AN INTELLIGENCE SYSTEM FOR OFDM WITH SUBCARRIER POWER MODULATION AND STBC TO IMPROVE SYSTEM PERFORMANCE

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Abstract

Orthogonal Frequency-Division Multiplexing with Subcarrier-Power Modulation (OFDMSPM) can be a promising transmission technique for future 5G and 6G wireless communications due to saving in transmission power and higher spectral efficiency. In this paper, OFDM-SPM technique is compounded with Alamouti Space Time Block Coding (STBC) and Artificial Neural Networks (ANN) to further study its effect on the performance parameters of the wireless system. We analyze the two main performance metrics – Bit-Error-Rate (BER) and Throughput for OFDM-SPM-BPSK-STBC and OFDM-SPM-BPSK-STBC-ANN technique. In order to make STBC work we propose an equalizer for detecting the SPM power bits, convenience model (OFDM-SPM) for the proposed technique and observe that there is a considerable improvement in the BER in the multi-path Rayleigh fading channels. We take two scenarios for SPM for OFDM-SPM-BPSK-STBC and OFDM-SPM-BPSK-STBC-ANN transmission. The first one is Power Reassignment Policy and the second one is Power Saving Policy. We conclude that the sub-carrier using ANN optimized power-reassignment scheme provides the best BER performance for the proposed transmission scheme while the power-saving policy for SPM provided the intermediate increase in average BER. Our results can provide the initial benchmark for the adoption and further analysis of OFDM-SPM in the future communication systems.

1. Introduction

The demands for higher data rate are increasing day by day, and the radio spectrum becoming more crowded, there is a need to design the techniques for higher spectrum efficiency. Orthogonal frequency division multiplexing(OFDM) is a widely accepted technique for transmission over Wi-Fi, Wi-MAX and LTE [1]. OFDM supports high data rate traffic by dividing the incoming serial data stream into parallel narrow band channels such that fading channel becomes frequency independent and flat while minimizing the co-channel and adjacent channel interference. However, the new requirements generated by the 5G and 6G communication technologies along with data-hungry application and wider application areas, there is need to add the new degrees of freedom to the existing OFDM technique. Moreover, working towards increasing the spectral efficiency, anew modulation technique namely OFDM with sub-carrier power modulation (OFDM-SPM) has been proposed in [2].The authors proposed to utilize the power of each subcarrier as means to transmit the information bits. It is shown that OFDM with SPM provides higher special efficiency along with the reduction in transmission power. It is also established that this technique maintains the gains when used with higher order constellations. But this technique provides marginal improvement in Bit-Error-Rate (BER) when considered in multi-path fading scenarios. Transmit diversity scheme proposed by Alamouti in [3] offers a new dimension in Space Time Block coding (STBC) and improves the BER of the signal in multi-path fading channels. Space-time coding realizes spatial diversity (and coding gain) by introducing temporal and spatial correlation into the signals transmitted from different transmits antennas. It has received an increased attention owing to the improvement in hardware technologies and their potential to provide increased capacity for next generation wireless systems. STBC-OFDM System under rayleigh fading channel with known and unknown CSI at the transmitter is analyzed in[4]. The authors use singular value decomposition (SVD)method to improve the BER performance and providing the CSI knowledge at the transmitter. However, the SVD of the channel adds the computational complexity into the system. To reduce the computational complexity, the authors in [5]presented the low complexity implementation of STBC coding for OFDM transmitters. The proposed scheme reduces the computational complexity by half when compared to the case without space-time coding. This results in approximately (40%) reduction in computational complexity while using specifications from Wi-Fi IEEE 802.11a. However, the authors in [6] compare the OFDM performance in MIMO considering the 5G scenario. Recently, the authors in [7]provides the analysis and implementation guidelines for very high data rates OFDM based wireless backhaul systems in5G service requirements. The authors use Low density parity check (LDPC) codes along with 1024-QAM constellation for providing higher data rates. But the sensitivity of the receiver for implementation of 1024-QAM constellation in practical scenario is the matter of further investigation. [8] an advanced novel small-scale non-orthogonal communication technique utilizing physical layer security (PLS) for enhanced security and reliability for two users is proposed, The proposed model uses the wireless channel characteristics to eliminates user interference as well as completely degrade the received signal at the eavesdropper's terminal, [9] The Author Proposed algorithms for enhancing physical layer security and spectral efficiency of Orthogonal Frequency Division Multiplexing (OFDM) with Index Modulation (IM) systems have been proposed, the first two algorithms named as OFDM-AIM-FCM and OFDM-AIMACM are designed for enhancing PLS and SE, while the third algorithm named as OFDM-VIM-VCM is designed for QoS based communication for enhancing SE. However, the implementation of simple OFDM-SPM along with STBC for higher constellation provides much promise to raise the performance and spectral efficiency of the system, which has not been investigated yet. Hence, analyzing the performance of OFDM-SPM along with STBC for enhancing the spectral efficiency is the subject of this paper.

The rest of the paper is organized as follows. Section 2 presents the system model and problem formulation of OFDM-SPM-STBC. The methodology and performance analysis are carried out in the section 3. Section 4presents a discussion on BER, section 5 presents the results and discussion and section 6 discusses the conclusion and possible future enhancements of the paper.

2. System Model for OFDM SPMSTBC

In this section, we discuss, transmitter, multi-path channel and receiver design which is used for analyzing the proposed OFDM-SPMSTBC scheme.

2.1 Transmitter design

The implementation of OFDM with sub-carrier-modulation is presented in detail in [10]. The block diagram of the implemented for transmitter design is shown in fig 1. In the transmitter, the random incoming bits are generated and are divided into two halves to implement the traditional modulation and sub-carrier power modulation. After the modulation, the data is given to STBC encoder. We use Alamouti STBC because it is only the STBC code that achieves the maximum diversity gain [11].

The null sub-carriers are added before performing IFFT to the above generated symbols such that the length of data becomes equal to the length of IFFT. Another purpose of adding the null-subcarriers is to synchronize the OFDM symbols at the receiver [12]. Moreover, in null subcarriers, no data symbols are transmitted and hence, no power but they still have sub-carriers for channel estimation. Hence, before adding the cyclic prefix, the stream for antenna1 and antenna 2 becomes, to mitigate the effect of Inter-Symbol-Interference (ISI), cyclic prefix is added. Cyclic prefix helps in mitigating the effect of ISI because an OFDM symbol has long symbol duration, therefore, ISI only affects the initial part of the OFDM symbol [13][14]. Hence, two STBC-OFDM-SPM streams are transmitted by two antennas from the transmitter.

2.2 Channel Model

We consider the Rayleigh multi-path fading channel with T taps which are considered as exponentially decaying taps. Let our multi-path Rayleigh faded channel be represented by *h*such that [15]

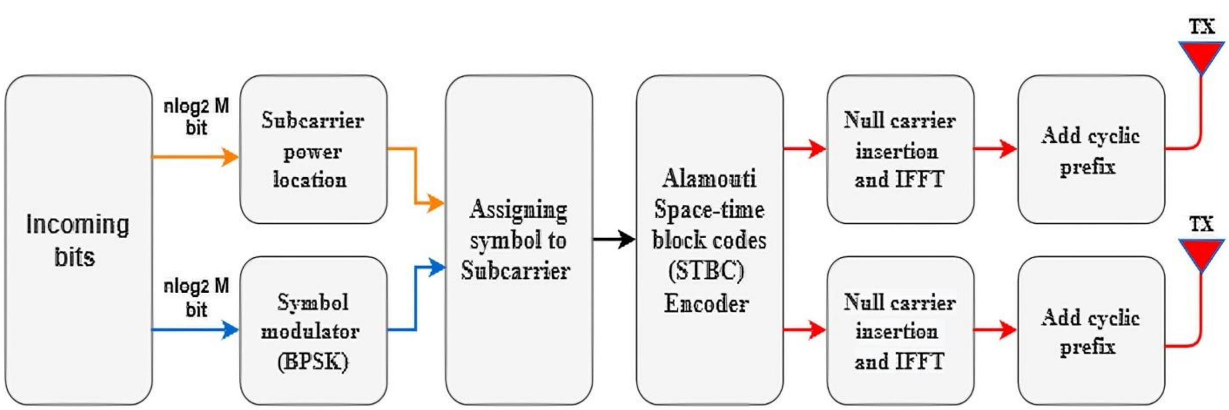

FIGURE 1: Transmitter design of OFDM-SPM with ALAMOUTI STBC

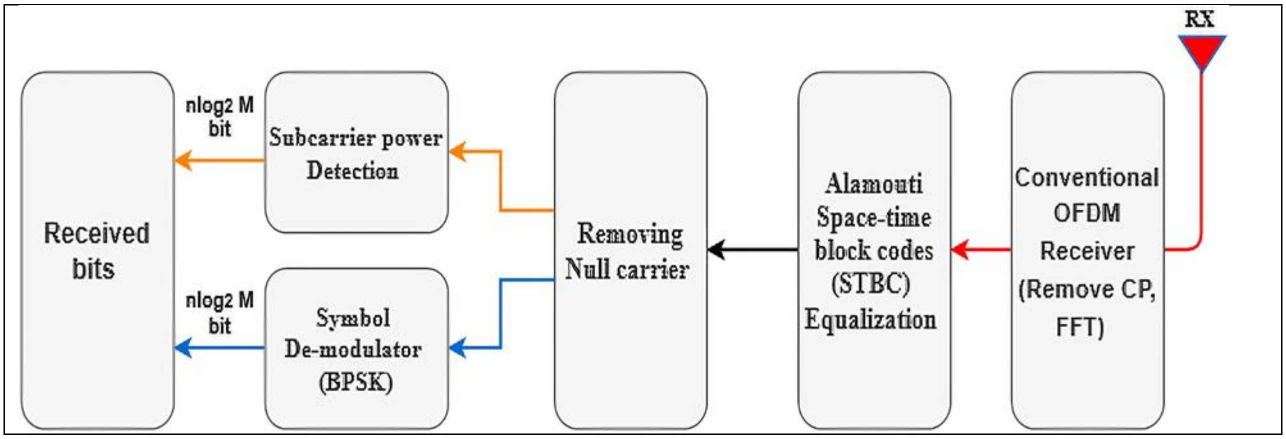

FIGURE 2: Receiver Design of OFDM-SPM with Alamouti STBC.

$h=[h_0,h_1,h_2,......,h_{(t-1)}]$.(1)

For two-transmit antennas and one receive antenna, two Rayleigh multi-path fading channels are considered. The channel from antenna-1 to receiver antenna is defined as

$h_1=[h_{1,0},h_{1,1},h_{1,2},......,h_{1(t-1)}]$. (2)

And the channel from antenna-2 to receive antenna is defined as

$h_2=[h_{2,0},h_{2,1},h_{2,2},......,h_{2(t-1)}]$. (3)

Converting to the frequency domain, the channel response becomes

$h_{F,1} = FFT(h_1)$, (4)

$h_{F,2} = FFT(h_2)$.

We also compute the frequency domain conjugate channels as

$h1_{F,1} = FFT(h^*_1)$,(5)

$h2_{F,2} = FFT(h^*_2)$.

These conjugate frequency-domain responses would belater used in the receiver section for equalization purposes.If the received signal at the receiver is denoted by y, then itcan be expressed as

$y=h_1\Theta X_1+h_2\Theta X_2+\eta_0$, (6) Here, Θ represents the convolution and *Xi* represents the stream of OFDM symbols transmitted by *ith* antenna and $\eta 0$ is the AWGN noise. The AWGN noise is added and controlled by varying the SNR values from 0 dB to 35 dB.

2.3 Receiver Design

The receiver design implementation for OFDM-SPM-STBC is shown in fig. 2. OFDM-SPM-STBC is capable of improving the BER and enhancing the spectral efficiency of the communication system. At the receiver, initial steps of the traditional OFDM receivers are followed. The CP is removed from the received signal and frequency domain STBC equalization is performed. The Null sub-carriers are removed and then, demodulation of the signal bits and power bits are performed in parallel as described in. The main part of the receiver section is the designing of OFDM-SPM-STBC equalizer.

3. System Model for Artificial Neural Networks

The wireless channel can indeed be thought of as a time and space variable. According to reflections in houses, hills, automobiles, and other barriers, the received signal could be several delayed receptions of something like the sent signal. The signal strength fluctuates owing to the unavailability of a line-of-sight (LOS) trajectory and the popularity of non-LOS (NLOS) components, differing attenuation, time delay, phase shift, and other factors in every path, destructive and constructive addendum of the constituent paths because of many phase shifts, and so on. Multipath fading is a phenomena caused by the interaction of these elements [16].

3.1 Fading Rayleigh multi - path channels

The LOS portion is absent in Rayleigh fading [17]. It's most common in land mobile channels in metropolitan locations, where there are several impediments that make LOS pathways uncommon. It's the worst extreme scenario for fading.

After transmitting an unmodulated carrier signal $\cos(2\pi f_c t)$, the receiving pass-band signal lacking noise can be expressed as

$$x(t) = \Sigma \alpha i(t)\ (2nfc(t — vi(t)))$$
$$=\mathrm{Re}[\Sigma \alpha i(t) e^{-j2nfcci(t)} e^{j2nfct}]$$

The real part of both the quantity is represented by Re, the time–varying attenuation coefficient of the i^{th} propagation delay is represented by i(t), the time–varying delay is represented by (t), and the carrier frequency is represented by fc.
After that, you can describe the comparable baseband signal as:

$$h(t) = \Sigma \alpha i(t)\ e^{-j2nfcci(t)}$$

When the components of h(t) are independent the probability density function of the amplitude r = h= γ has Rayleigh pdf:

$$f(r) = \frac{r}{a^2} e^{-\frac{r}{2a^2}}$$

where $E\{r^2\} = 2\sigma^2$ and $r \geq 0$.

3.2 Multi-Input-Multi-Output (MIMO)

Without adding bandwidth or transmit power, MIMO technology allows for significant gains in data speed and network range. Greater spectral efficiency and link dependability or diversity have been used to accomplish this. MIMO could also be utilised to boost capacity, which rises in direct proportion to the number of antennas [18]. The received signal y in a MIMO system can be calculated using the matrix equation below:

$$y = Hx + n$$

The transmit signal vector is x, and the separable complex zero-mean Gaussian random components with equality of variance are n [19]. H is the transmitter-receiver channel matrix.

3.3 Space Time Codes

STC (space-time code) is a mechanism used in wireless communications to enhance data transmission dependability when several antennas are used [20]. STCs work by sending several, redundant versions of a data stream towards the receiver in the hopes that at least several of them will withstand the physical passage amongst transmission and reception in good enough condition to allow for accurate decoding. STBC operates on a data block. It increases diversity but just not coding efficiency [21]. As a result, STBC has a lower complexity. A matrix is commonly used to represent an STBC. Each column indicates the transmissions of one antenna across time, whereas each formulated a time interval. A STBC matrix is shown in Figure 3.

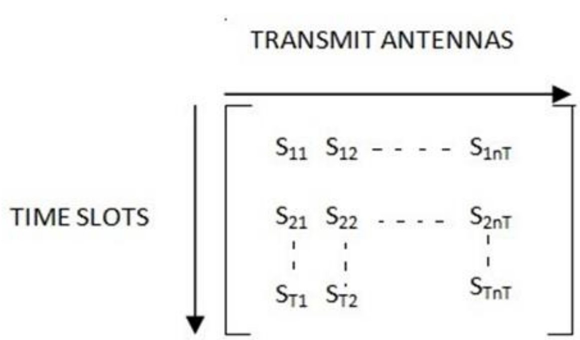

Figure 3: Matrix representation of STBC

We utilized Alamouti space-time block codes in this study and applied artificial Neural Networks to assess their effectiveness in Rayleigh fading channels.

3.4 Alamouti Space Time Block Codes

A wedge of two symbols is chosen from either the source data and delivered to the modulator throughout the Alamouti scheme on the transmission end. The two modulated symbols are then fed into the Alamouti space-time encoder. Let's take s1 and s2 one at a moment, bring an encoding matrix H with the symbols s1 and s2 assigned to two transmit antennas during two transmit timings as shown below.

$$H=\begin{vmatrix} S1 & S2 \\ S2* & S1 \end{vmatrix}$$

The complex conjugate is represented by the symbol *. The encoder outputs are broadcast from either the two transmit antennas in two successive transmission intervals. The signal s1 is generated from antenna one as well as the signal s2 is released from antenna two at the same time during the first transmission period. The signal -s2* is released from antenna one during the second transmission period, whereas the signal s1* is delivered from antenna two.

Once signals are obtained at the receiver, they are first merged, and then the broadcast signal is retrieved at the detector.

3.5 Artificial Neural Network

The Artificial Neural Network (ANN) is a hugely parallel and distributed processor that learns (trains) to gain knowledge. A generic ANN is a computer system made up of a collection of interlinked processing components known as neurons that process data in response to exterior stimuli.

Blind and non-blind methods of channel evaluation are commonly used in MIMO systems. Non-blind estimate, in which measurements are made appropriately to data and pilot are utilised together, does not involve training sequences. When obtaining an accurate and stable MIMO channel, pure training-based techniques can be regarded a benefit. However, when bandwidth efficiency is necessary, it could be a drawback. That was because simple training-based methods employ a long training sequence, which is required to produce a solid MIMO channel estimation, which reduces bandwidth efficiency significantly. An ANN could be used to evaluate the channel, which could help to reduce some of the problems associated with multi-user transmission. The ANN can be trained to be robust enough just to deal with numerous channel varieties, and a set-up can be devised and see if it would lead to a reduction in Bit Error Rate [22].

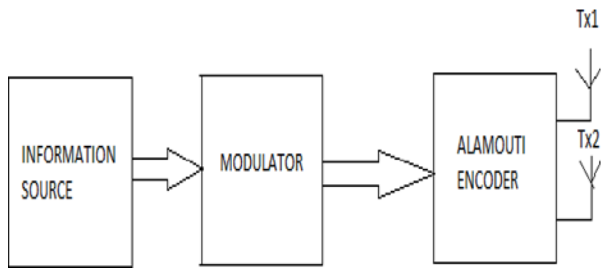

Figure 4: Alamouti space-time encoder diagram

The system model comprises of the blocks as shown in Figure 5.The signal is sent to the BPSK modulator then it is encoded with Alamouti STBC Encoder and transmitted through the channel. At the receiver end there is a ANN based channel estimator which will estimate the STBC encoded signal and then decode it and passed to the demodulator and the desired signal is obtained and BER is compared between the transmitted signal and the received signal.

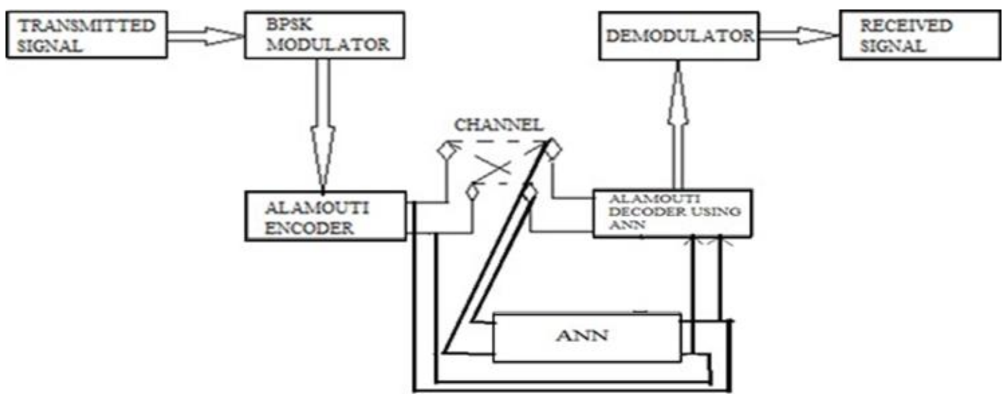

Figure 5: System Model

The use of an artificial neural network (ANN) takes into account two factors. The first phase is to convolutional neural network, and the second is to analyze the trained ANN underneath a variety of scenarios to ensure its robustness over a variety of channels.

The signal that is received is provided by

$y = Hx + n$

We've assessed the channel here by utilizing,

$H = y/x$

We considered that the AWGN ‘n' is specified or can be disregarded when training the neural network. During the training of the ANN, they acquired signal y as input and broadcast signal x as output, allowing us to appropriately predict the channel.

The ANN has three layers: one input, one hidden layer, as well as one output layer. The back propagation algorithm is used to update the network's weights. The feed-forward of the input training pattern, the back propagation of the associated error, and the adjustment of the weights are the three stages of back-propagation training for a neural network.

4. Results and Discussions

In this section, we discuss the simulation results for the proposed scheme and OFDM-SPM-STBC equalizer. We study mainly two parameters, BER and Throughput. We also change the base modulation of OFDM to higher constellation, and analyze the parameters. For OFDM-PSK, the SPM is taken as shown in the fig 6. In the shown fig, *L* and *H* denote the low and high-power levels of the subcarriers respectively, whereas Eb denotes the energy per bit. Specifically, *L* and *H* are power factors that determine the power of a subcarrier relative to the power given to a BPSK symbol. Generally, the power of BPSK symbols is taken as unity and hence, a subcarrier with *H* power indicates a subcarrier with *H* times the power of a BPSK symbol, and similarly for *L*. The table 1 shows the simulation settings for BER and throughput calculations. OFDM-SPM transmits two different bit sequences. First through conventional modulation and second through power modulation of sub-carriers is used. Hence, a bit can be received in error due to one of two possible reasons first, a bit can be received in error during the detection of the power levels of the sub-carriers incorrectly. Second, an error can arise from the detection of the BPSK modulated symbols carried by the sub-carriers. We try to detect both BER in power bits transmitted through sub-carrier power modulation and in BPSK modulation symbols. Then, we also plot the average BER by combing the above two BERs.

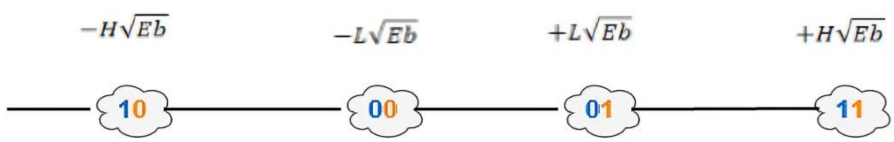

FIGURE 6: Constellation points of OFDM-SPM with BPSK

For implementing the SPM in OFDM, we consider two types of power policies. First is Power saving and second is power-reassignment. We take both cases one by one with STBC.

TABLE 1: SIMULATION PARAMETER SETTINGS

Modulation − Type	BPSK(M = 2)
IFFT/FFT size	64
Number of Active Subcarriers	52
Cyclic prefix	16
No of taps in multi-path channel	5
Number of inactive sub-carriers for out of band emission	12
Number of frames	$2x10^4$

Multi path channel delay samples location	[0 3 5 8]
Multi path channel tap power profile (dBm)	[0 -8 -17 -21 -25]
OFDM Bandwidth	20 MHz
OFDM symbol duration	4 µsec
Guard Interval	0.8 µsec

4.1 POWER SAVING POLICY FOR OFDM-SPM-STBC

OFDM-SPM aims to transmit more bits per subcarrier by manipulating the power of the subcarriers in an OFDM block in addition to those bits that are usually transmitted by conventional modulation schemes. Therefore, we can adjust the power of the sub-carrier in different ways, so as to achieve the sub-carrier power modulation. In the power saving policy, the power of sub-carriers is saved to match requirements of low power applications (e.g., IoT). This inherently results in a better power efficiency when compared to conventional OFDM, and were found as High-subcarrier power, H = 1.35and Low sub-carrier power, L = 0.4213. We plot the average BER for OFDM-SPM-BPSK and power bits BER for comparison. We observe from fig (4.2) that the proposed system (OFDM-SPM-BPSK-STBC) exhibits an advantage in the BER for the same SNR, when compared with the conventional OFDM-BPSK or OFDM-SPM-BPSK. For instance, at 20dB SNR, the conventional OFDM-BPSK has a BER of around 0.0055 whereas the BER of OFDM-SPM-BPSKSTBC is around 0.001 and the BER for OFDM-SPM-BPSK without STBC is around 0.01. As we observe from the result diagram in the case of normal OFDM-SPM at Power saving policy, getting a 10 – 3 BER we need a 30 dB Eb/No to send the subcarrier, While implementing the Space Time Block Coding (STBC) technique we only need a 20 dB Eb/No to achieve the same BER, which mean that our technique make the same result saving additional power which is suitable for IOT devices these results also compared with OFDM-SPM-BPSK-STBC-ANN, the BER (shown in figure 8) is also improved and the throughput is also better.

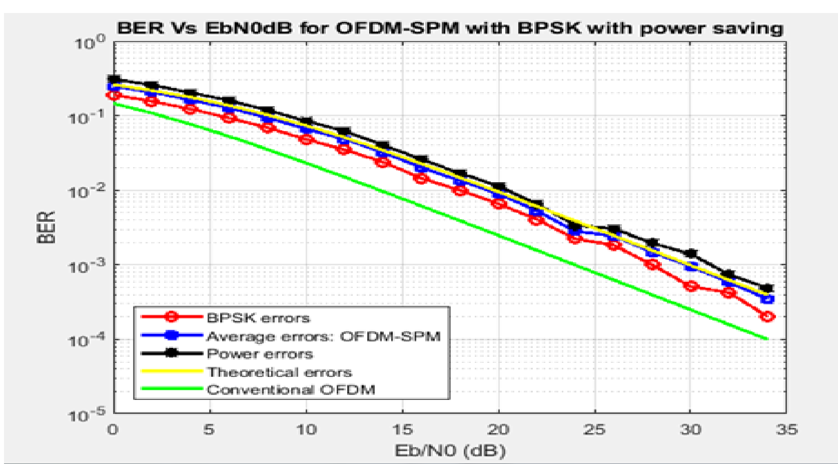

FIGURE 7: BER of OFDM-SPM-BPSK-STBC with power saving policy.

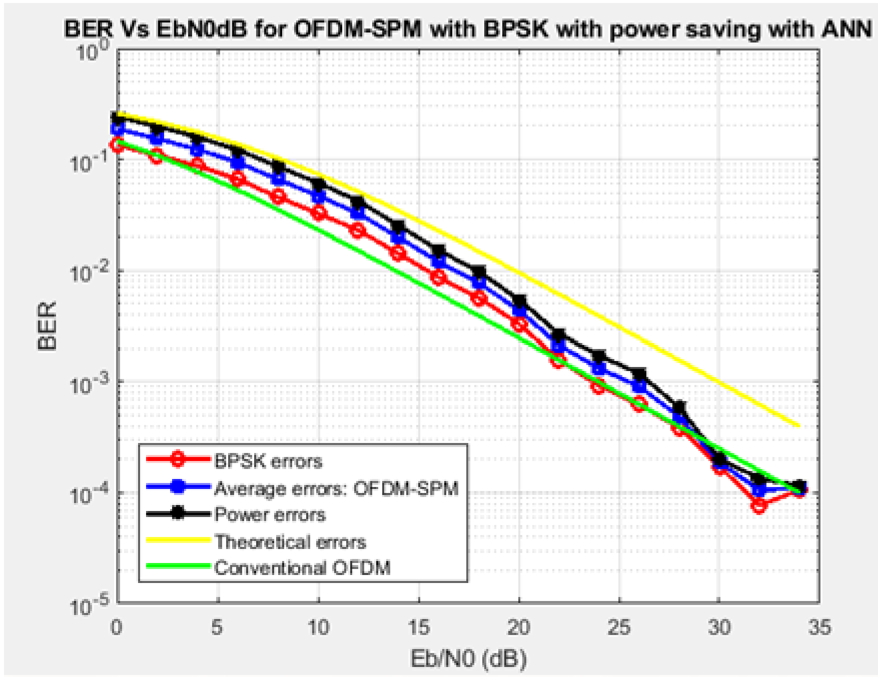

FIGURE 8: BER of OFDM-SPM-BPSK-STBC with power saving policy with ANN.

We plot the throughput for the same in fig (4.4). The throughput is also better in case of proposed OFDM-SPM-BPSKSTBC at low SNR values. However, at higher SNR values, the signal power increases and noise level becomes low and thus, STBC gain almost vanishes as can be seen from theplots in fig 9. Then these results are plot with OFDM-SPM-BPSK-STBC-ANN (shown in figure 10) the throughput is better. Table 4.2 shows the comparison between BER for power bits, BPSK bits and average at different SNR points for all the techniques.

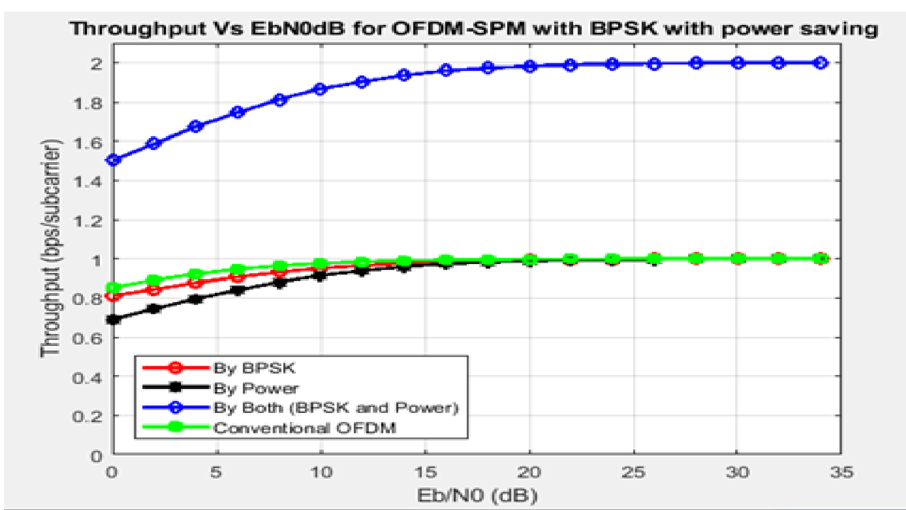

FIGURE 9: Throughput comparison for the proposedOFDM-SPM-BPSK-STBC

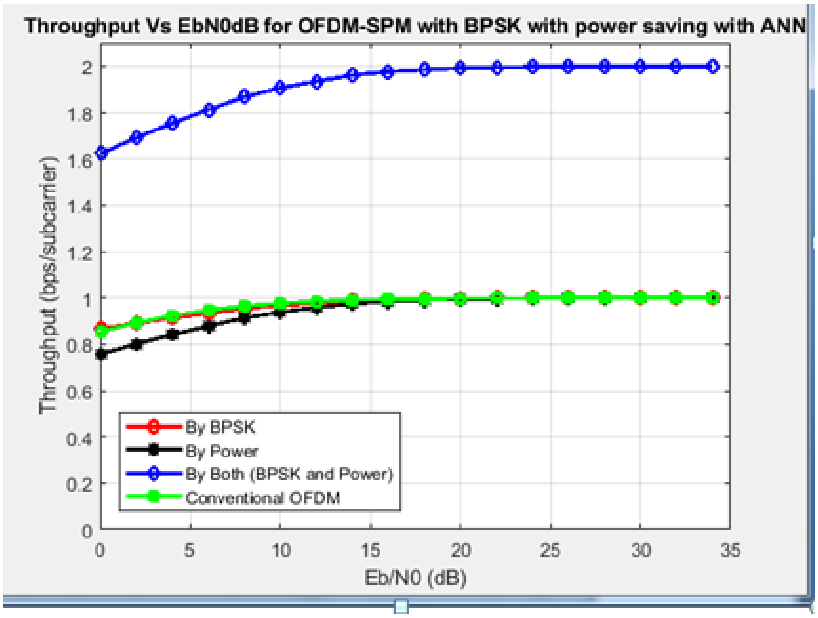

FIGURE 10: Throughput comparison for the proposed OFDM-SPM-BPSK-STBC with ANN

TABLE 2: BER Comparison among OFDM-SPM, OFDM-SPM-STBC and OFDM-SPM-STBC-ANN at different SNR values for Power saving policy

SNR Value	**OFDM-SPM**		
	By BPSK	**By Power**	**By Average**
10 (dB)	0.04984	0.0861	0.06797
15 (dB)	0.01836	0.0326	0.02548
20 (dB)	0.006446	0.01137	0.008908
SNR Value	**OFDM-SPM-STBC**		
	By BPSK	**By Power**	**By Average**
10 (dB)	0.005322	0.009231	0.007276
15 (dB)	0.001707	0.003019	0.002363
20 (dB)	0.0005465	0.0009454	0.000746

SNR Value	**OFDM-SPM-STBC-ANN**		
	By BPSK	By Power	By Average
10 (dB)	0.004322	0.008231	0.005276
15 (dB)	0.001700	0.003011	0.002321
20 (dB)	0.0005361	0.0007451	0.000642

4.2 Implementing Optimized Power Re-Assignment Policy

In re-assignment power policy, we re-assign the saved powerof power-saving policy; we simulate the optimized cases of power reassignment policy for OFDM-SPM-BPSK-STBC and OFDM-SPM-BPSK-STBC-ANN..

In this case the saved optimal-power is reassigned to the subcarriers, so that the optimal high and low power levels are obtained using H = 1.91, L = 0.56. This optimization is done under a constraint that ensures the average energy of an OFDM subcarrier in OFDM-SPM cannot exceed that of a subcarrier in conventional OFDM using BPSK symbol modulation. It has been observed from fig (11), the proposed model (OFDM-SPM-BPSK-STBC) exhibit great improvement in the BER when we implement optimized power reassignment policy to the subcarriers then we compare the proposed model with OFDM-SPM-BPSK-STBC-ANN. There is indeed an improvement in BPSK bits detection and power-bits detection resulting in improvement of the overall average bits detection. As we notice from fig 4.6, The Space Time Block Coding(STBC) technique in the case of Optimized Power Policy make a lot of improvement in the BER comparing to the convenience model OFDM-SPM, getting a 10 − 3 average BER we need a 27.5 dB Eb/No to send a subcarrier, But only 16 dB Eb/No will be needed at (OFDM-SPM-STBC)technique

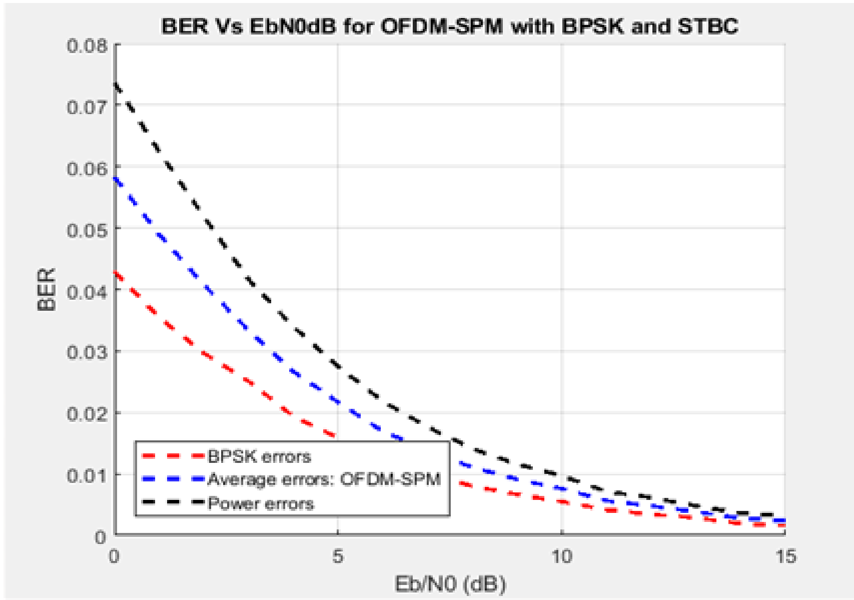

FIGURE 11: BER of OFDM-SPM-BPSK-STBC with optimized power reallocation policy.

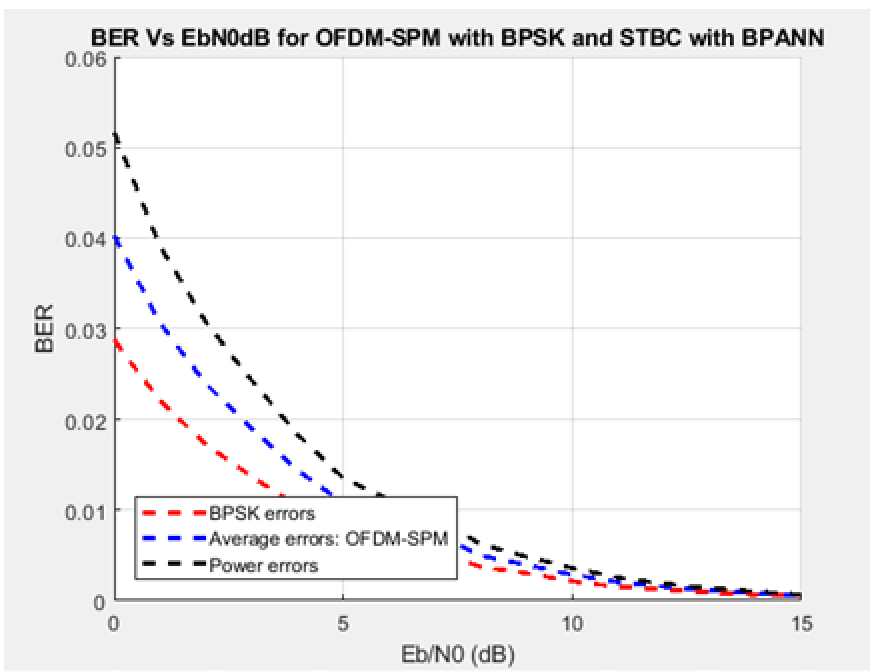

FIGURE 12: BER of OFDM-SPM-BPSK-STBC with optimized power reallocation policy with ANN

The throughput plotted in fig (13) is almost same with noeffect. The comparison of SNR is also drawn in the table 4.3 for the proposed OFDM-SPM-BPSK-STBC and STBCpower bit and average bits detection. It can be clearly seenthat the average BER has improvement in this case whencompared to power-saving and optimized case of OFDM-SPM-BPSK-STBC-ANN.

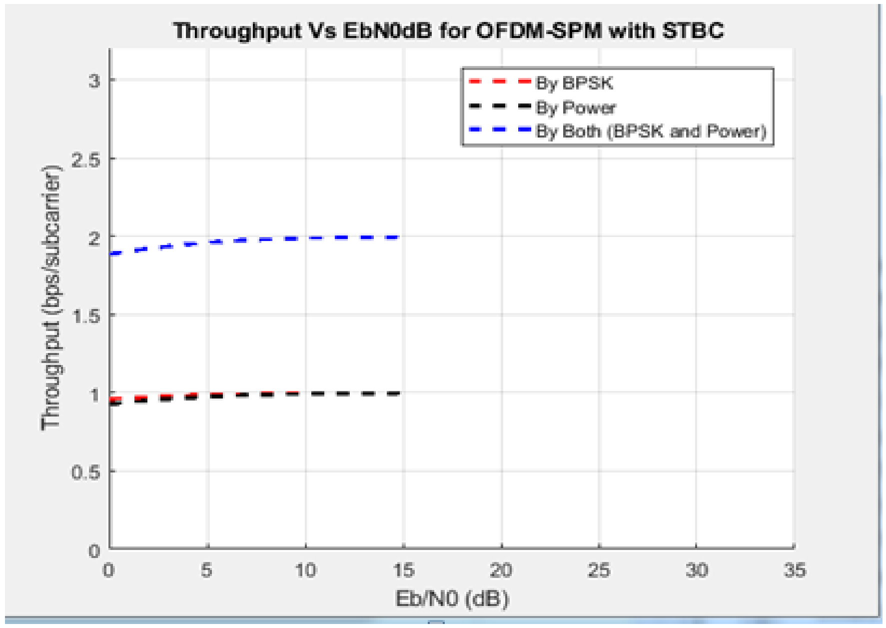

FIGURE 13: Throughput of OFDM-SPM-BPSK-STBC with optimized power reallocation policy

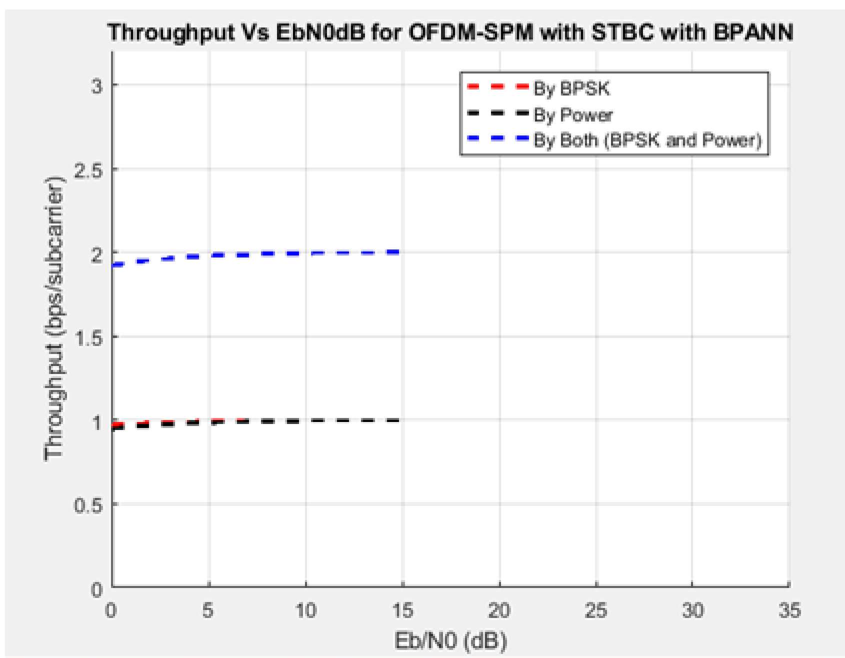

FIGURE 14: Throughput of OFDM-SPM-BPSK-STBC with optimized power reallocation policy with ANN

TABLE 3: BER Comparison of OFDM-SPM-BPSK-STBC and OFDM-SPM-BPSK at different value of SNR for optimized power policy

SNR Value	OFDM-SPM		
	By BPSK	By Power	By Average

10 (dB)	0.03051	0.04687	0.03869
15 (dB)	0.01043	0.01614	0.01329
20 (dB)	0.0034220.005264	0.004343	
SNR Value	OFDM-SPM-STBC		
	By BPSK	By Power	By Average
10 (dB)	0.002834	0.004507	0.003671
15 (dB)	0.0008946	0.001427	0.001161
20 (dB)	0.0002877	0.0007396	0.0003637
SNR Value	OFDM-SPM-STBC-ANN		
	By BPSK	By Power	By Average
10 (dB)	0.002812	0.002507	0.003121
15 (dB)	0.0005946	0.001112	0.001100
20 (dB)	0.0002231	0.0006396	0.0003132

5. Conclusions and Future Scope

In this thesis, OFDM-SPM with BPSK is combined with Alamouti STBC to further improve the BER of OFDM-SPMBPSK and then improved with OFDM-SPMBPSK-ANN over the Rayleigh multi-path fading channel. The spectral efficiency of OFDM-SPM-BPSK-STBC is almost doubled as compared the conventional OFDM and for OFDM-SPM-BPSK-STBC-ANN spectral efficiency is much better but the BER improvement is also significant. We can clearly figure out from the results that the BER improvement of BPSK as well as overall average BER improves considerably. We implement the proposed scheme with power-saving and power reassignment policies of SPM. We show that the power reassignment with optimized power allocation scheme has the highest improvement in the BER while the power-saving SPM scheme has the intermediate BER improvement and optimized power reassignment has the least. The bit error rate is improved in OFDMSPM-STBC-ANN techniques for all other conventional methods shown in table 4.2 and 4.3 on the basis of figure 7, 8, 11, 12. The throughput of the results is also better by using OFDMSPM-STBC-ANN techniques as the shown in figure for OFDMSPM-STBC throughput 1.45 (figure 9) but for OFDMSPM-STBC-ANN throughput is 1.6 (figure 10).Same as for optimized policy throughput is improved for OFDMSPM-STBC-ANN shown in figure 13 and 14. As a future research direction, we can implement this proposed OFDMSPM-

STBC-ANN scheme with higher constellation modulation schemes and also analyze the complexity and sensitivity of the equalizer and receiver. The sensitivity and complexity analysis would be of considerable interest because with higher constellation modulation, greater number of subcarrier power levels would be required and the detection of those sub-carrier power levels may need more sensitive receivers that would add complexity to the system. We can also formulate the multi-objective optimization problem for the trade-off between sensitivity and complexity of the OFDMSPM-STBC-ANN receiver

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