Abstract – Channel Estimation (CE) in multicarrier system especially in Orthogonal Frequency Division Multiplexing (OFDM) systems has become an important technique in wireless communication to reduce the overall effect of high data rate and increase links performance. In wireless channel, which has frequency selective distribution, the transmitted signals are corrupted and resulted in high error at the receiver. However, the existing techniques in use such as Least Square Estimation (LSE), Minimum Mean Square Error (MMSE) are based on single carrier system with pilot symbols for channel estimation to reduce the error. Therefore, in this paper, investigation of the performance of blind channel estimation in sixteen (16) subcarriers OFDM system using a Constant Modulus Algorithm (CMA) is carried out. The system model for sixteen subcarriers OFDM incorporating CMA is developed over the frequency selective fading channel. OFDM system consists of the following signal processing techniques; sixteen channel demultiplexer, Inverse Fast Fourier transform (IFFT), Cyclic Prefix (CP), sixteen channels multiplexer and the Radio Frequency (RF) transmit antenna all at the transmitter. Also, at the receiver are RF receive antenna, sixteen channel demultiplexer, Fast Fourier transform (FFT), sixteen channel multiplexer, Cyclic Prefix (CP) removal and decoder. The input data are generated randomly, converted to bits and divided among the subcarriers to reduce overlapping of bits. The signal processing techniques at both the transmitter and receiver process the signal. The system model is simulated by MATLAB application package and evaluated using Mean Square Error (MSE). This is now compared with the LSE and MMSE estimation. The results obtained using 16-subcarrier OFDM with CMA give lower MSE than with LSE over frequency selective environment.

Keywords – OFDM, Subcarriers, IFFT, Pilots, Blind Channel.

I. INTRODUCTION

Wireless communications allow people to communicate without physical connection over long distances. The wireless channel consists of many objects such as building, mountains, foliages and moving cars. These objects served as obstruction to the transmitted signal by scattering resulting in multipath propagation. The overall effects of these are signal fading, Delay spread, and Doppler spread. These are used in the classification of channel in which frequency selective is identified due to high delay spread. So when high data rate is transmitted over the frequency selective channel, It resulted in high error at the receiver. In order to recover the transmitted bits, these channel effects need to be compensated for at the receiver. Therefore, channel estimation is the process of obtaining the information about the channel which will be supplied to both transmitter and receiver for decoding [17],[10],[16],[14],[6],[13],[23].

According to [3], the channel state information can be obtained by using channel estimation at the receiver, because the OFDM system using coherent modulation needs channel state information to decode the transmitted signal at the receiver. Channel estimation is grouped into three categories namely: blind, semi-blind and non-blind techniques. The blind deals with getting the statistical information of the channel and the properties of transmitted signal, while the non-blind uses some portions of the transmitted signal, that is, pilot tones as training sequence. The pilot structures are classified into three groups namely: block type in which all the subcarriers are used as pilot tones in OFDM system and transmitted periodically, and secondly, a comb-type which has some of the subcarriers as pilot tones in each of the OFDM blocks. Thirdly is the lattice type in which the pilot tones are scattered in both time and frequency correlations of the channel while frequency correlation is used for low complexity estimators [4],[15],[20],[24],[7],[12].

There are various algorithms to reduce the overall effect of frequency selective fading channel and subsequently reducing the error in channel estimation such as Least Square algorithm (LS), Minimum Mean Square Estimation (MMSE) algorithm and Best Linear Unbiased Estimation (BLUE) algorithm all belong to Non-Blind estimation while Constant Modulus Algorithm (CMA) belongs to blind channel estimation. All these algorithms may be used in different platform. In this paper, 16-subcarrier OFDM system is used as the platform for the investigation. This consists of binary data which serves as input to the inter-leaver. The bit stream is modulated using QAM. The OFDM is performed on the modulated symbol and transmitted through the Radio Frequency (RF) transmit antenna. The OFDM signal is radiated through the frequency selective fading channel and received by RF receive antenna. The reverse operation of the OFDM is performed, properly estimated using CMA, demodulated to recover the original signal. A lot of researches have been carried out on channel estimation using different platforms and techniques especially on Non-blind estimation such as LE, MMSE, BLUE in either OFDM or MIMO-OFDM platform. In this paper, effectiveness of blind channel estimation in the platform of OFDM is investigated and compared with the commonly used Non-blind estimation especially LE and MMSE. This technique
is evaluated using Mean Square Error (MSE) [1,2,11,5,8,9,18,19,21,22].

A. Constant Modulus Algorithm

According to [20] CMA minimizes the dispersion of the output around a circular contour and the cost function for faster convergence. The algorithm continues adjusting the filter coefficients to minimize the modulus error. It is used for constant convergence is achieved. Then the filter coefficient is adjusted to update the filter estimator to give $x_\text{e}$.

The following steps are carried out to achieve constant modulus algorithm using the CMA model shown in Figure 1. The CMA filter coefficient $w_n$ is initialized by setting

$$w_n = \begin{cases} 1 & n = m/2 \\ 0 & \text{otherwise} \end{cases}$$  (1)

The incoming signal $r(n)$ is filtered to give $y(n)$ using

$$y(n) = w^n H(n) r(n)$$  (2)

This is then estimated using zero-memory non-linear estimator to give $x(y(n))$ that acts as the desired response. The estimation is carried out using

$$x(y(n)) = y(n)(1 + r^2 - |y(n)|^2)$$  (3)

The error $e(n)$ is obtained by finding the difference between the estimation output and the filter output, that is,

$$e(n) = x(y(n)) - y(n)$$  (4)

Then the filter coefficient is adjusted to update the filter coefficient. The whole process continues until stabilization or constant convergence is achieved.

$$\text{Updating filter coefficient}$$

**Fig. 1. CMA estimation**

B. Least Square Estimation

This is in form of coherent data detection in communication system. The transmitted signal $s(n)$ and the received signal $r(n)$ in vector form are expressed by [2] as

$$r(n) = [r(n,K_1), r(n,K_2), ..., r(n,k-1)]$$  (5)

$$s(n) = [s(n,K_1), s(n,K_2), ..., s(n,k-1)]$$  (6)

Where $K_1 = 0, K_2 = 1, K_3 = 2, ..., K_1 = 15$ are the numbers of subcarriers in an OFDM symbol.

The ratio of $r(n)$ to $s(n)$ gives the frequency response of the channel denoted by $H(n)$.

Therefore, the estimated frequency response of the channel

$$H(n,k) = \frac{r(n,k)}{s(n,k)} \quad \text{for} \quad k = 0,1,2,\ldots,k-1$$  (7)

The conjugate of the transmitted signal is $s^*(n,k)$

The estimated channel frequency response $\tilde{H}(n,k)$ is given by [2] as

$$\tilde{H}(n,k) = r(n,k)s^*(n,k), \text{for} \quad k = 0,1,\ldots,15$$  (8)

This indicates that the frequency response of the channel in each of 16 subcarriers OFDM is independent of each other. Though, LE estimation has low complexity and easy to implement but at the expense of large Mean Square Error (MSE).

In [3], LS channel method obtains channel estimate $\tilde{H}$ in such a way that the cost function is minimized

$$\tilde{H} = |R - S\tilde{H}|^2$$  (9)

where: $\tilde{H}$ is the estimate of channel $H(k), R$ is the received training signal

Equation (9) becomes

$$f(\tilde{H}) = (R - S\tilde{H})^H(R - S\tilde{H})$$  (10)

Where $(.)^H$ is Hermitian transpose

$$f(\tilde{H}) = (R^H R - \tilde{H}^H H^H R + \tilde{H}^H H^H S^H S \tilde{H})$$  (11)

$$f[H(n,k)] = \sum_{k=1}^{16} |r(n,k) - \sum_{i=1}^{16} \bar{H}_i[n,k]s_i[n,k]|^2$$  (12)

$$= \frac{k_0}{k_0} |r(n,k) - \sum_{i=1}^{16} \sum_{k=1}^{k_0} \bar{H}_i[n,k] \exp(-j2\pi n k_i/k)|^2$$  (13)

where $k_0$ is the channel delay profile

Finding the partial derivative with respect to $\tilde{H}$ and equate to zero

$$\frac{\partial f(\tilde{H})}{\partial \tilde{H}} = -2S^H R + 2(S^H S \tilde{H})^* = 0$$  (14)

But $S^H S \tilde{H} = S^* R$. gives the LS channel estimation, $\tilde{H}_\text{LS} = (S^H S)^{-1} S^H R = S^{-1} R$  (15)

Therefore, according to [3], $MSE_{\text{LS}} = \frac{\sigma_n^2}{\sigma_x^2}$ where $\sigma_n^2$ is the variance of the noise, $\sigma_x^2$ is the variance of the transmitted signal

C. Minimum Mean Square Estimation

This provides better performance in terms of MSE than LS estimator. The estimator makes use of several parameters such as Signal to Noise Ratio (SNR) as well as second-order statistics of the channel [1].

From the minimization of the LS cost function

$$\tilde{H}_\text{LS} = S^{-1} R$$  (16)

When the weight matrix $W$ is considered and defined by

$$\tilde{H}_{\text{MMSE}} = W\tilde{H}_\text{LS}$$

That is, $\tilde{H}_{\text{MMSE}} = W(S^{-1} R)$ corresponds to MMSE.  (17)

$$MSE$$ of the channel estimate $\tilde{H}_{\text{MMSE}}$ is given by [3] as

$$MSE_{\text{MMSE}}(\tilde{H}) = E[||e||^2] = E[||H - \tilde{H}_{\text{MMSE}}||^2]$$  (18)

where $E[. ]$ is the expected value of ‘e’

II. METHODOLOGY

The simulation model consists of 16 subcarriers OFDM in which the training symbol such as pilot tones inserted in every subcarrier in addition to data symbols for LSE and MMSE. The training data is not needed for CMA estimation. The OFDM system is divided into three sections namely the OFDM transmitter, the frequency selective channel and the OFDM receiver. The transmitter
consists of bits stream, modulated symbol, OFDM signal and RF transmit antenna. The bit stream consists of general data, Forward Error Correction (FEC) and bit interleaver. This serves as input to the QAM signaling scheme for up conversion to Radio Frequency (RF) signal. The QAM modulated signal is converted to 16 subcarriers or 16 channel by demultiplexer. This is, then, converted to time domain by the Inverse Fast Fourier Transform (IFFT) in which cyclic prefix is added to OFDM symbol time to have larger interval than the expected delay spread of the channel to eliminate ISI caused by the adjacent OFDM symbols. The OFDM signals at the transmitter consists of the addition of cyclic prefix, 16-channel multiplexer to convert to a single carrier for transmission through the RF transmit antenna. The OFDM signal passes through the frequency selective channel. The received signal through the RF receive antenna is demultiplexed into 16 subcarriers after cyclic removal. The 16 subcarriers are converted to digital signal and multiplexed by 16 channels multiplexer.

The signal is estimated using CMA by filtering, updating the filter coefficient until there is stabilization in the amplitude. The estimated signal is demodulated using QAM to recover the transmitted signal, interleaved and decoded. Fig. 2 is the simulation model for estimation. The 16 subcarriers are used to overcome the frequency selectivity of the wideband channel due to single-carrier transmission. The model is simulated using MATLAB application package.

The OFDM signal $s(n)$ in time varying channel is expressed by [3] as

$$s(n) = \sum_{k=0}^{N-1} s(k) e^{-j2\pi kn/N}$$

where $N = 15$, the corresponding signal received through a time varying wireless channel with $L$ paths can be expressed by [3] as

$$r(n) = \sum_{l=1}^{L-1} h_l(n) s(n - \tau_l) + \eta(n)$$

where $h_l(n)$ is the impulse response. $\tau_l$ is the delay time for the $l^{th}$ path $\eta(n)$ is the noise

Taking the Fast Fourier Transform (FFT) of equation (20) gives

$$r(k) = \frac{1}{16} \sum_{n=0}^{15} r(n) \exp \left( -j2\pi kn/15 \right)$$

$$r(k) = \sum_{m=0}^{16} \sum_{l=1}^{L-1} s(m) h_l(k - m) \exp \left( -j2\pi m/15 \right) + n(k)$$

Where $n(k)$ is the FFT of $\eta(n)$

$$H_l(k)$$ is the impulse response

$$h_l(n) = \frac{1}{16} \sum_{n=0}^{15} h_l(n) e^{-j2\pi nk/15}$$

A. Simulation Parameters

The simulation parameters used for the modeling are contained in Table 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel</td>
<td>Frequency selective</td>
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<td>Modulation Scheme</td>
<td>QAM</td>
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<tr>
<td>Noise</td>
<td>AWGN</td>
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<td>Serial to Parallel</td>
<td>16 Channel Demultiplexer</td>
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<tr>
<td>Parallel to Serial</td>
<td>16 Channel Demultiplexer</td>
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<td>SNR (dB)</td>
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<td>Number of Subcarrier</td>
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<td>Symbol Period</td>
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<td>Maximum Excess delay</td>
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<td>CMA filter order</td>
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<tr>
<td>Pilot Symbol</td>
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<tr>
<td>Pilot Symbol Spacing</td>
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</tbody>
</table>

Fig. 2. Simulation model for 16-subcarrier OFDM system incorporating CMA
III. RESULTS AND DISCUSSION

The performance of 16 subcarriers OFDM system with blind channel estimation especially ‘CMA’ has been evaluated using Mean Square Error (MSE), this is compared with the LS and MMSE under non-blind channel estimation adapted from [13] for comparison. The MSE values obtained for commonly used LS and MMSE are presented in Fig.3. At SNR of 5dB, the MSE value obtained for LSE and MMSE are 0.24 and 0.036 respectively, while at SNR of 20dB, 7.2 × 10^{-3} and 2.6 × 10^{-3} are the MSE values for LSE and MMSE respectively. Fig.4 depicts the MSE results of 16 subcarriers OFDM incorporating CMA. At SNR of 10dB MSE of 2.0 × 10^{-3} is obtained while at SNR of 20dB, MSE of 6.0 × 10^{-4} is obtained. Fig. 5 shows the simulation of MSE versus SNR for the combination of OFDM incorporating CMA, LSE and MMSE. From the Fig.5 at SNR of 10dB, the MSE values obtained are 2.0 × 10^{-3}, 7.2 × 10^{-2}, 1.7 × 10^{-2} for CMA, LSE and MMSE respectively.

These results are justifiable in that the LS estimation assumes independent components of the frequency response which does not use the correlation properties of the channel making it sensitive to error. The transmission of efficiencies of LSE and MMSE are reduced because of the additive effect of training symbol such as pilot tones which transmitted with data symbol. The inclusion of weight makes MMSE to have reduced MSE. Though CMA is not commonly used with OFDM system but has the lowest MSE values indicating the best performance under the stated simulation parameters.

![Fig. 3. Simulation of MSE versus SNR for LSE and MMSE adapted from [13] for comparison](image)

![Fig. 4. Simulation of MSE versus SNR for CMA](image)
IV. CONCLUSION

In this paper, Mean Square Error (MSE) of blind channel estimation using a constant modulus algorithm in 16-subcarrier OFDM system over frequency selective fading channel has been investigated. The system model for 16-subcarrier OFDM inserted with pilot tones has been developed over frequency selective channel. The channel is properly estimated for LSE and MMSE. Then, the system model for 16-subcarrier OFDM incorporating CMA is also developed over the same channel. These system models are simulated and evaluated in term of MSE. The results obtained show that pilot tones are inserted at each subcarrier which reduces the transmission efficiency but the performance is worse than CMA under the parameters considered. The performance, in this paper, has shown that CMA can still be used with OFDM for proper channel estimation.

REFERENCES


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