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# Comparative Analysis of CMA and MMSE in MIMO-OFDM System

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## Abstract

Channel estimation is one of the techniques used to achieve high data rates and low bit error rates in wireless communications. In wireless communication system, where Multiple Input Multiple Output - Orthogonal Frequency Division Multiplexing (MIMO-OFDM) exists, the effect of channel causes the received signal to be distorted which necessitates the receiver to have an insight of the channel known as the channel estimation. However, most of the existing techniques such as Least Square Error (LSE), Minimum Mean Square Error (MMSE) and Best Linear Unbiased Estimation Algorithm (BLUE) employ pilot symbols. High errors are observed in addition to computational complexity and in the platform other than MIMO-OFDM. In this paper, performances of Constant Modulus Algorithm (CMA) and MMSE are evaluated, and compared with each other in the 3x3 MIMO-OFDM systems. The system model for 3x3 MIMO-OFDM system incorporating each of CMA and MMSE consists of a transmitter, frequency selective channel and the receiver. 1000 bits are generated randomly and served as input signal. Three antennas configurations at the input of the frequency selective channel radiate the signal. The three antennas at the output of the channel receive the radiated power, processed by appropriate signal processing techniques. Each of MMSE and CMA techniques is performed at SNR of 5, 10 and 15dB. The system model is simulated using MATLAB 7.2 application package and evaluated using Mean Square Error (MSE) and convergence value. The results obtained show that CMA gives lower error than the MMSE and converges faster. Therefore, the study has shown the significant reduction in computational complexity and can be used by wireless design.

**Keywords**: Constant Modulus Algorithm, Orthogonality, Channel Estimation, Multiple Antenna, Cyclic Prefix.

## 1. Introduction

Channel estimation is the process of determining the Channel State Information (CSI) for appropriate signal detection in a wireless communication system. The proper estimation results in better system performance. This is necessary because, in wireless communication, the prediction of signal strength at a location is unpredictable due to multiple propagations of the transmitted signals. These multiple propagations cause the received signal to be distorted by the characteristics of the channel such as scattering, reflection and refraction by obstacles. The characteristics cause the receiver to appear as if it is not functioning. The channel that is mostly distorted the signal is the frequency selective channel where the effect of delay is significant or dominant, so the bits transmitted over this channel is usually distorted at the receiver [1], [2]. Therefore, the channel effect needs to be estimated and compensated at the receiver to recover the transmitted bits. This technique is known as channel estimation and can also be used to achieve high data rates and low bit error rates in wireless communication [3].

The basic channel estimations are block-type, where the pilots are in frequency direction, [4] comb type in time direction and lattice in which the pilot tones are scattered in frequency and time [5]. According to [4] there are three existing algorithms to reduce the bit error in channel estimation namely Least Square, Minimum Mean Square and Best Linear Unbiased Estimation Algorithms. These algorithms depend on the pilots arrangement. Pilot-based approaches are widely used to estimate the channel properties and correct the distorted signal. Some of the existing channel estimation techniques are not suitable for the fast and frequency selective fading channel. Channel estimation is an essential part of coherent data detection in Orthogonal Frequency Division Multiplexing System OFDM [6],[7],[8],[9],[10]. Though, many researchers have worked on channel estimation in wireless communications but some are not in the platform of MIMO-OFDM with CMA. The hybridization of MIMO-OFDM systems makes the practical realization possible ([6], [11],[12],[13].

The hybridization of OFDM and MIMO where multiple antennas are involved in the transmitter and receiver with proper correlation increases the channel capacity, data rate, low bit error and the system performance over frequency selective channel for reliable communication. OFDM based systems need accurate estimation to compensate for time-varying channel [14],[15]. In OFDM system, wide spectrum is divided into narrow band subchannels otherwise known as subcarriers where data is multiplexed for different users. This technique eliminates the overlapping of symbols known Inter symbol Interference (ISI) and needs channel estimation.

The subcarriers in OFDM system resolve the overlapping which may have occurred due to the channel. The effect of the wireless channel needs to be compensated. Channel State Information (CSI) needs to be supplied to or estimated at the receiver. The subcarriers are regarded as independent channel, maintaining the orthogonality among subcarriers. This orthogonality needs to be maintained by subcarriers to avoid InterCarrier Interference (ICI) and allows each subcarrier to have channel response. The transmitted signal can be recovered by estimating the channel response of each subcarrier. The channel can be estimated using pilot symbols known to both transmitter and receiver. The data as well as training signal can be used for channel estimation in MMSE. Incorporation of this system into the 3x3 MIMO enhances the overall performance.

A lot of researches have been carried out on channel estimation in wireless communication but are not in the platform of MIMO-OFDM system with CMA to the best of authors' knowledge. Therefore, in this paper, comparison of the performances of the commonly used MMSE under pilot based is compared with CMA in 3x3 MIMO-OFDM systems over fast frequency selective fading channel. The performances are evaluated using Mean Square Error (MSE) and convergence value.

## 2. Channel Estimation

According to [4], [5], channel estimation is the process of obtaining the channel response or channel state information to be used by the receiver to avoid Inter Symbol Interference (ISI) distortion. For coherent detection and decoding where the phase of the receiver is in locked with the transmitted signal, efficient channel estimations are needed. There are two challenges in channel estimation namely: the arrangement of pilots and high computational complexity, the channel estimation is performed in MIMO-OFDM systems to have a good trade-off [4]. The channel estimations are categorized according to the arrangement of pilots. Based on this, three types of pilot structure are identified namely; block type, comb type and lattice type. Fig 1 shows the channel estimation model in which the output is compared with the receiver to determine the error.

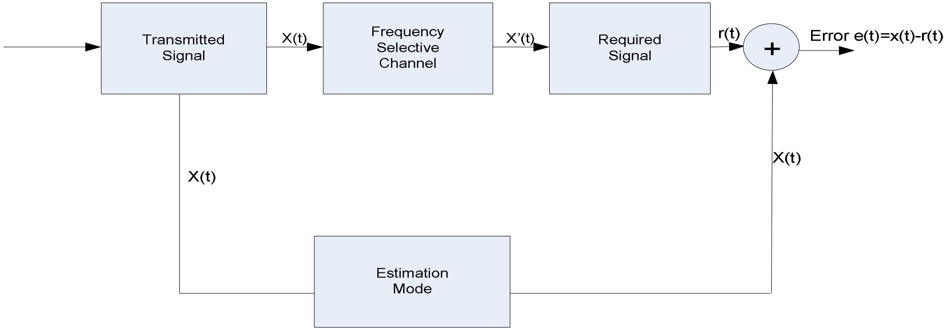

Fig 1: Channel estimation model

### 2.1 *Block Type*

According to [5], transmitted symbols with pilots at all subcarriers are transmitted periodically for estimation purpose. Time domain interpolation is required along the time axis. This is suitable for frequency selective channel.

### 2.2 *Comb Type*

This type has its symbol with pilots located at subcarriers periodically frequency domain interpolation is used to estimate the channel. The pilots need to be at coherent bandwidth for tracking of frequency-selective channel.

### 2.3 *Lattice Type*

The pilots are inserted along both the time and frequency axes that are scattered in time and frequency axes for proper interpolation in estimating the channel.

### 2.4 *Channel Estimation Algorithm*

In this paper, two channel estimation algorithms investigated are Minimum Mean Square Estimation (MMSE) and Constant Modulus Algorithm (CMA).

### 2.5 *Minimum Mean Square Estimation*

This is the error among the subcarriers which transmit signals to multiple antennas at the output of the transmitter; this is due correlation of frequency domain coefficients at different subcarriers. If the difference between the channel coefficients in the subcarriers is determined, then MMSE can be obtained. The response estimation based on MMSE gives good channel estimation but requires prior knowledge of the delay profile at the receivers. The MMSE has good BER performance at the expense of implementation problem which requires prior information of the delay spread. Interleavers are inserted after the encoder in the transmitter and deinterleavers before the encoder due to the permutation of the symbol in block of data [16]. All these contribute to computational complexity.

### *2.6 Constant Modulus Algorithm*

This is a stochastic gradient algorithm that minimizes the depression of the output for faster convergence. It consists of a filter in which its coefficient is adjusted by algorithm to minimize the modulus error [17]. CMA reduces the effect of ISI distortion and InterCarrier Interference which occur due to the large amount of delay from the multipath propagations by forcing the output of the adaptive filter to be of constant amplitude. It can also be used for Quadrature Amplitude Modulation (QAM) where the amplitude of the modulated signal is not the same at every instant [18]. This CMA is under the blind estimators which rely on the received signal and its pseudo-stationary [19],[20],[17].

## 3. System Model

The system model consists of 3 × 3 MIMO-OFDM systems incorporating each of CMA and MMSE. Figure 2 shows the simulation model for 3 × 3 MIMO-OFDM incorporating CMA and MMSE, The transmitter consists of bit streams, modulated symbol, OFDM signal and multiple antennas. The bit streams are obtained from the data source, properly coded by Forward Error Connection (FEC) and interleaved to avoid ISI. The bit streams are mapped using QAM mapper and converted to three (3) subcarriers. Inverse Fast Fourier Transform (IFFT) is performed on bits to convert them into time-domain signals, Cyclic Prefix (CP) to eliminate the ISI due to OFDM extension and send out through the antennas to the frequency selective fading channel, the transmitted bits are received through the three (3) receive antennas, processed by the Fast Fourier Transform (FFT) for conversion to digital signal after cyclic prefix removal. The three (3) subcarriers are converted to single carrier by parallel to serial converter. CMA is performed to estimate the channel effect and compensate for distortion. In turn, the channel is estimated using pilot bits known to both transmitter and receiver with MMSE. After the estimation, the QAM demapper, bit deinterleaver and FEC decoder in turn process the received signal. The system model is simulated using MATLAB application package. The performance of the system is evaluated using Mean Square Error (MSE) and convergence value for both CMA and MMSE.

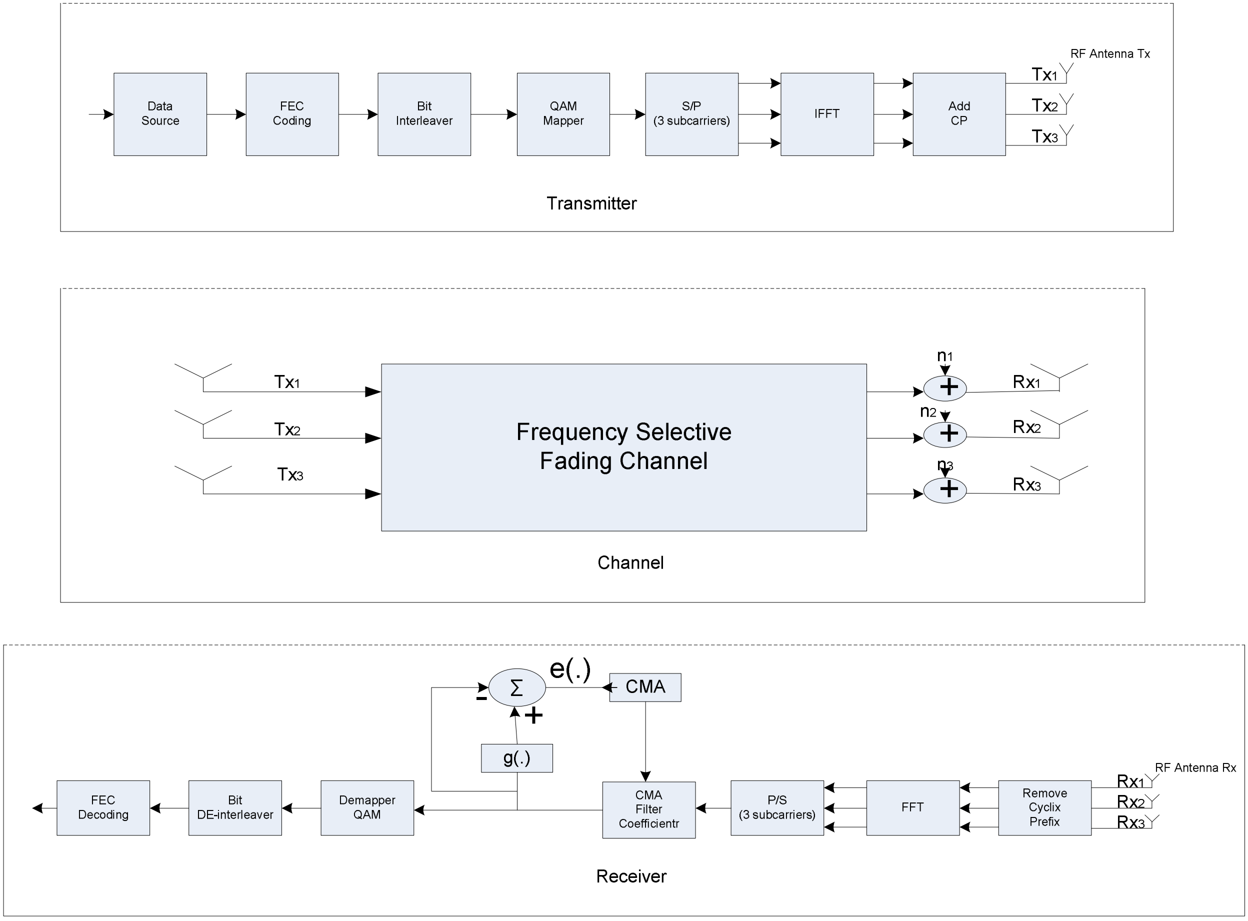

Figure 2. Simulation model for 3x3 MIMO-OFDM Systems incorporating CMA and MMSE

### *3.1 Multiple-Input Multiple-Output (MIMO)*

A MIMO-OFDM system with three transmit antennas and three receive antenna is shown in Fig3. The CMA block initializes the CMA filter to update the filter coefficients giving the output. The output of the filter is connected to memoryless non-linear estimator. The error is computed to update the filter coefficient.

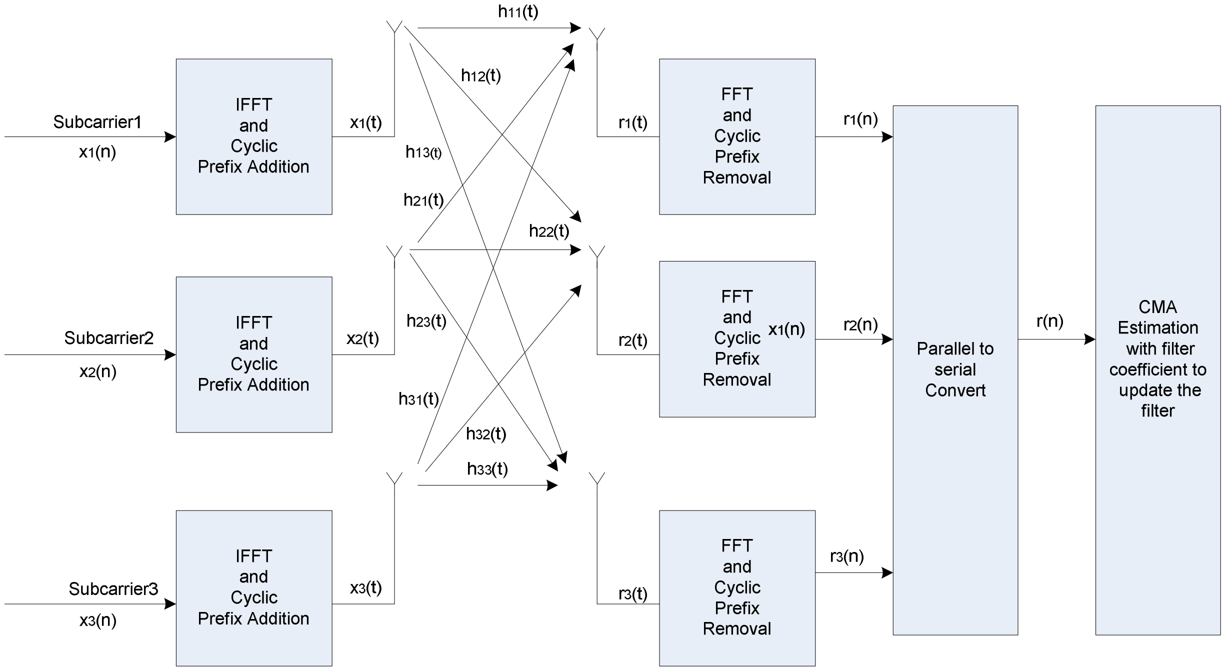

Figure 3: 3x3 MIMO-OFDM system

### *3.2 Inverse Fast Fourier Transform (IFFT) and Inverse Fast Fourier Transform (FFT)*

According to [21],[22],[23], a n-point IFFT is applied to the complex data symbols with n representing orthogonal subcarrier frequencies.

The complex baseband equivalent signal $\bar{x}(t)$ is given by [21],[6],[24] as

$$\bar{x}(t) = \frac{1}{3}\sum_{n=0}^{2}\bar{A}(t)e^{-j2\pi n\Delta f t} \qquad (1)$$

where: $\bar{A}(t)$ = Complex amplitude of the difference subcarrier
$\Delta f$ = Frequency separation between each sub-carrier

Assuming the total symbol period is $T_s$, then a block of '3' data points are defined as

$$x_n = \bar{x}\left(\frac{nTs}{3}\right) = \frac{1}{3}\sum_{n=0}^{2}\bar{A}_n e^{j2\pi Kn\Delta f Ts/3} \qquad (2)$$

K = 0, 1, 2, 3

For Orthogonality, $\Delta f\ T_s$=1

$$x_n = \frac{1}{3}\sum_{n=0}^{2}\bar{A}_n e^{j2\pi kn/3} \qquad (3)$$

FFT performs reverse operation of IFFT by converting the time domain back to discrete domain

Assuming $x_1(n), x_2(n), x_3(n)$ are the subcarriers of 1, 2 and 3 respectively to the IFFT block and $x_1(t), x_2(t)$, and $x_3(t)$ are the signals radiated. The received signals at the three antennas are expressed as

$$r_1(t) = h_{11}(t) * x_1(t) + h_{21}(t) * x_2(t) + h_{31}(t) * \mathrm{x}_3(\mathrm{t}) + \mathrm{n}_1(\mathrm{t}) \qquad (4)$$

$$r_2(t) = h_{12}(t) * x_1(t) + h_{22}(t) * x_2(t) + h_{32}(t) * x_3(t) + n_2(t) \qquad (5)$$

$$r_3(t) = h_{13}(t) * x_1(t) + h_{23}(t) * x_2(t) + h_{33}(t) * x_3(t) + n_3(t) \qquad (6)$$

where:

$r_1(t), r_2(t)$ *and* $r_3(t)$ are the received signal through the three antennas

$n_1(t), n_2(t)$ and $n_3(t)$ are the noises at each subcarrier.

After the FFT operation and cyclic prefix removal, the received signal at the $i^{th}$ subcarriers are given as

$$r_j[n] = \sum_{n=1}^{3} H_{ij}[n]\, x_i[n] + n_j[n] \qquad (7)$$

where: i= transmit antenna
j= receive antenna

$$\text{So in matrix form, } \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} x_1(n) \\ x_2(n) \\ x_3(n) \end{bmatrix} + \begin{bmatrix} n_1(n) \\ n_2(n) \\ n_3(n) \end{bmatrix} \qquad (8)$$

## 4. Results and Discussion

The performances of CMA and MMSE from blind channel and pilot symbol estimations respectively in 3x3 MIMO-OFDM System have been evaluated using Mean Square Error (MSE) and convergence value. The investigation is carried out using computer simulation. The MSE values obtained for both CMA and MMSE are presented in Figs. 4-6. The values for MMSE are obtained when 256 pilot symbols which give 1024 data length are used. From the Fig 4, at SNR of 5dB, the MSE values obtained are 0.0027 and 0.036 for CMA and MMSE respectively while at SNR of 20dB, 0.0006 and 0.0026 are the MSE values obtained for CMA and MMSE. Table 1 contains the same results for clarification.

Fig 5 (a-c) show the result of the simulation of MSE against the transmitted data for CMA at SNR of 5, 10 and 15dB respectively. It is confirmed that at SNR of 5dB, CMA converges at 700th data as indicated in the Fig 5a. In Fig 5b, the CMA converges at 600th data at SNR of 10dB while in Fig 5c; it converges at 100th data with the SNR of 15dB. This indicates that the CMA gives better results as SNR increases. Fig. 6 shows the combination of all the scenario at different SNR for comparison. This is justifiable in that CMA continues improving the initial conditions based on the received data to give better estimation. The convergence values for MMSE are constant at all SNR. Though, pilot symbols are inserted in MMSE to train the system but when the CMA algorithm step size is 0.1101, CMA filter order is 11 due to algorithm step selected and CMA dispersion constant is 0.1. The computational complexity of the MMSE increases exponentially due to number of subcarriers. Therefore, CMA performs better over frequency selective fading channel.

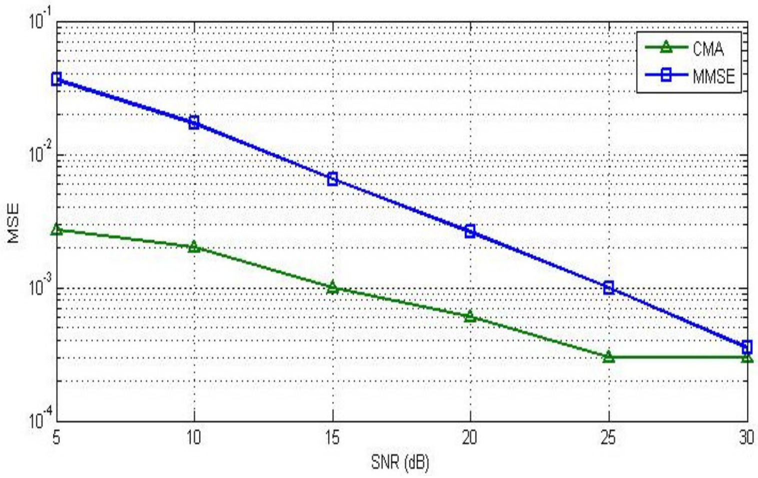

Figure 4; Simulation of MSE against SNR for CMA and MMSE

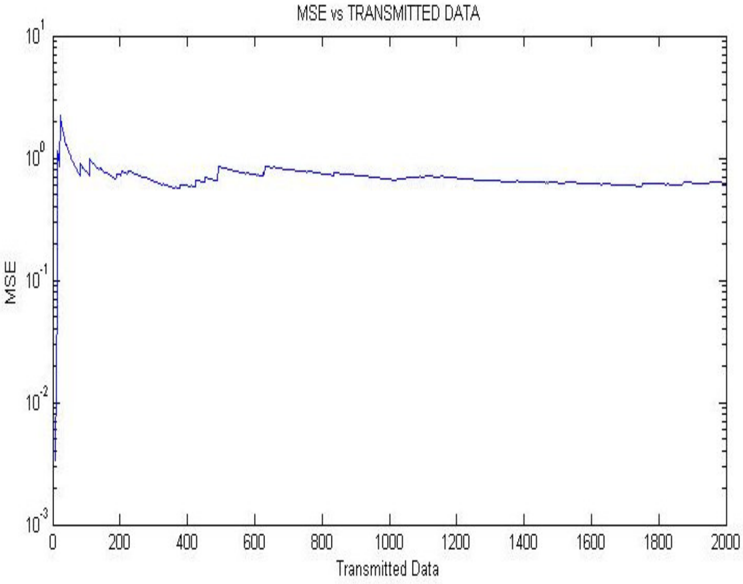

Figure 5a: Simulation of MSE against transmitted data at SNR of 5dB

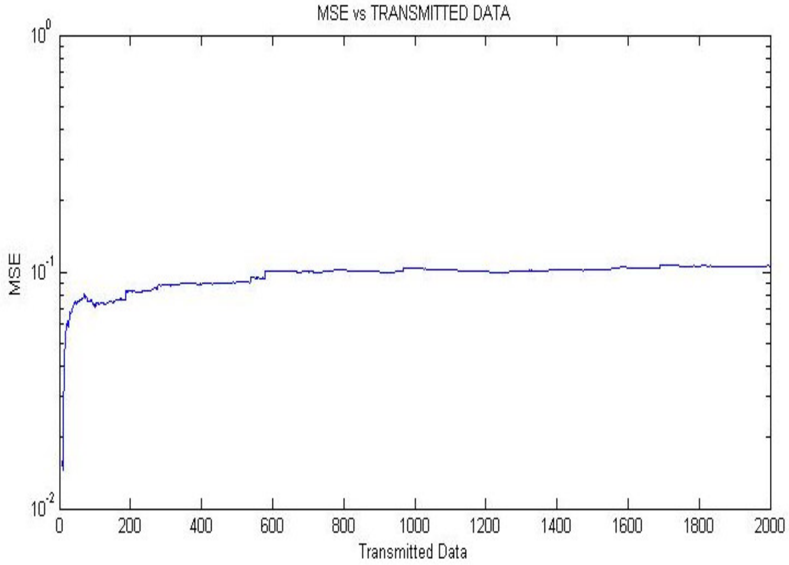

Figure 5b: Simulation of MSE against transmitted data at SNR of 10dB

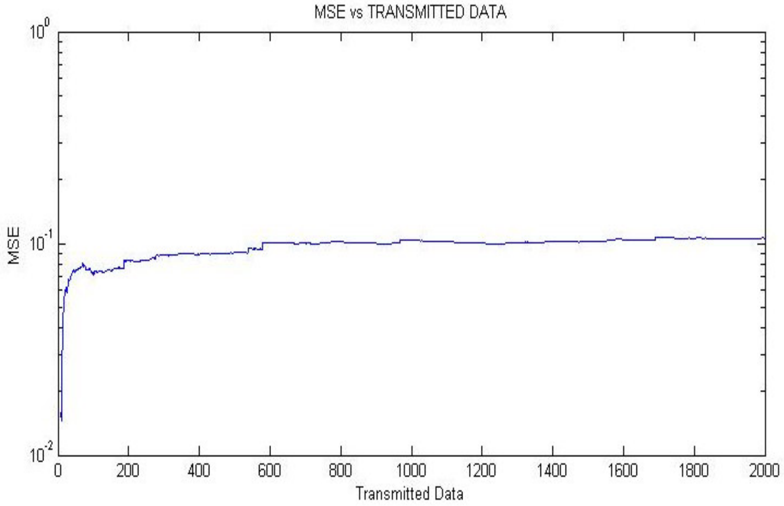

Figure 5c: Simulation of MSE against transmitted data at SNR of 15dB

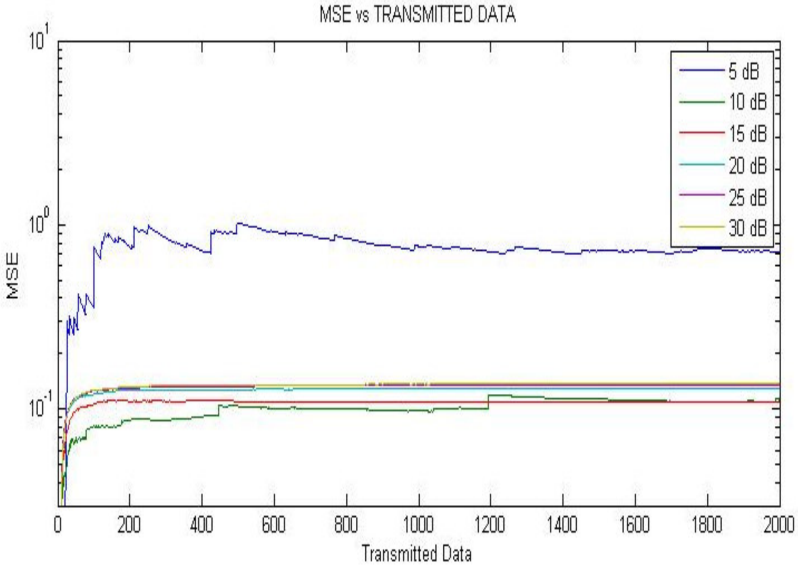

Figure 6: Simulation of MSE against transmitted data at different SNR

Table 1: MSE values for CMA and MMSE at different SNRs

| SNR(dB) | CMA | MMSE |
|---|---|---|
| 5 | 0.0027 | 0.036 |
| 10 | 0.0020 | 0.017 |
| 15 | 0.0010 | 0.0065 |

## 5. Conclusion

The comparative analysis of CMA and MMSE in3x3 MIMO-OFDM system has been investigated over frequency selective fading channel using MSE and algorithm convergence values. The system model for MIMO-OFDM incorporating each of 256 pilot symbols for MMSE and CMA separately has also been developed. The system model consists of a transmitter with signal processing techniques such as QAM mapper, IFFT, cyclic prefix addition and three (3) RF antennas for transmission over frequency selective channel, and the receiver with signal processing techniques. The model is simulated using MATLAB 7.2 software package with pilot symbols inserted at the transmitter for MMSE and in turn, with CMA at the receiver. The results obtained show that though pilot symbols are inserted at the transmitter for training but CMA performs better under the conditions considered. The analysis, in this paper, has shown that CMA can still be used for channel estimation to have reliable signals.

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