

Using EM algorithm as a new method for Synchronization and channel estimation of MIMO-OFDM systems

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Abstract

In this paper, a new algorithm has introduced the most estimation similarity, channel coefficients fading and moving the carrier frequency in MIMO-OFDM systems. The purpose of this paper provides an algorithm to synchronize and estimate channel coefficients which has low computational complexity. The proposed algorithm using the process sequence containing the training symbols, carrier frequency offset and channel coefficients fading, estimate in two consecutive stages. Consequently, low computational complexity and having easy implementation. Moreover, the algorithm can be used in a variety of STC-OFDM systems.

Keywords: *Multi-Input Multi-Output systems, Synchronization, Channel Estimation, EM algorithm*

1. Introduction

MIMO-OFDM systems are one of the systems which have become the basis of many communication researches nowadays. A system with several high speed inputs and outputs in sending information or suitable diversity between transmitter and receiver; however the estimation of the channel in this connection is complex. In order to reveal the coherent of received signals, digital communication systems must have an exact estimation of the situation of exchange channel between transmitter and receiver. Since increasing the number of transmitter and receiver antennas causes an increase in the number of unknowns (coefficients of the channel between both antennas of transmitter and receiver) the estimation of channels in multi-antenna systems is a lot more challenging than in one-antenna ones. [1]

A multi carrier orthogonal modulation system by using the immediate Fourier diversion technique creates interest range and changes the switch frequency to several flat sub channels; however simultaneously, lack of source and target and outbreak of delay by the channel, hardly decreases the

function of this system. In other words, this kind of system has a high sensitivity toward time and frequency delays.

More in the second section, the MIMO-OFDM systems are introduced. In the third section synchronizing methods, in fourth section estimating methods of coefficients of channel, and in fifth section proposed algorithm for estimating coefficients of fading channel and carrier frequency offset in MIMO-OFDM systems are described, and at the end the results of accomplished simulations are presented.

2. Introduction of MIMO OFDM systems

In a traditional wireless communication system, provided that the bandwidth is constant, there is no possibility of increasing the sending rate of information. In this kind of situation, only diversity methods can be used to improve the quality of revealing. In designing communication systems, bandwidth, information sending rate and software-hardware complexities are the important parameters. To expand the new generation of communication systems, methods such as MIMO, OFDM or integrating them together as MIMO-OFDM, are suggested.

2.1 MIMO-OFDM systems

The high intrinsic resistance of OFDM against the ISI event and its suitable function against fading destructive event, besides the high rate of information sending of MIMO, creates a very efficient complex in accession toward the fourth generation of wireless communication's demands. Like OFDM systems, the MIMO-OFDM systems have a great deal of sensitivity toward synchronization errors. Besides, according to the increase in number of unknowns, estimating the in these systems are a lot more complex than estimating channel in one antenna systems [2]. Diagram block of one kind of MIMO-OFDM systems, is shown in the figure1.

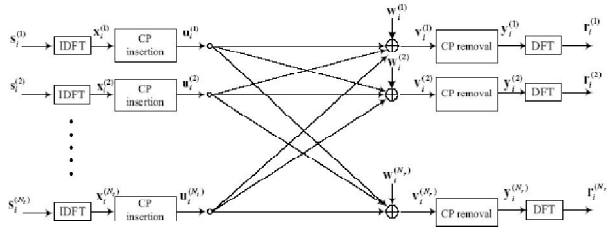


Fig. 1 Displaying a MIMO-OFDM system. [3]

According to the figure, the information in each antenna is sent after IDFT actions and addition of (CP) cyclic prefix. Each receiver antenna receives the sum of noise and signals sent by the transmitter's antenna. In each receiver antenna the revealing is done after removing CP and DFT actions.

3. Synchronization methods

The most important intrinsic restriction of the OFDM technique is its high sensitivity toward synchronizing errors. The first creator factor is called the asynchronicity of carrier frequency offset (CFO). This causes the loss of orthogonality between subcarriers and outbreak of interference between carriers. Another factor of asynchronicity is inequality of sending and receiving rate of samples precisely, which is introduced as sampling frequency delay. The proposed synchronizing algorithms for OFDM based systems are categorized to the following two main groups [4]:

A. Before FFT algorithms

The above-mentioned algorithms are divided to two groups of input based algorithms and non input based algorithms as follows:

Non input based algorithms: this group of algorithms estimates the synchronization parameters using the special structure of OFDM symbols. This group is also called cyclic prefix based methods [5] and [6].

Input based algorithms: this group of algorithms uses the educational symbols sent in information frames to estimate synchronization parameters [7], [8], [9] and [10].

B. After FFT algorithms

This algorithms of this group are also categorized in two groups of pilot based algorithms and direct decision algorithms. In comparing the two algorithms, although before FFT algorithms are faster than after FFT algorithms, but after FFT algorithms has a higher throughput spectral.

4. Channel estimation methods in MIMO OFDM systems

The major considered estimating channel methods are as follows:

A. Using educational sequence methods

By putting samples in the sent symbol which are known by the receiver, we can reach the channel's domain which is multiplied by sum symbol and shift results. Now by using the channels reached coefficients, we can reveal the rest of symbol samples which are the desired inputs and the receiver is unaware of them [11].

B. Blind methods

In this method which has no need of educational samples, using the covariance matrix, the receiver estimates the coefficients of channel and reveals the sent inputs by using them [12].

C. Half blind methods

In this method the between up between properties of the two previous methods are used [13].

5. Channel's coefficients estimation algorithm and the presented carrier frequency offset

A MIMO-OFDM system is supposed, with N transmitter antennas and M receiver antennas and K sub carrier which has the following diagram block.

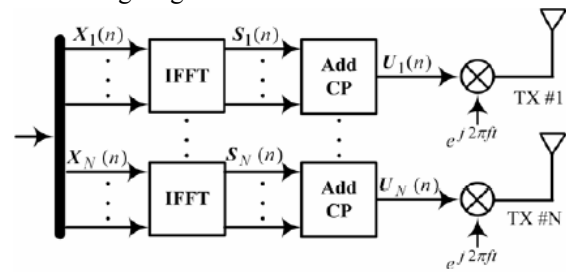


Fig. 2 Diagram block of MIMO-OFDM system's transmitter.

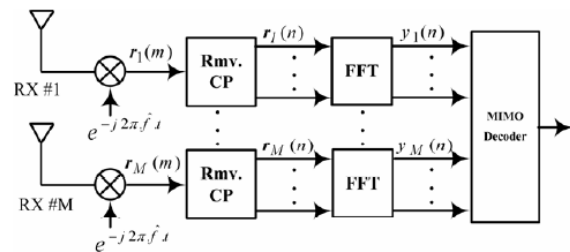


Fig. 3 Diagram block of MIMO-OFDM system's receiver.

With the assumption of the total synchronization of transmitter and receiver in time we have:

$$s(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j \frac{2\pi}{N} kn}; n = 0, 1, \dots, N-1 \quad (1)$$

It changes to following by adding the s(n) cyclic prefix:

$$S^{cp}(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) e^{j \frac{2\pi}{N} k(n-Ncp)}; n = 0, 1, \dots, N + Ncp - 1 \quad (2)$$

With a few calculations and removing the cyclic prefix, the $r(n)$ vector is calculated as follows:

$$r(n) = e^{j2\pi\Delta f(n+Ncp)} \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} X(i)H(i)e^{j \frac{2\pi}{N} in} + v(n) \quad (3)$$

In which the v is the complex Gaussian noise with a zero average. At the end what is received in the receiver is as follows:

$$y(n) = e^{jwNcp} \sum_{i=0}^{N-1} X(i)H(i)\delta_{i,k} + v(k) \quad (4)$$

$$w = 2\pi\Delta f$$

5.1 Estimating the carrier frequency offset and channel's coefficients

By studying the equation (4) again, we can observe that this relation has two unknown parameters of w and $h(i)$. Since v is supposed the white Gaussian noise with a zero average, estimating the maximum similarities of w and h_i unknown parameters, equals estimating their minimum squares. Estimating the maximum similarities of w and h_i can be obtained from the following cost function [14]:

$$\min_{w, h_i} \left\{ \sum_{i=1}^M |r_i - \Gamma(w)A h_i|^2 \right\}$$

$$\Gamma(w) = \text{diag}\{1, e^{jw}, \dots, e^{jw(k-1)}\}$$

$$A(n) = [e^{jwN_s}, A_1(n), \dots, e^{jwN_s} \cdot A_N(n)]_{k \times N.L} \quad (5)$$

Step 1 (estimating the carrier frequency offset): the question of estimating maximum similarity of carrier frequency offset can be presented as follows:

$$\hat{\omega} = \arg_w^{\max} \sum_{i=1}^M \log [p(r_i | w, h_i) p(h_i) dh_i] \quad (6)$$

There are some estimators in two limit modes of (NDA, DA) and one middle mode of (CA), separated from what is used as scale for estimation, related to the amount of receiver knowledge of assumed density function. The DA ML estimator does not exploit all the information available about the channel because it makes use of the datafree observation samples only. To improve the channel estimate quality, the channel can be estimated on the basis of the whole received burst, including both the training sequence and the data. However, when the transmitted sequence is unknown and encoded, the likelihood function exploiting the code is much more difficult to compute.

The EM algorithm enables iteratively solving this problem. The EM algorithm has been exploited previously to estimate the channel, but it has usually been used to estimate the channel taps only.

In order to reduce the high calculations of estimating maximum similarity, EM repetition based algorithm is used. The EM algorithm estimates carrier frequency offset in two following steps:

Step E: Expectation:

$$Q(w \setminus w^{(k)}) = E \left\{ \left[\sum_{i=1}^M \log p(r_i | w, h_i) \right] \middle| r_i, w^{(k)} \right\} \quad (7)$$

Step M: Maximization:

$$w^{(k+1)} = \arg_w^{\max} Q(w \setminus w^{(k)}) \quad (8)$$

In above relations, $w(k)$ show the estimated carrier frequency offset in the k^{th} repetition of EM.

At the end "Equation 8" after a series of calculations becomes like the following:

$$w^{(k+1)} = \arg_w^{\max} \left(\sum_{i=1}^M \sum_{p=0}^{k-1} \text{Re} \left[r_i^*(p) V_i^{(k)}(p) e^{jwp} \right] \right) \quad (9)$$

With the assumption of $S_i^{(k)}(p) = \Gamma_i^*(p) v_i^{(k)}(p)$, relation number 9 is rewritten like the following:

$$w^{(k+1)} = \arg_w^{\max} \text{Re} \left(\sum_{i=1}^M R_i^{(k)} \right) \quad (10)$$

The above relation can be calculated using FFT. Thus the proposed method has a suitable calculation speed.

Step 2 (estimating the coefficients of fading channel): after the estimation of rate of carrier frequency offset, it's time to estimate the maximum similarities of coefficients of fading channel h_i ($i = 1, \dots, M$). Thus the estimation of maximum similarities of channel's coefficients can be obtained from the following relation:

$$\hat{h}_i = (A^H A)^{-1} A^H \Gamma^H(\hat{\omega}) r_i, i = 1, \dots, M \quad (11)$$

5.2 Simulation results

Simulation for MIMO-OFDM system with 32 sub carriers and different number of transmitter and receiver antennas is repeated in switch frequency fading channels. The bandwidth has been assumed 1 MHz and its modulation QPSK and L is the tap of channel.

In the following figures, mean square error is shown according to signal to noise ratio. The carrier frequency offset is assumed a stable amount in simulations ($\Delta f = 0.1$).

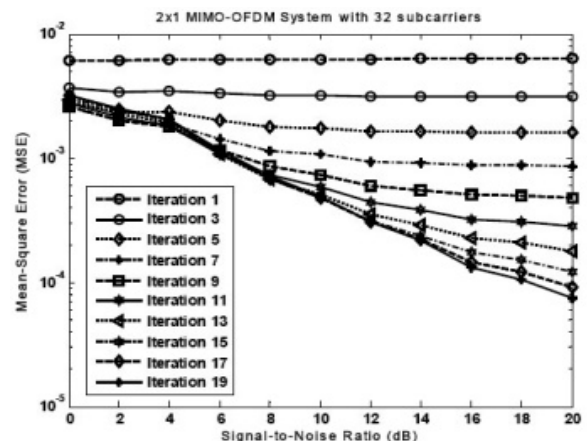


Fig. 4 Mean square error according to SNR for MIMO-OFDM system with 32 sub carriers, which uses 2 transmitter antennas and one receiver antenna with EM algorithm.

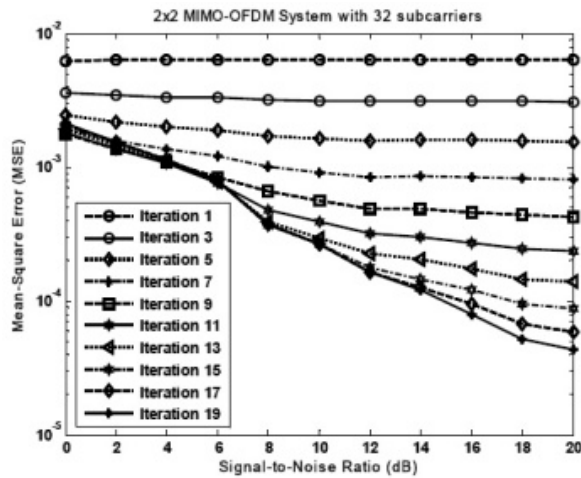


Fig. 5 Mean square error according to SNR for MIMO-OFDM system with 32 sub carriers, which uses 2 transmitter antennas and 2 receiver antennas with EM algorithm.

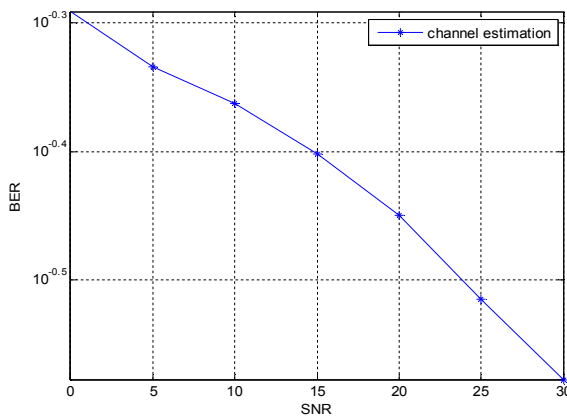


Fig. 6 Channel estimation in 2*2 MIMO-OFDM systems L=4 with synchronization.

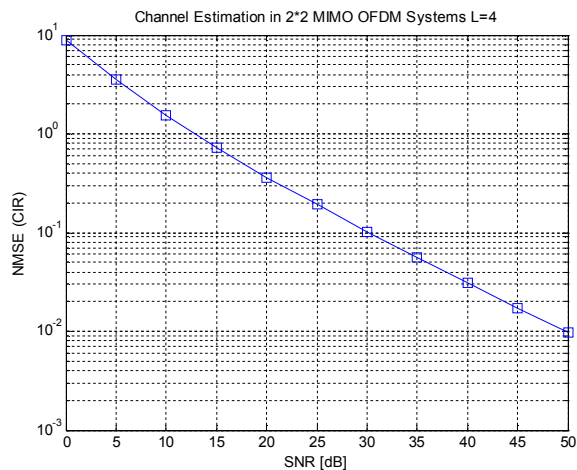


Fig. 7 Channel estimation in 2*2 MIMO-OFDM systems L=4 without synchronization.

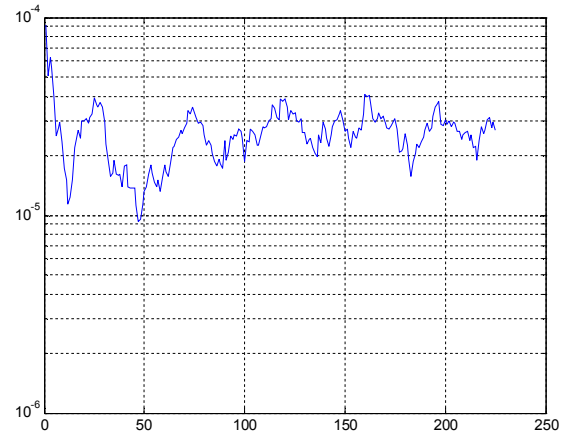


Fig. 8 Synchronization for SISO OFDM system.

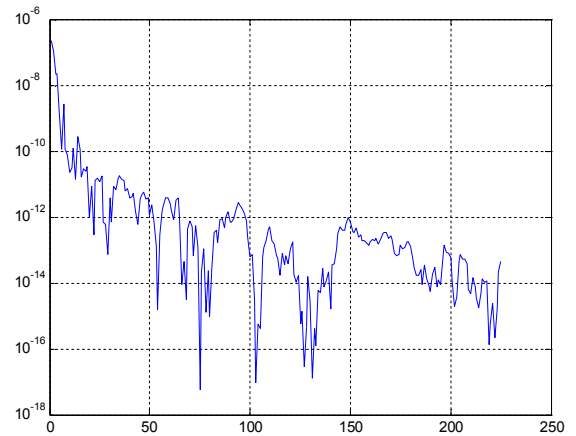


Fig. 9 Joint channel estimation and synchronization for SISO-OFDM systems.

Fig.10 reports the normalized MSE obtained after 10 iterations of the whole receiver, as a function of the average E_b/N_0 per receive antenna. The curve labeled "CRB" is the Cramer-Rao bound when all the symbols of the frame are known, that is to say the DA CRB. The MSE of the UEM-HEM estimator, i.e., the UEM channel estimator with the HEM noise-variance estimator, reaches that bound for E_b/N_0 above 5-6 dB. The DD estimator is also close to the CRB. The MSEs of the three other EM-based estimators are between those of the DD and DA estimators. All the iterative algorithms seem to perform better than the DA one, whose estimates are not iteratively refined. Regarding the noise variance, the EM estimator overestimates it more than the HEM one, as expected. For a $E_b/N_0=7$ dB, the bias of the EM-EM and UEM-EM estimators is 3 dB at iteration 2 and around 0.5-1.5 dB at iteration 10, whereas the bias of the EM-HEM and UEM-HEM estimators is only 2 dB at iteration 2 and around 0.05 dB at iteration 10 [15].

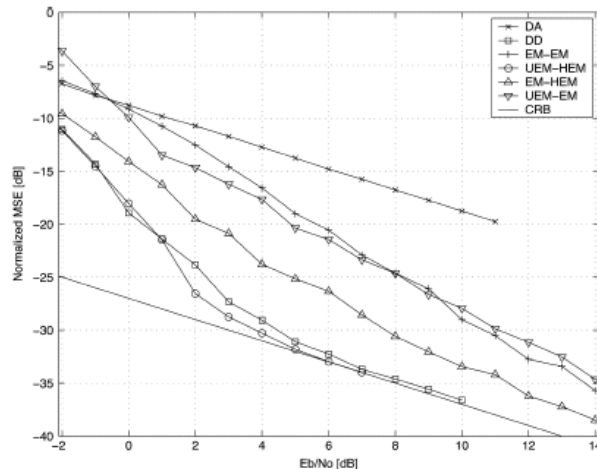


Fig. 10 Normalized MSE of the channel-tap estimates after 10 iterations for a 4*4 flat Rayleigh-fading channel.

6. Conclusions

Estimation of channel coefficients and synchronization parameters are two main challenges in realization of MIMO-OFDM systems which are practical. In almost all published references till now, estimation of channel coefficients is done with the assumption of total frequency synchronously of transmitter and receiver. The created frequency synchronously between transmitter and receiver, in practice, is always exposed to risk due to presence of factors such as Doppler phenomenon and phase noise. Therefore for exact estimation of fading channel status, it's necessary to keep the created frequency synchronously between transmitter and receiver, uninterrupted. The presented algorithm estimates the carrier frequency offset and fading channel coefficients in two sequential steps, using the header sequence at the beginning of sent frames. The aforementioned algorithm is also extendable to different STC-OFDM systems.

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