Performance Analysis of Various Equalizers for ISI reduction in MIMO-OFDM system

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Abstract-For high speed data transmission system quality is a big challenge. In case of multiple-input multiple-output (MIMO) system, orthogonal frequency division multiplexing (OFDM) modulation technique is used to achieve this target. Inter Symbol Interference has been a great challenge in MIMO system, which is required to be reduced and it can be achieved by using equalizers as it counters the multipath signal component. In this work, a 2x2 MIMO channel is designed and its performance is analyzed by implementing it with four different equalizers. Equalizers which are utilized here are Zero Forcing (ZF), Minimum Mean Square Error (MMSE), Zero Forcing Parallel Interference Cancelation (ZFPIC) and Maximum Likelihood (ML). After comparing, it is found that Maximum Likelihood technique is giving best result among all by 2.2 dB by its closest adversary which is ZFPIC.

Index Terms- MIMO, OFDM, Rayleigh fading channels, ISI.

1. INTRODUCTION

In wireless technology main objective is to provide high quality over data, voice, facsimile, still pictures and streaming video. Recent advancements in these dimensions are 3GPP LTE and terrestrial digital TV broadcasting using OFDM and CDMA technology. Orthogonal frequency division multiplexing (OFDM) has become a popular technique for transmission of signals over wireless channels. OFDM converts frequency – selective channel into a parallel collection of frequency flat sub channels [10].

In mobile radio systems where data bits are transmitted in radio space, channels are typically multipath fading channels, which cause inter-symbol interference (ISI) in the received signal. Due to ISI, bit error rates increases.ISI occurs when the bandwidth of modulation crosses the coherence bandwidth of the radio channel. To eliminate ISI from the signal, strong equalizer are used, which requires channel impulse response (CIR) [11]. Equalizers compensate the inter-symbol interference (ISI) which is created by multipath communication.

Equalizer is meant to work in such a way that BER should be low and SNR should be high [3]. Equalization techniques have enormous importance to design of high data rate wireless Systems. Equalizer situated at receiver side compensates for the average range of expected channel amplitude and delay characteristics.

There are three basic parameter which can describe the quality of wireless link those parameter are transmission rate, transmission range and transmission reliability. Conventionally, the transmission rate can be enhanced by reducing the transmission range and reliability. The transmission range may be extended at the cost of a lower transmission rate and reliability, while the transmission reliability may be improved by reducing the transmission rate and range. However, the mentioned three parameters can be simultaneously improved with the introduction of MIMO assisted OFDM systems. MIMO technology has attracted attention in wireless communications, since

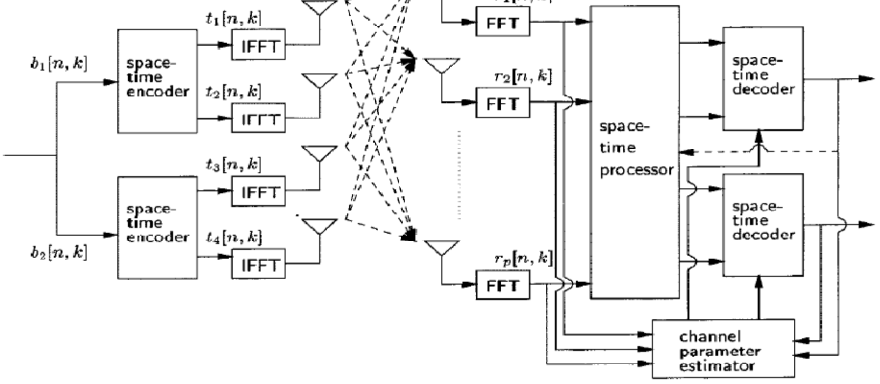

Fig. 1. Fig 1.1 A MIMO OFDM System

it offers significant increases in data throughput and link range without additional bandwidth or transmit power.

It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading). Because of these properties, MIMO is a current theme of international wireless research [7].

A multiple-input multiple-output (MIMO) communication system combined with the orthogonal frequency division multiplexing (OFDM) modulation technique can achieve reliable high data rate transmission over broadband wireless channels.[1] Initial field tests of broadband wireless MIMO-OFDM communication systems have shown that an improved capacity, coverage and reliability is achievable with the support of MIMO techniques. Furthermore, although MIMOs can be combined with any modulation or multiple access technique, latest research suggests that the performance of MIMO aided OFDM is more efficient, as a benefit of the straightforward matrix algebra invoked for processing the MIMO OFDM signals [9]. A MIMO-OFDM system is shown in Fig.1.1, with four transmitter antennas.

Here each of two data blocks, b_i [n, k] : for k= 0,1 i=1,2 are simultaneously transformed into two different signals,{t_2(i-1)+ j[n, k] : k =0,1 j=1,2}for i= 1and 2, correspondingly, through two space–time encoders. The k^{th} transmit antenna is modulated by t_i [n, k] at the k^{th} tone of the n^{th} OFDM block for the OFDM signal [12].

2. LITERATURE SURVEY

To reduce Inter Signal Interference in MIMO system, lots of work had been done. In this section result of various research papers had been discussed.

Sahu et. al. presented behaviors of MIMO systems under Rayleigh channel environments. They described MIMO transmission systems and their BER performance, SNR and their error performance with the diversity schemes with implementations of different equalizers. They correlated mutual coupling between antenna elements. Receiver diversity is analyzed especially with the Maximal Ratio Combining (MRC) technique and fair comparison is done with Equal Gain Combining (EGC) and Selection- Combing (SC). They performed equalization by Maximum Likelihood (ML), Maximum Mean Square Equalization (MMSE) and Zero Forcing (ZF). With the SNR of 10 dB, the ZF equalizer achieves the BER of 10^{-4}, MMSE equalizer shows it between 10^{-4} to 10^{-5}. But the ML equalizer performs better with exactly 10^{-5} [5].

Kanchan et. al. showed frequency-selective channel conditions in OFDM. They modeled OFDM system with two different equalizers, namely Zero Forcing (ZF) and Minimum Mean Square Error (MMSE), along with different tapping. The modulation with multicarrier is employed, which provides advantages like inter symbol interference (ISI) reduction, high reliability, and better performance in multi-path fading under various fading environments. More balanced linear equalizer is the Minimum Mean Square Error Equalizer, which does not eliminate ISI completely but instead minimizes the total power of the noise and ISI components in the output. They showed BER decreases as the number of receiving antenna increases with respect to number of transmitting antenna in MMSE equalizer [6].

Naveen et. al. showed that by combining OFDM with CDMA dispersive fading limitations of the cellular mobile can be overcome and the effects of co-channel interference can be reduced. In a flat fading Rayleigh multipath channel with BPSK modulation, to compensate ISI various equalization techniques are used like Zero Forcing (ZF) equalization, Minimum Mean Square Error (MMSE) equalization, Zero Forcing equalization with Successive Interference Cancellation (ZF-SIC), ZF-SIC with optimal ordering and MMSE SIC. They found that, as Compared to Zero Forcing equalization, addition of successive interference cancellation results in around 2.2dB of improvement for BER of 10^{-3}. Compared to Zero Forcing equalization with successive interference

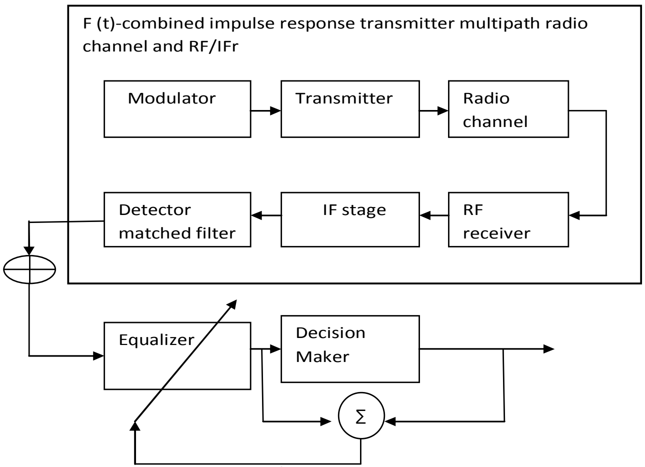

Fig. 3.1 Block Diagram of Receiver with Adaptive Equalizer

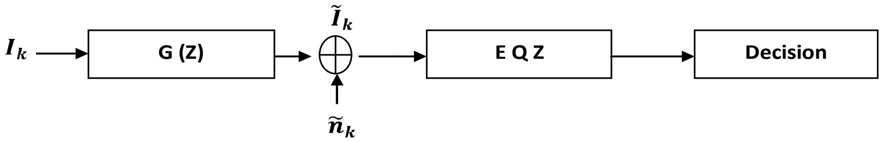

Fig. 3.2 Equivalent discrete-time white-noise linear filter model

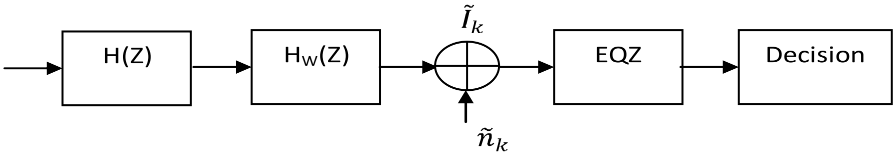

Figure 3.3 Equivalent discrete-time communication system models with white noise

cancellation case, addition of optimal ordering results in around 2.0dB of improvement for BER of 10^{-3}. Compared to Minimum Mean Square Equalization with simple successive interference cancellation case, addition of optimal ordering results in around 5.0dB of improvement for BER of 10^{-3}. So MMSE with SIC optimal ordering, interference can be cancelled at optimum level even in a mobile fading channel [2].

On the basis of this study, this work is performed where MIMO OFDM System is simulated with four different equalizers.

3. METHODOLOGY

Inter Symbol Interference is a major problem in wireless communication system, as noise get added in the message signal at the time of transmission. If the channel response of any channel is given by H(s) then input signal is multiplied by the reciprocal of the response. Finally the target is to remove the channel effect from the receiving signal, particularly the ISI. In this work, ISI is tried to reduce by four different equalizing techniques and further their results are compared.

An equalizer within a receiver compensates for the average range of expected channel amplitude and delay characteristics. On the basis of feedback provided, an equalizer is decided as for its linearity. If input of decision box is feedback then equalizer is non linear otherwise it is linear. An equalizer is usually implemented at the baseband or at IF in a receiver. Since the baseband complex envelope expression can be used to represent band pass waveforms, the channel response, demodulated signal and adaptive equalizer algorithms are usually simulated and implemented at the baseband signal.

Received signal fed to equalizer can be expressed as

$$Y(t) = X(t) \otimes f^{*}(t) + n_b(t) \qquad (1)$$

Where x(t) is original signal, f(t) is impulse response of the transmitter, channel and RF/IF sections of the receiver.

Output of equalizer is given by

$$\mathrm{d(t)} = \mathrm{X(t)} \otimes \mathrm{f^{*}(t)} \otimes \mathrm{h_{eq}(t)} + \mathrm{n_b(t)} \otimes \mathrm{h_{eq}(t)} \qquad (2)$$

$$\mathrm{d(t)} = \mathrm{h(t)} \otimes \mathrm{g(t)} + \mathrm{n_b(t)} \otimes \mathrm{h_{eq}(t)} \qquad (3)$$

Where f*(t) is complex conjugate of f (t), n_b (t) is the baseband noise at the input of the equalizer, is h_{eq} (t) is the impulse response of equalizer, g(t) is the combined response of the transmitter , channel ,RF/IF sections of the receiver and the equalizer at the receiver.

The impulse response of complex base band transversal filter equalizer is given by

$$h_{eq}(\mathrm{t}) = \sum\nolimits_{\mathrm{n}} \mathrm{Cn}\delta(t - nT) \qquad (4)$$

where C_n are the complex filter coefficients of the equalizer. The desired output of the equalizer is x(t).For forcing d (t) =x (t), g(t) must be calculated as

$$g(t) = f^{*}(t) \otimes \mathrm{h_{eq}(t)} = \delta(\mathrm{t}) \qquad (5)$$

The goal of equalization is to satisfy the given equation.

$$H_{eq}(f)F^{*}(-f) = 1 \qquad (6)$$

Where H_{eq} (f) and F (f) are Fourier transforms of h_{eq} (t) and f(t) respectively [13].

In this work four different equalizing techniques, which are compared are

1. Zero forcing equalizer.
2. Minimum mean square equalizer.
3. Zero forcing parallel interference cancellation equalizer.
4. Maximum likelihood equalizer.

Block Diagram showing equivalent circuit of receiver with equalizer for removing ISI is shown in figure 3.2 and figure 3.3.

3.1. *Zero Forcing Equalizer*

If Linear Time Invariant filters with transfer function H_E (z) is employed as the equalizing circuit then transfer function, H_E (z) = 1/G(z), is used to remove the ISI and hence output of the equalizer feedback the signal i.e., $\hat{I}(K) = I(K)$for all K,in absence of noise.

This method is zero-forcing equalization since the ISI component at the equalizer output is forced to zero. In ZF equalizers, when the transmission filter

H_T(f) is fixed, the matched filter is used as the receiving filter, i.e.,

$$H_R(\mathrm{f}) = H_T^*(f)H_c^*(f) \qquad (7)$$

$$H(e^{j2\pi ft}) = \frac{1}{T} = \sum_{n=-\infty}^{\infty} \left|H_T(f-\frac{n}{T})\,H_C(f-\frac{n}{T})\right|^2 \qquad (8)$$

and the power spectral density of the colored Gaussian noise samples $n_k$is given by

$$\emptyset_{nk} = (e^{j2\pi ft}) = \frac{N_0}{2T}\sum_{n=-\infty}^{\infty} \left|H_T(f-\frac{n}{T})\,H_C(f-\frac{n}{T})\right|^2 \qquad (9)$$

Hence, the noise-whitening filter H_W(z) can be chosen as[4]

$$H_W(e^{j2\pi ft}) = \frac{1}{\sqrt{H(e^{j2\pi fT})}} \qquad (10)$$

Hence the overall digital filter G(z) is

$$\begin{aligned} G(e^{j2\pi ft}) &= H(e^{j2\pi ft})H_W(e^{j2\pi ft}) \\ &= \sqrt{H(e^{j2\pi ft})} \end{aligned} \qquad (11)$$

And the zero-forcing filter H_E(z) will be given by

$$H_E(e^{j2\pi ft}) = \frac{1}{G(e^{j2\pi ft})} = \frac{1}{\sqrt{H(e^{j2\pi ft})}} \qquad (12)$$

3.2. *Minimum Mean Square Error (MMSE) Equalizer*

A minimum mean square error (MMSE) estimator describes the approach which minimizes the mean square error (MSE), which is a common measure of estimator quality. The main feature of MMSE equalizer is that it does not usually eliminate ISI completely but, minimizes the total power of the noise and ISI components in the output.[8] . Assume that the information sequence is wide sense stationary signal. To minimize the mean square error between the original information symbols and the output of the equalizer I_k is given by MSE.

$$\mathrm{MSE} = \mathrm{E}[e_k^2] = E\left[\left(I_k - \hat{I}_k\right)^2\right] \qquad (13)$$

For FIR filter of order 2L+1 as the equalizer, mean square error is given by

$$\mathrm{MSE} = \mathrm{E}\left[\left(I_k - \sum_{j=-j}^{L} \hat{I}_{k-j}h_{E-j}\right)^2\right] \qquad (13)$$

$$\mathrm{MSE} == E\left[\left(I_k - \tilde{I}_k^T h_E\right)^2\right] \qquad (14)$$

Where $\tilde{I}_k = [\tilde{I}_{k+l} \dots\dots\dots\dots\dots\dots\dots\dots.. \tilde{I}_{k-L}]^T$ *and*
$h_E = \left[h_{E,-L} \dots\dots\dots\dots\dots\dots\dots\dots.. h_{E,L}\right]^T$

Differentiating with respect to $h_{E,j}$ each and setting the result to zero,

$$E\left[\tilde{I}_k(I_k - \tilde{I}_k^T h_E)\right] = 0 \qquad (15)$$

Rearranging,

$$R\,h_E = d \qquad (16)$$

Where $R = E[\tilde{I}_k \tilde{I}_k^T]$ and $d = \mathrm{E}[I_k \tilde{I}_k^T]$

If R and d are known, then MMSE equalizer can be found out by solving the linear matrix equation.[9]

4. RESULTS

On the basis of experiment performed, it is found that when Binary Phase Shift keying Signal is fed in a 2 input and 2 output receiver system, bit error rate differs drastically for different equalization techniques. In each equalization technique BER decreases with increase in Signal to Noise ratio but output of Maximum Likelihood Technique is giving best performance. A comparison graph is being shown

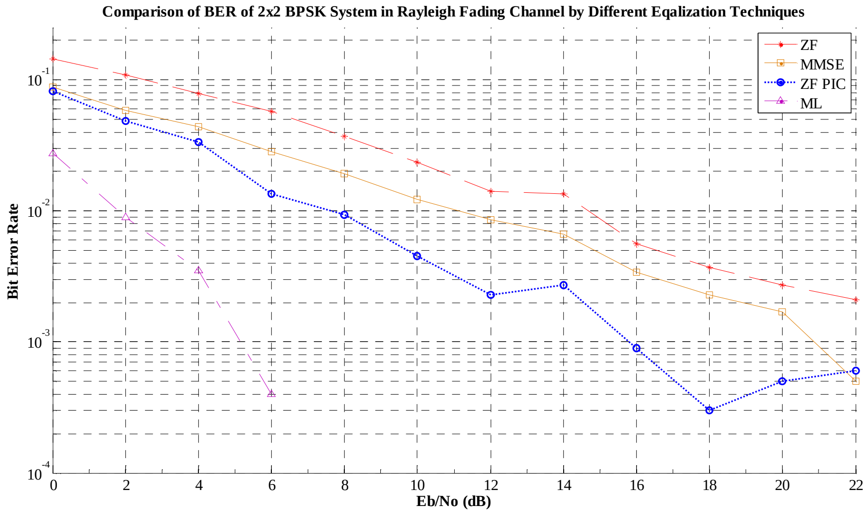

Figure 4.1 Equivalent discrete-time communication system models with white noise

in figure 4.1. It can be observed that, BER in Minimum Mean Square Error Technique is always better than Zero Forcing. At the same time, BER for ZF Parallel Interface Cancellation technique is less than that of MMSE in low SNR but with increase in SNR its BER increases and for the system designed BER of ZFPIC becomes greater than that of MMSE after 22dB. Comparative chart of performances of all equalization techniques with increase in SNR is shown in figure 4.1, from where it is clear that performance of maximum likelihood technique is always greater than other techniques. ML shows the best results in around 5.0dB of improvement for BER of 10^{-3}.

5. CONCLUSIONS

Equalization technique is required in high data rate wireless systems to reduce inter symbol interference in fading channels. In this paper, performances of 2x2 MIMO OFDM System with BPSK in different equalization techniques has been studied and best equalizer in Rayleigh multipath fading environment is tried to found out. In zero noise condition, Zero Forcing equalizer performs well. To counter inter symbol interference least mean square criterion in utilized in minimum mean square error equalizer. As compared to ZF, MMSE is giving 3dB improvement. However its result is further increased by 2.2dB in Parallel interference cancellation. But among all, maximum likelihood is showing highest improvement for BER with increase in signal to noise ratio.

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