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BER Improvement in Spatial Modulation using a Zero-Forcing Receiver

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***Abstract*:- Spatial Modulation (SM) is an emerging wireless technology, where the activation state of various transmitting antennas is also considered as information. Information inherent in the activation state of the antenna is extra information that is sent along with the message information in modulated form. Spatial modulation has been invented primarily to overcome the various drawbacks of MIMO systems [1, 2]. High energy efficiency and high spectral efficiency achieved in SM system make this technology far more superior as compared to MIMO systems. Further, SM systems require a lesser number of RF chains which makes the scheme cheaper as compared to MIMO [3].**

Recently, it has been shown by researchers that the introduction of Zero Forcing (ZF) receivers [4] forces inter-symbol interference (ISI) and noise to zero [5] in MIMO systems. In the present work, the introduction of the ZF receiver has been proposed to make the SM and Differential Spatial Modulation (DSM) system more robust .In an SM and DSM system with a ZF receiver, multiple antenna transmitters can null the effect of multi-user interference by the successive cancelation of noise due to other antenna by creating the pseudo inverse of channel matrix and make the system noise free. The comparison of ZF receiver with Maximum Likelihood receiver has been done. The results obtained confirm the improvement in bit error rate with ZF receiver.

1. INTRODUCTION

With an increase in population, there is a greater need for high data rates and bandwidth. To meet this demand, researchers are concentrating on other technologies that have extremely high capacities, extremely low latency, low power requirements, and massive connectivity over limited wireless resources. Researchers are driven to create new transmission technologies with high achievable throughput and low development costs due to the high volume of mobile data traffic, so spatial modulation was created in the early 21st century to meet requirements. However, early 21st-century preliminary SM was created, due to high cost because of requirement of large number of RF chain so it does not receive much attention, but after 2008 due to the creation of GSM [6] and DSM [7], SM became a well-known technology for wireless communication. Let us consider a system with a single antenna to show the cancellation of interference

Zero forcing receiver is used in spatial modulation to reduce noise at the receiver side by canceling successive interference due to another signal. The Pseudo inverse of channel matrix is created for the cancelation of interference

2. SPATIAL MODULATION TECHNIQUE

Spatial modulation is a special technique that conveys extra information as compared to the MIMO system which is according to the activation state of the antenna which is based on the antenna switching mechanism (8). So in SM information is conveyed by both modulation techniques used *eg* (BPSK, QPSK) and the activation state of the antenna (which antenna is activated at particular time instant).The distance between two antennae (d) [9] should be greater than half the wavelength of signal so that different antennas have different channel coefficients (h) *eg* Transmit antenna 1 transmit antenna 2, transmit antenna 3 have channel coefficient's (h_1, h_2, h_3) and channel matrix H contains all channel coefficient .These different channel coefficients are use to determine which antenna is use to send which bit of information.

Case 1st: Transmit 1 bit out of 3 message bits using various combinations of the active antenna. [8]

Using a single RF chain if we have to transmit a total of 3 message bits at a time instant then we need to transmit only 2 bits using various modulation techniques and the remaining one bit is transmitted using information about the activation state transmitting antenna.

Data bits	Antenna 1	Antenna2	Bits transmitted using a modulation technique	Information bit transmitted using information about activation state off antenna
000	Off	Off	00	0
001	Off	On	00	1
010	On	Off	01	0
011	Off	On	01	1
100	On	Off	10	0
101	Off	On	10	1
110	On	Off	11	0
111	Off	On	11	1

Here if the last message bit is 0 then antenna 1 is activated and the if last message bit is 1 then antenna 2 is activated .So we divide message bits in a group of 3 and the transmit first 2 bits using various modulation techniques and last message bit is transmitted using activation state order of antenna.

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Case 2nd: Transmit 2 bits out of 3 message bits using various combinations of the active antenna [8]

Data bits	Antenna 1	Antenna2	Antenna3	Bits transmitted using a modulation technique	Information bit transmitted using information about activation state off antenna
000	Off	Off	On	0	00
001	Off	On	Off	0	01
010	On	Off	Off	0	10
011	On	On	Off	0	11
100	Off	Off	Off	1	00
101	Off	On	Off	1	01
110	On	Off	Off	1	10
111	On	On	Off	1	11

If we have to transmit a total of 3 message bits at a time instant then we need to transmit only 1-bit using various modulation techniques then three RF chains are required because three antennae are activated at a time and the remaining two bits are transmitted using information about the activation state transmitting antenna.

The message bits are divided in a group of 3 and transmit the first 1 bit using various modulation technique and last 2 message bits are transmitted using activation state order of the antenna. Where 01 represent the first antenna is of and the second antenna is on, 10 represents first antenna is on and second antenna is off and 11 represent both antenna are on. When three consecutive message bits are zero then both first and second antennas is off and third antenna is on, So 00 represent by activating third antenna while first and second antenna are off.

Case 3rd: Transmit 2 bits out of 4 message bits using various combinations of the active antenna [8]

Data bits	Antenna 1	Antenna2	Antenna3	Bits transmitted using a modulation technique	Information bit transmitted using information about activation state off antenna
0000	Off	Off	On	00	00
0001	Off	On	Off	00	01
0010	On	Off	Off	00	10
0011	On	On	Off	00	11
0100	Off	Off	Off	01	00
0101	Off	On	Off	01	01
0110	On	Off	Off	01	10
0111	On	On	Off	01	11
1000	On	Off	Off	10	00
1001	Off	On	Off	10	01
1010	On	Off	Off	10	10
1011	On	On	Off	10	11
1100	Off	Off	Off	11	00
1101	Off	On	Off	11	01
1110	On	Off	Off	11	10
1111	On	On	Off	11	11

We divide message bits in a group of 4 and transmit the first 2 bits using various modulation technique and last 2 message bit is transmitted using activation state order of the antenna. Where
01 represents the first antenna is of and the second antenna is on, 10 represents the first antenna is on and the second antenna is off and 11 represents both antennas are on. 00 represent both antennas are off and at this time the third antenna is on and bits transferred through antennas is 00.

3. SPATIAL MODULATION TRANSMITTER [10]

In spatial modulation technique, message bits are to be transmitted using two different domains constellation domain and space domain. Where space domain bits represent which antenna or group of the antenna is activated at a particular time instant. And constellation domain represents which modulation technique (PSK/QPSK) is used to transmit data.
Message bits to be transmitted is divided into two part first part Space domain bits consisting of $\log_2(N_T)$ is applied to the index selector where N_T represents the number of transmit antenna and the second part constellation domain bit consisting of $\log_2(M)$ is applied to the spatial modulator and then through RF chain message bits are transmitted to switcher where the spatial modulation switching mechanism is used to transmit data to the receiver side. Here antenna switching mechanism is used such that the index of activation antenna changes randomly for each group of bits according to the spatial modulation switching mechanism

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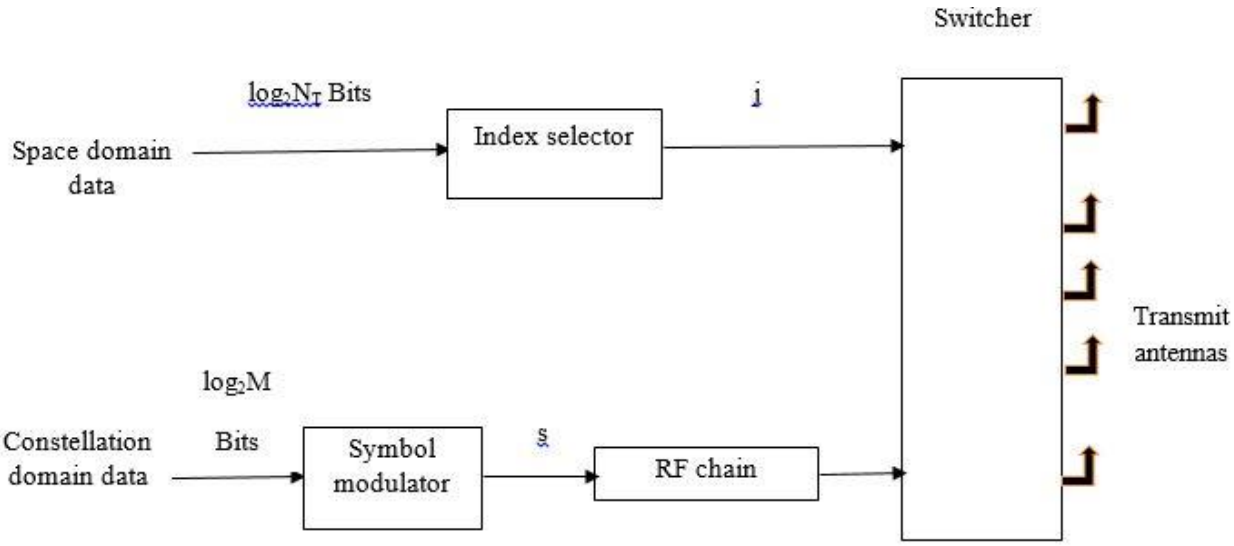

Fig 1 Transmitter diagram of SM system [10]

Spectral efficiency for spatial modulation system having N_T transmit antenna and use modulation index M is

$$S_{SM} = \log_2(N_T) + \log_2(M)$$

Constellation symbol s is carried out by n^{th} antenna so SM transmitter vector x is represented as

$$x = [0\ldots\ldots0\ldots\ldots0\ldots\ldots\ldots s\ldots\ldots\ldots0\ldots0]^T$$

n-1 antenna before the n^{th} antenna and N_T –n antenna after the n^{th} antenna are off because in single RF spatial modulation message bits are transmitted using a single RF chain.

When we take M=1 then the spatial modulation system changes to simple SSK (Space shift keying) where all the information bits are mapped according to the activation state of the antenna. Spectral efficiency in this case changes to.

$$S_{SSK} = \log_2(N_T) \quad [\text{ bpcu }]$$

3.1 Differential Spatial Modulation [10]

Differential Spatial modulation (DSMS) is a special type of spatial modulation where the space-time block code (STBC) technique is used in spatial modulation to increase the spectral efficiency of spatial modulation p to 15 times as compare to SM. In SM Chanel state information is required at the receiver side which a make system which make the system more costly and complex but due to use of STBC in spatial modulation channel state information is not required at receiver side so DSM is the most prominent technology used in wireless communication these day to users requirement of high data rate and high spectral efficiency.

Spectral efficiency of DSM having number of transmit antenna N_T and modulation index M is

$$S_{DSM} = [\log_2((N_T!)) + \log_2 M \text{ [bpcu]}.$$

4. ZERO FORCING RECEIVER IN SPATIAL MODULATION [11]

Received vector $\overline{Y}$ at receiver side in SM receiver is given as

$$\overline{Y} = H\,\overline{x} + \overline{w}$$

Where $\overline{Y}$ is r × 1 is received vector, $\overline{x}$ is t × 1 transmitted vector and H is r × t channel matrix and $\overline{w}$ is r × t is the white Gaussian noise matrix

To recover transmit vector $\overline{x}$ at receiver side we have to deal with 2 condition's

1. Number of transmit antenna are equal to number if receive antenna
2. Number of transmit antenna are not equal to number if receive antenna

1st condition: when number of transmitter t is equal to number of receiver r then channel matrix H become t × t square matrix so inverse of square matrix is possible.

$$\overline{Y} = H\overline{x}$$

When H is invertible input vector x is

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$$\hat{x} = H^{-1}\overline{Y}$$

2nd condition: when the number of transmitter t is not equal to the number of receiver r then H becomes r × t non square matrix so the inverse of a square matrix is not possible .hence special architecture is needed at receiver to retrieve input matrix $\overline{x}$ from received vector $\overline{Y}$.

If there are r receiver and t transmitter (r > t) so there are r equation and t unknown

Number of equation > number of unknown so it is set of inconsistent equations so we can't solve for x

Let us assume error vector $\overline{e}$ which is given as

$$\overline{e} = \overline{Y} - H\overline{x}$$

To minimize error

$$\text{Min } \|\overline{e}\|^2 = \min \| y - H\overline{x} \|$$

Find $\overline{x}$ such that $\|y - H\overline{x}\|$ is minimum

We differentiate it and put it equal to zero to find minimum then put it in equation.

However, $\overline{x}$ is a t×1 transmit vector so we have to differentiate with respect to $\overline{x}$. And after putting the minimum value of error on the output receive vector equation then we get the input vector as.

$$\hat{x} = (H^T H)^{-1} H^T \overline{Y}$$

$\hat{x}$ is zero forcing MIMO receiver output using the least square solution. If channel matrix H is complex then $\hat{x}$ becomes.

$$\hat{x} = (H^H H)^{-1} H^H \overline{Y}$$

H is t × r matrix and H^H is r × t matrix so $H^H H$ is t × t square matrix. H^{-1} of the non-square matrix is not possible so we calculate $(H^H)^{-1}$ which can be calculated for non-square matrix.

$(H^H H)^{-1} H^H$ is known as the pseudo inverse of H. We multiply pseudo inverse of H by H to get the identity matrix.

$$(H^H H)^{-1} H^H \times H = I$$

So with the help of pseudo inverse matrix we can calculate inverse of non-square matrix H

4.1 Bit error rate of spatial modulation using zero forcing receiver. [11,12]

Consider r × t channel matrix H with all element IID (independent and identical) with complex Gaussian average power =1.

Transmitted average power is given as

$$E\{|X|^2\} = 1$$

The error rate for BPSK with zero forcing receiver is given as.

$$BER = {}^{2L-1}C_L \{1/2SNR\}^L$$

Where $L = |N_T - N_R + 1|$,r and t represent number of receiver and transmitter antenna.

The Bit error rate for QPSK with zero forcing receiver is given as.

$$BER = {}^{2L-1}C_L \{1/2SNR\}^L$$

Where $L = | N_T - N_R + 3 |$

The Bit error rate for M-array PSK with zero forcing receiver is given as

$$BER = {}^{2L-1}C_L \{1/2SNR\}^L$$

Where $L = | N_T - N_R + M - 1 |$

4.1 Bit error rate of Differential Spatial Modulation using zero forcing receiver. [11,12]

Consider r × t channel matrix H with all element IID (independent and identical) with complex Gaussian average power =1.

Transmitted average power is given as

$$E\{|X|^2\} = 1$$

In DSM using Zero forcing receiver SNR value become half as compare to Maximum likely receiver.

The error rate for BPSK, DPSK with zero forcing receiver is given as.

$$SNR = {}^{2L-1}C_L \{1/SNR\}^L$$

Where $L = |N_T - N_R + 1|$,r and t represent number of receiver and transmitter antenna.

The Bit error rate for QPSK with zero forcing receiver is given as.

$$BER = {}^{2L-1}C_L \{1/SNR\}^L$$

Where $L = | N_T - N_R + 3 |$

The Bit error rate for M-array PSK with zero forcing receiver is given as

$$BER = {}^{2L-1}C_L \{1/SNR\}^L$$

Where $L = | N_T - N_R + M - 1 |$

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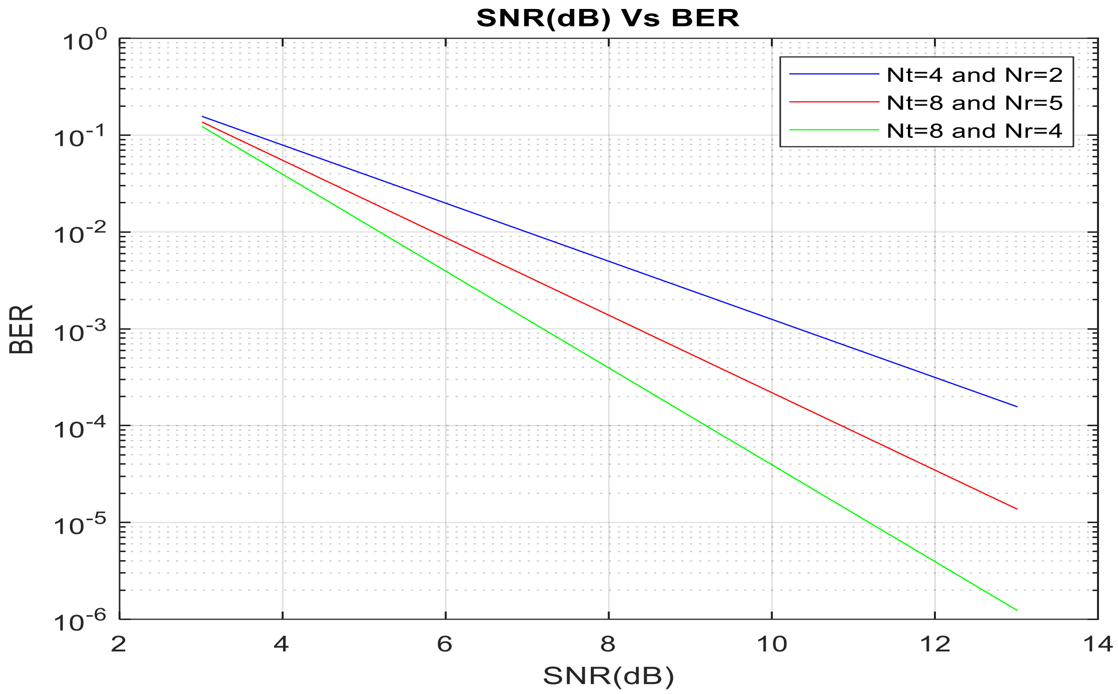

Fig 2 BER versus SNR graph of SM using Zero-forcing receiver system using BPSK for the different set of transmitting and receiving antenna

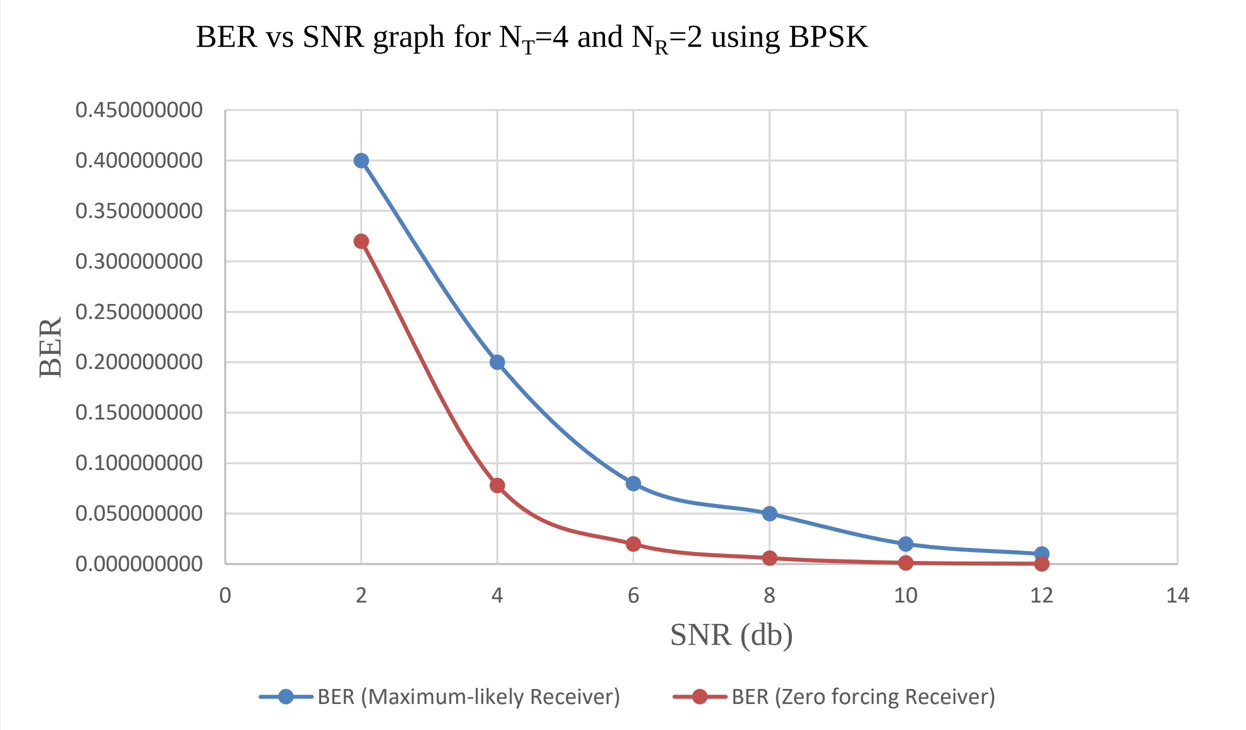

Fig 3 comparison of BER versus SNR graph of SM using Zero-forcing Receiver and Maximum-likely Receiver

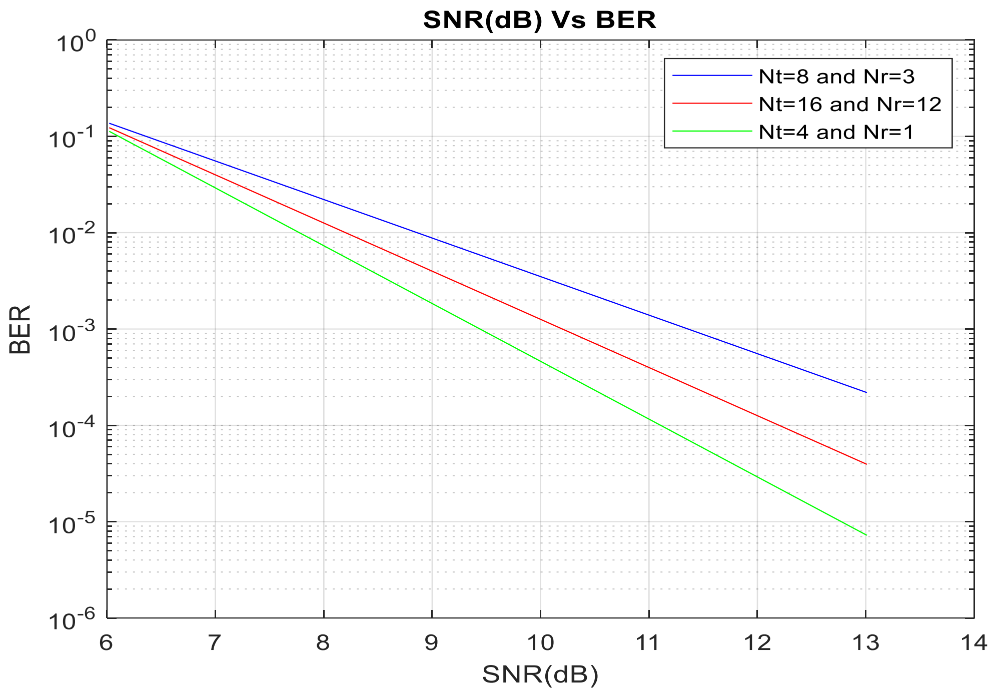

Fig 4 BER versus SNR graph of DSM using Zero-forcing receiver system using DPSK for the different sets of transmitting and receiving antenna

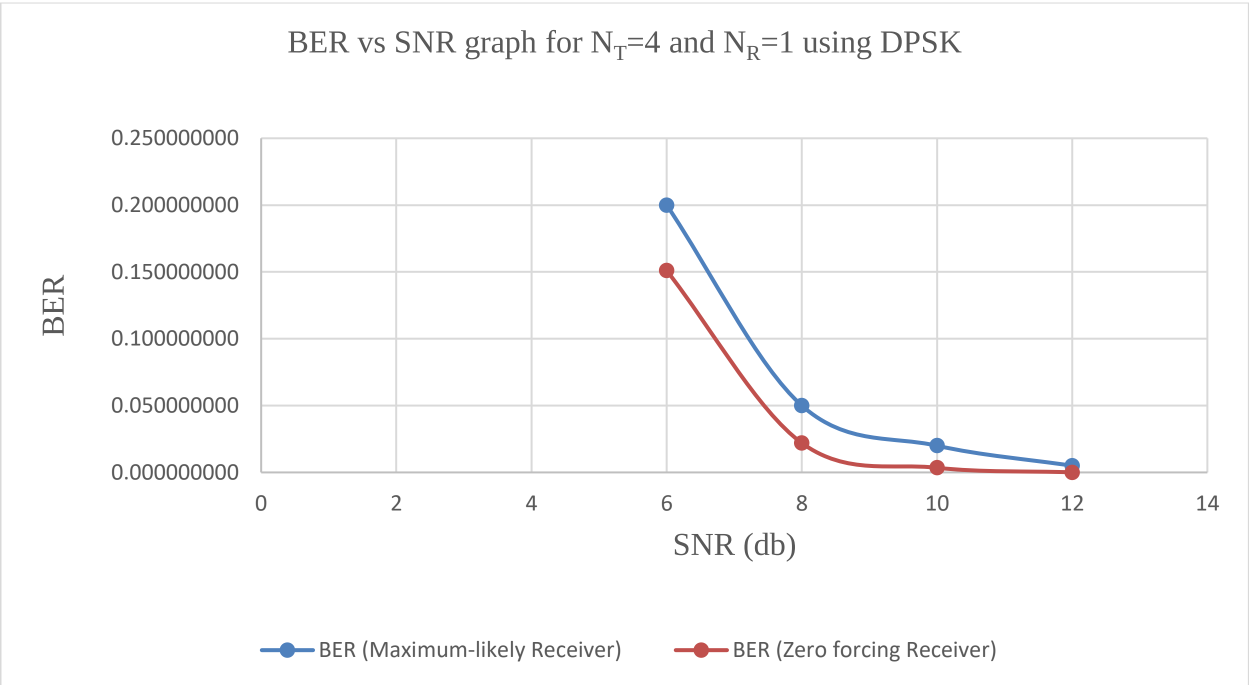

Fig 4 Comparison of BER versus SNR graph of SM using Zero-forcing Receiver and Maximum-likely Receiver

5. CONCLUSION

In the MIMO system model, all antennas are activated at a time so it requires RF chains equal to the number of transmitting antennas which increases the cost of the system and power requirement. So Spatial modulation system is developed where only one antenna is activated at a time which requires only one RF chain so cost is reduced .but with the increase in the requirement of bandwidth spatial modulation technology is modified which allows more than one antenna to activate at a time, which increases inter symbol interference and noise in the system so Zero-forcing receiver is used in spatial modulation and differential spatial modulation which reduces BER of the system more rapidly as compared to ML(maximum-likelihood) receiver. main drawback of zero forcing receiver is it is use only for higher values of SNR (db) for lower values of SNR in zero forcing receiver BER is high . So ZF receiver is not us for lower values of SNR.

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