Performance Analysis of Channel Estimation Algorithms

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***Abstract*—Channel estimation plays an important role in wireless communication due to its random nature of the channel. Randomness creates the constructive or destructive fading. The combination of Orthogonal frequency-division multiplexing (OFDM) with multiple antennas at both the base station and mobile terminal converts frequency selectivity of the channel fading into flat fading parallel sub-channels. The performance can be improved by perfect channel estimations, used for non coherent detection. The paper compares different types of channel estimators and proposed a reduced complexity channel estimator.**

Keyword-MIMO, OFDM, fading, non coherent detection

I. INTRODUCTION

The wireless multipath environment is usually suffered from fading, mobility and delay spread phenomenon. In such channels, the equalization at the receiver side of the single carrier modulation systems is complex due to multipath fading, results in Inter Symbol Interference (ISI) [1]-[4]. This causes a high probability of errors, the system‘s overall performance becomes very poor. An efficient approach used to mitigate the detrimental multipath effects is including OFDM-based wireless systems to combat hostile frequency-selective fading encountered in mobile communications, especially for high-speed data transmission [5]. Combining OFDM with MIMO yields synergistic effects, such as enhanced robustness against frequency-selective fading and high scalability in possible data-transmission rates.

The function of the channel estimator is to compensate the effect of the channel based on channel state information (CSI) [6]-[8]. For a coherent detection, the channel state information is derived from training sequence or pilot symbols which are known to both transmitter and receiver. For non-coherent detection, the channel gains are tracked at the receiver by efficient channel estimation procedures [9].

There are in general three categories in channel estimations which are training-based, blind and semi-blind methods. The training-based method requires extra bandwidth to accommodate the periodic known symbols and thus reduces the spectral efficiency [10]-[11]. The blind method saves the spectral efficiency by utilizing the statistics of received signals. But, this method requires many received signals to obtain accurate statistics [12]-[13]. Semi- blind methods, on the other hand, combine the blind method with few pilot symbols to solve the ambiguity problem occurred in blind methods [14]-[15]. The accuracy of channel estimator directly affects the performance of MIMO-OFDM systems. Therefore, channel estimation is an important topic to facilitate MIMO-OFDM for wireless communications.

The structure of the paper is organized as below. Section II describes the system model. Section III describes the analysis of types of channel estimations and section IV presents simulation results and discussion is given. Section V concludes the paper.

II. SYSTEM MODEL

The wireless channel can be represented as,

$$Y = H.X + N \tag{1}$$

Where, H= fading channel coefficient with rXt matrix, which is random in nature.

X= Transmitted symbol vector, tX1

Y= Received symbol vector, rX1

N= white Gaussian noise with mean zero and variance σ^2, rX1

The proposed channel estimator is shown in figure 1.

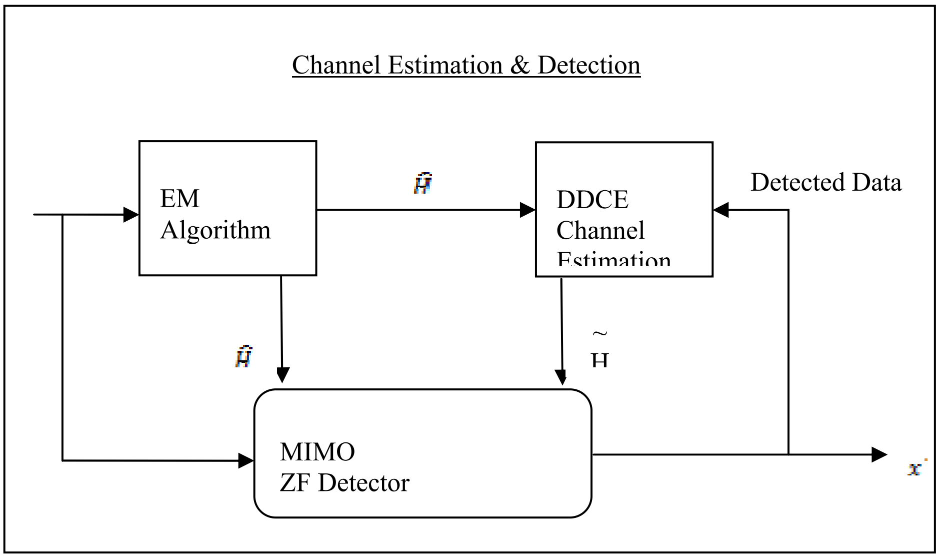

Fig. 1.Block diagram of proposed channel estimator

III. TYPES OF CHANNEL ESTIMATION METHODS

A. Data aided channel estimation method

Back ground: The demand for high-quality, high-bit-rate communications requires the knowledge of the channel state information to achieve an efficient detection of the transmitted signal. The conventional data-aided (DA) channel estimation is carried out with the help of training or pilot symbols [16]. However, the length of the required training sequence depends on the number of channel taps as in wideband multiple-input-multiple-output (MIMO) channels, results in a waste of bandwidth and transmitted power.

The data-aided (DA) estimator does not exploit completely all the information available about the channel due to the data free observation. 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 to compute the ML channel estimate if the transmitted symbols are known. The decision-directed scheme is used to estimate H, by applying the MAP method, i.e search for the channel estimate that maximizes the probability density function P(H|Y,S). Therefore, by applying the least minimum square (LMS) method [14], it minimizes the mean square error. But, this scheme requires a matrix inversion, where the matrix and relies on the data, which is very undesirable. Also, the convergence of the method depends on the SNR range. Besides the iterative algorithm generates a delay until a new channel estimate is available.

Disadvantages:

1. When the transmitted sequence is unknown and encoded, it is difficult to compute the likelihood.
2. In order to manage Doppler effects due to mobile wireless systems, the pilot sequence should be repeated periodically, and it may lead to a substantial reduction in functional bit rate.

Decision Directed based Channel Estimation Algorithm:

The main idea behind the Decision Directed based Channel Estimation (DDCE) is to use the previous channel estimation data of an OFDM symbol for the data detection and thereafter using the newly detected data is to feedback to the channel estimator for the estimation of the current channel.

It improves the receiver performance. Under slow fading, the channel estimation inside the OFDM block can be updated using the DDCE equalizer at each sub-carrier level. For fast fading, the comb-type pilot based channel estimation performs is used.

B. EM-based estimator

Expectation Maximization-based channel estimation (EM) algorithm has been considered in [17]–[18] for channel estimation. It is an attractive choice because it provides a theoretical framework to ensure the convergence towards a stationary point of the likelihood function under fairly general conditions [19].

With the available data only, i.e., the incomplete data set according to the EM terminology, the maximum-likelihood (ML) estimates are sometimes computationally too demanding. With complete data set, the partial set of elements of the complete data set is computed using ML estimates. The EM algorithm calculates iteratively the probabilities of the unknown parameters of the complete data set to be estimated.

First, as in [20], the target can be the channel estimation, the EM algorithm calculates the channel estimates iteratively using a posteriori probability (APPs). Secondly, as proposed by [21]–[24], the EM algorithm can be used to directly to estimate the symbols, since this is the final goal of the receiver. In this latter case, the symbol decisions are iteratively refined, computing APPs on the channel taps.

Disadvantages of the EM channel estimation:

1. The estimates are biased.
2. It degrades the receiver performance.

C. Proposed EMDDCE channel estimation

It is an efficient estimation of time-varying wireless channels (non stationary) is a tedious problem in OFDM systems. Pilot based schemes (DA) have generally been incorporated as an initial estimation for wireless channel estimation. However, for time-varying wireless channels, pilot symbols are required to be transmitted periodically to avoid the effects of time-selective fading.

Expectation Maximization (EM) based scheme may be incorporated in such scenarios by precluding the requirement for periodic retransmission of pilot sequences. To alleviate the complexity of EM procedure, we can utilize an EMDDCE based iterative algorithm to estimate time-varying non stationary wireless channel. This scheme is not only easy to implement than EM algorithm, but it also provides performance modification in comparison to traditional pilot based schemes. In this research work, we investigate a modified EM based scheme, wherein we first estimate transmitted sequences by DDCE technique, with the knowledge of wireless channel estimate at certain iteration. In E-step, estimation of the cost function is done only for sequences estimated by utilizing DDCE technique. This scheme is computationally less complex and needs few number of iterations than EM method, while providing better performance than pilot based traditional methods.

Advantages:

1. Making use of a modest number of pilot sequences or the wireless channel estimate of previous OFDM block to attain initial estimate, the proposed technique can accomplish near optimal estimates after a few iterations.
2. Also, this method may alleviate computational complexity and iteration time.
3. Simulation outcomes state that it exhibits low BER performance in comparison to conventional schemes.

Proposed EMDCE channel estimation algorithm is presented below.

Step 1: The first iteration is conventional. The transmitter transmits a training packet/pilot to the receiver. The receiver receives the training packet then estimates a channel quality using the training packet.

Step 2: The received signal is then equalized and channel decoded.

Step 3: The decoded decisions are then interleaved back to the channel estimator, which begins the next iteration.

Step 4: The channel estimator can now use the whole burst (both data and training bits) as known and re-estimate CIR.

Step 5: We use LMS adaptation rule here to avoid heavy computations.

$$H(k+1) = H(k) + \Delta\varepsilon_k Y_k \tag{2}$$

Where $\varepsilon_k = d_k - \hat{d}_k$ refers error between bit decisions and training sequence, Δ=step size.

The iterative DDCE method is one way to provide a better channel estimate but its convergence is not assured. The expectation-maximization (EM) algorithm enables to iteratively solve this problem.

Step 6: The log-likelihood function can be expressed as,

$$\ln\left(f\left(Y|H,X\right)\right) = \ln\left(\sum_{i=1}^{C} \frac{1}{C}\frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(-\frac{1}{2\sigma^2}|Y - H\cdot X|^2\right)\right) \tag{3}$$

Step 7: Compute the expected value of the log-likelihood function of H by taking expectation over X, conditioned on Y and using the latest estimate of H denoted as $H^{(p)}$, as follows

$$Q(H \mid H^{(p)}) = E_x\left\{f(Y, X \mid H) \mid Y, H^{(p)}\right\} \tag{4}$$

Step 8: Maximize H(p) over all possible values of H as:

$$H^{(p+1)} = \arg\max_{H} Q(H \mid H^{(p)}) \tag{5}$$

IV. SIMULATION PARAMETERS

The simulation paradigm has been constructed as below:

The whole wireless channel transmission bandwidth is 800 kHz, and it has 64 subcarriers (or tones). To make the tones orthogonal, the symbol period is selected to be 80 microseconds. An additional 20 microseconds CP (NCP=16) is utilized to give protection from ISI and ICI because of wireless channel delay spread. Therefore, total OFDM block length is Ts 100 microseconds and sub-channel symbol rate is 10 kbaud. The modulation scheme utilized in the proposed system is M-QAM. For those OFDM blocks containing pilot symbols, the initial estimate of CSI is obtained from the wireless channel estimate of previous OFDM block. The fade rate is set 0.05 fd.Ts and for the following outcomes with maximum Doppler spread 500 fd Hz .

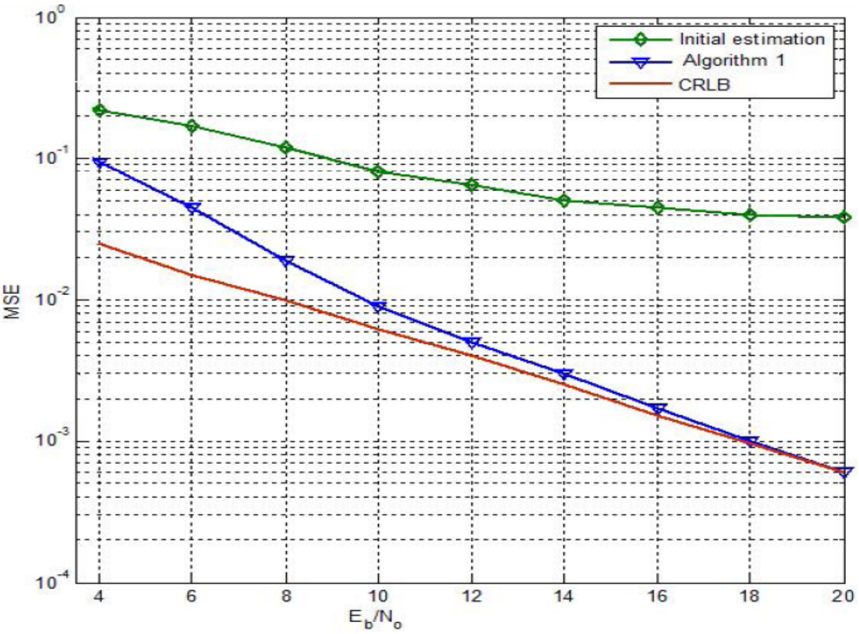

Fig. 2 MSE versus (dB) using DA method

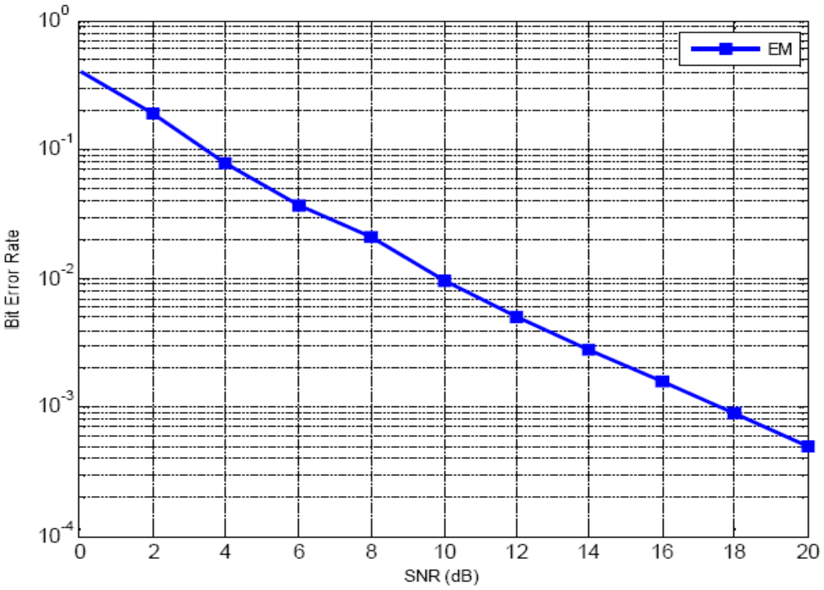

Fig. 2. BER performance for EM based channel estimator

at $f_d T_S = 0.005$

Under time-varying environment (non stationary), EM algorithm supersedes the initial estimation algorithm. This performance advantage gets elevated with the increasing value of Eb/No. At BER 0.03, the performance advantage of approximately 3.5dB is achieved by EM over the initial estimation algorithm in terms of Eb/No.

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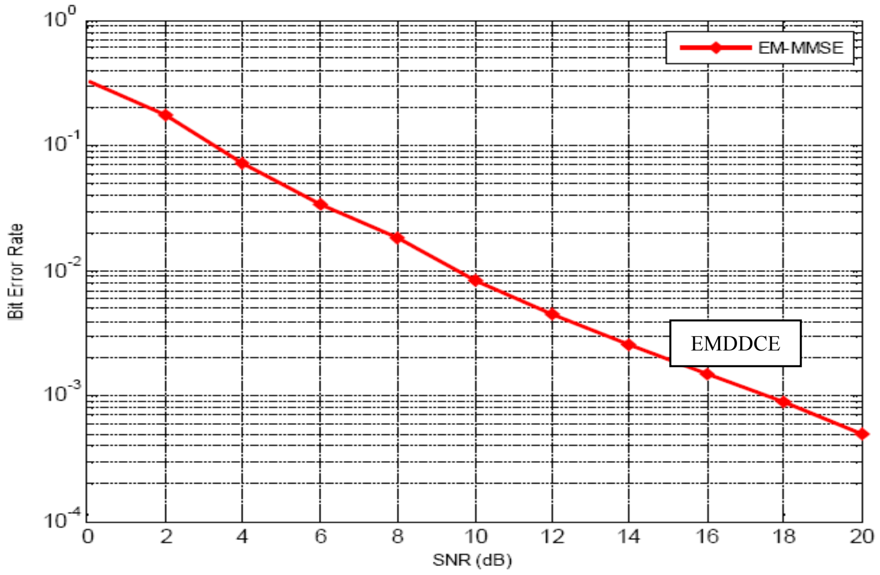

Fig. 3.BER performance for EMDDCE based channel estimator at f_dT_S=0.005

Under time-varying environment (non stationary), proposed EMDDCE based wireless channel estimator outperforms the initial estimation algorithm in terms of lower mean squared channel estimation error. This performance advantage gets elevated with the increasing value of Eb/No. At MSE 0.1, the performance advantage of approximately 4.8dB is observed by Algorithm3 over the initial estimation algorithm in terms of Eb/No. The performance of Algorithm3 approaches CRLB at about Eb/No is 14 dB. Therefore at a high value of Eb/No, EMDDCE performs better than DA when we consider CRLB.

V. CONCLUSION

EMDDCE based estimation alleviates mathematical computations and less number of iterations in comparison to traditional EM procedure, and it is still able to track wireless channel efficiently time-varying nonstationary wireless channel.

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