



# **A ROBUST AND EFFICIENT CHANNEL ESTIMATION SCHEME FOR OFDM SYSTEMS IN FREQUENCY SELECTIVE FADING CHANNELS**

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**Abstract-** Due to the requirement of high speed data transmission, orthogonal frequency division multiplexing (OFDM) is becoming a vital in wireless communication systems like 3G, 4G and even in 5G networks. OFDM is capable to provide higher mobility, higher throughput, maximum possible efficiency versus multipath fading and has a capability of ultra-rate transmission. Nevertheless, these systems should be capable to acquire perfect channel estimation for enabling and permitting of higher mobility practicability for symbol recovery in ultra-speed while handling the co-channel interference (CCI). To address this issue, we introduced a robust and efficient model for channel estimation (CE) for OFDM systems under frequency selective (FS) fading channels. Optimal preface based maximum likelihood (OP-ML) scheme is utilized for estimating the channel perfectly. Simulation results show that for a sufficiently long preface, the ML estimator performs as good as the situation when the channel is known perfectly at the receiver when compared to the conventional CE algorithms with respect to mean square error (MSE). Our proposed system model well suited for digital video broadcasting and optical communications applications.

**Keywords-** Orthogonal frequency division multiplexing, Channel Estimation, Frequency Selective Fading Channels, Co-channel Interference (CCI), Maximum Likelihood Estimator (MLE) and Mean Square Error (MSE).

## **1. INTRODUCTION**

In orthogonal frequency division multiplexing (OFDM) systems [1], a frequency selective (FS) channel is commuted into an accumulation of flat fading channels, which can be indemnified by simply using an equalizer of one-tap. Therefore, OFDM can greatly alter the design of equalizer while enabling rather higher data rates, which leads that it is used as a vital physical layer in many commercial systems. It's a modish technology in the era of wireless communications. it provides higher mobility, high robustness versus multipath fading and has capability of high rate transmission. The higher requirements for improved reliability and high data rates in today's wireless communication have made OFDM one of the key solutions for future generation wireless communication due to its potentiality to multipath exploitation while actualizing enhanced performance in spatial multiplexing, array gain and power. In case of fast time varying OFDM systems, channel equalization must be done effectively to remove Inter Symbol Interference (ISI) which usually occurs in frequency selective channels, so OFDM is used for this purpose [2]. OFDM systems can boost the rate of data transmission while dealing frequency-selective (FS) fading. It also has a capability of gratifying the next-generation wireless networks requirements such as Wireless Local Area Networks (WLANs) [3], Wireless Fidelity (Wi-Fi), and World-wide interoperability for Microwave Access (Wi-MAX), Cognitive Radio, 3rd Generation Partnership Project (3GPP) and LTE [4]. However, these sorts of systems should be capable to gain exact channel information to grant and enable high mobility practicability and for recovery of symbols in high speed while handling co-channel interference (CCI) and time selective (TS) fading. To do so, we need to estimate the channel in an effective manner by mitigating the mean square error (MSE). There are many CE algorithms presented in the literature for enhanced wireless communication system. However, the works implemented for CE in the past has lot of drawbacks which will be discussed in section II briefly. Here, we implemented OP-ML-CE algorithm which is a robust and effective CE algorithm for OFDM systems in FS fading channels. The novelty of our proposed work lies in the use of a filter that is matched to the preface, to acquire perfect estimated channel over conventional CE algorithms. Our CE model does not require any knowledge of the channel and noise statistics. Rest of the paper as follows: section 2 describes the related work already done in the field of channel estimation, section 3 explains the description of problem, system model has been described in section 4, simulation analysis in section 5 followed by conclusion in section 6 with references.

## **2. RELATED WORK**

In orthogonal frequency division multiplexing (OFDM) systems, a frequency selective (FS) channel is commuted into an accumulation of flat fading channels, which can be indemnified by simply using an equalizer of one-tap [5]. Therefore, OFDM can greatly alter the design of equalizer while enabling rather higher data rates, which leads that it is used as a vital physical layer in many commercial systems. Various early attempts have successfully made for estimating the channel in

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communication systems such as code division multiplexing (CDMA) and OFDM systems [6-7]. Due to the computational onus of Eigen value decomposition (EVD) and ineptness for adaptive processing of state-of-art schemes in the literature like multiple signal classification (MUSIC) method [8] and estimation of signal parameters via rotational invariance techniques (ESPRIT) [9]. Without any restraints about the channel, the estimated trouble's dimension can be quite huge. Still, in wireless communication systems the radio channel is frequently qualified by a few paths those are prevalent, typically two to six [10]. Moreover, the transmission of data at higher speeds results in a thin multipath channel. The signal subspace attribute of the correlation matrix can be effectively mitigated when the construction of correlation matrix of a channel based on the parametric channel model [10]. The authors in [11] and [12], proposes a least squares (LS) approach and Minimum Mean Square Error (MMSE) which are categorized under no prior information of channel. Among those, LS estimator is a simplest method and it has lower computational complexity when we compared with the MMSE estimator. But, however the results of MMSE are better than the LS estimator. Different interpolation methods are given in [12] and [13]. Compared with the existing methods, transformation-based methods will perform excellent with moderate complexity increase. In [14], the author explained DFT based CE method. It can improve the system efficiency by reducing the computational complexity by exploiting the fast Fourier transform (FFT) algorithm. However, it can't provide an excellent performance when a sample spaced path delay will be existed by the multi path fading channels. To overcome this drawback, windowed DFT-CE method has been proposed in [15] to improve the performance of the system. But, it reduces the utilization of frequency band. Then after to improve the performance of the system more accurately, the DCT based CE methods have been proposed in [16], [17] and [18]. These methods have got excellent performance at high SNR region, but at low SNR values it gives very poor performance. Expectation maximization (EM)-based joint channel estimation and exploitation of the diversity gain from IQ imbalances is addressed in [19]. Recently, author in [20] proposed an algorithm for CE by path diversity exploitation in both domains i.e., angle and power. The CE algorithms proposed in [22] shown that the robustness of transformations-based CE approaches such as discrete Fourier transform (DFT), discrete cosine transform (DCT) under various channel distributions. The experimental analysis given in [22] discloses that the comparison to the expurgated-DCT (E-DCT) with the conventional channel estimation algorithms such as the algorithm given in [25] like LS estimator, DFT and mirror-weighted DCT (MW-DCT). As per the author's concern the navigate symbol assisted E-DCT has performed superior over above mentioned conventional algorithms. Author in [24], presented a new trending CE algorithm for OFDM systems which utilized LS based DFT. The performance of MSE is quite better over classical LS and DFT individually. In general, the constriction to trust on sufficiently higher order polynomial model leading in complicated algorithms, showing an impractical solvent for real time CE where the pilot optimality finally reckons on the CE speed. To overcome all the above-mentioned issues and to improve the robustness and reliability of CE algorithms in OFDM systems, this article proposes a robust OP-ML-CE scheme which have been invented to actualize practical communications in FS channels.

2.1. LS Scheme

The general OFDM system model has given in fig1. Firstly, the binary data has given as an input to the M-QAM/QPSK modulator. After mapping and grouping the input data the comb-pilot insertion will be done to split the transmitted data into  $N$  low rate modulated symbols  $X(k)$ , where  $k= 0,1,2, \dots, N-1$ . Then the time domain signal  $x(n)$  can be written as a frequency domain signal  $X(k)$  after performing the IFFT:

$$x(n) = IDFT\{X(k)\}$$

$$IDFT\{X(k)\} = \sum_{k=0}^{N-1} X(k) \exp(j2\pi nk/N) \tag{1}$$

Where  $N$  is the number sub carriers

$$x_g(n) = \begin{cases} x(L_{cp} + n) & n = -L_{cp}, -L_{cp} + 1, \dots, -1 \\ x(n) & n = 0, 1, \dots, N - 1 \end{cases} \tag{2}$$

Where  $L_{cp}$  is the cyclic prefix (CP) length which reduces the ISI and as well as inter carrier interference (ICI).

If the length of the channel is less than the CP, then the received signal can be expressed as follows:

$$y_g(n) = x_g(n) \otimes h(n) + w(n) \tag{3}$$

Where  $n = 0, 1, 2, \dots, N - 1$ ,  $\otimes$  =circular convolution and  $w(n)$  = additive white gaussian noise (AWGN).

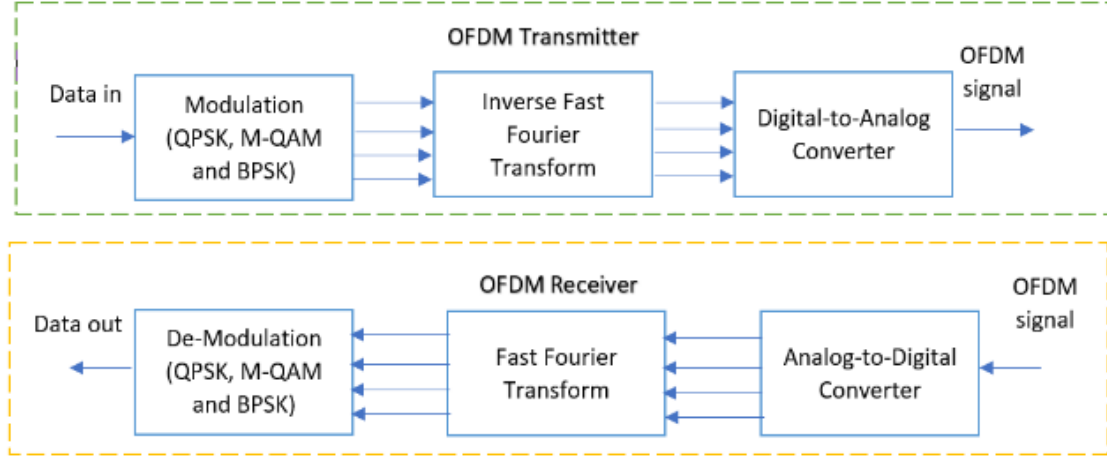


Figure 1. General model of OFDM block diagram

After applying discrete Fourier transform (DFT)

$$Y(k) = \sum_{n=0}^{N-1} y(n) e^{-j2\pi nk/N} \quad (4)$$

$$Y(k) = X(k)H(k) + W(k) \quad (5)$$

Where  $H(k) = \sum_{l=0}^{L-1} h(l) e^{-j2\pi kl/N}$  = transfer function of channel in frequency domain,  $W(k) = \sum_{n=0}^{N-1} w(n) e^{-j2\pi nk/N}$  is known as AWGN noise samples. LS is very simple and flexible approach, the channel estimation can be done by multiplying the sub symbols of received pilot carriers with the inverse of the sub symbols of reference pilot carriers, which can be described as follows:

$$\hat{H}_p^{LS} = X_p^{-1} Y_p = [X_{p_0}^{-1} Y_{p_0} \dots \dots X_{p_{p-1}}^{-1} Y_{p_{p-1}}]^T \quad (6)$$

Where  $X_p$  = reference pilot carrier sub symbols  $Y_p$  = received pilot carrier sub symbols and  $(p_0, p_1, \dots, p_{p-1})$  are the set of sub carriers which will be used to carry sub symbols of pilot. Then after, it estimates the channel by interpolating  $\hat{H}_{p_0}^{LS}$ , which are obtained at positions of pilot, where  $z = 0, 1, \dots, P-1$ , over the entire band to get the  $\hat{H}_{LS}(k)$ .

### 3. DESIGN OF PROPOSED SYSTEM

It is assumed that the data to be transmitted is organized into blocks, as depicted in Figure 2, which consists of QPSK modulated block in which the input data and preface data eq. (7) and (8) will be modulated, and the obtained results allowed by serial-to-parallel converter that converts the modulated data symbol streams into parallel data. There by inverse fast fourier transform (IFFT) utilized for the conversion of frequency domain data into time domain with less number of computations. Then after parallel-to-serial conversion is done by adding of cyclic prefix (CP). Our proposed model consists of a known preface of length  $L_p$  symbols, a cyclic prefix of length  $L_{cp}$ , followed by length of the data  $\ell$  symbols. Thus, the total length of the block is  $L_b = L_p + L_{cp} + \ell$ . Let us assume a channel traverse is equal to  $L_{tr}$ . The channel traverse assumed by the receiver is  $L_r (> L_c)$ . The length of the cyclic prefix is  $L_{cp} = L_r - 1$ . The output obtained after CP block has been sent over the channel that has to estimate by using eq. (18).

Note that,

$$\tilde{b}_{1,n} = \frac{1}{L_p} \sum_{i=0}^{L_p-1} \mathbb{B}_{1,i} e^{j2\pi ni/L_p} \quad (7)$$

$$\tilde{b}_{k,3,n} = \frac{1}{\ell} \sum_{i=0}^{\ell-1} \mathbb{B}_{k,3,i} e^{j2\pi ni/\ell} \quad (8)$$

It is assumed that  $\mathbb{B}_{k,3,i} \in \pm 1 \pm j$ . Since

$$E[|\tilde{b}_{1,n}|^2] = E[|\tilde{b}_{k,3,n}|^2] = 2/\ell \triangleq \sigma_b^2 \quad (9)$$

In other words, preface's average power must be equivalent to input data average power. The received signal for the  $k^{th}$  block can be written as (for  $0 \leq n \leq L + L_c - 2$ ):

$$\tilde{\mathbb{R}}_{k,n} = (\tilde{b}_{k,n} * \tilde{h}_{k,n}) e^{j(\omega_k n + \theta_k)} + \tilde{\mathbb{W}}_{k,n} \quad (10)$$

Where "\*" denotes convolution and based on channel output equation the convolution part in the first term can be written as:

$$\tilde{y}_{k,n} = \tilde{b}_{k,n} * \tilde{h}_{k,n} \quad (11)$$

The received sample set can be denoted as a vector:

$$\tilde{\mathbb{R}}_k = [\tilde{r}_{k,0} \dots \tilde{r}_{k,L+L_c-2}] \quad (12)$$

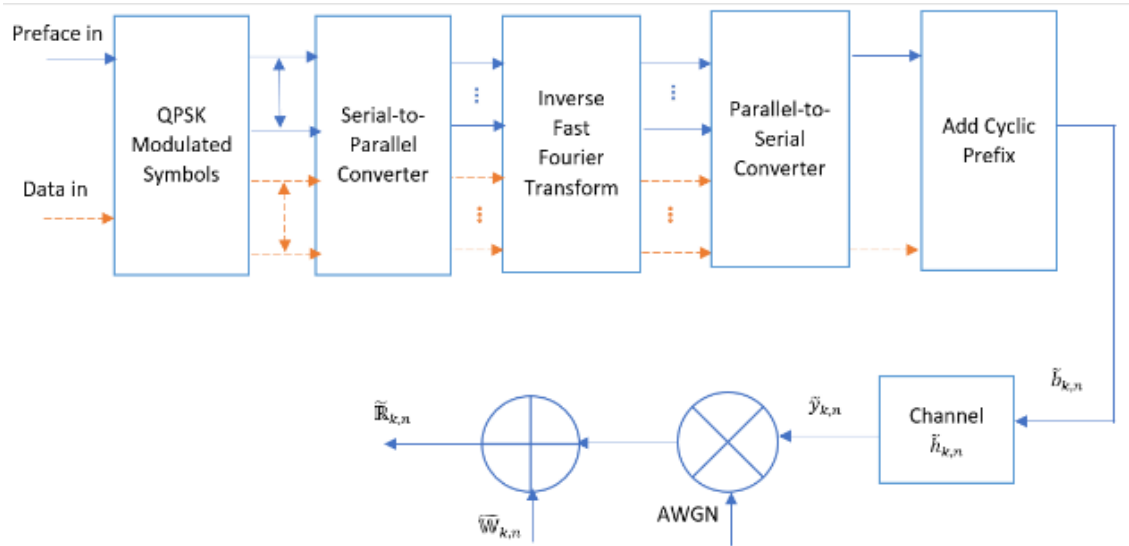


Figure 2. System model of proposed P-ML-CE algorithm

Let us assume that for the  $k^{\text{th}}$  block, there is a known channel impulse response (CIR) at the receiver end. The length of the channel is  $L_r (> L_c)$  such that the first  $L_c$  coefficients are identical to the coefficients of the channel and the remaining  $L_r - L_c$  coefficients are zeros. Define the  $g^{\text{th}}$  received vector as:

$$\tilde{\mathbf{R}}_{k,g} = [\tilde{r}_{k,g} \cdots \tilde{r}_{k,g+L_c}] \quad (13)$$

Where  $0 \leq g \leq L_{cp} + \ell + L_c + L_r - 2$

The steady state part of the preface of the transmitted signal appearing at the output of the channel can be represented by a vector:

$$\tilde{\mathbf{Y}}_{k,1} = [\tilde{y}_{k,L_p-1} \cdots \tilde{y}_{k,L_p-L_r}] \quad (14)$$

Define

$$\mathcal{G}_1 = \mathcal{G}_0 + L_c - 1 \quad (15)$$

The steady-state part of the preface of the received signal for the  $k^{\text{th}}$  block can be written as:

$$\tilde{\mathbf{R}}_{k,\mathcal{G}_1} = \tilde{\mathbf{B}}_1 \tilde{\mathbf{H}}_k + \tilde{\mathbf{W}}_{k,\mathcal{G}_1} \quad (16)$$

Where,

$$\tilde{\mathbf{R}}_{k,\mathcal{G}_1} = [\tilde{r}_{k,\mathcal{G}_1} \cdots \tilde{r}_{k,\mathcal{G}_1+L_p-L_r}]^T$$

$[(L_p - L_r + 1) \times 1]$  vector

$$\tilde{\mathbf{W}}_{k,\mathcal{G}_1} = [\tilde{w}_{k,\mathcal{G}_1} \cdots \tilde{w}_{k,\mathcal{G}_1+L_p-L_r}]^T$$

$[(L_p - L_r + 1) \times 1]$  vector

$$\tilde{\mathbf{H}}_k = [\tilde{h}_{k,0} \cdots \tilde{h}_{k,L_p-1}]^T$$

$[L_p \times 1]$  vector

$$\tilde{\mathbf{B}}_1 = \begin{bmatrix} \tilde{b}_{1,L_p-1} & \cdots & \tilde{b}_{1,0} \\ \vdots & \cdots & \vdots \\ \tilde{b}_{1,L_p-1} & \cdots & \tilde{b}_{1,L_p-L_r} \end{bmatrix}$$

$[(L_p - L_r + 1) \times L_c]$  matrix

where we assumed the channel length as  $L_r (> L_c)$  at the receiver end. Then the OP-ML-CE is as follows: find  $\hat{\tilde{\mathbf{H}}}_k$ , which is an estimate of  $\tilde{\mathbf{H}}_k$  such that the below term is minimized.

$$(\tilde{\mathbf{R}}_{k,\mathcal{G}_1} - \tilde{\mathbf{B}}_1 \hat{\tilde{\mathbf{H}}}_k)^H (\tilde{\mathbf{R}}_{k,\mathcal{G}_1} - \tilde{\mathbf{B}}_1 \hat{\tilde{\mathbf{H}}}_k) \quad (17)$$

Differentiating with respect to  $\hat{\tilde{\mathbf{H}}}_k$  and setting the output to zero yields

$$\hat{\tilde{\mathbf{H}}}_k = (\tilde{\mathbf{B}}_1^H \tilde{\mathbf{B}}_1)^{-1} \tilde{\mathbf{B}}_1^H \tilde{\mathbf{R}}_{k,\mathcal{G}_1} \quad (18)$$

The noise variance can be estimated from the P-ML-CE using eq. (18) is as follows:

$$\hat{\sigma}_w^2 = \frac{1}{2\hat{\epsilon}_1} (\hat{\mathbf{R}}_{k,\hat{\epsilon}_1} - \hat{\mathbf{B}}_1 \hat{\mathbf{H}}_k)^H (\hat{\mathbf{R}}_{k,\hat{\epsilon}_1} - \hat{\mathbf{B}}_1 \hat{\mathbf{H}}_k) \quad (19)$$

#### 4. RESULTS AND DISCUSSION

The results of the proposed P-ML-CE studied using the parameters set in Table 1 below and the mean squared error (MSE) of the channel estimates as compared to the original channels. The work presented in [21], shown that the analysis of both least square (LS) and minimum mean square error (MMSE) channel estimation algorithms. When SNR is 12 dB the LS estimator has a MSE of  $10^{-1}$ , which is higher than that of the MMSE estimator. In addition, the MMSE estimator can achieve the same MSE of  $10^{-1}$  but at lower SNR of 8 dB. Thus, the higher the SNR, the better the MMSE estimator performs in comparison to the LS estimator.

Table 1. Simulation parameters

Symbol	Parameter	Value
$\hat{\epsilon}_k$	Number of blocks	$10^3$
$L$	Length of Channel	10-tap channel
$L_c$	Assumed channel span	10
$L_{cp}$	Length of cyclic prefix	$L_c - 1$
$L_p$	Length of optimal preface	128, 256, 512
$N$	FFT/IFFT size	1024
$SNR$	Signal-to-noise Ratio	0:5:40 dB
$\sigma$	Length of fade of the CIR	0.5 dB

Figure 3 demonstrates that the performance of MSE with the SNR values for the value of  $L_p = 512$ . It shown that obtained results of proposed P-ML based CE algorithm out performs excellent over the conventional CE algorithms presented in [21], [22] and [24]. Algorithm presented in [22] achieved MSE of  $10^{-2}$  at the value of SNR around 20 dB whereas the same has achieved by [24] at a SNR of 22dB. Our proposed model obtained the same at just 12 dB of SNR which shows that the robustness and efficiency of the proposed CE model. Ideally, for any communication system should get better performance at lower SNR region. Our CE model has got an excellent performance at very lower SNR region as compared to the algorithms provided in the literature.

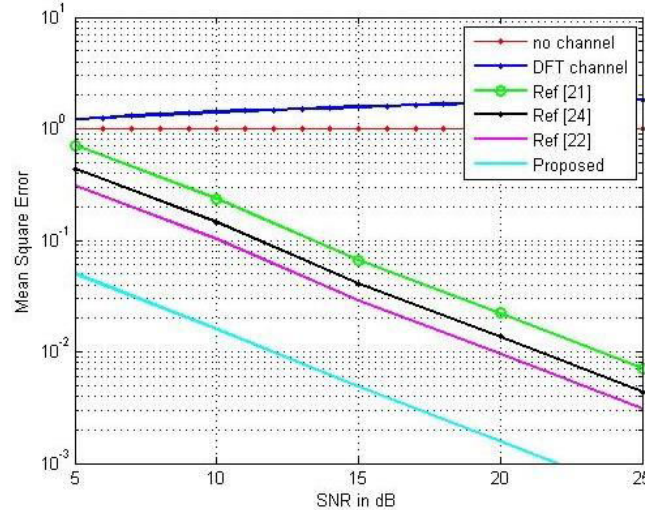


Figure 3. Performance of proposed OP-ML-CE for  $L_p = 512$  with conventional CE algorithms

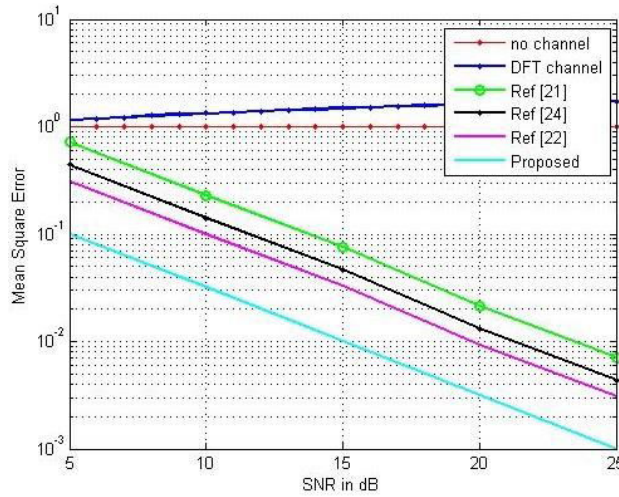


Figure4. Performance of proposed OP-ML-CE for  $L_p = 256$  with conventional CE algorithms

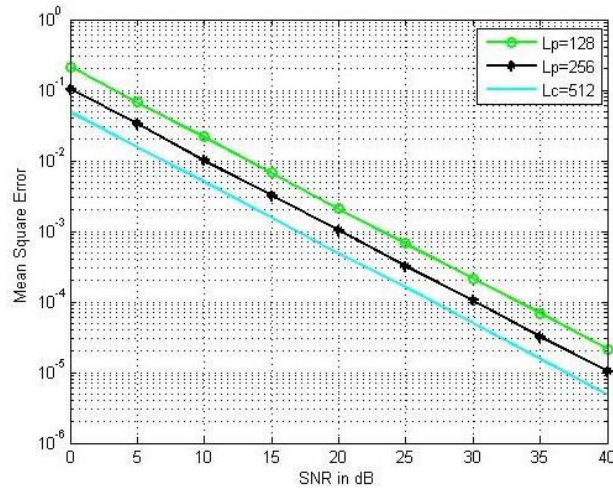


Figure 5. Performance of OP-ML-CE with variable  $L_p$  values

Figure 4 show that the performance of proposed CE model has get reduced when the length of preface got reduced to 256. Achievement of MSE value of  $10^{-2}$  is at around 15 dB of SNR, where the value of SNR got enhanced which indicates that the performance of overall system gets change while changing the value of  $L_p$ . Performance of proposed model with variable  $L_p$  disclosed in figure 5 where the MSE gets reducing while enhancing the value of  $L_p$ .

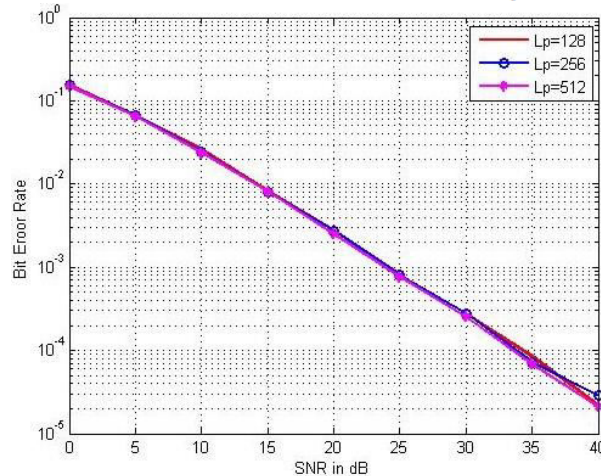


Figure 6. Performance of bit error rate with varying of  $L_p = 128, 256$  and  $512$

Bit error rate performance of proposed CE model demonstrated in figure 6, which show that the BER doesn't depend much on the value of  $L_p$ .

## 5. CONCLUSIONS

In this, a robust and efficient scheme for estimating the channel in OFDM systems over frequency selective Rayleigh fading channels was proposed. Channel estimation has been done by utilizing the optimal preface based maximum likelihood (OP-ML) methodology. Length of optimal preface was a vital parameter while handling the FS channels and quite impressive in enhancing the overall performance. Comparative analysis also provided with various CE algorithms from the literature. Extensive simulation results show that the performance of proposed OP-ML-CE model is quite superior to the conventional CE models.

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