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Mitigation Of ICI using Linear Time Varying In MIMO-OFDM

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Abstract---The technology and the implementation of digital systems have increased the data rate to unmatched levels to convey the information between two entities, the architectural model of orthogonal frequency division multiplexing (OFDM) has come up innovative orthogonality principle to meet the requirements with high data rates. The OFDM too suffers from drawbacks and the most underrated problem which has a huge impact on the overall system performance is the time varying channel usage, its usage can can introduce inter carrier interference (ICI). The ICI is the resultant outcome of the loss of orthogonality in OFDM and the usage of the time varying channels is the reason behind it. The proposed method introduced the linear time varying channels in place of traditional time varying channels to fetch low complexity while the traditional time varying channels records high complexity which makes them unused in real time. The complexity level has reached to OK^3 to OK which makes the proposed method to yield better results than the state-of-art methods in terms of both performance and accuracy, the proposed method reduces the ICI to unprecedented levels and in experimental results its been proved.

Keywords: OFDM, ICI, Complexity, Time varying channels, Linear time varying channels

1. INTRODUCTION

Communication industry has grown enormously in the past six decades and supports various applications belong to different research fields. Wireless communication is a major constituent of communication industry which has 75% of total market share. Wireless communication takes the communication domain to the next level in terms of reliability and performance. Mobile data transmission is considered as a 21st century system which offers higher data rate but suffers from complexity. It is well known that there is unmanageable growth of users in telecommunication industry. So the user's requirements become high for ubiquitous access, high data rate. Therefore, energy consumption in wireless communication has been increasing. As a result, CO_2 is emitted which makes the atmosphere polluted and become an obstacle in the development of wireless communication. According to Survey, ITU has submitted that the ICT industry produces 2% - 2.5% of total greenhouse gas emission. That includes PC 40%, data centers 23%, telecommunication 24% and printers 6%. So, out of all we are concentrating on telecommunication to reduce emission of CO_2. So to overcome this emission in telecommunication, energy efficiency has become a global trend in future wireless telecommunication networks.

Orthogonal frequency division multiplexing (OFDM) is used in most current and upcoming mobile communication systems. Such systems perform well when the channel is not varying during the duration of one OFDM symbol. However, mobile scenarios in which the channel is varying rapidly are becoming more and more important for intelligent traffic systems or high speed trains. If the channel is not constant during the transmission of one OFDM symbol, inter-carrier interference (ICI) occurs and the performance of the system is degraded. Therefore, there is a need to introduce receivers that combat ICI. The ICI for single input single output (SISO) and multiple input multiple output (MIMO) transmissions is analyzed. Pilot symbols located at adjacent subcarriers in order to estimate the ICI. This approach is in contradiction to the common agreement that scattered pilot symbols are optimal. Nevertheless, such an approach would be suitable for ICI estimation in the case of a SISO system. In the case of a MIMO system, such a pilot symbol pattern results in a huge overhead. The ICI estimation and mitigation assume that the channel is varying linearly in the time domain. We can use polynomials for channel estimation in MIMO. However, their estimator works only with a limited order of the polynomials. Numerous different equalization algorithms are proposed in which the authors assume perfect channel knowledge for each signal sample. However, this information is not available at the receiver and algorithms cannot estimate the time-variant channel impulse response at sample level precisely enough at high Doppler spreads.

In this paper, we propose a low-complexity ICI mitigation algorithm in MIMO systems based on similar channel model. The method is based on no assumption but linear time-varying (LTV) channel, which is a good approximation when the normalized Doppler frequency is up to 0.2. It exploits the structure of ICI in MIMO systems and decouples the symbols and the ICIs on each subcarrier. At the same time, it remains low complexity. Simulation shows that the algorithm outperforms the conventional equalizer based on time-invariant channel assumption by about 2 dB when the uncoded bit error rate is 10−3. The proposed method works perfectly when there are more receive units than transmit ones. The methodology implied in the low-complexity MIMO ICI mitigation is to divide the equalization process according to the structure of ICI contribution in linear time-varying channels, and demodulate the symbols independently on each subcarrier.

2. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

Orthogonal frequency division multiplexing (OFDM) and compatible usage in wireless standards like DVB, WIMAX, IEEE802.11a and LTE has been gained interest from worldwide research organizations. Recently an international meeting has conducted in order to discuss importance of orthogonal frequency division multiplexing (OFDM) and its usage in advance wireless standards makes Orthogonal frequency division multiplexing (OFDM) as an emerging technology to meet the requirements in practical scenario. Orthogonal frequency division multiplexing (OFDM) has high data rates compared to traditional communications systems and it suited well for frequency selective channels. Large delay spreads is a drawback which commonly occurs in the high speed wireless communication system and orthogonal frequency division multiplexing (OFDM) modulation scheme has ability to transform the wide frequency selective channel to narrow ones which creates the robust environment to resists against occurrence of the large delay spreads and preserves the Orthogonality in a perfect way in the frequency domain. Orthogonal frequency division multiplexing (OFDM) has one more unique advantage to reduce the complexity in the system by introducing the cyclic prefix at the transmitter end and performing scalar equalization at the receiver end in the wireless standards like WIFI and WIMAX.

In 21^{st} century, the role of the technology to offer high data rates and mobility is crucial and the technology is changing its face every other because of immense research work carried out on the advance wireless communications. Actually the research on parallel data transmission is traced out in the mid 1960's but it takes 25 long years to make it compatible to real time applications. The OFDM gradually seen its presence in the various application and now various international standards consider it as promising modulation scheme which initially supports wireless standards like WIFI, WIMAX, LTE etc. The two important parameters required better transmission of data from one entity to another are data rate and the modulation scheme should support different channel conditions to obtain better spectral efficiency.

The evolution of the third Generation Partnership Project (3GPP) development based on the Long term evolution (LTE) supports two networks namely Radio access network (RAN) and core network. The

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transformation of the 3G to 4G observes the changes in terms of data rate and spectral efficiency. International Telecommunication Union Radio communication Sector (ITU-R) initialized a set of requirements for the 4[th] generation cellular system and requirement of the high data rate is specified by International Mobile Telecommunications Advanced project (IMT-Advanced) for 4G. OFDM is a modulation scheme which is one of the techniques employed in LTE to enhance the data stream.

3. PROPOSED METHODOLOGY

3.1 SYSTEM MODEL

In this section, MIMO-OFDM transmission model in linear time-varying channels is introduced. The MIMO TDS-OFDM frame structure is also introduced as one of the possible frame structures that could be applied in our proposed approach for it can easily estimate linear time-varying channels.

A. MIMO-OFDM in Linear Time-Varying Channels

For MIMO-OFDM, denote the number of transmitters and receivers to be M and N, and the OFDM symbol length to be K. Denote the l-th channel tap between the m-th transmitter and the n-th receiver at time slot t by $h_{l,m,n}^{(t)}$, l = 0, 1,..., L − 1, where L is the channel length. Therefore, for linear time-varying channel model in one frame $h_{l,m,n}^{(t)} = h_{l.m.n}+\delta_{t-1}\alpha_{l,m,n}$, where $h_{l.m.n} = \frac{1}{K}\sum_{t=1}^{l+K-1} h_{l,m,n}^{(t)}$ is the timeinvariant part and αl,m,n is the time-varying factor of its l-th channel tap. $\delta_i = \frac{i}{K} - \frac{K-1}{2K}$ Indicates the time varying step.

In [18] and [19], the input-output relationship of SISO-OFDM in linear time-varying channels has been introduced. For MIMO-OFDM, by regarding each pair of transmitter m and receiver n as a SISO-OFDM link, and by similar approach in [18] and [19], the time domain signal received at the nth receiver from the m^{th} transmitter could be represented as

$$y_{m,n} = (H_{m,n} + A_{m,n}B)x_m \qquad (1)$$

where X_m is the time domain sequence transmitted from the m-th transmitter, $H_{m,n}$ is a K × K circulant matrix with the first column to be $[h_{0,m,n}, h_{l.m.n},\cdots, h_{L-1}, \mathrm{m}, \mathrm{n}, 0,\cdots,0]^T$ $A_{m,n}$ is a K × K circulant matrix with the first column to be$[\alpha_{0,m,n}, \alpha_{1,m,n},\cdots, \alpha_{L-1,m,n}, 0,\cdots,0]^T$, B is a diagonal matrix such that $\mathrm{B} = Diag([\delta_0, \delta_1, \dots, \delta_{k-1}]^T)$.Convert the signals to frequency domain,

$$Y_{m,n} = (H_{m,n} + A_{m,n}B)X_m \qquad (2)$$

Where $Y_{m,n}$= FK$y_{m,n}$ and $X_{m,n}$= FK $x_{m,n}$are the received and transmitted frequency domain symbol vectors. $H_{m,n}$= FK$H_{m,n}F_K^H$= Diag$\left(\{H_{m,n,k}\}_{K=1}^{K}\right)$and $A_{m,n}$=FK$\left(\{H_{m,n,k}\}_{K=1}^{K}\right)F_K^H$= Diag$\left(\{A_{m,n,k}\}_{K=1}^{K}\right)$are diagonal matrices according to the property of circulant matrix. $\{H_{m,n,k}\}_{K=1}^{K}$and$\{A_{m,n,k}\}_{K=1}^{K}$represent the K-point DFT of $[h_{0,m,n}, h_{l.m.n},\cdots, h_{L-1}, \mathrm{m}, \mathrm{n}, 0,\cdots,0]^T$and, $[\alpha_{0,m,n}, \alpha_{1,m,n},\cdots, \alpha_{L-1,m,n}, 0,\cdots,0]^T$respectively. B = $F_K B F_K^H$ is a precalculated matrix.

The ICI components reside in$A_{m,n}$, and the time invariant components reside in $H_{m,n}$. For SISO-OFDM where M = N = 1, low complexity ICI compensation in linear time-varying channel model could be achieved by exploiting the frequency domain input-output relationship (2): with both $H_{m,n}$and $A_{m,n}$being diagonal, and with B easily calculated by FFT, matrix inversion approximation by power series representation tremendously reduces the complexity in calculating the equalized symbols of $Y_{m,n}$ [18], [19]. For MIMO-OFDM, however, the problem gets much more complicated because the signal from one transmitter encounters interference from other transmitters. With the contribution from multiple transmitters, the ICI components could not be directly decoupled as in SISO-OFDM scenarios. Therefore, in order to pursuit new strategies to compensate ICI for MIMO-OFDM, we need to derive the input-output relationship considering all transmitters as follows.

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The received signal at the n-th receiver is the superposition of the received signals from different transmitters, contaminated by noise,

$$Y_n = \sum_{m=1}^{M} Y_{m,n} = \sum_{m=1}^{M} \left(H_{m,n} + A_{m,n}\right) X_m + V_n \qquad (3)$$

V_n is the frequency domain noise vector at the n-th receiver. Assume it follows Gaussian distribution $V_n \sim \mathcal{N}(0_{1\times k}, \delta^2 I_{K\times K})$. Vectorize all received signals, transmitted signals and the frequency domain noise vectors,

$$Y = [Y_1^T Y_2^T \dots Y_N^T]^T \qquad (4)$$

$$X = [X_1^T X_2^T \dots X_N^T]^T \qquad (5)$$

$$V = [V_1^T V_2^T \dots V_N^T]^T \qquad (6)$$

Then

$$Y = \begin{bmatrix} H'_{1,1} & H'_{2,1} & \cdots & H'_{M,1} \\ H'_{1,2} & H'_{2,2} & \cdots & H'_{M,2} \\ \vdots & \vdots & & \vdots \\ H'_{1,N} & H'_{2,N} & \cdots & H'_{M,N} \end{bmatrix} X + V \qquad (7)$$

With

$$H'_{m,n} = H_{m,n} + A_{m,n} B$$

B. Introduction of MIMO TDS-OFDM TDS-OFDM

adopts known sequences as the guard interval, serving the purpose of both channel estimation and synchronization [25]. MIMO TDS-OFDM uses pseudo-noise (PN) sequences as the guard interval. In time-varying channels, the channel estimation results from the PN sequences prior to and posteriori to the OFDM data block are put to estimate the channel variation model. In Fig. 1 and Fig. 2, the frame structure and receiver structure of MIMO TDS-OFDM using the proposed ICI mitigation algorithm are illustrated. [7] discussed about Improved Particle Swarm Optimization. The fuzzy filter based on particle swarm optimization is used to remove the high density image impulse noise, which occur during the transmission, data acquisition and processing. The proposed system has a fuzzy filter which has the parallel fuzzy inference mechanism, fuzzy mean process, and a fuzzy composition process. In particular, by using no-reference Q metric, the particle swarm optimization learning is sufficient to optimize the parameter necessitated by the particle swarm optimization based fuzzy filter, therefore the proposed fuzzy filter can cope with particle situation where the assumption of existence of "ground-truth" reference does not hold. The merging of the particle swarm optimization with the fuzzy filter helps to build an auto tuning mechanism for the fuzzy filter without any prior knowledge regarding the noise and the true image. Thus the reference measures are not need for removing the noise and in restoring the image. The final output image (Restored image) confirm that the fuzzy filter based on particle swarm optimization attain the excellent quality of restored images in term of peak signal-to-noise ratio, mean absolute error and mean square error even when the noise rate is above 0.5 and without having any reference measures.

III. PROPOSED ALGORITHM

In the proposed method, firstly rewrite (7) as

$$Y = (H + A\bar{B})X + V = [H\ A]\begin{bmatrix} I \\ \bar{B} \end{bmatrix} X + V$$

$$= (H + A)\tilde{X} + V = [H\ A]\begin{bmatrix} X \\ X' \end{bmatrix} + V, \qquad (8)$$

Where

$$H = \begin{bmatrix} H_{1,1} & H_{2,1} & \dots & H_{M,1} \\ H_{1,2} & H_{2,2} & \dots & H_{M,2} \\ \vdots & \vdots & \dots & \vdots \\ H_{1,N} & H_{2,N} & \dots & H_{M,N} \end{bmatrix} \qquad (9)$$

$$A = \begin{bmatrix} A_{1,1} & A_{2,1} & \dots & A_{M,1} \\ A_{1,2} & A_{2,2} & \dots & A_{M,2} \\ \vdots & \vdots & \dots & \vdots \\ A_{1,N} & A_{2,N} & \dots & A_{M,N} \end{bmatrix} \qquad (10)$$

$$\bar{B} = \begin{bmatrix} B & & & \\ & B & & \\ & & \ddots & \\ & & & B \end{bmatrix} \qquad (11)$$

$$\tilde{X} = \begin{bmatrix} I \\ \bar{B} \end{bmatrix} X = \begin{bmatrix} X \\ \bar{B}X \end{bmatrix} = \begin{bmatrix} X \\ X' \end{bmatrix} \qquad (12)$$

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In (12), the original transmitted symbols compose the vector X. Then what does the vector X' stand for? Actually, $X'=\bar{B}X$,and it is multiplied by A to construct the ICI. As $X=\{X_{n,k}\}_{n=1,k=1}^{N,K}=[X_1^T, X_2^T \ldots . X_N^T]^T$, X' is similarly formed as $X' = \{X'_{n,k}\}_{n=1,k=1}^{N,K}=[X_1'^T, X_2'^T \ldots . X_N'^T]^T$.In correspondence with $X_{n,k}$ which denotes the transmitted symbol at the k-th subcarrier from the n-th transmitter, the component n,k in X' stands for the interference at the k-th subcarrier 'from' the n-th transmitter. It's noted that the interference among different subcarriers is handled by $\bar{B}$, so $X'_{n,k}$ is the interference only on subcarrier k. Therefore, Matrix H represents the channel time-invariant part and describes the signal transfer without interference. Matrix A represents the channel time-varying part and describes the interference transfer itself. Regard the system transfer function in (8) as a 2M-transmitter N-receiver MIMO-OFDM with K subcarriers. As mentioned above, there is no inter-carrier interference any more in the equivalent system, therefore the equalizer can be parallelized on each subcarrier.

For subcarrier k,

$$\bar{Y}_k = [Y_{1,k} Y_{1,k} \ldots . Y_{N,k}]^T, \qquad (13)$$

$$\tilde{X}_k = [X_{1,k} X_{1,k} \ldots . X_{M,k}, X'_{1,k} X'_{2,k} \ldots . X'_{M,k}]^T, \qquad (14)$$

$$\bar{H}_k = \begin{bmatrix} H_{1,1,k} & H_{2,1,k} & \cdots & H_{M,1,k} \\ H_{1,2,k} & H_{2,2,k} & \cdots & H_{M,2,k} \\ \vdots & \vdots & \cdots & \vdots \\ H_{1,N,k} & H_{2,N,k} & \cdots & H_{M,N,k} \end{bmatrix} \qquad (15)$$

$$\bar{A}_k = \begin{bmatrix} A_{1,1,k} & A_{2,1,k} & \cdots & A_{M,1,k} \\ A_{1,2,k} & A_{2,2,k} & \cdots & A_{M,2,k} \\ \vdots & \vdots & \cdots & \vdots \\ A_{1,N,k} & A_{2,N,k} & \cdots & A_{M,N,k} \end{bmatrix} \qquad (16)$$

And

$$\bar{Y}_k = [\bar{H}_k \quad \bar{A}_k] \tilde{X}_k + \bar{V}_k \qquad (17)$$

This is a standard flat-fading MIMO system transfer expression with the transmitted symbol vector $\check{X}_k$ and received vector$\bar{Y}_K$. Therefore, traditional OFDM equalizer with 2M transmitters and N receivers could be used to equalize the transmitted symbols on subcarrier k [23], [24].

When a linear MMSE (LMMSE) equalizer is used,

$$\tilde{X}_k \approx C_{\tilde{X}_k} \begin{bmatrix} \bar{H}_k^H \\ \bar{A}_k^H \end{bmatrix} \left([\bar{H}_k \quad \bar{A}_k] C_{\tilde{X}_k} \begin{bmatrix} \bar{H}_k^H \\ \bar{A}_k^H \end{bmatrix} + \delta I \right)^{-1} \bar{Y}_k \qquad (18)$$

The vector $\tilde{X}$ contains the estimation of the transmitted symbols. To achieve better estimation performance, X is estimated as

$$\hat{X} = E\tilde{X} = C_{X\tilde{X}} C_{\tilde{X}\tilde{X}}^{-1} \tilde{X}$$

$$= [I \quad \bar{B}^H] \begin{bmatrix} I & \bar{B}^H \\ \bar{B} & \bar{B}\bar{B}^H \end{bmatrix}^{-1} \tilde{X} \qquad (19)$$

with the matrix

$$E = C_{X\tilde{X}} C_{\tilde{X}\tilde{X}}^{-1}$$

$$= [I \quad \bar{B}^H] \begin{bmatrix} I & \bar{B}^H \\ \bar{B} & \bar{B}\bar{B}^H \end{bmatrix}^{-1} \qquad (20)$$

Although inversion of a large matrix is involved in (19), the calculation of matrix E is determined only by M, N and K, thus it's irrelevant to channel realization. Therefore E is a pre calculated matrix and acts like a predesigned linear filter, the complexity is limited to filtering itself. $C_{\tilde{X}_k}$ in (18) is the covariance matrix of the transmitted symbol vector. The inversion of the $C_{\tilde{X}_k}$can also be pre-calculated because the matrix is a 2M × 2M sub-matrix composing of the elements at the k-th, K + k-th, ... and (2M − 1)K + k-th rows and columns of the matrix $C_{\tilde{X}\tilde{X}}$

In comparison, the conventional LMMSE equalizer in MIMO-OFDM also works subcarrier by subcarrier. The only difference is that the subsystem transfer function in each subcarrier does not contain the time varying matrix $\bar{A}_k$,

$$\bar{Y}_k = \bar{H}_k \bar{X}_K + \bar{V}_k \qquad (21)$$

So the demodulation in LTI channels is

$$\bar{X}_k \approx C_{\bar{X}_k} \bar{H}_k^H \left(\bar{H}_k C_{\bar{X}_k} \bar{H}_k^H + \delta I \right)^{-1} \bar{Y}_k \qquad (22)$$

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4. Experimental Results

FOR CHANNEL- B

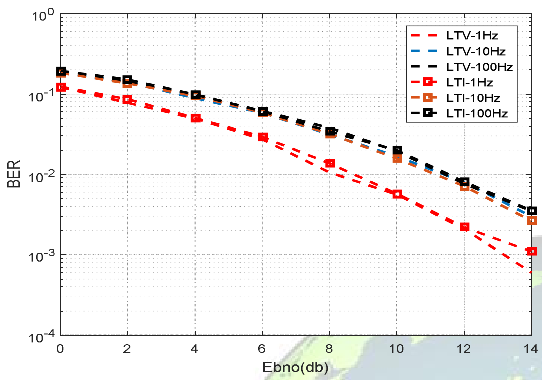

Fig.4.1 BER performance for both LTI and LTV channels having two transmitters and four receivers, modulation is QPSK

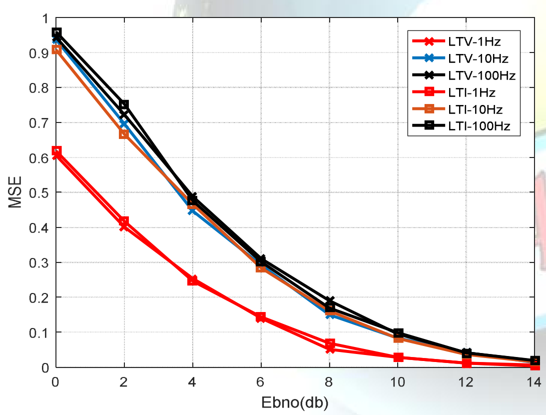

Fig.4.2 MSE performance for both LTI and LTV channels having two transmitters and four receivers, modulation is QPSK

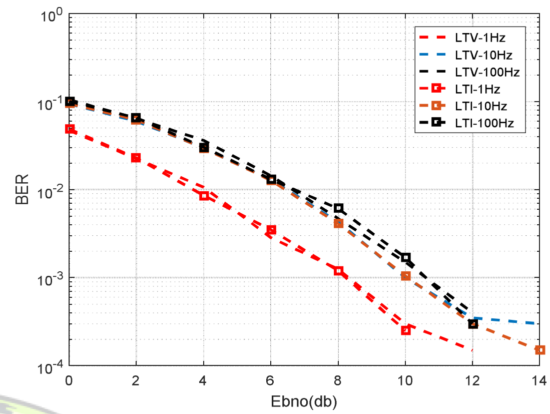

Fig.4.3 BER performance for both LTI and LTV channels having two transmitters and 8 receivers, modulation is QPSK

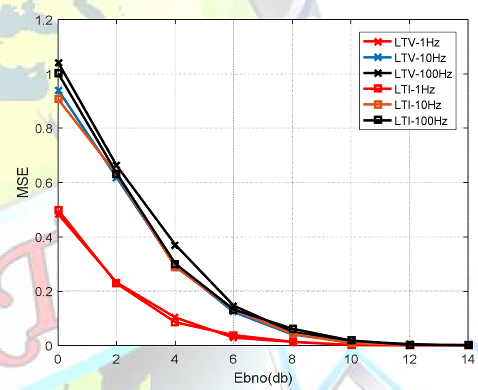

Fig.4.4 MSE performance for both LTI and LTV channels having two transmitters and 8 receivers, modulation is QPSK

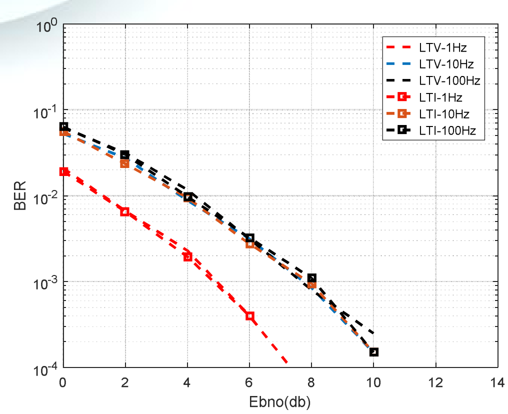

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Fig.4.5 BER performance for both LTI and LTV channels having two transmitters and 12 receivers, modulation is QPSK

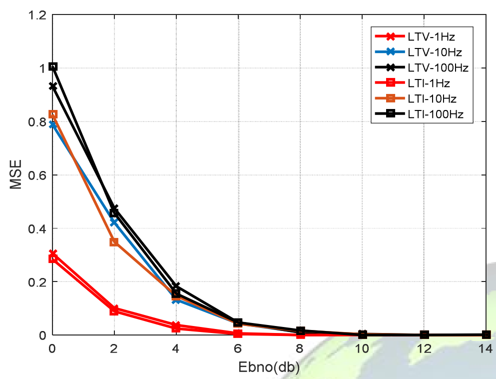

Fig.4.6 MSE performance for both LTI and LTV channels having two transmitters and 12 receivers, modulation is QPSK

FOR CHANNEL- A

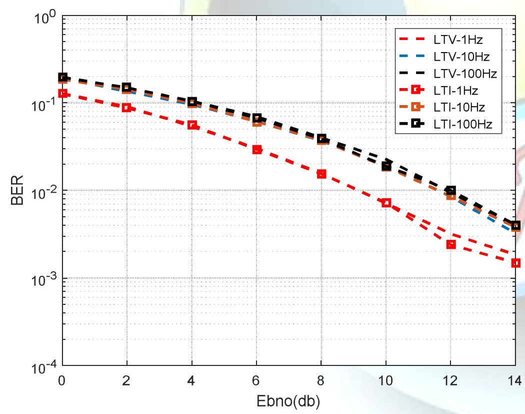

Fig.4.7 BER performance for both LTI and LTV channels having two transmitters and 4 receivers, modulation is QPSK

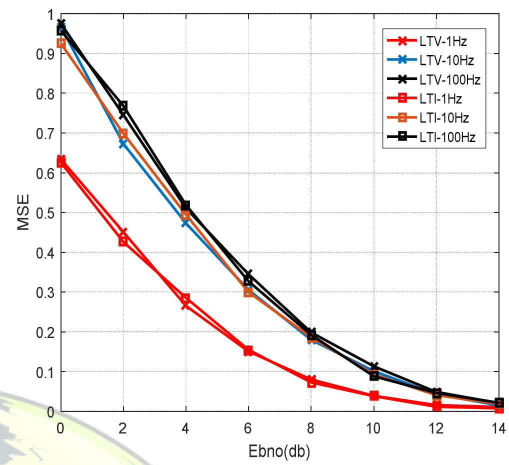

Fig.4.8 MSE performance for both LTI and LTV channels having two transmitters and 4 receivers, modulation is QPSK

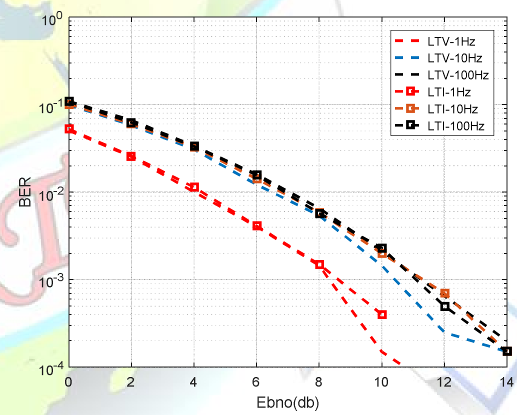

Fig.4.9 BER performance for both LTI and LTV channels having two transmitters and 8 receivers, modulation is QPSK

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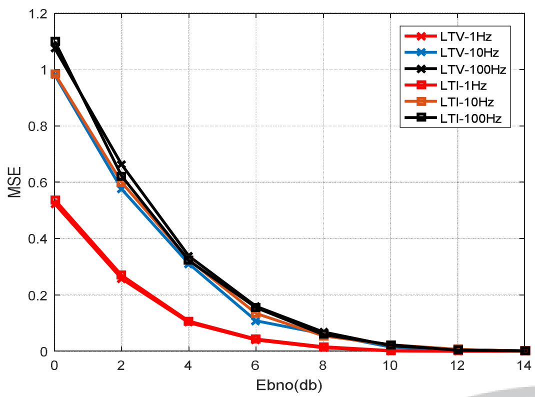

Fig.4.10 MSE performance for both LTI and LTV channels having two transmitters and 8 receivers, modulation is QPSK

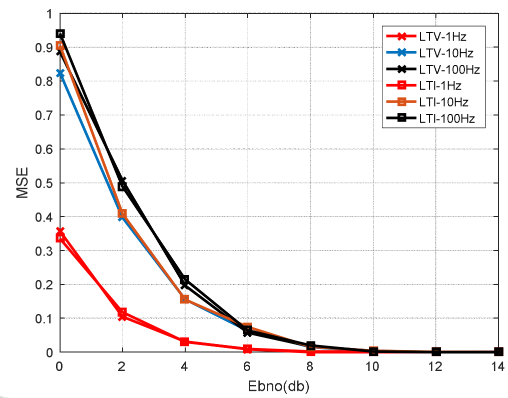

Fig.4.12 MSE performance for both LTI and LTV channels having two transmitters and 8 receivers, modulation is QPSK

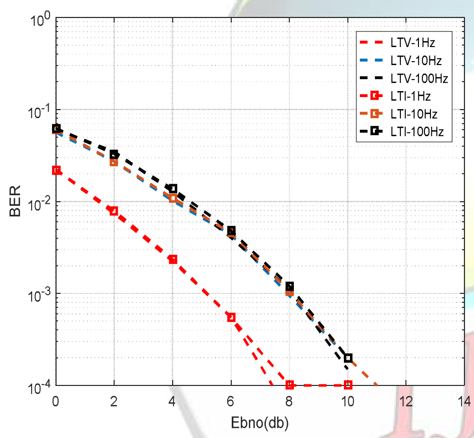

Fig.4.11 BER performance for both LTI and LTV channels having two transmitters and 8 receivers, modulation is QPSK

EXTENSION RESULTS

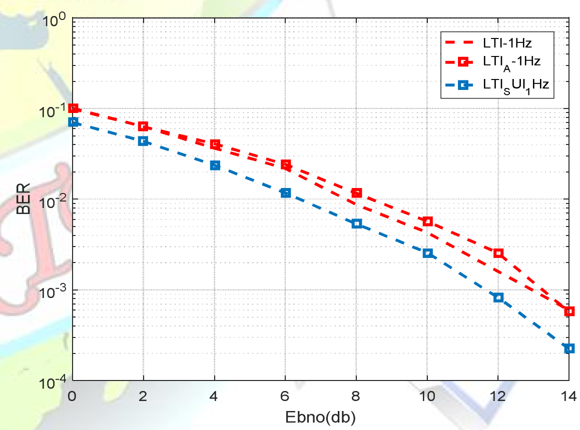

Fig.4.13 BER performance for both LTI and LTV channels having two transmitters and four receivers, modulation is QPSK FOR EXTENSION(USING SUI CHANNEL)

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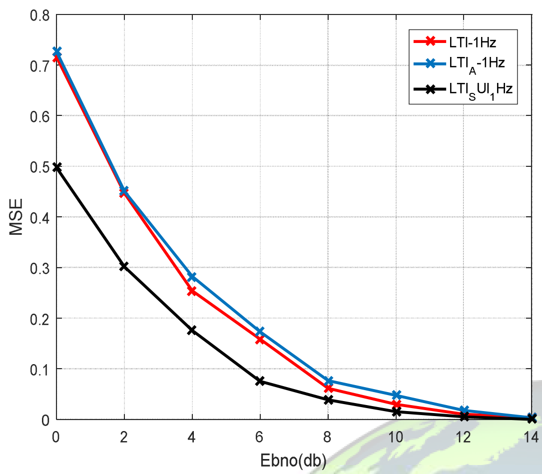

Fig.4.14 MSE performance for both LTI and LTV channels having two transmitters and four receivers, modulation is QPSK FOR EXTENSION(USING SUI CHANNEL)

5. CONCLUSION

The proposed methodology proposes a novel low complexity based linear time varying channel based OFDM system for controlling the ICI in an exceptional manner. The traditional time varying channels such as LTI assumption has fetched better performance, but at the cost of high complexity and the simulation result of the proposed methodology outperform the LTI assumption by 2dB SNR when the relative Doppler effect is 0.1 respectively. The time varying channel path is flexible enough to mitigate the ICI in OFDM system and the proposed methodology has a good estimation scheme in terms of accuracy and reliability.

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