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Performance analysis of coded MIMO OFDM with subcarrier power modulation

Amneen Naji Fadhel[1], Yahya Jasim Harbi[2]
[1]Department of Electronic and Communications Engineering, College of Engineering, University of Kufa, Najaf, Iraq
[2]Department of Electrical Engineering, College of Engineering, University of Kufa, Najaf, Iraq

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ABSTRACT

This study investigates a new technique known as orthogonal frequency division multiplexing with subcarrier power modulation (OFDM-SPM) when compounded with a multiple-input multiple-output (MIMO) system. This combination of the two wireless technologies offers additional benefits and characteristics, such as increased spectrum efficiency (SE), increased energy efficiency (EE), and decreased transmission latency, among others. However, as compared to a traditional MIMO-OFDM system, the system's bit error rate (BER) show degradation. In this paper, turbo code is proposed as a coding technique to enhance the system performance with three-power reallocation policies (PRPs). The simulation results show that the BER and throughput performance has gotten better, where the throughput is doubled and the BER achieves about 10 dB gain by utilizing the proposed methods and compare to the classical MIMO OFDM, which makes the system more suitable for use in future wireless systems.

Corresponding Author:

Amneen Naji Fadhel
Department of Electronics and Communication, Faculty of Engineering, University of Kufa
Najaf, Iraq
Email: amneenn.almashhadi@student.uokufa.edu.iq

1. INTRODUCTION

The field of mobile wireless communication networks has been rapidly expanding in recent years. Wireless communication became more powerful, enabling the development of multiple successive generations of cellular telephone technologies, which are today utilized by people all over the world. The evolution of mobile wireless communication has extended several generations. Starting with the first generation (1G) until now where the fourth generation (4G) is still used due to its fast and reliable data transmission. However, the new generations of wireless networks such as 5G and 6G support some applications and features that 4G seems unable to meet [1]–[5].

MIMO-OFDM is a technique that has been used in the past generation of mobile networks [6]–[9]. The success of this technology is due to the many features and advantages that it offers, such as effective usage of bandwidth (BW), overcoming the problems of inter-carrier interference (ICI), inter-symbol interference (ISI), and reducing the complexity of the system. However, this technique comes with a cost when trying to send more information (such as a high throughput for 5G), where the results show a noticeable degradation in the system performance in terms of throughput, bit error rate (BER), and complexity [10]. With this intention, the developers have been motivated to develop a lot of schemes and technologies to cope with the aforementioned limitations.

Orthogonal frequency division multiplexing with subcarrier power modulation (OFDM-SPM) is a new method developed by [11], [12] to enhance the OFDM system. It stands for orthogonal frequency division multiplexing with subcarrier power modulation. It's presented as a powerful technique to improve and enhance the OFDM system. The authors implement this scheme with Q-PSK modulation in additive white Gaussian noise (AWGN) and Rayleigh fading channels. The simulation results showed that the system has come with a lot of advantages that included improving system spectral efficiency (SE), reducing power consumption to half, and reducing the complexity of the system. The system use half number of subcarrier compare to the classical OFDM system for the same number of bits. This feature reduces the complexity by reducing the inverse fast fourier transform (IFFT) size and saving half of the power for the system to utilize in different applications. Hence, increasing the energy efficiency (EE) and BW efficiency of the system. From that point forward, the system was adopted in many other technologies.

Hamamreh and Abewa [13], [14] used the OFDM-SPM with non-coherent modulation to meet the requirements of IoT applications and make a trade-off between coherent and non-coherent modulation. On the negative side of this scheme, it suffers from a high BER. Hijazi and Hamamreh [15] suggested signal space diversity as a solution to enhance the system performance through the Rayleigh fading channel where they achieve a gain of more than 5 dB. Abuqamar *et al.* [16] suggested using Alamouti space-time block coding in a multiple-input-single-output over a multipath Rayleigh fading channel to enhance the throughput and BER performance.

In this paper, MIMO OFDM-SPM is proposed with coding technique to enhance both BER and the throughput of the system. In addition, to take advantage of the saved power, three power reallocation policies (PRPs) are evaluated. Before the modulation process, channel coding will be employed to achieve low BER. The creation of channel coding was driven by Shannon's theory [17], which states that the coding approach allows for low BER values. In the last 70 years, a variety of error coding systems have been invented, including turbo code [18]–[21]. In this paper, turbo code is recommended to enhance the system's performance. The remainder of this work is divided into the following sections: 1. Introduction, 2. The system design model, 3. Result and discussion, 4. Conclusion.

2. SYSTEM DESIGN MODEL

2.1. Transmitter design

Figure 1 shows the transmitter design for the proposed scheme. Two antennas are used in both the transmitter and receiver sides, where each antenna transmits the signal through coded OFDM-SPM. The incoming bits go through the encoder, and a turbo code is suggested with 4 number iterations and 1/3 code rate, due to its outstanding features to enhance the performance in a unique way [22]. The modulation step comes after encoding. The incoming bits will be split into two groups. The first one uses power modulation, which gives the bits high and low power levels depending on their values. The high power level for a bit with a value equal to ‘1’ and the low power level for a bit with a value equal to ‘0’. The amplitude of the high and low power levels can be counted by trial and error. The second group transmits using classical modulation such as QPSK. After that, the bits of each group will be assigned together to complete the steps of OFDM, such as IFFT, adding cyclic prefix (CP), and digital to analog converter (DAC) [23], [24]. The value of low power level (L) can be found according to (4) and after knowing the high power level (H) value.

Our design will consist of using three PRPs as shown in Table 1, where each policy differs from another one by energy ber bit ($\mathcal{E}_b$) and Euclidean distance (ED), where the ED (1) can be defined as the shortest distance between two points [25], [26]. It is also defined as a technique to reuse the saved power to enhance system performance or be used for carrying extra data bits. This gives the system more options for how to use the saved power and makes it better for the next generations of wireless systems.

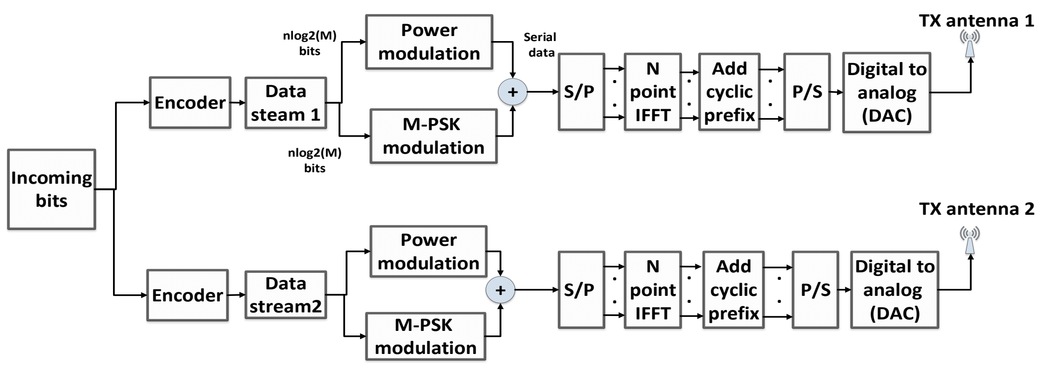

Figure 1. Transmitter design for MIMO OFDM-SPM with turbo code

$$d_{min} = \sqrt{2\log_2 \, M\mathcal{E}_b} \quad (1)$$

$$L^2 + H^2 = d_{min}{}^2 \quad (2)$$

$$L^2 + H^2 = 2\mathcal{E}_b \quad (3)$$

$$L = \sqrt{2\mathcal{E}_b - H^2} \quad (4)$$

Table 1. Definition of the PRPs that are used in the profposed system with their values and equations

Power reallocation policies	Definition	High and low power level equations	Values of H and L used in simulation results
Policy 1	Half of the power saved (2 E_b)	$L^2 + H^2 = 2\mathcal{E}_b$	H = 1.345 L = 0.421
Policy 2	E_b is equal to QPSK (4 E_b)	$L^2 + H^2 = 4\mathcal{E}_b$	H = 1.918 L = 0.566
Policy 3	E_b is equal to 16QAM (8 E_b)	$L^2 + H^2 = 8\mathcal{E}_b$	H = 2.7 L = 0.843

2.2. Receiver design

Figure 2 shows the block diagram of the receiver side. The signals from each antenna have arrived, and it goes through the steps of OFDM that include analog to digital converter (ADC), removing CP, fast fourier transforms (FFT), and MIMO detection. Next, the received bits will be split into two groups as mentioned in the transmitter. In the first group for power detection, which uses threshold point 'T' as in (5), if the received bits are larger than 'T', it is considered as '1' and vice versa. After that, the signals go through the decoding step. Finally, the bits are received and the errors between the transmitted and received bits are calculated.

$$\mathrm{T} = \left(\frac{\mathrm{L+H}}{2}\right)^2 \quad (5)$$

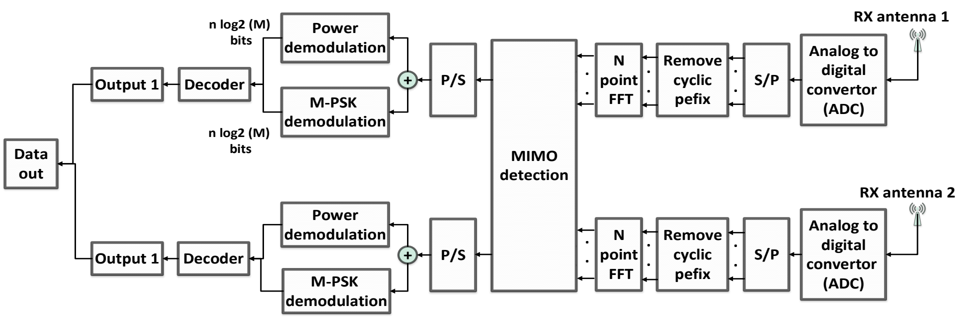

Figure 2. Receiver design for MIMO OFDM-SPM with decoder

3. RESULTS AND DISCUSSION

In the section, the simulation results for the proposed MIMO OFDM-SPM in terms of BER and throughput through the Rayleigh fading channel are demonstrated. The simulation results are for one antenna while the second one achieves the same performance. Table 2 shows the LTE parameters that were used in the proposed system.

Table 2. Simulation parameter used in the MIMO OFDM-SPM with turbo

Parameter	Value
Modulation type	QPSK
IFFT/FFT size	64
CP guard interval	16
Number of the total number of subcarriers (used +unused)	64
Bandwidth	20 MHz
Number of OFDM symbols to transmit	3 x 10^4
Multipath channel delay samples locations	[0 30 70 90 110 190 410]
Multipath channel tap power profile	[0 -1 -2 -3 -8 -17.2 -20.8]

3.1. Throughput

Throughput or SE is a critical aspect to consider while evaluating the performance of a modulation system. MIMO OFDM-SPM is an attractive option in terms of SE. In this section, the discussions of comparing the throughput of MIMO OFDM-SPM with and without turbo code and with classical MIMO OFDM are evaluated.

Policy 1: Figure 3 illustrates the throughput performance of coded MIMO OFDM-SPM. At 14 dB, it reaches 4 (bps/subcarrier) compare for 2 (bps/subcarrier) for classical MIMO OFDM with QPSK. This improves that using SPM in any system leads to enhancing the throughput performance by double compared to QPSK modulation. On the other hand, it reaches 4 (bps/subcarrier) at 12 SNR for classical MIMO OFDM with 16-QAM. After using turbo code, the throughput reaches 4 (bps/subcarrier) at almost 6 dB. Generally, using turbo code with MIMO OFDM-SPM in policy 1, make the system achieves a gain of about 8 dB when compared to MIMO OFDM-SPM without coding.

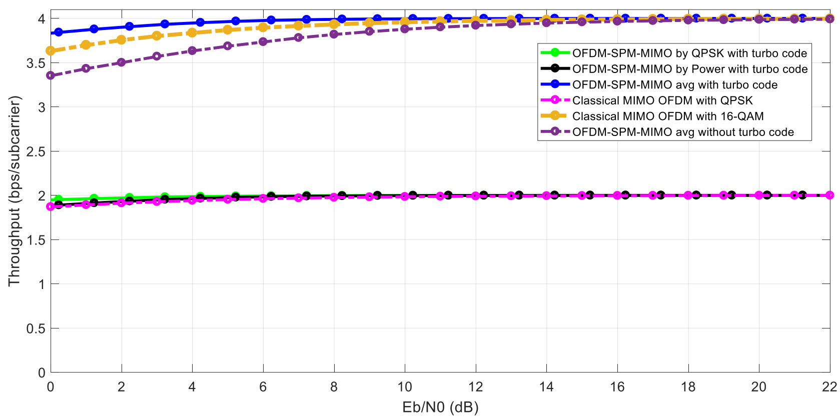

Figure 3. Throughput for coded MIMO OFDM-SPM in policy 1

Policy 2: In this scheme, the saved power is reused to enhance the system's performance. Figure 4 shows that the throughput of MIMO OFDM-SPM reaches 4 (bps/subcarrier) at 12 dB. It is clear from the Figure that using policy 2 without additional methods or techniques will enhance the system performance appropriately compared to the throughput of policy 1 without using turbo code. In addition, using turbo code with this scheme will also improve the system throughput performance, in which it reaches 4 (bps/subcarrier) at almost 3 dB, and enable the system to achieve a gain of about 9 dB.

Policy 3: In this policy, the result is compared with classical MIMO OFDM with 16-QAM as mentioned above. Figure 5 illustrates the BER performance for MIMO OFDM-SPM when compared with classical MIMO OFDM with QPSK and 16-QAM. The simulation platforms show that MIMO OFDM-SPM using policy 3 achieves throughput values almost the same as MIMO-OFDM with 16-QAM at high SNR. However, MIMO OFDM-SPM acquires a better performance at low SNR values. After using turbo code, the simulation results display that the system performance improved spectacularly, in which the throughput achieves 4 (bps/subcarrier) at all SNR values and a gain of about 10 dB compared to MIMO OFDM-SPM without turbo code.

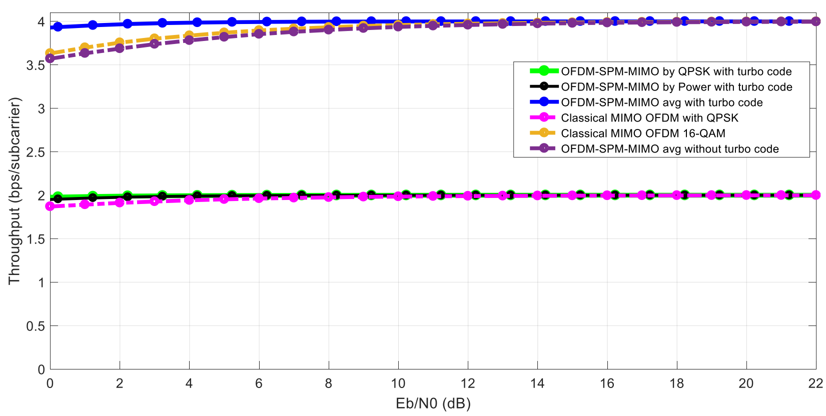

Figure 4. Throughput for coded MIMO OFDM-SPM in policy 2

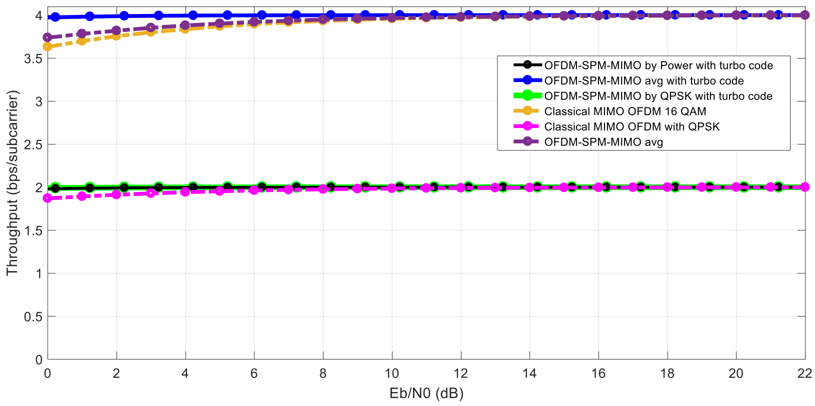

Figure 5. Throughput for coded MIMO OFDM-SPM in policy 3

3.2. Bit error rate (BER)

Evaluating the BER performance of the system is a convenient technique to measure the reliability of the system. In this section, comparing the BER of coded MIMO OFDM-SPM. With MIMO OFDM-SPM without turbo code and classical MIMO OFDM are demonstrated.

Policy 1: In this policy, the BER of MIMO OFDM-SPM shows a noticeable degradation in the performance when compared with classical MIMO OFDM, It reaches 10^{-2} BER at 15 dB compared to 9 dB for classical MIMO OFDM with QPSK and 14 dB for 16-QAM for the same value of BER. With this intention, using turbo code will improve the system's performance as shown in Figure 6. It reaches 10^{-2} BER at 5 dB, which makes the system achieve a gain of about 10 dB compared to the proposed scheme without turbo and a 9 dB gain compared to classical MIMO OFDM with 16-QAM. Also, it earns a 4 dB gain compared to classical MIMO OFDM with QPSK.

Policy 2: In this policy, the BER reaches 10^{-2} at 12 dB compared to 9 dB for classical MIMO OFDM with QPSK and 14 dB for 16-QAM. In this case, the BER reduce compared to MIMO OFDM-SPM in policy 1. It achieves a gain of about 3 dB without using any additional methods. However, it still shows degradation compared to classical MIMO OFDM with QPSK of about 3 dB. In the meanwhile, using turbo code as in Figure 7 will enhance the system BER performance. It reaches 10^{-2} at 1.5 dB, which enables the system to achieve a gain of about 10.5 dB compared to MIMO OFDM-SPM and almost 12.5 and 7.5 dB gains compared with classical MIMO OFDM with 16-QAM and QPSK respectively.

Policy 3: In this policy, the results compare to the BER of classical MIMO OFDM with 16-QAM, It is clear from Figure 8 that the proposed system performance is better than classical MIMO OFDM with 16-QAM. It reaches 10^{-2} at 9 dB compared to 14 dB for classical MIMO OFDM with 16-QAM, which enables the system to achieve a gain of about 3dB. In addition, it almost has the same performance as MIMO OFDM with QPSK. In contrast, utilizing the turbo code with this policy enables the proposed scheme to enhance the BER uniquely. It begins with a BER value below 10^{-2} and reaches 10^{-3} at 5 dB. Accordingly, it enables the proposed scheme to achieve a gain of about 9 dB compared to the scheme without turbo code and 14 and 9 dB gains compared to classical MIMO OFDM with 16-QAM and QPSK respectively.

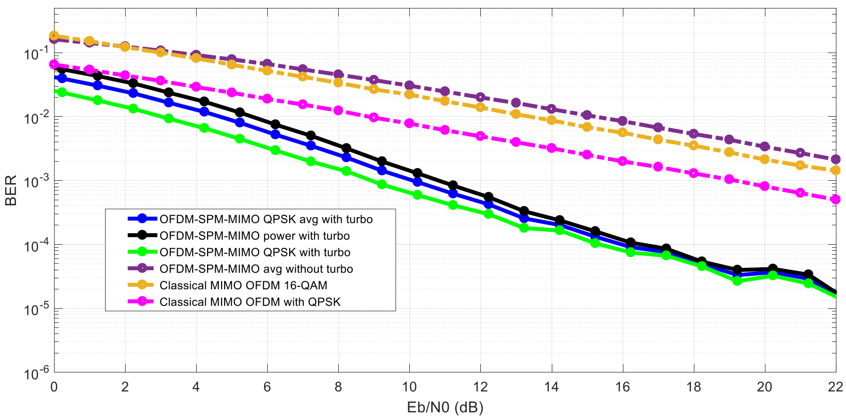

Figure 6. BER for coded MIMO OFDM-SPM in policy 1

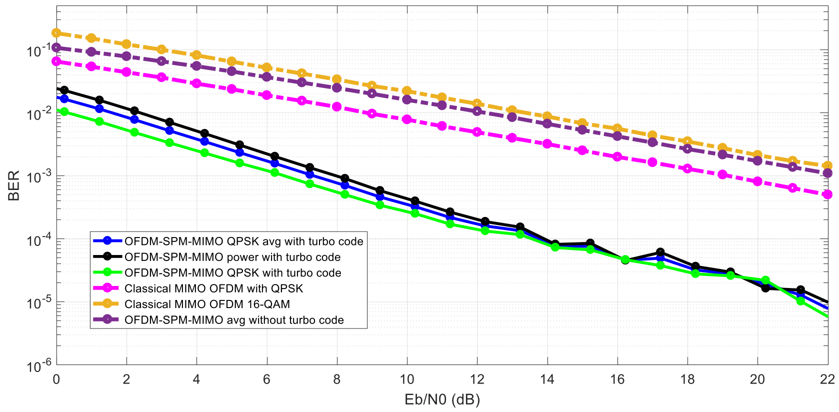

Figure 7. BER for coded MIMO OFDM-SPM in policy 2

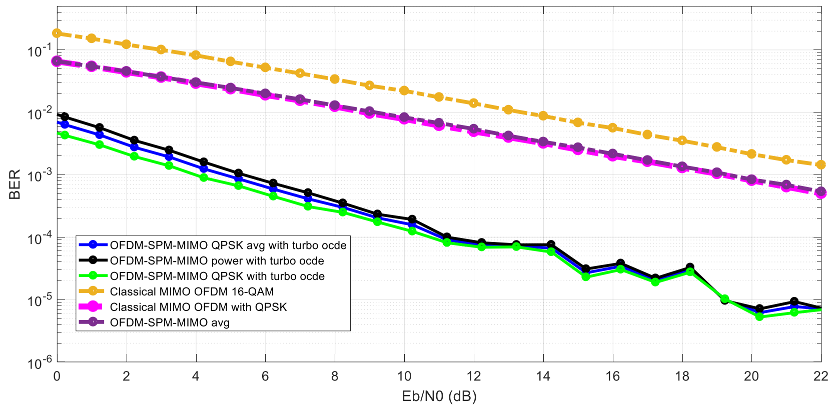

Figure 8. BER for coded MIMO OFDM-SPM in policy 3

4. CONCLUSION

In this paper, the performance of the combination of MIMO-OFDM while using SPM with turbo code has been investigated. Also, the simulation results were discussed while using three PRPs. In policy 1, the throughput reaches 4 (bps/subcarrier) at 6 dB compared to 14 dB for the proposed scheme without using turbo code. Furthermore, it achieves more than 10 dB gain for the BER compared with MIMO OFDM-SPM without turbo code. Policy 2 achieves 4 (bps/subcarrier) at 3 dB compared to 12 dB for the proposed scheme without turbo code. Furthermore, it achieves a 10.5 dB gain for the BER compared to MIMO OFDM-SPM without turbo code. Finally, in policy 3, where the saved power is reused as the power used in the 16-QAM, it shows spectacular improvements in the throughput, which achieves 4 (bps/subcarrier) at all the values of SNR and the BER achieves 10^{-3} at 5 dB and a 9 dB gain compared to MIMO OFDM-SPM without turbo code. All the features that the system provides make it more suitable for high throughput applications such as IoT applications, telemedicine, virtual reality, and future wireless systems such as 5G and 6G. Also, using the saved power of the system with turbo code improves the BER and throughput system performance uniquely.

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BIOGRAPHIES OF AUTHORS

Amneen Naji Fadhel received the B.Eng. degree in the Department of Electronic and Communication Engineering, Kufa University, Najaf, Iraq, in 2019. She is currently an M.Sc. student in the last stage at the Department of Electronic & Communication Engineering, Kufa University, Najaf, Iraq. Her current research interests are in the area of mobile communication, OFDM, channel coding, and MIMO systems. She can be contacted at email: amneen.almashhadi@gmail.com.

Yahya Jasim Harbi received the B.Sc. and M.Sc. degrees in electrical engineering from the University of Baghdad, Iraq, in 2000 and 2002, respectively, and the Ph.D. degree in electronics engineering from the University of York, U.K., in 2017. He has been a Lecturer with the University of Kufa, Iraq, since 2004. His research interests are in wireless systems, iterative technique, MIMO and massive MIMO systems. He can be contacted by email: yahyaj.harbi@uokufa.edu.iq.