DOI: 10.26418/positron.v12i2.46613

Performance Analysis of Multiple Input Multiple Output (MIMO) Multi-Carrier Code-Division Multiple Access (MC-CDMA) Combined with Quasi-Orthogonal Space Time Block Coding (QO-STBC) in Rayleigh Fading Channel

Eka Kusumawardhani[a], Rina Pudji Astuti[b], Nachwan Mufti Adriansyah[b], Fitri Imansyah[a],
Leonardus Sandy Ade Putra[a],

[a]Jurusan Teknik Elektro, Fakultas Teknik, Universitas Tanjungpura, Jl. Prof. Dr. H. Hadari Nawawi,
Kota Pontianak, Kalimantan Barat
[b]Schoof of Electrical Engineering, Telkom University, Jl. Telekomunikasi No. 1, Kab. Bandung, Jawa Barat
*Email : Ekawardhani@ee.untan.ac.id

(Diterima 30 April 2021; Disetujui 24 Februari 2022; Dipublikasikan 30 November 2022)

Abstract

The need for a communication system with a higher data rate and mobility grows along with information and communication technology development. Combining MC-CDMA with the MIMO system and supporting the system with a good transmit diversity technique is a promising idea to provide the needed communication system, especially in high mobility conditions. MC-CDMA can support ubiquitous communications without affecting the achievable BER and is more capable of high-speed mobility. It integrates the benefit of both OFDM and CDMA. On the other hand, QO-STBC increases the bit rate without using additional bandwidth to transmit diversity in the MIMO system. So, this study proposed a system combining the MIMO MC-CDMA system with QO-STBC. The proposed system is investigated under high mobility conditions to see the system's performance. The simulation results show that our system performs better than the MC-CDMA STBC system and the QOSTBC system but not better than the MC-CDMA multilevel coding scheme. To reach the value of BER 10^{-3}, MC-CDMA multilevel Coding requires less power, around 5 dB, than the proposed system.

Keywords: Communication System, Transmit Diversity, OFDM, CDMA, MC-CDMA, QOSTBC, Rayleigh Fading

1. Introduction

As the need for communication services that provide high data rates and mobility grows, various methodologies have been studied to enhance the system's performance and overcome the problem caused by communication services that provide high data rates and mobility. Such as improving modulation technique by using multiple antennas at both transmitter and receiver, increasing, and employing modulation technique and multiple antennas simultaneously.

Several modulation techniques are commonly used, such as Orthogonal Frequency Division Multiplexing (OFDM) and Code Division Multiple Access (CDMA). The OFDM is sensitive to frequency selective fading and lacks subcarrier synchronization difficulties, frequency offset sensitivity, and non-linear amplification. Meanwhile, robustness against frequency selective fading is the CDMA's advantage. The OFDM and CDMA combination schemes, known as Multi-Carrier Code-Division Multiple Access (MC-CDMA), might not expect any synergistic effect, but those schemes have two significant advantages. First, capabilities of lowering the symbol rate in every subcarrier. Secondly, MC-CDMA can effectively combine the received signals' energy, which is spread over the frequency domain. Particularly for high-speed transmission cases, as discussed in[1].

A few studies have already proposed and developed the MC-CDMA scheme by different researchers, such as MC-CDMA [2,3], Multi-Carrier Direct-Sequence Code-Division Multiple Access (MC-DS-CDMA) [2,4] and Multitone Code-Division Multiple Access (MT-CDMA) [5,6]. Each scheme that has been proposed has for and against in spectral efficiency, transmitter, and receiver structures, and Bit Error Rate (BER) performance in the downlink. Not all of them are suitable for high mobility and data rate environment. Multiple Input Multiple Output (MIMO) MC-DS-CDMA combined with transmit diversity technique formed an optimistic multiple access scheme that effectively avoids the numerous design limitations in high mobility and data rate environments [5]. So, this study will propose a MIMO MC-DS-CDMA combined with transmit diversity technique.

Transmit diversity is a popular technique to alleviate fading impacts over a communication link. A transmit diversity scheme using two transmit antennas that offer maximum diversity gain has been proposed [7]. It has been the basis for creating Orthogonal Codes. Orthogonal codes are a space-time block code class that can achieve full diversity gain and has a simple single-symbol decoder. However, orthogonal code has a deficiency in its code rate. An orthogonal design of rate-one and full diversity cannot be constructed for more than two transmit antennas. A popular approach to overcome the problem is Orthogonal space-time block codes [8,9]. Orthogonal Space Time Block Code (OSTBC) has attracted much attention due to its Maximum-likelihood (ML) decoding and diversity [9]. Nonetheless, the OSTBC's symbol rates exponentially decrease as the transmit antenna is more than 2-Tx. To elevate the symbol rates of OSTBCs, Jafarkhani [10] and Tirkkonen-Boariu-Hottinen [11] generalized a Quasi-Orthogonal STBC (QOSTBC) by loosening the orthogonality in the columns of the design.

This study aims to develop a transmission technique that can be used to resolve the already mentioned above and investigate the system's performance in high mobility conditions. The proposed system is a MIMO MC-DS-CDMA combined with QO-STBC. Both systems are combined to create a new coding scheme without adding complexity and maintaining system performance under high mobility conditions.

The study is organized as follows; in section II, we study the proposed system and MC-DS-CDMA and QO-STBC. In section III, we will evaluate the performance of MIMO MC-CDMA combined with QO-STBC. Lastly, the summarized conclusion of this study is presented in section IV.

2. The Proposed System Model

MC-CDMA schemes can be divided into two different schemes[12]. The first is MC-CDMA, which spreads the original data using a predetermined spreading code and modulates each chip with a unique subcarrier. The second is MC-CDMA, which distributes parallel data streams using a Walsh-Hadamard code-generated spreading code and modulates a distinct subcarrier for each data stream. The second MC-CDMA system is often referred to as multi-carrier direct sequence CDMA (MC-DS-CDMA). This study will employ MC-DS-CDMA since it will be simpler to implement various orthogonal sequences.

In most cases, MC-DS-CDMA transmits T-Domain direct sequence spread signal using multiple subcarriers. The MC-DS CDMA transmitter integrates a serial-to-parallel converter, decreasing the subcarrier data rate by mapping them into several reduced-rate parallel streams[13]. The MC-DS-CDMA system makes advantage of direct sequence-based T-domain subcarrier spreading to increase the possible processing gain for each subcarrier signal. F-domain spreading across a subcarrier is utilized to increase the total processing gain that is feasible.

Furthermore, QOSTBC is a scheme proposed by Jafarkhani [10] and TBH [12] to overcome the disadvantages of OSTBC that experienced a lower code rate when a complex signal constellation and the complexity that more than 2-Tx antennas are used. When the number of antennas is 2^k, the orthogonal design of $2^k x 2^k$ in complex symbols $x_1, x_2, .. x_{k+1}$ is given by

$$G(x_1, \dots, x_{k+1}) = \begin{bmatrix} G(x_1, \dots, x_k) & x_{k+1} I_{2^{k-1}} \\ -x^*_{k+1} I_{2^{k-1}} & \left(G_{x_1, \dots, x_k}\right)^H \end{bmatrix} \qquad (1)$$

Where $G(x_1, \dots, x_{k+1})$ is an orthogonal design of $2^{(k-1)}2^{(k+1)}$ This code permits $(k+1)/2^k$ complex symbols per channel and k =1 which is compatible with the Alamouti Code.

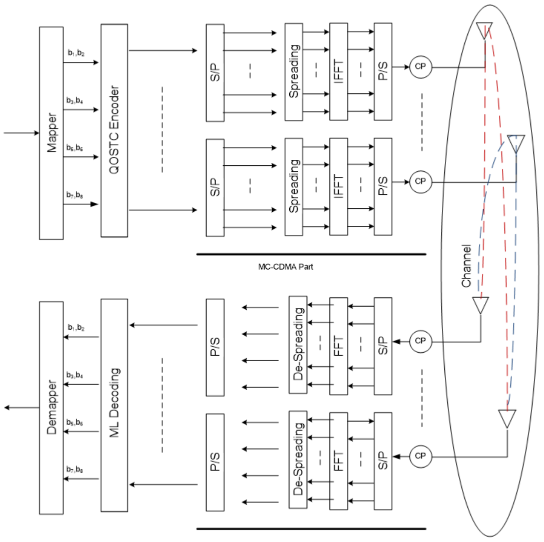

Figure 1. The proposed system of MIMO MC-CDMA with QO-STBC using spreading gain 2x

The maximum symbol rate for OSTBC with more 4-Tx antennas is $^{3}/_{4}$. For 4-Tx antennas escalating the symbol rate of OSTBC has been generalized QO-STBC [14,15]. For 4-Tx antennas, if A and B state the Alamouti Code in variable a_1a_2 and a_3a_4, respectively

$$A = \begin{bmatrix} a_1 & a_2 \\ -a_2^* & a_1^* \end{bmatrix}, B = \begin{bmatrix} a_3 & a_4 \\ -a_4^* & a_3^* \end{bmatrix} \tag{2}$$

The QOSTBC is given by [10,11]

$$C_J = \begin{bmatrix} A & B \\ -B^* & A^* \end{bmatrix}, C_r = \begin{bmatrix} A & B \\ B & A \end{bmatrix} \tag{3}$$

where X^* stands for the complex conjugate of each element matrix X. The symbol rate in both schemes is 1.

A. Multi-Carrier Code-Division Multiple Access (MC-CDMA)

Figure 1 represents the diagram of the proposed system. The input data is converted into a serial to parallel block process and multiplied with the spreading code generated by Walsh-Hadamard code afterward. After multiplied with spreading code, the output data are modulated with multi-carrier. The output of the u_{th} user signal $S_u(t)$ consists of the sum of all carriers of the u_{th} user. The sum of all the user signals is the total output $S(t)$. After high-power amplifier (HPA), the output of all signals is transmitted.

The transmitted signal following with the n_{th} data symbol of the u_{th} user is [16].

$$S_n^u(t) = \sum_{m=0}^{M-1} \sum_{o=0}^{O-1} d_m^u E_{m,q}^u \mathcal{P}_m(t - qT_c - nT) e^{j2\pi fmt} \tag{4}$$

The number of user is u , the number of carriers is m, the number of chips is q, symbol duration is T_c and equals qT_c . The spreading code's length is O. The data of m_{th} subcarrier and u_{th} user is d_m^u, root raised cosine plus of m_{th} carrier frequency is $\mathcal{P}_m(t)$. The total transmitted signal corresponds to the n_{th} data symbol of the u_{th} user, when the total number of users K is [16].

$$S_n(t) = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} \sum_{o=0}^{O-1} d_m^u E_{m,q}^u \mathcal{P}_m(t - qT_c - nT) e^{j2\pi fmt} \tag{5}$$

B. Quasi-Orthogonal Space-Time Block Coding (QO-STBC)

As shown in Figure 1, the output from the mapper taken from the user is entered into the QOSTBC encoder to construct the matrix by Tirkonnen [11]. This scheme constructs a symbol matrix using the Alamouti scheme to derive matrix $4x4$ for $4x4$ antennas, as in equation (2).

a_1, a_2, a_3, a_4 are symbol matrices which sent and introduced by Alamouti [7], then the matrix is derived using ABBA format as shown in equation (3). Matrix for $4x4$ antennas shown in the equation (5) and (6)

$$C_{4x4} = \begin{bmatrix} A & B \\ B & A \end{bmatrix} \tag{5}$$

$$C_{4x4} = \begin{bmatrix} a_1 & a_2 & a_3 & a_4 \\ -a_2^* & a_1^* & -a_4^* & a_3^* \\ a_3 & a_4 & a_1 & a_2 \\ -a_4^* & a_3^* & -a_2^* & a_1^* \end{bmatrix} \tag{6}$$

where the channel matrix of the QO-STBC scheme is shown in the equation (7)

$$H = \begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ -h_2^* & h_1^* & -h_4^* & h_3^* \\ h_3 & h_4 & h_1 & h_2 \\ -h_4^* & h_3^* & -h_2^* & h_1^* \end{bmatrix} \tag{7}$$

The non-orthonormality of TBH QO-STBC scheme is given by equation (8)

$$N = 2R_e[a_1a_3^* + a_2a_4^*] \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \tag{8}$$

The only interference is between symbols a_1, a_3, and a_2, a_4.

C. QO-STBC Decoding

This study applied the MRC technique [17] by multiplying the received signal Y with H to decode the QO-STBC,

$$R = H_v H C_{4x4} + H_v c_n = D_4 C_{4x4} + H_v c_n \tag{9}$$

The detection matrix used to decode the received signal is D_4, H_v is the hermitian of H, and c_n is the channel's noise. The detection matrix for QO-STBC in this study can be shown below [18]:

$$D_4 = H_v H = \begin{bmatrix} \alpha & 0 & \beta & 0 \\ 0 & \alpha & 0 & \beta \\ \beta & 0 & \alpha & 0 \\ 0 & \beta & 0 & \alpha \end{bmatrix} \tag{10}$$

where

$$\begin{gathered} \alpha = |h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2 \\ \beta = h_1{h_3}^* + h_2{h_4}^* + {h_1}^*h_3 + {h_2}^*h_4 \end{gathered} \tag{11}$$

Therefore to detect the estimate $\hat{R}$ are [19]:

$$\begin{gathered} \hat{R} = (H_vH)^{-1} H_v.Y = (H_vH)^{-1} H_vHR \\ +(H_vH)^{-1}H_vH_n \end{gathered} \tag{12}$$

3. Simulation Result

This study concentrated on the system's capabilities in the downlink transmission and emphasized investigating the MC-CDMA system's capabilities with QO-STBC. The purpose is to minimize the high data rate, frequency selective fading, fast fading, and power efficiency problems. We perform various scenarios to see the proposed system's capabilities in various parameter simulations. The simulation was carried out using MATLAB 2019 software. The following scenario in the study is shown in Table 1, and the simulation parameter is shown in Table 2.

Table 1. Simulation Scenario

Scenario	**Explanation**
1st Scenario	To show the proposed system's capabilities compared to the OFDM system.
2nd Scenario	To see the effect of using different MC-CDMA spreading gain in the proposed system.
3rd Scenario	To see the proposed system's capabilities in high mobility conditions using various user speeds.
4th Scenario	To see the proposed system's capabilities compared with the MC-CDMA, the MC-CDMA Multilevel Coding, and the QOSTBC system.

Table 2. Simulation Parameter

Parameter	**Value**
User Speed	60, 150, 300 km/h
Channel	AWGN, Rayleigh Fading
Mapper	QPSK
Channel Coding	Convolutional Code
Code Rate	½
Frequency	2.6 GHz
Subcarrier	256

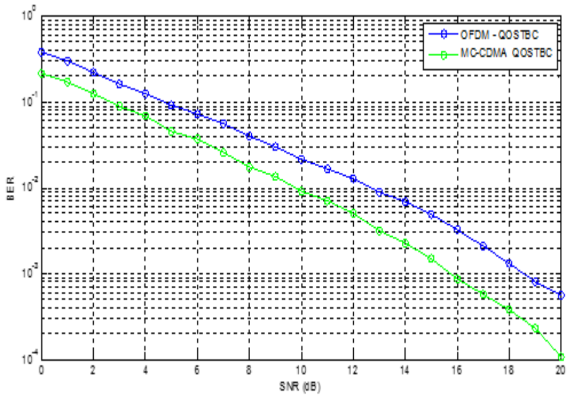

Figure 2. Simulation result between the proposed system and OFDM QO-STBC in AWGN channel

Figure 2 shows the MC-CDMA QO-STBC's simulation result compared to the OFDM QO-STBC system in Additive White Gaussian Noise (AWGN) and Rayleigh fading channel in high mobility conditions.

As shown in Figure 2, there is only a slightly different result between MC-CDMA QO-STBC and OFDM QO-STBC in the AWGN channel. To reach the value of BER 10^{-3}, the proposed system requires less power, around 3 dB, than the OFDM QO-STBC. The proposed system tends to perform better in high mobility conditions than OFDM QO-STBC because of the improvement factor from spreading code in MC-CDMA. After dividing into each subcarrier in MC-CDMA, the signal undergoes a multiplication process with the spreading code. So, with this process in MC-CDMA, the probability of signal experiencing intersymbol interference (ISI) is decreased, resulting in improved BER performance of the system.

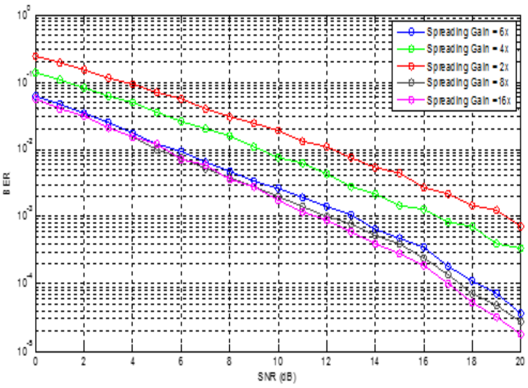

Figure 3. Simulation result of system performance with different spreading gain.

Figure 3 shows the simulation result of MC-CDMA with QOSTBC with different spreading gains. As shown in Figure 3, the system's performance improves as the spreading gain increases. However, the higher number of spreading gains lowers the system's spectral efficiency because the number of the same symbol transmitted into different subcarriers increases. The higher number of spreading gains provides a better Signal to Noise Ratio (SNR) value because the probability of the signal encounter error is negligible as the number of spreading gains increases. Moreover, as shown in the figure above, the number of spreading gains 8, 16, and 32 do not show any significant performance system changes.

So, we can conclude that MC-CDMA has reached the optimum spreading gains at the number spreading gain 8. Because the number of spreading gains 16 and 32 do not show many differences in system performance, we have to choose the number of spreading gains wisely to consider the system's spectral efficiency.

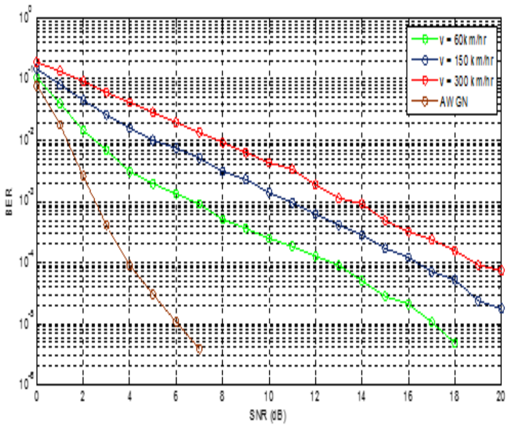

Figure 4. Simulation result of the proposed system in AWGN Channel and different user speed

Figure 4 shows the simulation result of MC-CDMA QOSTBC with different user speeds. The proposed system in the AWGN channel tends to have a better SNR value, whereas getting a BER value of 10^{-3} only requires around 3 dB of SNR. Because, in the AWGN channel, the signal is only influenced by thermal noise in the device. The signal in the AWGN Channel is considered LOS, which means that the mobile station's signal is not disturbed. AWGN channel does not account for the impairment of fading, frequency selectivity, interference, nonlinearity, or dispersion.

Figure 5 shows simulation results between the MC-CDMA scheme, QOSTBC scheme, and the proposed scheme. The simulation results above indicate that the proposed MC- CDMA QOSTBC performs better in high-speed Rayleigh fading channels than the other two schemes. The implementation of QOSTBC in MC-CDMA can reduce interference between BER symbols by minimizing the non-orthogonality of symbols and improving BER performance.

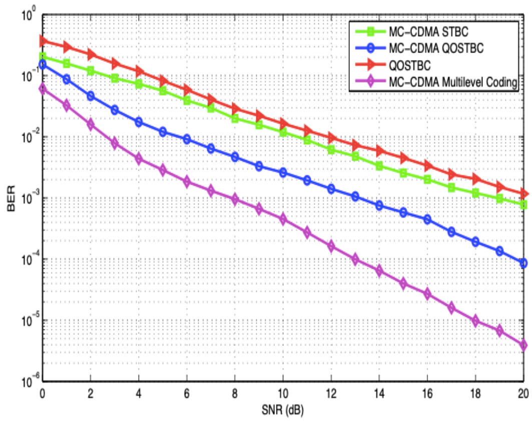

Fig 5. Simulation result of MC-CDMA STBC system, QOSTBC Scheme, MC-CDMA Multilevel Coding, and the proposed system in Rayleigh Fading Channel.

The performance of multilevel MC-CDMA [12] is better than the proposed system. To reach the value of BER 10^{-3}, MC-CDMA multilevel Coding requires less power, around 5 dB, than the proposed system. MC-CDMA multilevel coding tends to perform better than the proposed system because of DUSTFM. The unitary code from DUSTFM was mapped in time, space, and frequency and combined with symbol detection to separate the symbol from different transmitters resulting in good resistance to error rather than the proposed system. However, MC-CDMA multilevel coding has higher decoding complexity than the proposed system, which should be considered implemented.

4. Conclusion

The first simulation result shows that the proposed system performs better in high mobility conditions than OFDM QO-STBC because of the improvement factor from spreading code in MC-CDMA. The spreading gain 8 reaches the optimum spreading gain used for MC-CDMA and provides better SNR at 13 dB to reach the value of BER 10^{-3} in the second scenario. The number of spreading gains must be chosen wisely due to the spectral efficiency problem. From the result of various scenarios that were already done, we can conclude that the proposed system generally maintained a better performance than other schemes except for the MC-CDMA Multilevel Coding scheme in the simulation. The combination between MC-CDMA and QOSTBC system can be more investigated in high mobility conditions.

5. References

[1] Abidur Rahman, H. M., Hasan, F., Hoque, Md. M., Rahman, Md. M., and Rahman, Md., WMC-CDMA System for Multi-User Using Walsh Code on Rayleigh Fading Channel, in 5th International Conference on Electrical Engineering and Information Communication Technology (ICEEICT), 2021, pp. 1-5.

[2] Lee, Y. Performance Analysis of DS-CDMA and MC-CDMA Systems, in 9th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON), 2018, pp. 842-846.

[3] Sakib, Md. S. and Ferdous, Md. R., Performance evaluation of MC-CDMA system for the next generation wireless networks, International Conference on Innovation in Engineering and Technology (ICIET), 2018, pp. 1-5.

[4] Wu, K. , Cosman, P. C. , and Milstein, L. B. , Multicarrier DS-CDMA System Under Fast Rician Fading and Partial-Time Partial-Band Jamming, IEEE Transactions on Communications, **67**(10), pp.7183–7194, 2019.

[5] Li, K. and Darwazeh, I. System performance comparison of fast-OFDM with overlapping MC-DS-CDMA and MT-CDMA systems, in 6th International Conference on Information, Communications & Signal Processing, 2007, pp. 1-4.

[6] Enayati, A. R. and Salahi, A., A novel bandwidth efficient channel coding scheme for S/P-Replica MT-CDMA systems, IEEE International Symposium on Wireless Communication Systems, 2008, pp. 290-294.

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

[8] Larsson, E. G., Stoica, P., and Ganesan, G., Space-time block coding for wireless communications, Cambridge University Press, 2003.

[9] M. K., A., OSTBC Transmission in Large MIMO Systems, IEEE Communications Letters, **20**(11), pp.2308–2311, 2016.

[10] Jafarkhani, H., A quasi-orthogonal space-time block code, IEEE Transactions on Communications, **49**(1), pp.1–4, 2001.

[11] Tirkkonen, O., Boariu, A., and Hottinen, A., Minimal non-orthogonality rate 1 space-time block code for 3+ Tx antennas, IEEE Sixth International Symposium on Spread Spectrum Techniques and Applications. ISSTA, 2000, pp. 429-432 vol.2.

[12] Astuti, R. P., Suksmono, A. B., Sugihartono, and Kurniawan, A., A Novel MC-CDMA Multilevel Coding Scheme on High Data Rate MIMO-Wireless Communication Systems, IFIP International Conference on Wireless and Optical Communications Networks, 2007, pp. 1-5.

[13] Shahbaztabar, D. , Alirezaee, S. , Ahmadi, M. , and Heydari, R. , A MC-CDMA system based on orthogonal filter banks of wavelet transforms and partial combining, AEU - International Journal of Electronics and Communications, **94,** pp.128–138, 2018.

[14] Park, U. , Kim, S. , Lim, K. , and Li, J. , A novel QO-STBC scheme with linear decoding for three and four transmit antennas, IEEE Communications Letters, **12**(12), pp.868–870, 2008.

[15] YODA, N. , AHN, C.-J. , and HASHIMOTO, K. , Single Symbol Decodable QO-STBC with Full Diversity, IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences, **E97.A**(1), pp.2–6, 2014.

[16] Goldsmith, A., Wireless communications, Cambridge University Press, 2005.

[17] Dama, Y. A. S., Abd-Alhameed, R. A. , Ghazaany, T. S. , and Zhu, S., A new approach for OSTBC and QOSTBC, International Journal of Computer Applications, **67**(6), 2013.

[18] Jeong, J. J. , A Minimum Mean-Square-Error (MMSE) Decoder for Quasi-Orthogonal Space–Time Block Code, Electronics, **8**(7), pp.732, 2019.

[19] Park, U. , Kim, S. , Lim, K. , and Li, J. , A novel QO-STBC scheme with linear decoding for three and four transmit antennas, IEEE Communications Letters, **12**(12), pp.868–870, 2008.