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BER REDUCTION USING VARIOUS INTERFERENCE CANCELLATION DETECTOR IN MIMO SYSTEMS

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ABSTRACT
Multiple-input–multiple-output (MIMO) technology is a latter development in wireless communications and has been shown to increase channel capacity in single user systems. The use of multiple antennas at both the transmitter and receiver can considerably increase the channel capacity. These systems are called the multiple input multiple-output (MIMO)systems.
Growth of mobile data applications has increased the requirement for wireless communication systems which offers high throughput, wide coverage, and improved reliability. The main challenges in the design of such systems are the limited resources (like transmission power, scarce frequency bandwidth and limited implementation complexity) and the impairments of the wireless channels which includes noise, interference, and fading effects. MIMO system is one of the favorable wireless technologies that can attain above demands.
In this thesis, the performance of Multiple-input–multiple-output (MIMO) scheme is analyzed under Rayleigh fading channel for Minimum mean square error (MMSE), MMSE-SIC, Zero-forcing (ZF), ZF- Successive interference cancellation (ZF-SIC) equalization techniques. The analysis of this combining method is done on the basis of two major factors, E_b/N_0 (Signal to Noise Ratio) and Bit Error Rate (BER) performance using QAM modulation technique. We analyzed BER of QAM modulation with 2x2 MIMO with ZF-SIC and MMSE-SIC and it shows that MMSE-SIC gives better BER performance than ZF-SIC equalizer. Zero Forcing equalizer performs effectively only in theoretical assumptions that are when noise is zero. Its performance reduces in mobile fading environment. The MMSE equalizer results in improvement when compared to zero forcing equalizer.

Keywords:MIMO, Successive interference cancellation, Zero Forcing and Minimum mean square error equalization

INTRODUCTION

Communication between humans was first by the sound through voice. With the desire for slightly more distance communication, there came devices like drums, some visual methods like, smoke signals and signal flags were used. The optical communication devices, utilized the light portion of the electromagnetic spectrum. With the advancement of the technology, now the electromagnetic spectrum, outside the visible region, has been employedforcommunication,throughtheuseofradio.Oneofthehumankind'sgreatest natural resource is the electromagnetic spectrum and antenna is key factor for utilizing thisresource.

Wireless Communication:

Transmission from one place to another without using wires or cables is termed as Wireless Communication. In general, Wireless communication is considered as a subdivision of telecommunications. In broadcasting systems such as radio and TV is termed as one-way communication and in mobile phones is two-way communication. People do not remain in the same location, they can move one place to another, like office or home, and they need reliable connections. Wireless communication allows these facilities like users communicate to one another while travelling in car or bus or walking in streets. In traditional wire-based systems (such as telephones) wires required installation of cables or wires in one fixed location but now

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wireless communication provides such technologies those are available without any difficulties. Wired communication includes many types of fixed, cellular telephone, portable two-way radios communication devices and mobiles. Other examples are satellite television, headsets, keyboards and wireless computer mice, broadcast television[1].

MIMO

MIMOcommunication systemscan be defined intuitively [GSS+03PNG03] by considering that multiple antennas are used at the transmitting end as well as at the receiving end. The core idea behind MIMO is that signals samples in the spatial domain at both ends are combined in such a way that they either create effective multiple parallel spatial data pipes (therefore increasing the data rate), and/or add diversity to improve the quality (bit-error rate or BER) of thecommunication[5].

MIMO makes antennas work smarter by enabling them to merge data streams arriving from different paths and at different times to effectively increase receiver signal-capturing power. MIMO Systems have multiple transmit antennas and receive antennas having identical Receiver and Transmitter. These transmit Several Information flow in parallel in available space so termed as Spatial Multiplexing. Spatial diversity technology is used in smart antennas, which sets surplus antennas to better use. MIMO technology takes advantages of a natural radio-wave phenomenon known as multipath. Problems with multipath consider refraction, atmospheric ducting, and ionospheric reflection, terrestrial objects and reflection from water bodies such as hills and buildings. Where there is more than single antenna at transmitter and receiver end of the radio link, this is termed MIMO. MIMO can be used to provide improvement in channel throughputs as well as channel robustness.

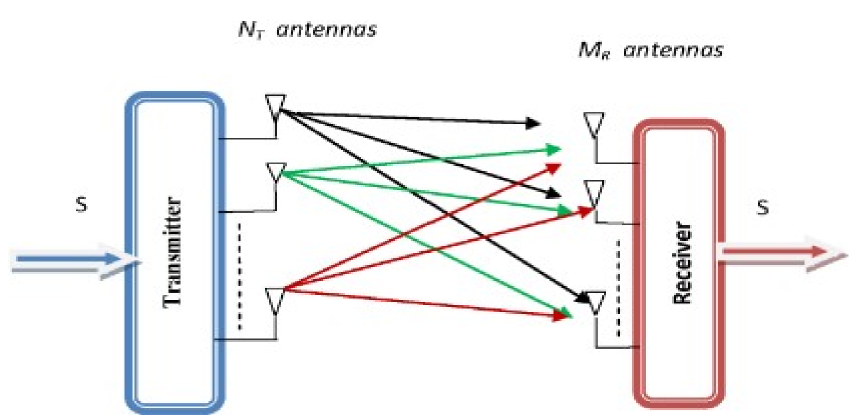

Fig 1 MIMO system for $N_T$transmit antenna and $M_R$receive antenna [6]

Figure 1 shows that MIMO system consists of $N_T$transmitting antennas and $M_R$receiving antennas. In order to derive the received signal matrix from this MIMO system.

Consider 2 × 2 MIMO system with Rayleigh faded channel assumed.

The received signal on the first receive antenna is,

$$y_1 = h_{11}x_1 + h_{12}x_2 + n_1 = \begin{bmatrix} h_{11} & h_{12} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1$$

The received signal on the second receive antenna is,

$$y_2 = h_{21}x_1 + h_{22}x_2 + n_2 = \begin{bmatrix} h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$$

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Where,
y_1, y_2 are the received symbol on the first and second antenna respectively,
$h_{1,1}$ is the channel from 1st transmit antenna to 1st receive antenna,
$h_{1,2}$ is the channel from 2nd transmit antenna to 1st receive antenna,
$h_{2,1}$ is the channel from 1st transmit antenna to 2nd receive antenna,
$h_{2,2}$ is the channel from 2nd transmit antenna to 2nd receive antenna,
x_1, x_2 are the transmitted symbols and
n_1, n_2 is the noise on 1st, 2nd receive antennas.
We assume that the receiver knows $h_{1,1}$, $h_{1,2}$, $h_{2,1}$ and $h_{2,2}$. The receiver also knows y_1 and y_2. For convenience, the above equation can be represented in matrix notation as follows:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

Equivalently,

$$y = Hx + n$$

In order to and reduce multipath and fading, some simpler versions of MIMO systems are used sometimes. These are as mentioned in the hierarchical order in which these were introduced in the industry and is mentioned in next subsections.

Single Input Single Output

SISO - Single Input Single Output is the simplest term of the radio link is specified in MIMO. This system works with a single antenna at transmitter as well as receiver side. There is no requirement of addition processing and diversity. Figure 2 shows a SISO system block diagram [7].

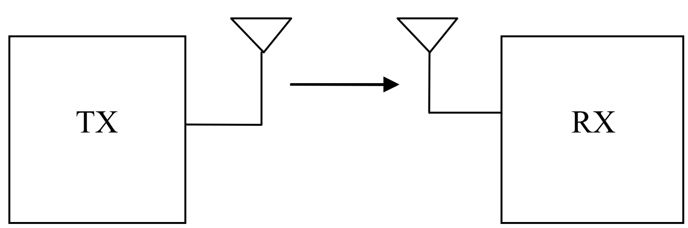

Fig 2 Block Diagram of SISO [3]

Single Input Multiple Output

The multiple output version of MIMO is SIMO (single Input Multiple Output), take place where the single antenna at the transmitter side and the multiple antennas at the receiver side. It is frequently used to capable a receiver system which receives signals from a number of commutative sources to combat the effects of fading. It has been used for many years with short wave listening/receiving stations to combat the effects of and interference ionospheric fading. The SIMO systems are satisfactory in some applications except where the receiving system is situated in the mobile device like mobile phones, the execution may be restricted by size battery, cost and cost [7]. Figure 3 shows a SIMO system blockdiagram.

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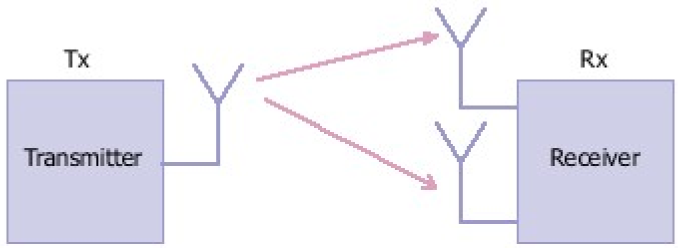

Fig 3. Block Diagram of SIMO [3]

Multiple Input Single Output

MISO or the multiple input and single output is a scheme in which there are multiple antennas at the transmitters side and single receiving antenna at the receiver side. It is a scheme of Radio Frequency (RF) wireless communication system. MISO is like SIMO except at the receiver side, a single antenna is employed. MISO is known as transmit diversity as well. In this scenario, the identical data is communicated unnecessarily from the two transmitter antennas. Then the receiver is capable to receive the best signal then that can be used to take out the necessary data. Figure 4 shows a MISO system block diagram [7].

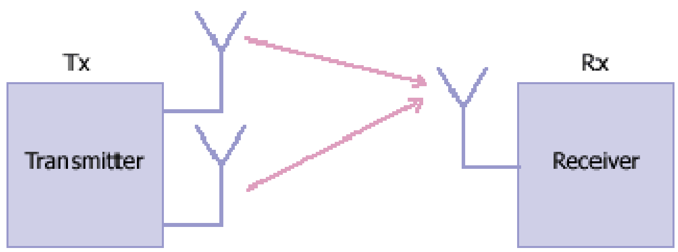

Fig 4. Block Diagram of MISO [3]

Using MISO, the advantage is that, multiple antennas and the unneeded processing is displaced from the source to the destination. This strategy has different applications like in W-LANS, Digital television. These systems are beneficial as the unneeded processing has been moved from receiving side for the transmitting side and therefore say in illustration of less power, processing and mobile phones is needed at the receiver end or the userend.

Multipath is the propagation phenomenon in the wireless communication that results in radio signals caused by two or more paths received at the receiving end. Causes of multipath consider refraction, atmospheric ducting, and ionospheric reflection, terrestrial objects and reflection from water bodies such as hills and buildings. Thus there would be multipath interference, problem with multipath fading. These paths include re-radiation by the ionospheric layers, ionospheric refraction, ground waves,etc.

Benefits of MIMO Systems

MIMO leads to significant increase in data rates that are possible in wireless communication systems and therefore this is a very crucial technology in 3G, 4G wireless communications since these 3G, 4G systems are based on very high data rates. They enable transmission of very high data rates above the wireless lines.

MIMO systems are used to enhance or improve the throughput (data rate) of wireless access, even under circumstances of multipath, interference and signal fading for far distances.

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MIMO EQUALIZATION

The distortion is established in the channel in terms of delay and amplitude when the signal passes throughout the channel those results in Inter Symbol Interference (ISI). ISI deforms the transmitted data that causing bit error at the receiver side. ISI has been known as the main hazard in high speed data transmission over wireless media. Therefore, Equalizers are used to deal with ISI. An equalizer is executed at the baseband or at IF in a receiver. And the essential receiving method of any communication resides with noise signal performance. Therefore to reduce the noise element exists in communication, equalization techniques are used. To present baseband waveforms the baseband complex envelope term can be used, the channel answer demodulated signal and adaptive equalizer algorithms are generally simulated and applied at thebaseband.

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Linear Detection Techniques

The idea behind linear detection techniques is to linearly filter received signals using filter matrices, as depicted in Figure 5. This category includes Zero-Forcing (ZF) and Minimum Mean Square Error (MMSE) techniques. Although linear detection schemes are easy to implement, they lead to high degradation in the achieved diversity order and error performance due to the linear filtering [7].

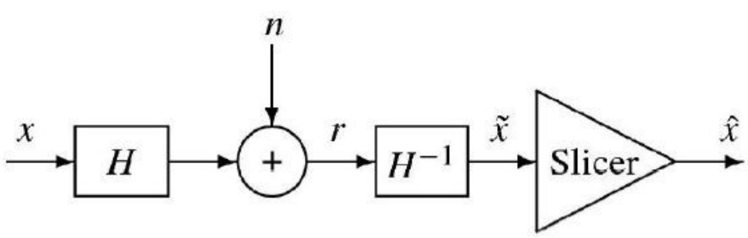

Fig 5. MIMO SM with linear receiver

Zero-Forcing

Zero-Forcing (ZF) technique is the simplest MIMO detection technique, which was proposed by Foschini (1996), where filtering matrix is constructed using the ZF performance-based criterion. ZF can be implemented by using the inverse of the channel matrix H to produce the estimate of transmitted vector $\hat{x}$.

$$\begin{aligned} \hat{x} &= H^{-1} r \\ &= H^{-1}(Hx) \qquad (1) \\ \hat{x} &= x \end{aligned}$$

where $^{-1}$ denotes the pseudo-inverse. Considering the noise term, the postprocessing signal is given by:

$$\begin{aligned} \hat{x} &= H^{-1} R \\ &= H^{-1}(Hx + n) \qquad (2) \\ \hat{x} &= x + H^{-1} n \end{aligned}$$

x consists of the decoded vector x plus a combination of the inverted channel matrix and the unknown noise vector. Because the pseudo-inverse of the channel matrix may have high power when the channel matrix is ill-conditioned, the noise variance is consequently increased and the performance is degraded. To alleviate for the

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noise enhancement introduced by the ZF detector, the MMSE detector was proposed, where the noise variance is considered in the construction of the filtering matrix.

Minimum Mean Square Error

Minimum Mean Square Error (MMSE) approach alleviates the noise enhancement problem by taking into consideration the noise power when constructing the filtering matrix using the MMSE performance-based criterion.

$$y = Hx + n$$

The Minimum Mean Square Error (MMSE) approach tries to find a coefficient 'W' which minimizes the criterion,

$$E \{ [Wy-x][Wy-x]^H \}$$

Solving,

$$W=[H^H H + N_0 I]^{-1} H^H. \quad (3)$$

where N_0 is the noise variance. The term offers a trade-off between the residual interference and the noise enhancement. As the SNR grows large, the MMSE detector converges to the ZF detector, but at low SNR it prevents the worst Eigen values from being inverted

When comparing to the equation 2 , apart from the '$N_0 I$' term both the equations are comparable. In fact, when the noise term is zero, the MMSE equalizer reduces to Zero Forcing equalizer.

NON LINEAR EQUALIZATION TECHNIQUE:

Maximum Likelihood Detector

Maximum Likelihood Detector (MLD) is considered as the optimum detector for a MIMO system given by Equation (3.1). The transmitted signal could be effectively recovered at the receiver based on the following minimum distance criterion,

$$\tilde{x} = \arg_{x_k \in (x_1, x_2, \_\_\_, x_N)} \min \| r - H_{x_k} \| \quad (4)$$

where x is the estimated symbol vector. Using the above criterion, MLD compares the received signal with all possible transmitted signal vector which is modified by channel matrix H and estimates transmit symbol vector x. Although MLD achieves the best performance and diversity order, it requires a brute-force search which has an exponential complexity in the number of transmit antennas and constellation size. For example, if the modulation scheme is 64-QAM and 4 transmit antenna, a total of 64^4 = 16777216 comparisons per symbol are required to be performed for each transmitted symbol. Thus, for high modulation order and high transmit antenna, N MLD becomes infeasible [8].

Maximum A posteriori Probability (MAP)

The MAP decision criterion is based on selecting the symbol corresponding to the maximum of the set of posterior probabilities $\{P(w_m/y)\}$. The posterior probability is defined as

$$\{P(w_m/y)\}= P(signal\ being\ transmitted | y) \quad (5)$$

where y is the received vector. Although MAP rule offers optimal error performance, it suffers from complexity issues.

SUCCESSIVE INTERFERENCE CANCELLATION (SIC)

As simultaneous wireless systems are flattering increasingly interference-restricted, there is a rising concern in using advanced interference moderation methods to better the system execution in addition to the conventional scheme of treating interference as background noise [4]. One important scheme is successive interference cancellation (SIC). The optimum signal is perceived first rather than of jointly perceiving signals from all the antennas and its interference is cancelled from the individual received signal in the SIC receiver. Then the second optimum signal is perceived and its interference cancelled from the rest of the signals and so on. This technique is known as successive interference cancellation (SIC) [5].

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SIC is also called as OSIC (Ordered Successive Interference Cancellation) method. It is a collection of linear receivers where every receiver perceives one of the parallel data streams, with the perceived signal elements successively cancelled by the received signal at individual stage. Particularly the received signal in is subtracted by the perceived signal so that in the subsequent stage rest of the signals among the less interference can be used. Figure 6 shows the block diagram of SIC signal estimation.

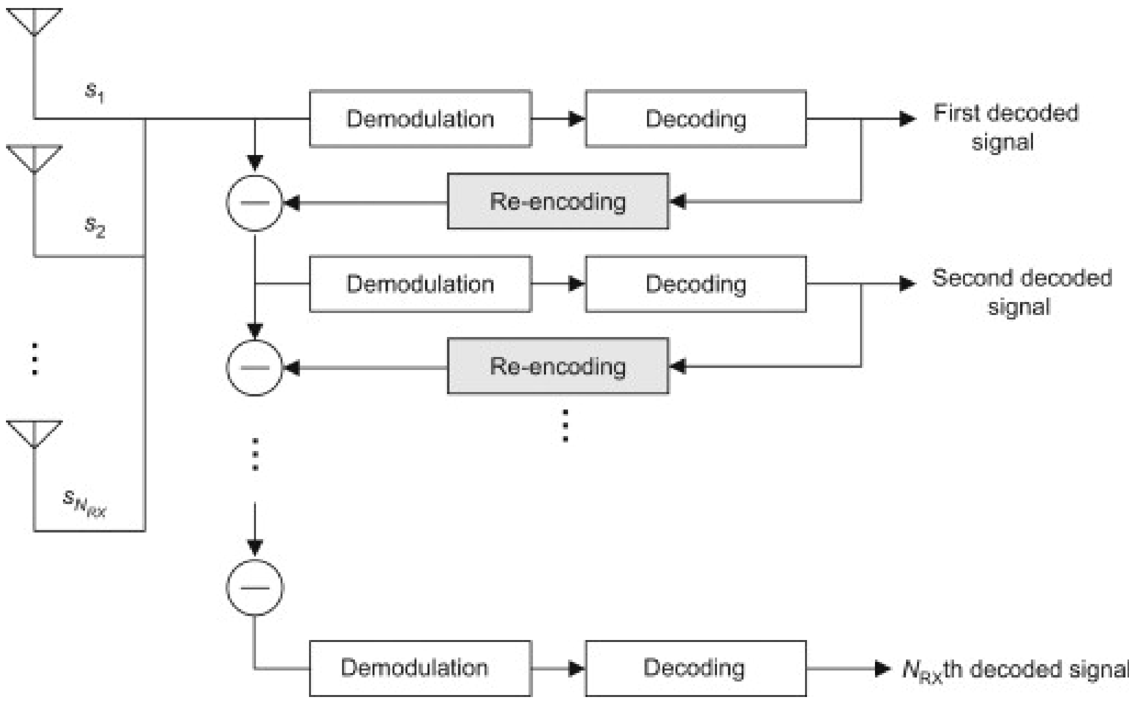

Fig 6 SIC signal estimation [5]

In the previously described successive interference cancellation technique, estimated symbol is chosen arbitrarily and then later on its effect is subtracted from the received symbol *y1* and *y2*. A better result can be achieved if we choose estimated symbol who has greater influence than other symbol. For this to take effect, first of all the power of both the symbol is calculated at thereceiversendandthenthesymbolwithhigherpowerischosen for subtractionprocess.

The power of transmitted symbol x_1 is given by the following equation,

$$P_{x_1} = |h_{11}|^2 + |h_{21}|^2$$

Similarly the power of the transmitted symbol x_2 is given by the following equation,

$$P_{x_2} = |h_{12}|^2 + |h_{22}|^2$$

If $P_{x1} > P_{x2}$, the x_1 is subtracted from y_1 and y_2 and then this technique re-estimate the $\hat{x}_2$.

i.e.,

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} y_1 - h_{11}\widehat{x_1} \\ y_2 - h_{12}\widehat{x_1} \end{bmatrix} = \begin{bmatrix} h_{12}\widehat{x_1} + n_1 \\ h_{22}\widehat{x_1} + n_2 \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{12} \\ h_{22} \end{bmatrix} x_2 + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

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$$r = h\,x_2 + n$$

By applying maximum ratio combining (MRC) step, the equalized symbol is given by the following formula,

$$\widehat{x_2} = \frac{h^h\,r}{h^h\,h} \qquad (7)$$

Similarly if , the $x_2$is subtracted from y_1 and y_2 and re-estimation of $\widehat{x_1}$ is carried out.

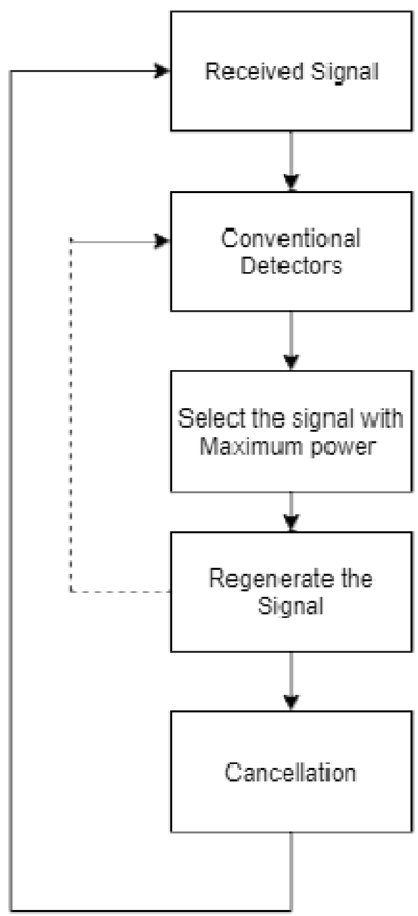

Figure 7. Algorithm Used by SIC[4]

The successive interference cancellation scheme uses the algorithm shown in Figure 3.2. During every iteration of the scheme, all the user's signals are estimated. The signal with the largest power is then regenerated and subtracted from the buffered received signal. The remaining signals are now re-estimated and a new largest user is selected. The process is continued until all the users' signals have been recovered or the maximum allowable number of cancellations is reached. Successive interference cancellation is robust to imperfect power control in a CDMA system. This is because of the fact that the interference offered by the best estimated signals are eliminated from the received waveform. Estimating the power of the user is fairly straightforward in a

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coherent DS BPSKsystem, since the receiver is equipped with the knowledge of the amplitudes and phase of the signal we can reconstruct the signal for reconstruction.

The reasons for cancelling the signals in descending order of signal strength are obvious. First, it is easier to acquire and perform demodulation on the strongest users i.e. the probability of making a correct decision is high. Second, the removal of strongest users offers the maximum benefit for the remaining users.The SIC detector requires only a minimal amount of additional hardware and has the potential to provide significant improvement over the conventional detector. It does, however, pose a couple of implementation difficulties. First, one additional bit delay is required per stage of cancellation. Thus, a trade-off must be made between the number of users that are cancelled the amount of delay that can be tolerated. Second, there is a need to re-order the signals whenever the power profile changes. Again, a trade-off must be made between theprecision of the power ordering and the acceptable processing complexity.

METHODOLOGY

ZF-SIC and MMSE-SIC equalizers with 2x2 MIMO system with QAM (Quadrature Amplitude modulation) in Rayleigh fading environment has been designed.In this methodology we have discuss about the modified SIC that is integration of SIC with linear receivers. This integration has caused the increased in efficiency of the MMSE and ZF equalizers.

Modified SIC

As we have discussed about the linear and nonlinear equalization techniques used in the detection of the transmitted signals in MIMO. The SIC is modified to increase the efficiency of the receiver by combining the linear and nonlinear receivers together. SIC is combined along the MMSE and ZF to increase the performance of the equalizer. It adopted so that there will be better reception of the data at the receivers. We will discuss about the MMSE-SIC and ZF-SIC further.

MMSE based SIC detection

MMSE based SIC detection MMSE method is used for symbol estimation. The MMSE weight matrix is given by:

$$W=[H^H H + N_0 I]^{-1} H^H \tag{8}$$

Where N_0 is the noise variance.

The 1st stream is calculated with the 1st row vector of the MMSE weight matrix. After calculation and segment to produce $\widehat{x_{(1)}}$ the rest of the signal in the first stage is formed by subtracting it from the received signal, thatis:

$$\begin{aligned}\widehat{y_{(1)}} &= y - h_{(1)}\widehat{x_{(1)}} \\ &= h_{(1)}\left(x_{(1)} - \widehat{x_{(1)}}\right) + h_{(2)}x_{(2)} + \cdots + h_{(M_T)}x_{(M_T)} + n\end{aligned} \tag{9}$$

If $x_{(1)}= \widehat{x_{(1)}}$ in that case the interference is effectively rejected in the course of calculating $x_{(2)}$; but, if $x_{(1)} \neq \widehat{x_{(1)}}$, in this error propagation is sustained because the minimum mean square error weight, which has been considered under the situationof $x_{(1)}= \widehat{x_{(1)}}$ is used for calculating $x_{(2)}$.

In the previous stage, owing to the error propagation caused by incorrect decision,the order of detection has major control on the overall performance of ordered successive interference cancellation detection. So we use the post2-detection SINR (Signal-to Interference-Noise-Ratio) for order. Signals having higher post-detection SINR"s are perceived first. Consider the linear minimum mean square error detection with the following post-detection SINR,

$$SINR_i = \frac{E_x|W_{i,MMSC}h_i|^2}{E_x \sum_{l\neq i}|W_{i,MMSC}h_l| + \sigma^2 |W_{i,MMSC}|^2} \quad i = 1,2,\ldots\ldots, M_T \quad (10)$$

Where, $E_x$is the energy of the transmitted signals, $h_i$is the i_{th} column vector of the channel matrix H.

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ZF based SICdetection:

In this ZF weight matrix is used for symbol estimation that is given by:

$$□_{□□} = (□^{□}□)^{-1}□^{□} \quad (11)$$

The 1st stream vector is calculated with the 1st row vector of the ZF weight matrix. After calculation and segment to produce □, the rest of the signal in the first stage is formed by subtracting it from the received signal, that is:

$$\widehat{y_{(1)}} = y - h_{(1)}\widehat{x_{(1)}}$$
$$= h_{(1)}\left(x_{(1)} - \widehat{x_{(1)}}\right) + h_{(2)}x_{(2)} + \cdots + h_{(M_T)}x_{(M_T)} + n(12)$$

If $x_{(1)} = \widehat{x_{(1)}}$ in that case the interference is effectively rejected in the course of calculating $x_{(2)}$; but, if $x_{(1)} \neq \widehat{x_{(1)}}$, in this error propagation is sustained because the minimum mean square error weight, which has been considered under the situationof $x_{(1)} = \widehat{x_{(1)}}$ is used for calculating $x_{(2)}$.

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Signals with a higher post-detection Signal-to Interference-Noise-Ratio are perceived first. Once □□SINR values are estimated by using the zero forcing weight matrix, we select the resultant layer with the highest SINR. In the course of selecting the second perceived symbol, the interference owing to the first perceived symbol is rejected from the received signals. Assume that (1)= □ (i.e., the lth symbol has been rejected first). Then, the channel matrix is customized by removing the channel gain vector corresponding to the l^{th} symbol asfollows:

$$H_{(l)} = [h_1\ h_2 \ldots\ldots\ldots\ h_{l-1}\ h_{l+1} \ldots\ldots\ldots\ h_N]$$

Using the modified channel matrix $□^{(1)}$in the place of H the ZF weight matrix is re- estimated. Now (M_T-1) symbols are estimated to select the symbol with the maximum SINR. The same procedure is repeated with the rest of the symbols after rejecting the after that symbol with the maximum SINR [6].

Proposed Methodology

Initially data is generated using the random bit generator for specified number of bits. The bits are generated with equal probability. The number receivers and transmitters are specified at the initial state of the program. In this work we have assumed the number of transmitters and receivers both as 2.

The transmitter is designed with QAM modulation in this work as seen in the below flow chart. QAM (quadrature amplitude modulation) is a method of combining two amplitude-modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. In a QAM signal, there are two carriers, each having the same frequency but differing in phase by 90 degrees (one quarter of a cycle, from which the term quadrature arises). One signal is called the I signal, and the other is called the Q signal. Mathematically, one of the signals can be represented by a sine wave, and the other by a cosine wave. The two modulated carriers are combined at the source for transmission. At the destination, the carriers are separated, the data is extracted from each, and then the data is combined into the original modulating information.

The Rayleigh model is used as the channel. The signal is faded based on the signal to be transmitted. Then the Rayleigh fading model is multiplied with the signal to be transmitted to get the receiver signal. The received signal is faded as the real time fading in the wireless channel. The Rayleigh channel is designed as,

$$h = \frac{1}{\sqrt{2}}(h_R + jh_I) \quad (13)$$

The transmitted signal 'x' is then multiplied with the channel gain 'h'. Even the AWGN noise is added to the received signal. Since the Rayleigh channel also includes the noise components that get added. Final received signal is obtained as,

$$y = hx + n$$

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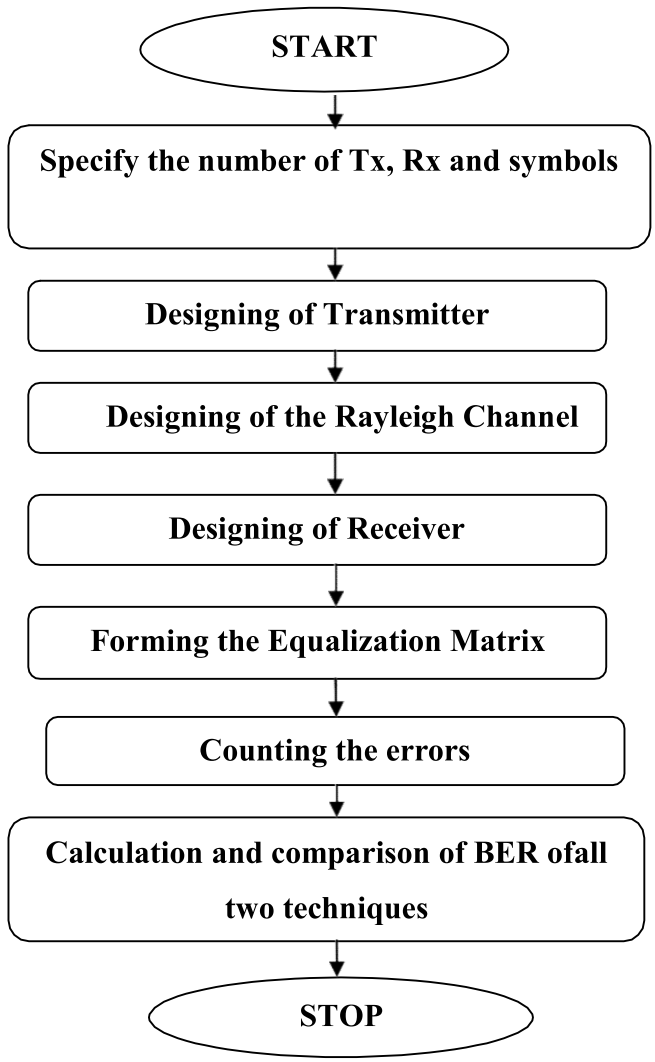

Figure 8 Flow chart of the Proposed work

The receiver is designed based equalization required. The MMSE and ZF receiver model is explained in the above sections. The receiver design is given by the equation (2) and equation (3). The model is simulated based on this equalization technique. The equalization matrix is obtained using this equation. Further error are calculated compared to the original signals transmitted. The same model is used for ZF-SIC and MMSE-SIC equalizer.

In order to compare the performance of ZF and MMSE with ZF-SIC and MMSE-SIC combine in a typical MIMO system with 2x2 receivers was considered. The receivers were using QAM modulation with BER defined by equation(2). Simulations were carried out using MATLAB 2019.

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RESULTS AND DISCUSSION

As mentioned in the above chapter the equalizers are designed based on the Modified SIC section. The proposed methodology is followed to reduce the BER for the equalizer compared to the ZF and MMSE receiver. As compared with the paper which shows the results for the MMSE and ZF equalizer. For same number of combinations of the transmitter and receiver antennas. The MMSE-SIC and ZF-SIC equalizer is designed for all those combinations and compared with the results obtained in the base paper [1].

Table 5.1: General Parameters of the Model.

Parameter	Value
Modulation type	16-QAM
N	2,4
M	2,4
Mode of channels	Rayleigh
Order of SIC	1

Figure 9 shows the graph of SER v/s SNR for the MMSE and ZF with 16-QAM of 2X2 MIMO. From the above results we can conclude MMSE and ZF based on SIC has better BER. For example, with the SNR of 20 db the BER for MMSE and ZF is almost similar closer to 0.5 but the BER for same SNR for the improved MMSE and ZF based on SIC have a improved BER, MMSE-SIC with 0.00036 and ZF with 0.0014. BER has improved compared to the previous method.

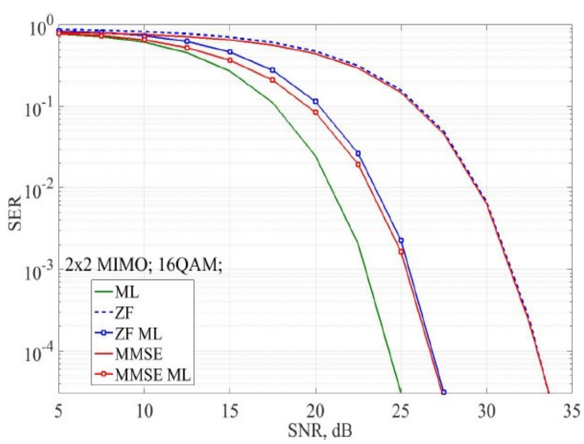

Figure 9 SER v/s SNR for2x2 MIMO with MMSE and ZF

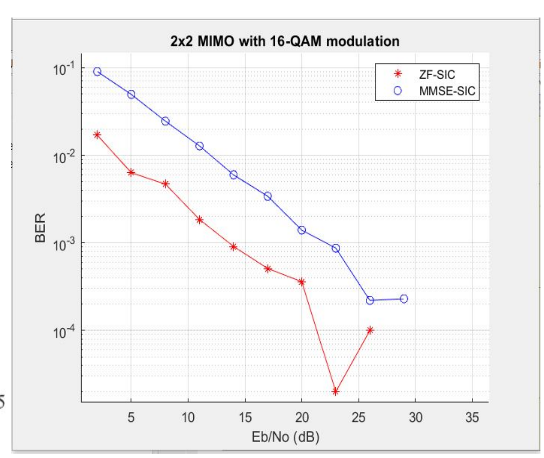

Figure 10 SER v/s SNR for 2x2 MIMO with MMSE-SIC and ZF-SIC

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Figure 9 shows the graph of SER v/s SNR for the MMSE and ZF with 16-QAM of 2X2 MIMO. From the above results we can conclude MMSE and ZF based on SIC has better BER. For example, with the SNR of 20 db the BER for MMSE and ZF is almost similar closer to 0.5 but the BER for same SNR for the improved MMSE and ZF based on SIC have a improved BER, MMSE-SIC with 0.00036 and ZF with 0.0014. BER has improved compared to the previous method.

It can be observed from the figures 9 and 10 that:

- MMSE and ZF based on ZF equalizers have better results compared to MMSE and ZF.
- BER has decreased with increase in E_b/N_0(signal to noise ratio).
- MMSE-SIC is better compared to ZF-SIC.
- Equalizers based on SIC have fluctuations at higher E_b/N_0.

Since MMSE-SIC give an optimized performance in terms of SNR and BER thus it is considered for current 2x2 MIMO systems with QAM modulation scheme.

Figure 11 shows the graph of SER v/s SNR for the MMSE and ZF with 16-QAM of 4X4 MIMO. From the above results we can conclude MMSE and ZF based on SIC has better BER according to Figure 12. For example, with the SNR of 20 db the BER for MMSE and ZF is almost similar closer to 0.5 but the BER for same SNR for the improved MMSE and ZF based on SIC has a improved BER, MMSE-SIC with 0.00011 and ZF with 0.00055. BER has improved compared to the previous method.

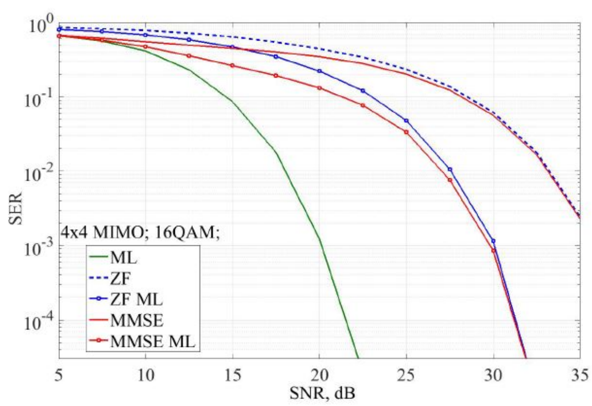

Figure 11 SER v/s SNR for 4x4 MIMO with MMSE and ZF

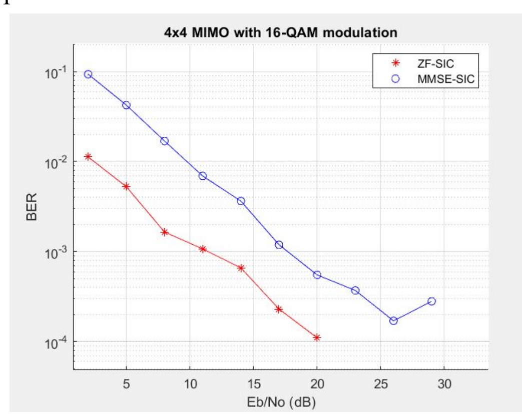

Figure 12. SER v/s SNR for 4x4 MIMO with MMSE-SIC and ZF-SIC

From the above results we can conclude that MMSE and ZF based on SIC have better results compared to the MMSE and ZF equalizer with Rayleigh channel. MMSE-SIC is more efficient compared to ZF-SIC because the ZF equalizer do not work efficiently in presence of noise. With the improvement of ZF into MMSE, the results have improved.

CONCLUSION

Equalization techniques are of more importance in the design of high data rate wireless systems. They can tackle for inter symbol interference even in mobile fading Channel with high efficiency. Here we analyzed the performance of different equalization techniques to find out suitable equalizer for 2x2 and 4x4 MIMO channel in Rayleigh multipath fadingenvironment.

We analyzed BER of QAM modulation with 2x2 MIMO with ZF-SIC and MMSE-SIC and it shows that MMSE-SIC gives better BER performance than ZF-SIC equalizer. Zero Forcing equalizer performs effectively only in theoretical assumptions that are when noise is zero. Its performance reduces in mobile fading environment. Minimum Mean Square Error (MMSE) equalizer uses LMS (Least Mean Square) as standard to

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compensate ISI. The MMSE equalizer results in improvement when compared to zero forcing equalizer.

From the results we conclude that Minimum Mean Square Equalization with simple successive interference cancellation (MMSE-SIC) case, addition of optimal ordering results in improvement for BER. So, by observing the simulation results we conclude that by using MMSE with SIC, interference can be cancelled at optimum level even in a mobile fading channel.

In this work the performance of MIMO data transmission system is analysed for a channel with a flat fading. Method of improving a performance of decoders Zero-Forcing and MMSE based on a combination with successive interference cancellation is proposed. The proposed algorithm can significantly increase a performance of classical algorithms ZF and MMSE with an equal number of transmitting and receiving antennas. However, a complexity of these algorithms increases but remains significantly smaller for SIC algorithm. Combination of Zero-Forcing or MMSE with SIC algorithm don't lose in efficiency.

FUTURE SCOPE

- In future work, for further improvement of the BER performance of MIMO systems will use more number of antennas both at Transmitter and Receiver side (2x4 and4x6).
- Also there is a chance to implement the MIMO system by using different Modulation types such as 64-QAM (Quadrature Amplitude Modulation), MSK (Minimum ShiftKeying).
- We examined our work with Rayleigh fading environment. For further improvement we can use different fading environments such as Rician fading and Nakagamifading.
- We used in this AGWN noise and further we can use shot noise, thermal noiseetc.
- Here in this thesis we used ideal environment with channel information known and further we can use with this unknown channelinformation.

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