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Application of STBC in MIMO-OFDM Broadband Wireless Communications

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ABSTRACT

The Space Time Block Coding (STBC) is applied in multiple transmit antennas using data transfer for fading channels. After being encoded, the data is broken into *n* streams of continuously broadcast strings over *n* transmit antennas using STBC. The received signal is the combination of *n* broadcast signals and it becomes erroneous due to the entry of noise at receiver end. The probabilistic decoding approach is applied instead of joint detection approach for recovering data via decoupling of signals delivered from various antennas. The maximum likelihood decoding scheme employs the orthogonal structure of STBC called as OSTBC (Orthogonal Space Time Block Code) for providing the maximum likelihood decoding algorithm depending upon linear computation at receiver. In the present work, a MATLAB/SIMULINK environment of OSTBC has been used in order to acquire the highest dimension of variability for specific number of broadcasts as well as receive antennas utilizing a simple decoding techniques. With or without Grey Coding, OSTBC / STBC is used in MATLAB / SIMULINK blocs. The OSTBC algorithm calculates the highest achievable transmission rate for every amount of transmit antennas in any constellations including M-PSK array. M-PSK STBCs are used for different complex constellations to achieve ½ as well as ¾ of highest allowable transmission rate for Multiple Input Multiple Output (MIMO) transmit antennas utilizing various constellations.

Key words : STBC, OSTBC, Multiple Input Multiple Output Channel, Broadband Wireless Communications, Transmit Diversity and M-PSK.

1. INTRODUCTION

A simple two-branch transmit diversity scheme using 2TX-1RX antenna scheme has been demonstrated which provided the same diversity order as obtained by maximal-ratio receiver combining (MRRC) with 1Tx-2RX antenna system [1]. The performance analysis of digital data transmission over frequency-selective fading channels has been found [2]. The use of multiple Tx-Rx antennas for single user communications over the AWGN channel with and without fading was discussed and investigated in order to show that the potential gains of proposed scheme over single Tx-Rx antenna systems rather large under independence assumptions for the fades and noises at different Rx antennas [3].

The exploitation of Multi-Element-Array (MEA) technology has been examined to improve wireless capacities using some basic information theory results and the better improvement was found with MEA [4-5]. A survey on reviews of Space-Time signal processing (STP) in mobile wireless communications has been presented in [6]. The design of channel codes in order to improve the data rate and the reliability of communications over fading channels using multiple transmit antennas has been elaborated in the literature [7-8].

An orthogonal frequency-division multiplexing (OFDM)-based downlink transmission scheme was proposed for large-scale multi-user (MU) Multiple-Input Multiple-Output (MIMO) wireless systems [9]. A new technique based on continuous modulus algorithm has been proposed to eliminate the problem of inter-carrier interference (ICI), high out-of-band radiation, and degradation of bit error rate performance [10]. The low-complexity fully-connected hybrid precoding design was investigated for multiuser massive MIMO systems over frequency-selective fading channels [11]. A pilot contamination precoding scheme has been demonstrated to mitigate multi-cell pilot contamination [12].A novel approach was proposed by combining the PTS and Gaussian pulse-based TR techniques in order to reduce the PAPR [13]. the problem of CE MIMO-OFDM precoding for transmission over frequency selective channels was handled using a novel efficient formulation and the Gauss-Newton algorithm [14-16].

In article [17], the imaginary interference-free method was presented for FBMC/OQAM, which is appropriate for both of the subcarrier based singular valued decomposition (SVD) precoding as well as subband-based precoding with codebook schemes. An optimized pilot symbol (OPS) technique has been proposed to reduce the PAPR of OFDMA systems [18]. In article [24], broadband wireless access solutions based on OFDM access in IEEE 802.16 was presented. an OFDM based downlink transmission scheme has been investigated for large-scale multi-user (MU) MIMO wireless systems [25]. An overview of various PAPR reduction techniques for multicarrier transmission have been discussed in [19-23, 26-30].

2. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

The OFDM system is designed to enable large data rates with multiple carrier signals. OFDM may reduce Inter Symbol Interference (ISI) more significantly than additional multiplexing techniques. Though, improved Frequency Division Multiplexing (FDM) is performing in the same manner since FDM has a guard band to reduce interference among various frequencies but the disadvantage of FDM is that it consumes a higher bandwidth whereas there is no inter-carrier guard band in OFDM and it may manage ISI more effectively as compared to FDM, resulting a far better technique for WiMAX with more effective spectrum use at low transmission costs. Furthermore, in OFDM, the multipath effects are compensated by transforming serial data into multiple parallel data streams using the Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT).

Since multicarrier modulation is utilized in OFDM, data transfer is sufficient while comparing with FDM and this becomes possible by dividing high data bits into low data bits and sending each sub-stream in many concurrent sub- channels called as OFDM subcarriers which are opposite to each other, and every subcarrier has a substantially smaller bandwidth than entire bandwidth. OFDM decrease / reduce the Inter Symbol Interference (ISI) since every sub-symbol channel's time T_s is greater than just the channel delay dispersion. Figure 1 shows that the OFDM eliminates the multipath effects by using a lower frequency bandwidth as well as a longer period of time resulting in higher spectral efficiency.

2.1 Working and Architecture of OFDM

There are two variants of WiMAX which have distinct implementations of the OFDM physical layer. The FFT size for OFDM-PHY is set at 256 bits for stationary WiMAX, whereas it can be 128, 512, 1024 and 2048 bits for mobile WiMAX [1]. This aids in the reduction of ISI and Doppler spread. The difference between OFDM-PHY with OFDMA-PHY is that OFDM separates a single high bit rate data stream into numerous low bit rate data sub-streams in parallel, each of that is modulated using IFFT whereas OFDMA receives multiple users' data and multiplexes it into a downlink sub-channel. The uplink sub-channel provides several uplink accesses.

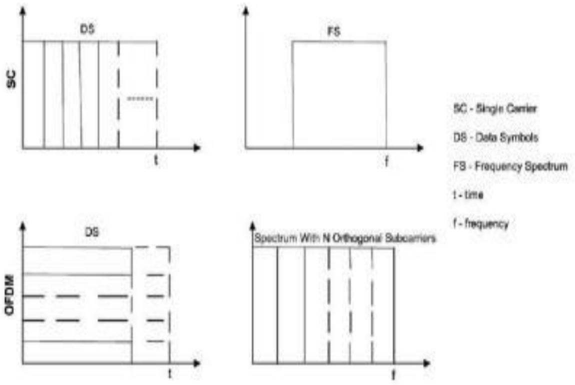

Figure 1: Time and Frequency diagram of single and Multi-carrier signals [7]

Table 1: Parameters of OFDM-PHY **[23].**

Parameters	*Size*
FFT Size	*256 bits*
Data Subcarriers	*192*
Pilot Subcarriers for Synchronization and Channel Estimation	*8*
Null Subcarriers	*56*
WiMAX Channel Bandwidth	*3.5 MHz however it changes depending on subcarrier spacing*
Ideal Symbol Time	*64 seconds*
Symbol Length	*72 seconds,*
Guard Time Spacing	*15.625 kHz*

OFDM-PHY:

In this case, subcarrier spacing increases as bandwidth increases tending towards the reduction in symbol time and increment in delay spread. OFDM-PHY assigns a considerable portion of guard space to minimize delay dispersion. The parameters of OFDM-PHY is given in Table 1.

OFDMA-PHY:

The FFT size in mobile WiMAX can vary within 128 to 2048, as well as the FFT length must be set to preserve the subcarrier spacing at 10.94 KHz, that helps to limit Doppler spreads. Because several channel bandwidths exist, such as 1.25, 5,10, and 20 MHz, FFT sizes are 128, 512, 1024, and 2048. The appropriate symbol time for OFDMA-PHY is 91.4 seconds, the symbol duration is 102.9 seconds, as well as the length of symbols in 5 ms frames is 48.0 [23].

2.2 Widening of Coverage Area

WiMAX organizes the existing subcarriers into groups and assigns them to various users based on channel circumstances and user requirements. Sub-channelization is the term for this technique. Sub-channeling divides the transmit power across smaller groups of subcarriers to boost system gain and extend coverage area while reducing absorption losses caused by buildings as well as other impediments. The connection budget would be unbalanced without sub-channelization, therefore bandwidth monitoring might be poor [7]. On just the uplink, fixed WiMAX-based OFDM-PHY allows for a small amount of sub-channelization. Transmission can take occur in one, two, four, eight, or all of the 16 conventional sub-channels of the SS's uplink. SS adjusts the transmitted power level according on the available sub-channels. The transmission power level increases when the number of allowed sub-channels for uplink users grows, and it drops when the number of allotted sub-channels declines. The maximum level of transmitted power is never exceeded. Uplink sub-channelization allows the SS to transmit just a portion of the bandwidth allotted by the BS in constant WiMAX to enhance link budget as well as the performance of the SS battery [24].

OFDMA-PHY in mobile WiMAX allows sub-channelization including both uplink as well as downlink channels. In the analysis of multiple access approach, the BS assigns the minimum frequency as well as sub-channels to distinct users. This type of OFDM is known as OFDMA (Orthogonal Frequency Division Multiple Access). The generation of dispersed subcarriers provides frequency diversity across mobile applications. Numerous distributed carrier dependent sub-channelization methods are available for mobile WiMAX. Adaptive Modulation and Coding (AMC) is another sub-channelization system based on unbroken subcarriers that prioritizes multiuser variety. In this case, users are assigned sub-channels depending on their frequency response. Although continuous sub-channels are especially suitable for constant as well as low mobility applications, they can provide a small increase in total system capacity [24].

Figure 3 shows the upstream transmission of OFDM spectrum through a CPE with carriers that are fourth the length of those in Figure 2 [7]. Figure 4 shows the transmitted upstream OFDM spectrum from a CPE using carriers that have the identical size as well as range as BS but have a lower capacity [7].

2.3 Applications of OFDM in Wireless Communication

The mobile WiMAX access technique is based on OFDMA, also known as Multiuser-OFDMA, which was developed specifically for 4^{th} generation wireless networks. This is a mixture of Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA) since it divides the possible size to accommodate multiple users in same way as these access techniques do. OFDMA is an alternative of CDMA in which each user receives a variable amount of spreading codes with varied data speeds. Minimal data rate users can transfer data with low transmission power as well as uniform and shorter latency, similar to an alternate TDMA. It can also be said that OFDMA is a hybrid of time domain and frequency domain multiple accesses, including resources separated into time-frequency spaces and slots as well as an OFDM subcarrier index. To keep the data rate and error probability for each user, different numbers of subcarriers can be assigned to varying numbers of users. Lastly, it can be said that, OFDMA is the most efficient multi-user access technique [25].

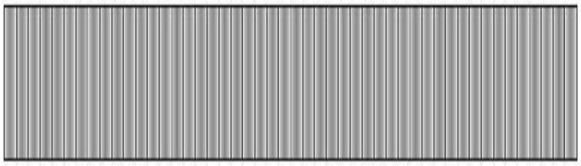

Figure 2: Downstream Transmission of OFDM Spectrum [7]

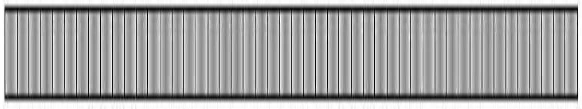

Figure 3: Upstream Transmission of OFDM Spectrum [7]

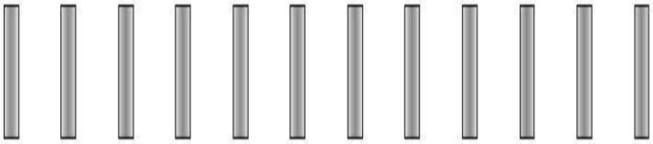

Figure 4: Upstream Transmission of OFDM Spectrum from CPE [7]

3. MIMO System

Digital communication via a wireless link with multiple inputs and outputs (MIMO) is now one of the most prevalent technological applications in modern communications. This technique focuses mostly on a list of recent technological advancements that have the potential to solve traffic capacity challenges for future Internet-connected wireless networks. It appears that this technology has infiltrated large-scale standards-driven commercial wireless devices and networks such as broadband wireless systems, wireless LAN, third-generation networks, and beyond in the early years following its inception.

MIMO systems are described as a wireless communication method with such a connection in which both the transmitter and receiver sides are configured using multiple antenna devices as shown in Figure 5. Its signals on the transmit (Tx) antennas at one end and the receive (Rx) antennas from the other end are "combined" in MIMO to improve the communication efficiency (Bit-Error Rate or BER) or data rate (bits/sec) for each MIMO user. Such advantages are utilized to dramatically increase both network's reliability of the service and the operator's income. In MIMO systems, the key process is space–time signal processing, that combines time (the natural dimension of digital communication information) with the spatial dimension introduced by the use of many geographically spread antennas. In this approach, MIMO systems may be the extensions of smart antennas tending towards the prominent technology that uses antenna arrays to improve wireless transmission.

In the present work, a simulation model with the multiple antenna setup is built as shown in Figure 6. A transmitting unit comprising the functions of error control coding as well as (potentially united with) mapping to complex modulation symbols (M Phase-Shift Keying (MPSK), M-QAM, etc.) receives digital source information in the shape of a binary stream. This results in a number of distinct symbol streams, ranging from impartial to partially redundant and then to entirely redundant. After then, every symbol stream is assigned to one of the many Tx antennas. Either linear spatial weighting of antenna components or linear antenna space–time pre coding is used in mapping. The signals are released through into wireless channel following upward frequency conversions, filtering, with amplification. Signals are collected by several antennas at the receiver, where demodulation and demapping processes are conducted to retrieve the message. Depending on the requirements, the amount of intelligence, difficulty and a priori channel information employed in choosing the coding and antenna mapping techniques might vary greatly. This defines the class and quality of the developed multi-antenna system.

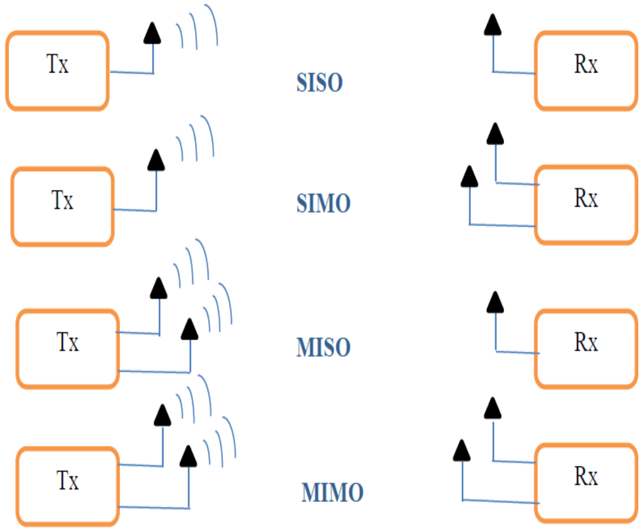

Figure 5: A Wireless Communication System having Multiple Antennas as Transmitter and Receiver [4]

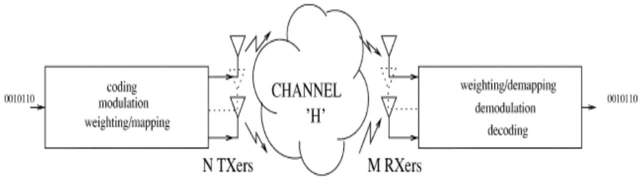

Figure 6: MIMO wireless transmission method having multiple antenna components for transmitter and the receiver

Only the transmitter or receiver is really equipped with even more than one component in standard smart antenna nomenclature, which is often the base station (BTS), in which the extra cost and space have so far been viewed as more easily accessible than on a mobile phone device. Even though the introduction of Space–Time Codes (STCs) is changing this notion, the expertise of the multi antenna system is traditionally found in the weight selection method instead of the coding side.

In the case of poor propagation circumstances like as multipath fading with interference, simple linear antenna array merging can provide a better robust communication path. Beam shaping, that boosts the overall Signal-to-Noise ratio (SNR) by directing energy in desirable direction in either transmit or receive, is an important aspect in smart antennas. Indeed, by estimating the response within each antenna array to a particular intended signal, as well as any interference signal(s), one may combine the components optimally using weights determined by the response of each element. The average target signal level may thus be maximized while additional elements like noise and co-channel interference are minimized.

The idea of spatial diversity is another major impact of smart antennas. The probability of discarding the signal diminishes exponentially with the amount of decorrelated antenna components deployed in the context of random fading induced by multipath propagation. The diversity order, that is determined by the amount of decorrelated spatial branches accessible at the transmitter or receiver, is a fundamental notion here. Smart antennas have been demonstrated to increase the coverage range vs quality tradeoff supplied to wireless users when used together [6].

The stringent size as well as complexity limits are getting less restrictive as subscriber units (SU) evolve into robust wireless Internet connection devices rather than simple pocket cellphones. Even while transferring most of the computation and expense to network's side (i.e., BTS) generally provides engineering logic, it makes numerous antenna element transceivers a possibility on both parts of the link. However, the advantages of traditional smart antennas are preserved in a MIMO link because the multi antenna signals are optimized in a greater space, allowing for more degrees - of - freedom. MIMO systems, in particular, may give a combined

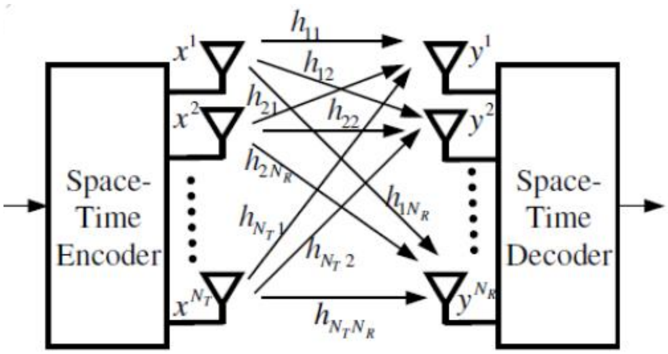

Figure 7: MIMO Structure Model

transmit-receive diversity gain and an array gain by integrating the antenna elements in a coherent manner (assuming prior channel estimation). In truth, MIMO's benefits are significantly more basic. Beyond the extra diversity or array gain benefits, the fundamental mathematical architecture of MIMO, wherein data is carried via a matrix instead of a vector channel, provides new and huge capabilities (see Figure 7)..

4. RESULTS AND DISCUSSIONS

In this section, a MATLAB / SIMULINK model is created to study the effectiveness of SISO and MIMO systems as shown in Fig. 8-10. Three alternative models are designed for comparative study and analysis i.e. SISO model, MIMO 12 - 3 Tx and 2 Rx model at rate 1/2 and MIMO 3/4 - 3Tx and 2 Rx model at rate 3/4. In the present work, four distinct modulation techniques: BPSK, QPSK, 8PSK and 16PSK have been used for each model. The data transmission has been employed with and without grey coding for each modulation technique. The data is broadcast via a Rayleigh fading channel with a maximum Doppler shift of 3 Hz. An AWGN channel is considered to estimate the BER at various SNRs for a specific design that utilizes condensation of distinct modulation coding methods.

At varied SNRs ranging from 1 to 25db, the response is expressed as a scatter plot and bit error rate. Because the signal strength increases with the SNR, the dispersion of the signal constellations reduces. The BER is a parameter that is equivalent to the channel noise, meaning that higher the noise, higher the BER. The BER is determined by the number of error bits divided by the total number of bits. The BER values have been acquired by running each simulation design in the SIMULINK environment for 10 seconds. The BER values for various SNR levels are given in Table 2. The results obtained have been described by the BER below one by one.

Tables 2, 3, and 4 show the values of BER for SISO model (see Figure 8), MIMO1/2 (see Figure 9) and MIMO3/4 (Fig. 10) designs, respectively, where B denotes binary coding and G denotes grey coding for every row in the table. Each column displays the bit error rate for various SNR levels in decibels. Table 2 shows that the BER value varies from 0.48 to 0.505 depending on the coding and modulation technique used. The simulation results in the Table 2 and Figure 11 show that no effect on BER is obtained using alternative coding and modulation techniques in case of SISO model.

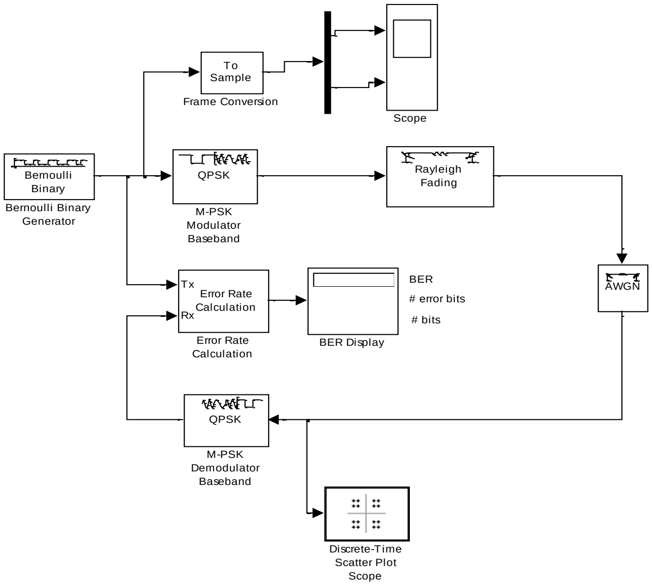

Figure 8: SIMULINK Model of SISO System

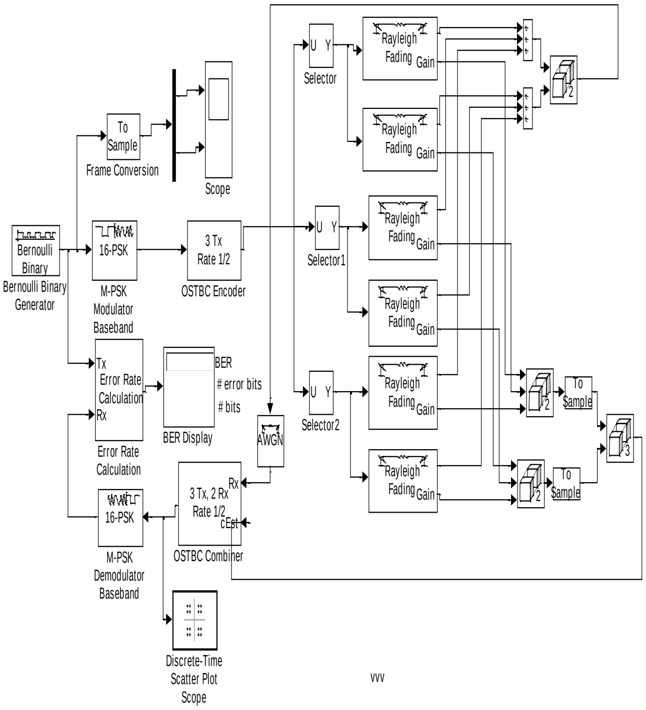

Figure 9: SIMULINK Model of MIMO1/2 System

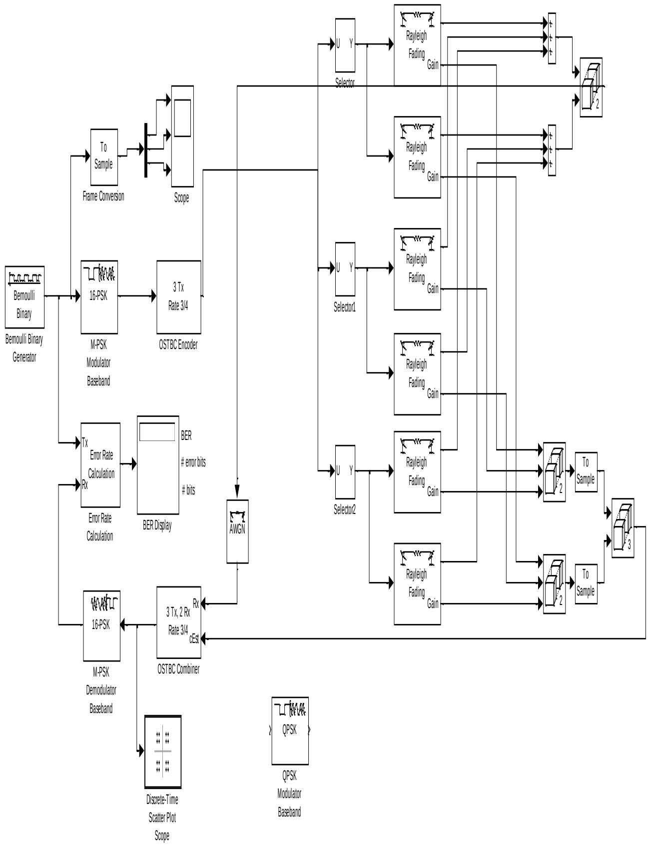

Figure 10: SIMULINK Model of MIMO3/4 System

Table 2: Variation in BER with SNR using Various Modulation Schemes + Binary and Grey Coding Schemes for SISO System

SNR	BPSK (B) / BPSK (G)	QPSK (B) / QPSK (G)	8PSK (B) / 8PSK (G)	16PSK (B) / 16PSK (G)
1	0.504	0.492	0.4955	0.4965
	0.504	0.4958	0.4946	0.4918
5	0.4993	0.4852	0.4862	0.4963
	0.4993	0.4953	0.4876	0.4928
10	0.497	0.471	0.4878	0.4927
	0.497	0.4903	0.4782	0.488
15	0.502	0.4603	0.4894	0.4858
	0.502	0.4846	0.4748	0.4893
20	0.5003	0.4574	0.4883	0.4870
	0.5003	0.4862	0.4737	0.4887
25	0.5006	0.4563	0.486	0.4828
	0.5006	0.4875	0.4743	0.489

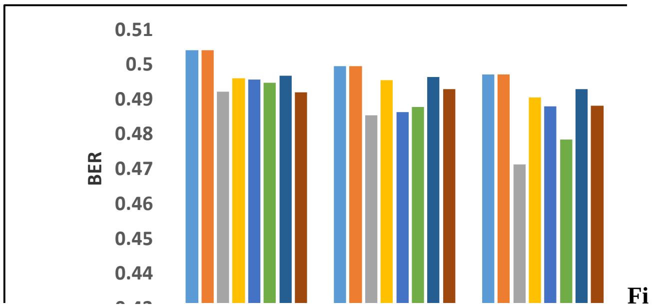

Figure 11: Variation in BER with SNR using Various Modulation Schemes +Binary and Grey Coding Schemes for SISO System Table 3.2: Variation in BER with SNR using Various Modulation Schemes + Binary and Grey Coding Schemes for SISO System

Table 3 show the variation in BER along with SNR for proposed MIMO1/2 system as shown in Figure 9 considering different coding and modulation techniques. The same variation is also shown in Figure 12. Table 3 and Figure 12 show that the BER value varies from 0.000 to 0.2551 depending on the coding and modulation technique used. The simulation results (see Table 3 and Figure 12) shows that both the alternative coding schemes and modulation techniques put a great effect on BER in the MIMO. The results also show that less BER is achieved for the same SNR and same Coding Schemes and Modulation Techniques for MIMO1/2 system than SISO system.

Table 3: Variation in BER with SNR using Various Modulation Schemes + Binary and Grey Coding Schemes for MIMO1/2

SNR	BPSK (B) / BPSK (G)	QPSK (B) / QPSK (G)	8PSK (B) / 8PSK (G)	16PSK (B) / 16PSK (G)
1	0.01191	0.04337	0.1916	0.2551
	0.01191	0.03754	0.1111	0.2315
5	0.000799	0.008258	0.00535	0.1977
	0.0007998	0.005998	0.03667	0.11ter26
10	0	0.0003332	0.007164	0.0546
	0	0.000288	0.005199	0.03791
15	0	0	0.0003999	0.01562
	0	0	0.0003333	0.007985
20	0	0	0	0.001132
	0	0	0	0.0007327
25	0	0	0	0.0001332
	0	0	0	0

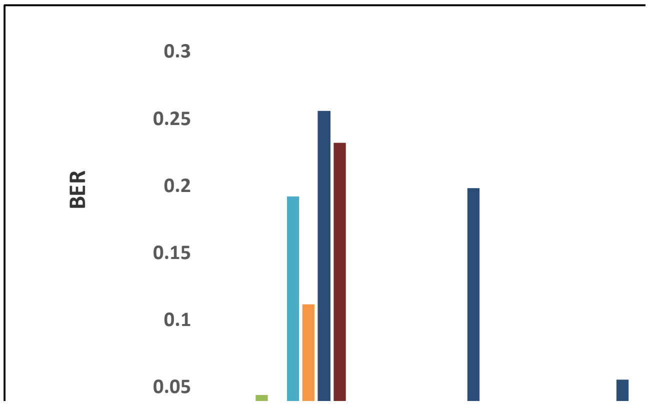

Figure 12: Variation in BER with SNR using Various Modulation Schemes + Binary and Grey Coding Schemes for MIMO1/2

Table 4: Variation in BER with SNR using Various Modulation Schemes + Binary and Grey Coding Schemes for MIMO3/4 System

SNR	BPSK (B) / BPSK (G)	QPSK (B) / QPSK (G)	8PSK (B) / 8PSK (G)	16PSK (B) / 16PSK (G)
1	0.01075	0.5165	0.1809	0.3607
	0.01075	0.04464	0.1126	0.2155
5	0.0002	0.01012	0.7154	0.2777
	0.0002	0.006197	0.04467	0.1167
10	0	0	0.006898	0.09027
	0	0	0.004598	0.03787
15	0	0	0	0.0113
	0	0	0	0.006094
20	0	0	0	0.000399
	0	0	0	0.0002
25	0	0	0	0
	0	0	0	0

Table 4 shows the variation in BER along with SNR for proposed MIMO ¾ system as shown in Figure 10 considering different coding and modulation techniques. The same variation is also shown in Figure 13. Table 4 and Figure 13 shows that the BER value varies from 0.000 to 0.7154 depending on the coding and modulation technique used. The simulation results (see Table 4 and Figure 13) reveal that both alternative coding and modulation techniques put a great effect on BER and the practical value of BER is nearest to the actual value in the MIMO ¾ **system** . The results also show that less BER is achieved for the same SNR and same Coding Schemes and modulation techniques for MIMO¾ **as** compared **to** MIMO1/2 and SISO systems.

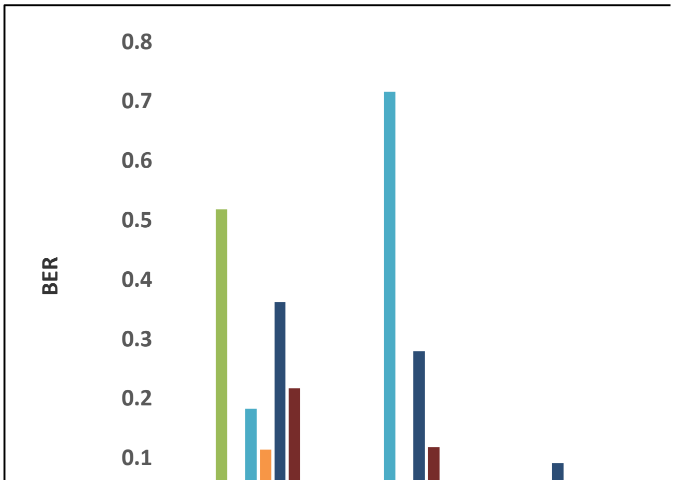

Figure 13: Variation in BER with SNR using Various Modulation Schemes + Binary and Grey Coding Schemes for MIMO3/4 System

5. CONCLUSION

In the present work, the Multiple Input Multiple Output (MIMO) system demonstrates its potential to meet demands by boosting spectrum efficiency through the use of spatial multiple route gain and improving resiliency via the use of antenna diversity gain. A number of issues in the field of MIMO wireless communication have been studied in this Thesis. The problem with the MIMO system i.e. high Bit Error Rate (BER) occurred due to channel fading has been studied in this Chapter. Several MIMO models have been developed in the MATLAB / SIMULINK environment such as : MIMO 1/2 and MIMO3/4 transmitter receiver antennas along with SISO Transmit Receive System and the combination of grey coding and binary coding with the various modulation techniques is also introduced in signal trial. Following conclusions have been given below:

- Even at the tiny noise power mirror, the BER in the SISO system mode is quite substantial for any form of modulation scheme (see Table 2 / Figure 11). In case of SISO System, BER is never less than 0.4 due to the fading channel.
- For any kind of modulation scheme (B / G), BER has achieved zero for MIMO1/2 and MIMO3/4 designing at SNR greater than and equal to 25dB (Tables 3-4 and Figures 12-13).
- The BER for BPSK modulation is negligible in the MIMO1/2 and MIMO3/4 design and it is about the same for binary and grey coding.
- The less BER is obtained using grey coding as compared to BER using binary coding. in case of BPSK, QPSK, 8PSK and 16PSK. Similarly, the BER of the MIMO $^3/_4$ model is lower due to the grey coding modulation strategy. it can be concluded that grey coding improves data transmission efficiency in MIMO1/2 and MIMO3/4.

- While comparing MIMO1/2 and MIMO3/4 design, it has been found that less BER is obtained in MIMO1/2 mode for BPSK modulation technique at all SNR levels. The MIMO ¾ model is better than MIMO1/2 model for QPSK, however, in case of 8PSK and 16PSK modulation technique, the proposed MIMO1/2 design exhibits a lower BER than MIMO3/4 design, especially at SNRs greater than or equal to 10db.

Finally, it can be concluded from the major scenario obtained in Table 3.2-3.4 that the MIMO1/2 channel design outperforms the MIMO3/4 channel design.

REFERENCES

1. S.M. Alamouti, **A simple transmit diversity technique for wireless communications**, *IEEE Journal on Selected Areas in Communications"*, Vol. 16, No. 8, pp. 1451-1458,1998,

2. P. Balaban & J. Salz, **Dual diversity combining and equalization in digital cellular mobile radio**, *IEEE Transactions on Vehicular Technology*, Vol. 40, No. 2, pp. 342-354, 1991.

3. I. E. Telatar, **Capacity of multi-antenna gaussian channels**, *European Transactions on Telecommunications*, Vol. 10, No. 6, pp. 585-595, 1999.

4. M. Ergen, **Multiple antenna systems**, *Chapter First Online*, 01 January 2008.

5. A. V. Geramita, J. Seberry & M Dekker, **Orthogonal designs: quadratic forms and hadamard matrices**, *Mathematics*, 1979.

6. A.J. Paulraj & C. B. Papadias, **Space-time processing for wireless communications**, *IEEE Signal Processing Mag.*,Vol. 14, pp. 49–83, Nov. 1997.

7. V. Tarokh, N. Seshadri & A. R. Calderbank, **Space–time codes for high data rate wireless communication: Performance analysis and code construction,** *IEEE Trans. Inform. Theory*, Vol. 44,No.2, pp. 744–765, 1998.

8. M. Ström, **Low PAPR waveform synthesis with application to wideband MIMO radar**, *4th IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP)*, San Juan, PR, USA, 13-16 December 2011.

9. C. Studer, PAR-**aware large-scale multi-user MIMO-OFDM downlink**, *IEEE Journal on Selected Areas in Communications*, Vol. 31, No. 2, pp. 303 – 313, 2013.

10. H. Kumawat, K. Kumawat, **PAPR reduction in MIMO OFDM system using improved constant modulus algorithm**, *International Journal of Computer Science and Mobile Applications*, Vol.3, No. 3, pp. 01-06, 2015.

11. Y. Liu & J. Wang, **Low-complexity OFDM-based hybrid precoding for multiuser massive MIMO systems**, *IEEE Wireless Communications Letters*, Vol. 9, No. 3, pp. 263–266, 2020.

12. F. Manman, Xu Yaohua, **Low-complexity linear precoding for pilot contamination mitigation in multi-cell massive MIMO systems**, *International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS)*, Xiamen, China, November 6-7, 2017.

13. M. Vijayalakshmi, K. R. Reddy, **An effective hybrid approach for PAPR reduction in MIMO-OFDM**, *Analog Integrated Circuits and Signal Processin*g, Vol. 102, pp. 145–153, 2020.

14. S. Domouchtsidis, C. Tsinos, S. Chatzinotas & B. Ottersten, **Constant envelope massive MIMO-OFDM precoding: an improved formulation and solution**, *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Barcelona, Spain, 04-08 May 2020.

15. C. Tarver, A. B. Stimming, C. Studer & J. R. Cavallaro, "**OFDM-based beam-oriented digital predistortion for massive MIMO**, *IEEE International Symposium on Circuits and Systems (ISCAS)*, Daegu, Korea, 22-28 May, 2021.

16. S. Kant & M. Bengtsson, B. Göransson, G. Fodor & C. Fischione, S. Sweden, **Efficient optimization for large-scale MIMO-OFDM spectral precoding,** *IEEE Transactions on Wireless Communications*, Vol. 20, No. 9, pp. 5496 – 5513, 2021.

17. Y. Xu, Z. Feng, J. Zou, D. Kong, Y. Xin & T. Jiang, **An imaginary interference-free method for mimo precoding in FBMC/OQAM systems**, *IEEE Transactions on Broadcasting*, Vol. 67, No. 3, pp. 642 – 650, 2021.

18. Y. Zhang, A. Yongacoglu & J.Y. Chouinard, **Orthogonal frequency division multiple access peak-to-average power ratio reduction using optimized pilot symbols**, *International Conference on Communication Technology Proceedings (Cat. No.00EX420)*, Beijing, China, 21-25 August 2000.

19. S. H. Han & J. H. Lee, **An overview of peak-to-average power ratio reduction techniques for multicarrier transmission**, *IEEE Wireless Communications*, Vol. 12, No. 2, pp. 56 - 65 , 2005.

20. R. F. H. Fischer, "Peak-to-**average power ratio (PAR) reduction in OFDM based on lattice decoding**", January, 2006.

21. C. Siegl, R. F. H. Fischer, **Partial transmit sequences for peak-to-average power ratio reduction in multi antenna OFDM,** *EURASIP Journal on Wireless Communications and Networking*, Vol. 2008, No. 325829, 2007.

22. R. F. H. Fischer; M. Hoch, **Peak-to-average power ratio reduction in MIMO OFDM**", I*EEE International Conference on Communications*, Glasgow, UK, 24-28 June 2007.

23. M. Ström, M. Viberg, **Low PAPR waveform synthesis with application to wideband MIMO radar**, *4th IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP)*, San Juan, PR, USA, 13-16 December 2011.

24. I. Koffman; V. Roman, **Broadband wireless access solutions based on OFDM access in IEEE 802.16,**

IEEE Communications Magazine, Vol. 40, No. 4, pp. 96 – 103, 2002.

25. C. Studer, E. G. Larsson, “PAR-**aware large-scale multi-user MIMO-OFDM downlink**, *IEEE Journal on Selected Areas in Communications,* Vol. 31, No. 2, pp. 303 – 313, 2013.

26. S. Sujatha, P. Dananjayan, “PAPR **reduction in MIMO OFDM system using modified SLM based constant modulus algorithm with IDCT matrix**, *Journal of Computer Science IJCSIS*, Vol. 14, No. 5, 2016.

27. M. H. Aghdam & A.A. Sharifi, **A novel ant colony optimization algorithm for PAPR reduction of OFDM signals**, *International Journal of Communication Systems*, Vol. 34, No. 1, 2021.

28. R.Ahmad & A. Srivastava, **PAPR reduction of OFDM signal through DFT precoding and GMSK pulse shaping in indoor VLC**, *IEEE Access*, Vol. 8, pp. 122092 – 122103, 2020.

29. Z. Xing, K. Liu, A. S. Rajasekaran, H. Yanikomeroglu & Y. Liu, **A hybrid companding and clipping scheme for PAPR reduction in OFDM systems**, *IEEE Access*, Vol. 9, pp. 61565 – 61576, 2021.

30. X. Wang, N. Jin &, J. Wei, “**A model-driven DL algorithm for PAPR reduction in OFDM system**, I*EEE Communications Letters*, Vol. 25, No.7, 2021.

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