Mobile and Embedded Technology International Conference (MECON - 2013)
Proceedings published in International Journal of Computer Applications® (IJCA) (0975 – 8887)

Adaptive Gain Aided Multi Antenna Set-ups for Stochastic Wireless Channels

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ABSTRACT

One of the options to mitigate fading effects in mobile communication is adaptive transmitter gain. This paper proposes a simple technique to eliminate the effects of fading in different multi antenna set-ups by varying the transmitter gain. The multi antenna set-ups considered in this paper include Single input-single output (SISO), Single input-multi output (SIMO), Multi input-single output (MISO), Multi input-multi output (MIMO) systems. For all these set-ups, the data streams after doing BPSK modulation is transmitted together with the transmitter gain through a frequency-selective Rayleigh fading channel. The Channel State Information (CSI) is unknown to the receiver and so, before doing equalization the channel characteristics are determined using the Least Mean Square (LMS) algorithm. The average Bit Error Rate (BER) for different values of the transmitter gain is calculated and the performances of the different set-ups are compared. Also, the BER for different Signal-to-Noise Ratio (SNR) are obtained for the different systems. Both the above BER analysis schemes are then repeated by applying three different error correction codes. The error correction coding schemes used in this paper includes Linear block coding, Cyclic coding and Hamming coding. Out of the three coding techniques, the one that gives the best possible result is taken into consideration and the difference in BER for the coded and uncoded multi antenna systems are analyzed. Performance is also analyzed in terms of the coding gain. All the above cases are repeated for Rician channel as well. Finally, we will see that our results are identical to that of some previously reported works.

Keywords

Rayleigh fading; Rician fading; Linear block codes; Cyclic codes; Hamming codes; Coding gain; LMS (Least Mean Square); Transmitter gain.

1. INTRODUCTION

Mobile communications and wireless network have experienced massive growth and commercial success in the recent years. However, the wireless radio link poses a severe challenge as a medium for reliable high-speed communication. Fading, a limiting factor in the performance of a wireless communication system is caused either due to interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times or due to shadowing from obstacles affecting the wave propagation [1]. The wireless radio link is not just susceptible to noise, interference and other channel impairments, but it is highly random, unpredictable and time-variant which causes the received signal to fluctuate. To overcome the effects of fading, the knowledge of Channel State Information (CSI), either accurately or partially at the receiver, plays a significant role in achieving reliable communication over unreliable wireless channels. Also, adaptive transmitter gain contributes significantly to mitigate the effects of fading. Channel coding for error correction helps the communication system mitigate the effects of a noisy transmission channel. Error control coding has been widely used in all types of wire line and wireless communication systems for many years. The various coding techniques provide a mean to obtain reliable communication in a highly mobile environment, where the assumption of perfect CSI becomes a bit complex. Hence, in our case for the different multi antenna set-ups an estimate of the different channel matrices are made using the Least Mean Square (LMS) algorithm as the CSI is unknown to the receiver. Depending upon the performance recorded, the transmitter gain is adaptively varied.

We first analyze our technique for a Single input-single output (SISO) set-up by transmitting a BPSK modulated data stream along with the transmitter gain through a frequency-selective Rayleigh fading channel. At the receiver, equalization of the received stream is performed and it is demodulated to obtain the original data stream. Average BER is calculated for varying transmitter gain. Average BER for an SNR range of 0 to 35dB is also calculated and expected results are obtained. To achieve a better performance, the above situation is repeated by applying error correction coding techniques. In this case, the data stream is first encoded using linear block coding, cyclic coding and hamming coding and then modulated and transmitted. After equalization at the receiver, the received stream is demodulated and decoded and accordingly BER is obtained. Finally, the coding gain is derived. This simplest technique is then expanded to different multi antenna set-ups where we consider a 1×2 SIMO, a 2×1 MISO, and a 2×2 MIMO system. We also perform the same for Rician channel as well. Expected results are obtained for all the cases. The rest of the paper is organized as follows:

In Section 2, we briefly cover the related theoretical considerations. In Section 3, the system model is included. Experimental details and results are included in Section 4 and 5 respectively. Section 6 concludes the work.

2. THEORETICAL BACKGROUND

Here, we briefly describe the theoretical considerations related to the work.

2.1 Frequency-selective fading

If the channel possesses a constant-gain and linear phase response over a bandwidth that is smaller than the bandwidth of the transmitted signal, then the channel creates frequency selective fading on the received signal. Under such conditions, the channel impulse response has a multipath delay spread which is greater than the reciprocal bandwidth of the transmitted message waveform. The channel induces intersymbol interference (ISI) as a result of frequency selective fading [1].

2.2 Rayleigh fading

In Rayleigh fading, the direct wave from the transmitter to the receiver is blocked. Each of the waves has a different phase and this phase can be considered as an independent uniform distribution, with the phase associated with each wave being equally likely to take on any value. This situation is called non-line-of-sight propagation (NLOS) [2].

2.3 Rician fading

In Rician fading, a single strong path is received along with multipath energy from local scatterers. Here, the light-of-sight (LOS) component exists [2].

2.4 Linear block codes

In any error control code, data from a source or source encoder enters the channel coder, where redundant data is added to the message to add protection against random or burst errors. For k bits of binary information, there are $M=2^k$ valid codeword. If the encoder adds n-k check bits to the message to form a codeword, the receiver may receive any of 2^n codeword, where 2^n-2^k could be in error.

If we denote the i^{th} bit of a codeword K by x_i, then all 2^k valid codeword represented by K satisfy n-k linear equations in x_i for i = 1,2,…,n. That is, a code is considered linear if it can be defined by a homogeneous system of linear equations. Since there are n-k equations in n unknowns, there are n-(n-k) = k independent variables and, hence, 2^k solutions to the system [3]. It requires a generator polynomial G, of size k×n for its implementation.

For any linear code, we can find a matrix $B_{(n-k)\times n}$ with its rows orthogonal to the rows of G :

$$GB^T=0 \tag{1}$$

B is called the parity check matrix and its rows are linearly independent.

For systematic linear block codes:

$$B= [I_{n-k}|P^T] \tag{2}$$

2.5 Cyclic codes

Cyclic codes are a subset of linear block codes that satisfies the additional condition that any cyclic shift of the elements of a codeword yields a word that is also a codeword.

2.6 Hamming codes

Hamming codes are a subclass of linear block codes that are expressed as a function of a single integer, m≥2. Here the codeword length is given by $n = 2^m-1$, number of information bits is given by k = n-m-1, number of parity bits is n-k = m. The columns of the parity check matrix, B consists of all non-zero binary m-tuples.

2.7 Coding gain

The usual figure of merit for a communication system is the ratio of energy per information symbol to noise spectral density (E_b/N_0) that is required to achieve a given probability of error. The term 'coding gain' describes the amount of improvement that is achieved when a particular coding scheme is used [4]. Coding gain is determined by the given expression:

$$G\ (\mathrm{dB}) = \left(\frac{E_b}{N_0}\right)_{\mathrm{uncoded}} [\mathrm{dB}] - \left(\frac{E_b}{N_0}\right)_{\mathrm{coded}} [\mathrm{dB}] \tag{3}$$

2.8 Least mean square (LMS) algorithm

LMS is the simplest algorithm used for adaptive processing. The LMS algorithm is based on the steepest-descent method which recursively computes and updates the weight vector [5].

$$y(n) = w^H x(n), \tag{4}$$

$$e(n) = d(n) – y(n), \tag{5}$$

$$w(n+1) = w(n) + \mu x(n)e^*(n) \tag{6}$$

where, w(n) is the input to the adaptive filter, y(n) is the signal at the output of the filter, d(n) is the desired signal, e(n) is the error signal, w^H is the weight vector and μ is the step size.

3. SYSTEM MODEL

The system model for the different multi antenna set-ups are shown here. We consider two states for each of the antenna set-ups, first without error correction coding schemes and then with coding schemes.

3.1 SISO set-up

The system model for a SISO environment without coding is shown in Fig. 1. It simply consists of a transmitter and a receiver with a single transmitting and receiving antenna.

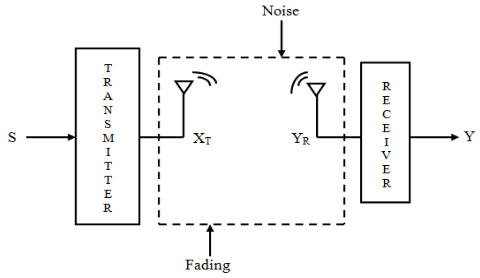

Figure 1: Block diagram of SISO set-up

As seen from the block diagram, the data stream, S after passing through the transmitter block goes through the channel to the receiver block. The transmitter block consists of a BPSK modulator where the data after modulation is aided with the transmitter gain. The data is then transmitted through a frequency selective Rayleigh fading channel where it is subjected to noise and other channel impairments. The transmitted data is

$$X_T = gS, \tag{7}$$

where g is the transmitter gain.

Due to the effect of noise, v and the channel H, the received data at the receiver becomes

$$Y_R = HX_T + v \tag{8}$$

The channel matrix, H is not known to the receiver. So, by applying the LMS algorithm an estimate of H is obtained as discussed below-

The received signal at the receiver input is the input to the adaptive filter and the reference signal (desired) is the delayed version of the received signal. The weights are updated using (6). So, in this case using (4) and (5)

$$\hat{Y} = w\,(n)Y_R\,(n), \tag{9}$$

$$e(n)= Y_R(n-1) – Y_R(n). \tag{10}$$

When e(n) → 0

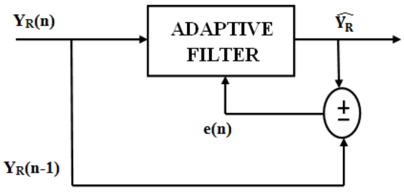

Figure 2: Adaptive filter

$$\hat{Y}_R = Y_R(n-1) \tag{11}$$

Therefore,

$$\hat{H} = \frac{\hat{Y}_R}{X_T(n-1)} \tag{12}$$

$\hat{H}$ contains noise, v. So, it has to be removed from $\hat{H}$. Finally, the actual estimated $\hat{h}$ is obtained by subtracting the noise from $\hat{H}$

$$\hat{h} = \hat{H} - v \tag{13}$$

Thus, the recovered data at the receiver output is

$$Y = \frac{Y_R}{\hat{h}} \tag{14}$$

$$Y = \frac{hX_T + V}{\hat{h}} \tag{15}$$

$$Y = X_T + \tilde{v} \tag{16}$$

where $\tilde{v} = \frac{v}{h}$ is the additive noise scaled by the channel coefficient.

The block diagram for a SISO environment with coding (methods discussed in Section II.) is exactly similar to Fig.1. The difference lies only in the internal structure of the transmitter and the receiver. Here, in addition to the BPSK modulator, an encoder is also present in the transmitter block. The data stream before modulation is chopped into blocks of k bits. Each block is encoded into a larger block of n bits. The coded bits are then modulated and sent over the channel. After passing through the channel the received bits are recovered in the same manner as the case discussed without coding and then decoded to get the original data. For both the states-without coding and with coding, BER is obtained for varying SNR and transmitter gain.

3.2 SIMO set-up

The system model for a SIMO environment without coding is shown in Fig. 3. It has one transmitting and two receiving antennas.

The single data stream is transmitted in a similar fashion as in the SISO case given by (7). This data is received by both the receiving antennas through two different paths. The received streams at both the receiving antennas are given by-

$$Y_{R1} = H_1X_T + v \tag{17}$$
$$Y_{R2} = H_2X_T + v \tag{18}$$

So, the first objective here will be to determine the channel matrices for both these paths.

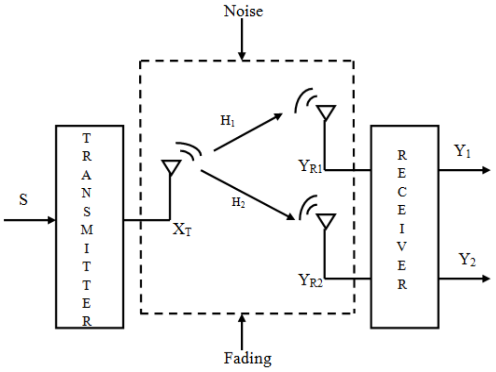

Figure 3: Block diagram of SIMO system

Estimate of the channel matrices are done separately at both the receiving antennas as discussed in the SISO case, and equalization is performed. Thus, the recovered data streams are-

$$Y_1 = \frac{Y_{R1}}{\hat{h}_1} \tag{19}$$

$$Y_1 = \frac{h_1X_T + v}{\hat{h}_1} \tag{20}$$

$$Y_1 = X_T + \tilde{v}_1 \tag{21}$$

$$Y_2 = \frac{Y_{R2}}{\hat{h}_2} \tag{22}$$

$$Y_2 = \frac{h_2X_T + v}{\hat{h}_2} \tag{23}$$

$$Y_2 = X_T + \tilde{v}_2 \tag{24}$$

where $\tilde{v}_1 = \frac{v}{h_1}$ and $\tilde{v}_2 = \frac{v}{h_2}$ is the additive noise scaled by the first and second channel coefficients respectively.

When using coding techniques, encoding of the data stream is done just like the previous situation of the SISO set-up but decoding is done at both the receiving antennas separately for each of the received streams. Average BER is obtained for both the received outputs for varying SNR and transmitter gain once without using coding techniques and then using coding techniques.

3.3 MISO set-up

The system model for a MISO environment without coding is shown in Fig. 4. It has two transmitting and one receiving antenna.

From the block diagram it can be seen that, two separate data streams after BPSK modulation are transmitted from the two transmitting antennas together with the transmitter gain.

$$X_{T1} = g_1S_1, \tag{25}$$
$$X_{T2} = g_2S_2, \tag{26}$$

where g_1 and g_2 are the gains at the first and second transmitting antennas respectively.

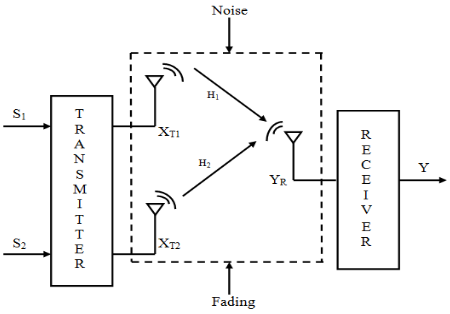

Figure 4: Block diagram of MISO system

These two data streams arrive at the receiving antenna through two different paths as

$$Y_R = H_1X_{T1} + H_2X_{T2} + v \tag{27}$$

At the receiver, an estimate of the delayed version of the received stream is made using (4) , (5), and (6). Proceeding in the same manner as the SISO case and using (9), (10) and (11), we determine the channel matrices H_1 and H_2 . Thus

$$\widehat{H_1} = \frac{\widehat{Y_R} - H_2X_{T2}}{X_{T1(n-1)}} \tag{28}$$

$$\widehat{H_2} = \frac{\widehat{Y_R} - H_1X_{T1}}{X_{T2(n-1)}} \tag{29}$$

Noiseless channel matrices are given by-

$$\widehat{h_1} = \widehat{H_1} - v \tag{30}$$

$$\widehat{h_2} = \widehat{H_2} - v \tag{31}$$

The two data streams are recovered as shown below-

$$Y_1 = \frac{h_1X_{T1} + v}{\widehat{h_1}} \tag{32}$$

$$Y_1 = X_{T1} + \tilde{v}_1 \tag{33}$$

$$Y_2 = \frac{h_2X_{T2} + v}{\widehat{h_2}} \tag{34}$$

$$Y_2 = X_{T2} + \tilde{v}_2 \tag{35}$$

Since we receive two copies of the data at the output, in our case, both the results are combined to get a single output, Y. This may alter as per the requirement of the system. Average of BER for variable gain and SNR is found to test the performance.

The same procedure is repeated using coding techniques as well.

3.4 MIMO set-up

The block diagram for a MIMO set-up is shown in Fig. 5. It has two transmitting and two receiving antennas.
The transmitter side is similar to the MISO case, where two separate data streams are transmitted along with the transmitter gain. But the receiver side is somewhat different. Each of the receiving antennas receives both the transmitted data streams which are distorted due to the channel and noise.
The data arrive at the receiving antennas through four different paths and hence at both the receivers, the primary objective is to determine the four channel matrices.

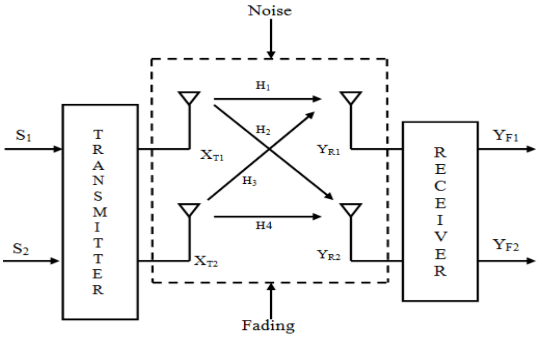

Figure 5: Block diagram of MIMO system

This is done in a similar way as the MISO case at both the receiving sides. The transmitted streams are given by (25) and (26). The received streams at the first and the second receiving antennas are

$$Y_{R1} = H_1X_{T1} + H_2X_{T2} + v \tag{36}$$

$$Y_{R2} = H_3X_{T1} + H_4X_{T2} + v \tag{37}$$

At the receiver, equalization is performed separately for both the received streams in the same way as the MISO case. Thus, the final outputs are

$$Y_1 = X_{T1} + \tilde{v}_1 \tag{38}$$

$$Y_2 = X_{T2} + \tilde{v}_2 \tag{39}$$

$$Y_3 = X_{T1} + \tilde{v}_3 \tag{40}$$

$$Y_4 = X_{T2} + \tilde{v}_4 \tag{41}$$

Y_1 and Y_2 are combined to get the first received stream, Y_{F1} and Y_3 and Y_4 are combined to get the second received stream, Y_{F2}. BER is obtained for Y_1, Y_2, Y_3 and Y_4 separately by varying the SNR and the transmitter gain and an average is taken. All the steps are then repeated using different coding techniques discussed in Section II and BER is obtained for this case as well.

All the steps discussed above are repeated for a Rician channel.

4. EXPERIMENTAL DETAILS

The different multi antenna set-ups discussed in Section III are coded and simulated. The simulation parameters considered for simulation are given in Table 1.

Table 1. Simulation parameters considered for simulation

Parameter	**Value/Type**
Sample size	Multiple block of 1000 bits
SNR range	0 to 35dB
Transmitter gain range	0.1 to 1
Carrier modulation used	BPSK
Channel used	Rayleigh, Rician
Coding techniques used	Linear block (15,10), Cyclic (15,10), Hamming (15,11).

From Table 1, we see a clear view of the modulation and coding techniques used as well as the type of channel through which the data is allowed to pass.

5. RESULTS AND DISCUSSIONS

In this section, the experiments performed are used to investigate the BER performance of the proposed technique.

5.1 SNR vs. BER plot

The SNR vs. average BER curves for the different multi antenna set-ups for coded, uncoded and some previous related work are shown in Fig. 6.

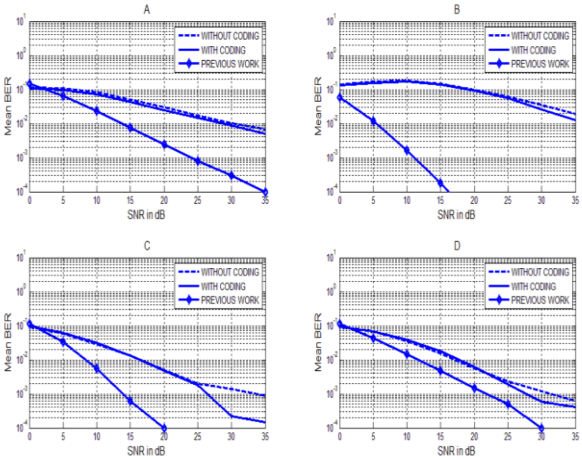

Figure 6: SNR vs. BER curves for coded, uncoded and previous work in SISO, SIMO, MISO and MIMO set-ups.

Here, the first plot (Fig. 6A) is for SISO set-up. For the SNR range shown in Table 1, it is seen that the BER decreases with an increase in SNR. With coding, the performance is somewhat better. The result is compared to a SISO system with BPSK modulation for a Rayleigh channel [6], and we find that our approach is satisfactory.

The second plot (Fig. 6B) shows the result for the SIMO system in which similar conclusion can be drawn. The work is compared with the BER of a 1×2 Maximal Ratio Combining scheme [7]. We see from Fig. 6B that our approach represents a falling BER curve but does not show much improvement to that of the previous work. For both the SISO and SIMO cases the transmitter gain is kept fixed at 0.8.

Third plot (Fig. 6C) and fourth plot (Fig. 6D) shows the MISO and MIMO BER curves. It is also clear that the performance of the MISO and the MIMO systems are better compared to the SISO and SIMO systems. Also, the performance is better with coding. In these two cases, gain of the first and second transmitting antennas is kept fixed at 0.7 and 0.8 respectively. The MISO case is compared with a 2×1 Alamouti STBC scheme [8] and the MIMO with a MIMO system with Zero-Forcing Successive Interference Cancellation scheme [7] and we find that in the MISO and MIMO cases, our recovery method, with rise in SNR suits best to the condition and give a BER performance improvement.

Among the three coding techniques that we employ in our study, we find satisfactory result with cyclic coding and so we are only showing the result derived for this case only. As a Rayleigh channel environment is considered as the worst case scenario, we are not repeating the results for a Rician channel.

5.2 Transmitter gain vs. BER plot

Fig 7. shows the transmitter gain vs. BER curves for all the multi antenna set-ups with and without coding.

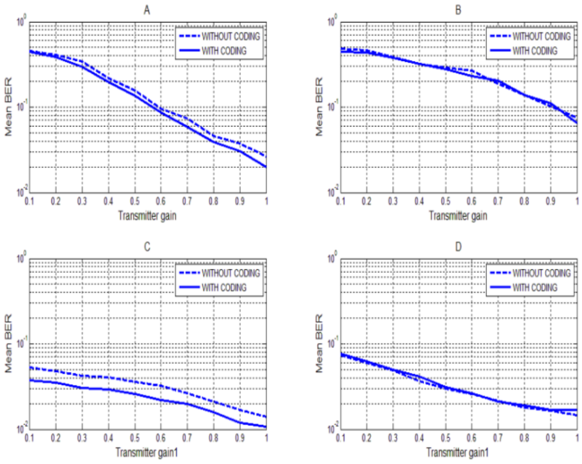

Figure 7: Transmitter gain vs. BER curves in SISO, SIMO, MISO and MIMO set-ups with and without coding.

Here, the first plot (Fig. 7A) is for the transmitter gain vs. BER curve for a SISO system. We see that, with an increase in the transmitter gain (range is shown in Table 1), there is an improvement in the BER and hence, in the system performance. When coding scheme is employed the performance is better to some extent. Similar result can be seen for the SIMO (Fig. 7B), MISO (Fig. 7C) and MIMO (Fig. 7D) systems. In this case, the SNR is kept fixed at 15dB. In the MISO amd MIMO systems, since there are two transmitting antennas, there exists two transmitter gain. So, in our case, we are keeping the second transmitter gain fixed at 0.6 and only the first transmitter gain is varied to analyze the performance. We achieve expected falling BER curves for all the multi antenna systems with and without coding and thus, our technique works best with such systems. The same experiment is repeated for a Rician channel and similar performance is observed. With coding techniques, cyclic codes gives us a better performance and hence, we are showing only the BER plots for cyclic codes.

The improvement in BER performance with rise in transmitter gain provides us the possibilities of using an adaptive antenna system at the transmitter. The antenna with reconfigurable properties can aid transmissions with adaptive gain leading to improved BER performance. This can be considered as a future direction of this work.

5.3 Performance table

Table 2. shows the various performance analysis parameters, which gives a clear picture of the work and the results obtained.

From Table 2, we see that with rise in SNR, MISO and MIMO systems shows best results for both coded and uncoded schemes. The maximum percentage improvement in BER with 100 percent rise in SNR for about twenty trials is shown. The best coding gain is achieved for a MISO system which is 5.3dB at a BER of 10^{-3}. It is satisfactory for a SISO system with only 0.20dB at a BER of 10^{-2}. Thus, with increasing SNR, BER performance improves considerably for MISO and MIMO systems compared to SISO and SIMO systems.

Table 2. also shows the BER performance of the different systems with rise in transmitter gain.

Table 2. Average performance analysis parameters

Set-ups	For SNR of 0 to 35dB BER improvement			For T_X gain of 0.1 to 1 BER improvement	
	Uncoded	***Coded***	***Coding gain***	***Uncoded***	***Coded***
SISO	38.8%	46.9%	0.20dB (BER-10^{-2})	38.5%	36.6%
SIMO	51.0%	51.5%	0.45dB (BER-10^{-2})	29.3%	41.2%
MISO	62.0%	65.6%	5.3dB (BER-10^{-3})	45.7%	30.0%
MIMO	60.9%	75.0%	4.1dB (BER-10^{-3})	27.4%	25.9%

The results obtained are for twenty trials of experiments. We see that without coding, a MISO system shows better result and with coding a SIMO system shows better result. This can also be clearly seen from Fig. 7 which shows that the maximum percentage fall in BER for 100 percent rise in transmitter gain without coding for a MISO system is more than the other systems. With coding, the maximum percentage fall in BER in SIMO system shows good result compared to the MISO and the MIMO systems. This is perhaps due to the complexity of the MISO and the MIMO systems which induces co-channel interference at an SNR of 15dB. The SISO system with and without coding shows satisfactory result due to its simplicity. Thus, our proposed technique with transmitter gain shows better performance in a MISO system without coding and in a SIMO system with coding despite the presence of Rayleigh and Rician channels. We specially note that on an average for BPSK modulation, all the multi antenna set-ups shows improved BER performance for the entire SNR range (Table 1.) for both Rayleigh and Rician channels with all the ten transmitter gains (Table 1.) considered. This establishes the relevance of the present work.

6. CONCLUSION

In this paper, adaptive transmitter gain aided multi antenna set-ups in stochastic wireless channels are tested. The proposed scheme has been verified in frequency-selective Rayleigh and Rician channels for BPSK modulation. It has been observed that the BER performances of the different multi antenna systems are enhanced with increasing SNR and transmitter gain. Future extension of this work has a lot of scope as noted in Section V. The proposed technique with transmitter gain does not show improved performance for a MIMO system both with coding and without coding. So, better recovery technique can be employed to enhance the performance of a MIMO set-up.

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