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Original Research Article

Performance Improvement for Maximizing Capacity of Crowded Spectrum using Advanced Modulation and Coding Techniques

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ABSTRACT

The requirement of data transfer poses a big threat because of numerous challenges such as adjacent and co-channel interference problems, spectral congestion and noise corrupted data reception. These challenges require the development of new encoding, modulation, demodulation and decoding techniques for newer transmission channels. This is the motivation for the current work. The method employed the development of orthogonal frequency division multiplexing (OFDM) models with space time block code (STBC) and without space time block code. The performance of bit-error-rate (BER) and signal-to-noise ratio (SNR) was obtained using Matlab/Simulink. The results of the simulation showed that the highest value for BER with STBC was $8x10^{-5}$ and highest value for BER without STBC was $9x10^{-5}$. The highest value for SNR with STBC and the highest value for SNR without STBC were 21.78 dB and 10.84 dB while the lowest value for SNR with STBC and the lowest value for SNR without STBC were 22.23 dB and 0 dB respectively. Again, when SNR was 5 dB, the BER ($X10^{-4}$) for Binary Phase Shift Keying, Quadrature Phase Shift Keying, 8-Quadrature Amplitude Modulation, 16- Quadrature Amplitude Modulation and 64- Quadrature Amplitude Modulation was 40, 20, 4, 10 and 30 and when SNR was 10 dB, the BER($X10^{-4}$) was 4, 2, 0.4, 1 and 3. However, it was observed that OFDM model with STBC produces better performance than OFDM model without STBC. This indicated that the bit-error-rate decreases with an increase in signal-to-noise ratio and also improve the quality of service of the crowded spectrum.

1. INTRODUCTION

Spectrum in its uniqueness deals with radio waves, which exist all around everyone at all times as far as communication is concerned and this made it to be regulated. Spectrums are divided into bands by government agencies to avoid interference because once there is traffic everything stops working. Telecommunication spectrum starts from 800 MHz and goes up to 2300 MHz. Also, technology such as Wireless-Fidelity (Wi-Fi) uses 2.4 GHz and also increased up to 5 GHz band which are unlicensed bands (Hussain, 2016).

According to the global system for mobile communication (GSM) alliance, the most suitable spectrum for telecommunication is between 400 MHz to 4 GHz range and these bands are globally used for various telecommunication purposes. Actually, different standards such as GSM, wideband code division multiple access (WCDMA) and long term evolution (LTE) were developed over time to use these bands and creates an ecosystem of technology that operator can deploy. Again, lower frequencies use less power, travel further, get less affected by disturbances and provide better coverage inside buildings (John et al., 2020).

With spectrum being a finite entity, it is always in short supply, since most of the electromagnetic frequency spectrum has been assigned over the years and most of them are actively used. Shortages now exist in the cellular and land mobile radio sectors, inhibiting the expansion of services such as high data speeds as well as the addition of new subscribers, (Fawaz, 2016). One approach to solving the problem is to improve the efficiency of usage by squeezing more users into the same or less spectrum and achieving higher data rates. One of the most crowded areas of spectrum is the land mobile radio (LMR) and private mobile radio (PMR) spectrum used by the federal government, state government and local public safety agencies like fire and police departments (Ajose et al., 2018).

The radio frequency spectrum is divided into small chunks for a huge number of applications from AM and FM radio, television and cellular networks to walkie-talkies, satellite communications, military application and even to send and receive signals into outer space and hoping for a reply. Transmitters and receivers are modulated to hear only the specific programmed frequency but depending on the power and frequency, there can be bleeding which can cause interference (Fanous and Ephremides, 2014).

Some segments of spectrum are more useful than others, and those segments are essentially full. These full segments include VHF, UHF and the low microwave frequencies from roughly 100 MHz to 4 GHz. That is where cell phones, broadcast TV, wireless local-area networks (WLANs) and lots of popular short-range technologies like Bluetooth and Wi-Fi operate. Without more spectrums, there will be crisis in wireless expansion. The spectrum crisis is the lack of spectrum to expand cell-phone and broadband wireless services. Several key trends are making the problem worse growth in mobile Web access as a result of the smart phone's exceptional adoption and success and growth in the "Internet of Things" connectivity phenomenon, with wireless Machine-to-Machine (M2M) communications (Ahmed et al., 2016).

Radio frequency spectrum cannot be expanded but can only be reused under limited circumstances, and the scarcity of this resource led to the design of various modulation, coding, link adaptation and medium access control mechanisms (Mohamed, 2020).

The aim of this study is to maximize the capacity of crowded spectrum using advanced modulation and coding techniques to improve the quality of service by increasing the signal-to-noise ratio and reducing the bit-error-rate.

2. MATERIALS AND METHODS

The materials used in this paper are Hp Laptop, MATLAB/SIMULINK software and Data generator. The method adopted makes use of orthogonal frequency division multiplexing with space-time block coding and without space-time block coding.

However, in order to solve the bandwidth efficiency problem in frequency division multiplexing, orthogonal frequency division multiplexing was engaged when the different carriers were orthogonal to each other.

With OFDM, it was possible to have overlapped sub-channels in the frequency domain, thereby increasing the transmission rate. This carrier spacing provides optimal spectral efficiency and OFDM became the chosen modulation technique for wireless communications. OFDM can provide large data rates with sufficient robustness to radio channel impairments.

The implementation of OFDM with space-time block coding makes use of the BPSK, QPSK, 8-QAM, 16-QAM and 64-QAM techniques.

Alamouti was one of popular designs of orthogonal space-time block coding (OSTBC) that provides full data rate and full diversity in addition to a simple decoding. It provides a way of distributing the transmitted data among the transmitted antennas in a derivative manner to get orthogonally between transmitted signals. It sends a block of data stream in multiple parts out of multiple antennas that interleaved with conjugated version of the same data. The use of STBC for multiple-input multiple-output systems has helped to improved BER performance in the wireless systems. According to Gunjan et al., (2012), the Alamouti scheme is the first space-time block code which provides full transmit diversity for the system with transmit antennas of two and its encoding matrix form is given in Equation (1).

$$X_2 = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \tag{1}$$

where x_1 and x_2 are two different data symbols transmitted simultaneously from antennas 1 and 2. During the first symbol period, $-x_2^*$ and x_1^* are launched from antennas 1 and 2, respectively.

The maximum achievable bit-rate is referred to as the channel capacity C. The Shannon-Hartley Theorem states mathematically in Equation (2) (Abdullahi, 2019).

$$C = Blog_2\left[1 + \frac{S}{N}\right] \tag{2}$$

where C is capacity in bit/sec, S/N is the signal to noise ratio, B is the bandwidth of the channel in hertz and the logarithm is in base 2.

To eliminate the use of log 2 in Equation (2), it is converted to logarithm in base 10 as shown in Equation (3).

$$C = \frac{1}{\log_{10} 2} Blog_{10}\left[1 + \frac{S}{N}\right] \tag{3}$$

Various factors such as bandwidth and compatibility should be considered for choosing a particular modulation scheme to be used in a communication system.

The relationship between constellation points and bits per symbol is given in Equation (4) (Hussain, 2016).

$$\mathrm{M} = 2^{\mathrm{n}} \tag{4}$$

where M = number of constellation points and n = bits/symbol

$$\mathrm{n} = \log_2(\mathrm{M}) \tag{5}$$

The forward error correction (FEC) from Figures 1 and 2 consists of a reed Solomon outer code concatenated with a rate compatible inner convolutional code. The orthogonal frequency division multiplexing transmission uses 192 sub-carriers, 8-pilots, 256 point Fast Fourier Transforms (FFTs) and a variable cyclic prefix length. Also, there was a generation of random bit data that models a downlink burst which consists of an integral number of OFDM symbols (Rawat, et al., 2014). Alamouti's scheme which uses space time block coding was employed with the embedded MATLAB function blocks for both the encoder at the transmitter and the combiner at the receiver. A single OFDM symbol preamble was transmitted from both antennas and a multiple-input single output (MISO) fading channel with AWGN was used for the STBC model. The combiner for OSTBC at the receiver side provides soft information on the transmitted symbols which can be utilized for decoding or demodulation of an outer code (Lau, 2021). Also, there is a generation of random bit data that models a downlink burst which consists of an integral number of OFDM symbols. Figure 1 shows the OFDM with space time block code and modulation bank. For non-STBC model shown in Figure 2, a choice of non-fading, flat-fading or dispersive multipath receiver that included channel estimation uses the inserted preambles (Geetu et al., 2012). Both models shown in Figures 1 and 2 used an adaptive rate control scheme based on SNR estimates at the receiver to vary the data rate based on the channel conditions. When either of the two models was simulated, windows came up automatically to display the spectrum plots of the transmitted signal per antenna and a scatter plot of the received signal was obtained with respect to demodulation. Figure 2 shows the OFDM without space-time block code and modulation bank.

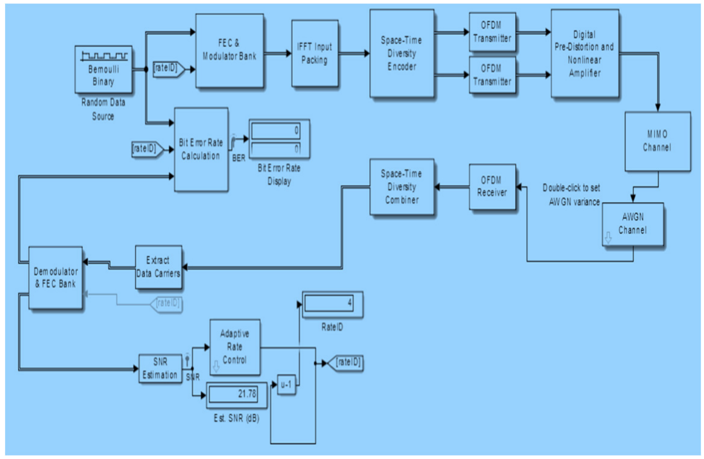

Figure 1: OFDM with space-time block code and modulation bank (Sujatha, 2012).

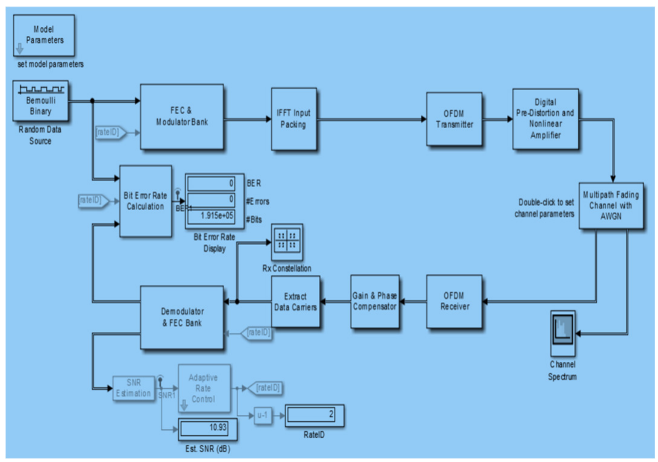

Figure 2: OFDM without space-time block code and modulation bank (Sujatha, 2012).

3. RESULTS AND DISCUSSION

The simulation results obtained indicated the bit error rate values from different modulation techniques using binary phase shift keying, quadrature phase shift keying, 8-quadrature amplitude modulation, 16-quadrature amplitude modulation and 64-quadrature amplitude modulation as shown in Table 1. The results of bit error rates and signal to noise ratios with STBC and without STBC were tabulated and shown in Table 2. The plot of BERs against SNRs is plotted for different modulation techniques as shown in Figure 3. The plots of the antenna transmission spectrum are shown in Figures 4 and 5, respectively. Figure 3 showed the plot of OFDM using various modulation techniques**.** It was observed that the performance of BER of 16-QAM was higher than the performance of BER of QPSK. This is due to the number of bit in 16-QAM when compared with the number of bits in QPSK. It was also observed that the performance of BER of QPSK was higher than the performance of BPSK (Mahalakshmi, 2018). The plot of BER against SNR showed that at the origin both BPSK, 64-QAM, QPSK, 16-QAM and 8-QAM modulation techniques decrease to the same SNR of 10 dB which corresponds to BER of 400, 300, 200, 100 and 40. This implies that 16-QAM has better BER performance than QPSK and QPSK has better BER performance than BPSK.

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Table 1: Results of OFDM with space-time block code using BPSK, QPSK, 8-QAM, 16-QAM and 64-QAM modulation techniques

SNR	BER ($x10^{-4}$) using BPSK	BER ($x10^{-4}$) using QPSK	BER ($x10^{-4}$) using 8-QAM	BER ($x10^{-4}$) using 16-QAM	BER ($x10^{-4}$) using 64-QAM
0	400.0000	200.0000	39.8679	100.0000	300.0000
1	252.3829	126.1913	25.2385	63.0957	189.2872
2	159.2429	79.6214	15.9434	39.8107	119.4322
3	100.4755	50.2377	10.0475	25.1189	75.3566
4	63.2957	31.6979	6.5596	18.8489	47.5465
5	40.0000	20.0000	4.0000	10.0000	30.0000
6	25.2313	12.6191	2.5258	6.3096	18.9287
7	15.9243	7.9621	1.5924	3.9811	11.9432
8	11.0475	5.0238	1.0042	2.5119	7.5357
9	6.3396	3.1698	0.6340	1.5849	4.7847
10	4.0000	2.0000	0.4000	1.0000	3.0000

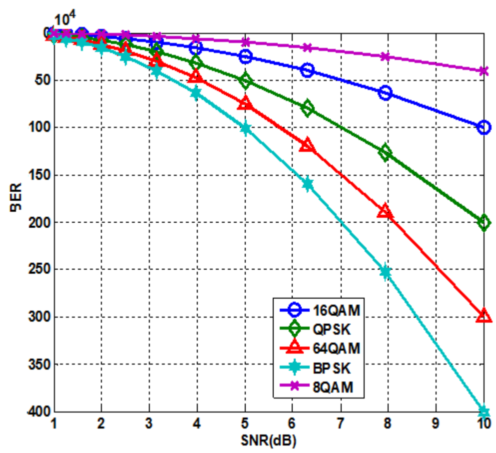

Figure 3: Graph of OFDM using various modulation techniques

In Figure 4, the total modulation scheme of the spectrum with a space time block code represents the size of multiple input-multiple output antennas with its frequencies. To provide frequency guards between channels and to ensure that the signal of one sub-channel did not overlap with the signal from an adjacent channel, pilot carriers were introduced between the different sub-channels for channel tracking and synchronization (Sadeque, 2015). The plot of antenna against frequency indicates that -88, the signal radiates linearly and overlapped with a noisy signal between -72 to -57 and further decreases to a frequency of 0.9. Again at -80, the signal radiates linearly and overlapped with a noisy signal between -74 to -55 and further decreases with a noisy signal between -74 to -55 and further decreases a frequency of 0.9. This showed that the presence of the guard bands mitigated inter-channel interference and increasing of the number of guard bands will increase the channel bandwidth. In Figure 5, the plot of antenna against frequency indicates that the signal radiates linearly from -159 to -58 and produces a noisy signal between the frequency range of -1.4 and -1.6 and then decreases to a frequency of 2. This is an indication that there will be inter-channel interference due to inefficiencies of the guard band. To ensure that the signal of one sub channel did not overlap with the signal from an adjacent channel, some guard-band was left between the different sub channels and this guard-band led to inefficiencies (Mahalakshmi, 2018).

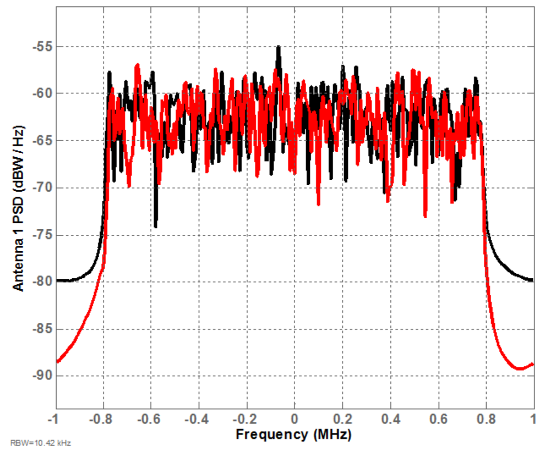

Figure 4: Antenna transmission spectrum with STBC

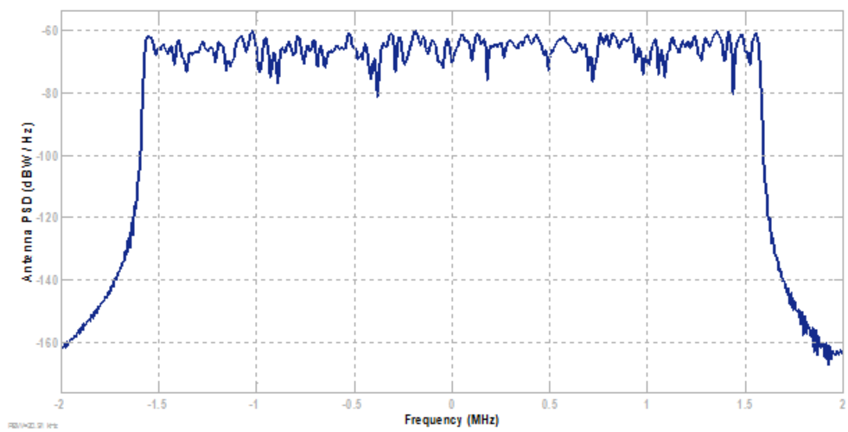

Figure 5: Antenna transmission spectrum without STBC

Table 2: Results of bit-error-rate and signal-to-noise ratio with and without space time block code

BER ($x10^{-4}$)	SNR with STBC	BER ($x10^{-4}$)	SNR without STBC
0	22.23	0	0
1112	22.11	7608	11.04
9496	22.16	15620	10.90
38910	22.29	44220	10.93
75590	22.58	84260	11.15
119400	22.05	125400	10.99
125700	22.34	163200	10.96
154300	22.42	198300	10.92
171100	21.90	244000	11.02
199600	21.99	284500	11.00
234400	21.46	323400	11.01
248900	22.04	362600	11.00
280300	21.87	405700	10.90
298200	21.61	442700	10.82
314200	21.68	485800	11.06
334300	21.73	564000	11.14
345800	21.78	711600	10.84

Figure 6 showed the graph of bit-error rate against time with and without STBC. At the origin, the signal without STBC increases linearly with a higher BER of 9 x 10^5 than the signal with STBC which increases linearly with a lower BER of 8 x 10^5. This implies that OFDM with STBC has better BER performance than OFDM without STBC. When this was compared with previous studies (Ajose, et al, 2018), it was observed that there was an increase in BER without STBC which reduces the quality of signal. Also, it was observed that there was an improvement in the quality of signal with STBC which reduces the BER. Figure 7 showed the graph of SNR against BER with and without STBC. It was observed that there was a reduction in bit-error-rate as the SNR increases. When compared with previous studies (Lau, 2021), it was observed that the SNR had the highest value of 22.58dB with STBC which increases the quality of signal of crowded spectrum and the lowest value of 11.15dB without STBC with an increase in BER. There is a significant reduction in BER as the SNR increases which is an indication that OFDM with STBC performs far better than OFDM without STBC.

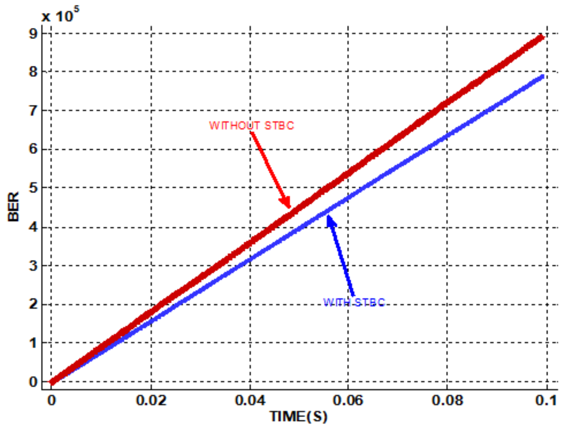

Figure 6: Plot of bit error rate with and without STBC

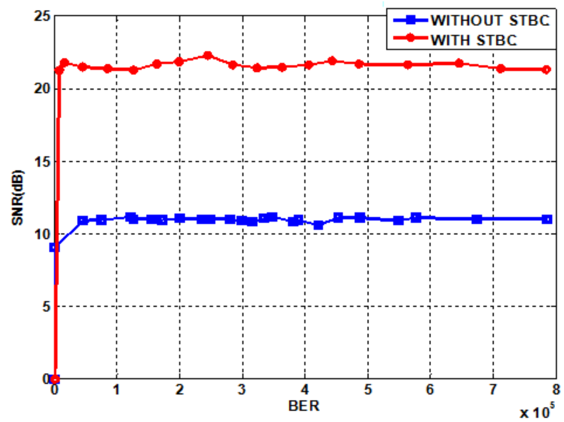

Figure 7: Plot of SNR against BER with and without STBC

4. CONCLUSION

The performance of space-time block codes depends on the type of modulation schemes, number of transmitted and received antennas. Complex modulations give better bit-error-rate performance than real modulation and this occur when the number of transmitted antennas is more than two. However, space-time block code with real modulation will have better bandwidth efficiency than complex modulation. This is because space-time block codes with real modulation require less transmitting data than space-time block codes with complex modulation. Again, OFDM makes efficient use of available spectrum by allowing overlapping among the carriers. This converts the high data rate stream into several parallel lower data rate stream and eliminates the frequency selective fading. It was observed that OFDM is a powerful modulation technique with high data rate that can eliminate Inter Symbol Interference (ISI).

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Abdullahi, M. B. (2019). Evaluation of BER performance of FFT- OFDM for Wireless Communication Networks. *International Journal of Engineering Technologies and Management Research, (IJETMR),* 6(2), pp. 14-26.

Ahmed, S., Mahmoud, M. E., Ahmed, S. and Ahab, A. (2016). Partial Contention Free Random Access Protocol for M2M Communication in LTE Networks. *Journal of Wireless Networking and Communications,* 6(3), pp. 66 -72.

Ahmed, M. F., Ahmed, M. Faysal and Abuzafor, T.I (2021) Comparison of Bit Error Rate Performance of various Digital Modulation Schemes over AWGN and Rayleigh fading Channels using Simulink. *International Journal of Ambient Systems and Applications (IJASA),* 9(2), pp. 7-16.

Ajose, S. O., Imoize., A. L. and Obiukwu., O. M. (2018). Bit Error Analysis of Different Digital Modulation Schemes in Orthogonal Frequency Division Multiplexing Systems, *Nigerian journal of technology*, 37(3), pp. 727-734.

Geetu, H. S. and Singh, M. (2012). Optimization Method for Analysis of Bit Error Rate with BPSK Modulation Technique. *International Journal of Scientific and Engineering Research, (IJSER)*, 3(6), pp. 1-4.

Gunjan M., Alka K., and Sanjeev K. (2012). Performance Analysis of STBC-OFDM System Under Multipath Fading Channel, *International Journal of Soft Computing and Engineering (IJSCE)* ISSN: 2231-2307, Volume-1, Issue-6

Fawaz, A. (2016). A New Wireless Sensor Network Scheme to Provide Quality of Service (QoS) for Smart Grid Applications. *Journal of wireless networking and communications,* 6(3), pp. 57-65.

Fanous, A. and Ephremides, A. (2014). Enhanced access schemes based on channel statistics for cognitive wireless networks. *IEEE International Symposium on Information Theory,* pp. 1406-1410.

Hussain, N. A. (2016). A performance Analysis of E-learning over WIFI-based long Distance *Network. Journal of Wireless Networking and Communications,* 6(4), pp. 85-93.

John, A. K., Efstathios, S., Apostolos, X., Konstantinos, K., and Georgios, S. (2020). Mobility Tracking of Signaling Optimization in Mobile Networks. *Journal of Wireless Networking and Communications,* 10(1), pp. 17-21.

Lau, C. (2021). Performance of MIMO Systems using Space Time Block Codes (STBC). *Open Journal of Applied Sciences*, 11, pp. 273-286.

Mahalakshmi, R. (2018). Performance Evaluation of Various Digital Modulation Schemes for Efficient Wireless Mobile Communication System. *International Research Journal of Engineering and Technology*, 5(9), pp. 381-384.

Mohamed, H. E. (2020). Robust MIMO Detection for Non-Gaussian Channels, *Journal of Wireless Networking and Communication,* 10(1), pp. 1-8.

Rawat, P., Kamal, D. S., Hakima, C. and Jean, M. B. (2014). Wireless Sensor Networks: A survey on Recent Developments and Potential Synergies. *The Journal of Supercomputing*, 68(1), pp. 1-48.

Sadeque, M.G. (2015). Bit error rate (BER) comparison of AWGN channels for different types of digital modulation using MATLAB Simulink, *American Scientific Research journal for Engineering, Technology and Sciences (ASRJETs)*, 13(1), pp. 61-71.

Sujatha, B.R. (2012). Space Time Block Coding (STBC) for Wireless Networks. *International Journal of Distributed and Parallel Systems (IJDPS)*, 3, pp. 183-195.