Slope Intercept Model Estimation for MIMO–OFDM system in the WiMAX Environment

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Abstract: **-** Channel fading in complex as well as in erratic manner, a rare spectrum of radio type, restrictions on the energy and the dimensions of mobile nodes are the prime restraints in communications of wireless type. Centred on these limitations novel schemes are put forth. Worldwide Interoperability for Microwave Access (WiMAX) is a promising domain to pursue work for wireless communication of broadband type, amidst a variety of emerging schemes. The scheme of WiMAX is a consistent method among IEEE 802.16d and among the principal of the WiMAX schemes, one can name Orthogonal Frequency Division Multiplexing (OFDM) as the core. A model of practical channel is needed to analyse the WiMAX method's performances. Inclusive of Stanford University Interim (SUI) channel also known as slope intercept model, several models of channel are suggested to replicate the global situation. Lime light shone on this scheme prompting many a researchers to pursue in the recent past. Employing a variety of SUI models of channel, this paper analyses the performances in the context of Normalized Means Square Error (NMSE) of IEEE 802.16d. By analysing performance of different algorithms, proficient channel estimation scheme is arrived.

Key Terms: --MWA, MIMO-OFDM, SUI, Channel Estimation, NMSE

1 Introduction

The domain of Broadband Wireless Access (BWA) Networks, of late had seen rampant strides, in place of Digital Subscriber Line (DSL) and cable modem schemes. Undivided attention is gathered by BWA as a substitute in the latest scheme. Being wireless by nature it is quick to organise, handy to scale up and more supple. Clients who are unhappy with wired broadband schemes can be provided with this scheme.

Interference due to adjacent channel, fading in multipath and delay spread are the restricting factors affecting the functioning of BWA. The first version of the IEEE 802.16 standard (Fixed Broadband wireless access) comes into operation in 10–66 GHz frequency range and needs a communication of Line-of-Sight (LOS) type. The later standard stretched its operation through various physical layer specifications to 2-11 GHz spectrum ranged permitting a Non Line-of-Sight (NLOS) communication. The performance impairments caused by the fading due to multipath signal propagation is overcome by this later version [1]. Larger rates of data transmission, better flexibility, average throughput as well as good system capacity are provided by WiMAX. Capacity to offer capable support to the additional symmetric links that is beneficial to applications that are fixed in nature, to quote an example T1 replacement; this is one more benefit of WiMAX. The ratios of data rates of downlink-to-uplink can be flexibly as well as dynamically adjusted. Clients who use wireless gadgets and operators are assured many benefits by WiMAX. The operators are provided with an opportunity of global service by allotting spectrum in bands which are licensed/ unlicensed. In situations when heavy traffic is present temporarily, one can think of WiMAX which aptly serve; it can even cater to the need of local areas as well. In places where the existence of a cable infrastructure is not there, like developing as well as under-developed countries WiMAX is a very beneficial one. WiMAX BSs will offer clients access to the broadband, thus avoiding the work of cable laying throughout the nation. WiMAX is going to be much more popular technology in the immediate future as far as services in wireless domain for the clients using wireless and also to the wireless operators.

IEEE 802.16 (2004) is stretched and gives definition for Mobile WiMAX standard-IEEE 802.16e. The important technologies namely, Orthogonal Frequency Division Multiplexing (OFDM) as well as Multiple Input Multiple Output (MIMO) are adopted in WiMAX standard of mobile domain [2]. Transmission of data at high rate over multiple numbers of path as well as frequency selective fading channels is provided by this version.

In an ambience of hostile wireless channel, the PHY layer is enabled to offer a broadband service which is of robust kind, by making use of benefits of OFDM technique [3]. In wireless communication, primary restrictions on performance are posed by the radio channel of mobile domain. One of the toughest portions in designed mobile radio system proved by history is the radio channel modelling. A precise feature of the wireless channel is essentially required for assessment of a scheme in applications of BWA. For naming the channel's impulse response an apt model is arrived in this work. For aptly detecting signals that are transmitted, an accurate estimation of MIMO channel as well as equalization of MIMO are needed at the MIMO-OFDM system's receiver end. But for executing of MIMO-OFDM signals' coherent detection, it is tedious to obtain precise channel state information (CSI). Employing of different equalizing methods of MIMO, enables detections of the signals transmitted by entire antennae, provided at the receiver end the CSI is available. During the immediate past capably designing MIMO equalizing methods are given due importance [4-6]. Different MIMO OFDM channel estimation algorithms are analysed and Normalized Mean Square Error (NMSE) is used to measure its performance.

2. System Model

Initially, random data input is mapped into symbols with appropriate modulation technique, supported by WiMAX standard. MIMO is used to increase spectral efficiency of the system considered. To compensate loss in signal strength due to fading and thermal noise at the receiver, space time coding techniques like space time block code (STBC), space frequency block code(SFBC) etc., are used. It involves the transmission of multiple redundant replicas of data. Since space time block codes achieve superior performance in combination with OFDM, mapped symbols are encoded spatially using STBC [7-8]. To form parallel data of a number of sub channels, they are transformed from serial to parallel type. Sequences of symbols which are complex valued are obtained by converting the group of binary bits, at the stage of symbol mapping. The stipulations define the mandatory constellations are QPSK as well as 16 QAM, while 64 QAM is an optional constellation. If not for others, at least in the case of downlink, WiMAX systems mostly implement 64 QAM, even though it is an optional one. As far as subcarriers are concerned, there are three classifications in Mobile WiMAX [2]. The information of data symbols are contained in data subcarriers N_u. In the same way, at the side of both transmitter as well as receiver, pilot subcarriers N_g are used to know information in prior. To adjust the total bin size N, null subcarriers are employed where energy is not provided. Hence, to every parallel sub channel containing N_u data subcarriers, along with N_g pilots subcarriers are being added. After that arrangement is made adding another set of null carriers so that the total subcarriers are in the form of N point FFT. Later IFFT block are fed symbol by symbol, so that time domain signal transformations can take place as indicated in the following equation.

$$d(n) = \sum_{-\frac{N_{used}}{2}}^{\frac{N_{used}}{2}} D(K) e^{\frac{j2nk}{N_{FFT}}}, 0 \le n \le N-1,$$

$$where\ k \neq 0 \qquad (1)$$

Here d(n) stands for the data symbol transmitted at the OFDM 's k^{th} subcarrier, N_{used} denotes the count of subcarriers which are non-suppressed. After this process through the wireless channel, the signal is transmitted. To define the channel's impulse response SUI model is employed, that is being upheld by WiMAX forum. Figure 1 depicts the system model. IEEE 802.16e-2005 OFDM symbol frequency domain description which defines the typical N point FFT containing every subcarrier is presented in Figure 2 [9].

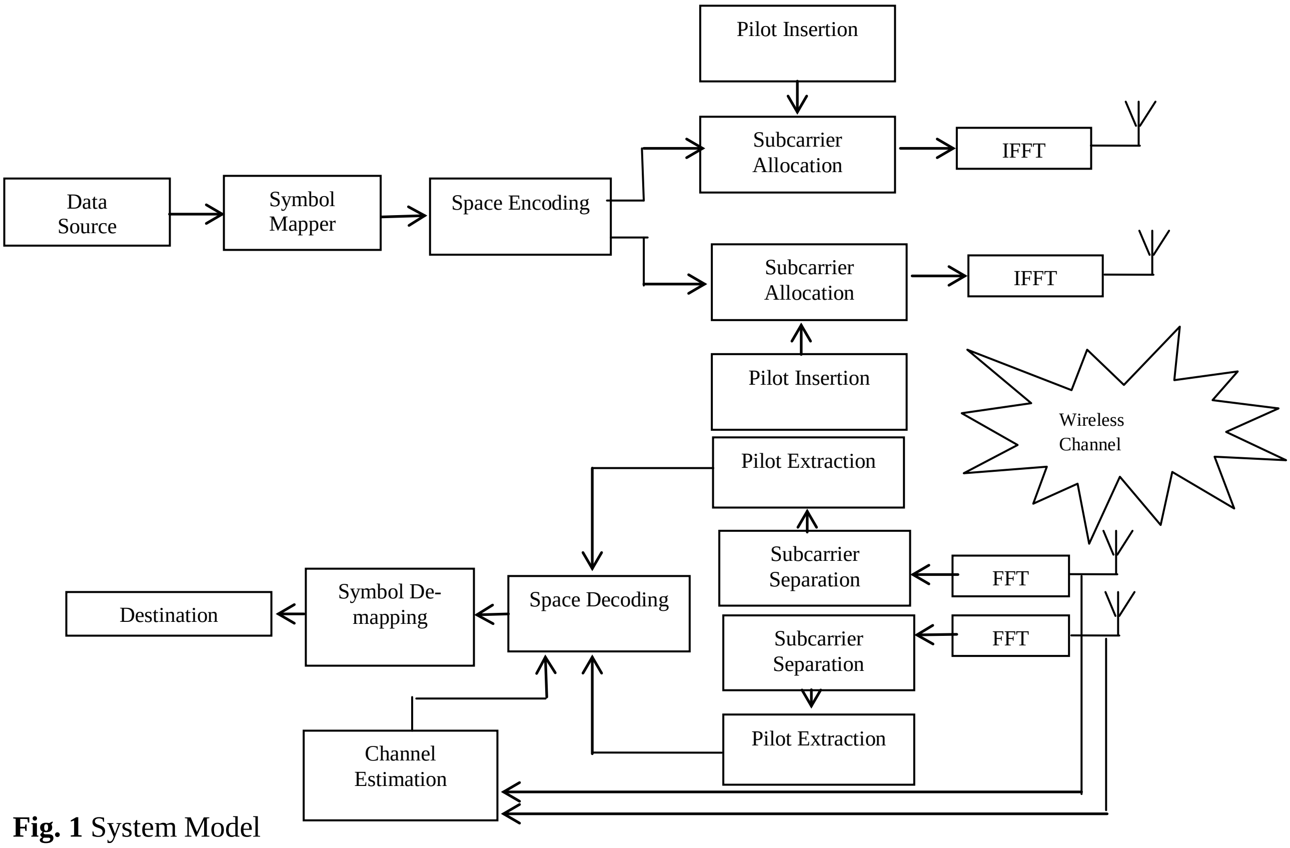


Fig. 1 System Model

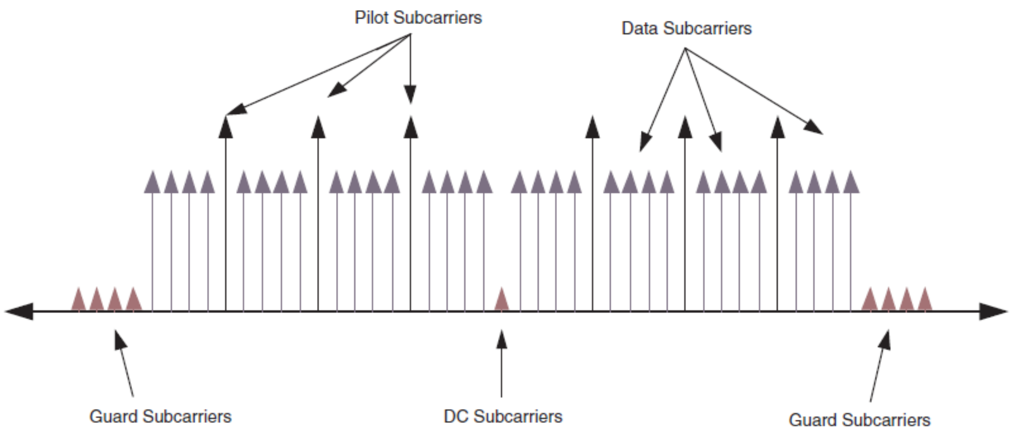


Fig. 2 Frequency domain description of OFDM symbol

The impulse response is completely lying inside the guard time interval is the assumption here. The channel noise affected signal is collected at the receiver. After removing cyclic prefix, reduced baseband model samples r(n) are received and it is given as,

$$r(n) = \sum_{l=0}^{L-1} d(n-l)h(l) + w(n) \tag{2}$$

L denotes the count of channel taps, *w*(*n*) stands for the additive white Gaussian noise (AWGN) sample with zero mean and variance of σ^2 and *h*(*l*) stands for the instantaneous OFDM symbol's time domain channel's impulse response (CIR). Ideal time and frequency synchronization is the assumption here. After receiving the signal, FFT is applied. Then, the expression for samples in frequency domain is,

$$R(K) = D(k)H(k) + W(k) \tag{3}$$

The estimation of pilot response is done with the assistance of efficient channel estimation. This is utilized for data subcarriers estimation. The original information is recovered after decoding as well as demodulating.

3. Propagation Models

The characteristics of the propagation environment are effectively captured by the aid of modelling of an accurate channel. The channel of mobile radio domain has certain basic shortcomings. When it is applied in wireless communication schemes, it can cause certain disturbances. The most difficult part in the design of mobile radio system is the radio channel modelling especially in MIMO techniques [10]. For utilising services in Broadband Wireless domain, precise description of the wireless channel is a vital need for arriving at a suitable technology. The radio architecture is the one, which is much relied upon by most of the models of channels. Fading, Delay Spread in Multipath, Losses in Path (inclusive of shadowing), Spread due to Doppler Effect, Interference from Co-channel as well as adjacent channel are the characteristics associated with the wireless channel [11]. Currently, much pursuit in research area is in the models of Path loss propagation. Path loss arises, whenever EM wave transmission through space arrives at the receiver from transmitter. Reflection, distance of the path, diffraction, loss in free space, scattering, as well as absorption by the neighbouring terrain, trees and buildings cause attenuation in the signal. The influence of ambience affects the signal transmission to a large extent whether it is City/Town/ Village. The constraints fading due to shadowing effect, azimuth spread, loss in path, delay spread alone vary, while the modelling as well as methodology applied in simulation process remain unchanged for the entire region [12].

Deterministic, stochastic and Empirical models are the three divisions usually employed for studying these losses. For determining the losses of path during propagation, deterministic models are very apt compared to the other two models. The probability density function determination enables analysing of probability in the stochastic model. While in the case of empirical method, several output measurements are gathered and made available to provide field measured data input. This procedure yields very precise outcomes. The practical parameters are affecting the average value of power. This is shown by the above method; this is the basic benefit. But, in this type of model complexities in computation is the primary shortcoming. They are not stretchable to an extensive parameter range. This is the prominent disadvantage.

Ultimately, for computing the radio channel behaviour in an almost precise way, combination of statistical along with deterministic schemes will be a better option. Compared to the deterministic models, charge of processing is at a affordable rate. Flexibility is greater compared to the empirical counterparts. Currently to suit different ambiance, COST 231 topology, Stanford University Interim (SUI) model, WINNER models and such other channel models are developed. One of the best models developed for WIMAX is the Stanford University Interim (SUI) model due to its salient features [13]. Based on the striking features of SUI model, for pioneering work in studying the behaviour of fading effect in wireless link, SUI models are chosen.

Topography, dense trees, height of antennae, width of beam, that year's season as well as speed of wind , are the strategic factors of SUI model. Moderate to heavy tree density contained in hilly topography is classified as category A; the loss of the path is large here; sparse tree density found in flat terrain is categorised as C; here losses in path is small. While either a hilly terrain with a few number of trees or flat terrain with a thick cluster of trees will be categorized as B; as far as losses in path is concerned it is intermediate. To arrive at such a channel depiction, many combinations of parameters are possible. The terrain category is the key factor in deciding the levels of various predefined threshold values, influencing the performance of the system. Apart from this, some factors such as beam-forming, height antennae and frequency effect due to Doppler Effect can influence the performance of the system, while the category of terrain remains the same.

Basic equation for losses of path containing factors of correction, for the slope intercept model i.e SUI model is presented in [14].

$$PL = a + 10\gamma\, log_{10}\left(\frac{d}{d_0}\right) + X_f + X_h + s \; for \; d > d_0 \tag{4}$$

Here, d is the spacing from BS to antenna at receiving end in meter; d_0 is 100 meters; λ represents wavelength in meter; $\boldsymbol{X_f}$ denotes frequency correction greater than two gigahertz; $\boldsymbol{X_h}$ is the height correction factor for antennae at receiving end; s represents shadow correction factor in decibels; γ is the exponent for losses of path [11].

Parameter A is defined as:

$$A = 20\ log_{10}\langle 4\pi d_0 f | C\rangle \tag{5}$$

Next the loss in path exponent γ is denoted as follows:

$$\gamma = a - bh_b + \left(\frac{c}{h_b}\right) \tag{6}$$

Here, h_b stands for the height of antenna at the BS in the range of 10 to 80 meters. The nature of terrain decides the values of a, b and c. In a city area for propagation in free space the numerical value of $\gamma = 2$, $3 < \gamma < 5$ for urban NLOS ambience; $\gamma > 5$ for propagation inside a confined area. In the case of A type terrain, $X_f = 6.0\ log_{10}\ (f/2000)$; *while for B type*, $X_h = -10.8\ log_{10}\ (h_r/2000)$ *and for C category* $X_h = -20.0 log_{10}\ (h_r/20000)$. Here the frequency of operation, f expressed in megahertz; the height of antenna at the receiving end is h_r .For the categories of different terrains (city/ town/ village) ambience, this model is widely employed for the estimation of losses in path making use of the above specification. For MIMO setup description, the SUI channel's generic structure is depicted in figure 3.

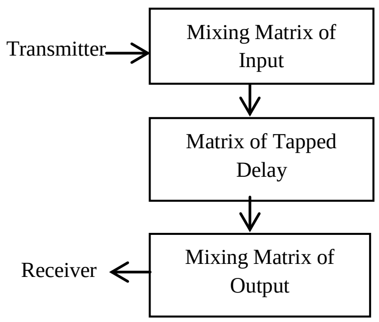


Fig.3 Slope intercept model Generic Structure for MIMO

While employing multiple antennae for transmission and reception, matrices of Input and Output respectively will be generated, for defining correlation among signals of corresponding input and output. While for multipath fading, matrix of tapped delay line is employed. A tapped – delay link with three taps containing non uniform delays is made use of, to assess the fading in multipath propagation. The maximum value of Doppler frequency and distribution both together decide the gain attached to each tap.

4. Channel Estimation

The capability to uphold a greater mobility is a typical vital feature of communication structures in wireless domain for the days to come. But, algorithms in estimating impulse response of the channel are facing a challenge in high mobility environment. Spectrum efficiency and fading in multipath channel are the two difficult issues posed to researchers. Either CE which employs Training sequences or blind CE (where such training sequences are not employed), can be done for estimating the response of the Channel. Since blind estimator lacks overhead in training, speed of convergence and precision in estimating process, both of them are noticeably traded off. However, it yields high spectrum efficiency. WiMAX stipulations, uphold channel estimation algorithm which utilizes training sequences since it is dependable and well established [9]. Estimation of Channel Impulse response algorithms plays a key aspect in Mobile Wireless Access (MWA) architecture. Downlink Partially Used Sub channelization Orthogonal Frequency Division Multiple Access (DL-PUSC OFDMA) utilizes data pilot centred estimation technique. With the aid of the training sequences which are transmitted with data, the methods employed for estimation are namely, least squares (LS), transform domain as well as minimum mean-square error (MMSE). For practical WiMAX systems, it is vital to have specific algorithm for pilots present in WiMAX, even though many estimation techniques are presently available.

Available transmitted pilot's inverse is multiplied by the received pilot, in simple channel estimating circumstances. The above method is labelled as LS estimator [14]. The LS does not require any channel statistics. However they are affected by large mean square error. The scaled LS (SLS) estimator is arrived at, by improving LS estimator. But, in advance it needs the ratio of trace of channel correlation matrix and noise power at receiver end. To reduce the MSE, the MMSE estimator makes use of the channel's second order statistics [15].

To strike a balance between computational complexity and system capability, power delay profile (PDP) with uniform value is employed in MMSE technique [14]. But with the observation sample, its complexity of computational process raises in an exponential manner. A novel method namely linear MMSE (LMMSE) comes for rescue to overcome that. Initially, subcarrier of pilot's channel response is measured by LS or LMMSE. Later on, this information enables detection of data subcarrier with the help of the process of interpolation. It gives better performance at small SNR than in the case of LS at the cost of increase in complexity.

The MMSE channel estimate in the frequency domain is,

$$\hat{H} = AR$$

(7)

H,R represents the point Discrete Fourier Transform of CIR and the signal received on every subcarrier output, and the matrix $\boldsymbol{A}$ is calculated as,

$$A = R_H(R_H + \sigma^2(D^*D)^{-1})^{-1}\, D^{-1} \tag{8}$$

R_H indicates the covariance matrix of the channel with a variance of σ^2. When noise is ignored, that is σ^2 is set to zero, both LS as well as MMSE estimator are one and the same. Need of covariance matrix of the channel in time as well as frequency domains are the disadvantage of traditional LMMSE estimation.

However at the receiver, channel's covariance matrix is not known in advance. Based on earlier information on estimates of channel, it also essentials to be predicted. For reckoning as well as tracking the channel covariance matrix is difficult in applications of mobile communication, because of rapid changes in characteristics of the channel. In this ambience, only faction of the channel's covariance matrix is likely to be available. For instance, computation of restraints on the covariance matrix of the real channel is feasible, when only the channel's maximum delay in addition to the Doppler spread are available. Full channel covariance information is required in traditional LMMSE algorithm. However, remarkable performance improvement is observed in modified LMMSE with merely fractional information. Trace of the wireless channel correlations matrix as well as the noise power at the receiver end is sufficient in relaxed MMSE (RMMSE) algorithm. This is simplified and imprecise version of the linear MMSE [3].

Error of channel estimation in RMMSE is compared with LS under orthogonal training vector with the constraint for transmit power (T) and given as [3],

$$\frac{E_{RMMSE}}{E_{LS}} = \frac{tr\{R_H\}\mathrm{T}}{tr\{R_H\}\mathrm{T} + \sigma^2 N_t {N_r}^2} \tag{9}$$

A lesser amount of estimation error is expected in RMMSE compared to LS when $\sigma^2 > 0$. At low SNR, this error performance improvement is more prominent.

5. Simulation Outcomes and Discussion

System is simulated in Matlab environment with the parameters given in Table 1 and 2 under different SUI channel models. The performance of various channel estimation algorithm like LS, SLS, MMSE, and RMMSE are analysed as well as compared. Results are verified in two different terrains A and C.

Table 1: MIMO OFDM Simulation Parameters

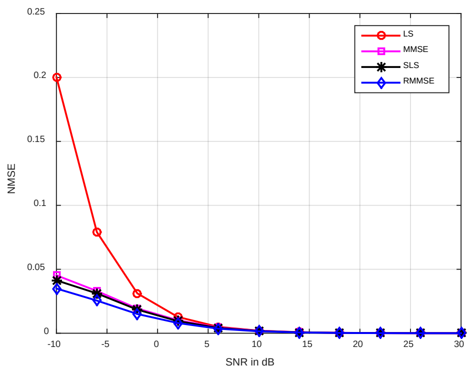
Parameter	**Specification**
Input symbol rate	1 Mbps
Number of Tx and Rx antennas	2×2 and 4×4
Number of OFDM subcarriers	1024
Number of OFDM frames	1024
Space Encoding	STBC

Table 2 Channel Parameters

Parameter	**Channel Specification**	
	SUI – 1	**SUI – 5**
Number of paths	3	3
Path delay in µsec	0, 0.4, 0.9	0, 4, 10
Path gain in dB	0, -15 ,-20	0,-5, -10
Max Doppler Shift (for all path)	0.5 Hz	2.5 Hz
Ricean Factor	2	2

Normalized mean square error of the LS, SLS, MMSE, and RMMSE channel estimators are measured and compared for various value of signal to noise ratio and shown in figure 4 and 5. From the result it is verified that the MMSE outperforms the LS as well as SLS algorithms. Also it is observed that the LS performance is worst compared to all other methods discussed.

Both SLS and RMMSE techniques error performance are same if and only if orthogonal training is used as expected from theory. Error performance is best in MMSE compared to other estimators tested. However it requires channel information well in advance.



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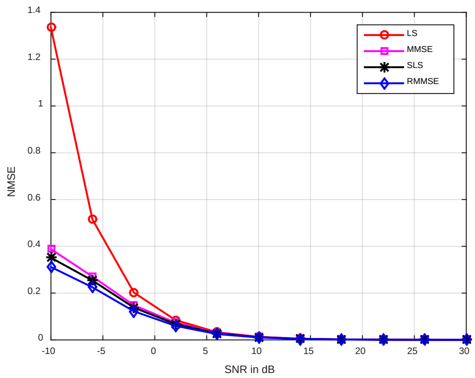
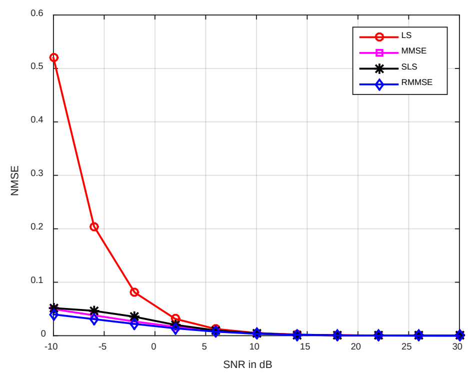


(b)

Fig. 4 SUI-1 Channel estimation in LS, SLS, MMSE and RMMSE estimators with (a) N_t=N_r=2 (b) N_t=N_r=4



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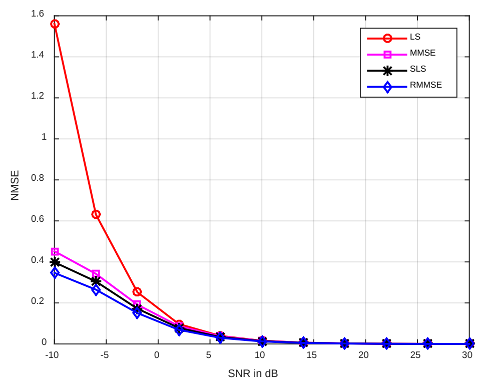
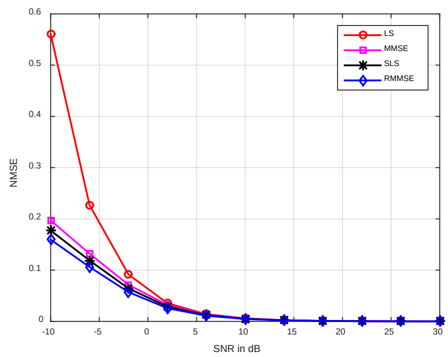


(b)

Fig. 5 SUI-5 Channel estimation in LS, SLS, MMSE and RMMSE estimators with (a) N_t=N_r=2 (b) N_t=N_r=4

Figure 6 shows that, in a highly correlated channel, MMSE performance is strikingly decreased, with the usage of the orthogonal probing. However, when the number of antenna at the transmitter end is large as well as with low SNR this effect becomes more prominent.



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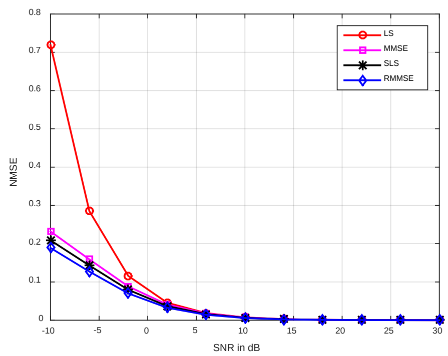

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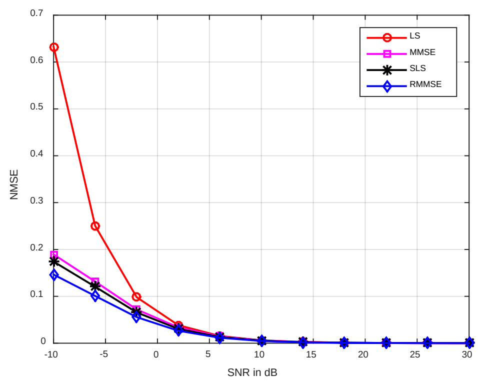

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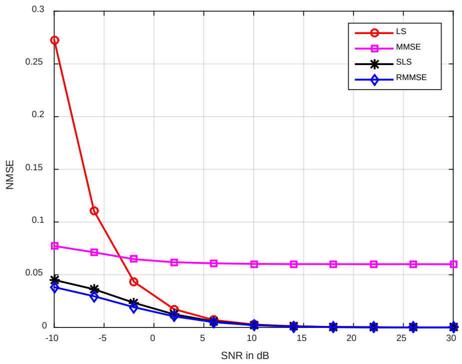
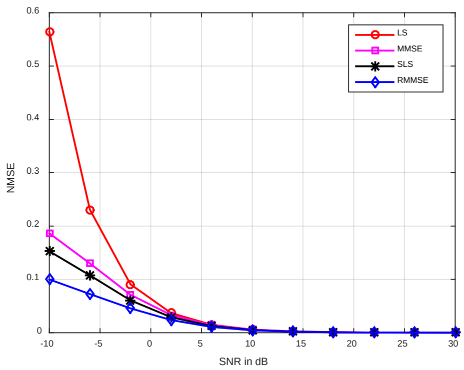


(d)

Figure 6 SUI-1Channel estimation in LS, SLS, MMSE and RMMSE estimators with (a) N_t=N_r=2 & k=0.2 (b) N_t=N_r=2 & k=0.4 (c) N_t=N_r=2 & k=0.5 (d) N_t=N_r=4 & k=0.7

SUI-1 and SUI-5 channel estimation for various values of correlation factors are given below in Figure 7 and 8. The Results verifies that when correlation factor increases, the performance of the estimators also improves



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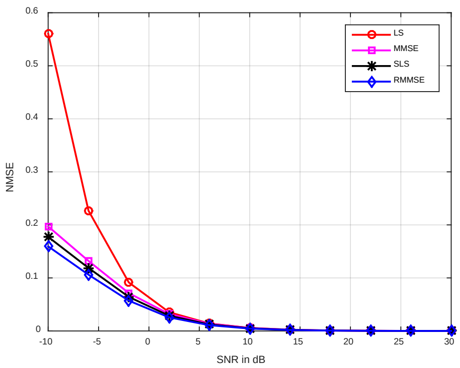
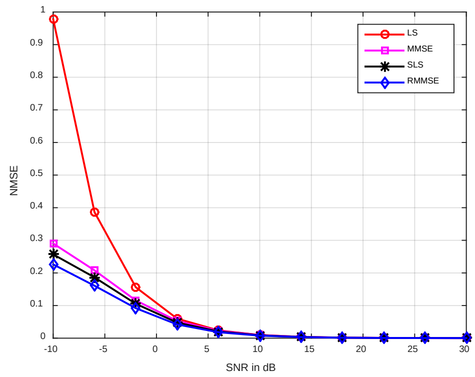


(b)

Figure 7 SUI-1 model with (a) N_t=N_r=2; k=0.7 (b) N_t=N_r=2; k=0.2



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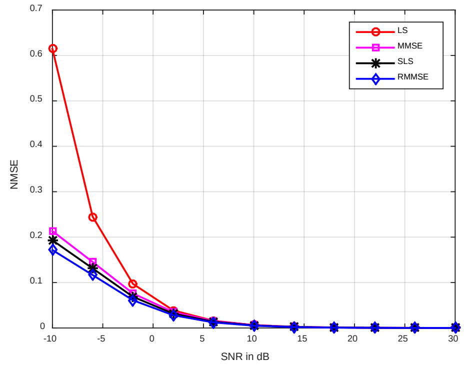

(b)

Figure 8 SUI-5 model with (a) Nt=Nr=2, k=0.7 (b) Nt=Nr=2, k=0.2

6. Conclusion

A number of training-based MIMO channel estimation methods and their performance are investigated. The prevalent LS, MMSE schemes are measured along with a novel SLS and relaxed MMSE techniques. The latter two techniques have the enhanced performance than the former two schemes. To understand the stated techniques, a rudimentary knowledge in the second-order statistics of the channel is enough. The different kind of training matrices are analysed and optimal selection is made and applied. For each of the considered techniques, performances are measured and compared in terms of normalized mean square error. LS method performance is inferior to SLS, MMSE and RMMSE. MMSE performance is decreased when the channel is highly correlated. Also it is observed that, the functioning of the estimator improves when the correlation increases. The result is verified in Matlab simulation environment with SUI-1 and SUI-5 Channel model for various combinations of transmitting and receiving antennae and for different correlation values. The result shows that the RMMSE estimation performs better in all scenarios.

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