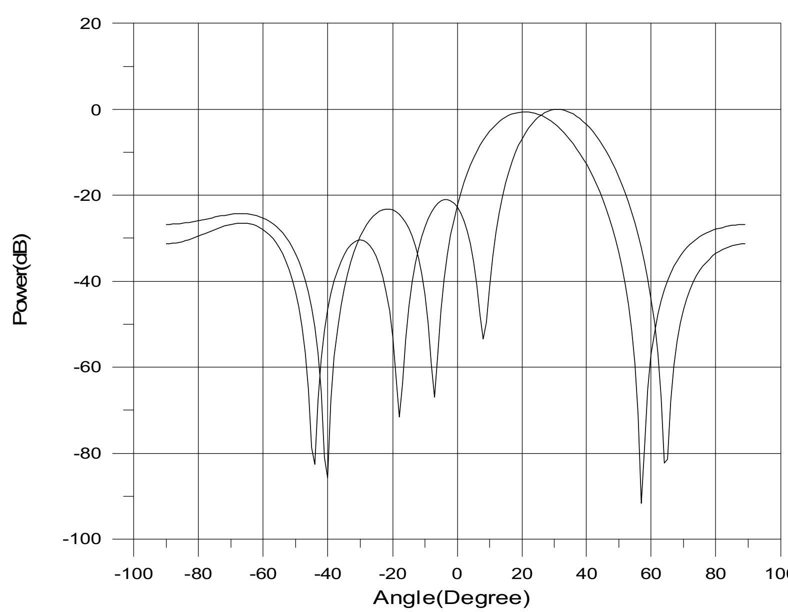

Figure 2. Beam pattern of MIMO-OFDMA system when the proposed beamforming scheme is applied.

(DOA1=20°, DOA2=30°, DOAs of interferer = random, *Nr*=5, SIR=10dB)

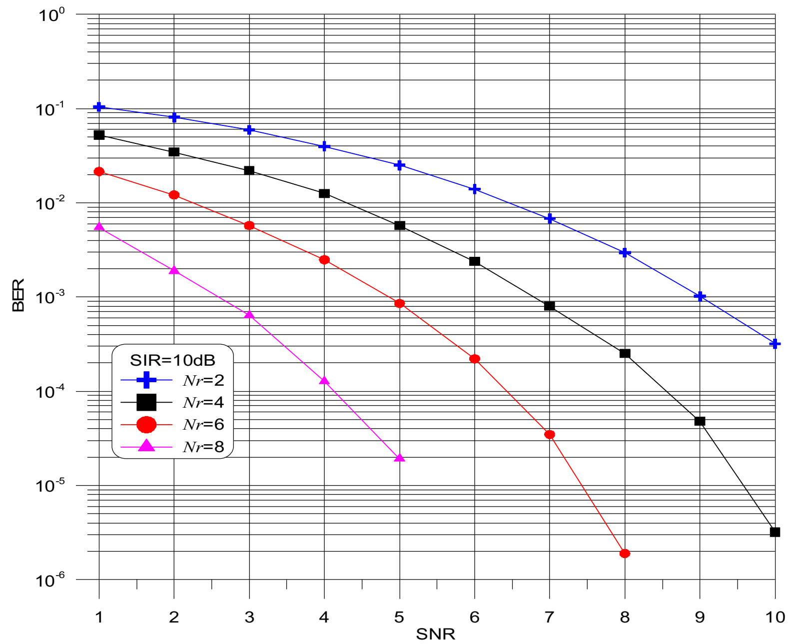

Figure 3. BER comparison of MIMO-OFDMA system with proposed algorithm for various number of receiver antennas

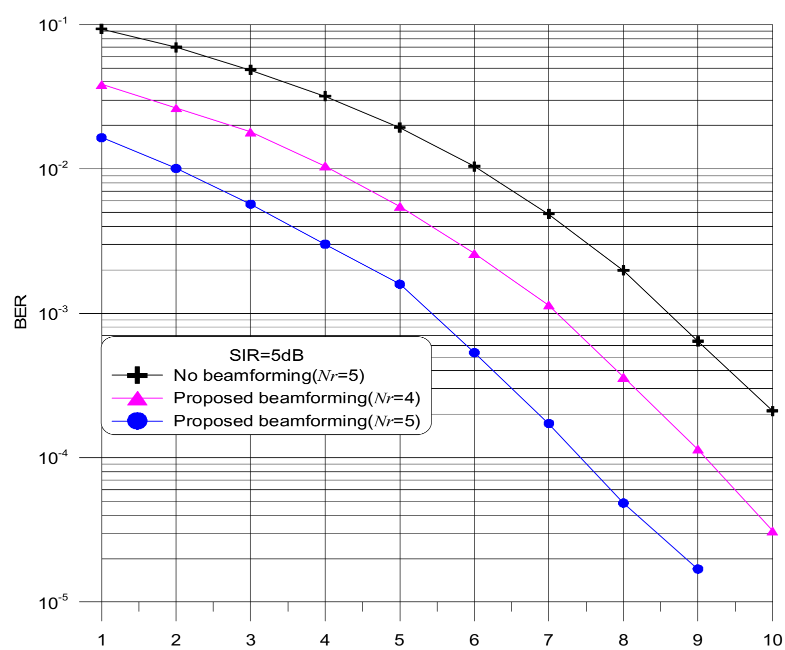

Figure 4. BER comparison between the proposed adaptive beamfoming and no beamforming in the MIMO-OFDMA system.

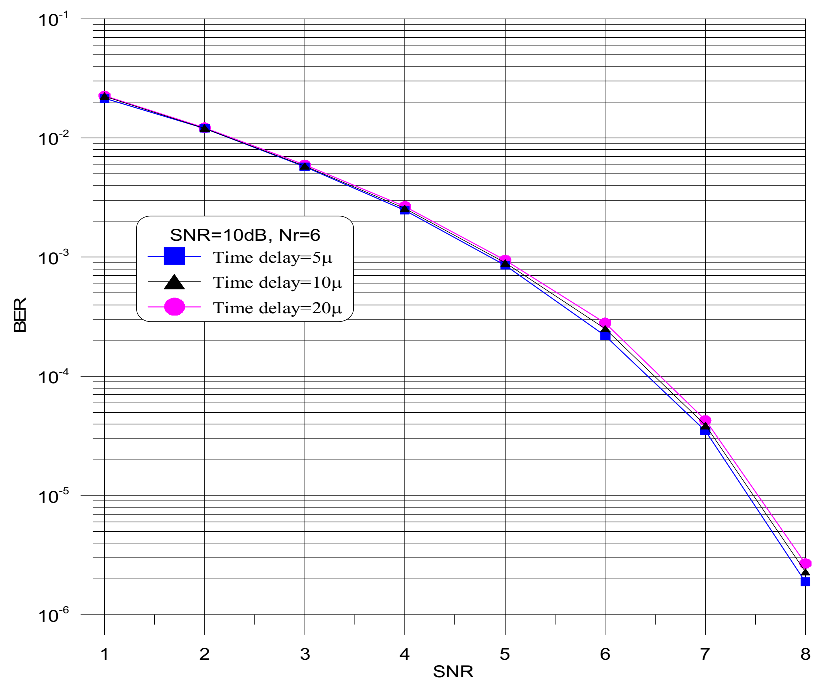

Figure 5. BER performance of MIMO-OFDMA system in the multipath channel with different time delays

4. Conclusion

In this paper, the proposed algorithm was an effective CCI cancellation technique based on MMSE (minimizing the mean squared error) for MIMO-OFDMA system with multiple antennas while preserving the STC diversity. By the proposed algorithm, we could track the DOA of each signal from the multiple antennas of the desired user without being greatly dependent on the impinging angle and directly beamform toward the multiple transmitters of the desired user. And then, the proposed approach could effectively could remove cochannel interference(CCI) and mitigate the impairment of delay spread. From the simulation results, we concluded that the proposed approach could significantly increase the performance of MIMO-OFDMA system in the multipath fading channel with CCI. Also, BER performance of the proposed scheme is not affected by the time delay due to removing the delayed path. We will further study mm-wave beamforming for MIMO.

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