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Capacity Improvement of MIMO Channel using Dirty Paper Coding

Hemant Jain[1], Purneshwari Varshney[2]

[1]*M. Tech. Scholar, Department of Electronics & Communication Engineering, JIET, Jodhpur,*
hemant.jain@jietjodhpur.com

[2] *Assistant Professor, Department of Electronics & Communication Engineering, JIET Group of Institutions, Jodhpur,*
purneshwari1@gmail.com

Abstract *— MIMO is abbreviation of Multiple Input Multiple Output. In wireless communication, MIMO technology offers significant increase in data throughput and link range without additional bandwidth. The dirty paper coding (DPC) achieves the sum rate capacity of Gaussian MIMO broadcast channel. The dirty paper coding is a technique for efficient transmission of digital data through a channel that is subject to some interference that is known to the transmitter. The technique consists of precoding the data so as to cancel the effect of interference . The use of dirty paper coding closely achieves the sum-rate capacity region of broadcast channel. In MIMO fading environment, the so called degenerating channels or keyholes may exist that exhibit low partial fading correlation at both ends of the link but still have poor rank properties, and hence low ergodic capacity. The performance of dirty-paper coding over MIMO keyhole channels has been analyzed. The keyhole condition, where the MIMO channel has only one degree of freedom, impairs the performance of the systems. Under these conditions, one may wish to design codes that are robust to this situation.*

Keywords*- MIMO, BER, DPC*

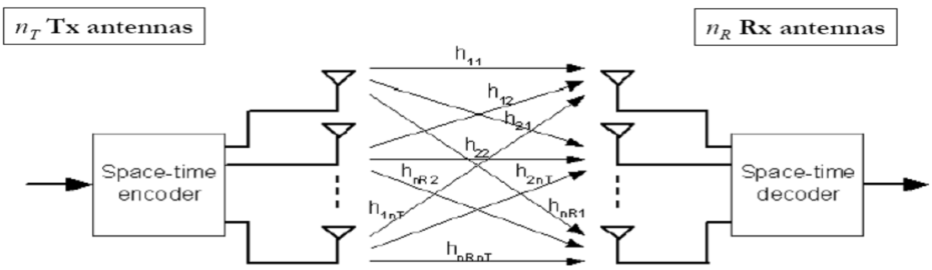
I. INTRODUCTION

Multiple-Input Multiple-Output (MIMO) system has been one of the key to achieve high data rate and high reliability over wireless downlink (broadcast channel). Broadcast is a communication scenario where a single transmitter sends independent information to multiple un-cooperative receivers. The downlink of a multiuser transmission is called broadcast channel (BC) and the reverse; many to one uplink are known as multiple access channel (MAC). There is duality between achievable region of BC and capacity region of MAC exists. Dirty Paper Coding is used to achieve the capacity region of MIMO broadcast channel. DPC in fact achieves the full capacity region of MIMO BC. However, DPC is rather new and complicated scheme and yet to be implemented in practical system. Basically DPC states that if the transmitter has perfect, non causal knowledge of additive interference in the channel then the capacity of the channel is same as if there was no interference. In MIMO BC, this technique is used at the transmitter to choose code words for different receivers.

II. MIMO BROADCAST CHANNEL

In radio, multiple- input and multiple- output (MIMO) technology is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology. In multi user MIMO systems, the multiple transmitter and receiver share the same communication medium and cause mutual interference to each other. However, cooperation between multiple transmitter and receiver is possible to deal with the interference. When transmitter cooperate and receiver do not, the channel scenario is called the MIMO broadcast channel. The other channel scenario is called multiple access channel (MAC) where transmitter do not cooperate and receivers do.

Consider MIMO channel model shown below:



$$\begin{bmatrix} y_1 \\ \vdots \\ y_{n_R} \end{bmatrix} = \begin{bmatrix} h_{11} & \cdots & h_{1n_T} \\ \vdots & \ddots & \vdots \\ h_{n_R 1} & \cdots & h_{n_R n_T} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_{n_T} \end{bmatrix} + \begin{bmatrix} n_1 \\ \vdots \\ n_{n_R} \end{bmatrix}, \qquad \mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n}, \quad \mathbf{n} \sim N(0, \sigma^2 I)$$

Figure 1. MIMO channel model

As shown in Figure 1, MIMO channel consist of n_T transmitting antennas and n_R receiving antenna and after that input is provided at space time encoder which is transmitted through channel by transmitted antennas and at receiving side receiving antennas receive and decode signal through space- time decoder. Here y is output vector, x is input vector of the model, H is channel transition matrix and n is the noise vector which is AWGN.

III. DIRTY PAPER CODING

For In 1983, Costa gives the idea of dirty paper coding and proves that, if the transmitter has perfect, non causal knowledge of additive interference in the channel, then the capacity of the channel is the same as if there was no additive interference in the channel [1]. According to Costa, a piece of paper covered with independent dirt spots and a written message on it with a limited amount of ink, the dirty paper, with the message on it, is then send to someone else and acquires more dirt along the way. If the recipient cannot distinguish between the ink and dirt, then it can send just as much information on such a dirty piece of paper and gave away to get that capacity. A dirty paper code is a way for the writer to adapt his message to the dirt already on the paper the writer and the reader agree ahead of time on which dirty paper code they will use for the messages.

The Costa channel is shown below:

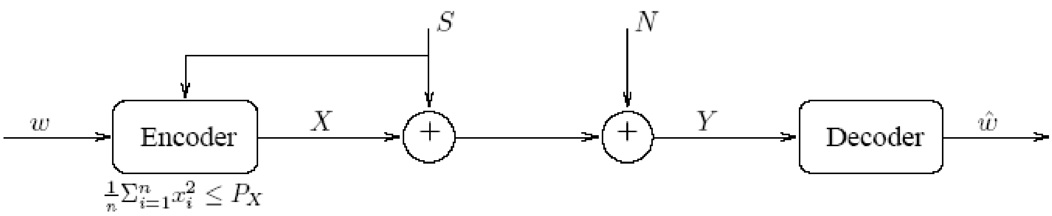


Figure 2. Dirty Paper Channel

The received signal is $Y = X + S + N$ (1)

Where, S is arbitrarily interference non-causally known to at transmitter is independent Gaussian random variable with variance P_n and P_x is the power constraint on the transmitted signal .The output of the encoder given as X which obeys the transmitter power constraints. The interferences and the noise are Gaussian i.i.d. The Costa's results, shows that the capacity of this channel is the same as if the interference is not present:

$$C_{DPC} = \frac{1}{2} \log (1+P_x/P_n) \qquad (2)$$

3.1. Implementation of Dirty Paper Coding

In high SNR regime, dirty paper coding can be approximated by Tomlinson-Harashima precoding (THP).THP was originally introduced in the context of ISI channel. The basic idea is illustrated in figure 3. As shown; the system intends to send a message v from transmitter to compensate the interference in the channel to the receiver through AWGN channel which is corrupted by interferences. The TH precoder involves two stages. In the first stages the interference s is subtracted directly from the source v to compensate the interference in the channel but the power of v-s may exceed the transmitter power constraint. A modulo operator is lied to sustain the power constraint at transmitter. At the receiver, another modulo operation is performed to recover the intended message v.

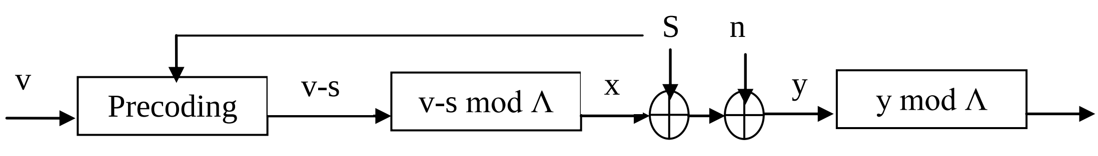


Figure 3. DPC implementation with THP

<u>Transmitter</u>: The encoder sends:

$$X= (v - s - u) \bmod \Lambda. \qquad (3)$$

<u>Receiver:</u> The receiver computes:

$$\hat{v} = (y + u) \bmod \Lambda. \qquad (4)$$

u is the common dither shared by the receiver and the transmitter and is uniformly distributed over (Λ/2,-Λ/2), which makes sure that the channel input x has uniform distribution. From Figure 3, it is seen that

$$y = x + s + n + u = (v - s- u) \bmod\Lambda + s + n = v + n- m\Lambda \qquad (5)$$

where m is an integer.

Then we have,

$$\hat{v} = y \bmod \Lambda = (v + n) \bmod \Lambda. \quad (6)$$

The quantizer Λ is chosen to meet the power constraints without causing any ambiguity in v. In the absence of noise, the message v can be fully recovered at the receiver. From the expression of $\hat{v}$, it is clear that quantization introduces extra noise in demodulation. The basic premise of dirty paper coding is that if interference to a given user is known in advance, the encoding strategy can exploit the structure of the interference such that the capacity is the same as if there was no interference at all. The encoding strategy cleverly distributes the codeword's based on the interference, and the decoder must know how to read these codewords. Dirty paper coding is a natural technique to use on the broadcast channel since the interference between all users is known. An achievable region for the MIMO BC based on dirty paper coding was first proposed in [5]. In [15], the region was extended to the more general multiple-user, multiple-antenna case using the following extension of the dirty paper result [2] to the vector case:

Consider a channel with $y_k = H_k x_k + s_k + n_k$, where y_k is the received vector, x_k the transmitted vector, s_k the vector Gaussian interference, and n_k the vector white Gaussian noise. If s_k and n_k are independent and non-causal knowledge of s_k is available at the transmitter but not at the receiver, then the capacity of the channel is the same as if s_k is not present. The transmission strategy under dirty paper coding first picks a codeword for receiver 1. The transmitter then chooses a codeword for receiver 2 with full (non- causal) knowledge of the codeword intended for receiver 1. Therefore receiver 2 does not see the codeword intended for receiver 1 as interference. Similarly, the codeword for receiver 3 is chosen such that receiver 3 does not see the signals intended for receivers 1 and 2 as interference. This process continues for all K receivers.

IV. SIMULATION RESULTS

In this paper, the performance of MIMO system with two transmit antenna and two receive antennas has been compared. In the simulations, it is assumed that the receiver has perfect CSI and that the fading between transmit and receive antennas is mutually independent .As we have seen throughout this thesis our emphasis on the improvement of performance of the MIMO channel. This improvement of MIMO performance is achieved by the interference cancellation technique, Dirty paper coding and the implementation of DPC is done by Tomlinson-Harashima Precoding(THP) and this technique has been discussed in chapter-5 in detail. Now we move to our simulation results. All simulation results have been done on MATLAB.

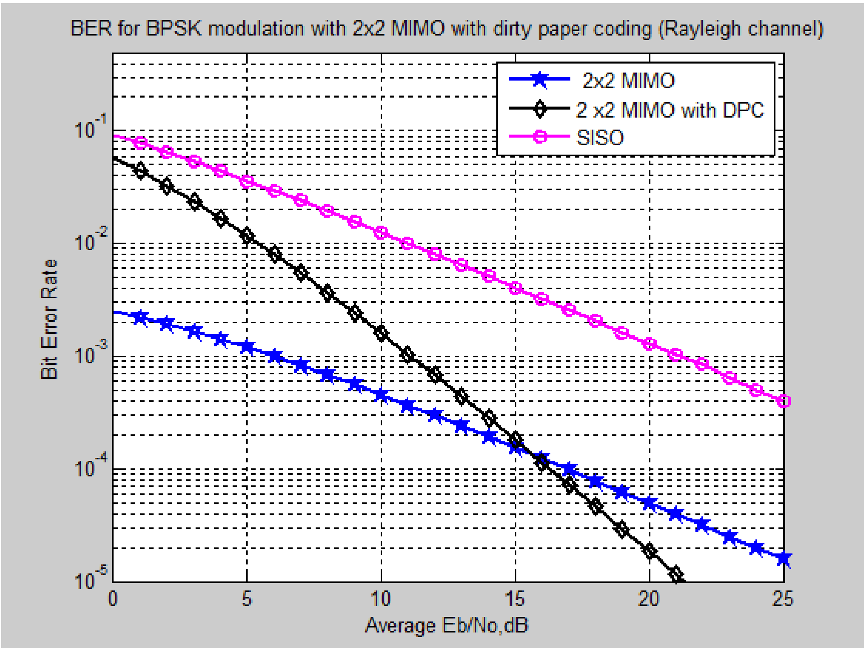


Figure 4. Bit Error Performance of SISO,2x2 MIMO and 2x2 MIMO with DPC

Figure 4 shows the Bit error rate performance of 2x2 MIMO with BPSK modulation in Rayleigh Channel. As we see in Figure 4, pink line shows the performance of SISO where single antenna at transmitter end and single antenna at receiver end, which shows the poor bit error rate, so to improve this performance we take 2 Tx antenna and 2 Rx antenna . Blue line shows the performance of 2x2 MIMO. Now if we use dirty paper coding with 2x2 MIMO as we see from the figure at low SNR region and approximately 5 dB gain has been achieved with using DPC at BER of 10^{-5} .

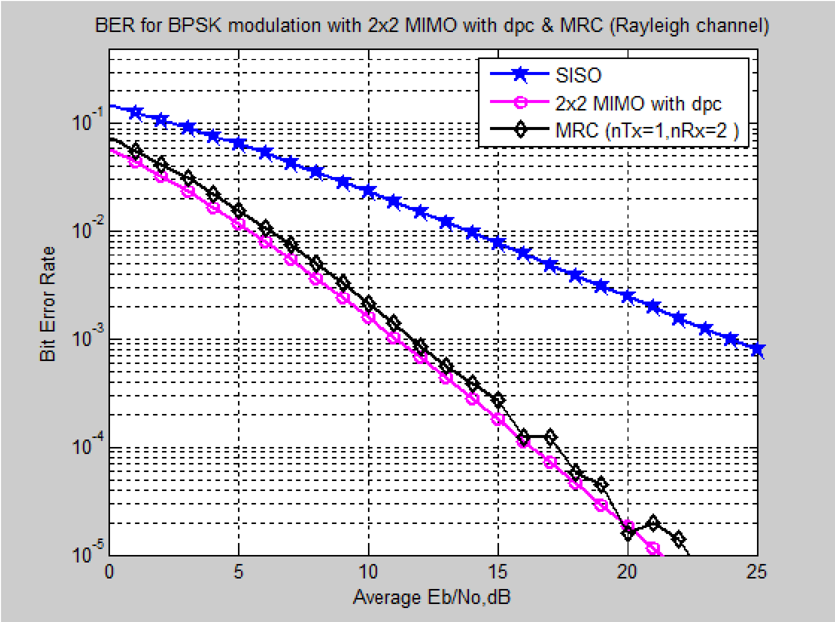


Figure 5. Bit error rate performance of 2x2 MIMO with DPC and Maximal ratio combining

Figure 5 shows the Bit error rate performance of 2x2 MIMO using DPC with bpsk modulation in Rayleigh Channel and its comparison with the performance of Maximal ratio combining (MRC) which is receiver diversity technique where multiple antenna at receiver. Here we take 1x2 MRC and as we have seen from the Figure 5, the performance of 2x2 MIMO using DPC is very close to the maximal ratio combining. To improve the performance we change the modulation technique now we take QPSK in Rayleigh channel. Figure 6 shows the Bit error rate performance of 2x2 MIMO using DPC with QPSK modulation.

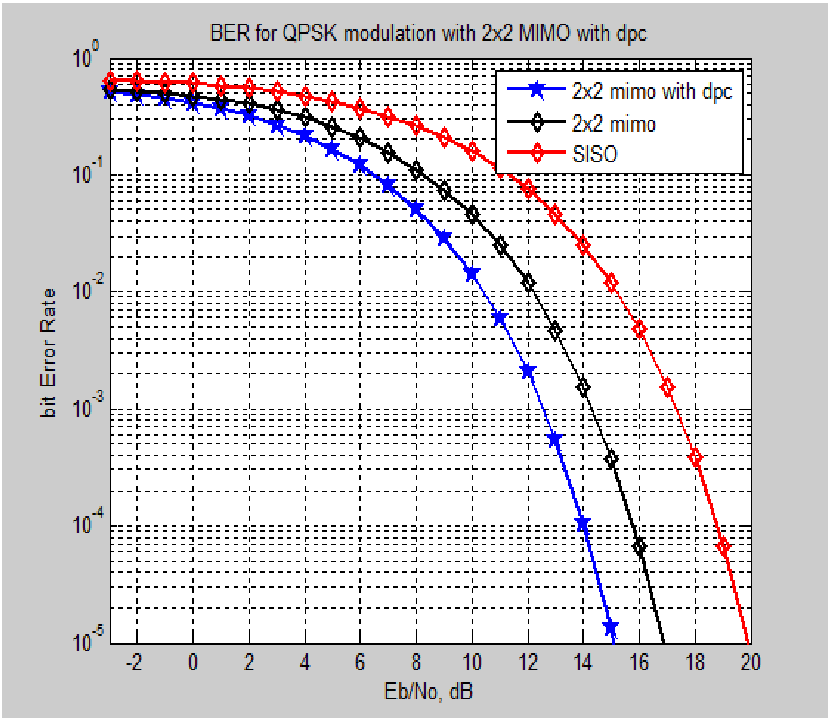


Figure 6. Improved Performance of 2x2 MIMO for QPSK using DIRTY PAPER CODING

As we see in the Figure 6, with the using QPSK as modulation technique , the performance has been improved for both SISO and 2x2 MIMO as compared to BPSK technique. And after that by using dirty paper coding approximately 2-dB gain has been achieved. Now we consider the 2x2 MIMO keyhole channel in this case we assume that these two set of antennas are separated by a screen with a small hole in it (keyhole or pinhole effect) so that the transmitted signals pass through the keyhole.

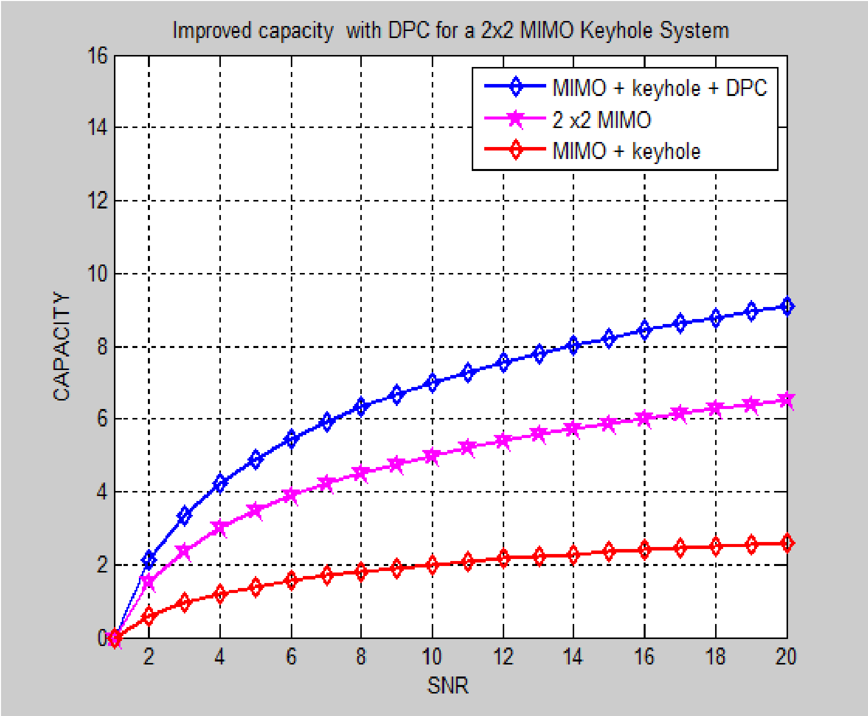


Figure 7. Improved Capacity of MIMO keyhole channel with Dirty paper coding and without DPC

Figure 7 shows the performance of keyhole channel. We observe the drop in capacity compare to regular channel. We observe a significant improvement in the capacity of a MIMO keyhole channel using DPC. We consider a N transmit diversity system with a single receive antenna and no feedback.

V. CONCLUSION

In this, we have studied the MIMO broadcast channel. This concept is used to obtain the minimum rate capacity region of a fading MAC channel. We introduce the notion of dirty paper coding for this channel, which subtracts out the effect of known interference and thus achieves much higher rates than other techniques such as HDR. We conjecture that dirty paper coding achieves the entire region, but this proof requires Gaussian inputs to be optimal for this channel, which we have not yet shown. It is shown that the degenerate channels, called 'keyholes', may arise under realistic assumptions which have zero correlation between the entries of the channel matrix H and yet only a single degree of freedom. The keyholes present low correlation at both transmitter and receiver. Anticipate that keyhole effect due to real-world waveguides like tunnels or corridors will usually be very weak and the correlation is the major capacity-reducing effect. The application of dirty paper coding gives capacity gain in the keyhole MIMO channel. If we observe the simulation result, we find that performance of 2x2 MIMO has been improved to a greater extent by using dirty paper coding. We also observe that by increasing diversity to a given limit a better gain in dB has been achieved, and it also suppressed the effect of fading. So we concluded that dirty paper coding has been emerged out as a very effective technique to overcome the interference in the different channel scenario.

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