International Journal of Research and Development in Applied Science and Engineering (IJRDASE)
ISSN: 2454-6844

Design and Analysis of MIMO Communication Systems Employing Diversity and Space-Time Coding

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Abstract: Space–Time Block Coding (STBC) is an effective diversity technique used in wireless communication to combat multipath fading. It encodes information across multiple transmit antennas and time slots to improve transmission reliability. The encoded symbols are transmitted simultaneously through different antennas, creating spatial diversity. At the receiver, the received signal is a combination of all transmitted signals affected by channel fading and noise. Signal recovery is performed using decoding algorithms that separate the transmitted data streams. Orthogonal Space–Time Block Codes (OSTBCs) simplify this process by maintaining orthogonality among transmitted codewords. This property enables maximum likelihood (ML) decoding with low computational complexity. Linear processing at the receiver ensures efficient and accurate signal detection. OSTBC provides full diversity gain while maintaining practical implementation complexity. Consequently, it enhances bit error rate (BER) performance and communication reliability. In this work, an OSTBC-based communication system is modeled using MATLAB/Simulink. The model employs a simple maximum likelihood decoding algorithm for signal detection. Performance is evaluated under fading channel conditions with multiple transmit and receive antennas. The proposed implementation achieves maximum diversity gain for the selected antenna configuration. Overall, the system demonstrates improved robustness and reliable wireless data transmission.

Keywords: MIMO, OSTBC, Transmitter, Receiver.

1. Introduction:

Cooperative communication has emerged as a promising technology for enhancing the performance of modern wireless communication systems by enabling single-antenna mobile devices to work together as a distributed antenna array. Instead of relying on multiple antennas installed on a single device, neighboring wireless nodes cooperate by sharing their communication resources to create a virtual Multiple-Input Multiple-Output (MIMO) system. Through this cooperation, the participating nodes jointly transmit and receive information, thereby achieving spatial diversity and improving communication reliability. The concept of cooperative communication is particularly beneficial in scenarios where the installation of multiple antennas on mobile terminals is impractical because of limitations in size, power consumption, cost, and hardware complexity. As a result, cooperative communication has become an attractive solution for next-generation wireless networks, including 5G, 6G, wireless sensor networks, Internet of Things (IoT), and vehicular communication systems.

Multiple-Input Multiple-Output (MIMO) technology is one of the most effective antenna diversity techniques used to increase system capacity and improve transmission quality over wireless fading channels. In a MIMO system, multiple antennas are deployed at both the transmitter and receiver to transmit several independent data streams simultaneously. This parallel transmission significantly enhances spectral efficiency and increases data throughput without requiring additional bandwidth or transmission power. Furthermore, MIMO technology effectively combats multipath fading, improves signal quality, and enhances the reliability of wireless links. Depending on the number of transmitting and receiving antennas, wireless communication systems are generally classified into four categories: Single-Input Single-Output (SISO), Single-Input Multiple-Output (SIMO), Multiple-Input Single-Output (MISO), and Multiple-Input Multiple-Output (MIMO). Among these configurations, MIMO provides the highest diversity gain, spectral efficiency, and communication capacity, making it a fundamental technology in modern wireless standards.

Wireless communication channels are inherently affected by several impairments, including multipath propagation, shadowing, interference, and additive noise, all of which degrade system performance and increase the bit error rate (BER). As the demand for high-speed and reliable wireless communication continues to grow, efficient utilization of the available spectrum has become increasingly important. MIMO technology addresses these challenges by exploiting spatial multiplexing and diversity techniques that improve channel capacity while maintaining the same bandwidth. By transmitting multiple data streams through different antennas simultaneously, MIMO systems achieve significantly higher data rates and more reliable communication compared to conventional single-antenna systems.

An important enhancement to MIMO systems is the incorporation of space–time coding techniques, which encode information across both spatial and temporal domains before transmission. Space–Time Block Coding (STBC), particularly Orthogonal Space–Time Block Coding (OSTBC), provides transmit diversity while maintaining a simple decoding process at the receiver. These coding techniques improve resistance to channel fading and substantially reduce the bit error rate without increasing transmission power or occupying additional bandwidth. Consequently, space–time coding has become an essential component of modern MIMO communication systems.

Despite the remarkable advantages of conventional MIMO technology, practical implementation on mobile devices remains challenging. The limited physical dimensions of handheld devices restrict the number of antennas that can be installed while maintaining sufficient antenna spacing to minimize correlation. Additional antennas also increase hardware complexity, manufacturing cost, power consumption, and signal processing requirements. Cooperative communication effectively overcomes these limitations by allowing independent wireless nodes to function collectively as a virtual MIMO system. Through distributed cooperation, the network achieves many of the benefits of conventional MIMO, including enhanced diversity gain, improved coverage, increased reliability, and better energy efficiency, without requiring multiple antennas on individual devices.

Owing to these advantages, cooperative MIMO combined with advanced space–time coding techniques has become a key research area in modern wireless communications. Such systems provide an effective solution for improving spectral efficiency, reducing transmission errors, and enhancing overall network performance under challenging channel conditions. Consequently, cooperative MIMO is expected to play a vital role in future wireless communication technologies, supporting the increasing demand for high data rates, reliable connectivity, and efficient utilization of radio spectrum.

2. Related Work:

Mehboob Ul Amin et al. (2013) investigated Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) as a promising air-interface technology for future Wireless Local Area Networks (WLANs), Wireless Metropolitan Area Networks (WMANs), and fourth-generation (4G) mobile communication systems. The authors identified the high Peak-to-Average Power Ratio (PAPR) of OFDM signals as one of the major limitations affecting the efficiency of power amplifiers and overall system performance. To address this challenge, they proposed a hybrid PAPR reduction technique that combines the Discrete Cosine Transform (DCT)-based Selective Mapping (SLM) method with an Orthogonal Space-Time Block Coding (OSTBC) encoder. The DCT reduces signal correlation, while the SLM technique generates multiple candidate signal sequences to select the one with the lowest PAPR. The incorporation of OSTBC further enhances transmission reliability by providing spatial diversity. Simulation results demonstrated that the proposed hybrid scheme significantly outperformed conventional SLM techniques, particularly for larger numbers of subcarriers and transmit antennas. The proposed approach achieved considerable PAPR reduction while preserving signal quality, making it highly suitable for high-speed wireless communication systems and future broadband networks. The study concluded that integrating DCT, SLM, and OSTBC provides an effective solution for improving both transmission efficiency and system reliability in MIMO-OFDM environments [1].

Apoorva Pandey et al. (2013) focused on mitigating the adverse effects of wireless channel fading, which remains one of the primary causes of performance degradation in mobile communication systems. The study compared two widely used diversity techniques, namely the Alamouti Space-Time Block Coding (STBC) scheme and Maximum Ratio Combining (MRC), under Rayleigh fading channel conditions. Both techniques exploit spatial diversity by transmitting and combining multiple copies of the same information signal to improve detection accuracy. Performance evaluation was carried out using Binary Phase Shift Keying (BPSK) modulation over Additive White Gaussian Noise (AWGN) and Rayleigh fading channels. The simulation results indicated that an MRC system employing one transmit antenna and two receive antennas achieved diversity performance comparable to that of the Alamouti scheme with two transmit antennas and one receive antenna. Furthermore, increasing the number of receive antennas in the MRC configuration further improved the bit error rate (BER) performance, even when the average transmitted power varied. The study demonstrated that both Alamouti STBC and MRC effectively combat multipath fading and significantly enhance communication reliability in wireless MIMO systems. These findings confirm the effectiveness of spatial diversity techniques in achieving robust and reliable wireless communication under challenging propagation conditions [2].

H. A. Mohammed et al. (2012) examined the integration of Multiple-Input Multiple-Output (MIMO) technology with Orthogonal Frequency Division Multiplexing (OFDM) to support next-generation wireless communication systems, including fourth-generation (4G) cellular networks and advanced Wireless Local Area Networks (WLANs). The study emphasized that MIMO-OFDM offers high spectral efficiency, increased channel capacity, and improved resistance to multipath fading, making it one of the most promising physical-layer technologies for broadband wireless communication. The authors developed a comprehensive MIMO-OFDM physical-layer model using MATLAB/Simulink and evaluated its performance under high-speed vehicular mobility scenarios, where Doppler frequency shifts significantly affect signal quality. In addition, the research investigated the application of High Altitude Platform (HAP) systems as relay platforms to reduce the impact of Doppler effects and extend communication coverage. Simulation results demonstrated that the proposed MIMO-OFDM model maintained reliable communication performance even under high mobility conditions, while the incorporation of HAP technology further improved system robustness and transmission quality. The study concluded that MIMO-OFDM combined with advanced mobility support techniques represents a practical and efficient solution for future high-data-rate wireless communication systems [3].

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3. Methodology:

Wireless communication channels are inherently unpredictable because they are continuously affected by channel impairments such as additive noise, interference, shadowing, and multipath fading. These impairments introduce fluctuations in the received signal strength, resulting in increased bit error rates (BER) and degraded communication reliability. As modern wireless systems demand higher data rates and improved quality of service, overcoming channel fading has become one of the primary research challenges. To address these issues, several diversity techniques have been developed to improve the robustness of wireless communication systems. Initially, time diversity and frequency diversity techniques were widely employed; however, the introduction of space diversity using multiple antennas has demonstrated significant improvements in system capacity, spectral efficiency, and transmission reliability. The pioneering work on Multiple-Input Multiple-Output (MIMO) systems established that multiple antennas operating in fading environments can substantially increase channel capacity without requiring additional bandwidth or transmission power, thereby motivating extensive research on efficient MIMO transmission techniques and coding schemes.

One of the earliest approaches to exploit spatial diversity involved the use of multiple receive antennas combined with Maximum Ratio Combining (MRC). In MRC, signals received through independent fading paths are coherently combined to maximize the received signal-to-noise ratio (SNR), thereby improving detection accuracy and reducing transmission errors. Although MRC provides excellent diversity gain, its implementation generally requires multiple receive antennas and significant signal processing capability at the receiver. Consequently, receive diversity techniques are more suitable for base stations, which possess sufficient computational resources and power availability. In contrast, implementing similar processing at mobile terminals is often impractical because portable devices are constrained by limited battery capacity, compact size, and reduced processing capability. Although continuous advancements in Very Large Scale Integration (VLSI), Application-Specific Integrated Circuits (ASICs), and System-on-Chip (SoC) technologies have reduced hardware complexity and power consumption, minimizing computational burden at mobile devices remains an important design objective.

To overcome the limitations associated with receive diversity, several transmit diversity techniques were developed, allowing most of the signal processing complexity to be shifted from the mobile station to the base station. Early transmit diversity methods included antenna switching schemes with feedback information, feedforward-based diversity techniques, training-assisted transmission methods, and blind transmit diversity algorithms. These techniques aimed to improve communication reliability while maintaining low receiver complexity. Subsequently, Space-Time Trellis Coding (STTC) emerged as a powerful transmit diversity technique by jointly integrating channel coding, modulation, and multiple-antenna transmission. STTC offers excellent coding gain, diversity gain, and error performance over flat fading channels. However, these advantages are achieved at the expense of significantly increased decoding complexity. The computational requirements of STTC grow exponentially with the number of transmit antennas, transmission rate, and diversity order, making its implementation challenging for practical wireless systems.

To reduce decoding complexity while preserving diversity performance, Orthogonal Space-Time Block Coding (OSTBC) was introduced as an efficient alternative to STTC. Initially designed for two transmit antennas using the Alamouti coding scheme, OSTBC was later generalized to support multiple transmit antenna configurations. The orthogonal structure of OSTBC enables simple linear Maximum Likelihood (ML) decoding at the receiver while still achieving full spatial diversity. Although OSTBC generally provides slightly lower coding gain than STTC, its significantly lower computational complexity, ease of implementation, and robust performance make it highly attractive for practical MIMO communication systems. Furthermore, studies have demonstrated that when OSTBC is combined with suitable channel coding techniques, its performance can equal or even surpass that of STTC while maintaining considerably lower implementation complexity. Consequently, OSTBC has become one of the most widely adopted transmit diversity techniques in modern wireless communication standards due to its excellent balance between performance, reliability, and computational efficiency.

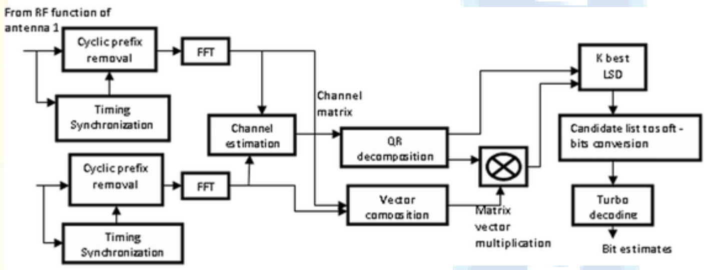

Fig. 1: Baseband representation of OSTBC G_2 of (1.4) with one receive antenna

4. Result and Discussion:

In this part, we'll go through how to use MATLAB SIMULINK to create simulation data for effectiveness study of SISO as well as MIMO systems. In terms of scatter plot as well as bit error rate, there are three design styles that describe the model design and reactions (BER). Three alternative models are designed for step-by-step analysis: (1) SISO model, (2) MIMO 12 - 3 Tx and 2 Rx model at rate 1/2, and (3) MIMO 3/4 - 3 Tx as well as 2 Rx model at rate 3/4. We used four distinct modulation techniques for each model: BPSK, QPSK, 8PSK, and 16PSK. We employed data transmission without and with grey coding for every modulation technique. The data is broadcast via a Rayleigh fading channel with a maximum Doppler shift of 3 Hz. We utilized an AWGN channel simulink blocks to estimate the BER at various SNRs for a specific design that utilized 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 the higher the

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noise, the higher the BER. The BER is determined by the number of error bits divided by the total number of bits. We acquired the BER values by running each simulation design in the simulink environment for 10 seconds and recording the BER values in a tabular manner for various SNR levels. BER will describe and discuss our simulation model results one by one in the following sections.

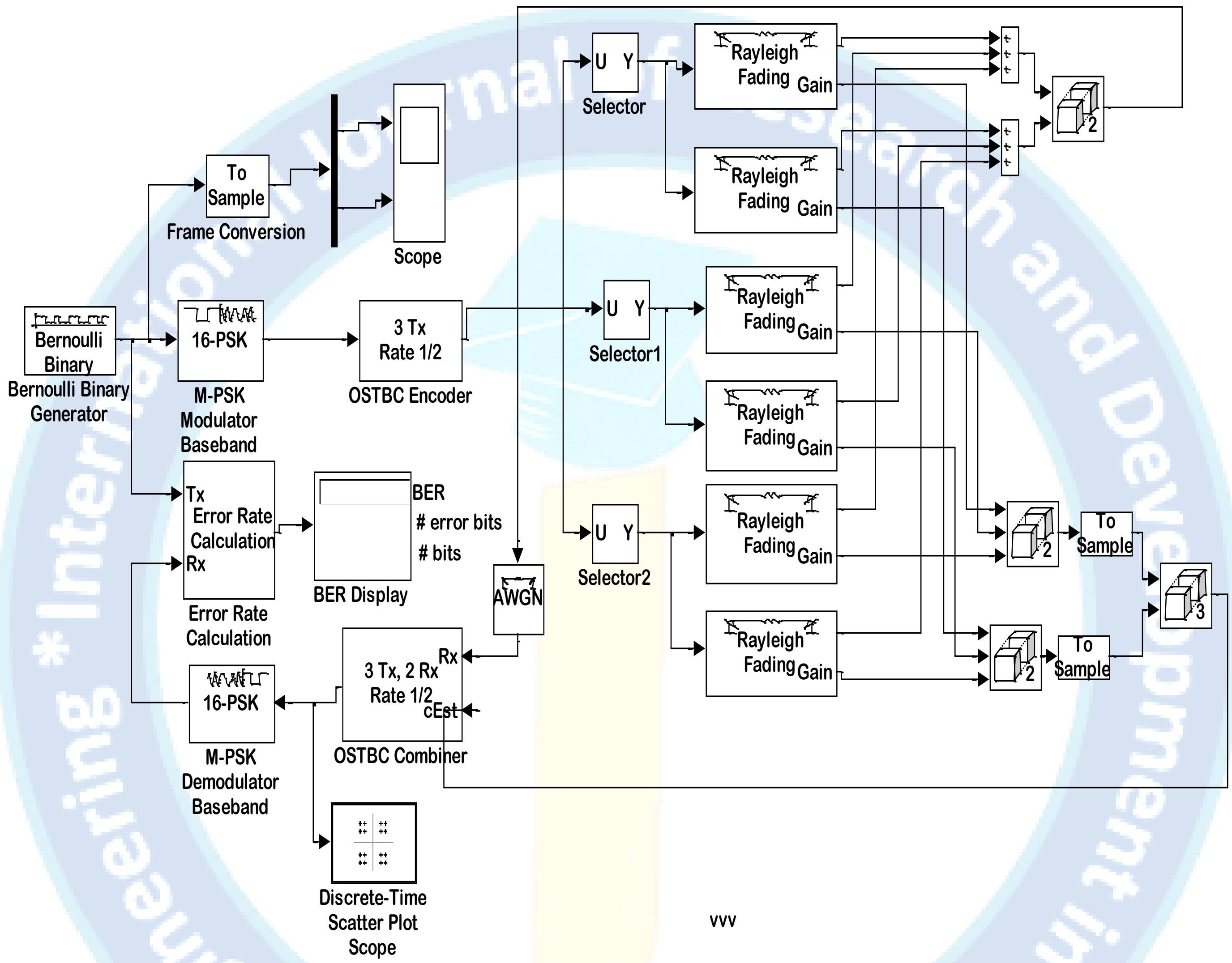

Fig 2: Simulink Model of MIMO1/2 Structure

5. Conclusion:

Multiple-Input Multiple-Output (MIMO) technology has emerged as one of the most effective solutions for meeting the increasing demands of modern wireless communication systems. By exploiting spatial multiplexing and antenna diversity, MIMO significantly improves spectral efficiency, enhances channel capacity, and increases communication reliability without requiring additional bandwidth or transmission power. Extensive theoretical studies and practical hardware implementations have demonstrated the feasibility of MIMO technology for deployment in current and next-generation wireless networks. Continuous advancements in signal processing algorithms, antenna design, and integrated circuit technologies have further accelerated its adoption in practical communication systems.

Despite these advantages, MIMO systems continue to face several challenges, among which channel fading remains one of the most significant factors contributing to increased bit error rate (BER). Multipath propagation and time-varying wireless channels can severely degrade signal quality, thereby affecting the overall system performance. To address this issue, different transmit diversity and coding techniques have been developed to improve communication reliability under fading conditions.

In this study, two MIMO system configurations employing 1/2 and 3/4 transmit–receive antenna arrangements are designed and analyzed to evaluate their performance over fading channels. The proposed models incorporate Gray coding prior to the modulation stage to minimize symbol errors caused by adjacent constellation mapping. The inclusion of Gray coding reduces the probability of bit errors by ensuring that neighboring modulation symbols differ by only one bit. The performance of the proposed MIMO configurations is evaluated in terms of BER under various channel conditions, demonstrating the effectiveness of antenna diversity and Gray-coded modulation in improving the reliability and efficiency of wireless communication systems.

References:

[1]. J. Mitola, ―Cognitive Radio an Integrated Agent Architecture for Software Defined Radio," Ph.D. Dissertation, Teleinformatics, KTH, Stockholm, 2008.

[2]. V. Tarokh, N. Seshadri, and A.R. Calderbank. ―Space-time codes for high data rate wireless communication: Performance criterion and code construction,‖ IEEE journal on Inform.Theory, vol. 44, pp.744-765, Mar.1998.

[3]. W. Jiangzhou, S. Hyundong, A. Ramesh, Z. Moe, and others, ―Wireless Cooperative Networks,‖ EURASIP Journal on Advances in Signal Processing, vol. 2008, 2008.

[4]. W. P. Sriwongpairat, T. Himsoon, ‖Optimum Threshold-Selection Relaying for Decode-and-Forward Cooperation Protocol‖ IEEE WCNC Proceeding, pp. 1015-1020, 2006.

[5]. T. Fujii and Y. Suzuki, ―Ad Hoc Cognitive Radio Development Frequency Sharing System by Using Multi-hop Network,‖ IEEE DvSPAN, PP.589-592, Maryland, November 2005.

[6]. T. Q. Duong and H-J. Zupernick, ‖On the performance gain of hybrid decode-amplify-forward cooperative communication‖, EURASIP Journal on wireless Communication Networking, PP. 1-3, 2009.

[7]. H. Shahzad and B. Jaishankar, "Applying OSTBC Cooperative Radio Networks", Master Thesis BTH University, Sweden, 2010.

[8]. J. Feldman, M. J. Wainwright and D.R.Karger,"Using linear programming to Decode Binary linear codes,", IEEE Transactions on Information Theory, 51:954-972, March 2005.

[9] Mehboob Ul Amin et al "A New Method for PAPR Reduction in MIMOOFDM Using Combination of OSTBC Encoder and DCT Matrix" International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-2, Issue-2, May 2013.

[10] Apoorva Pandey et al " Comparison of Wireless MIMO System Under Alamouti's Scheme and Maximum Ratio Combining Technique" I.J. Image, Graphics and Signal Processing, 2013, 2, 31-37 Published Online February 2013 in MECS (http://www.mecs-press.org/) DOI: 10.5815/ijigsp.2013.02.05.

[11] H A Mohammed et al "Investigation of Doppler Effects on high mobility OFDMMIMO
systems with the support of High Altitude Platforms (HAPs)" Journal of Physics: Conference Series 364 (2012) 012048 doi:10.1088/1742-6596/364/1/012048.

[12] Srikrishna Bardhan et al " Capacity and Performance Analysis of MIMO-STBC in Rayleigh Fading Channels" International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 8, October - 2012 .

[13] Soukayna Ghandour-Haidar et al' "On the Use of First-order Autoregressive Modeling for Rayleigh Flat Fading Channel Estimation with Kalman Filter" Author manuscript, published in "Signal Processing 92, 2 (2012) 601-606" DOI : 10.1016/j.sigpro.2011.08.014.

[14] Angel Lozano et al, "Transmit Diversity v. Spatial Multiplexing in ModernMIMO Systems" arXiv:0811.3887v2 [cs.IT] 5 Mar 2009.

[15] Harsh Shah et al, "Performance of Concatenated Channel Codes and Orthogonal Space-Time Block Codes" IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 5, NO. 6, JUNE 2006.

[16] S. Alamouti, "A simple transmit diversity technique for wireless communications," IEEE Journal on Selected Areas in Communications, vol. 16, pp. 1451-1458, Oct. 1998.

[17] V. Tarokh, H. Jafarkhani, and A. Calderbank, "Space-time block codes from orthogonal designs," IEEE Transactions on Information Theory, vol. 45, pp. 1456-1467, July 1999.

[18] V. Tarokh, H. Jafarkhani, and A. Calderbank, "Space-time block coding for wireless communications: Performance results," IEEE Journal on Selected Areas in Communications, vol. 17, pp. 451-460, Mar. 1999.

[19] G. Ganesan and P. Stoica, "Space-time block codes: A maximum SNR approach," IEEE Transactions on Information Theory, vol. 47, pp. 1650-1656, May 2001.

[20] 0. Tirkkonen and A. Hottinen, "Square-matrix embeddable space-time block codes for complex signal constellations," IEEE Transactions on Information Theory, vol. 48, pp. 1122-1126, Feb. 2002.

[21] W. Su and X.G Xia, "Two generalized complex orthogonal space-time block codes of rates 7/11 and 315 for 5 and 6 transmit antennas," IEEE Transactions on Information Theory, vol. 49, pp. 313 -316, Jan. 2003.

[22] O. Tirkkonen and A. Hottinen, "Square-matrix embeddable space time block codes for complex signal constellations" IEEE TransInformation Theory, vol. 48, no. 2, pp. 384-395, Feb. 2002.