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Minimizing performance loss of MMSE algorithm for CDMA-based O-MIMO-OFDM

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ABSTRACT

This paper presents an algorithm to minimize the performance loss (PL) of minimum mean square error (MMSE) in code division multiple access (CDMA) based optical multiple input multiple output orthogonal frequency division multiplexing (O-MIMO-OFDM) systems over 1200 km of standard single mode fiber (SSMF). The performance of the system using proposed algorithm scheme is compared to MMSE scheme by simulation results. It shows the superior performance of proposed algorithm.

1. Introduction

Spectral efficiency (SE) of any communication systems will be improved by applying multiple input multiple output (MIMO) technique [1]. A lot of study has been done by integrating MIMO systems into orthogonal frequency division multiplexing (OFDM). Optical MIMO-OFDM [2,7–14] is a multi-carrier modulation technology that has been proposed for fiber optic communication because it is an effective solution to inter symbol interference (ISI), when symbol period of each subcarrier is longer than the delay spread caused by group velocity dispersion (GVD) [3,4,7–13]. It has several advantages including efficient bandwidth usage, transformation of a frequency selective fading channel into a flat fading channel and simplified channel equalization.

On the other hand, CDMA technique is a promising method for MIMO-OFDM systems since it can conflict strong fading, eliminate the effect of narrowband interference and provide high capacity.

MMSE algorithm can recover the transmitted data considering the trade-off between system performance and complexity. Unfortunately, the performance loss is considerable. To minimize the performance loss of MMSE in CDMA based O-MIMO-OFDM systems over 1200 km of SSMF, an efficient algorithm is proposed without increasing considerably the computational complexity.

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2. System model

By assuming the instance assigning spreading chips over the subcarriers, the relationship between input and output for the synchronous CDMA-based O-MIMO-OFDM systems is given as:

$$y = ABx + n \tag{1}$$

where x, y and n are transmitted signal vector of all users, received signal vector of all antennas at the receiver and noise vector of all antennas at the receiver, respectively. x, y and n can be represented as:

$$x = [\, x_1^T \quad x_2^T \quad x_3^T \quad \ldots \quad x_U^T \,]^T \tag{2}$$

$$y = [\, y_1^T \quad y_2^T \quad y_3^T \quad \ldots \quad y_N^T \,]^T \tag{3}$$

$$n = [\, n_1^T \quad n_2^T \quad n_3^T \quad \ldots \quad n_N^T \,]^T \tag{4}$$

where x_u is the transmitted signal vector for user number u, $u = 1, 2, 3, \ldots, U$ and U is the number of active users; y_j is the received signal vector for subcarrier number j, $j = 1, 2, 3, \ldots N$ and N is the number of subcarriers; n_j is the noise vector for subcarrier number j, $j = 1, 2, 3, \ldots N$, respectively.

By the way, A and B in Eq. (1) are defined as:

$$A = \begin{bmatrix} H_{1,1}s_{1,1}I_z & 0 & \dots & 0 \\ 0 & H_{2,2}s_{2,2}I_z & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & H_{N,N}s_{N,N}I_z \end{bmatrix} \quad (5)$$

$$B = \text{diag}\left\{ \text{diag}(\, B_{1,1} \quad \dots \quad B_{z,1}\,) \quad \dots \quad \text{diag}(\, B_{1,U} \quad \dots \quad B_{z,U}\,) \right\} \quad (6)$$

where $H_{j,u}$, $s_{j,u}$, $B_{i,u}$, i and I_z are the channel coefficient matrix of the jth subcarrier of uth user, the jth chip of the spreading code (SC) of uth user, symbol amplitude for corresponding transmit antenna, $i = 1, 2, 3, \dots, z$ and $z \times z$ identity matrix, respectively.

To have an accurate tradeoff between system performance and computational complexity, a MMSE algorithm is advised. x_u is estimated as below using MMSE algorithm [5]:

$$\tilde{x}_u = z_u^H y \quad (7)$$

where z_u satisfies equation below:

$$z_u = arg\left(\min(E||x_u - z_u^H y||^2)\right) \quad (8)$$

By solving Eq. (8), z_u will be obtained as [5]:

$$z_u = (E[yy^H])^{-1} E[yx_u^H] \quad (9)$$

By replacing z_u from Eqs. (7)–(9), $\tilde{x}_u$ will be obtained as:

$$\tilde{x}_u = E[x_u y^H](E[yy^H])^{-1} y \quad (10)$$

By substituting y from Eq. (3), $E\left[x_u y^H\right]$ and $E\left[yy^H\right]$ can be obtained as:

$$\begin{aligned} E[x_u y^H] &= E[x_u(ABx+n)^H] = E[x_u(x^H B^H A^H + n^H)] \\ &= E[x_u x^H B^H A^H] + E[x_u n^H] = B_u^H A^H + 0 \\ &= B_u^H A^H = B_u^H s_u^H H^H \end{aligned} \quad (11)$$

where B_u is symbol amplitude for corresponding antenna. H and S also are given as:

$$H = \begin{bmatrix} H_{1,1} & 0 & \dots & 0 \\ 0 & H_{2,2} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & H_{N,N} \end{bmatrix}. \quad (12)$$

$$S = \begin{bmatrix} s_{1,1} & 0 & \dots & 0 \\ 0 & s_{2,2} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & s_{N,N} \end{bmatrix}. \quad (13)$$

$$\begin{aligned} E[yy^H] &= E[(ABx+n)(ABx+n)^H] = E[(ABx+n)(x^H B^H A^H + n^H)] \\ &= E[ABxx^H B^H A^H + ABxn^H + nx^H B^H A^H + nn^H] \\ &= E[ABxx^H B^H A^H + 0 + 0 + nn^H] = E[ABxx^H B^H A^H] \\ &\quad + E[nn^H] = E[HSBxx^H B^H S^H H^H] + E[nn^H] \\ &= ||B||^2 HE[SS^H]H^H + \sigma^2 I_{N^2} \end{aligned} \quad (14)$$

where σ^2 is the variance of the noise and $||B||^2$ is defined as:

$$||B||^2 = BB^H \quad (15)$$

If the SCs for all active users are known by any user, then Eq. (10) will be obtained as:

$$\tilde{x}_u = B_u^H s_u^H H^H (||B||^2 HSS^H H^H + \sigma^2 I_{N^2})^{-1} y \quad (16)$$

As each user must know the SCs for all active users, therefore some information about signal needs to be sent time by time to the users. Consequently, the SE will be reduced.

If the SCs for all active users are not known by other users but they know the number of active users, then Eq. (10) will be obtained as:

$$\tilde{x}_u = B_u^H s_u^H H^H (||B||^2 HH^H + \sigma^2 I_{N^2})^{-1} y \quad (17)$$

Using Eq. (17) to estimate x_u compared to using Eq. (16), has larger PL when the number of active users is less than number of users which be supported in a spreading block.

To overcome the problems mentioned above, a new algorithm is proposed to minimize the PL for the MMSE in CDMA based O-MIMO-OFDM systems. In this method, there is no need for the users to know the SCs. Users must know the channel. However, to implement the new algorithm, SS^H in Eq. (16) must be estimated. The computational complexity will not significantly increased by using new algorithm because SS^H can be repeatedly used for multiple spreading block.

By multiplying both sides of Eq. (3) to H^{-1}, Eq. (3) will be modified as:

$$H^{-1}y = H^{-1}ABx + H^{-1}n = H^{-1}HSBx + H^{-1}n = SBx + H^{-1}n \quad (18)$$

Now, the autocorrelation function of $H^{-1}y$ will be obtained as:

$$\begin{aligned} r_{H^{-1}yH^{-1}y} &= E[(H^{-1}y)(H^{-1}y)^H] = E[(SBx + H^{-1}n)(SBx + H^{-1}n)^H] \\ &= E[SBxx^H B^H S^H] + E[SBxn^H H^{-1H}] + E[H^{-1}nx^H B^H S^H] \\ &\quad + E[H^{-1}nn^H H^{-1H}] = ||B||^2 SS^H + 0 + 0 + \sigma^2 E[H^{-1}H^{-1H}] \\ &= ||B||^2 SS^H + \sigma^2 r_{H^{-1}H^{-1}} \end{aligned} \quad (19)$$

$r_{H^{-1}H^{-1}}$ can be broken down as:

$$r_{H^{-1}H^{-1}} = \text{diag}(r_{H_1^{-1}H_1^{-1}} \dots r_{H_N^{-1}H_N^{-1}}) \quad (20)$$

By assuming identical distribution for OFDM subchannels, we have:

$$r_{H_1^{-1}H_1^{-1}} = r_{H_2^{-1}H_2^{-1}} = \dots = r_{H_N^{-1}H_N^{-1}} \quad (21)$$

Then, only $r_{H_1^{-1}H_1^{-1}}$ must be computed and Eq. (20) will be rewritten as:

$$r_{H^{-1}H^{-1}} = I_N \otimes r_{H_1^{-1}H_1^{-1}} \quad (22)$$

Then, by combining Eqs. (18) and (22), SS^H will be obtained as:

$$\begin{aligned} SS^H &= \frac{1}{||B||^2} r_{H^{-1}yH^{-1}y} - \frac{\sigma^2}{||B||^2}(I_N \otimes r_{H_1^{-1}H_1^{-1}}) \\ &= \frac{1}{N||B||^2}\sum_{i=1}^{N} H(i)^{-1} y(i) y(i)^H H(i)^{-1H} \\ &\quad - \frac{\sigma^2}{N||B||^2}\sum_{i=1}^{N} H(i)^{-1} H(i)^{-1H} \end{aligned} \quad (23)$$

where $H(i)$ and $y(i)$ are channel matrix and received vector of the ith spreading block, respectively.

SS^H is a non-negative matrix so that second term of Eq. (23) must be smaller than the first term of Eq. (23). For the higher signal to noise ratio the second term is much smaller of the first term.