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Providing a Technique to Reduce and Eliminate the Interference in MIMO-OFDM Systems

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Abstract - Despite strong resistance against the destructive effects of communication channels ,OFDM systems are highly sensitive to the effect of interference from other sources .beam forming techniques have been proposed to resist against the effects of interference in these systems .These methods are generally categorized into Pre - FFT (processing in the time domain) Post - FFT (processing in the frequency domain) and time-frequency and space-time combined methods that in these methods ,beam forming is carried out in the receiver .In this paper, considering the characteristics of MIMO structure, multiple antennas are used for sending the desired source . On the other hand, the beam forming is carried out at the transmitter and receiver antennas .It has been shown that the proposed method, better performance than the space-time and time-frequency methods in all conditions. Especially when sources are relatively close together, the performance of other methods is reduced more than the proposed method .Since we want to compare the proposed method with SIMO previous methods such as space-time and time-frequency ,we use LMS adaptive algorithm used in SIMO structure.

***Keywords**:Adaptive algorithm, array antennas, interference, beam forming, MIMO – OFDM*

I. INTRODUCTION

One of the major problems of modern commercial wireless systems is the limited number of users and low quality of services in the presence of interference signals .Given the fact that the current demand for wireless services has increased, these limitations are discussed more seriously. Among the many strategies that have been proposed to deal with these limitations diversity is considered as one of the most powerful ways to increase the number of users and improve the efficiency,[1]. Among different methods of spatial diversity through the use of array antennas and beam forming techniques in transmitter and receiver have received considerable attention in recent years. Using beam forming techniques, the efficiency and the ability of communication systems get closer to the wireless channel theoretical capacity limit .In this method, the signals sent by different users can be separated using antenna array and spatial filtering. In other words, if the original signal and the interference signal transmitters are located in different spatial locations ,an antenna array has acted as a spatial filter and separates the main signal from the interference signals. Thus the capacity of the system can be increased . Therefore, location-based processing is considered as a powerful tool in multi-user systems. In OFDM[1] systems, if the angle between desired signal and interference is different, the use of antenna array in the structure can eliminate the effect of the interference signal and increase the channel capacity to some extent. Through radiation pattern circulation in the atmosphere(with no physical circulation),array antennas make it possible to seek for the array element signals more closely or in other words, the best radiation pattern for the receiver input and/or transmitter output is selected. So far, the use of adaptive algorithms in antenna array has been studied for single-carrier systems, several times. But the application of beam forming techniques in OFDM systems has been under debate in recent years.

II. PRE-FFT STRUCTURE

Figure 1 shows the receiver structure of Pre-FFT method,[6] .As can be seen in the Figure, the received signal on receiver antennas $u_m(n)$ m=1 ,......, M is multiplied by the weights of time domain v_{prem} and beam forming has occurred and time domain output is created $\underline{y} = [y(1)y(2).......y(N)]^T$.

Using Fourier transform for $\underline{y}$ vector, frequency domain output is obtained $\underline{Y} = [Y(1)Y(2).....Y(N)]^T$ In case of Pre-FFT, adaptive algorithm is used to update the weights .In order to carry out the update, the error signal must be calculated, first and considering the fact that weight is in the time domain ,the error signal should be transferred to the time domain. .

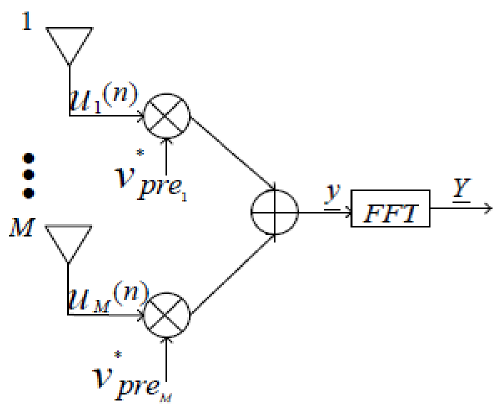

Fig .1. Receiver structure for pre-FFT method.

III. POST-FFT STRUCTURE

Figure 2 shows Post-FFT receiver structure,[6] .As can be seen in Figure 2, the received signal on each receiver antenna enters into the FFT block and $U_{n,m}$ $n = 1,2\ldots\ldots,N$ frequency domain signal is generated .By multiplying the weights of $v_{Post_{n,m}}$ $m = 1,\ldots.M$ by n-th sub-carrier, beam forming carried out in the frequency domain in the receiver antennas and the corresponding output is obtained .As noted ,several FFT blocks are needed in this structure that lead to complexity of the Post-FFT method. In Post-FFT like Pre-FFT, adaptive algorithms are used for updating the weights, but in this case, because the weights are in the frequency domain, there is no need to transfer the error signal to the time domain.

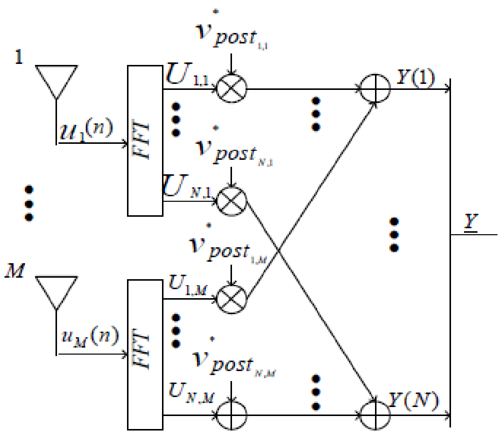

Fig .2. Receiver structure for post-FFT method.

IV. SIMULTANEOUS BEAM FORMING TECHNIQUE IN TRANSMITTER AND RECEIVER ANTENNAS

Figure 3 shows simultaneous beam forming in both transmitter and receiver antennas .As can be seen in the figure, unlike the Pre-FFT and Post-FFT structures in which one antenna was used for sending the desired source in this structure ,multiple antennas are used for sending the desired source .On the other hand ,beam forming only occurred in the receiver antennas ,while in the proposed method, the beam forming is simultaneously occurred in the both transmitter and receiver antennas .After performing inverse Fourier transform for the frequency domain signal vector of X, the time domain signal Xm: m=1-2-……-MT is obtained on each antenna.. Temporal signals on each transmitter antenna are multiplied by specific weight of Vm and beam forming operation takes place in the transmitter antennas. In order to eliminate ISI[2], protective time is added to beam forming output signal in each transmitter antenna, then the signal is sent by the transmitter antennas .After passing through the channel ,the signal sent by transmitter antennas is received by the receiver antennas .At the receiver of each antenna, first the protective time is removed from the received signal .In the next phase, beam forming is done in the receiver .The signal of each antenna is multiplied by special weights and the time domain output y is generated. By FFT transformation of time domain output ,frequency domain output Y is obtained, [3]. According to the figure, we can write:

$$y(n) = \underline{W}^{H}\underline{r}(n) \tag{1}$$

$$\underline{W} = [w_1 \;\; w_2 \;\; w_{Mn}]^T \tag{2}$$

$$\underline{r}(n) = [r_1(n) \;\; r_2(n) \;\; \ldots r_{M_R}(n)]^T \tag{3}$$

In the above equation, r(n) is time domain received signal on the receiver antennas and W is the weight vector of receiver antennas.

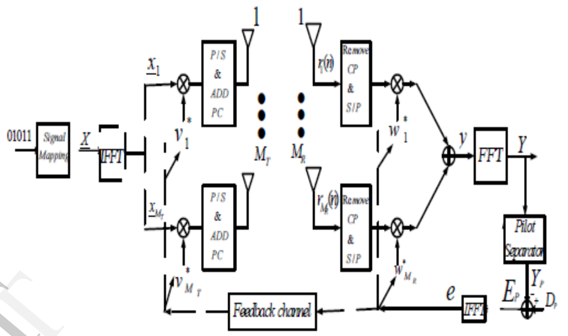

Figure .3. Simultaneous beam forming technique in transmitter and receiver antennas.

V. UPDATING RECEIVER ANTENNAS WEIGHTS

Like Pre-FFT and Post-FFT techniques, the weights of receiver antennas must be updated at each OFDM block .The error signal in the frequency domain can be obtained by comparing y(K) K=1,2,..N with its corresponding guiding value, [2]. Given that the weight of receivers is updated in the time domain, but the errors obtained in the frequency domain , the errors must be mapped to the time domain .If the number of guide sub- carriers (P) is less than the total number of sub- carriers (N), the frequency domain error vector ($\underline{E}p$) with N dimensions is defined as follows:

$$\underline{E}p = \underline{D}p - \underline{Y}p \tag{4}$$

In the above equation, $\underline{D}p$ and $\underline{Y}p$ are the vectors corresponding to the desired signal and the received signal, respectively. If the K-th sub- carrier is not a guide, the k -th element of both vectors will be equal to zero. Time domain error signal is obtained from the following equation:

$$\underline{e} = \frac{1}{N} F^{H}\underline{E}p \tag{5}$$

In above equation, $\underline{e} = [e(1)\ \ e(2)\ \ ...e(N)]^T$ is a vector of N dimensions and F is FFT matrix with N × N dimensions and is defined as follows:

$$F = [f_{p,l}] = [e^{\frac{-i\,2\pi(p-1)(l-1)}{N}}] \tag{6}$$

Like the time-frequency and space-time methods the weight of the receiver in block (q + 1) is updated by adaptive method and using LMS[3] algorithm as follows:

$$\underline{W}_{pre}(q+1) = \underline{W}_{pre}(q) + 2\mu \sum_{n=1}^{N} \underline{r}(n) e^*(n) \tag{7}$$

In the above equation, μ is motional step and* is a conjugate symbol.

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VI. UPDATING TRANSMITTER ANTENNAS WEIGHTS

Transmitter antenna weights ($v_m \ \ m = 1, 2, \ldots, M_T$) should be updated at each OFDM block .The updating of transmitter antennas weights in receiver is performed by error signal .Before the update, first, the equation of channel impulse response in the time domain is defined as follows:

$$h = \sum_{m=1}^{M_T} \sum_{l=1}^{L} \alpha_{m,l}\, \delta(n - \tau_{m.l}) \underline{s}_{m.l} \tag{8}$$

Where $\alpha_{m,l}$ is the gain of l-th path for the m-th transmitter antenna and $\underline{s}_{m.l}$ is the l-th path delay vector for the m-th transmitter antenna defined as follows:

$$\underline{s}_{m,l} = [s^1_{m,l}\ ,\ s^2_{m,l}\ ,\ \ldots\ ,\ s^{M_R}_{m,l}\ ]^T_{l \times M_R} \tag{9}$$

The data on the receiver antennas $\underline{\mathrm{r}}(\mathrm{n})$ can be written in terms of h channel convolution and the data on the transmitter antennas $\underline{g}(\mathrm{n})$ defined as follows:

$$\underline{r}(n) = h(n) \otimes \underline{g}(n) = \sum_{m=1}^{M_T} \sum_{l=1}^{L} \alpha_{m,l}\, g(n - \tau_{m.l}) \underline{s}_{m.l} \tag{10}$$

In equation (10), $\otimes$ is the convolution symbol and $g(n - \tau_{m.l})$ is the m-th symbol transmitted by transmitter antenna through I-th path. The equation of incoming data of receiver antenna can be written as a matrix multiplication:

$$\underline{r}(n) = hSx\underline{V} \tag{11}$$

$$\mathbf{h} = \begin{bmatrix} \underline{\alpha}_1 & \cdots & \underline{\alpha}_{M_T} & & 0_{1\times(M_R-1)M_TL} \\ 0_{1\times M_TL} & \underline{\alpha}_1 & \cdots & \underline{\alpha}_{M_T} & 0_{1\times(M_R-2)M_TL} \\ \vdots & \vdots & & & \vdots \\ 0_{1\times(M_R-1)M_TL} & & \underline{\alpha}_1 & \underline{\alpha}_2 & \underline{\alpha}_{M_T} \end{bmatrix} \tag{12}$$

$$\mathbf{S} = \begin{bmatrix} diag(S_1^1) & 0_{L\times L} & \cdots & 0_{(M_T-1)L\times L} \\ & diag(S_2^1) & \cdots & \\ 0_{(M_T-1)L\times L} & 0_{(M_T-2)L\times L} & \cdots & diag(S_{M_T}^1) \\ diag(S_1^2) & 0_{L\times L} & \cdots & 0_{(M_T-1)L\times L} \\ & diag(S_2^2) & \cdots & \\ 0_{(M_T-1)L\times L} & 0_{(M_T-2)L\times L} & \cdots & diag(S_{M_T}^2) \\ \vdots & \vdots & \vdots & \vdots \\ diag(S_1^{M_R}) & 0_{L\times L} & \cdots & 0_{(M_T-1)L\times L} \\ & diag(S_2^{M_R}) & \cdots & \\ 0_{(M_T-1)L\times L} & 0_{(M_T-2)L\times L} & \cdots & diag(S_{M_T}^{M_R}) \end{bmatrix} \tag{13}$$

where h is the gain matrix of channel paths and its dimensions are $M_R \times M_R M_T L$. In the above equation ,S is the $M_R M_T L \times M_T L$ matrix, $\underline{s}^{m_R}_{m_t}$ is the delay vector of all paths between the m_t-th transmitter antenna and m_R-th receiver antenna, compared to the first receiver the is defined as follows:

$$\underline{s}^{m_r}_{m_t} = \left[s^{m_r}_{m_t,1}\ ,\ldots,\ s^{m_r}_{m_t,L} \right]^T_{1\times L} \quad \begin{cases} m_t = 1,\ldots,M_T \\ m_r = 1,\ldots,M_R \end{cases} \tag{14}$$

$diag(\underline{s}^{m_R}_{m_t})$ is a diagonal matrix where the diagonal elements are the members of $\underline{s}^{m_R}_{m_t}$ vector.

$$\mathbf{x(n)} = \begin{bmatrix} \underline{x}_1(n) & 0_{L\times 1} & \cdots & 0_{L\times 1} \\ 0_{L\times 1} & \underline{x}_2(n) & \cdots & 0_{L\times 1} \\ \vdots & \vdots & & \vdots \\ 0_{L\times 1} & 0_{L\times 1} & \cdots & \underline{x}_{M_T}(n) \end{bmatrix}_{M_TL\times M_T} \tag{15}$$

In the above equation, X(n) is the data matrix transmitted by all the transmitter antennas .Weights vector is as follows:

$$\underline{V} = [v_1,\ v_2,\ \ldots v_{MT}\ ]^T_{l\times M_T} \tag{16}$$

According to the above equation, the output of time domain in the receiver can be obtained as follows:

$$y(n) = \underline{W}^H hSx(n)\underline{V} \tag{17}$$

In this case, like receiver antennas and based on the error signal at the receiver ,the weights of the transmitter antenna update based on equation (18):

$$\underline{V}(q+1) = \underline{V}(q) + 2\mu \sum_{n=1}^{N} (\underline{W}^H hSx(n))^T e^*(n) \tag{18}$$

In the above equation, $\underline{V}(q+1)$ is the weight vector of block (q+ 1) and $\underline{V}(q)$ is the weight vector of the block (q).

The number of independent weights in the time-frequency method is equal to the number of antennas in the number of sub-carriers, plus the number of receiver antennas and in time-space method, it is equal to the number of receiver antennas in the taps, plus one,[5] and in the proposed method, it is equal to the number of transmitter and receiver antennas .Therefore ,it can be said that the computational complexity of the proposed method is less than the two other methods, especially the time-frequency method.

VII. SIMULATION

In order to compare the proposed method of simultaneous beam forming in transmitter and receiver antennas in MIMO[4]-OFDM structure with time-frequency and space-time techniques in OFDM structure, it is assumed that the transmitter sends the desired proposed source structure from three antennas and the receiver uses a uniform linear array with 8 antennas .The total number of sub-carriers per OFDM block is equal to 64 and the protective time is more than the maximum channel delay for each added block .In transmitter, the bits modulation is of 16-QAM[5] type .Also, it is assumed that we have two sources of interference except the desirable source .Angle of arrival of the desired signals is 70 degrees and the angle of interference sources signal are 20 and 120, respectively .The angle scattering for all signals is 5 degrees .The guide sub-carriers are distributed uniformly among OFDM blocks .The noise is assumed as Gaussian white and independent of the signals .As mentioned, due to its MIMO nature and also simultaneous beam forming both at the transmitter and receiver antennas, the proposed method, more appropriate response compared to PRE-FFT and POST-FFT. Figure 4 shows BER[6] diagram of comparison of the proposed method with time - frequency and space-time methods .As can be seen, the performance of the proposed method is better than the other two methods .As noted above, the time –frequency and space-time methods, outperform of PRE-FFT and POST-FFT methods .But due to lack of MIMO structure and also beam forming only in the receiver ,time-frequency and space-time methods have worse performance than the proposed method in this paper .Figures 4,5 and 6 show the BER and MSE[7] diagrams of the four methods .As we see, the proposed method of this paper outperforms of the other three methods.

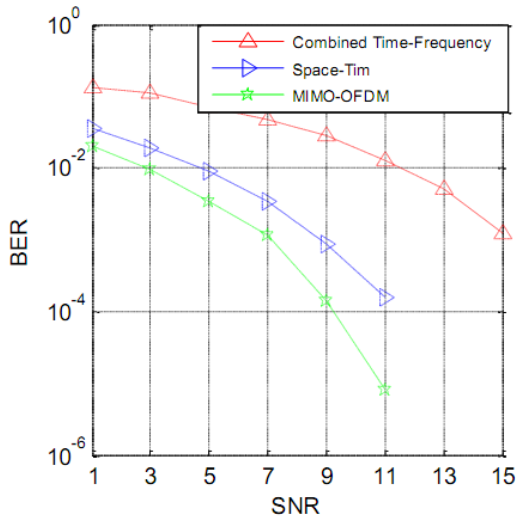

Figure.4. BER diagram .Comparison of the proposed method with time - frequency and space-time methods.

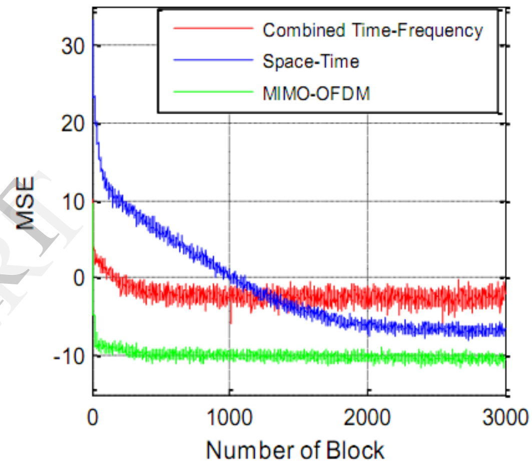

Figure.5. MSE diagram .Comparison of the proposed method with time - frequency and space-time methods.

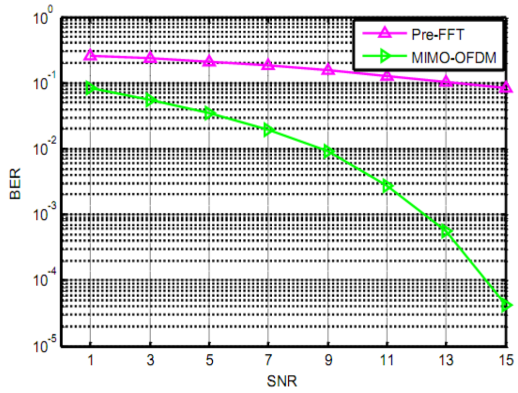

Figure .6. BER diagram. Comparison of the proposed method with PRE-FFT method.

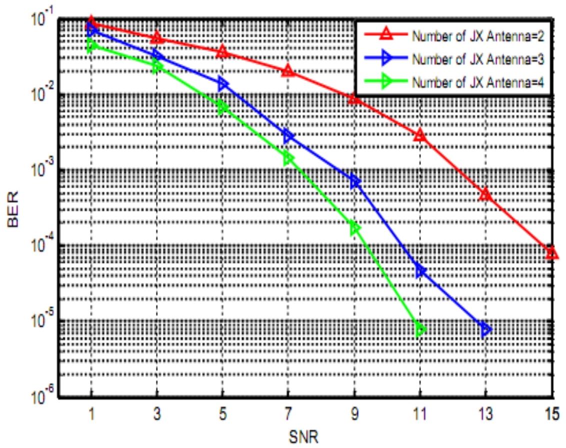

Figure .7. BER diagram in terms of the number of transmitter antennas in proposed method.

Figure 7 shows the effect of applying MIMO on the desired transmitter in the proposed method of the paper. In this figure, BER diagram is plotted for different number of transmitter antennas. As can be seen , as the number of desired transmitter antennas increases, MIMO property is more established. As a result, the receiver receives a better signal which decreases the BER. In Figure 7, the BER value is decreased with increasing number of transmitter antennas.

VIII. CONCLUSIONS

In this paper, based on the guide sub-carriers in MIMO-OFDM structure, a method was proposed for simultaneous beam forming both at the transmitter and receiver antennas .Given its MIMO structure properties and simultaneous beam forming in both the transmitter and receiver antennas ,the proposed method offered more appropriate response compared to PRE-FFT, POST-FFT, the space-time and time-frequency methods in all conditions.

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