International Journal of Advanced Robotics and Intelligent Systems
Volume 1, Issue 04, 2025

BER PERFORMANCE COMPARISON OF THE 4X4 EXTENDED ALAMOUTI SCHEME FOR DIFFERENT FADING CHANNELS

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Research Article

Date of Submission: 05-08-2025 **Date of Acceptance: 10-09-2025** **Date of Publication: 09-11-2025**

ABSTRACT: The primary goal of next-generation wireless communication and mobile systems is to maximize bandwidth usage while achieving greater data speeds. The MIMO communication technique is now used for such. One diversity scheme utilized to enhance error performance is the EXTENDED ALAMOUTI scheme with 4X4 diversity order, which we portray in this study. The error performance of this novel diversity technique on several fading channels, namely AWGN, RICIAN, RAYLEIGH, and NAKAGAMI, is discussed in this work. The error performance comparison between this novel scheme and the ALAMOUTI system with 2XM diversity order across all four fading channels using an ML detector is shown in this study. In order to clarify the differences between the four fading channels, this research also compares them using a BER vs. SNR graph.

Keywords: ML, AWGN, MIMO, BER, and ALAMOUTI.

I. INTRODUCTION

Due to certain effective improvements in error performances, spectrum efficiency, bandwidth utilization, better throughput, etc., MIMO technology has gained increasing attention in the context of wireless communication systems these days. Many well-known cellular technologies, including LTE (Long Term Evolution), 3GPP-LTE, CDMA-2000, Mobile Wi-MAX, WIBRO (Wireless Broadband Internet) (IEEE 802.16), WLAN (IEEE 802.11x), and some video broadcasting methods, like DVB, DAB, DVB-T, etc., are utilized as a result of these advancements in wireless communication systems and cellular systems [2-3].

Some interleaved coding techniques, including as space-block codes based on transmit, receiver, and transmit-receiver diversity schemes for MISO, SIMO, and MIMO systems, respectively, are being employed to eliminate the influence of fading. The MRRC (Maximal Receiver Ratio Combining) scheme of diversity order 1XM is one of the most well-known receiver diversity schemes. Then, SIVASH M. ALAMOUTI created two additional schemes to eliminate its drawbacks and enhance its performance. The ALAMOUTI scheme, as shown in [2], became one of the well-known space temporal diversity schemes.

The structure of this document is as follows: The fundamental details of various fading channels and the channel parameter are covered in Section II. The paper's main body will begin with Section III, which covers the theoretical underpinnings of diversity schemes that have already been devised, such as those found in [2], and then presents a novel version of that scheme with a double coding rate. The simulation results for each of the four fading channels for the M-PSK modulation scheme are then shown in Section IV, along with a comparison between each fading channel and the prior system.

II. FADING & MIMO CHANNEL MODELS

The main and most important issue in wireless communication systems is MIMO wireless communication channels. The primary cause of this is because wireless communication channels are more dynamic than wired ones. Any MIMO communication channel must now be represented in matrix form. as shown in below equation – (1). Now, first of all consider the MIMO channel example shown in figure – (1):-

$$\begin{pmatrix} h_{11} & \cdots & h_{1n} \\ \vdots & \ddots & \vdots \\ h_{ml} & \square & h_{mn} \end{pmatrix} \quad \ldots\ldots (1)$$

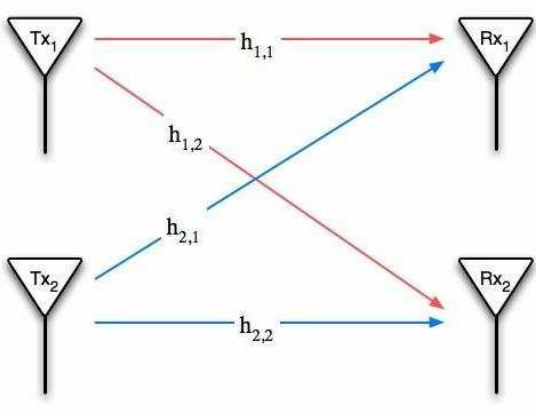


Fig. 1 MIMO COMMUNICATION CHANNEL

Now, each of the matrix components hi,j in equation (1) above represents the channel's impedance parameter between the broadcasting antenna (i) and the receiving antenna (j). Thus, the value of this hi,j parameter varies depending on the LOS (Line-of-Sight) parameter, fading distribution, and fading impact depending on the various channels.

Now, it's important to define fading before moving on to the various kinds of fading channels. The height of the mobile antenna may be lower than the surrounding buildings in the majority of mobile or cellular systems. It is thus very rare that there is a direct or line-of-sight link between the transmitter and the receiver. In this situation, propagation is mostly caused by diffraction over and/or around the buildings as well as reflection and scattering from them. In actuality, a multi-path scenario is created when the broadcast signal reaches the receiver by many pathways with varying time delays [5].

These multi-path waves with randomly dispersed phases and amplitudes combine at the receiver to produce a signal that varies in both space and time. Because of the shift in the phase connection between the incoming radio waves, a receiver at one point may get a signal that is significantly different from the signal at another position, even if they are just a short distance apart. Significant variations in the signal's amplitude result from this. Fading is the word used to describe this phenomena of unpredictable variations in the received signal intensity [4-5].

Many fading models, which are widely used in wireless communication systems as a wireless communication channel, are currently available based on the fading distribution. Currently, we are primarily looking at four models: AWGN, RAYLEIGH, RACIAN, and NAKAGAM.I fade the following channel models: A.AWGN Channel

A universal channel model for analyzing any novel scheme is the additive white Gaussian noise (AWGN) channel. The channel in this approach only adds white Gaussian noise to the signal that is going through it. There is either no fading or very little of it. The AWGN is the sole source of distortion. The AWGN channel is a theoretical channel that is solely used for analysis.So, if s(t) is transmitted symbol then the received symbol is given as:-

$$R(t)=s(t)+\eta(t) \quad (2)$$

Where η(t) is the Additive White Gaussian Noise (AWGN).

A. Rayleigh Channel

A statistical channel model called Rayleigh fading is used to depict the impact of a multi-path propagation environment on radio signals or transmission symbols. A channel is referred to be a RAYLEIGH channel when the transmitted signal that passes through it varies randomly or fades in accordance with the Rayleigh distribution.

Rayleigh fading is primarily only relevant in situations when the transmitter and receiver are not in line of sight.So, if s(t) is transmitted symbol then the received symbol is given as:-

$$R(t)=s(t)*h(t)+\eta(t) \quad (3)$$

Here R(t) is distributed by using Rayleigh distribution function as shown in [5]. Where
η(t) is the Additive White Gaussian Noise (AWGN).

B. Rician Channel

The Rician fading channel is a statistical model for multipath radio transmission that results from the transmitted symbols' partial affection. This indicates that Rician fading happens when one path—usually a line of sight signal—is much stronger than the others. Thus, a Rician distribution characterizes the amplitude gain.

So, if s(t) is transmitted symbol then the received symbol is given as:-

$$R(t)=s(t)*h(t)+\eta(t) \quad (4)$$

Here, received signal is distributed by Rician probability distribution function as in [5].

C. Nakagami Channel

Both Rayleigh and Rician fading channels may be described by changing only one parameter, which is often represented by the letter "m." In this case, the probability distribution function's value shifts toward the Rician or Rayleigh fading distribution, respectively, when the value of the nakagami factor "m" increases or decreases.

When we choose m<1, the Nakagami channel functions as a Rayleigh channel. Likewise, the Nakagami channel functions as a Rician channel when we raise the value of the Nakagami factor, i.e., when it is m>1 (m=1.5, 2, 4, etc.). Thus, when we alter the value of the nakagami factor m, we may see the various BER performances. [5]

III. THEORETICAL BACKGROUND OF DIVERSITY SCHEME

The fundamental history of the ALAMOUTI scheme with 2xM diversity order as in [1-2] and the EXTENDED ALAMOUTI SCHEME with 4x4 diversity order will be covered in this part.

A. Alamouti scheme Figure (2) shows the Alamouti system for two transmitting antennas. Now, all of the transmitting symbols—the two s1 and s2—are typically coded as shown in the image. These coded symbols are then typically interspersed throughout two time slots at a coding rate of two symbols per second. This indicates that two coded symbols, such as -s* and *, are broadcast during the second time slot while two symbols, s1 and s2, are transmitted during the first time slot.

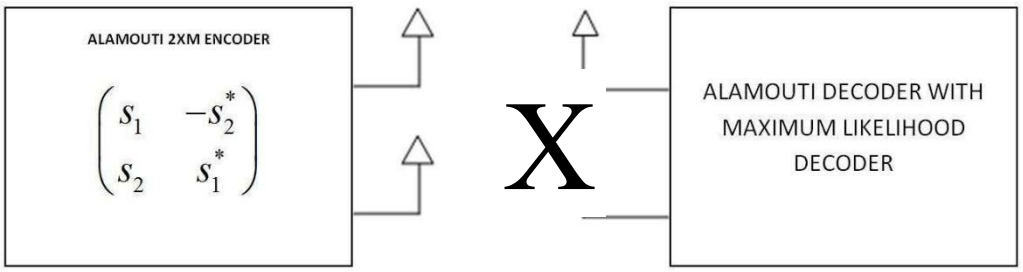


Fig. 2 ALAMOUTI SCHEME FOR 2 TRANSMITTING ANTENNA

Now, these symbols are transmitted through the channel whose parameters are according to the no of transmitting and receiving antennas respectively as shown in equation-(1). Now, the receiving sequences are given by:-

$$R=H*S+\eta \quad (5)$$

Now, these received sequences are then given to the Alamouti decoder which consists of combiner and channel estimator. Output of the combiner is given as below equation-(6):-

$$\hat{S}=H^{\dagger}*Y \quad (6)$$

Where,

$$Y=\begin{pmatrix} R_1 \\ R_3^* \\ R_4 \end{pmatrix} \& H^{\dagger}=\begin{pmatrix} h_1 & h_2 \\ h_3^* & -h_4^* \\ h_4^* & -h_3^* \end{pmatrix} \quad (7)$$

So, the output of the combiner, which is then given to the ML detector in order to detect the symbols and then they are compared with the transmitted symbols s_1 and s_2 in order to develop the error performance for ALAMOUTI 2x2 diversity technique.

A. Extended Alamouti scheme

Now, for better error performance this ALAMOUTI 2xM scheme is generally extended for 4 transmitting antennas as shown in [7] for MISO case that is for 4x1. Now, it is extended for 4x4 in order to achieve better error performance as well as code rates.

Now, the extended Alamouti 4x4 scheme is illustrated in figure (3). Now, here all the transmitting symbols those are four s_1, s_2, s_3 and s_4 are coded and interleaved within four time-slots in such a way that it provides the code-rate of 4 symbols per time-slots. This coded transmission symbol matrix and other required circuitry is shown in block diagram format in below figure-(3):-

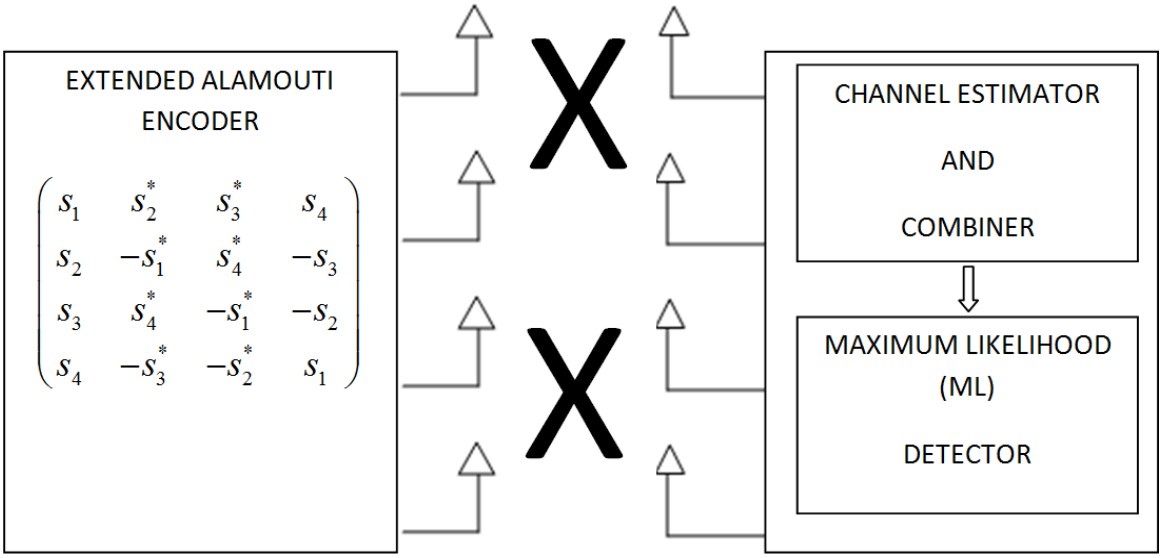


Fig. 3 ALAMOUTI SCHEME FOR 2 TRANSMITTING ANTENNA

Now, these symbols are transmitted through the channel whose parameters are according to the no of transmitting and receiving antennas respectively as shown in equation-(1). Now, the receiving sequences are given by: -

$$R=H*S+\eta \quad \text{.....(8)}$$

Now, these received sequences are then given to the Alamouti decoder which consists of combiner and channel estimator. Output of the combiner is given as below equation-(6):-

$$\tilde{S}=H^{\dagger}*Y \quad \text{.....(9)}$$

So, the output of the combiner, which is then given to the ML detector in order to detect the symbols and then they are compared with the transmitted symbols s_1, s_2, s_3 and s_4 in order to develop the error performance for this diversity technique. Where:-

$$Y=\begin{pmatrix} R^1 \\ R^{2*} \\ R^{3*} \\ R^4 \end{pmatrix} \quad \text{..... (10)}$$

& another factor is given by equation – (11) which is shown below: -

$$\begin{matrix} h^* \\ h^* \end{matrix}$$

$$\begin{pmatrix} -h_{3,3}^{*} & -h_{3,4}^{*} & h_{3,1}^{*} & h_{3,2}^{*} \\ -h_{4,3}^{*} & -h_{4,4}^{*} & h_{4,1}^{*} & h_{4,2}^{*} \\ h_{2,4}^{1,4} & h_{2,3}^{1,3} & h_{2,2}^{1,2} & h_{2,1}^{1,1} \\ h_{3,4}^{3,4} & h_{3,3}^{3,3} & h_{3,2}^{3,2} & h_{3,1}^{3,1} \end{pmatrix} \quad \text{.....(11)}$$

IV. SIMULATION RESULTS & DISCUSSION

The findings of the BER vs. SNR for illustrating the error performances of various diversity schemes discussed in the preceding section make up the primary portion of this section. The simulation results for four fading channels and M-PSK (QPSK) modulation schemes are now included in this section. MATLAB software is used to produce these findings.

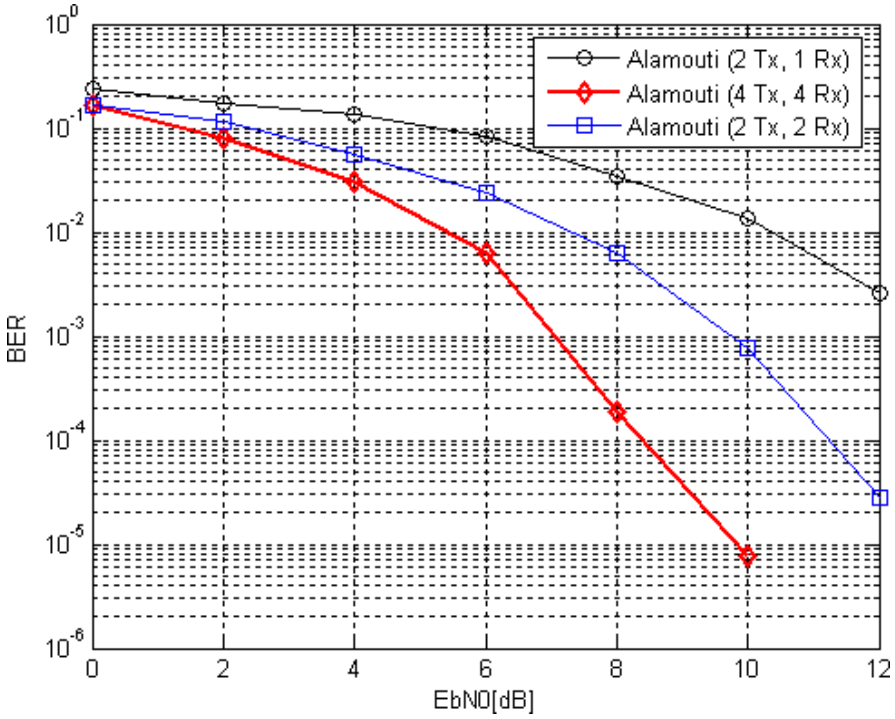


Fig. 4 BER PERFORMANCE COMPARISON FOR AWGN CHANNEL

First, the findings for QPSK according to the various fading channels are shown in Figures 4 through 7. Figure 4 displays the findings for the Alamouti 2X1, Alamouti 2X2, and extended Alamouti 4X4 schemes for the AWGN channel. With a greater code rate of four symbols per timeslot, the new extended scheme, as seen in Figure 4, offers improved error performance as compared to existing schemes in terms of coding and diversity gain.

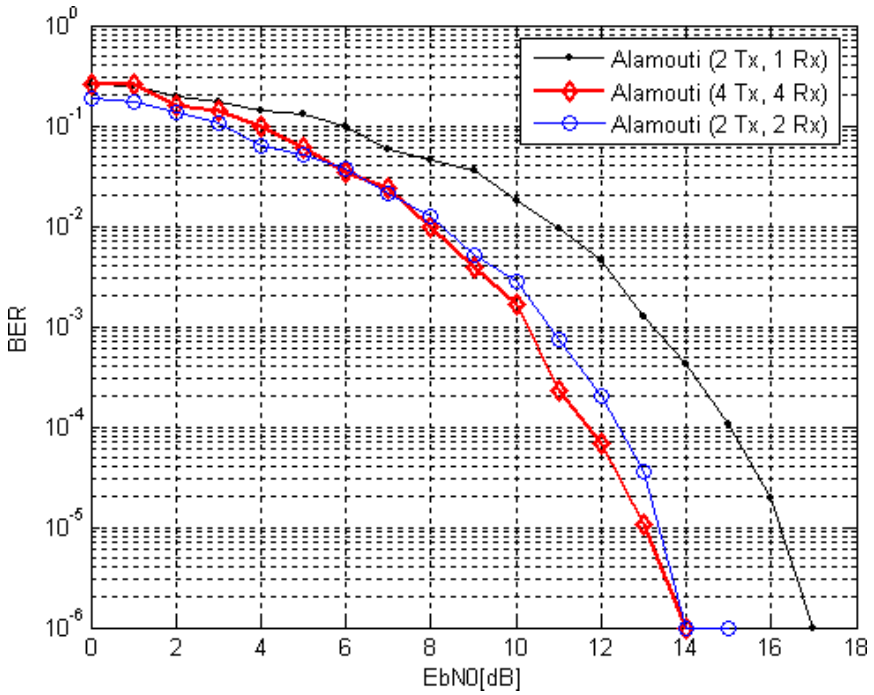


Fig. 5 BER PERFORMANCE COMPARISON FOR RICIAN CHANNEL

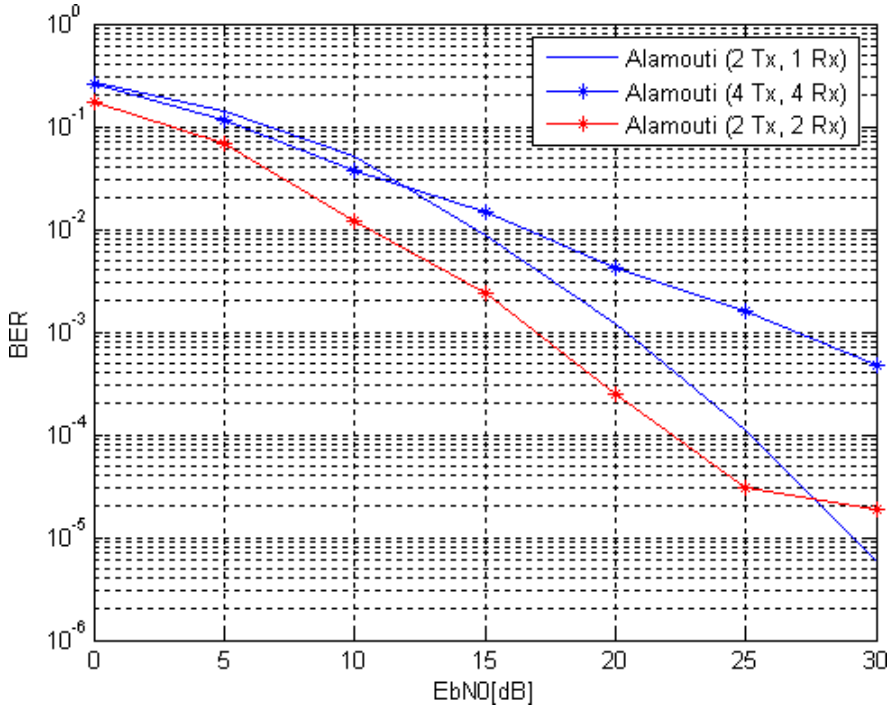


Fig. 6 BER PERFORMANCE COMPARISON FOR RAYLEIGH CHANNEL

The findings for the Alamouti 2X1, Alamouti 2X2, and extended Alamouti 4X4 schemes for the Rician fading channel are shown in Figure 5. Now, as Figure 5 illustrates, the new extended method offers error performance that is comparable to and somewhat superior than 2X2 and 2X1, respectively. In this situation, the Rayleigh fading channel with the worst fading characteristics often produced the poorest outcome. However, the double coding rate of four symbols per timeslot is still offered by the enlarged system.

Here, below figure-7 shows the results of the error performance for the one of the well known fading channel i.e. nakagami fading channel. As the nakagami factor is increased from 0.5 to 4 then, the error performance results moving

towards the Rician fading channel and as we decreases the nakagami factor value from 1 than, the error performance results moving towards the Rayleigh fading channel for all schemes.

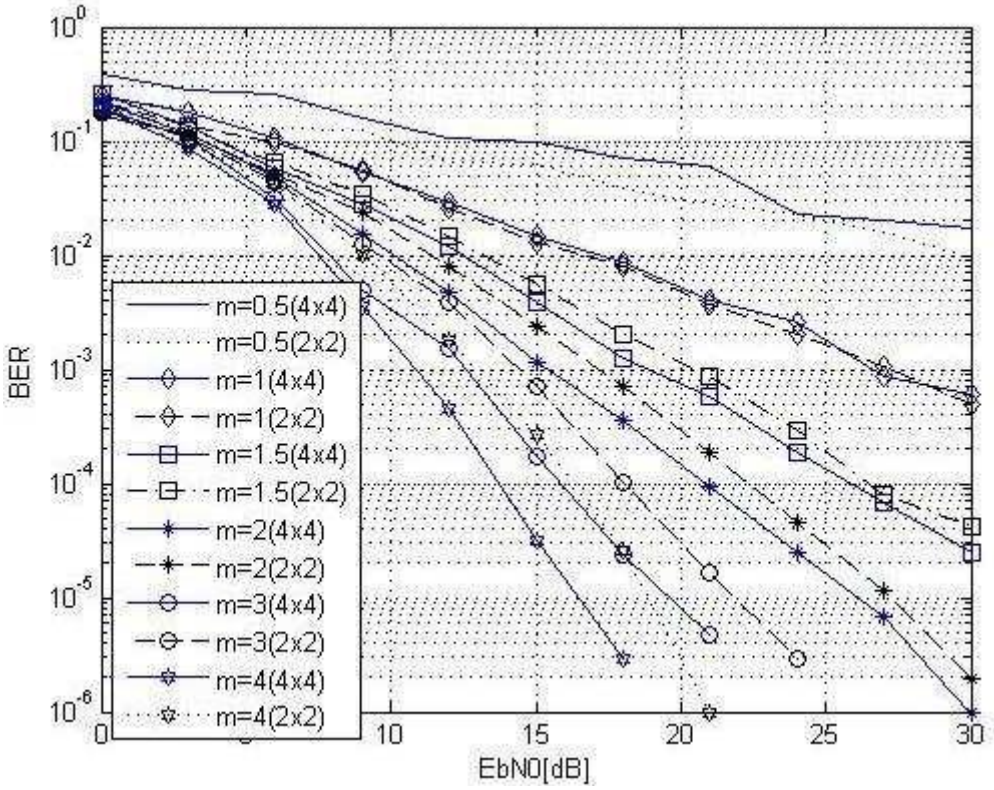


Fig. 7 BER PERFORMANCE COMPARISON FOR NAKAGAMI CHANNEL

Here, below table – I shows the comparison of all wireless channels for the different values of SNR for extended Alamouti scheme with 4x4 diversity order.

TABLE I
BER COMPARISON OF DIFFERENT WIRELESS COMMUNICATION CHANNEL FOR EXTENDED ALAMOUTI SCHEME

DIFFERENT WIRELESS COMMUNICATION CHANNELS	AT SNR=5dB	AT SNR=10dB	AT SNR=20dB
AWGN	0.0011765	8.6538E-006	0 at 11 dB
RAYLEIGH	0.11538	0.037063	0.0042224
RICIAN	0.057143	0.0012531	0 at 15 dB
NAKAGAMI WITH m=0.5	0.22885	0.1359	0.040769
NAKAGAMI WITH m=1	0.069615	0.026923	0.004931
NAKAGAMI WITH m=1.5	0.068462	0.020588	0.00057911
NAKAGAMI WITH m=2	0.059231	0.010577	0.00012801
NAKAGAMI WITH m=3	0.053846	0.0038462	4.4077E-006
NAKAGAMI WITH m=4	0.044462	0.001717	1.9231E-006

V. CONCLUSION

According to the simulation findings and Table I, the ALAMOUTI 4x4 scheme outperforms the ALAMOUTI 2x2 scheme in terms of coding gain and diversity gain for less faded (AWGN) and significantly faded with Line-Of-Sight (RICIAN) channels. However, as compared to the 2x2 ALAMOUTI scheme, it yields the poorest results for the very faded channel (RAYLEIGH). Similarly, in the NAKAGAMI fading channel, error performance shifts from the Rayleigh to the Rician channel when the value of the Nakagami factor "m" increases from 0.5 to 4. Because there is less fading, the AWGN channel produces better results than other channels. When compared to the Rayleigh channel, the Rician channel yields superior outcomes. Its error performance deteriorates with higher order modulation schemes.

ACKNOWLEDGMENT

For the simulation findings presented in this work, the authors would like to thank MATLAB7.0. Additionally, the authors would like to express their gratitude to S. M. Alamouti, V. Tarokh, H. Jafarkhami, A.R. Calderbank, and M. Rupp for their contributions to the new expansion of this research and their work on space time block codes and diversity methodologies.

REFERENCES

[1] [1] S. M. Alamouti, "A simple transmit diversity scheme for wireless communications," October 1998, IEEE Journal on Selected Areas in Communications, pp. 1451–1458.
[2] [2] Y. S. Cho, J. Kim, W. Y. Yang, and C. G. Kang, "MIMO-OFDM wireless communications with MATLAB," John Wiley & Sons, Ltd., 2010.
[3] [3] Foundations of Wireless Communication, D. Tse and P. Viswanath, Cambridge University Press, USA, 2005
[4] [4]F. H. Gregorio, "SPACE TIME CODING FOR MIMO SYSTEMS," Helsinki University of Technology, Signal Processing Laboratory, POB 3000, FIN-02015 HUT, Finland
[5] [5] "Simulation of Flat fading using MATLAB for Classroom Instruction," Drexel University, Philadelphia, PA 19104, G. S. Prabhu and P. Mohana Shankar.
[6] [6] "Performance Analysis of MIMO-OFDM System Using QOSTBC Code Structure for M-QAM," Canadian Journal on Signal Processing, Vol. 2, No. 2, May 2011, L. Kansal, A. Kansal, and K. Singh.
[7] [7] Generalized Alamouti Codes for Trading Quality of Service versus Data Rate in MIMO UMTS, C. F. Mecklenbrauker and M. Rupp, EURASIP Journal on Applied Signal Processing 2004:5, 662-675.
[8] [8] H. Jafarkhani, "A Quasi Orthogonal Space-Time Block Code," IEEE Trans. Comm., vol. 49, Jan. 2001, pp. 1-4
[9] [9] Communications Systems Engineering, J. G. Proakis and M. Salehi. Prentice-Hall, Upper Saddle River, NJ, 1994, pp. 265-267.
[10] [10] C. Langton and B. Sklar, "Tutorial 27 – Finding MIMO," [online] October 2011, http://www.complextoreal.com (accessed: August 12, 2012).
[11] [11] "Study on Extension of Alamouti Scheme for 4X4 diversity order," M. Rindani and A. Bavarva, NCIET, ISBN 978-81-925650-0-2, 2013.