RESEARCH PAPER

Least Mean Square Frequency Domain Equalization for MIMO SC-FDMA System

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ABSTRACT:
Because single carrier modulation has low peak average power ratio (PAPR), it is used instead of multicarrier modulation in uplink transmission in Long Term Evolution (LTE). Channel state information (CSI) is very important issue in SC-FDMA system when applying equalization technique especially in high frequency selective fading channels where a linear equalizer is inefficient to remove the fading channel effects. To solve the inefficient performance of the multiple output multiple input (MIMO) SC-FDMA system in high frequency selective fading channels, an iterative (adaptive) frequency domain equalizer is presented using least mean square algorithm (IFDE-LMS or AFDE-LMS). The proposed IFDE-LMS shows better system performance compared to conventional zero forcing (ZF) equalizer. Simulation results show the effect of IFDE-LMS on the performance of MIMO SC-FDMA system using both localized SC-FDMA (LSC-FDMA) and interleaved SC-FDMA (ISC-FDMA) transmission types, where LSC-FDMA outperforms ISC-FDMA.

KEYWORDS: SC-FDMA; iterative equalizer; LMS algorithm
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1. INTRODUCTION:
Time domain algorithms have computational complexity when applied for high data rate applications, P. A. Dmochowski (2001). Frequency domain equalization offers low complexity growth with an increase of equalizer length compared to time domain, M. V. Clark (1998).

The received signal-to-interference-plus-noise ratio (SINR) mathematical expression for multiuser MIMO SC-FDMA was derived in, Z. Lin (2010), and an improved frequency domain receiver algorithm was proved to be superior to conventional linear minimum mean square error (MMSE) receiver for both (SINR) and bit error rate (BER) performance.

In M. Jar (2012), frequency domain equalizer (FDE) was used for reducing both intersymbol interference (ISI) and inter-antenna interference (IAI) together but the effect of reduction was neglected when ISI dominates the overall interference and the achievable throughput was limited to low data rates. Therefore, an iterative MIMO receiver with FDE based parallel interference cancellation (PIC) was able to equalize both ISI and IAI together and reducing their effects, Seifert (2014).
A frequency domain decision feedback equalizer (DFE) is a type of FDE used in high rate wireless communications. In G. Huang (2008), a hybrid DFE was developed for each user in SC-FDMA system. While in N. Benvenuto (2005), a causality problem was solved by applying iterative procedure using feedforward and feedback filters. Both Filters are frequency domain based. A good complexity reduction in SC-FDMA using these filters and DFE was obtained compared to a hybrid DFE. In C. Zhang (2010), DFE was designed with optimal weights in SC-FDMA system and the performance was better than frequency domain linear equalizer in frequency selective fading channels.

To solve the inefficient performance of the multiple output multiple input (MIMO) SC-FDMA system in high frequency selective fading channels, an iterative (adaptive) frequency domain equalizer using least mean square algorithm (IFDE-LMS or AFDE-LMS) is presented. The proposed IFDE-LMS shows better system performance compared to conventional zero forcing (ZF) equalizer. Simulation results show the effect of IFDE-LMS on the performance of MIMO SC-FDMA system using both localized SC-FDMA (LSC-FDMA) and interleaved SC-FDMA (ISC-FDMA) transmission types, where LSC-FDMA outperforms ISC-FDMA. The remainder of this research is organized as follows; section 2 describes the system model based IDFE. In section 3, the concept of IFDE is described. In section 4 simulation results are discussed and conclusions are offered in section 5.

2. SYSTEM MODEL

Fig.1 shows the proposed transceiver of SC-FDMA using localized (LSC-FDMA) and interleaved (ISC-FDMA) transmission types. The input symbols (information) are fed to a convolutional encoder and modulated using quadrature phase shift keying (QPSK) constellation. An N-point fast Fourier transform (FFT) is used to convert the modulated signal to a frequency domain. In, H.G. Myung (2006), and J. Zhang (2015), the sample at kth subcarrier for user u (u = 1, 2, ..., U) is represented as

$$S_k^u = \sum_{n=0}^{N-1} x_n^u e^{-j\frac{2\pi nk}{N}}$$  \hspace{1cm} (1)

Where, \(x_n^u\) is the nth symbol for the uth user. The frequency domain samples are mapped to M subcarriers then converted to a time domain using M-point inverse FFT (IFFT), where M>N. A cyclic prefix (CP) is put at the end of each block and must be greater than the channel impulse response (CIR) to ensure the elimination of intersymbol interference (ISI). After adding CP, these blocks are transmitted over a MIMO channel. To ensure high capacity and data rates of wireless communications, spatial multiplexing (SM) is used, where the number of transmit antennas is Nt = 4 and receive antennas is Nr = 4. The received signals at Nr receive antenna can be expressed as:

$$r = \sum_{u=1}^{U} H^u d^u + n$$  \hspace{1cm} (2)

Each component in Eq. (2) for one user is given as follows:

$$H = \begin{bmatrix} H_{11} & H_{12} & H_{13} & H_{14} \\ H_{21} & H_{22} & H_{23} & H_{24} \\ H_{31} & H_{32} & H_{33} & H_{34} \\ H_{41} & H_{42} & H_{43} & H_{44} \end{bmatrix}$$  \hspace{1cm} (3)

$$r = [r_1, r_2, r_3, r_4]^T$$ \hspace{1cm} (4)

$$d = [d_1, d_2, d_3, d_4]^T$$ \hspace{1cm} (5)

$$n = [n_1, n_2, n_3, n_4]^T$$ \hspace{1cm} (6)

Where, \((.)^T\) is the transpose operator, \(d_j\) is an Mx1 transmitting vector of the jth transmit antenna, \(r_i\) is an Mx1 receiving vector at the ith receive antenna, and \(n_i\) is an Mx1 noise vector at the ith receive antenna. In J. Zhang (2015), multipath channel matrix between the jth transmit antenna and the ith receive antenna is \(H_{ij}\) of dimension MxM. It is given as:

$$H_{ij} = \begin{bmatrix} h_{ij}(0) & 0 & \cdots & h_{ij}(L) & \cdots & h_{ij}(1) \\ h_{ij}(1) & h_{ij}(0) & \cdots & h_{ij}(L) & \cdots & \vdots \\ \vdots & h_{ij}(1) & \cdots & h_{ij}(L) & \cdots & h_{ij}(0) \\ h_{ij}(L-1) & \cdots & h_{ij}(0) & \vdots & \vdots & \vdots \\ \vdots & h_{ij}(L) & \cdots & h_{ij}(0) & \vdots & \vdots \\ 0 & \cdots & h_{ij}(L-1) & \cdots & h_{ij}(0) \end{bmatrix}$$ \hspace{1cm} (7)

Where, \(h_{ij}\) is the channel impulse response (CIR) coefficient between the jth transmit antenna and the ith receive antenna. In J. Zhang (2015), the circulant matrix \(H_{ij}\), can be expressed via FFT matrix operator as:

$$H_{ij} = F_M^H A_{ij} F_M$$ \hspace{1cm} (8)
Where, \((\cdot)^{H}\) is Hermitian operator, the dimension of the diagonal matrix \(\Lambda_{ij}\) is an MxM containing FFT coefficients of the \(H_{ij}\). An M-point FFT block is used to convert the signals in Eq. (2) to frequency domain as follows:

\[
R = \sum_{i=1}^{U} A^i D^i + \mathcal{N} \quad (9)
\]

The received vector for each user after demapping is entered to iterative (adaptive) frequency domain equalizer based LMS algorithm (IFDE-LMS or AFDE-LMS) which will be presented in section 3. In each diversity branch, the equalized vector is Nx1 vector combined with other branches to form Nx1 vector and is converted to a time domain vector using IFFT block. The time domain vector is then passed to QPSK demodulator and convolutional decoder to give the estimated information.

3. ITERATIVE (ADAPTIVE) FREQUENCY DOMAIN EQUALIZER (IFDE-AFDE)

In SC-FDMA system, channel state information (CSI) is an important issue and it is found by using pilot symbols inserted in each block of data with an optimum equalization technique must be used to remove its effect. Therefore, an iterative (adaptive) frequency domain equalizer can be used in SC-FDMA system that does not relay on CSI estimation. J. Zhang (2015).

In SM SC-FDMA, multi-users use the same frequency and time slots to transmit data; hence the number of antennas is equal to the number of users. The IFDE uses LMS algorithm to update the equalizer coefficients in the frequency domain and the noise power at each antenna is estimated frame by frame. To optimize equalizer coefficients, the mean square error (MSE) between the desired equalizer output \(d_p\) and actual equalizer output, \(c_p^Tx_p\) is calculated, M. Morelli (2005), i.e.,

\[
J = E \left\{ \left[ d_p - c_p^Tx_p \right]^2 \right\} \quad (10)
\]

Where, \(c_p\) are the equalizer vector coefficients at the pth sample. Fig. 2 shows IFDE-LMS (AFDE-LMS) for one user, four IFDE-LMS are used for 4x4 MIMO SC-FDMA system. In, P. A. Dmochowski (2001), M.V. Clark (1998), and M. Morelli (2005), the LMS algorithm may be computed iteratively by the following equations:

Equalizer output: \(d^{'p}_p = c^{'p}_px_p\) \quad (11)

Error signal: \(e_p = d_p - d^{'p}_p\) \quad (12)

Coefficients adaptation: \(c_p = c_p + \mu e_p x^*_p\) \quad (13)

Where, \(e_p\) is the error signal vector between the \(p\)th transmitted symbol \(d_p\) and its corresponding estimate \(d^{'p}_p\) at the equalizer output. The step size parameter \(\mu\) is used to control the adaptation rate of the equalizer and the stability of LMS algorithm.

4. SIMULATION RESULTS

The BER performance of the IFDE-LMS (AFDE-LMS) for MIMO SC-FDMA system based on spatial multiplexing over multipath Rayleigh fading channel is evaluated using MATLAB simulation program as shown in Fig. 3.

Simulation parameters for MIMO SC-FDMA system are tabulated in Table 1.

Table 1. Simulation parameters

Two mapping techniques for SC-FDMA are used and their performances are compared using ZF equalizer and IFDE-LMS. From Fig. 3, it can be shown that IFDE-LMS outperforms ZF equalizer for both mapping techniques. For ZF equalizer, at BER = 2x10^{-3}, LSC-FDMA-ZF provides 3dB gain compared to ISC-FDMA-ZF. For IFDE-LMS equalizer, at BER = 3x10^{-4}, LSC-FDMA provides 1.7 dB gain compared to ISC-FDMA.

5. CONCLUSIONS

In this research, the inefficient performance of the MIMO SC-FDMA system in high frequency selective fading channels was solved using an iterative (adaptive) frequency domain equalizer. This equalizer uses least mean square algorithm (IFDE-LMS or AFDE-LMS). The proposed IFDE-LMS shows better system performance compared to conventional zero forcing (ZF) equalizer when applied to LSC-FDMA and ISC-FDMA systems. Also LSC-FDMA system outperforms ISC-FDMA system when using IFDE-LMS and ZF equalizer. Although the complexity of ZF is lower than IFDE but it suffers from noise enhancement as well as its performance becomes unsatisfactory over fast fading channels.
Table 1. Simulation parameters.

| Parameter            | Description                                      |
|----------------------|---------------------------------------------------|
| System bandwidth     | 5 MHz                                             |
| Modulation           | QPSK                                              |
| FFT size             | 128                                               |
| IFFT size            | 512                                               |
| Subcarrier mapping   | LSC-FDMA and ISC-FDMA                             |
| MIMO technique       | SM                                                |
| Number of transmit antennas | \( N_t = 4 \)                                    |
| Number of receive antennas | \( N_r = 4 \)                                    |
| Channel model        | Rayleigh fading channel (Jake’s model), 3 paths   |
| Channel coding       | Rate =1/2, memory length=7, and generator polynomial = (171 133) |
| Equalizer type       | Adaptive frequency domain equalizer based LMS algorithm |

Figure 1. Block diagram of proposed transceiver of 4x4 SM SC-FDMA

Figure 2. Adaptive equalizer based LMS algorithm.

Figure 3. BER performance of 4x4 SM SC-FDMA system.

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