

PERFORMANCE ANALYSIS OF PILOT BASED CHANNEL ESTIMATION TECHNIQUES IN MB OFDM SYSTEMS

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Abstract

Ultra wideband (UWB) communication is mainly used for short range of communication in wireless personal area networks. Orthogonal Frequency Division Multiplexing (OFDM) is being used as a key physical layer technology for Fourth Generation (4G) wireless communication. OFDM based communication gives high spectral efficiency and mitigates Inter-symbol Interference (ISI) in a wireless medium. In this paper the IEEE 802.15.3a based Multiband OFDM (MB OFDM) system is considered. The pilot based channel estimation techniques are considered to analyze the performance of MB OFDM systems over Linear Time Invariant (LTI) Channel models. In this paper, pilot based Least Square (LS) and Least Minimum Mean Square Error (LMMSE) channel estimation technique has been considered for UWB OFDM system. In the proposed method, the estimated Channel Impulse Responses (CIRs) are filtered in the time domain for the consideration of the channel delay spread. Also the performance of proposed system has been analyzed for different modulation techniques for various pilot density patterns.

Keywords:

UWB, OFDM, Least Square, Wireless Channel, Least Minimum Mean Square

1. INTRODUCTION

UWB communications is more suitable for high frequency range of communication over the distance between transmitter and receiver is small. The restriction of transmitter power has motivated the research in UWB communication for short range applications particularly in Sensor networks (SN) and Wireless Personal Area Networks (WPANs). Many GHz bandwidths has been allocated for free communication in which the license is given by the Federal Communication Commission (FCC) in united states. The allocation of the frequency range is from 3.1 GHz to 10.6 GHz with the bandwidth of 20% of center frequency [1].

The principle of OFDM is large bandwidth signals are divided into many number of subcarrier signals. In which, the signals are transmitted parallel for different carrier frequencies. The interference between two symbols is avoided in OFDM transmission by the use of cyclic prefix (CP). It has been recently applied in Wireless Local Area Networks (WLANs) for high data rate communications. UWB OFDM communication was proposed in wireless personal area networks such as IEEE 802.1.3a in the physical layer for wideband communication [2].

In this paper, there are three channel models considered which suits for pedestrian, vehicular, and typical urban propagation scenarios. The channel models are Extended Pedestrian-A (EPA), Extended Vehicular-A (EVA) and Extended Typical Urban (ETU). The detailed explanation for channel models is given in chapter 2.

In this paper, the two major factors are considered for designing the channel estimation in wireless OFDM system. The first factor is the arrangement of pilot information over one OFDM symbol. The pilot signal is trained signal used by the transmitter and it known at the receiver. The second factor is selection of channel estimation with less complexity and the ability of the channel tracking is good. The channel estimation is performed by placing pilot tones into each OFDM symbol.

The channel estimation is mainly classified in to two types. First one is block type pilot arrangement and the second one is comb type pilot arrangement. Least Square (LS) and Least Minimum Mean Square Error (LMMSE) channel estimation techniques comes under block type pilot arrangement. In this type of arrangement is more suitable for slow fading channels. The MMSE estimates Mean Square Error (MSE) and Signal to Noise Ratio (SNR) of channel estimation over LS channel estimation algorithm. For equalizing the effect of fast time varying channel comb type pilot arrangement has been used. In this type of arrangement is used to estimate the channel at pilot frequencies.

The key parameters for UWB channel environments are described by Molisch [3]. Liano et al. [4] has reported the parameters of UWB channel model based on frequency domain approach with lognormal statistics. It is very useful for UWB propagation, leading to the derivation of more accurate channel models in both system design and performance optimization. The analysis of channel estimation algorithms is presented in Saqib Saleem and Qamar-Ul-Islam [5]. In this paper, the performance of LS and LMMSE channel estimation techniques is analyzed for different channel impulse response samples. Neetu Sood et al.[6] has reported on channel estimation of OFDM for Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) modulation techniques.

Keeping the above facts, LS and LMMSE based channel estimation methods are considered in this paper. The estimated channel responses are filtered using time domain low pass filter in which the channel delay spread is assumed as known parameter. The filtered channel coefficients are converted into frequency domain and the interpolation is performed. The interpolation is an important role for channel estimation to mitigate the noise components in wireless medium [7]. The interpolation techniques are classified as, linear interpolation, second order interpolation, low pass interpolation, Spine cubic interpolation and time domain interpolation. The performance of MB OFDM system with LS and MMSE based pilot channel estimation techniques with various interpolation techniques has also been analyzed in this paper and results are given in chapter 4.

2. SYSTEM MODEL AND CHANNEL MODEL

2.1 MB OFDM SYSTEM MODEL

The generalized block diagram of Multiband OFDM (MB OFDM) system is shown in Fig.1. The binary signals are combined in the form of vector and it is applied in to mapper. The function of mapper is performs the modulation operation. The modulated signals are converted from serial to parallel form which is more efficient for high speed data transmission. Pilot positions are selected based on the channel conditions and accordingly pilot bits are inserted with the data bits.

In block-type pilot arrangement, the estimated symbols are transmitted sequentially, in which the pilots are used in all the subcarriers. If there is no variation in the channel, the channel estimation error is zero since the pilots are sent all the carriers but in the comb type pilot arrangement for entire bandwidth the pilot are uniformly inserted [8].

The insertion of pilot signals can be mathematically expressed as,

$$X(k) = X(mL + l) \tag{1}$$

where, $\begin{cases} x_p(m), & l = 0 \\ \text{Data}, & l = 1, \dots, (L-1) \end{cases}$

L is the number of carriers in which the pilot bits are inserted uniformly. $x_p(m)$ is the m^{th} pilot carrier value and $X(k)$ is the frequency domain value at the k^{th} subcarrier of the OFDM symbol. The insertion of pilot tones uniformly to all subcarriers

in the data sequence N . The frequency domain signals are converted in to time domain at the end of IFFT block [9].

The frequency domain value $x(k)$ is transferred into time domain and it can be written as,

$$x(n) = \text{IFFT}\{X(k)\}$$

where, $n = 0, 1, 2, \dots, N-1$

$$x(n) = \sum_{k=0}^{N-1} X(k)e^{j(2\pi kn/N)} \tag{2}$$

where, N is the FFT/IFFT length and $x(n)$ is the time domain value of the sample n . After IFFT block, Cyclic Prefix (CP) is inserted in order to avoid the guard band between the subcarriers. The cyclic prefix depends upon the 10 to 25 percent of original symbol and it is always greater than the delay spread of the channel. The insertion of CP will avoid Inter-Carrier Interference (ICI) by maintaining the orthogonality across all the subcarriers.

The resultant OFDM symbol can be represented as,

$$x_f(n) = \begin{cases} x(N-n), & n = N_{CP}, N_{CP}-1, \dots, 1 \\ x(n), & n = 0, 1, \dots, N-1 \end{cases} \tag{3}$$

where, N_{CP} is the number of cyclic prefix samples inserted in the OFDM symbol. The impulse response of the channel $h(n)$ is convolved with transmitted signal $x(n)$ and it is added with noise signal $w(n)$.

The received signal can be represented as,

$$y(n) = h(n) * x(n) + w(n) \tag{4}$$

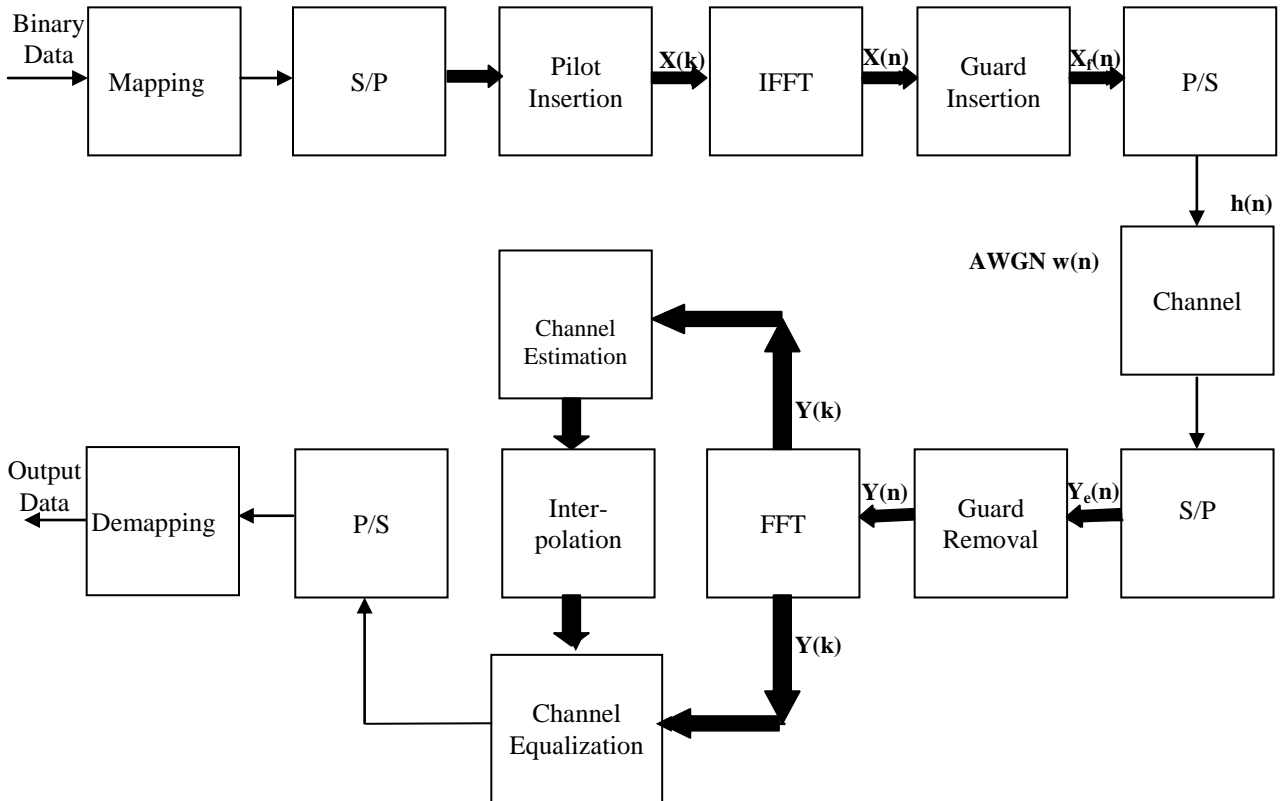


Fig.1. Block Diagram for OFDM System

After IFFT operation the received signal $y(n)$ converted into $Y(k)$ and it can be written as,

$$Y(k) = \text{FFT}\{y(n)\}$$

where, $k = 0, 1, 2, \dots, N-1$

$$Y(k) = \frac{1}{N} \sum_{n=0}^{N-1} y(n) e^{-j(2\pi kn/N)} \quad (5)$$

Assume there is no ISI due to the channel, the resultant signal $Y(k)$ can be related as,

$$Y(k) = X(k)H(k) + I(k) + W(k) \quad (6)$$

where, $k = 0, 1, 2, \dots, N-1$

$H(k)$ is the Frequency Domain (FD) representation of CIR and $I(k)$ is the interference part. The pilot symbols are extracted from the received symbol $Y(k)$ and channel estimation process is performed. $H_e(k)$ is the estimated channel responses which can be defined as,

$$H_e(k) = \frac{Y_p(k)}{X_p(k)} \quad (7)$$

where, $Y_p(k)$ and $X_p(k)$ are the pilot signal values at the transmitter and the receiver. The frequency domain channel responses for the data subcarriers are derived from $H_e(k)$ using interpolation operation. The transmitted data symbols are estimated using the interpolated channel responses and it is finally demapped at the receiver [9]. The received symbols are equalized using interpolated channel responses and given to the modulation de-mapper.

2.2 CHANNEL MODEL

The channel realization with finite impulse response can be mathematically expressed as,

$$h(t) = \sum_{r=0}^{N-1} \alpha_r \delta(t - s\Delta) \quad (8)$$

where, α_r is the path gain, Δ is the multipath resolution and $s\Delta$ is the maximum delay spread. When the input signal is passed through the multipath channel and the received signal can be represented as,

$$r(t) = x(t) * h(t) = \sum_{r=0}^{N-1} \alpha_r x(t - s\Delta) \quad (9)$$

The performance of the channel models has been varied based on the bandwidth in order to reflect the characteristics of the radio channel. The resolution of the channel depends on the bandwidth [10], [11].

The recent wireless standards like Long Term Evolution (LTE) based on the synthesis of existing models such as International Telecommunication Union (ITU) channel models [12],[13]. The coverage of ITU channel models based on the variation of delay spread. The maximum delay spread is varied from in terms of few nano seconds to thousands of nano seconds. In this paper, the wide band models with low, medium and large delay spread channel models has been identified.

In this way, extended wideband models with low, medium, and large delay spread values are identified in this paper. The example of low delay spread is Extended Pedestrian A (EPA)

model which is employed in an urban environment with fairly small cell sizes. The range of the small size cells can be varied up to 2 km in suburban environments with low delay spread [14]. The medium and large delay spreads give an Extended Vehicular A (EVA) model and Extended TU (ETU) model respectively. The r.m.s. delay spread values for the three extended models is represented in Table.1.

The maximum excess delay of ETU channel model is varied up to 5000 ns which is not vary typical in urban environments[15], [16]. The extended channel models are applied with low, medium and high Doppler shifts, namely 5Hz, 70Hz and 300Hz which at a 2.5GHz carrier frequency correspond roughly to mobile velocities of 2, 30 and 130 km/h respectively. The extended channel model can also be applied with low, medium and high doppler shifts. In low, medium and high doppler shifts frequency range is 5Hz, 70Hz and 300Hz respectively which is at 2.5GHz carrier frequency.

Table.1. ITU channel conditions for Propagation in multipath fading

Tap Number	ITU pedestrian A		ITU pedestrian A		ITU Vehicular A	
	Relative delay (ns)	Relative mean power (dB)	Relative delay (ns)	Relative mean power (dB)	Relative delay (ns)	Relative mean power (dB)
1	0	0	0	0	0	0
2	110	-9.7	200	-0.9	310	-1.0
3	190	-19.2	800	-4.9	710	-9.0
4	410	-22.8	1200	-8.0	1000	-10.0
5	-	-	2300	-7.8	1730	-15.0
6	-	-	3700	-23.9	2510	-20.0

3. CHANNEL ESTIMATION IN OFDM SYSTEM

The block type pilot based channel estimation is shown in Fig.2. In block type channel estimation, is more suitable for slow fading channel. The concept of block type pilot arrangement is inserting pilot tones into all subcarriers of OFDM symbol.

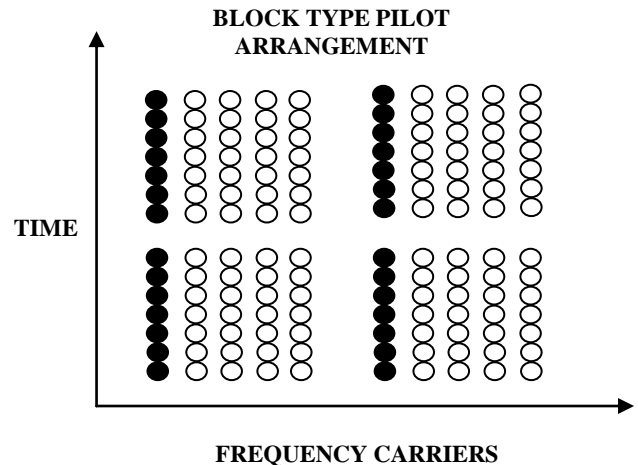


Fig.2. Block Type Pilot Arrangement

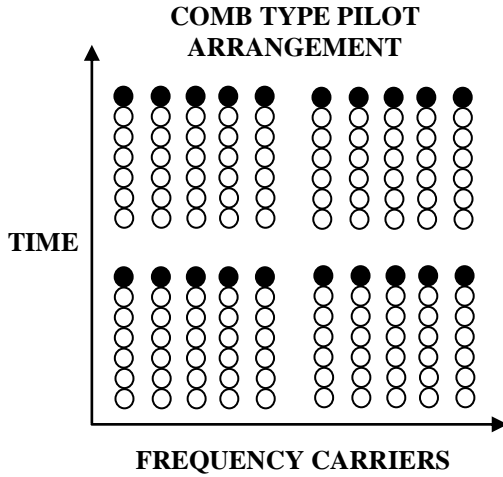


Fig.3. Comb Type Pilot Arrangement

The comb type pilot based channel estimation is shown in Fig.3. In comb-type pilot channel estimation, is mainly used for equalizing the channel from one OFDM block to the subsequent one. The concept of comb type pilot arrangement is inserting pilot tones into particular subcarriers of each OFDM symbol. The interpolation is needed to estimate the conditions of the other data subcarriers. In this paper, block type channel estimation technique is considered. The LS and MMSE based channel estimation methods are considered.

3.1 LEAST SQUARE CHANNEL ESTIMATION

The LS estimation method is the simplest and computationally least complex method of obtaining the channel estimates. Since the transmit as well as the received data are known at the reference signal locations, the LS channel estimates at those locations are given by,

$$H_e(k) = \frac{Y_p(k)}{X_p(k)} \quad (10)$$

$$H_e(k) = H_p(k) + \frac{V_p(k)}{X_p(k)} \quad (11)$$

The variance of $H_e(k)$ depends on the variance of $\frac{V_p(k)}{X_p(k)}$.

Both the variances are same in case of BPSK modulation. The LS method is computationally cheap but it has higher estimation Mean Squared Error (MSE).

3.2 MMSE CHANNEL ESTIMATION

The standard alternative to the Least Squares (LS) method is the Minimum Mean Squared Error (MMSE) method for obtaining the channel estimates. The MMSE method also considers the channel statistics as well as the noise statistics for obtaining the estimates which results in an improved channel estimate. The estimation of channel frequency response as per wiener filter equation is,

$$R_{HH} = E\{\bar{H}\bar{H}^H\} = E\left\{\left(F_{\bar{g}}\right)\left(F_{\bar{g}}\right)^H\right\} = FR_{gg}F^H \quad (12)$$

where, \bar{g} is the vector consists of time domain channel coefficients. \bar{H} is the vector consists of frequency domain channel coefficients.

$$\bar{H} = FFT(\bar{g})$$

$$R_{gy} = E\{\bar{g}\bar{Y}^H\} = E\left\{\bar{g}\left(XF_{\bar{g}} + \bar{N}\right)^H\right\} = R_{gg}F^H X^H \quad (13)$$

$$R_{YY} = E\{\bar{Y}\bar{Y}^H\} = XFR_{gg}F^H X^H + \sigma_N^2 I_N \quad (14)$$

where, R_{gg} , R_{HH} and R_{YY} is the auto covariance matrix of \bar{g} , \bar{H} and \bar{Y} respectively. R_{gy} is the cross covariance matrix between \bar{g} and \bar{Y} respectively. σ_N^2 is the noise variance of white gaussian noise.

The channel vector \bar{g} and the noise \bar{N} are uncorrelated and R_{gg} and σ_N^2 are known at the receiver in advance, the MMSE estimator of \bar{g} is given by,

$$\hat{h}_{MMSE} = R_{gy}R_{yy}^{-1}y^{HH} \quad (15)$$

The mean square value of linear estimator is given by,

$$\begin{aligned} \hat{H}_{MMSE} &= Fh_{MMSE} = F[(F^H X^H)^{-1}R_{gg}^{-1}\sigma_N^2 + XF]^{-1}\bar{Y} \\ &= FR_{gg}[(F^H X^H XF)^{-1}\sigma_N^2 + R_{gg}]^{-1}F^{-1}\hat{H}_{LS} \\ &= R_{HH}[R_{HH} + \sigma_N^2(XX^H)^{-1}]^{-1}\hat{H}_{LS} \end{aligned} \quad (16)$$

In low Signal to Noise Ratio (SNR) levels, the MMSE gives better performance compared with LS channel estimation technique. The complexity is very high in MMSE estimator incase of matrix inversions are needed each time when the input changes. In time domain windowing approach, the estimated channel responses H_{LS} are converted into time domain and multiply with a window. The length of the window is equal to the delay spread of the channel and it is also expressed as,

$$H_{\text{modified}} = H_{LS} \times w \quad (17)$$

where, w is the time domain filter and $w = [(\text{ones}(1, \text{length}(\text{delay spread})) \text{ zeros}(\text{No. of pilots} - \text{length}(\text{delay spread})))$. The modified channel estimates are given to input to the MMSE module.

4. RESULTS AND DISCUSSIONS

Table.2 presents the system parameters are considered for simulations. In this paper the perfect synchronization has been assumed for estimating the channel performance.

Table.2 Selected simulation parameters

Parameter	Value
Modulation	BPSK/QPSK/QAM
FFT Size	1024
Cyclic Prefix (CP) Length	1/16
Signal to Noise Ratio (SNR)	0 to 50 dB
Pilot Density	1:1/1:3/1:7
Velocity (Km/Hr)	700
Carrier Frequency	1 GHz
Interpolation	Linear/pchip/spline
Channel Estimation	LS/LMMSE

The performance analysis of MB OFDM systems over Additive White Gaussian Noise channel for different phase shift keying techniques is shown in Fig.4. It shows that, the performance of the 64 PSK is 5 to 10 dB better compared with 32 PSK.

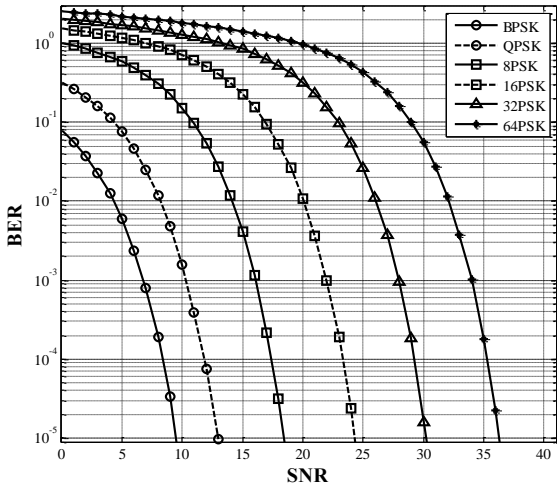


Fig.4. BER Performance analysis for different PSK modulation techniques

The performance of BER for EPA,EVA and ETU channel models is shown in Fig.5. It can be seen that, for EPA channel model the BER is low compared with EVA and ETU channel models. This is because there is a variation in the channel delay spread.

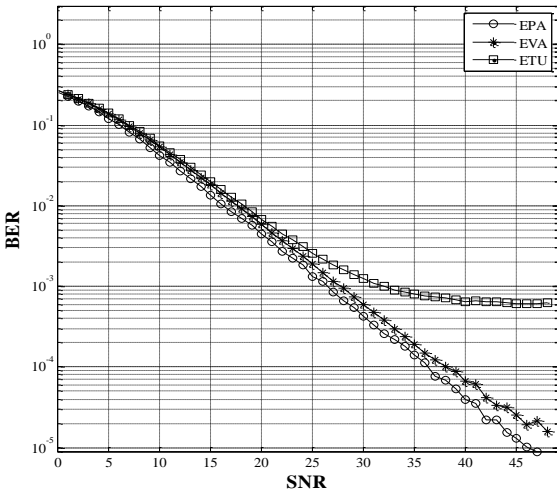


Fig.5. BER performance of EPA, EVA and ETU channel models

The Bit Error Rate(BER) performance has been analyzed for different pilot density patterns is shown in Fig.6. The pilot density patterns which are considered are 1:1,1:3 and 1:7. 1:1 means, for each data subcarriers there will be one pilot. In Fig.6, the performance of the system improves where there is high number of pilot for the cost of less throughput efficiency.

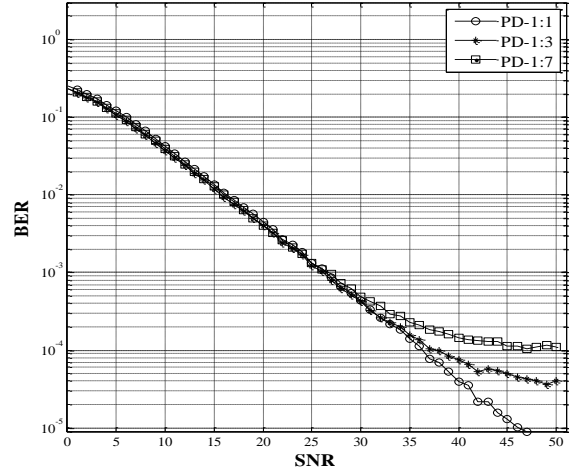


Fig.6. BER performance of different pilot density patterns channel

The performance of various interpolation techniques based on bit error rate is shown in Fig.7. The figure portrays that p chip interpolation gives the better performance compared with linear and spline interpolation techniques.

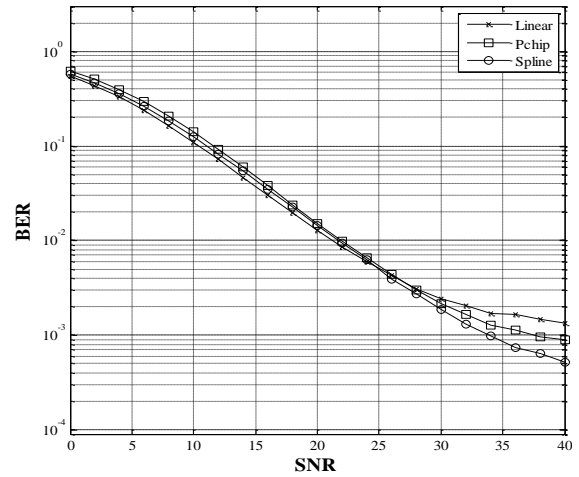


Fig.7. BER performance of various interpolation techniques

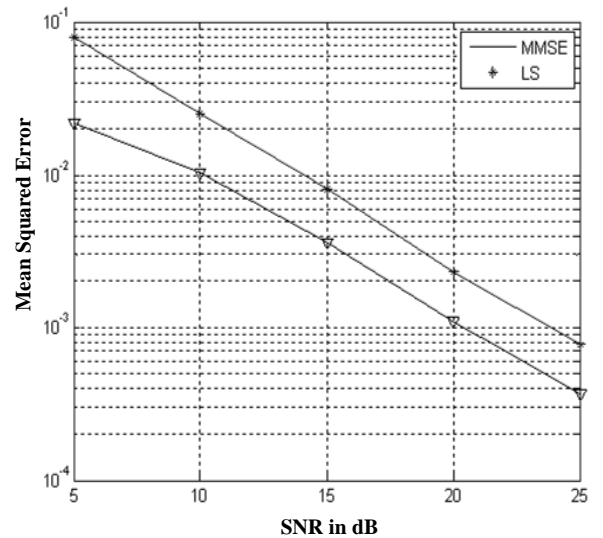


Fig.8. MSE analysis of LS and MMSE algorithms

The performance of LS and MMSE channel estimation techniques based on mean square error is shown in Fig.8. The figure portrays that, based on the mean square error MMSE gives the better performance compared with LS estimation technique.

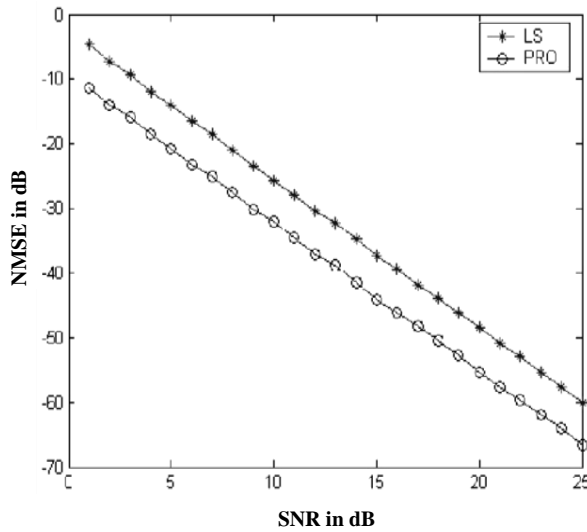


Fig.9. Performance comparison of channel estimation schemes between LS and proposed methods

Fig.9 shows comparison of the predicted channel coefficients using LS method and filtered method in terms the normalized mean square error. It portrays that NMSE of the filtered one gives 5dB better performance than the LS method.

5. CONCLUSION

In this paper, some of the major issues for design of multicarrier UWB communications have been analyzed. The LS and MMSE based channel estimation algorithm has been analyzed in MB OFDM system by considering EPA, EVA and ETU channel models with different interpolation techniques. It has been observed from the simulation results that the MB OFDM system provides considerable results for vehicular and pedestrian channel models. This work can be extended by considering various capacity enhancement techniques in the OFDM system.

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