# DIFFERENT DIGITAL MODULATION SCHEMES USING MIMO OFDM SYSTEMS

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## ABSTRACT

This paper presents an overview of recent progressin the area of multiple-input–multiple-output (MIMO) space–time coded wireless systems. After some background on this concept leading to the discovery of the enormous potential of MIMO wireless links, by highlighting the different classes of techniques and algorithms proposed which attempt to realize the various benefits of MIMO including spatial multiplexing and space–time coding schemes. These algorithms are often derived and analyzed under ideal independent fading conditions. The transmission of data in MIMO is done using Rayleigh fading channel capacity where we use the Zero forcing equalizer. By presenting the state of the art in channel modeling and measurements, leading to a better understanding of actual MIMO gains. Finally, the paper addresses current questions regarding the integration of MIMO links in practical wireless systems and standards.

*Key Words:* **channel models, diversity, multiple- input–multiple-output (MIMO), Shannon capacity, space–time coding.**

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## I. INTRODUCTION

**D**IGITAL communication using multiple-input–multiple output (MIMO), sometimes called a “volume-to-volume” wireless link, has recently emerged as one of the most significant technical breakthroughs in modern communications. The technology figures prominently on the list of recent technical advances with a chance of resolving the bottleneck of traffic capacity in future Internet-intensive wireless networks. Perhaps even more surprising is that just a few years after its invention the technology seems poised to penetrate large-scale standards-driven commercial wireless products and networks such as broadband wireless access systems, wireless local area networks (WLAN), third-generation (3G)1 networks and beyond. MIMO systems can be defined simply. Given an arbitrary wireless communication system, consider a link for which the transmitting end as well as the receiving end is equipped with multiple antenna elements. Such a setup is illustrated in Fig. 1. The idea behind MIMO is that the signals on the transmit (TX) antennas at one end and the receive (RX) antennas at the other end are “combined” in such a way that the quality (bit-error rate or BER) or the data rate (bits/sec) of the communication for each MIMO user will be improved. Such an advantage can be used to increase both the network’s quality of service and the operator’s revenues significantly. A core idea in MIMO systems is *space–time* signal processing in which time (the natural dimension of digital communication data) is complemented with the spatial dimension inherent in the use of multiple spatially distributed antennas. As such MIMO systems can be viewed as an extension of the so-called *smart antennas*, a popular technology using antenna arrays for improving wireless transmission dating back several decades.

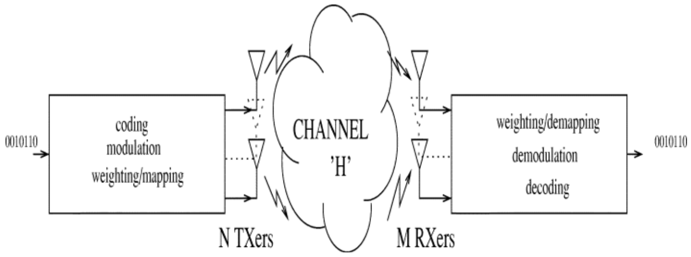

**Figure 1: MIMO Transmission system**

A key feature of MIMO systems is the ability to turn multipath propagation, traditionally a pitfall of wireless transmission, into a benefit for the user. MIMO effectively takes advantage of random fading [1]–[3] and when available, multipath delay spread [4], [5], for multiplying transfer rates. The prospect of many orders of magnitude improvement in wireless communication performance at no cost of extra spectrum (only hardware and complexity are added) is largely responsible for the success of MIMO. This has prompted progress in areas as diverse as channel modeling, information theory and coding, signal processing, antenna design and multi antenna aware cellular design, fixed or mobile. This paper discusses the recent advances, adopting successively several complementing views from theory to real-world network applications. This paper forms a synthesis of the more fundamental ideas presented over the last few years in this area, although some very recent progress is also mentioned.

## II. PRINCIPLES OF SPACE-TIME (MIMO) SYSTEMS

Consider the multi antenna system diagram in Fig. 1. A compressed digital source in the form of a binary data stream is fed to a simplified transmitting block encompassing the functions of error control coding and (possibly joined with) mapping to complex modulation symbols (quaternary phase-shift keying (QPSK), M-QAM, etc.). The latter produces several separate symbol streams which range from independent to partially redundant to fully redundant. Each is then mapped onto one of the multiple TX antennas. Mapping may include linear spatial weighting of the antenna elements or linear antenna space–time *precoding*. After upward frequency conversion, filtering and amplification, the signals are launched into the wireless channel. At the receiver, the signals are captured by possibly multiple antennas and demodulation and demapping operations are performed to recover the message. The level of intelligence, complexity, and *a priori* channel knowledge used in selecting the coding and antenna mapping algorithms can vary a great deal depending on the application[12]. This determines the class and performance of the multiantenna solution that is implemented.

In the conventional smart antenna terminology, only the transmitter or the receiver is actually equipped with more than one element, being typically the base station (BTS), where the extra cost and space have so far been perceived as more easily affordable than on a small phone handset. Traditionally, the intelligence of the multiantenna system is located in the weight selection algorithm rather than in the coding side although the development of *space–time codes (STCs)* is transforming this view[30]. Simple linear antenna array combining can offer a more reliable communications link in the presence of adverse propagation conditions such as multipath fading and interference. A key concept in smart antennas is that of beamforming by which one increases the average signal-to-noise ratio (SNR) through focusing energy into desired directions, in either transmit or receiver. Indeed, if one estimates the response of each antenna element to a given desired signal, and possibly to interference signal(s), one can optimally combine the elements with weights selected as a function of each element response. One can then maximize the average desired signal level or minimize the level of other components whether noise or co-channel interference. Another powerful effect of smart antennas lies in the concept of *spatial diversity*. In the presence of random fading caused by multipath propagation, the probability of losing the signal vanishes exponentially with the number of decorrelated antenna elements being used. A key concept here is that of *diversity order* which is defined by the number of decorrelated spatial branches available at the transmitter or receiver. When combined together, leverages of smart antennas are shown to improve the coverage range versus quality tradeoff offered to the wireless user [6].As subscriber units (SU) are gradually evolving to become sophisticated wireless Internet access devices rather than just pocket telephones, the stringent size and complexity constraints are becoming somewhat more relaxed. This makes multiple antenna elements transceivers a possibility at both sides of the link, even though pushing much of the processing and cost to the network's side (i.e., BTS) still makes engineering sense. Clearly, in a MIMO link, the benefits of conventional smart antennas are retained since the optimization of the multiantenna signals is carried out in a larger space, thus providing additional degrees of freedom. In particular, MIMO systems can provide a joint transmit-receive diversity gain, as well as an array gain upon coherent combining of the antenna elements (assuming prior channel estimation)[25].

## III. 2×2 MIMO channel

In a 2×2 MIMO channel, probable usage of the available 2 transmit antennas can be as follows: Consider a transmission sequence,$\{x_1,x_2,\ldots x_n\}$.In normal transmission, $x_1$will be sent in the first time slot, $x_2$ in the second time slot, $x_3$ and so on. However, by taking 2 transmit antennas, group the symbols into groups of two. In the first time slot, send $x_1$ and $x_2$ from the first and second antenna. In second time slot, send $x_3$ and $x_4$ from the first and second antenna, send $x_5$ and $x_6$ in the third time slot and so on. Notice that the grouping two symbols and sending them in one time slot, transmission of data need only n/2 time slots to complete the transmission – **data rate is doubled** !. This forms the simple explanation of a probable MIMO transmission scheme with 2 transmit antennas and 2 receive antennas[13,23].

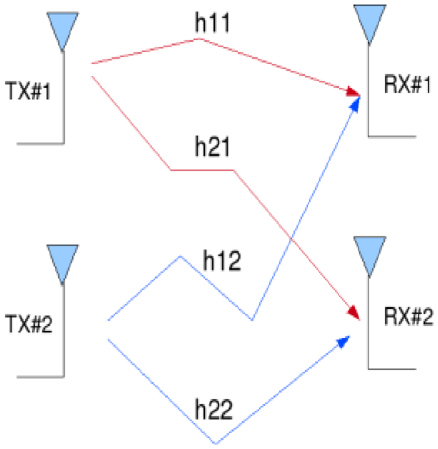

**Figure: 2 Transmit 2 Receive (2×2) MIMO channel**

**Zero forcing (ZF) equalizer for 2×2 MIMO channel**

Let us now try to understand the math for extracting the two symbols which interfered with each other. In the first time slot, the received signal on the first receive antenna is,

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = [h_{1,1}\ h_{1,2}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \text{---(1)}$$

The received signal on the second receive antenna is,

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = [h_{2,1}\ h_{2,2}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \text{.—(2)}$$

Where $y_1$, $y_2$ are the received symbol on the first and second antenna respectively, $h_{1,1}$ is the channel from $1^{st}$ transmit antenna to $1^{st}$ receive antenna, $h_{1,2}$ is the channel from $2^{nd}$ transmit antenna to $1^{st}$ receive antenna, $h_{2,1}$ is the channel from $1^{st}$ transmit antenna to $2^{nd}$ receive antenna, $h_{2,2}$ is the channel from $2^{nd}$ transmit antenna to $2^{nd}$ receive antenna, $x_1$ , $x_2$ are the transmitted symbols and $n_1$, $n_2$ is the noise on $1^{st}$, $2^{nd}$ receive antennas.
A strong analogy can be made with code-division multiple-access (CDMA) transmission in which multipleusers sharing the same time/frequency channel are mixed upon transmission and recovered through their unique codes. Here, however, the advantage of MIMO is that the unique signatures of input streams ("virtual users") are provided by nature in a close-to-orthogonal manner (depending however on the fading correlation) without frequency spreading, hence at no cost of spectrum efficiency[20]. Another advantage of MIMO is the ability to jointly code and decode the multiple streams since those are intended to the same user. However, the isomorphism between MIMO and CDMA can extend quite far into the domain of receiver algorithm design [16]

Note that, unlike in CDMA where user's signatures are quasi-orthogonal by design, the separability of the MIMO channel relies on the presence of rich multipath which is needed to make the channel spatially selective. Therefore, MIMO can be said to effectively *exploit* multipath. In contrast, some smart antenna systems (beamforming, interference rejection- based) will perform better in line-of-sight (LOS) or close to LOS conditions. This is especially true when the optimization criterion depends explicitly on angle of arrival/departure parameters[13]. Alternatively, diversity-oriented smart antenna techniques perform well in nonline-of-sight (NLOS), but they really try to mitigate multipath rather than exploiting it. In general, one will define the *rank* of the MIMO channel as the number of independent equations offered by the above mentioned linear system. It is also equal to the algebraic rank of the channel matrix. Clearly, the rank is always both less than the number of TX antennas and less than the number of RX antennas[28]. In turn, following the linear algebra analogy, one expects that the number of independent signals that one may safely transmit through the MIMO system is at most equal to the rank. In the example above, the rank is assumed full (equalto three) and the system shows a *nominal* spectrum efficiency gain of three, with no coding. In an engineering sense, however, both the number of transmitted streams and the level of BER on each stream determine the link's efficiency (goodput3 per TX antenna times number of antennas) rather than just the number of independent input streams[24,7]. Since the use of coding on the multiantenna signals (a.k.a. space–time coding) has a critical effect on the BER behavior, it becomes an important component of MIMO design.

## IV. BIT ERROR RATE

**BER computation in AWGN**, the probability of error for transmission of either +1 or -1 is computed by integrating the tail of the Gaussian probability density function for a given value of bit energy to noise ratio $\frac{E_b}{N_0}$. The bit error rate is,

$$P_b = \frac{1}{2}erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \text{. ------ (3)}$$

However in the presence of channel $h$ , the effective bit energy to noise ratio is $\frac{|h|^2 E_b}{N_0}$ . So the bit error probability for a given value of $h$ is,

$$P_{b|h} = \frac{1}{2}erfc\left(\sqrt{\frac{|h|^2 E_b}{N_0}}\right) = \frac{1}{2}erfc(\sqrt{\gamma})$$

where $\gamma = \frac{|h|^2 E_b}{N_0}$ -----(4)

To find the error probability over all random values of $|h|^2$, one must evaluate the conditional probability density function $P_{b|h}$ over the probability density function of $\gamma$.

**Probability density function of $\gamma$**

From chi-square random variable. if $|h|$ is a Rayleigh distributed random variable, then $|h|^2$ is chi-square distributed with two degrees of freedom. since $|h|^2$ is chi square distributed, $\gamma$ is also chi square distributed. The probability density function of $\gamma$ is,

$$p(\gamma)=\frac{1}{(E_b/N_0)}e^{\frac{-\gamma}{(E_b/N_0)}},\ \gamma \geq 0$$ ----(5)

**Error probability:**So the error probability is,

$$P_b=\int_0^{\infty}\frac{1}{2}erfc(\sqrt{\gamma})p(\gamma)d\gamma$$ -----(6)

Somehow, this equation reduces to

$$P_b=\frac{1}{2}\left(1-\sqrt{\frac{(E_b/N_0)}{(E_b/N_0)+1}}\right)$$ -----(7)

When compared to the AWGN case, around 25dB degradation due to the multipath channel (at the $10^{-4}$ point). This is both good and bad: bad because it need to spend so much energy to get a reliable wireless link up (in this era of global warming), and good because the signal processing engineers are trying to figure out ways for improving the performance. Assuming a block of independent data of size is transmitted over the MIMO system, the receiver will obtain where is of size . In order to perform symbol detection, the receiver must unmix the channel, in one of several various possible ways[22].

Zero-forcing (ZF) techniques use a straight matrix inversion,a simple approach which can also result in poor results when the matrix becomes very ill conditioned as in certain random fading events or in the presence of LOS. The use of a MSE linear receiver may help in this case, but improvements are found to be limited (1.5 to 2 dB in the 2 2 case) if knowledge of nontrivial noise/interference statistics (e.g., covariance matrix) are not exploited in the MMSE[1].

## V. TRANSMIT DIVERSITY vs RECEIVER DIVERSITY

Multiple-Input-Multiple-Output (MIMO) systems, which use multiple antennas at the transmitter and receiver ends of a wireless communication system. MIMO systems are increasingly being adopted in communication systems for the potential gains in capacity they realize when using multiple antennas. Multiple antennas use the spatial dimension in addition to the time and frequency ones, without changing the bandwidth requirements of the system[5]. For a generic communications link, this demo focuses on transmit diversity in lieu of traditional receive diversity. Using the flat-fading Rayleigh channel, it illustrates the concept of Orthogonal Space-Time Block Coding, which is employable when multiple transmitter antennas are used. It is assumed here that the channel undergoes independent fading between the multiple transmit-receive antenna pairs[4].

For a chosen system, it also provides a measure of the performance degradation when the channel is imperfectly estimated at the receiver, compared to the case of perfect channel knowledge at the receiver. Using diversity reception is a well-known technique to mitigate the effects of fading over a communications link. However, it has mostly been relegated to the receiver end. In [1], Alamouti proposes a transmit diversity scheme that offers similar diversity gains, using multiple antennas at the transmitter[19].

This was conceived to be more practical as, for example, it would only require multiple antennas at the base station in comparison to multiple antennas for every mobile in a cellular communications system[11]. This section highlights this comparison of transmit vs. receive diversity by simulating coherent binary phase-shift keying (BPSK) modulation over flat-fading Rayleigh channels. For transmit diversity, by using two transmit antennas and one receive antenna (2x1 notationally), while for receive diversity employing one transmit antenna and two receive antennas (1x2 notationally)[25]. The simulation covers an end-to-end system showing the encoded and/or transmitted signal, channel model, and reception and demodulation of the received signal. It also provides the no-diversity link (single transmit- receive antenna case) and theoretical performance of second-order diversity link for comparison. It is assumed here that the channel is known perfectly at the receiver for all systems. run the simulation over a range of Eb/No points to generate BER results that allow us to compare the different systems.

The transmit diversity system has a computation complexity very similar to that of the receive diversity system. The resulting simulation results show that using two transmit antennas and one receive antenna provides the same diversity order as the maximal-ratio combined (MRC) system of one transmit antenna and two receive antennas[4]. Also observe that transmit diversity has a 3 dB disadvantage when compared to MRC receive diversity. This is because of modeling the total transmitted power to be the same in both cases[13]. If calibrate the transmitted power and the received power for these two cases is same, then the performance would be identical. The theoretical performance of second-order diversity link matches the transmit diversity system as it normalizes the total power across all the diversity branches.

## VI. SPACE TIME BLOCK CODING WITH CHANNEL ESTIMATION

Building on the theory of orthogonal designs, generalized Alamouti's transmit diversity scheme to an arbitrary number of transmitter antennas, leading to the concept of Space-Time Block Codes. For complex signal constellations, they showed that Alamouti's scheme is the only full-rate scheme for two transmit antennas. In this section, the performance of such a scheme with two receive antennas (i.e., a 2x2 system) with and without channel estimation[19,8] is present. In the realistic scenario where the channel state information is not known at the receiver, this has to be extracted from the received signal. assume that the channel estimator performs this using orthogonal pilot signals that are prepended to every packet [3]. It is assumed that the channel remains unchanged for the length of the packet[3] (i.e., it undergoes slow fading).

A simulation similar to the one described in the previous section is employed here, which leads us to estimate the BER performance for a space-time block coded system using two transmit and two receive antennas[9]. Data is encoded using a space-time block code, and the encoded data is split into n streams which are simultaneously transmitted using n transmit antennas. The received signal at each receive antenna is a linear superposition of the n transmitted signals perturbed by noise[9]. Maximum likelihood decoding is achieved in a simple way through decoupling of the signals transmitted from different antennas rather than joint detection. This uses the orthogonal structure of the space-time block code and gives a

maximum likelihood decoding algorithm which is based only on linear processing at the receiver[5].

## VII. SIMULATION RESULTS

This plot explains the BER of MIMO diversity of given data

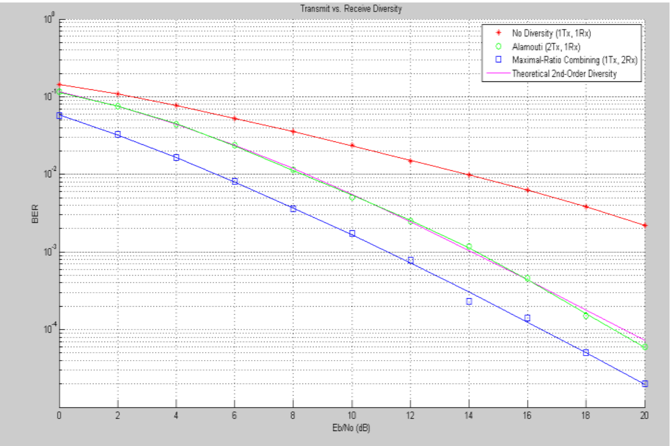

**Figure 3: BER OF MIMO Diversity of Tx Vs Rx**

This plot explains the orthogonal space coding of 8 bits for Transmitter and Receiver.

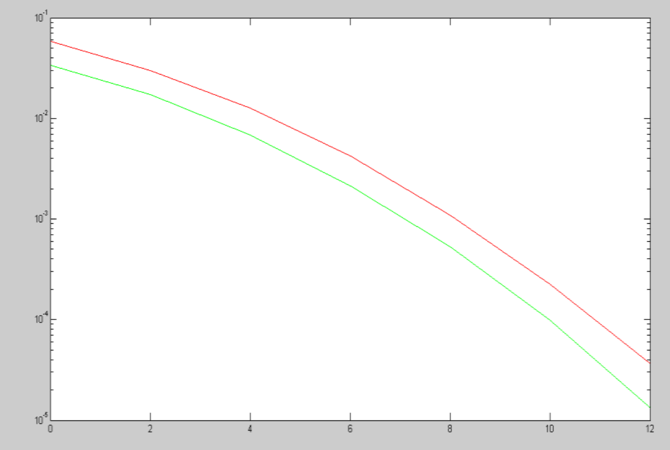

**Figure 4: Orthogonal Space Coding Tx and Rx 8 bits of Channel**

This plot explains the BER of BPSK,QPSK techniques of MIMO diversity.

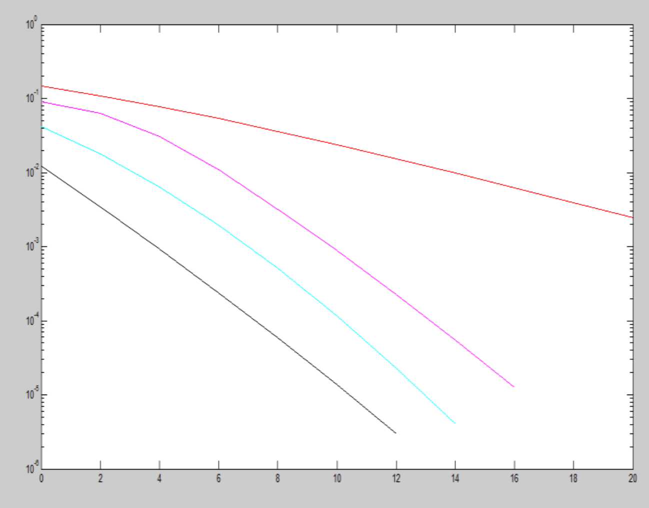

Figure 5: BER OF BPSK,QPSK OF MIMO DIVERSITY

This plot shows the BER of theoretical and practical values of QPSK Technique.

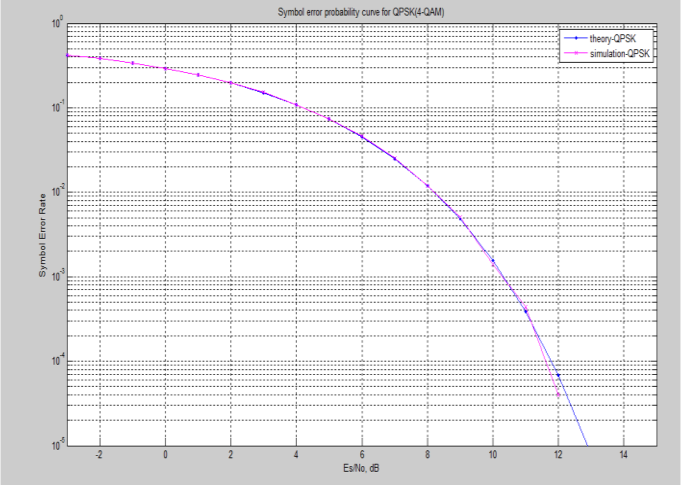

Figure 6: BER of MIMO QPSK

This plot explain the AWGN, Rayleigh of implementation theoretical and practically of the signal.

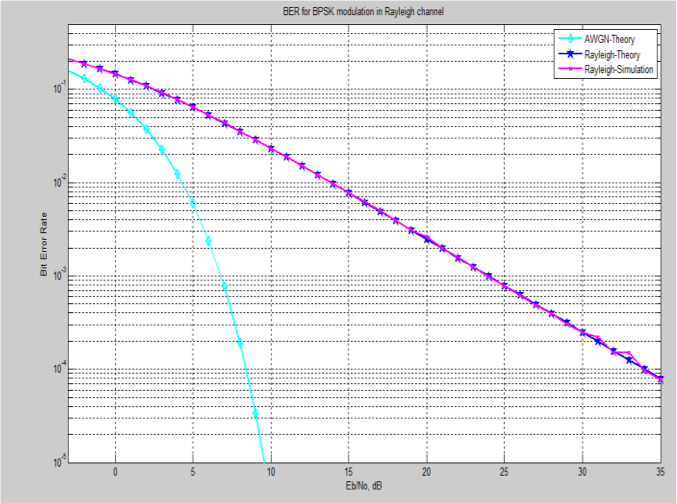

Figure 7: MIMO Rayleigh, AWGN Outputs

This plot explains the BER of BPSK technique between transmitting antenna and receiver antenna using MRC, alamouti of STBC.

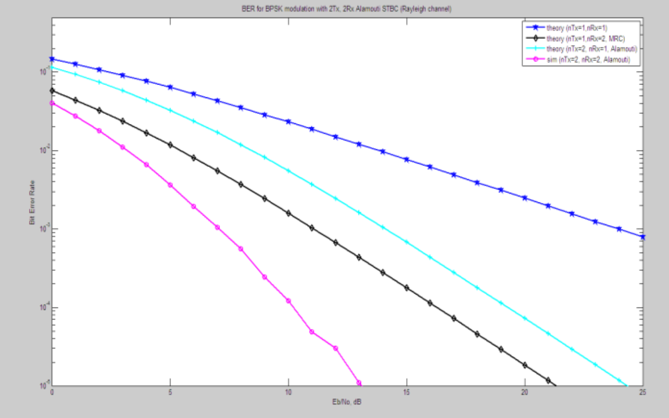

**Figure 8: BER calculation of BPSK Technique**

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