International Conference on Intelligent Technologies & Science - 2022
(ICITS-2022)

Advanced Communication in MIMO Systems Utilizing Space-Time Coding and Diversity Techniques

Rajat Gupta[1], Vikas Soni[2]
Engineering and Technology Department,
Career Point University, Kota, India
Rajat4747@gmail.com, vikassonieck@gmail.com

Abstract: Multiple-Input Multiple-Output (MIMO) systems have revolutionized wireless communication by enhancing spectral efficiency, reliability, and coverage. Space-Time Coding (STC) plays a critical role in maximizing the benefits of MIMO systems by exploiting the spatial and temporal dimensions of signal transmission. This paper explores the integration of STC in advanced MIMO systems, focusing on design principles, performance analysis, and practical applications. Simulation results demonstrate the superiority of STC-enabled MIMO systems in diverse wireless communication scenarios.

Keywords: MIMO, space time coding, diversity and combining scheme, channel estimation.

1. Introduction

Wireless communication has witnessed exponential growth in demand for high data rates, low latency, and reliable connectivity. MIMO technology, leveraging multiple antennas at both the transmitter and receiver, has emerged as a cornerstone of modern communication systems. Space-Time Coding, a technique that combines signal coding over space and time, enhances the performance of MIMO systems by introducing diversity gain and mitigating multipath fading effects. This paper delves into the principles and advancements in STC for MIMO systems, with a focus on its applications in next-generation wireless networks.

Overview of MIMO Systems

MIMO systems leverage spatial multiplexing and diversity techniques to improve communication performance. Key features include:

- Spatial Multiplexing: Enables simultaneous transmission of independent data streams, increasing spectral efficiency.
- Diversity Gain: Combats fading by transmitting redundant information across multiple antennas.
- Beamforming: Enhances signal strength in specific directions, reducing interference.

These features make MIMO a vital component in technologies such as 5G, Wi-Fi 6, and IoT networks.

Fundamentals of Space-Time Coding

STC introduces redundancy across spatial and temporal domains, offering resilience to channel impairments. Key types of STC include:

- Space-Time Block Codes (STBC): Simplifies encoding and decoding while achieving full diversity. Alamouti's scheme is a prominent example.
- Space-Time Trellis Codes (STTC): Provides coding gain by combining trellis coding with spatial diversity.

The design criteria for effective STC include maximizing diversity gain, minimizing decoding complexity, and ensuring robustness to channel variations.

Advanced MIMO-STC Integration

Integrating STC with advanced MIMO systems involves optimizing both hardware and algorithms. Key advancements include:

- Adaptive STC: Dynamically adjusts coding schemes based on channel state information (CSI).
- Hybrid MIMO-STC Techniques: Combines spatial multiplexing and STC for enhanced performance.
- Machine Learning in STC: Utilizes deep learning to optimize coding and decoding processes.

Performance Analysis

Simulation studies reveal significant improvements in Bit Error Rate (BER) and spectral efficiency for STC-enabled MIMO systems under varying channel conditions. Key findings include:

- Enhanced diversity gain in Rayleigh and Rician fading channels.
- Robust performance in the presence of interference and noise.
- Scalability for higher antenna configurations.

Applications

MIMO-STC systems find applications in:

- 5G and Beyond: Enhances reliability and efficiency in massive MIMO deployments.
- Wireless Local Area Networks (WLAN): Improves coverage and throughput in Wi-Fi systems.
- Satellite Communication: Mitigates fading and ensures robust links in harsh environments.
- Internet of Things (IoT): Enables reliable communication for low-power devices.

2. Research Methodology

The technique for the model-in-the-loop testing, research type, instruments and materials utilized for the study, data collecting, validation, and analysis is covered in the section that follows.

a. Main Design Process

Firstly, the intended research field was further investigated to gain a deeper understanding of the dynamic properties of the proposed objectives. This was followed by the development and implementation of models for an interactive wireless data transmission scheme. Relevant data was collected for the channel parameters. Subsequently, space time multiplexing schemes based on MIMO systems which followed different development principles—namely data-driven and model-based channel estimation schemes—were developed and tested. The algorithm design process contained the following steps with their respective challenges:

b. Creating a Wireless Network Simulation: The Wireless Network environment was simulated by considering source and destination nodes at random locations with equal topology. The source, channel and sink together with the MIMO transmission system governing the relationship between inputs and outputs, was determined and established.

c. Parameter Selection: Error rate and QoS-driven parameters selected as variables, analyzing the wireless network performance. Simulation experiments conducted in the channel fading environment to obtain the results.

d. Analysis: To control the data transmission system, feedback synthesis in the form of coding schemes antenna configuration strategies planned and adjusted. Network error and QoS criteria as controlling functions assessed by checking the associated feedback parameters in terms of the performance metrics.

e. Simulating the wireless network for data transmission Phase for the Proposed Algorithm: A virtual platform on MATLAB software simulated all system architecture and generate channel behaviors within the scope of a programming-based simulation environment. This simulation verifies the machine learning-based scheme by evaluating bit error after discrete time steps. The performance verified by comparing results between each run. Finally, the schemes implemented, verified, and validated in the different modulation schemes environment.

These steps and their respective challenges provided a comprehensive approach to developing and testing machine learning-based data transmission using space time multiplexing schemes in MIMO systems.

4. Result and Discussion:

a. **AI-Based Channel Estimation**: This study introduces a novel Artificial Intelligence (AI)-based channel estimator, leveraging artificial neural networks (ANNs) for simultaneous channel estimation and decoding in MIMO systems. This approach improves channel prediction accuracy and reduces computational complexity.
b. **Enhanced MIMO-OSTBC Framework**: A modified Orthogonal Space-Time Block Code (OSTBC) model is proposed, tailored for dynamic 2x1 and 2x2 MIMO configurations, demonstrating better BER performance with minimal power losses.
c. **Comparative Diversity Analysis**: The work comprehensively contrasts transmit diversity (Alamouti coding) and receive diversity (MRC) across multiple modulation schemes (BPSK, QPSK, 8PSK, 16PSK), showcasing how transmit diversity achieves 3 dB performance gains over receive diversity under equivalent power conditions.
d. **Pilot Symbol Optimization**: The study investigates the impact of varying pilot symbol counts on BER and system performance, revealing that beyond a certain threshold, increased pilot symbols provide negligible improvements in BER but add computational overhead.
e. **Comprehensive Modulation and Elapsed Time Study**: A thorough analysis of BER and elapsed time for BPSK, QPSK, and 8PSK modulation schemes is conducted, demonstrating the efficiency of the 2x2 MIMO system with smart channel estimation.
f. **Performance Validation**: Theoretical BER values are validated through extensive simulation, proving the universal applicability and improved reliability of the proposed MIMO-OSTBC communication system.

This work stands out by integrating ANN-based smart channel estimation with MIMO-OSTBC systems and providing practical insights into optimization and performance trade-offs

Table 1: Comparison Table

					BER	BPSK						
		pilot=8				pilot=12				pilot=20		
SNR (dB)	1x1	2x1	1x2	2x2	1x1	2x1	1x2	2x2	1x1	2x1	1x2	2x2
0	0.1458	0.1127	0.0564	0.0756	0.1458	0.1127	0.0564	0.0602	0.1458	0.1127	0.0564	0.0473
2	0.1074	0.0762	0.032	0.0307	0.1074	0.0762	0.032	0.03	0.1074	0.0762	0.032	0.0235
4	0.0764	0.0456	0.0168	0.0104	0.0764	0.0456	0.0168	0.0119	0.0764	0.0456	0.0168	0.0099
6	0.0523	0.024	0.0081	0.0034	0.0523	0.024	0.0081	0.0035	0.0523	0.024	0.0081	0.0034
8	0.0348	0.0115	0.0036	0.001	0.0348	0.0115	0.0036	0.0008	0.0348	0.0115	0.0036	0.0009
10	0.0227	0.0055	0.0015	0.0002	0.0227	0.0055	0.0015	0.0002	0.0227	0.0055	0.0015	0.0002

12	0.0146	0.0026	0.0006	0	0.0146	0.0026	0.0006	0	0.0146	0.0026	0.0006	0
14	0.0093	0.0011	0.0003	0	0.0093	0.0011	0.0003	0	0.0093	0.0011	0.0003	0
16	0.0059	0.0004	0.0001	0	0.0059	0.0004	0.0001	0	0.0059	0.0004	0.0001	0
18	0.0037	0.0001	0	0	0.0037	0.0001	0	0	0.0037	0.0001	0	0
20	0.0024	0.0001	0	0	0.0024	0.0001	0	0	0.0024	0.0001	0	0
					BER	**QPSK**						
0	0.1458	0.3347	0.2077	0.2868	0.1458	0.3347	0.2077	0.234	0.1458	0.3347	0.2077	0.234
2	0.1074	0.2499	0.1391	0.1468	0.1074	0.2499	0.1391	0.1515	0.1074	0.2499	0.1391	0.1515
4	0.0764	0.1715	0.0826	0.078	0.0764	0.1715	0.0826	0.0759	0.0764	0.1715	0.0826	0.0759
6	0.0523	0.1077	0.0445	0.0349	0.0523	0.1077	0.0445	0.0346	0.0523	0.1077	0.0445	0.0346
8	0.0348	0.0618	0.0221	0.0121	0.0348	0.0618	0.0221	0.014	0.0348	0.0618	0.0221	0.014
10	0.0227	0.0324	0.0104	0.0035	0.0227	0.0324	0.0104	0.0042	0.0227	0.0324	0.0104	0.0042
12	0.0146	0.0156	0.0046	0.0009	0.0146	0.0156	0.0046	0.0008	0.0146	0.0156	0.0046	0.0008
14	0.0093	0.007	0.002	0	0.0093	0.007	0.002	0	0.0093	0.007	0.002	0
16	0.0059	0.003	0.0009	0	0.0059	0.003	0.0009	0	0.0059	0.003	0.0009	0
18	0.0037	0.0013	0.0004	0	0.0037	0.0013	0.0004	0	0.0037	0.0013	0.0004	0
20	0.0024	0.0007	0.0002	0	0.0024	0.0007	0.0002	0	0.0024	0.0007	0.0002	0
					BER	**8PSK**						
0	0.1458	0.599	0.4757	0.535	0.1458	0.599	0.4757	0.4913	0.1458	0.599	0.4757	0.5037
2	0.1074	0.5203	0.3858	0.4564	0.1074	0.5203	0.3858	0.4081	0.1074	0.5203	0.3858	0.3899
4	0.0764	0.4327	0.2917	0.3497	0.0764	0.4327	0.2917	0.3317	0.0764	0.4327	0.2917	0.2794
6	0.0523	0.3374	0.201	0.2256	0.0523	0.3374	0.201	0.2271	0.0523	0.3374	0.201	0.1813
8	0.0348	0.2432	0.1257	0.1144	0.0348	0.2432	0.1257	0.1164	0.0348	0.2432	0.1257	0.104
10	0.0227	0.1605	0.0719	0.0494	0.0227	0.1605	0.0719	0.0533	0.0227	0.1605	0.0719	0.0518
12	0.0146	0.0967	0.0381	0.0304	0.0146	0.0967	0.0381	0.026	0.0146	0.0967	0.0381	0.0229
14	0.0093	0.0533	0.0187	0	0.0093	0.0533	0.0187	0	0.0093	0.0533	0.0187	0
16	0.0059	0.0271	0.0086	0	0.0059	0.0271	0.0086	0	0.0059	0.0271	0.0086	0
18	0.0037	0.0129	0.0036	0	0.0037	0.0129	0.0036	0	0.0037	0.0129	0.0036	0
20	0.0024	0.0058	0.0015	0	0.0024	0.0058	0.0015	0	0.0024	0.0058	0.0015	0

Table 2: Compare with Existing work

Author	Year	BER	SNR (dB)
Proposed work		$2\text{x}10^{-4}$	10
Avner Elgam et al.	2022	$6\text{x}10^{-4}$	10
S. Naser, et al.	2022	$1.2\text{x}10^{-3}$	155
A. Alwarafy et al.	2018	$1.7\text{x}10^{-3}$	40
K.M. Matter et al.	2022	$1.03\text{x}10^{-3}$	22
M. Taher et al.	2019	$1.06\text{x}10^{-3}$	25
Mohd. G. Al-Hamiri et al.	2023	$1.01\text{x}10^{-3}$	20

The proposed work has the lowest BER (2×10^{-4}), which is better than all other studies. Other works have similar BER values (1×10^{-3}), except for Avner Elgam et al. (6×10^{-4}) which is slightly better than most but not as low as the proposed work. The best BER **(2×10^{-4}),** indicating potentially higher reliability or accuracy compared to others.

5. Conclusion

The integration of Space-Time Coding into advanced MIMO systems offers unparalleled benefits in wireless communication. By addressing existing challenges and leveraging emerging technologies, MIMO-STC systems can meet the demands of future networks, ensuring reliable, efficient, and high-capacity communication.

References

[1] Foschini, G. J., & Gans, M. J. (1998). On limits of wireless communications in a fading environment when using multiple antennas. *Wireless Personal Communications*, 6(3), 311-335.

[2] Alamouti, S. M. (1998). A simple transmit diversity technique for wireless communications. *IEEE Journal on Selected Areas in Communications*, 16(8), 1451-1458.

[3] Tse, D., & Viswanath, P. (2005). *Fundamentals of Wireless Communication*. Cambridge University Press.

[4] Larsson, E. G., Edfors, O., Tufvesson, F., & Marzetta, T. L. (2014). Massive MIMO for next generation wireless systems. *IEEE Communications Magazine*, 52(2), 186-195.

[5] Biglieri, E., Calderbank, A. R., Constantinescu, F., & Proakis, J. G. (1998). *Coding for Wireless Channels*. Springer.

[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.