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A Critical Analysis of Pilot and Blind channel Estimation Techniques for OFDM systems

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Abstract: The channel estimation techniques for OFDM systems based on pilot arrangement and blind estimation are investigated in the proposed work. Various channel estimation techniques are employed in order to judge the physical effects of the medium present. In this proposed work, we have analyzed and implemented various estimation techniques for MIMO OFDM Systems such as Least Squares (LS), Minimum Mean Square Error (MMSE), Constant Modulus Algorithm (CMA) and linear Pre-coding. These techniques are therefore compared to effectively estimate the channel in MIMO OFDM Systems. The objective of the proposed work is to further aid in the development of NDA based channel estimation methods by serving as an analytical tool for comparison between the existing methods and new methods being developed.

Keywords: OFDM, CMA, linear precoding, minimum mean square error

I. Introduction

The increasing require for high-bit-rate digital mobile communications has incited the appearance of Orthogonal Frequency-Division Multiplexing (OFDM) for achieving good performance in high rate data transmission [1] [2]. It is also an effective technique that produces a high spectral efficiency and a good scheme to combat frequency-selective fading channels in wireless communication systems without forgetting the major property that is subcarrier orthogonality. Hence, the symbol duration must be significantly larger than the channel delay spread. In orthogonal frequency division multiplexing (OFDM), the entire channel is divided into many narrow sub channels. Splitting the high-rate serial data stream into many low-rate parallel streams, each parallel stream modulates orthogonal subcarriers by means of the inverse fast Fourier transform (IFFT). If the bandwidth of each subcarrier is much less than the channel coherence bandwidth, a frequency flat channel model can be assumed for each subcarrier. Moreover, inserting a cyclic prefix (or guard interval) results in an inter-symbol interference (ISI) free channel assuming that the length of the guard interval is greater than the delay spread of the channel. Therefore, the effect of the multipath channel on each subcarrier can be represented by a single complex multiplier, affecting the amplitude and phase of each subcarrier. Hence, the equalizer at the receiver can be implemented by a set of complex multipliers, one for each subcarrier. Under multi path spread situation, a dynamic estimation of channel is necessary before the demodulation of OFDM signals to ensure a coherent detection and since the radio channel is frequency selective and time-varying for wideband mobile communication systems [2].

In the literature, many channel estimation schemes are found and depends on if the channel is constant, slowly or fast time varying. Traditionally, channel estimation is achieved by sending training sequences through the channel. However, when the channel is varying, even slowly, the training sequence needs to be sent periodically in order to update the channel estimates. Hence, the transmission efficiency is reduced [2]. The increasing demand for high-bit-rate digital mobile communications makes blind channel identification and equalization very attractive, since they do not require the transmission of a training sequence.

This paper investigates and compares both pilot based and blind channel based estimators for OFDM systems. The primary objective of the proposed work is to aid in further development of blind channel estimation techniques by providing a critical review of the existing systems. Such analysis will be of great help in comparing and analyzing the performance of new techniques in related to the techniques existing in the literature.

II. System Model

The baseband OFDM system is practically the same for all the schemes of channel estimations and differs just from the block of the channel but some schemes can add another block used especially for interpolation or for equalization.

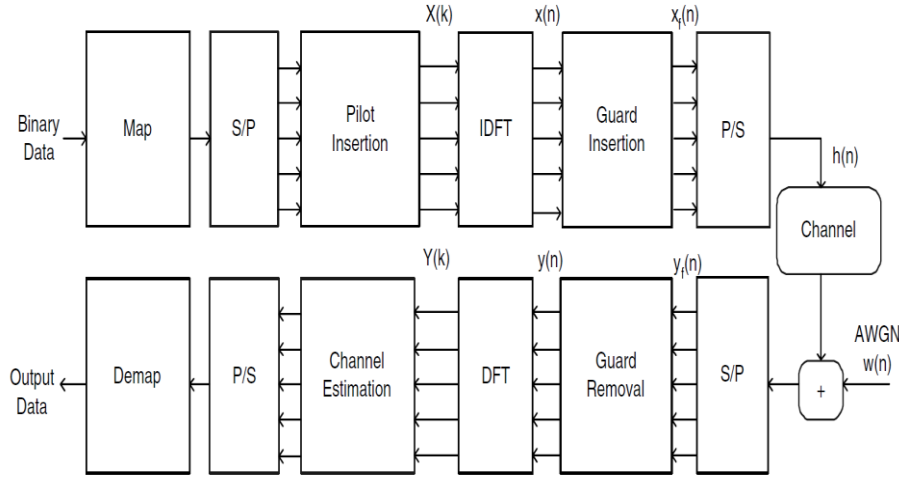


Figure 1: A Base Band OFDM System.

III. OFDM System for Channel Estimation based on Pilot Arrangement

The OFDM system model used for training sequence (pilot signal) consists of mainly of a mapper block forwarded by a S/P conversion, then there is an insertion pilot block follow up of an IDFT calculation of the information data [4]. After that we find the guard insertion block and a P/S conversion before reaching the channel which is affected by an AWGN noise. The data stream will be converted on a parallel stream, and then the guard interval is removed and will sail towards the frequency domain. Channel estimation is afterward performed before carrying out a P/S conversion and attainment of the demapper block to restore back the data stream. After crossing the S/P block, the pilot used here will be inserted in all sub carriers of one OFDM symbol with a specific period or uniformly between data sequence for a block pilot type estimator or in some specific sub carriers for the comb pilot type. Then, the data sequence will pass up the IDFT block for the transformation to time domain and the expression of $x(n)$ (N being the DFT length) is given as follow:

$$\begin{aligned} x(n) &= IDFT\{X(k)\} \quad n = 0, 1, 2, \dots, N-1 \\ &= \sum_{k=0}^{N-1} X(k) e^{j(2\pi kn/N)} \end{aligned} \quad (1)$$

After that, the cyclic prefix will be inserted to preserve orthogonality of the sub carriers on the one hand and to evade inter symbol interference between adjacent OFDM symbols on the other hand. The guard time which contains this cyclic prefix having a length N_g is chosen to be greater than the delay spread [5]. Then the resulting symbol is:

$$x_f(n) = \begin{cases} x(N+n), & n = -N_g, -N_g+1, \dots, -1 \\ x(n), & n = 0, 1, \dots, N-1 \end{cases} \quad (2)$$

After a P/S conversion, the OFDM symbol will cross the channel expected to be frequency selective and time varying fading channel with an additive noise and will be given by

$$y_f(n) = x_f(n) \otimes h(n) + w(n) \quad (3)$$

$h(n)$ is the channel impulse response represented by

$$h(n) = \sum_{i=0}^{r-1} h_i e^{j(\frac{2\pi}{N})f_{Di}T_n} \delta(\lambda - \tau_i), \quad 0 \leq n \leq N-1 \quad (4)$$

Where r is the total number of propagation paths, h_i is the complex impulse response of the i th path, f_{Di} is the i th path Doppler frequency shift is the delay spread index, T is the sample period and τ_i is the i th path delay normalized by the sampling time.

$$y_f(n) \text{ for } -N_g \leq n \leq N-1$$

$$y(n) = y_f(n + N_g) \quad n = 0, 1, 2, \dots, N-1 \quad (5)$$

The frequency form of this resulting signal will be expressed as follow:

$$\begin{aligned} Y(k) &= DFT\{y(n)\} \quad k = 0, 1, 2, \dots, N-1 \\ &= \frac{1}{N} \sum_{n=0}^{N-1} y(n) e^{-j\left(\frac{2\pi kn}{N}\right)} \end{aligned} \quad (6)$$

By supposing a transmission without an inter symbol interference ISI, the relation between the frequency components is

$$Y(k) = X(k)H(k) + I(k) + W(k) \quad (7)$$

Where $H(k) = DFT\{h(n)\}$, $I(k)$ is the inter-carrier interference because of the Doppler frequency and $W(k) = DFT\{w(n)\}$. The pilot signals are then extracted and cross the channel estimation block, after that the estimated channel $\hat{H}(k)$ for the data sub-channel is obtained and the transmitted data is estimated. At last, the binary data sequence is recovered by the signal demapper block

IV. OFDM System for Blind Estimation

In OFDM systems, the serial data are converted into M parallel streams. Each parallel data stream modulates a different carrier [3][6]. The frequency separation between the adjacent carriers is $1/T$, where T is the symbol duration for the parallel data that is M times of the symbol duration for the serial data. Let us consider an OFDM signal in the interval $(nT, (n+1)T)$ as

$$s(t) = \sum_{m=0}^{M-1} a_m(n) e^{j\omega_m t} \quad (8)$$

Where $a_m(n)$ are symbols resulting from a modulation constellation like QAM. ω_m is the frequency of m^{th} carrier

$$s(nM + i) = \sum_{m=0}^{M-1} a_m(n) e^{j\frac{2\pi}{M}mi} \quad (9)$$

From this equation, the M samples can be seen as the inverse discrete Fourier transform (IDFT) of a block for M input symbols. Theoretically speaking, when the number of carriers is large enough, symbol duration T is much larger than the duration of FIR channel; ISI is negligible. However, for the high-bit-rate communications, it is impractical to choose very large M to make ISI negligible. Therefore, a cyclic prefix of length P is added into each block of IDFT output at the transmitter. The length of the prefix is chosen to be longer than the length of the channel impulse response in order to avoid inter-block interference (IBI). That results with total cancellation of ISI and inter carrier interference (ICI). The input data will be as follow

$$\begin{aligned} s(n(M + P) + i) &= \sum_{m=0}^{M-1} a_m(n) e^{j\frac{2\pi}{M}(i-P)m} \\ i &= 0, 1, \dots, M + P - 1 \end{aligned} \quad (10)$$

$$y_i(n) = a_i(n)H\left(\frac{2\pi}{M}i\right) + v_i(n) \quad (11)$$

Where $H(\cdot)$ is the frequency response of the channel. It is evident from the equation above that the ISI is completely cancelled and the effect of the channel at the receiver is simply a complex gain and AWGN

V. Channel Estimation Techniques

Channel Estimation is the process of characterizing the effect of the physical medium on the input sequence. It is an important and necessary function for wireless systems [3]. Even with a limited knowledge of the wireless channel properties, a receiver can gain insight into the data sent over by the transmitter. The main goal of Channel Estimation is to measure the effects of the channel on known or partially known set of transmissions [3]. Orthogonal Frequency division multiplexing (OFDM) Systems are especially suited for channel estimation. The sub carriers are closely spaced. While the system is generally used in high speed applications that are capable of computing channel estimates with minimum delay. There are primarily two major classification of channel estimation techniques in to Pilot based channel Estimation and Blind Channel estimation [3] [8].

Pilot based Channel estimation is based on the training sequence which is known to both transmitters and receiver. The receiver can utilize the known training bits and the corresponding received samples for estimating the Channel. Some of the major approaches in this technique include Least Squares (LS) and Minimum Mean Squares (MMSE) among others. In the Least Squares Error (LSE) estimation method can be used to estimate the system $h[m]$ by minimizing the squared error between estimation and detection. In Minimum Mean Square Error (MMSE) the estimator minimizes the mean-square error [7]. Although ISI can be avoided, via the use of cyclic prefix in OFDM modulation, the phase and gain of each sub channel is needed for coherent symbol detection. An estimate of these parameters can be obtained with pilot/training symbols, at the expense of bandwidth. Blind channel estimation methods avoid the use of pilot symbols, which makes them good candidates for achieving high spectral-efficiency[3][8]. Existing blind channel estimation methods for OFDM systems can be classified as: 1. Statistical. 2. Deterministic.

The statistical methods explore the cyclo-stationarity that the cyclic prefix induces to the transmitted signal [9]. They recover the channel using cyclic statistics of the received signal, or subspace decomposition of the correlation matrix of the pre-DFT received blocks. The deterministic methods process the post DFT received fblocks, and exploit the finite alphabet property of the information bearing symbols. Maximum likelihood and iterative Bayesian methods are two examples taking into account, specific properties of M-PSK or QAM signals, while utilizing an exhaustive search. In comparison to the statistical methods, the deterministic ones converge much faster; however, they involve high complexity, which becomes even higher as the constellation order increases [3] [9]. Equalization technique employed is from the deterministic class of blind channel estimation. It involves the use of equalizers. An equalizer removes the channel effects on a transmitted signal and reduces the Intersymbol Interference (ISI).

The type of equalization, capable of tracking a slowly time-varying channel response is known as adaptive equalization. It can be implemented to perform tap-weight adjustments periodically or continually. Periodic adjustments are accomplished by periodically transmitting a preamble or short training sequence of digital data that is known to the receiver in advance. The receiver also uses the preamble to detect start of transmission, to set the automatic gain control (AGC) level. Continual adjustments are accomplished by replacing the known training sequence with a sequence of data. These algorithms adjust filter co-efficients in response to sample statistics rather than in response to sample decisions [9].

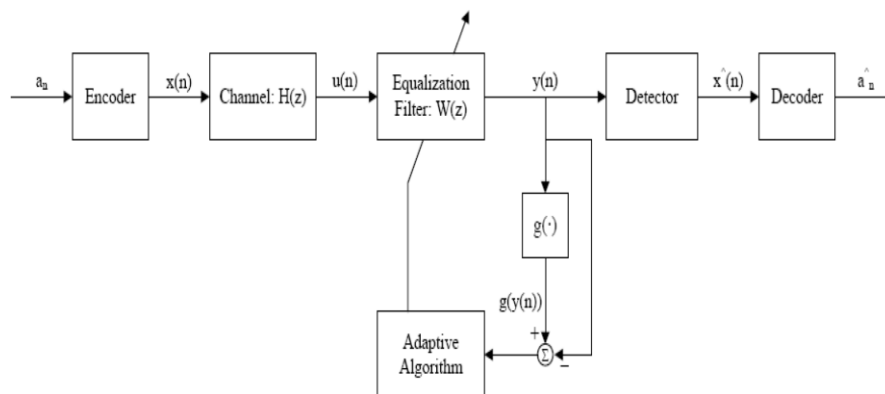


Figure 2: Adaptive equalization.

In Blind channel equalizer, the channel input is reconstructed as accurately as possible by using an adaptive filter to cancel the adverse effects of the channel, particularly the presence of Intersymbol Interference (ISI) and additive noise. Many blind equalization algorithms are available in the literature with different cost functions

namely, Bussgang algorithm, Stato algorithm, Constant Modulus algorithm and Godard algorithm among others [9]. In the proposed work we have implemented and analyzed one deterministic type method namely the Constant Modulus algorithm and one Statistical type method in the form of Linear Precoding.

VI. Simulation, Results, and Discussion

The proposed system was coded in MATLAB environment. We have coded the system for both MIMO and SISO based OFDM systems. In order to illustrate the effect of Carrier Frequency Offset (CFO) and Symbol Timing Offset in OFDM in regard to ISI we have also coded their effects in OFDM signal. The following figures and discussion summarizes the simulation results of the proposed work.

The following figure demonstrates the effect of CFO and STO in OFDM. It is demonstrated for QAM type Modulation

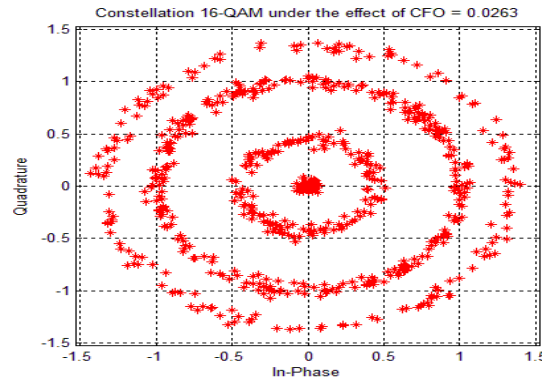


Figure 3: A 16 QAM Constellation under the effect of CFO.

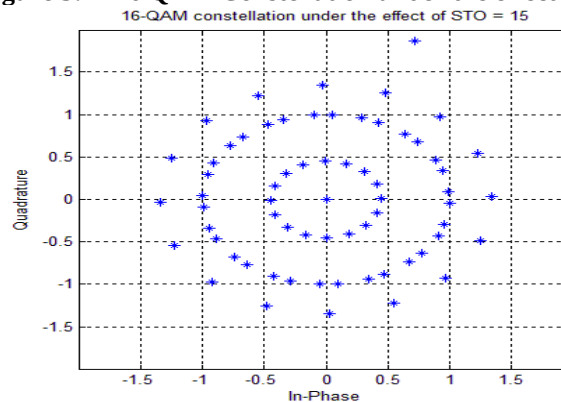


Figure 4: A 16 QAM Constellation under the effect of STO.

From the above figures it can be inferred that the pilots are not static but are rotating around the centre. During such a situation the phase estimation of the signal can not be perfect because of the presence of a time varying phase which is not constant over a symbol period. Higher the offset more the phase changes over one OFDM symbol and estimation becomes much more difficult

The following figures demonstrate the results of simulation of channel estimation using the pilot based approach of LSE and MMSE.

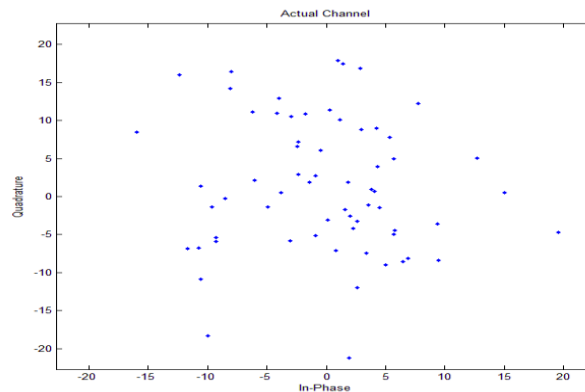


Figure 5: The Plot of Actual Channel.

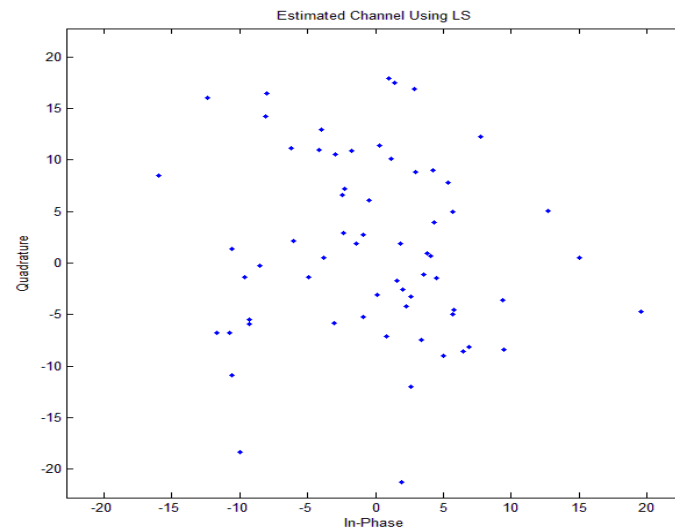


Figure 6: The Plot of Channel Estimated Using LS.

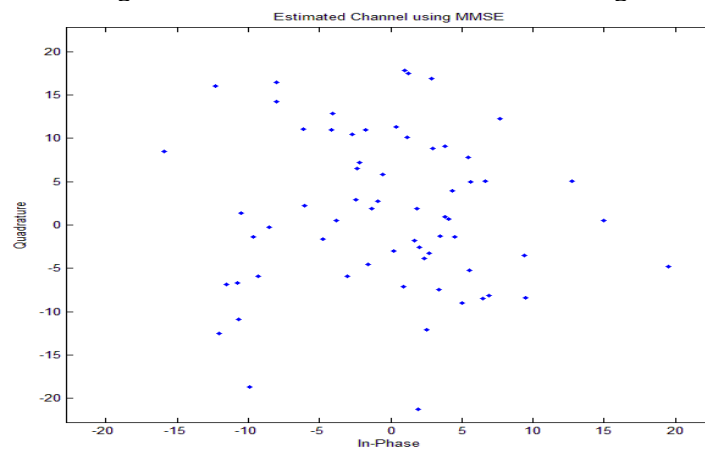


Figure 7: The Plot of Channel Estimated Using MMSE.

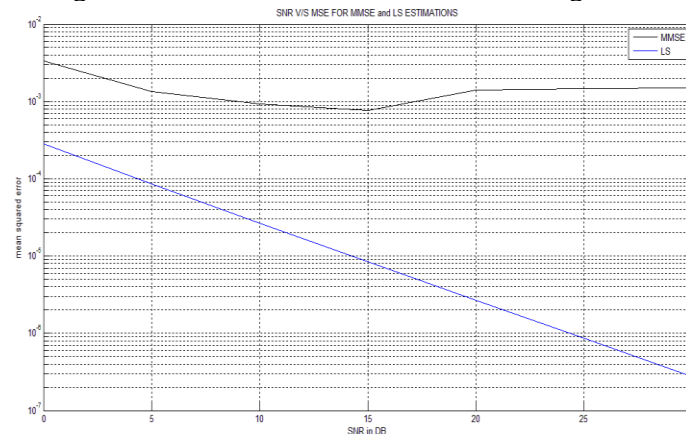


Figure 8: The Plot of SNR and Mean Squared Error for LS and MMSE based Estimator.

Figure (6) and Figure (7) depicts the estimation using LS and MMSE methods in comparison to the original signal as depicted in Figure (5). The above pilot based approaches are effective as long as the training sequence is available to the receiver. Figure (8) demonstrates the mean square error of channel estimation at different SNR in dB as SNR increases mean square error decreases for both LSE and MMSE. It can also be observed that for a given SNR, MMSE estimator shows better performance than LSE estimator. The complexity of MMSE estimators will be larger than LSE estimators but gives a better performance in comparison to LSE.

The below mentioned figures demonstrate the implementation of estimation using blind channel estimation techniques.

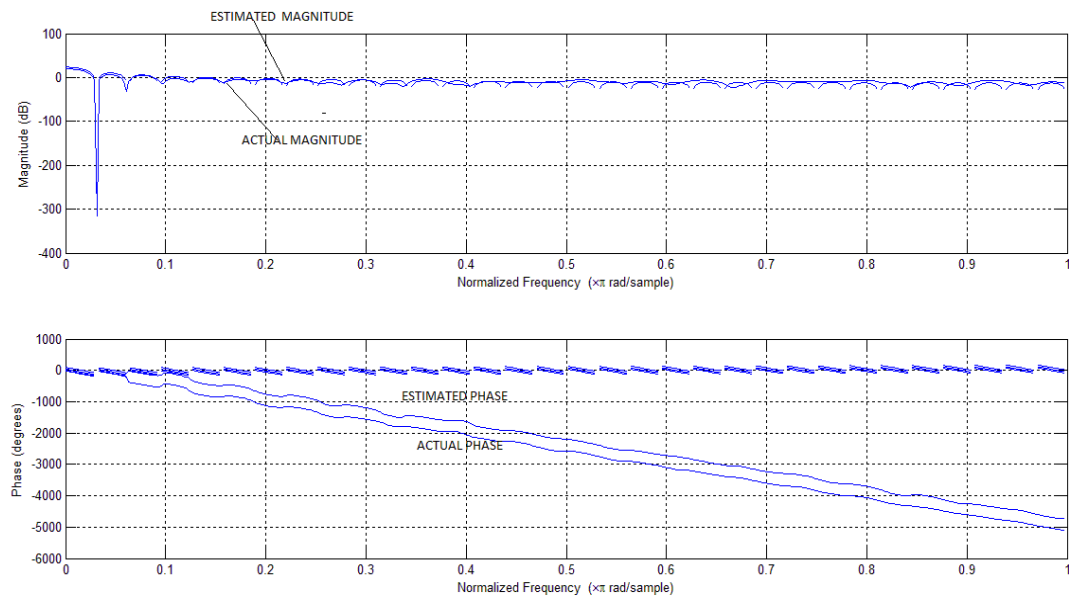


Figure 9: Blind Channel Estimation Based on CMA QAM based frequency response.

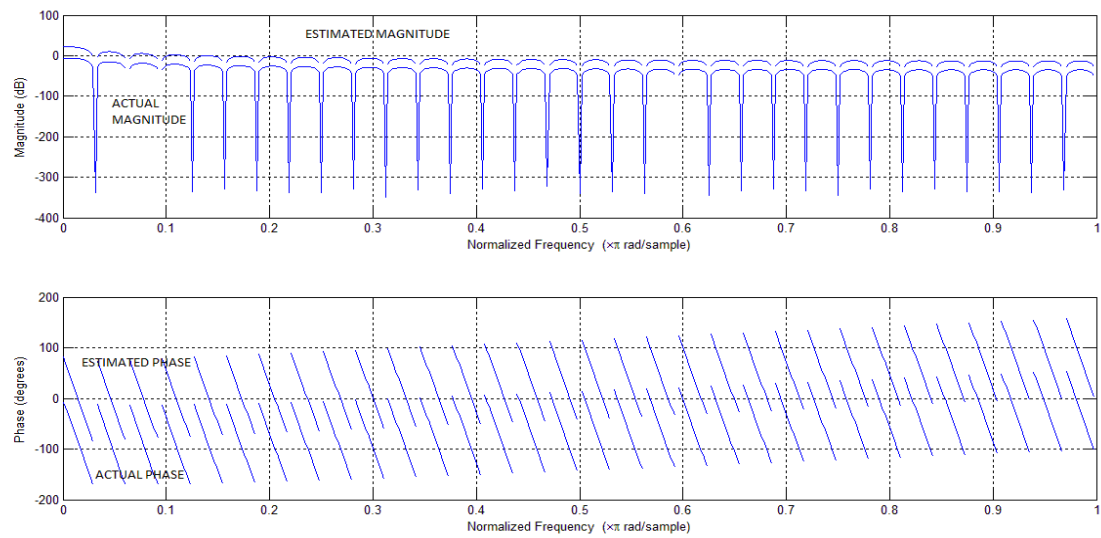


Figure 10: Blind Channel Estimation Based on Precoding for QAM based frequency response.

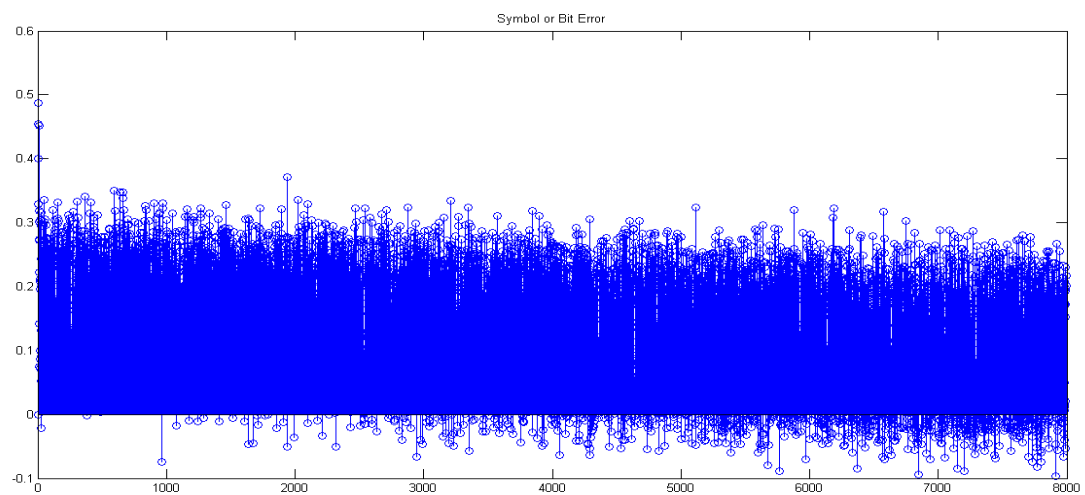


Figure 11: Symbol or Bit error For Blind Channel Estimation.

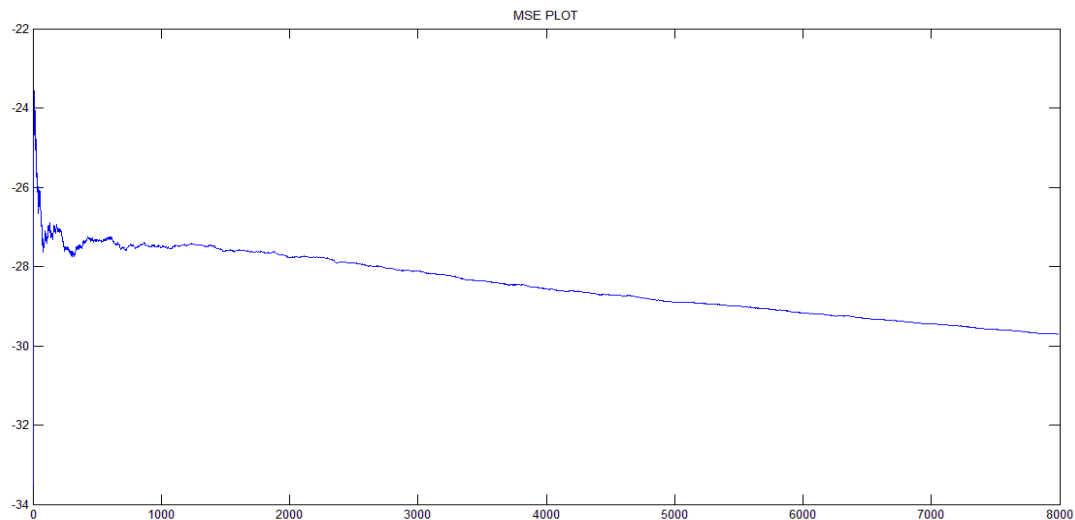


Figure 12: MSE Estimated using CMA over 8000 Data Points.

Figure (9) and Figure (10) blind channel approaches exhibits better performance as compared to the training-based one for the case of fast varying channels. The BER result is shown in Figure (11) and by using the MSE estimate in Figure (12) one can see that these methods achieves much better performance that the training based one. But these methods are too computationally intensive to be used with higher N and constellation orders.

VII. Conclusions

A MATLAB based schema for performance analysis of pilot based channel estimation techniques and blind channel estimation techniques is implemented. In CMA type Blind channel Estimation BPSK type modulation was considered over 8000 data Points. The results for different techniques are compared and observed. The obtained results show that blind channel estimation can be used in future wireless communications especially, when the spectrum efficiency, low complexity and low level of received signal powers are considered. In an embedded transceiver design, the blind techniques can easily be employed with bearable performance degradation. The performance of LSE with MMSE estimator is also investigated. It is observed that MMSE estimation is better that LSE estimator in low SNRs; whereas at high SNRs, performance of LSE estimator is comparable to that of the MMSE estimator.

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