# BER Analysis of MIMO-OFDM System using Alamouti STBC and MRC Diversity Scheme over Rayleigh Multipath Channel

Ripan Kumar Roy[1] and Tushar Kanti Roy[2]

1

*Received: 13 December 2012 Accepted: 3 January 2013 Published: 15 January 2013*

## Abstract

This paper represents a bit error rate performance analysis of multiple-input-multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) system with Alamouti Space Time Block Code (STBC) and Maximal Ratio Combining (MRC) diversity scheme over Rayleigh fading channel. Recently, Alamouti STBC has gained much attention as an effective transmit diversity scheme to provide reliable transmission with high peak data rates to increase the capacity of wireless communication system. In this paper, the analysis of Alamouti STBC is used in MIMO-OFDM system to assure transmit diversity and the receive diversity is resolved with MRC diversity technique. For a fixed number of transmit antennas, the performance of Alamouti STBC is analyzed in terms of probability of bit error and diversity gain for a Rayleigh fading channel. At the receiving end, the signals received from multiple paths are weighted and summed in accordance with MRC scheme which provides maximum performance improvement by maximizing the SNR of the MIMO-OFDM system. The simulated results depict that the proposed MIMO-OFDM system concatenated with Alamouti STBC and MRC outperforms conventional SISO-OFDM, MISO-OFDM with Alamouti STBC and SIMO- OFDM with MRC technique in a scattering environment.

***Index terms***— Alamouti STBC, BPSK modulation, BER, MRC diversity, MIMO, OFDM, Rayleigh channel, SNR.

rthogonal frequency division multiplexing (OFDM) is an emerging technique for high data rate wireless communication systems over frequency selective channels and can be considered as one of the most promising techniques for future wireless system. However, it is well known that OFDM-based systems are sensitive to the inter-carrier interference (ICI) generated by a carrier frequency offset (CFO), which degrades the error probability performance for both single-antenna OFDM systems [1]. Moreover, in a multipath fading environment, performances of OFDM system in a wireless channel are severely degraded by random variations in the amplitude of the received signals as well as by the presence of inter-symbolinterference (ISI) and inter-carrier-interference (ICI) which also limit the OFDM system performance. To address these challenges, a promising combination has been exploited [2], namely, MIMO with OFDM which has already been adopted for present and future broadband communication standards such as LTE or WiMax.

Alamouti coded OFDM is one type of MISO-OFDM system using the Alamouti code proposed by Siavash M .Alamouti in 1998 as a space time block code for transmit diversity which uses two transmit antennas and one receive antenna [3]. A simple space-time coded orthogonal frequency division multiplexing (OFDM) transmitter diversity technique for wireless communications over frequency selective fading channels is presented in [4]. The BER performance of an OFDM system with diversity, in particular Orthogonal Space Time Block Code (OSTBC) systems have been analyzed including a broadband nonlinear power amplifier and closed-form expressions is analyzed in [5]. In [6], a detailed study of diversity coding for MIMO systems including Alamouti's STBC for 2 transmit antennas as well as orthogonal STBC for 3 and 4 transmit antennas was explored.

However, it is well known that MRC as receive diversity provides the maximum performance relative to all other diversity combining schemes by maximizing the SNR at the combiner output. Recently, in the advanced mobile systems, MRC scheme shows the best performance and it tends to be the mostly employed among other diversity schemes **??**7]. A BER of OFDM with MRC diversity and pulse shaping in Rayleigh fading environments was analyzed in [8].

Although, the performance of Alamouti STBC and maximal ratio combining has been investigated, their performance evaluation and application to OFDM system are not available in the literatures [4,5, **??**,12]. The works in this paper are as follows: Firstly, the probability of error and hence effective SNR expressions are derived for a multiple-input-multiple-output (MIMO) OFDM system employing the MRC diversity technique as receive diversity and Alamouti Coded OFDM as transmit diversity. Secondly, MATLAB simulations are represented to evaluate the BER with respect to SNR to analyse the MIMO-OFDM system performance applying both Alamouti STBC and MRC diversity over Rayleigh fading channel. Thirdly, a comparison among the SISO, MISO, SIMO and MIMO in OFDM system is made that ensures MIMO-OFDM is the preferable technique for present and future broadband communication standards such as Long Term Evolution (LTE) or Worldwide Interoperability for Microwave Access (WiMax).

The rest of the paper is organized as follows: Section II-III represents OFDM system model with MIMO implementation. Section IV gives a simple overview about the Raleigh multipath fading channel. In section V-VI, Alamouti STBC and MRC diversity are discussed in OFDM application. The simulated results are represented and discussed in section VII. At last, a conclusion of the research work is made in section VIII.

OFDM is simply defined as a form of multicarrier modulation where the carrier spacing is carefully selected so that each subcarrier is orthogonal to the other subcarriers. The architectures of a typical OFDM transmitter and receiver are shown as an OFDM transceiver in Fig- 1. In the transmitting end, the incoming modulated serial bits are converted into parallel streams by using a serial to parallel converter. These parallel bit streams are subjected to Inverse Fast Fourier Transform (IFFT) block for baseband OFDM modulation. To prevent overlapping of the data at the receiver, Cyclic Prefix (CP) is inserted whose duration is one fourth of the total OFDM symbol duration. The modulated data are sent to the channel through a digital-to-analog converter. At the receiver side, firstly the data is received through N linear receivers followed by a linear combiner. This linear combiner is designed in such a way that the output SNR is maximized at each instant of time. Then this data is converted again to the digital domain by passing it through an analog to digital converter. After removing the cyclic prefix, data are again converted into serial to parallel by a serial-toparallel converter. These parallel bit streams are demodulated using Fast Fourier Transform (FFT) to get back the original data by converting parallel bit streams into a serial bit stream. Denote X l (l=0, 1, 2,?? N-1) as the modulated symbols of the light transmitting subcarrier of OFDM symbol at the transmitter, which are assumed to be independent, zero-mean random variables, with average power ? x 2 . The complex baseband OFDM signal at output of the IFFT can be written [13] as:nl N j N l l n e X N X ? 2 1 0 1 ? ? ? ? (1)

where N is the total number of subcarriers and the OFDM symbol duration is T seconds. At the receiver the received OFDM signal is mixed with local oscillator signal, with the frequency offset deviated from the carrier frequency of the received signal owing to frequency estimation error or Doppler velocity, the received signal is given by [13]:n fT n N j n n z e h x x ? ? ? ? ? ? 2 ) (**(2)**

where fT N j n e h ? ? 2 and z n represent the channel impulse response, the corresponding frequency offset at the sampling instants. Assuming that a cyclic prefix is employed; the receiver has perfect time synchronization. Then the output of the FFT in frequency domain signal on the k th receiving subcarrier becomes [13]: k N l k l l l k Z Y H X X ? ? ? ? ? ? 1 0 ? ? ? ? ? ? ? ? ? 1 , 0 N k l l k k l l l o k k Z Y H X U H X (3)? ? ? ? ? ? ? ? 1 0 ) ( 2 1 N n fT k l n N j k l e N Y ? (4)

When the channel is flat, Y l-k can be considered as a complex weighting function of the transmitted data symbols in frequency domain.

Consider a MIMO-OFDM system as shown in Fig- 2 which uses N subcarriers with N T antennas at the transmitter and N R antennas at the receiver. We assume independent channel coefficients in the T R N N ? channel matrix, H k , for all subcarriers k. We assume that the sampled impulse response of the channel is shorter than the cyclic prefix. After removing the cyclic prefix, the channel for the k-th subcarrier after the DFT, can then be described as a T R N N ? complex channel matrix, H k . The received vector of the k-th subcarrier can be written as Where the channel matrix for the k-th subcarrier,k k k K n S H R ? ? (5)H k is a T R N N ? channel matrix defined by ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? k N N k N k N k N k k k N k k k T R R R T T H H H H H H H H H H ? ? ? ? ? ? ? ? 2 1 2 22 21 1 12 11 (6)

The entries, k ij H , are the (narrow band, flat fading) complex channel gains between the j th transmit antenna and the i th receive antenna.

In this investigation, we assume that the channel is flat fading. In simple terms, it means that the multipath channel has only one tap. Rayleigh channel is modeled with a circularly symmetric complex Gaussian random variable having the following form:im re jh h h ? ? (7)

The real and imaginary parts are zero mean independent and identically distributed Gaussian random variables with mean 0 and variance 2 ? . The probability density function of the magnitude h of complex Gaussian random variable has been defined which is expressed [14] as2 2 2 2 ) ( ? ? h e h h P ? ? (8)

The received signal in a Rayleigh fading channel is of the form,n hx y ? ? (9)

Here y is the received symbol and h is the complex scaling factor corresponding to Rayleigh multipath channel, x is the transmitted symbol and n is the Additive White Gaussian Noise (AWGN). The channel is randomly varying in time. It means that each transmitted symbol gets multiplied by a randomly varying complex number h. Since h is modeled as Rayleigh channel, the real and imaginary parts are Gaussian distributed having mean 0 and variance ½.

A single-user Alamouti coded OFDM system with two transmit antennas and one receive antenna is shown in Fig. **??**. Two SISO channels from the two transmit antennas to the receive antenna are assumed to be both time-and frequency selective. They both have a maximum channel delay spread that is smaller than the OFDM cyclic prefix (CP) length L.

We assume the OFDM system has N subcarriers, N A of which are active. The remainingA V N N N ? ?

virtual subcarriers are used as frequency guard bands, with 2 / V N virtual carriers on both ends of the spectral band. The bit streams at the transmitter are grouped and mapped into complex symbols. Since we assume the channel delay spread is smaller than the CP length L, after removing the CP at the receiver, it is enough to consider only the two consecutive OFDM symbols which constitute an Alamouti code word.

Assume S i , i = 1, 2 are the two consecutive OFDM symbols which can be written as? ? T N T i T N i V V O s O s 1 2 / 1 2 / ? ? ? (10)

where the 0's indicate the guard bands and i s is the data vector of lengthV A N N N ? ?

, which yields of a set of data symbols with power two consecutive OFDM symbol periods can be written [9] as? ? ? ? 1 2 1 , 2 1 1 , 1 1 n s F H s F H y H H ? ? ? (11) ? ? ? ? 2 1 2 , 2 2 2 , 1 2 n s F H s F H y H H ? ? ? ? ? ? (12)

where? i y is the received 1 ? N vector in i th symbol period, ? j i

H , is the time domain N N ? channel matrix between transmit antenna i and the receive antenna in symbol period j and? i n is the 1 ? N

circularly symmetric zero-mean white complex Gaussian random noise. After the serial/parallel conversion, the FFT operation converts the received time-domain signal back to the frequency domain. Before the FFT, a timedomain receiver window is often used to make the frequency-domain channel matrix more banded [10]. In that case, we obtain.? ? 1 1 1 FWn FWy y ? ? (13) ? ? 2 2 2

FWn FWy y ? ? (14) where W=diag(w) with w the time-domain receiver window. Note that for classical OFDM, we have W = I N. Stacking y 1 and ? 2 * in one vector, we obtain.? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? 2 1 2 1 2 , 1 2 , 2 1 , 2 1 , 1 2 1 n n s s H H H H y y (15)

In order to allow for low-complexity equalization, we approximate the frequency domain channel matrix j i H , by its banded versionQ j i j i H B ? ? ? , ,**(16)**

where Effective bit energy to noise ratio in N receive antenna case is N times the bit energy to noise ratio for single antenna case. In case of a two-fold diversity scheme, the combining equation is given by:Q ? is the N N ? Toeplitz matrix.k k k k k z r z r z 2 2 2 1 ? ? (23)

where, r 1k and r 2k represent the instantaneous envelopes of the signals received at each of the diversity branches. The SNR per bit at the output of the maximal ratio combiner can be written as: For large values of N, a closed form expression does exist for this problem given by [11]:? ? ? ? ? ? N k N k k o b k R N E r! )! 1 ( )! 1 2 ( 4 1 N N N P N c e ? ? ? ? ? ? ? ? ? ? ? ? (27)

From the above equation it can be inferred that the P e varies as c ? raises to the N th power. Thus, with MRC, the BER decreases inversely with the N th power of the SNR.

In order to make an investigation of performance analysis of the MIMO-OFDM system with Alamouti Space Time Block Code as the transmit diversity and MRC diversity technique as the receive diversity over a Rayleigh fading channel, we deal with MATLAB simulation using the parameters based on IEEE802.a standard. BPSK modulation was used to determine the BER versus SNR performance of the system. We consider an MIMO-OFDM system with N = 64 subcarriers, CP length L =16 over Rayleigh fading channel.

# 1 a) Simulated BER of OFDM without diversity

Here we represent the BER performance of BPSK digital modulation with a simple OFDM system over Rayleigh fading channel. The result involved with this SISO-OFDM system shows the BER performance as a function of the energy per bit to noise ratio. Fig- 5 shows the BER Vs SNR curve for the OFDM system with one transmit antenna and one receive antenna (i.e., SISO-OFDM) for a Rayleigh fading environment. However, it is seen from the figure that as the energy per bit to noise ratio increases in the system, a decrement in the bit error rate is encountered. Alamouti Space Time Code is a simple Transmit diversity that offers a simple method for achieving spatial diversity with two transmit antennas. Using two transmit antennas and one receive antenna the scheme provides the same diversity order as maximal-ratio combining (MRC) with one transmit antenna, and two receive antennas. The Alamouti STBC as a transmit diversity associated with OFDM system forms a MISO-OFDM system we are calling here so far. The channel experienced by each transmit antenna is independent from the channel experienced by other transmit antennas. For the i th transmit antenna, each transmitted symbol gets multiplied by a randomly varying complex number h i . As the channel under consideration is a Rayleigh channel, the real and imaginary parts of h i are Gaussian distributed having mean µ=0 and variance 2 1 2 ? ? . The channel experienced between each transmit to the receive antenna is randomly varying in time. However, the channel is assumed to remain constant over two time slots. The simulated BER versus SNR performance of

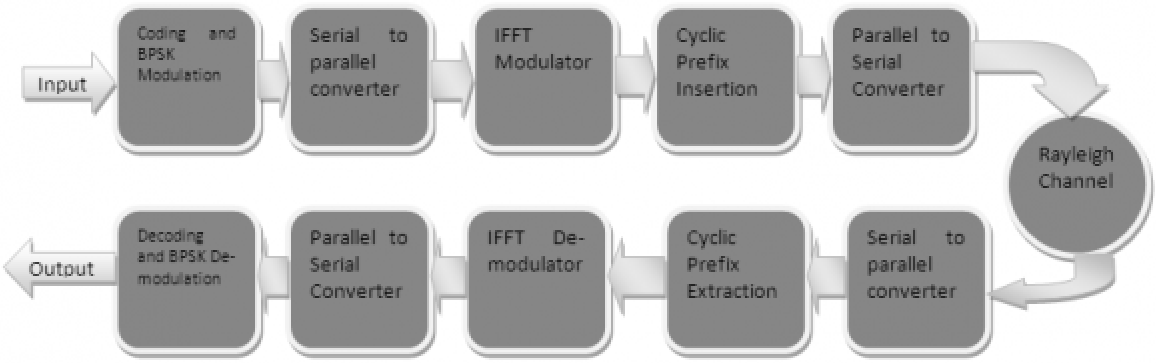
Alamouti STBC as a transmit diversity involved with OFDM system has been shown in Fig- 6 in a multipath fading channel. It is depicted from the figure that to keep a BER at 10 -4, the SNR gain is 17dB and with BER at 10 -3 , the SNR gain is 12dB. Hence the simulated result shows that the more the bit error rate decreases, the curve moves more downward. This figure shows that the effective SNR gain increases with increasing number of receiving antenna. It also illustrates that the gain increases at a high rate till the number of receiving antenna be eight. In Fig- 8, we investigate the performance analysis of MIMO-OFDM system employing both the transmit diversity and receive diversity over a Rayleigh fading channel. In the transmitting end, we incorporate with Alamouti STBC as the transmit diversity with two transmit antenna and one receive antenna. With the help of simulation result, it is pointed out from the figure that the proposed Alamouti STBC gives a BER of

# 2 1?

antenna configuration provides a diversity gain of 5dB at BER of 10 -2 which is 3dB better improvement than the two branch Alamouti STBC. This 3-dB penalty is incurred because each transmit antenna radiates half the energy in order to ensure the same total radiated power as with one transmit antenna. If the BER was drawn against the average SNR per transmit antenna, then the performance curves for the new scheme would shift 3 dB to the left and overlap with the MRC curves. In the latter case, we examine the performance of the MIMO-OFDM system improved by both the schemes. The Alamouti STBC is confined to two transmit antenna while at the transmitter the number of receiving antenna is increased in accordance with MRC scheme. In this paper, the performance of the MIMO-OFDM system has been analyzed with the use of Alamouti STBC and MRC technique as the transmit and receive diversity respectively over a Rayleigh multipath fading channel. The Alamouti STBC is the only STBC that can achieve its full diversity gain without needing to sacrifice its data rate, this property usually gives Alamouti's code a significant advantage over the higher-order STBCs even though they achieve a better errorrate performance. Maximal Ratio Combiner is the optimum combiner for independent Rayleigh fading and AWGN channels. The simulation result represents that the performance of the Alamouti scheme with two transmitters and a single receiver is 3 dB worse than MRC diversity with one transmit and two receive antenna. However, the 3-dB penalty is incurred because the simulations assume that each transmit antenna radiates half the energy in order to ensure the same total radiated power as with one transmit antenna. If each transmit antenna in the new scheme was to radiate the same energy as the single transmit antenna for MRC, however, the performance would be identical. From the simulation result, it is clear that the proposed MIMO-OFDM system concatenated with Alamouti STBC and MRC diversity provides maximum SNR improvement with minimum BER as compared to both MISO-OFDM or SIMO-OFDM system with either Alamouti STBC or MRC scheme respectively. [1] [2] [3]

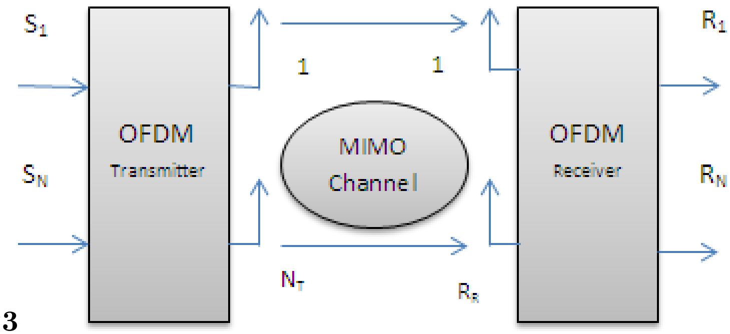
**1**

Figure 1: Figure 1 :




**2**

Figure 2: Figure 2 :




**23**

Figure 3: 2 s?Figure 3 :

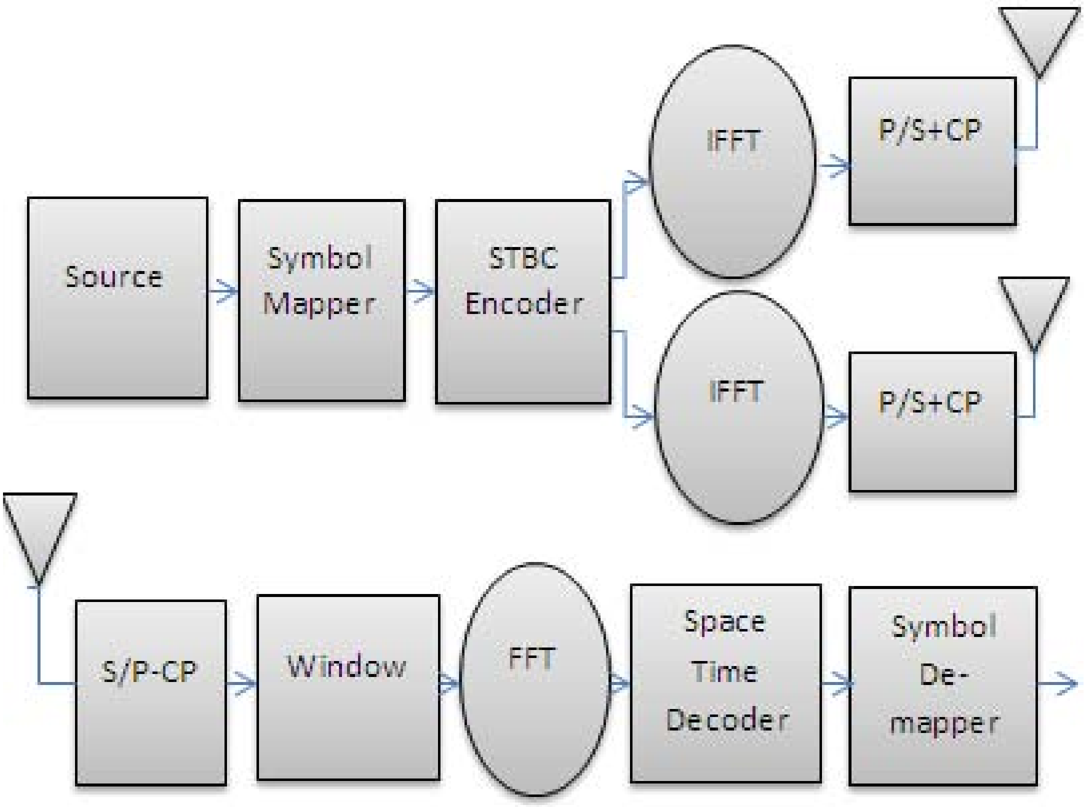
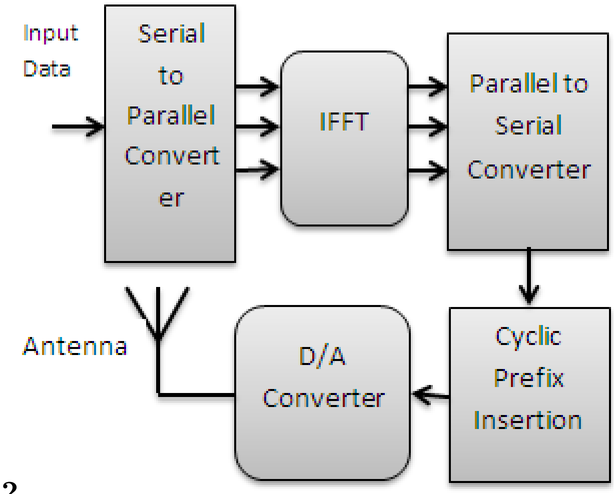
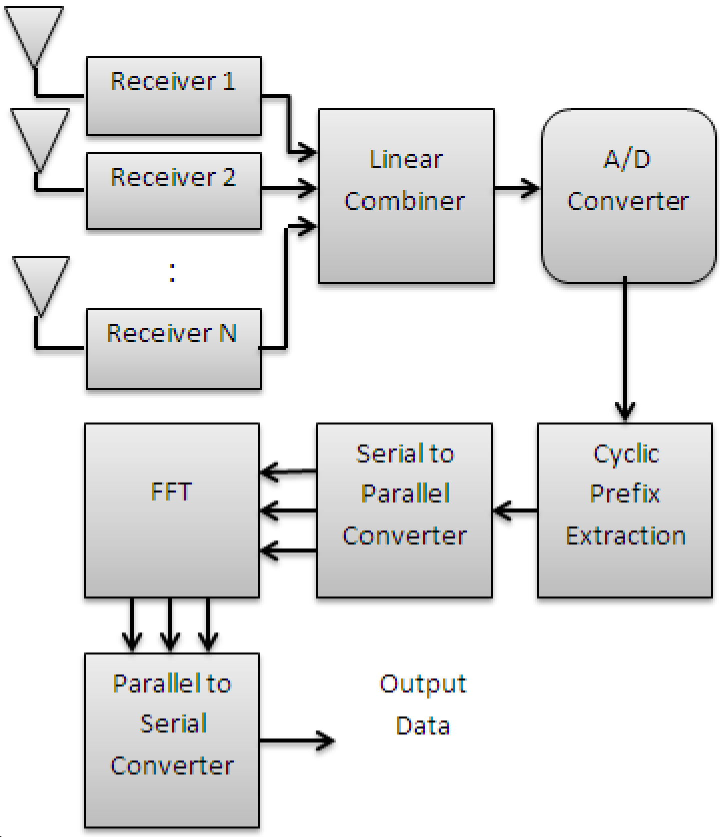



Figure 4:




**2**

Figure 5: 2 ?




**4**

Figure 6: Figure 4 (

198 [4] [5]

[1] © 2013 Global Journals Inc. (US) ( )

[2] F © 2013 Global Journals Inc. (US)

[3] © 2013 Global Journals Inc. (US) ( )

[4] F © 2013 Global Journals Inc. (US)where

[5] © 2013 Global Journals Inc. (US) ( )

[Siavash and Alamouti (1998)] ‘A simple transmit diversity technique for wireless communications’. M Siavash , Alamouti . *IEEE Journal Select. Areas Communication* Oct. 1998. 16 (8) p. .

[Lee and Williams (2000)] ‘A space-time coded transmitter diversity technique for frequency selective fading channels’. K F Lee , D B Williams . *Proc. IEEE SAM*, (IEEE SAMCambridge, MA) 2000. Mar. 2000. p. .

[Gregorio et al. (2007)] ‘BEP analysis of OSTBC-OFDM systems broadband PA and imperfect memory compensation’. F Gregorio , S Werner , J Hämäläinen , R Wichman , J Cousseau . *IEEE Commun. Lett* Dec. 2007. 11 p. .

[Rugini and Banelli (2005)] ‘BER of OFDM systems impaired by carrier frequency offset in multipath fading channels’. L Rugini , P Banelli . *IEEE Trans. Wireless Communication* Sept. 2005. 4 p. .

[Khoa et al. ()] ‘BER of OFDM with diversity and pulse shaping in Rayleigh fading environments’. N Khoa , Kishor P Le , Dabke . `www.elsevier.com` *Digital Signal Processing* 2010. 20 p. .

[Tushar Kanti (2012)] ‘BER Performance Analysis of MRC for OFDM System using Different Modulation Schemes over Rayleigh Fading Channel’. Roy Tushar Kanti . *International Journal of Computing Communication and Networking Research* June-2012. 1 (3) .

[Rugini et al.] *Block DFE and Windowing for Doppler-Affected OFDM Systems*, L Rugini , P Banelli , G Leus .

[Fang et al. ()] Kun Fang , Geert Leus , Luca Rugini . *Alamouti Space-Time Coded OFDM Systems in Time-and Frequency-Selective Channels*, (San Francisco, CA) 2006. 200. (Global Telecommunications Conference)

[Kansal et al. (2011)] Lavish Kansal , Ankush Kansal , Kulbir Singh . *Performance Analysis of MIMO-OFDM System Using QOSTBC Code Structure for M-QAM*, May 2011. 2.

[Miguel Cort´es-Pe?na et al.] Luis Miguel Cort´es-Pe?na , ; Communications , Georgia Tech . *MIMO Space-Time Block Coding (STBC): Simulations and Results*, 6604. (DESIGN PROJECT: PERSONAL AND MOBILE)

[Tushar et al. ()] ‘Performance Analysis of PDC over Rayleigh Fading Channel for OFDM System’. Kanti Tushar , Monir Roy , Morshed . *International Journal of Computing Communication and Networking Research* 2013. 02. (Issue-01)

[Proc. of SPAWC 2005 (2005)] *Proc. of SPAWC 2005*, (of SPAWC 2005New York City, NY) June 2005. p. .

[Saxena Naveen and Gupta ()] ‘System Design and Analysis of MIMO STBC-OFDM System with or without Clipping Technique’. Kuldeep Saxena & Naveen , Gupta . *International Journal of Advanced Electrical and Electronics Engineering* (Print): 2278-8948. 2012. (1) .

[Theodore and Rappaport ()] ‘Wireless Communications’. . S Theodore , Rappaport . *Prentice-Hall Communications Engineering and Emerging Technologies Series*, 2002. 22 p. 323. (Second Edition)