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5G Performance Enhancement Utilizing Adaboost Technique

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ABSTRACT

In this paper, the AdaBoost algorithm is involved in modulation techniques, as it works on improving the bit error rate (BER). Inputting a noisy signal received from a sender into AdaBoost yields the original signal after removing noise. This is done through the reconstruction of the constellation diagram of the modulation technique, by eliminating the noise filling the data's signal space. The AdaBoost algorithm is then added to the fifth generation (5G) mobile systems such as orthogonal frequency division multiplexing (OFDM) and multiple input multiple output OFDM (MIMO-OFDM). It is utilized to enhance the BER performance of the entire system in the presence of different estimation techniques such as Least Squares (LS), Least Mean Squares (LMS) and Recursive Least Squares (RLS) and for different modulation techniques such as 256 Quadrature Amplitude Modulation (QAM) and 1024 QAM in a Rayleigh fading environment. The obtained results revealed that the highest value of enhancement for the OFDM system is 2 dB, which comes from using both RLS and LS technique with 1024QAM modulation. Also, the highest values of enhancement for the MIMO-OFDM system is 1.9 dB and 2 dB which comes from using LS technique with both 256QAM and 1024QAM modulation.

1. Introduction

Lots of research has been carried out on 5G networks, in recent years. As per 3rd Generation Partnership Project (3GPP), ultra-reliable and low-latency communications (URLLC) are among the services that 5G mobile networks are expected to support, along with massive machine-type communications (mMTC) and enhanced mobile broadband (eMBB). Another important service that should be supported by 5G networks is enhanced vehicle-to-everything (eV2X). These types of service require high throughput, better spectrum efficiency (SE), and massive connectivity. Upon designing 5G networks, this type of applications should be considered, as they require certain preparations to avoid the challenges imposed by these new types of services. As such, research is currently focused on new modulation and multiple access (MA) schemes [1]. Currently, fourth generations (4G) systems

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provide the necessary infrastructure for fast data services, as opposed to previously employed systems.

However, services expected to be needed in societies of the future require a higher level of efficiency, which should be accommodated by 5G new radio (NR) systems [2]. When designing 5G NR networks, waveform is of major importance. Thus, a better OFDM-based waveform having a flexible framework is suggested for adoption in the design of such networks [2]. These OFDM systems have different factors affecting performance degradation, employed in system recognition. However, the most important of these factors are channel estimation (CE) and compensation [3]. To perform CE, pilot signals are inserted on OFDM symbols. Different types of interpolation have been applied to the conventional channel estimation techniques (least squares (LS) and minimum mean square error (MMSE)) for improved performance [4]. However, it is difficult to achieve perfect CE, as pilots are usually contaminated with noise at the receiving end. On another note, even if an optimum CE technique is employed, channel compensation causes the maximization of the receiving noise. Also, upon demodulation, the sensitivity of noise increases, depending on the condition of the channel.

From this concept, the Adaptive Boosting (AdaBoost) algorithm spun [5,6]. It is the first of its kind, and remains in use, under study, and involved in practical applications in various fields to this day. This research uses the AdaBoost algorithm to enhance the BER of various channel estimation techniques, such as the Least Squares (LS), Least Mean Squares (LMS) and Recursive Least Squares (RLS). The adaptative boost, or AdaBoost, algorithm is a boosting ensemble technique that is predicated on the idea that students grow in steps. Additionally, each instance with erroneously classified instances receives a new assignment of weights with higher weights. Apart from its speed, simplicity, and ease of programming, AdaBoost stands out for its ability to be combined with any machine learning (ML) algorithms. Nevertheless, it has a high sensitivity to noisy data. Yan *et al.,* [7]. More details of using the AdaBoost algorithm in MIMO wireless systems can be found in reference [8], where the AdaBoost ML mode helps in decreasing the Signal-to-Noise Ratio (SNR) of the system.

The AdaBoost algorithm is added to enhance the BER performance in a Rayleigh fading environment. The technique allows benefiting from its learning capabilities as a machine learning algorithm in overcoming the effect of noise and fading channel on the received signals. The application of AdaBoost helps detect the various characteristics of a signal, as it recovers the originally sent data from the received signal, containing noise. The result is an improvement in BER. This algorithm is well known in the field of image processing and feature recognition and the novelty of this paper is the application of this algorithm in the field of wireless communication and transmitted signals. This application has many benefits, seen in its boosting capabilities, leading to an improvement in the results reached.

2. OFDM System Model

OFDM technology has certain characteristics, which help it in transmitting signals through wireless channels. Among these characteristics, there are the low cost of implementing its transceivers, its high efficiency from a spectral standpoint, its feasibility, and its robustness in frequency selective fading [9].

A special case of multi-carrier transmission is the OFDM system. In this system, a number of low-rate subcarriers are used to transmit a single data stream. OFDM is based on the idea of obtaining a number of orthogonal subcarriers from splitting the entirety of the transmission bandwidth. Thus, the parallel transmission of symbols is done over these subcarriers. Many communication standards, such as wireless local area networks (LANs), digital radio broadcasting, and digital terrestrial television (DTT), are based on OFDM [10]. Figure 1 shows a diagram for the OFDM transceiver system.

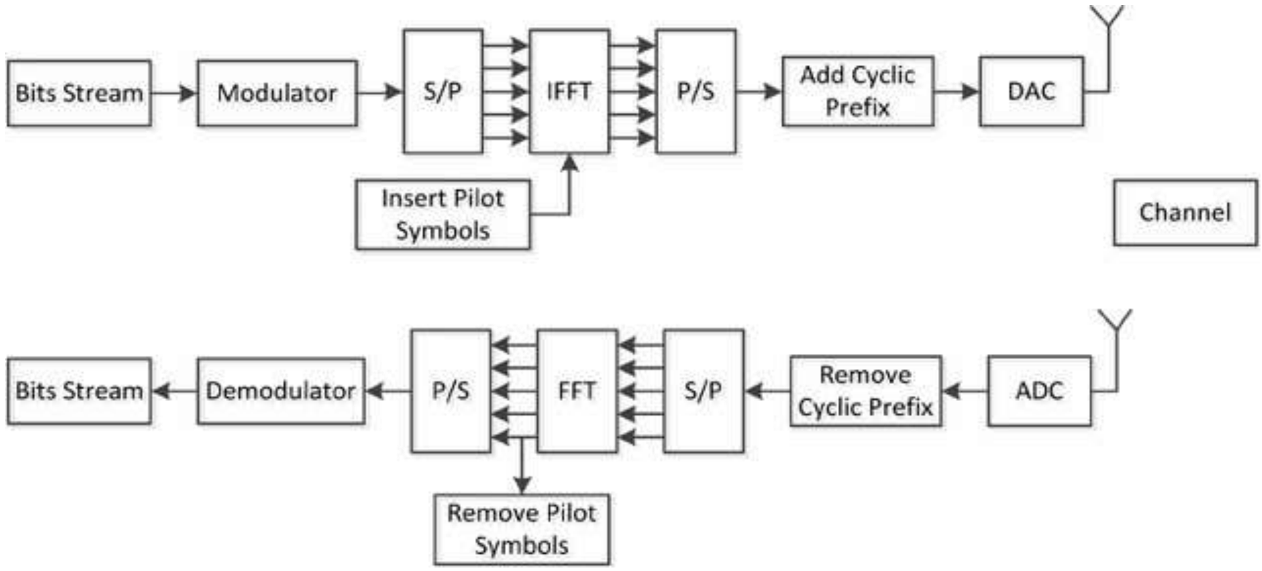

Fig. 1. Block diagram of an OFDM system [11]

3. MIMO-OFDM System Model

In 4G and 5G wireless communication, MIMO-OFDM is the most dominant of the air interfaces [12-14]. This is a combination of two technologies MIMO and OFDM, where the former transmits different signals through multiple antennas to multiply capacity. As for the latter, it aims for reliable communication over high speed. Thus, it divides a radio channel into a large number of sub-channels, in close proximity to one another. MIMO-OFDM has many advantages. It offers the highest capacity and data throughput, as it realizes the highest spectral efficiency. As such, it is considered the origin of advancement in wireless local area and mobile broadband networks. MIMO was first invented by Greg Raleigh in 1996. This was done by proving that different data streams could be sent over the same frequency at the same time. To achieve this, the advantage of the ability of signals to bounce off objects, including the ground, and reach the receiver through different paths, was put into consideration [15].

This means that different paths could be used for the transmission of data streams, through the use of multiple antennas and by pre-coding data. Raleigh's study of MIMO continued and he reached the conclusion that OFDM modulation would be highly efficient for use with MIMO at high speed. This is due to the fact that OFDM is able to use a number of lower-speed channels, parallel in their setup after their conversion from high-speed data channels. Combining MIMO and OFDM in a single process leads to powerful results. This is because MIMO does not work on the mitigation of multipath propagation, while OFDM stays away from signal equalization. Even in the case of absence of channel state information (CSI) in the transmitter, MIMO-OFDM is able to reach extremely high spectral efficiency. In the presence of a transmitter's CSI, which can be reached through the application of training sequences, the theoretical channel capacity can be used. The architecture of a MIMO-OFDM system is illustrated in Figure 2 [16].

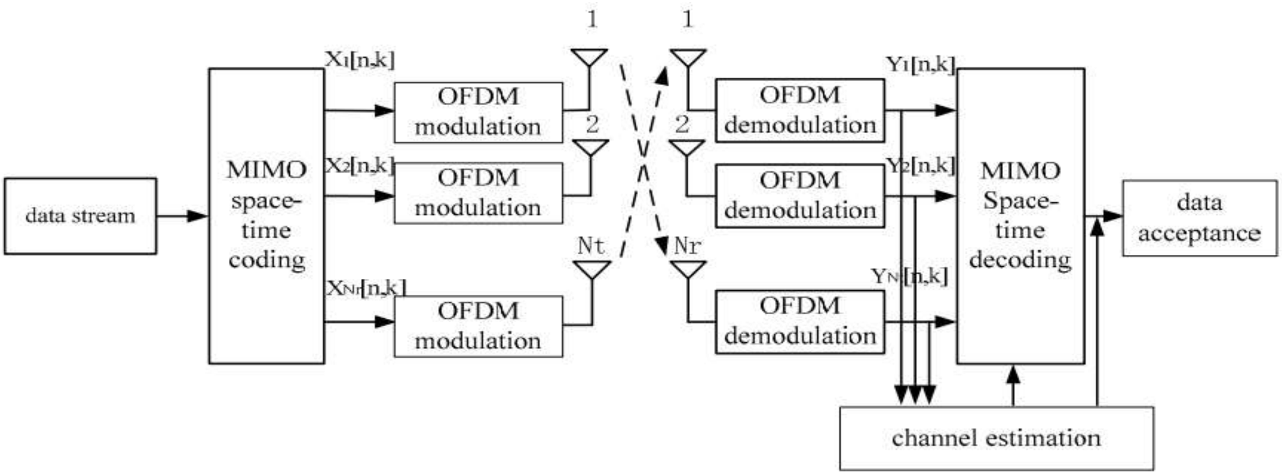

Fig. 2. Architecture of a MIMO-OFDM system

4. AdaBoost Algorithm

xi :the input (predictor variable)
ci :output (response variable)
w_i :observation weights
n: number of samples
M: number of iterations
T(x): weak classifier
$err^{(m)}$: error rate
α(m): weight assigned to classifier
C(x): final classification rule
K: number of classes (1,2,…,k)

As shown in algorithm 1 (Eq. 1) steps, first the weight (w_i) of all samples is initialized, meaning that it is equal for all the samples:

i. Initialization of the observation weights $w_i = 1/n$, i = 1, 2, ..., n.

Secondly, a number of iterations (M) is performed, where it goes through all possible weak classifiers to find the best one. That is which will minimize error rate with respect to w_i.

ii. For m = 1 to M:

(a) Fitting a classifier $T^{(m)}(x)$ to the training data using weights w_i.
(b) Calculate

$$err^{(m)} = \sum_{i=1}^{n} w_i \mathbb{I}\left(c_i \neq T^{(m)}(x_i)\right) / \sum_{i=1}^{n} w_i \quad (1)$$

The error rate $err^{(m)}$ is the summation of the previous process for all the number of samples

(c) Compute (Eq. 2)

$$\alpha^{(m)} = \log \frac{1 - err^{(m)}}{err^{(m)}} + \log(K - 1) \quad (2)$$

A weight α(m) is assigned to the classifier, the term log(K-1) is added to consider the number of classes in this algorithm as it is a multiclass algorithm.

(d) Set (Eq. 3)

$$w_i \leftarrow w_i \cdot \exp\left(\alpha^{(m)} \cdot \mathbb{I}\left(c_i \neq T^{(m)}(x_i)\right)\right), i = 1, \ldots, n \quad (3)$$

The weight w_i is then updated where the wrongly classified samples will have more weight.

(e) Re-normalization of w_i.

5. Simulation Results

In this section, the simulation results are presented after adding the AdaBoost to the 5G mobile systems such as the OFDM and the MIMO-OFDM. The results are presented in the form of a comparison between the BER curves of the system with and without the AdaBoost algorithm. The system is simulated for different modulation techniques such as 256QAM and 1024QAM in a Rayleigh fading environment.

5.1. OFDM Simulation Results

As seen from Figure 3, the system simulated is an OFDM system using a 256QAM modulation technique using RLS channel estimation. It is simulated in a Rayleigh fading environment. The Fast Fourier Transform (FFT) size is NFFT =1024, the number of frames=15, the number of pilot carrier is Np = 3, number of taps=20 and number of AdaBoost classifiers =10. After adding the AdaBoost technique to the system, the BER curve showed a better result than the system without the AdaBoost. It is also shown that even when compared with the RLS system in Rayleigh fading channel, it showed a better result. At signal to noise ratio (SNR) = 5 dB, the AdaBoost simulated system showed an enhancement in results of about 1.9 dB and at SNR of 21 dB, the enhancement is about 0.9 dB. After that, starting from SNR of 25 dB to 50 dB, the two curves coincide with each other in a perfect match.

In Figure 4, the same system is simulated but using LMS channel estimation. It is seen that the AdaBoost shows a better performance than the LMS. At SNR = 5 dB, there is an enhancement of about 1.9 dB while at SNR of 21 dB, the amount of enhancement is equal to 1.3 dB. Similar to the RLS system, starting from SNR of 25 dB to 50 dB, the two curves coincide with each other.

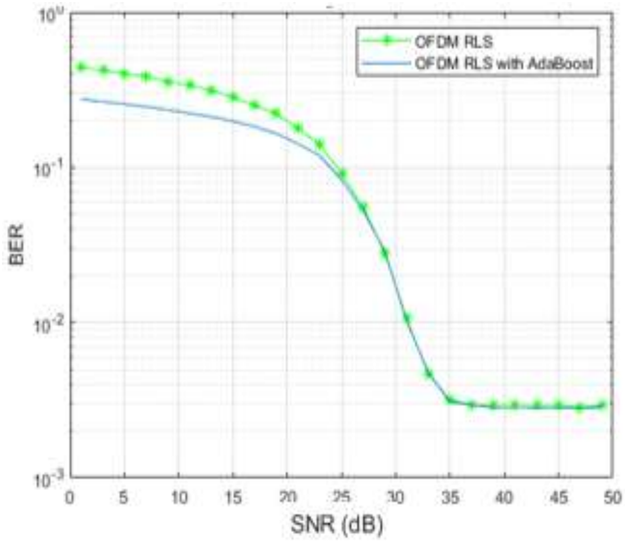

Fig. 3. BER vs. SNR for 256 QAM OFDM system using RLS channel estimation

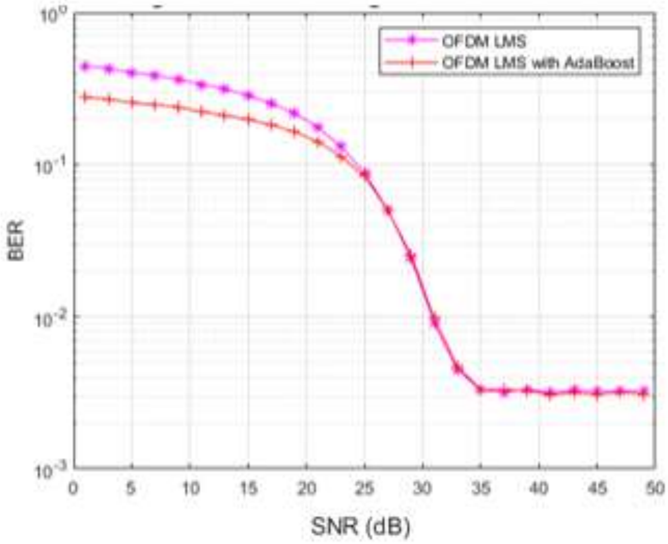

Fig. 4. BER vs. SNR for 256 QAM OFDM system using LMS channel estimation

Figure 5 displays the same simulated system again but using LS channel estimation. The enhancement at SNR of 5 dB is 1.9 dB, while at SNR of 21 dB, it is about 0.9 dB. As for the rest of the graph, the two curves match one another starting from SNR of 25dB to SNR of 50 dB.

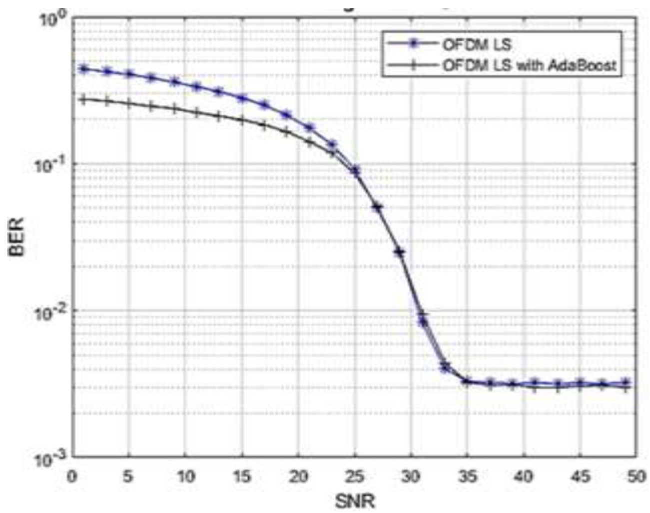

Fig. 5. BER vs. SNR for 256 QAM OFDM system using LS channel estimation

As seen in [17], the modified shows an enhancement of 2 dB when compared with LS estimator which is similar to the amount of enhancement achieved by our proposed system. In the following figures, the simulation results show the relation between the BER and SNR for 1024 QAM. The same system is simulated again, using the same parameters. As it can be seen from Figure 6, at SNR of 5 dB, the enhancement is equal to 2 dB and at SNR of 25 dB, the enhancement is about 1.2 dB. Figure 7 illustrates the simulation results of the system in case of LMS channel estimation. It is seen that the value of enhancement is equal to 1.9 dB at SNR of 5dB. At SNR of 21 dB, the enhancement is about 1.4 dB.

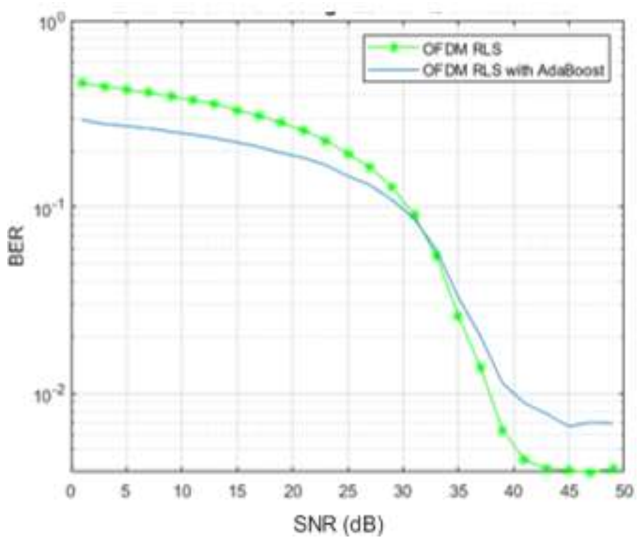

Fig. 6. BER vs. SNR for 1024 QAM OFDM system using RLS channel estimation

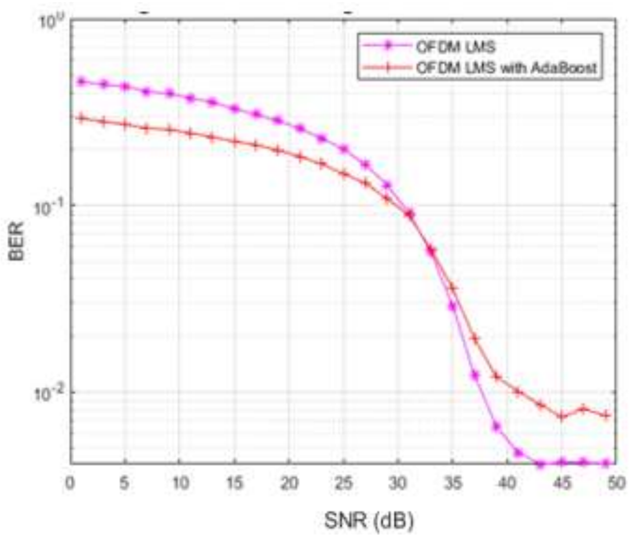

Fig. 7. BER vs. SNR for 1024 QAM OFDM system using LMS channel estimation

As shown in Figure 8, the AdaBoost simulated system shows an enhancement of about 2 dB at SNR of 5 dB. At SNR of 25 dB, the enhancement is 1.1 dB.

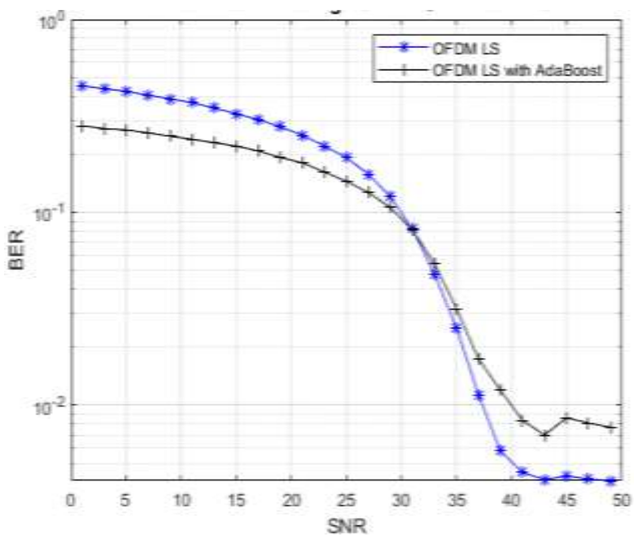

Fig. 8. BER vs. SNR for 1024 QAM OFDM system using LS channel estimation

Comparing the proposed algorithm in [18] to our model, it can be found that the amount of enhancement is up to 2.5 dB for the uncoded case and 1 dB in the coded case. In [9], a modified MMSE estimator for OFDM system gives a performance improvement of around 2 dB.

5.2 MIMO-OFDM Simulation Results

Figure 9 shows the MIMO-OFDM simulated system using a 256QAM modulation technique with RLS channel estimation. It is simulated in a Rayleigh fading environment. The FFT size is NFFT =1024, the number of frames=15, the number of pilot carrier is Np = 3, number of taps=20 and number of AdaBoost classifiers =10. The system is a 2x2 MIMO-OFDM, where the number of transmit antenna is NT=2 and the number of receive antenna is NR=2. After adding the AdaBoost technique, the simulated system showed an enhancement of about 1.6 dB at SNR of 5 dB. At SNR equals 21 dB, the enhancement is 0.7 dB. In Figure 10, the same MIMO-OFDM system is simulated using LMS channel estimation. The simulation results shows an enhancement of 1.6 dB at SNR of 5 dB while at SNR of 21 dB, the enhancement is about 0.8 dB.

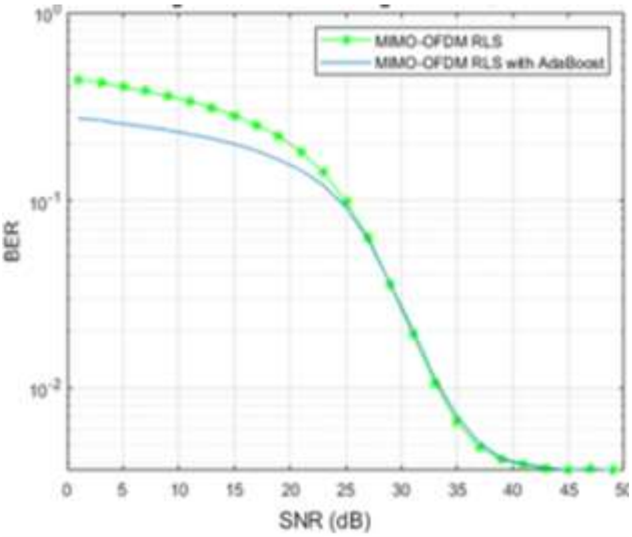

Fig. 9. BER vs. SNR for 256 QAM MIMO-OFDM system using RLS channel estimation

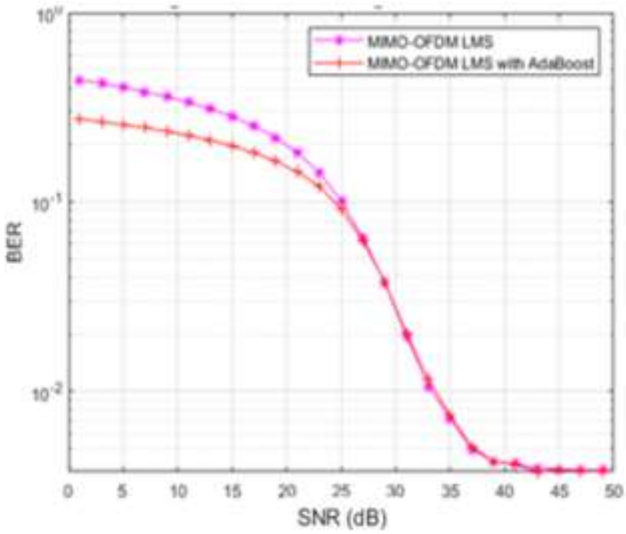

Fig. 10. BER vs. SNR for 256 QAM MIMO-OFDM using RLS channel estimation

As seen in Figure 11, the MIMO-OFDM system is simulated using LS channel estimation. The simulation results shows an enhancement of 1.9 dB at SNR of 5 dB, while at SNR of 21 dB, the enhancement is about 0.9 dB.

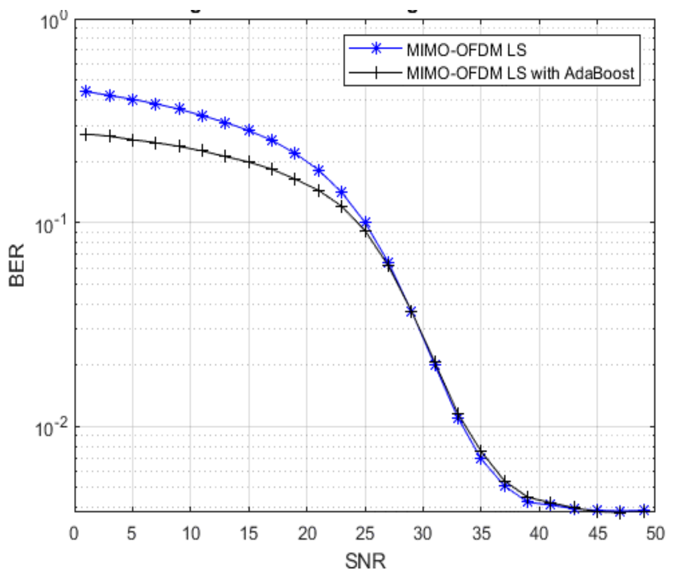

Fig. 11. BER vs. SNR for 256 QAM MIMO-OFDM system using LS channel estimation

Starting from the following figures, the same MIMO-OFDM system is simulated again but this time for 1024QAM and the number of AdaBoost classifiers equal to 5 classifiers. As seen in Figure 12, the simulated system is using RLS channel estimation. It can be noticed that at SNR of 5 dB, the enhancement value is equal to 1.6 dB, while at SNR of 21 dB, the enhancement is 1.1 dB. Moving on to Figure 13, where the same system is simulated using LMS channel estimation, it is found that the enhancement ranges from 1.12 dB to 1.6 dB at SNR from 21 dB to 5 dB.

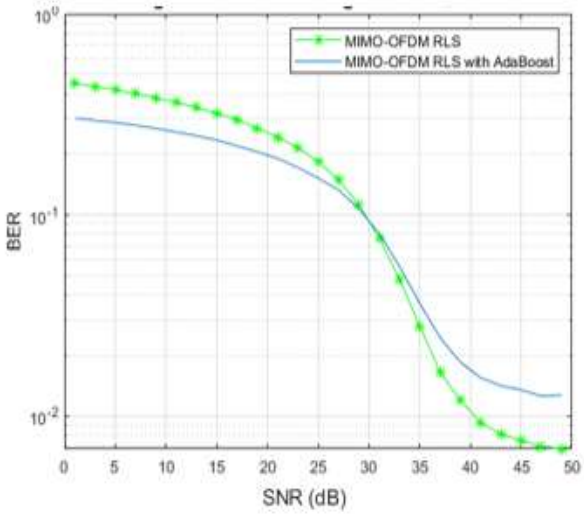

Fig. 12. BER vs. SNR for 1024 QAM MIMO-OFDM system using RLS channel estimation

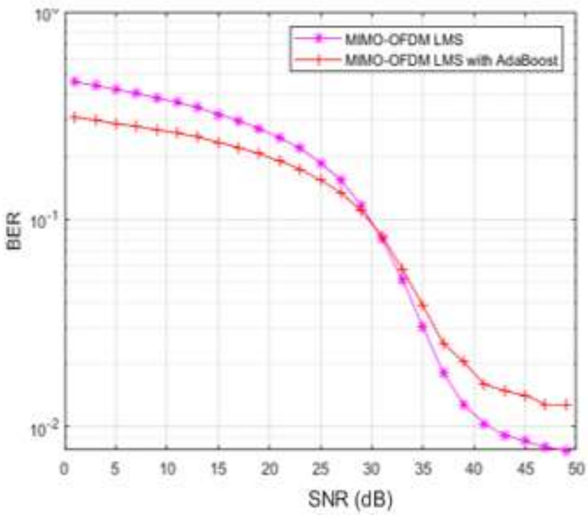

Fig. 13. BER vs. SNR for 1024 QAM MIMO-OFDM system using LMS channel estimation

In the Figure 14, the AdaBoost, LS MIMO-OFDM simulated system shows an enhancement of 2 dB at SNR of 5 dB and 1.4 dB at SNR of 21 dB.

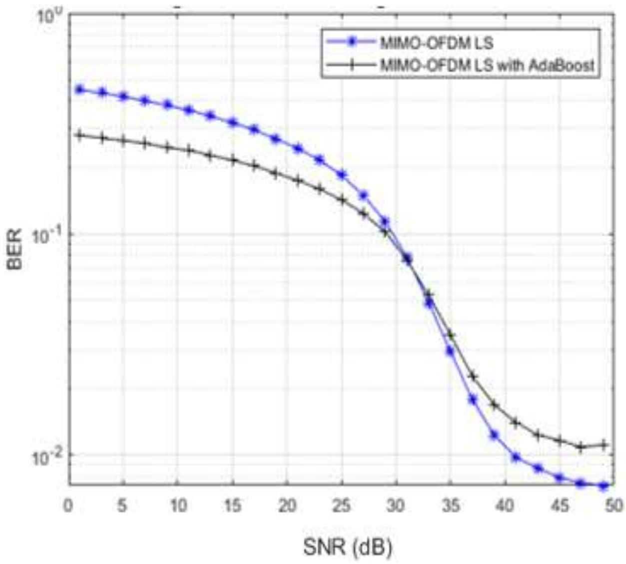

Fig. 14. BER vs. SNR for 1024 QAM MIMO-OFDM system using LS channel estimation

6. Conclusion

From all the previously shown simulation results, it can be concluded that using the AdaBoost algorithm is able to achieve an enhancement with the 5G mobile systems using OFDM and MIMO-OFDM techniques. The simulation was applied on different modulation techniques such as 256QAM and 1024QAM using different types of channel estimation techniques such as LS, LMS and RLS. A comparison of all the simulation results in this paper is summarized in Tables 1 and 2.

Table 1
Comparison between the results of the OFDM system with AdaBoost

256 QAM with AdaBoost

	RLS		LMS		LS	
SNR(dB)	5	21	5	21	5	21
Enhancement in BER(dB)	1.9 dB	0.9 dB	1.9 dB	1.3 dB	1.9 dB	0.9 dB

1024QAM with AdaBoost

	RLS		LMS		LS	
SNR(dB)	5	25	5	21	5	25
Enhancement in BER(dB)	2 dB	1.2 dB	1.9 dB	1.4 dB	2 dB	1.1 dB

Table 2
Comparison between the results of the MIMO-OFDM system with AdaBoost

256 QAM with AdaBoost

	RLS		LMS		LS	
SNR (dB)	5	21	5	21	5	21
Enhancement in BER (dB)	1.6	0.7	1.6	0.8	1.9	0.9

1024 QAM with AdaBoost

	RLS		LMS		LS	
SNR (dB)	5	21	5	21	5	21
Enhancement in BER (dB)	1.6	1.1	1.6	1.12	2	1.4

As stated in [19], the Generalized Multiple-Mode (GMM)-OFDM-IM (Index Modulation) obtains approximately 1 dB gain. The OFDM-IM achieves a gain of about 0.5 dB over classical OFDM while our proposed model shows better performance ranging from 0.9 dB to 2 dB enhancements. The proposed system in [20] shows an improvement of 0.5 dB in case of 4x4 MIMO. As for the 2×2 MIMO case, it showed an improvement of 1 dB. This shows the superiority of our work as compared to previously published results.

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References
[1] 3GPP. *Study on Scenarios and Requirements for Next Generation Access Technologies*. TR 38.913. 2016.
[2] *"Making 5G NR a Reality: Leading the Technology Inventions for a Unified, More Capable 5G Air Interface."* 2016.
[3] Saxena, Rajiv, and Hem Dutt Joshi. "OFDM and its major concerns: a study with way out." *IETE Journal of Education* 54, no. 1 (2013): 26-49. https://doi.org/10.1080/09747338.2013.10876104
[4] Abdelgader, Abdeldime Mohamed Salih, Shu Feng, and Lenan Wu. "On channel estimation in vehicular networks." *IET Communications* 11, no. 1 (2017): 142-149. https://doi.org/10.1049/iet-com.2016.0577
[5] Gamal, Heba, Nour Eldin Ismail, M. R. M. Rizk, Mohamed E. Khedr, and Moustafa H. Aly. "A coherent performance for noncoherent wireless systems using adaboost technique." *Applied Sciences* 9, no. 2 (2019): 256. https://doi.org/10.3390/app9020256
[6] Heba Gamal, Nour Eldin Ismail, M. R. M. Rizk, Mohamed E. Khedr, and Moustafa H. Aly, "AdaBoost Algorithm-Based Channel Estimation: Enhanced Performance," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 32, no. 3, pp. 296-306, 12 Nov. 2023. https://doi.org/10.37934/araset.32.3.296306
[7] Yan, Yichao, Jinpeng Li, Jie Qin, Peng Zheng, Shengcai Liao, and Xiaokang Yang. "Efficient person search: An anchor-free approach." *International Journal of Computer Vision* 131, no. 7 (2023): 1642-1661. https://doi.org/10.1007/s11263-023-01772-3

[8] Ding, Jupeng, Chih-Lin I, Jintao Wang, Hui Yang, and Lili Wang. "Performance comparison of repetition coding MIMO optical wireless communications with distinct light beams." *Sensors* 22, no. 3 (2022): 1256. https://doi.org/10.3390/s22031256
[9] Ma, Tian-Ming, Yu-Song Shi, and Ying-Guan Wang. "A low complexity MMSE for OFDM systems over frequency-selective fading channels." *IEEE Communications Letters* 16, no. 3 (2012): 304-306. https://doi.org/10.1109/LCOMM.2012.012412.112328
[10] Bhardwaj, Manushree, Arun Gangwar, and Devendra Soni. "A review on OFDM: concept, scope & its applications." *IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE)* 1, no. 1 (2012): 07-11. https://doi.org/10.9790/1684-0110711
[11] Zheng, Jianping, and Ru Chen. "Achieving transmit diversity in OFDM-IM by utilizing multiple signal constellations." *IEEE Access* 5 (2017): 8978-8988. https://doi.org/10.1109/ACCESS.2017.2708718
[12] Zaki, Amira, Ahmed Métwalli, Moustafa H. Aly, and Waleed K. Badawi. "5G and beyond: Channel classification enhancement using VIF-driven preprocessing and machine learning." *Electronics* 12, no. 16 (2023): 3496. https://doi.org/10.3390/electronics12163496
[13] Dhandapani, Gokila, Rakan A. Alsowail, D. Rajesh Kumar, and Moustafa H. Aly. "Dual-band MIMO antenna design for enhanced 5G performance: simulation, implementation, and evaluation." *Optical and Quantum Electronics* 56, no. 7 (2024): 1248. https://doi.org/10.1007/s11082-024-07151-7
[14] Aly, Rana M., Amira Zaki, Waleed K. Badawi, and Moustafa H. Aly. "Time coding OTDM MIMO system based on singular value decomposition for 5G applications." *Applied Sciences* 9, no. 13 (2019): 2691. https://doi.org/10.3390/app9132691
[15] Raleigh, Gregory G., and V. K. Jones. "Multivariate modulation and coding for wireless communication." *IEEE Journal on Selected Areas in Communications* 17, no. 5 (2002): 851-866. https://doi.org/10.1109/49.768200
[16] Li, Guomin, and Guisheng Liao. "A pilot-pattern based algorithm for MIMO-OFDM channel estimation." *Algorithms* 10, no. 1 (2016): 3. https://doi.org/10.3390/a10010003
[17] Van De Beek, J-J., Ove Edfors, Magnus Sandell, Sarah Kate Wilson, and P. Ola Borjesson. "On channel estimation in OFDM systems." In *1995 IEEE 45th Vehicular Technology Conference. Countdown to the Wireless Twenty-First Century*, vol. 2, pp. 815-819. IEEE, 1995. https://doi.org/10.1109/VETEC.1995.504981
[18] Sohail, Muhammad S., and Tareq Y. Al-Naffouri. "An EM based frequency domain channel estimation algorithm for multi-access OFDM systems." *Signal processing* 90, no. 5 (2010): 1562-1572. https://doi.org/10.1016/j.sigpro.2009.10.026
[19] Wen, Miaowen, Qiang Li, Ertugrul Basar, and Wensong Zhang. "Generalized multiple-mode OFDM with index modulation." *IEEE Transactions on Wireless Communications* 17, no. 10 (2018): 6531-6543. https://doi.org/10.1109/TWC.2018.2860954
[20] Al-Ansi, Mohammed, Syed Alwee Aljunid, and Essam Sourour. "Performance improvement of space shift keying MIMO systems with orthogonal codebook-based phase-rotation precoding." *Wireless Communications and Mobile Computing* 2017, no. 1 (2017): 4359843. https://doi.org/10.1155/2017/4359843