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# SPLIT MLSE ADAPTIVE EQUALIZATION IN SEVERELY FADED RAYLEIGH MIMO CHANNELS

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**Abstract-** This paper presents an overview of adaptive equalization used in multiple-input-multiple-output (MIMO) wireless systems. In this paper, we consider two-user transmission over a Rayleigh frequency selective fading channel, in which the Channel State Information (CSI) is known by the receiver. Subject to an average transmit power constraint, we study the performance with Rayleigh fading. Besides an approximation result of such performance is proposed, and by conducting numerical comparison it is shown that our suggested approximation result has a better performance in approximating Rayleigh fading using Maximum-Likelihood Sequence Estimation (MLSE) algorithm. We here proposed a split MLSE adaptive equalization for use in faded MIMO channels. The proposed system is analyzed in terms of bit error rate (BER) with signals to noise ratio (SNR). Evaluation and comparison of the performances of MIMO system in the Additive White Gaussian Noise (AWGN) channel, and Rayleigh fading channel are provided. Experimental results show that the proposed split MLSE based adaptive equalization gives better results compared to composite equalization done traditionally.

**Keywords-** *Multiple-Input-Multiple-Output (MIMO) systems, Binary Phase Shift Keying (BPSK), adaptive equalizers, Bit Error Rate (BER), Signal to Noise ratio (SNR), Rayleigh fading channels, multipath channels, Maximum-Likelihood Sequence Estimation (MLSE), Space Time Block Codes (STBC), wireless communication.*

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## I. INTRODUCTION

Wireless transmission introduces Fading in which multiple paths with different phases add up at the receiver, Inter Symbol Interference (ISI), Co-channel Interference (CCI) and Noise. The use of MIMO for increasing capacity dates back to Winters in [1]. Such a system is called a MIMO system. Advantages of MIMO systems include [2],[3]: Beamforming, Spatial diversity and Spatial multiplexing. Wireless communication systems are moving towards high transmission speeds and high capacity. This can be achieved by using higher system frequencies to enable a wide frequency band and using advanced system technology to achieve high quality and signal multiplexing. Antenna requirement for such advanced systems are: High-gain and high-efficiency technology and Multi-antenna technology. Digital communication using multiple-input-multiple-output (MIMO) has recently emerged as one of the most significant technical breakthroughs in modern communications [3]. Given an arbitrary wireless communication system, we consider a link for which the transmitting ends as well as the receiving end is equipped with multiple antenna elements. In order to choose the most suitable modulation, several criteria such as power efficiency, bandwidth efficiency and bit error rate (BER) are used for evaluation. This paper focuses on error performance of MIMO system considering the Rayleigh channel and the Maximum-Likelihood Sequence Estimation (MLSE) algorithm so as to reduce the bit error rates (BER). The modulation scheme used in this is the binary phase shift keying (BPSK) modulation. A channel in mobile communication can be simulated in many different -

ways. The main considerations include the effect of multipath scattering, fading and Doppler shift that arise from the relative motion between the transmitter and the receiver. In our simulations, we have considered the two most commonly used channels: the Additive White Gaussian Noise (AWGN) channel where the noise gets spread over the whole spectrum of frequencies and the Rayleigh fading channel.

This paper presents an overview of the performance in the area of MIMO wireless systems. In this paper, we consider two-user transmission over a Rayleigh frequency selective fading channel, in which the Channel State Information (CSI) is known by the receiver only. Subject to an average transmit power constraint, we study the performance with Rayleigh fading. Besides an approximation result of such performance is proposed, and by conducting numerical comparison it is shown that our suggested approximation result has a better performance in approximating Rayleigh fading using Maximum-Likelihood Sequence Estimation (MLSE) algorithm. We here describe the design of a split MLSE adaptive equalization for use in faded MIMO channels. The proposed system is analyzed in terms of bit error rate (BER) with signals to noise ratio (SNR). Evaluation and comparison of the performances of MIMO system in the Additive White Gaussian Noise (AWGN) channel, and Rayleigh fading channel are provided. Experimental results show that the proposed split MLSE based adaptive equalization gives better results compared to composite equalization done traditionally. The received signal at

each receive antenna is a linear superposition of the  $n$  transmitted signals perturbed by noise. The main purpose of this paper is to evaluate the performance of the MIMO system with the stated approach.

Organization of this paper is as follows. Section II presents the theoretical background. Section III presents the system model and experimental details. Section IV includes the experimental results where as the conclusion is given in section V followed by the reference.

## II. THEORETICAL BACKGROUND

Here we briefly provide the basic theoretical considerations related to the work.

A) Wireless Channel - Wireless networks widely used today include: cellular networks, wireless mesh networks (WMNs), wireless Local Area Networks (WLANs), personal area networks (PANs), and wireless sensor networks (WSNs). Wireless communication systems are moving towards high transmission speed and high capacity. This can be achieved by using higher system frequencies to enable a wide frequency band and using advanced system technology to achieve high quality and signal multiplexing. When multiple communications are carried out simultaneously, then in multipath environment the interference from different directions will also increase. This multipath propagation causes the signal at the receiver to distort and fade significantly, leading to higher bit error rates (BER) [4].

B) Equalization - An equalizer attempts to mitigate ISI and improve receiver performance. The different classes of equalizers are listed below:

1) Linear Equalizers - This class is further divided into the following categories: Symbol spaced equalizers and Fractionally spaced equalizers (FSEs).

2) Decision-feedback equalizers (DFEs) - The RLS Decision Feedback Equalizer block uses a decision feedback equalizer and the RLS algorithm to equalize a linearly modulated baseband signal through a dispersive channel. During the simulation, the block uses the RLS algorithm to update the weights, once per symbol. When you set the Number of samples per symbol parameter to 1, the block implements a symbol-spaced equalizer and update the filter weights once for each symbol. When you set the Number of samples per symbol parameter to a value greater than 1, the weights are updated once every  $N^{\text{th}}$  sample, for a fractionally spaced equalizer.

3) Maximum-likelihood Sequence Estimation (MLSE) equalizers that uses the Viterbi algorithm. Linear and decision-feedback equalizers are adaptive equalizers

that use an adaptive algorithm when operating. The different adaptive equalizers are: i) Least mean square (LMS), ii) Signed LMS, including these types: sign LMS, signed regressor LMS, and sign-sign LMS, iii) Normalized LMS, iv) Variable-step-size LMS, v) Recursive least squares (RLS), vi) Constant modulus algorithm (CMA).

C) Adaptive Equalization - An adaptive equalizer is an equalizer that automatically adapts to time-varying properties of the communication channel. It is frequently used with coherent modulations such as phase shift keying (PSK), mitigating the effects of multipath propagation and Doppler spreading.

D) MIMO - MIMO systems are composed of three main elements, namely the transmitter (TX), the channel (H), and the receiver (RX).  $N_t$  is denoted as the number of antenna elements at the transmitter, and  $N_r$  is denoted as the number of elements at the receiver. Figure 1 depicts such MIMO system block diagram. It is worth noting that system is described in terms of the channel. For example, the Multiple-Inputs are located at the output of the TX (the input to the channel), and similarly, the Multiple-outputs are located at the input of the RX (the output of the channel) [4].



Figure 1: Block diagram of a MIMO wireless transmission system.

E) Channel Model - The transmitted waveform gets corrupted by noise  $n$ , typically referred to as Additive White Gaussian noise (AWGN). The Additive is the one where the noise gets 'added' (and not multiplied) to the received signal. The White is where the spectrum of the noise is flat for all frequencies. Gaussian refers to the values of the noise  $n$  follows the Gaussian probability distribution function,

$$p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \text{ with } \mu = 0 \text{ and } \sigma^2 = \frac{N_0}{2}.$$

F) Bit error Rate (BER) - The probability of error for transmission of either +1 or -1 is computed by integrating the tail of the Gaussian probability density function for a given value of bit energy to noise ratio  $\frac{E_b}{N_0}$ . The bit error rate is [3][5],

$$P_b = \frac{1}{2} \operatorname{erfc} \left( \sqrt{\frac{E_b}{N_0}} \right).$$

However in the presence of channel  $h$ , the effective bit energy to noise ratio is  $\frac{|h|^2 E_b}{N_0}$ . So the bit error probability for a given value of  $h$  is,

$$P_{b/n} = \frac{1}{2} \operatorname{erfc} \left( \sqrt{\frac{|h|^2 E_b}{N_0}} \right) = \frac{1}{2} \operatorname{erfc} (\sqrt{\gamma})$$

Where  $\gamma = \frac{|h|^2}{N_0}$ .

To find the error probability over all random values of  $|h|^2$ , one must evaluate the conditional probability density function  $P_{b/n}$  over the probability density function of  $\gamma$ .

The received signal,

$$\begin{aligned} y &= s_1 + n, \text{ when bit 1 is transmitted and} \\ y &= s_0 + n \text{ when bit 0 is transmitted.} \end{aligned}$$

### III. SYSTEM MODEL AND EXPERIMENTAL DETAILS

The proposed system model is shown in Figure 2.

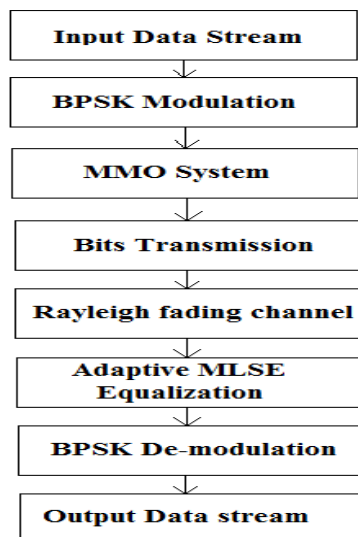


Figure 2: Proposed system model of MIMO system

At transmitter first, the data is generated from a random source, consists of a series of ones and zeros. Data input bits are converted into symbol vector using modulation. Modulation scheme used to map the bits to symbols is BPSK. At each time slot  $t$ , signals  $s_i$ ,  $i=2$  are transmitted simultaneously from the transmit antennas. The channel is assumed to be frequency selective fading channel and the path gain from transmit antenna  $i$  to receive antenna  $j$  is defined to be  $h_{i,j}$ . At time  $t$  the signal  $r_t^j$ , received at antenna  $j$ , is given by [6]

$$r_t^j = \sum_{i=1}^n \alpha_{i,j} C_t^i + \eta_t^j$$

where the noise samples  $\eta_t^j$  are independent samples of a zero-mean complex Gaussian random variable with variance  $n/(2 \text{ SNR})$  per complex dimension. The average energy of the symbols transmitted from each

antenna is normalized to be one, so that the average power of the received signal at each receive antenna is  $n$  and the signal-to-noise ratio is SNR.

With the transmitted signal vector  $x$ , the received signal vector  $y$  is given by,  $y=x+n$  where ' $n$ ' represents additive white Gaussian noise vector. It follows the normal distribution with mean  $\mu$  and variance  $\sigma^2$  [3].

$$f(n) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(n-\mu)^2}{2\sigma^2}\right)$$

Assume that the channel total bandwidth is  $B$  and the transmit power is  $S$ . Then the noise power in the bandwidth  $B$  is then  $N_0 B$ . The channel Signal-Noise Ratio (SNR) is [7]

$$\gamma = \frac{S}{N_0 B}$$

We here have considered AWGN and Rayleigh Channel. The channel also has frequency selective behavior. In this model the channel is considered as a multi-path fading channel. It consists of multiple independent Rayleigh faders, which is modeled as complex-value random processes. Causes of multipath include atmospheric ducting, ionosphere reflection and refraction, and reflection from water bodies and terrestrial objects such as mountains and buildings. By assuming uniform antenna pattern and uniform distributed incident power, the received signal at the receiver can be expressed as [3]

$$y = \sum_j a_j * x + n$$

where ' $n$ ' is the additive white Gaussian noise and ' $j$ ' represents multi-path from transmitter.

In Rayleigh fading, there is no direct component, and all signals reaching the receiver are reflected. Mathematically, the multipath Rayleigh fading wireless channels modeled by the channel impulse response (CIR) [8]

$$h(t) = \sum_{l=0}^{L_p-1} \alpha_l \delta(t - \zeta_l)$$

where,  $L_p$  is the number of channel paths,  $\alpha_l$  and  $\zeta_l$  are the complex value and delay of path  $l$ , respectively. The paths are assumed to be statistically independent, with normalized average power.

This is the final part of the communication system and the most important one. In the receiver the signal is received by forming the beam in the desired signal direction, demodulated and then combined by using receiver, and probabilistic symbol estimation is performed. At receiver, first of all, the directions of arrival of the multipath signals are determined. Here the assumption is that the multipath components of the

signal are strong enough to distinguish them from noise.

The subsequent part of the work is related to the use of adaptive equalization based on Maximum-Likelihood Sequence Estimation (MLSE) algorithm in each of the MIMO receiver branches. The MLSE equalizer block uses the Viterbi algorithm to equalize a linearly modulated signal through a dispersive channel. Both the function and the block output the maximum likelihood sequence estimate of the signal, using an estimate of the channel modeled as a finite input response (FIR) filter. When using the MLSE equalizer block, we specify the channel estimate and the signal constellation that the modulator in our model uses. The MLSE has two operation modes. The first is the continuous operation mode which enables us to process a series of vectors using repeated calls to the function where, the function saves its internal state information from one call to the next. The second is the reset operation mode which enables us to specify a preamble and postamble that accompanies our data. The block diagram of MIMO system using MLSE adaptive equalizer is as shown in the Figure 3.

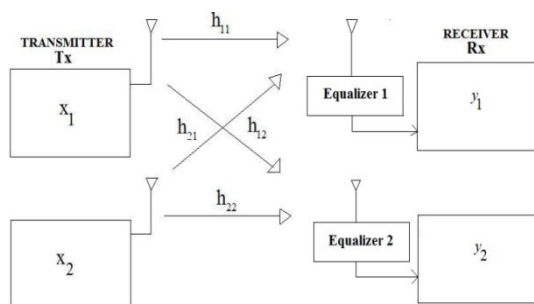


Figure 3: Block Diagram of MIMO system using MLSE adaptive equalizer.

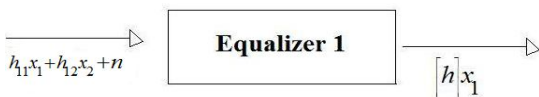


Figure 4: Diagram of equalizer 1

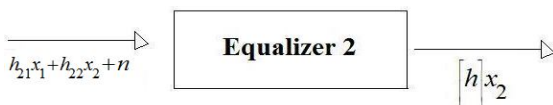


Figure 5: Diagram of equalizer 2

#### IV. EXPERIMENTAL RESULTS

The diagram shown in Figure 4 is the first equalizer, which receives the inputs obtained at first MIMO branch. For a  $2 \times 2$  case this is  $y_1 = h_{11}x_1 + h_{12}x_2 + n$ . Similarly, the diagram shown in Figure 5 is for the second arm, for which the received signal is  $y_2 = h_{21}x_1 + h_{22}x_2 + n$ . The use of equalizers improves the performance of the system. Once we know the offset between the transmitted and received bit vectors, we are ready to calculate the bit errors. BER has been measured by the error count over the total

number of bits. For any given modulation, the BER is normally expressed in terms of signal to noise ratio (SNR). For bit values of zero and one, a simple difference will reveal bit errors. Whenever there is a bit error, the difference between the bits will be  $\pm 1$ , and whenever there is not a bit error, the difference will be zero. The plot of BPSK modulation is shown in Figure 6. MIMO having two transmit and two receive antenna has diversity at both end of the wireless communication so the BER performance of MIMO system is better than SISO over same SNR.

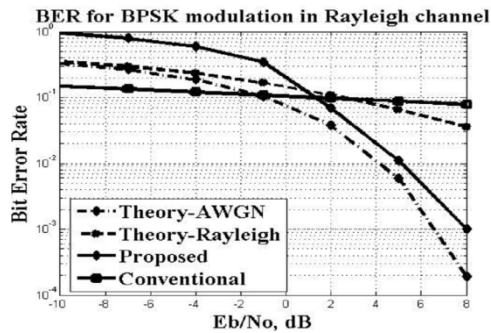
The MLSE equalizer yields the best performance, but is computationally intensive. The Table I consists the simulation parameters considered for simulation. Experimental results show that the MLSE based split equalizer is superior to conventional approaches. The Table II shows the symbol error rate (SER) for the proposed approach with two and four separate iterations. We see that the results are better with two iterations and gives less computational complexity. So in our work we consider the 2-iteration block to be the standard norm for performing the split MLSE equalization. In Figure 7, we show the composite plot of BER values obtained from AWGN, Rayleigh, conventional and proposed approaches between 1 to 7 dB SNR. We see that the proposed approaches provide 75% performance improvement at 7dB compared to conventional equalization method. This shows the superiority of the work. Some of the related work has been reported in [9].

TABLE-I SIMULATION PARAMETERS CONSIDERED

Parameter	Specification
Number of bits transmitted	1000
Number of Transmitters	2
Number of Receivers	2
Size for modulation (M)	4
Eb_No_dB	-10:10
Modulation Type	BPSK
Channel Model	AWGN, Rayleigh Fading Channel
Sample Time	1/9600 seconds
Maximum Doppler Shift	50 Hz
Path Delays	[0 1/10 <sup>4</sup> 2.1/10 <sup>4</sup> ]
Average Path Gains	[0, -2, -2]
Equalizer	MLSE
Length of training sequence	15
Traceback depth for equalizer	2
Number of Input sample per symbol	1
Number of Iterations	2

TABLE-II SER VALUES FOR THE PROPOSED METHOD

SI/No	SNR in dB	SER for 2 iterations	SER for 4 iterations
1	1	0.9690	1.9010
2	2	0.7880	1.6110
3	3	0.6210	1.1820
4	4	0.3220	0.6270
5	5	0.0900	0.1900
6	6	0.0070	0.0290
7	7	0.0010	0.0010

Figure 7: Curve for  $E_b/N_0$ , dB vs BER

## V. CONCLUSION AND FUTURE WORK

Here, we have proposed a split adaptive equalizer based on MLSE for MIMO channels. Experimental results show that the proposed approach is superior to conventional methods in terms of SER and BER in both AWGN and Rayleigh channels. The proposed work can also be improved by using Space Time Block Codes (STBC). This method can also be used for improving the capacity of MIMO channels

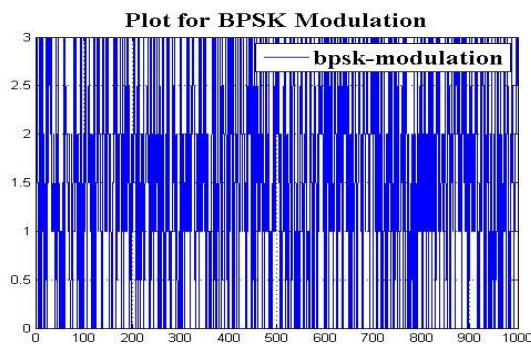


Figure 6: BPSK Modulation



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