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CCI Cancellation for Cooperative Communication Systems using MMSE SIC with Optimal Ordering

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Abstract: *In the cellular environment, there will be channel reuse and therefore co-channel interference from other cells exists and as a result the performance will be degraded. So it is necessary to reject the co-channel interference. In this paper, co-channel interference (CCI) cancellation scheme for cooperative communication systems in wireless communication network has been proposed. In the multipath environment, CCI causes more performance degradation in wireless network. Several interference signal mitigation methods have been proposed including Maximum Likelihood (ML), Zero Forcing (ZF), MMSE and Successive Interference Cancellation (SIC). Of all these techniques, MMSE SIC with optimal ordering will reject CCI efficiently and offers performance improvement compared with conventional SIC. In this paper, the overall system performance has been demonstrated in terms of bit error rate (BER) by considering Rayleigh fading channel.*

Keywords: *Cooperative communication, Co-channel interference, ZF, MMSE, SIC, optimal ordering*

I. INTRODUCTION

From recent years, the technology of wireless communication has developed rapidly and the users have higher requirements on the quality of communications. Today, wireless devices are evolving into multipurpose systems with data extensive applications running on them. Such applications require high-speed connectivity and strong error protection. Those needs, along with the exploding growth of wireless networks and limited spectrum resources, have created a capacity crunch and high interference in today's wireless networks. This situation entails a move towards the development of new wireless techniques that can achieve a more efficient use of the available spectrum. While emerging techniques such as multi-input multi-output systems (MIMO) increase the spectrum efficiency in terms of the number of bits per hertz of bandwidth, its usage is limited because of the size, cost, and power constraints posed by portable wireless devices. An alternative approach called cooperative communications promises to deliver some of the benefits of MIMO within the given constraints. Cooperative communication refers to the collaborative processing and retransmission of the overheard information at those stations surrounding the source. The notion of cooperation takes full advantage of the broadcast nature of the wireless channel and creates spatial diversity, in particular transmission diversity, thereby achieving tremendous improvements in system robustness, capacity, delay, interference and coverage range [1-2].

In the multipath environment, Co-channel Interference (CCI) is caused due to the cells that reuse the same frequency set [3]. This can severely affect the performance of wireless LAN (WLAN) system. The sources of CCI other than frequency reuse are antenna height, size, directionality and channel capacity degradation. In this paper, we analyse the co-channel interference and its cancellation methods for wireless systems using MIMO technology in detail. CCI is mitigated by several interference cancellation methods such as Zero Forcing (ZF), MMSE and Successive Interference Cancellation (SIC). Among these, the combination of MMSE with SIC is going to be used. Besides MMSE SIC with optimal ordering will be used for rejecting CCI efficiently in order to achieve additional diversity gain.

The rest of the paper is organized as follows. Section II deals with cooperative communication network. Section III describes the interference scenario. In Section IV CCI cancellation schemes with linear receivers of ZF, MMSE and SIC with optimal ordering has been discussed. Simulation results are carried out in section V. Finally, the paper is concluded in section VI.

II. Cooperative Communication

The broadcast nature of wireless communications suggests that a source signal transmitted towards the destination can be "overhead" at neighbouring nodes. Cooperative communication refers to processing of this overhead information at the surrounding nodes and retransmission towards the destination to create spatial diversity, thereby to obtain higher throughput and reliability. In wireless networks, it has become more and more attractive recently since it could mitigate the severe channel impairments arising from multipath propagation. We inscribe the benefits of cooperative transmission than traditional non–cooperative communication. In a cooperative communication system, each wireless user is assumed to transmit data as well as act as a cooperative agent for another user [1]. In this system, sources first transmit their data to the Relay Nodes (RN) as shown in Figure 1. Each RN then processes and forwards its received data information to the destination nodes following some cooperation protocols. With the received signal from the RNs, the destinations decode the data from their corresponding sources.

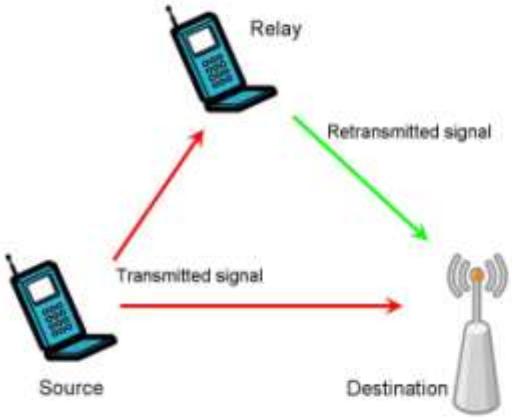

Figure 1: Cooperative communication network

Recently, cooperative communications for wireless networks have gained much interest due to its ability to mitigate fading in wireless networks through achieving spatial diversity, while resolving the difficulties of installing multiple antennas on small communication terminals [2]. In cooperative communication, a number of relay nodes are assigned to help a source in forwarding its information to its destination, hence forming a virtual antenna array. This type of communication is more attractive, since it mitigates the severe channel impairments arising from multipath propagation. Cooperative diversity systems consist of multiple nodes that share resources in order to create multiple diversity channels and thereby improve system performance, typically in terms of availability, range and throughput. It is shown that that cooperative communications are very promising techniques in order to boost the performance of practical wireless network. Whenever by employing this cooperative communication network, one of the main problem encountered in the wireless communication system is "Co-channel Interference (CCI)", which causes degradation of system performance. This CCI occurs due to co-channel reuse utilization [3].

III. Co-channel Interference

The signal which leaks its energy into the other band is known as "Interference". It is a major limiting factor in the performance of wireless systems which causes degradation in the quality of signal.
There are two major types of interference namely–

1. Adjacent channel interference (ACI)
2. Co-channel interference (CCI).

1. Adjacent Channel Interference: It is a type of interference resulting from signals which are adjacent in frequency to the desired signal. This can be reduced by keeping the frequency separation between each channel in a given cell is as large as possible.
2. Co-Channel Interference: It is a type of interference due to the phenomenon of frequency reuse. Co-channel interference occurs between two access points (APs) that are on the same frequency channel. The sources of co-channel interference other than frequency reuse are antenna height, size and directionality.

In this paper, co-channel interference (CCI) cancellation strategy for cooperative communication systems in wireless communication network has been proposed. For a small coverage area system, this co-channel interference is a major consideration by the reuse of frequencies [3].

IV. CCI Cancellation Methods

There are several interference signal mitigation methods including Zero Forcing (ZF), Minimum Mean Square Error (MMSE) and Successive Interference Cancellation (SIC).

A. Zero Forcing (ZF) Equalizer:

It is a linear equalization technique which inverts the frequency response of the channel to the received signal. The name itself corresponds to bringing down the interference to zero in a noise free case. If the channel response for a particular channel is H(s) then the input signal is multiplied by the reciprocal of this. This is intended to remove the effect of channel from the received signal, by reducing the interference [4].
For simplicity, let us consider a 2x2 MIMO channel, the channel is modelled as,
In the first time slot, the received signal on the first receive antenna is,

$$r_1 = h_{1,1}t_1 + h_{1,2}t_2 + n_1 = \begin{bmatrix} h_{1,1} & h_{1,2} \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \end{bmatrix} + n_1 \quad \textbf{(1)}$$

The received signal on the second receive antenna is,

$$r_2 = h_{2,1}t_1+h_{2,2}t_2+n_2 = \begin{bmatrix} h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \end{bmatrix} + n_2 \quad \textbf{(2)}$$

where r_1, r_2 are the received signals; t_1, t_2 are the transmitted signals and n_1, n_2 is the noise on 1^{st} and 2^{nd} receiver antennas respectively.

For convenience, the above equations can be represented in matrix notation as follows:

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad \textbf{(3)}$$

Equivalently, $R = HT + N$ **(4)**

where R is received signal, T is transmitted signal, H is channel matrix and N is channel noise.

We consider the ZF linear detector in order to reject the interference, by satisfying the condition given below and there by solving T,

$$W_{ZF}H = I \quad \textbf{(5)}$$

where I is Identity matrix and W_{ZF} is Equalization matrix/ZF decoding matrix given as

$$W_{ZF} = (H^H H)^{-1} H^H \text{ and } H = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \quad \textbf{(6)}$$

The term,

$$H^H H = \begin{bmatrix} h^*_{1,1} & h^*_{2,1} \\ h^*_{1,2} & h^*_{2,2} \end{bmatrix} \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} = \begin{bmatrix} |h^2_{1,1}| + |h^2_{2,1}| & h^*_{1,1}h_{1,2} + h^*_{2,1}h_{2,2} \\ h^*_{1,2}h_{1,1} + h^*_{2,2}h_{2,1} & |h^2_{1,2}| + |h^2_{2,2}| \end{bmatrix} \quad \textbf{(7)}$$

This matrix is known as the Pseudo Inverse for a general m x n matrix.

By using ZF equalization, the receiver can obtain an estimated signal for the received signal R and is given by

$$\widehat{T} = W_{ZF}R \quad \textbf{(8)}$$

where $\widehat{T}$ is an estimate matrix of the transmitted signal.

And after ZF decoding the estimated signal can be expressed as

$$\hat{t}_1 = t_1 + \frac{h_{2,2}n_1 - h_{1,2}n_2}{h_{1,1}h_{2,2} - h_{1,2}h_{2,1}} \quad \textbf{(9)}$$

$$\hat{t}_2 = t_2 + \frac{h_{1,1}n_2 - h_{2,1}n_1}{h_{1,1}h_{2,2} - h_{1,2}h_{2,1}} \quad \textbf{(10)}$$

The Zero Forcing algorithm is ideal when the channel is noiseless. However, when the channel is noisy, the ZF algorithm will amplify the noise greatly where the channel has small magnitude in the attempt to invert the channel completely.

B. MMSE Equalizer:

A Minimum Mean Square Error (MMSE) estimator is a method 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 CCI completely, but minimizes the total power of the noise and interference components in the output [4].

The Minimum Mean Square Error (MMSE) approach tries to find a coefficient W which minimizes the power of the noise component and is given by

$$E\{[W_{MMSE}\,R - T][W_{MMSE}\,R - T]\text{^}H\} \quad \textbf{(11)}$$

where W_{MMSE} is Equalization matrix/MMSE decoding matrix

$$W_{MMSE} = \arg_{W_{MMSE}} \min E\lfloor \|W_{MMSE}\,R - T\|^2 \rfloor \quad \textbf{(12)}$$

By using an orthogonality principle, the following result is obtained

$$E\lfloor (W_{MMSE}\ R - T)T^H \rfloor = 0_{2,2} \quad \textbf{(13)}$$

From (12) and (13) equations, the decoding matrix can be expressed as

$$W_{MMSE} = [H^H H + N_0 I]^{-1} H^H \quad \textbf{(14)}$$

where W_{MMSE} is the Equalization matrix/MMSE decoding matrix, H is the channel matrix, I is the identity matrix, N_0 is the channel noise and $0_{2,2}$ is 2x2 zero matrix.

The big difference about two equalizers is, ZF equalizer increases significantly the noise term in order to recover the original signal, MMSE does not do. In fact, when the noise term is zero, the MMSE equalizer reduces to ZF equalizer.

C. SIC:

Successive Interference Cancellation (SIC) is a well-known technique to extract the target signal from multiple signals which causes the unwanted interferences by signal collision or overlapping [5]. SIC uses successive signal subtraction using strong reference signals. In this approach, users are cancelled serially from strongest to weakest on the basis of power assumption.

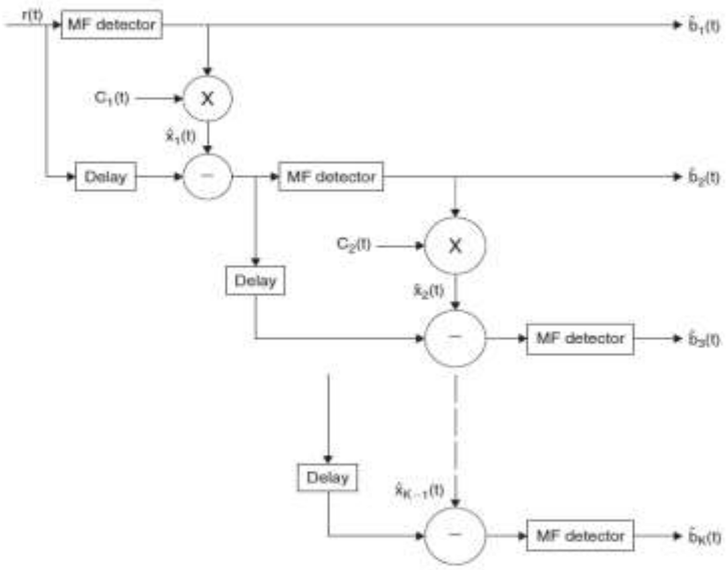

Figure 2: Schematic showing Successive Interference Cancellation

D. ZF and MMSE with SIC:

After linear equalization, additional diversity gain can be achieved by adopting interference cancellation technique. To achieve better performance, interference cancellation techniques can be combined with SIC. If the ZF or MMSE decoding process is completed, interference can be perfectly cancelled by employing SIC scheme [6].

For 2X2 MIMO system, Let us find out the transmit signal which comes at higher power at the receiver. The received power at both antennas corresponding to the transmitted signal t_1 is

$$p_{t_1} = |h_{1,1}|^2 + |h_{2,1}|^2 \quad \textbf{(15)}$$

Similarly for transmitted signal t_2, the received power is

$$p_{t_2} = |h_{1,2}|^2 + |h_{2,2}|^2 \quad \textbf{(16)}$$

If $p_{t_1} < p_{t_2}$, then receiver decides to remove the effect of $\hat{t}_2$ from the received signals r_1 and r_2 and obtain

$$\begin{bmatrix} E_1 \\ E_2 \end{bmatrix} = \begin{bmatrix} r_1 - h_{1,2}\hat{t}_2 \\ r_2 - h_{2,2}\hat{t}_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} \\ h_{2,1} \end{bmatrix} t_1 + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad \textbf{(17)}$$

where E is the re-estimated signal vector and can be generalized as $E = ht_1 + n$

Thus $\hat{t}_1$ can be re-estimated as

$$\hat{t}_1 = \frac{h^H E}{h^H h} = \frac{\begin{bmatrix} h_{1,1} \\ h_{2,1} \end{bmatrix}^H \begin{bmatrix} E_1 \\ E_2 \end{bmatrix}}{\begin{bmatrix} h_{1,1} \\ h_{2,1} \end{bmatrix}^H \begin{bmatrix} h_{1,1} \\ h_{2,1} \end{bmatrix}} \quad \textbf{(18)}$$

In the same way, if $p_{t_1} > p_{t_2}$, then receiver decides to remove the effect of $\hat{t}_1$ from the received signals r_1 and r_2 and obtain

$$\begin{bmatrix} E_1 \\ E_2 \end{bmatrix} = \begin{bmatrix} r_1 - h_{1,1}\hat{t}_1 \\ r_2 - h_{2,1}\hat{t}_1 \end{bmatrix} = \begin{bmatrix} h_{1,2} \\ h_{2,2} \end{bmatrix} t_2 + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad \textbf{(19)}$$

And thus $\hat{t}_2$ can be re-estimated as

$$\hat{t}_2 = \frac{h^H E}{h^H h} = \frac{\begin{bmatrix} h_{1,2} \\ h_{2,2} \end{bmatrix}^H \begin{bmatrix} E_1 \\ E_2 \end{bmatrix}}{\begin{bmatrix} h_{1,2} \\ h_{2,2} \end{bmatrix}^H \begin{bmatrix} h_{1,2} \\ h_{2,2} \end{bmatrix}} \quad \textbf{(20)}$$

Using the ZF and MMSE equalization approach described above, the receiver can obtain an estimate of the two transmitted signals t_1 and t_2 by using $\widehat{T} = W_{ZF}R$ and $\widehat{T} = W_{MMSE}R$ i.e.

$$\begin{bmatrix} \hat{t}_1 \\ \hat{t}_2 \end{bmatrix} = (H^H H)^{-1} H^H \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} \quad \textbf{(21)}$$

$$\begin{bmatrix} \hat{t}_1 \\ \hat{t}_2 \end{bmatrix} = (H^H H + N_0 I)^{-1} H^H \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} \quad \textbf{(22)}$$

E. SIC with Optimal Ordering:

In conventional SIC scheme, an estimated signal is selected randomly in order to remove its effect from the received signal. By this way, if the decision of estimated signal selection is wrong and error occurs. Furthermore, an erroneous detection at any stage will be fed back to cause error propagation in the following stages which increases, rather than decreases the interference level. To resolve this problem, SIC scheme with optimal ordering is adopted. In this proposed method, the transmitted signal which is having higher bit energy to noise ratio will be found out at the receiver, the selected signal whose effect needs to be eliminated from the received signal will be decoded. This procedure is repeated until the user with weakest signal is detected. Optimally ordered Successive Interference Cancellation (OSIC) strategy ensures that the signal which is decoded first is guaranteed to have a lower error probability than the other signal. In this OSIC scheme, data rate can be increased and the chances of incorrect decisions can be reduced. Hence SIC with optimal ordering offers performance enhancement compared with SIC without optimal ordering.

V. SIMULATION RESULTS

In this section, interference cancellation performance is simulated in terms of bit error rate and bit energy to noise ratio (E_b/N_0). BER decreases as E_b/N_0 increases which results in better interference cancellation. Here the system performance is evaluated under BPSK and QPSK modulation schemes by considering the channel as flat fading Rayleigh multipath channel.

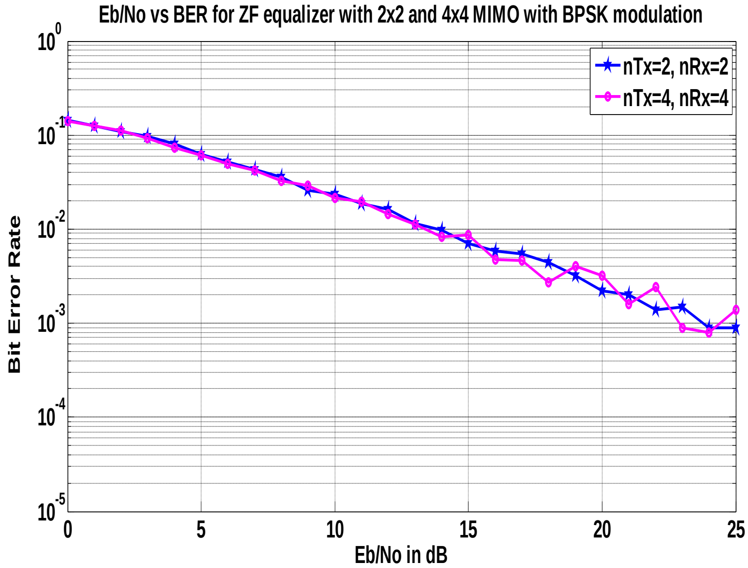

Figure 3: Simulation results for 2X2 and 4X4 MIMO ZF equalizers.

Table 1. Comparison of 2X2 and 4X4 MIMO ZF equalizers

E_b/N_0 / BER	2X2 MIMO ZF	4X4 MIMO ZF
5db	**0.061**	0.061
15db	**0.007**	0.009
25db	**0.0006**	0.001

From figure 3, it can be concluded that 2X2 MIMO gives minimum value of BER as 0.0006 than 4X4 MIMO ZF equalizer with BER as 0.001 at corresponding E_b/N_o of 25db and computational complexity is also more for 4X4 MIMO. Hence the simulation is done with 2X2 MIMO.

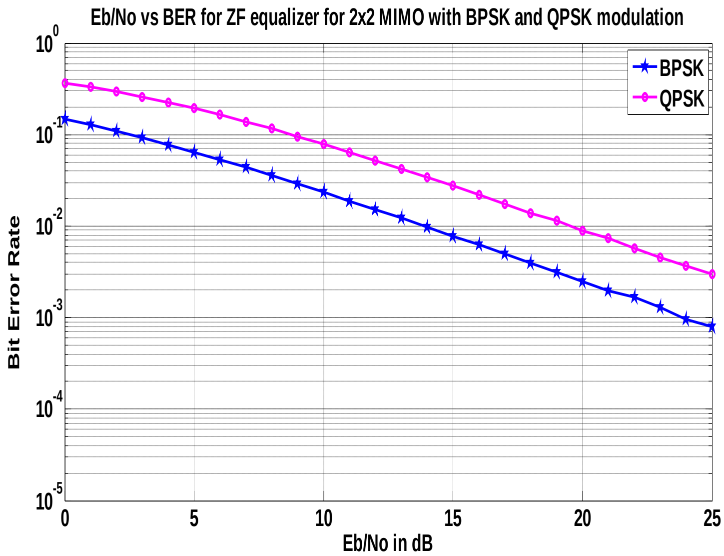

Figure 4: Simulation results for ZF equalizer with BPSK and QPSK modulation.

Table 2. Comparison of BPSK and QPSK modulated ZF equalizers

E_b/N_0 / BER	BPSK ZF	QPSK ZF
5db	**0.064**	0.193
15db	**0.007**	0.027
25db	**0.0007**	0.0029

From figure 4, it can be observed that BPSK modulation gives minimum value of BER as 0.0007 than QPSK modulated ZF equalizer with BER as 0.0029 at corresponding E_b/N_o of 25db. Hence BPSK modulation is more suitable for simulation.

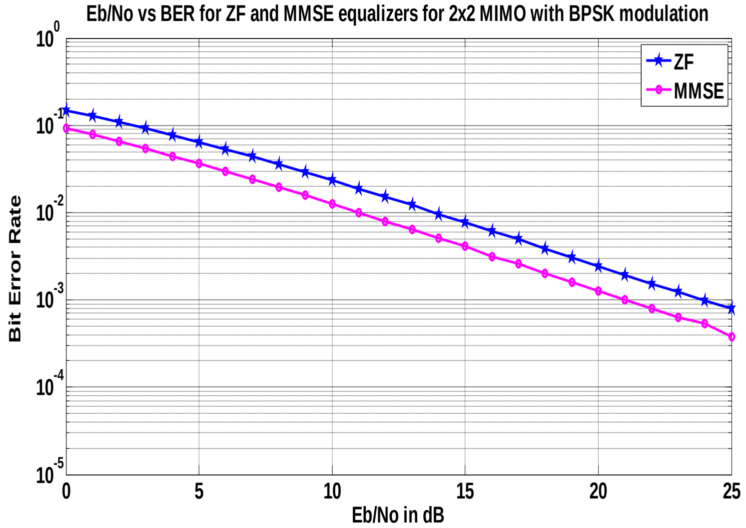

Figure 5: Simulation results for ZF and MMSE equalizer.

Table 3. Comparison of ZF and MMSE equalizers with BPSK modulation

E_b/N_0 / BER	ZF	MMSE
5db	0.064	**0.036**
15db	0.007	**0.004**
25db	0.0007	**0.0003**

From figure 5, it can be observed that MMSE equalizer gives minimum value of BER as 0.0003 than ZF equalizer with BER as 0.0007 at corresponding E_b/N_o of 25db. Hence MMSE equalizer is better than ZF equalizer.

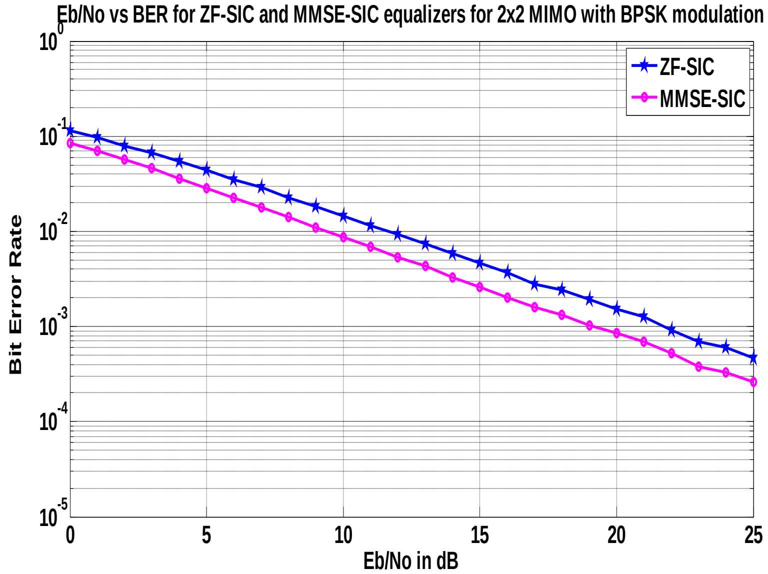

Figure 6: Simulation results for ZF-SIC and MMSE-SIC equalizers.

Table 4. Comparison of ZF-SIC and MMSE-SIC equalizers with BPSK modulation

E_b/N_0 / BER	ZF-SIC	MMSE-SIC
5db	0.043	**0.028**
15db	0.004	**0.002**
25db	0.0004	**0.0002**

From figure 6, it can be concluded that MMSE with SIC equalizer gives minimum value of BER as 0.0002 than ZF with SIC equalizer with BER as 0.0004 at corresponding E_b/N_o of 25db. Hence MMSE-SIC equalizer is better than ZF-SIC equalizer.

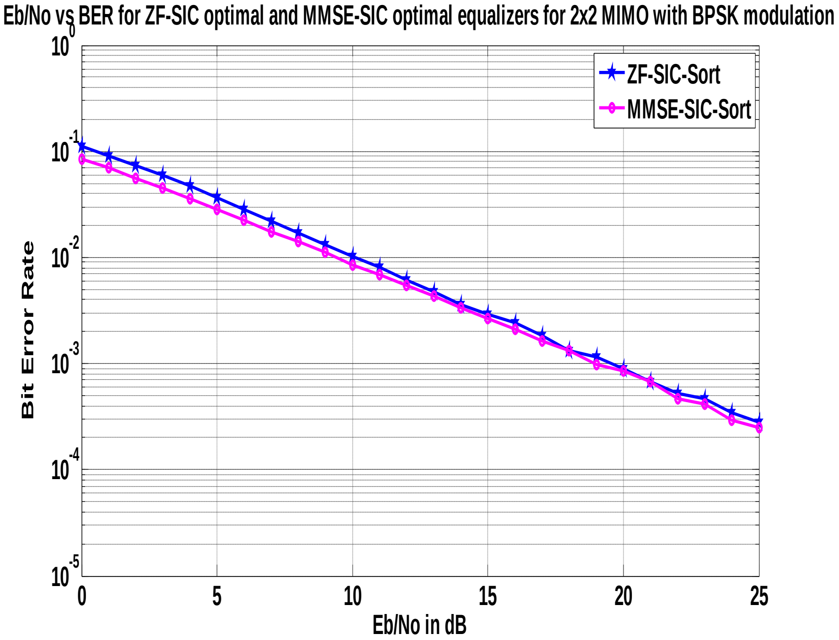

Figure 7: Simulation results for ZF-SIC optimal and MMSE-SIC optimal equalizers.

Table 5. Comparison of ZF-SIC optimal and MMSE-SIC optimal equalizers with BPSK modulation

E_b/N_0 / BER	ZF-SIC Optimal	MMSE-SIC Optimal
5db	0.036	**0.028**
15db	0.0029	**0.0026**
25db	0.0003	**0.0002**

From figure 7, it can be concluded that MMSE-SIC with optimal equalizer gives minimum value of BER as 0.0002 than ZF-SIC with optimal equalizer with BER as 0.0003 at corresponding E_b/N_o of 25db. Hence MMSE-SIC optimal equalizer is better than ZF-SIC optimal equalizer.
By considering the results of figure 5 to 7, it can be observed that optimal ordered MMSE-SIC gives less BER value of 0.0002 than conventional MMSE with BER value of 0.0003 at corresponding E_b/N_o of 25db. The values of all receivers for different values of E_b/N_0 and BER are tabulated in Table 1 to 5 from the simulation results. By comparing the simulation results of various techniques, MMSE SIC with Optimal Ordering gives better BER than others.

VI. CONCLUSION

In this paper, interference cancellation has been done with linear receivers such as ZF, MMSE and SIC. ZF receiver is absolute when the interference is significant compared to noise. However, when the system has noisy channel then this ZF receiver amplifies the noise instead of rejecting it. Hence we are going for MMSE equalizer but it doesn't eliminate the interference completely. Therefore, these linear receivers are combined with SIC in order to achieve better performance. With this SIC technique, there will be error propagation because of incorrect decision making. To overcome this problem, optimal ordered SIC is used. Also, Optimal ordered SIC performs better interference cancellation when compared to conventional SIC. Finally, it can be concluded that MMSE-SIC with optimal ordering is the most efficient for rejecting CCI in the cooperative communication system.

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