International Journal of Engineering & Technology, 7 (4) (2018) 3710-3721

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v7i4.21060
Research paper

Performance analysis of OFDM system in AWGN and practical Rayleigh fading channels

Ghadeer1 Haider Iskander [1] *, Ahmed N. Jabbar [1], Ibrahim A. Murdas [1]

[1] *University of Babylon, College of Engineering, Dept. of Electrical Eng*
**Corresponding author E-mail: dr.ibrahim_ba@yahoo.com*

Abstract

In this work, a multi-parameters OFDM communication system has been simulated to analyze and study the performance and behavior of the OFDM over practical distorting noisy channels. The analysis covered in this research includes the QAM-levels, the SNR, and the number of the FFT subcarriers. These parameters were tested over practical ITU channels to examine the OFDM performance under mildly distorting channel using the In-Door channel, moderately distorting channel using the Out-Door channel and severely distorting channel using the GSM channel models. The performance was measured using the Bit Error Rate (BER). This analysis includes for the first time the connection between these various parameters; the SNR, the subcarriers and the QAM levels, into three dimensional surface to give the reader a deep sight to the OFDM behavior. Adding to that, we introduced the connection between the QAM-levels and the Peak to Average Power Ration (PAPR) and why sometimes we should resort to higher QAM-levels despite the increase in BER. This research, also, describes step by step the creation of practical OFDM system using the Simulink for further analysis.

Keywords: *Wireless Communication; OFDM; QAM; AWGN; Rayleigh Channel; Multipath; PAPR.*

1. Introduction

Modern communication systems are competing to offer high bit rate transmission. These high bit rates can offer the user more services and in return increase the communication companies' revenues. Adding to that the higher the bit rate the more utilization for the channel spectrum. The channel can be defined as any medium capable of transporting the data from the transmitter to the receiver. These channels, like any other system, has a finite bandwidth with linear and nonlinear parts. Increasing the bitrate will push the transmission to overlap with the channel nonlinear part which leads to a higher Bit Error Rate (BER) [1]. Therefore, the communication systems should adhere themselves to the linear part all the time. Hence, to increase the throughput in such concise bandwidth, the spectrum should be fully augmented with data. The augmentation can be accomplished through the share of the available channel with the users. The share is coordinated using two different parameters that are the time and frequency.

When the frequency is used to share the channel, this type of communication system is called Frequency Division Multiplexing FDM. In FDM, the channel is subdivided into smaller frequency slots and each slot is assigned to a user that can use all the time. This type of multiplexing is simple cheap but the utilization is poor. Therefore, to increase the channel utilization, the engineers devised a new technique by which the whole channel spectrum is assigned to a single user for a certain slot in time. This is called the Time division Multiplexing TDM. The appearance and spread of the digital signals helped a lot in the spread of the TDM. This type has a high utilization but suffers from complexity and high sensitivity to multipath. Another type of multiplexing appeared recently that is the Code Division Multiplexing (CDM), which adopts the spread spectrum technique to enable the users to use the complete channel spectrum all the time. Nevertheless, this technique has the lowest efficiency due to the limited number of user that is governed by the spreading code efficiency [2].

The channels are diverse and come with different media. The most widely used channel is the wireless channel in which the data are transmitted into the free space. These wireless channels are the most important types of channels because they are very cheap, dependable, and available with high bandwidths. Despite that, the free space channels suffers from different type of impairments that bounds the transmission rates. The most important impairments are the Additive White Gaussian Noise (AWGN) and the multipath. The AWGN is a normally distributed independent random variable that carry no information and tends to embed itself with the transmitted data causing them to be lost. The sources of noise are either man made, like electric generators and transmission lines, or natural sources like the sun or the atmosphere [3].

The multipath is a more complicated impairment that originates from the physical phenomenon that are the reflection, refraction and diffraction. When the electromagnetic signal falls on an obstacles on its way, like buildings, trees, mountains they will be subjected to the above mentioned phenomenon. These phenomenon will create a miniaturized copies of the original signal with different phases. The multipath will direct these copies towards the receiver with a time delay depending on the path length causing the copies to collide with other data resulting in what is called Inter-Symbol Interference ISI. The ISI is in another word a self-convolved signal with time causing a deterioration in signal quality. The higher the bit rate the worse the ISI effect will be. In this sense, we have to compromise the bit rate with the signal quality.

To overcome the damping effect of the ISI on the high bit rates, the engineers developed a new technology for modulating the signal that is called the Orthogonal Frequency Division Multiplexing OFDM [4].

The OFDM by its origin of creation ensures high bit rate with minimum ISI effect. Therefore, it was presented as a revolutionary transmission system to handle the extreme bit rates of the 4G (fourth generation) technology [5]. The OFDM concepts will be discussed in the following section

2. OFDM model

The OFDM is based on an early system that was used frequently which is the FDM. The basic idea of the OFDM is also based on dividing the available channel bandwidth to a narrower bandwidth slots and assign a carrier to each slot. The term Orthogonal frequency division multiplexing refers to the fact that these sub carries should be orthogonal to each other which consequently are allowed to overlap without any interference. The researchers found a solid relation between the ISI and the increase in the bit rate. Therefore, the OFDM came with a very brilliant idea by which is to trick the system to work with lower bit rates even when the incoming stream has a high bit rate [6]. To explain this conflicting concept consider a typical OFDM system block diagram shown in Fig. 1

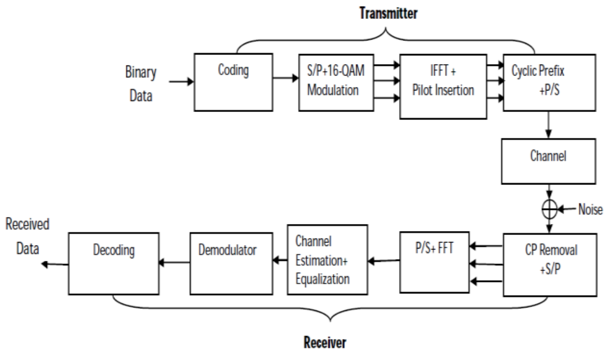


Fig. 1: The Block Diagram of a Typical OFDM System.

In the OFDM system, the high bit rate serially injected data are converted to a multiple parallel streams. As a result, the parallel streams will have a lower bit rate than the original data. The down conversion factor is given by Eq. 1

$$D_f = \frac{R}{P} \tag{1}$$

Where:
R: is the serial stream rate.
P: is the parallel output lines.
After generating the parallel streams, these streams are then mapped using any modulation scheme such as QAM or PSK. After mapping the parallel data, each parallel data is assigned a separate carrier. These carriers are generated such that each one of them is orthogonal to the rest. To generate a series of orthogonal carries, the Inverse Fast Fourier Transform (IFFT) is used as shown in Eq. 2

$$s(t) = \sum_{k=1}^{N} s_k \exp\left(j2\pi k f_k t\right) \tag{2}$$

Where:
s_k : The input sampled data.
f_k : is the instantaneous subcarrier $f_k = \frac{BW}{P}$, BW is the channel bandwidth.
The FFT by its mathematical formulation, converts any signal to it equivalent frequency components such that each component is spaced by 2f0 where f0 is the fundamental frequency as it behaves as a running filter bank. Given that $T = \frac{1}{f_o}$ and by using the Nyquist theorem we have $T = \frac{2}{BW}$ then

$$s(pT) = \sum_{k=1}^{N} s_k \exp\left(j2\pi \frac{kp}{P}\right) \tag{3}$$

Where:
pT: is the subcarrier allocation in the channel.
p: is the instantaneous subcarrier.
The output spectrum of the OFDM signal is shown in Fig. 2

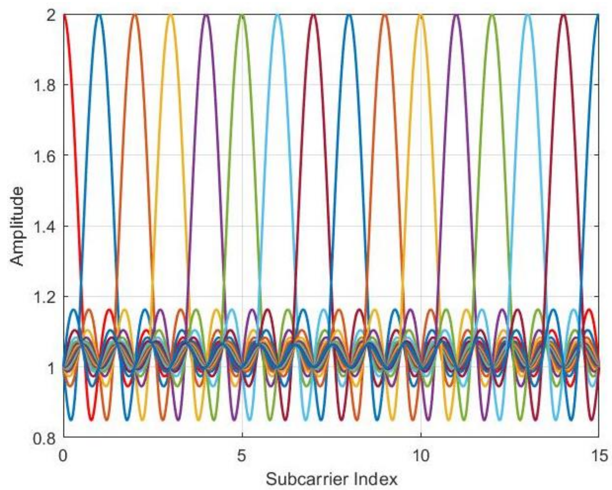


Fig. 2: The OFDM Signal Spectrum for 16 Subcarriers.

After generating the OFDM signal, a Cyclic Prefix CP is added to simplify the removal of the channel nonlinearity. At the receiver, this CP is removed or used with the equalizer as a training stream. The next stage is to demodulated the incoming signal (de-map) to acquire the time domain signal. After that, the signal is fed to the FFT circuit to reverse the IFFT transformation and retrieve the original data. The output of the FFT is then converted from parallel to serial to be directed to the users.
From Fig. 2, we can see the superiority of the OFDM to the other modulation techniques because it allows the occurrence of multiple signal at the same location without interference. This is the compact form of transmission that allows the channel augmentation.

2.1. PAPR in OFDM signal

The Peak to Average Power Ratio is one of many challenges facing multi carrier modulation systems. Due to the fact that many carriers exist at the same time, these carriers tend to overlap with each other creating a high peak pulse that will affect the performance of the system. The PAPR can be expressed as in Eq. 4 [7-8]:

$$\mathrm{PAPR} = 10\log_{10} \frac{\text{Peak power}}{\text{Average power}} \tag{4}$$

Assume a complex modulated signal s(t) having a single tone then Eq. 4 can be written as Eq. 45 in dB

$$\mathrm{PAPR} = 10\log_{10}\left(\frac{\max\left[s(t)\cdot s^*(t)\right]}{\mathrm{E}\left[s(t)\cdot s^*(t)\right]}\right) \tag{5}$$

The * means the complex conjugate of the signal. The s(t) can be expressed as $s(t) = e^{j2\pi f}$ then its maximum equals to 1. The expected value will also be 1. For m complex carriers signal s(t), the max(s(t))= m2, while its average is m. The PAPR in this case will be m. Therefore, the increase in the number of the subcarriers yields in the increase of the PAPR. This will limit the utilization of the OFDM because we should be careful when designing the OFDM system [9-12].

3. Channels model

The channels, as said before, are the medium that is responsible to deliver the data from the source to the destination. Therefore, the channel should be efficient and dependable as much as possible. The performance of any communication system depends mainly on the channel characteristics. The channel in its nature is a dynamical system that fluctuates randomly affected by the environment changes. Hence, the estimation of the channel impulse response is crucial in order to take the required measure and complete the communication system settings to acquire maximum performance. The most important factors in the channel that should be studied thoroughly are the noise and the multipath [13-16].

3.1. AWGN and Rayleigh channel

The Additive White Gaussian Noise (AWGN) are unwanted signals that carry no information. When these signals are mixed with the data signals, the will mask and deform the received information. When the noise level is high, they will overwhelm the data power causing them to disappear. These independent random variables are called Gaussian because the follow the normal (Gauss) probability density function according to the central limit theorem. Additive comes from the fact they insert themselves additively with the signal as shown be Eq. 6. The term White come from the fact they cover the entire spectrum from $-\infty$ to ∞ like the white light that contains all the colors.

$$r(t)=s(t)+n(t) \tag{6}$$

Where:
S (t): is the transmitted signal
N (t): is the noise signal
It is important to understand how the noise will affect and behave with the complex signal. If we assume the transmitted signal has a real and imaginary part $s(t)=e^{j2\pi f}$, the then [17-20]

$$\begin{aligned} r(t)&=s(t)+n(t)=e^{j2\pi f}+n(t) \\ &=\mathrm{Re}\left[s(t)+n_R(t)\right]+\mathrm{Im}\left[s(t)+n_I(t)\right] \end{aligned} \tag{7}$$

Eq. 7 shows that there are two components for the complex noise that are $n_R(t)$ and $n_I(t)$. Assume a complex random variable Z that contains the real and imaginary parts of the noise $X=n_R(t)$, $Y=n_I(t)$ then Z is $Z=X+jY$. Any random vector is characterized by its mean and variance then the mean of Z is given by Eq. 8

$$E[z]=E\left[e^{j\theta}Z\right]=e^{j\theta}E[Z] \tag{8}$$

Eq. 9 gives the Z variance

$$\sigma^2=E\left[Z^2\right] \tag{9}$$

Substituting Eqs. 8 and 9 in the Gaussian distribution we have the resultant distribution for Z as shown by Eq. 10

$$pdf(Z)=\frac{Z}{\sigma^2}e^{\frac{-Z^2}{2\sigma^2}} \qquad Z\geq 0 \tag{10}$$

Eq. 10 shows that the complex noise will follow the Rayleigh distribution at the receiver envelop detector.

3.2. Multipath channel

The commercial communication systems are usually a point to multi point system because they are trying to deliver the data to as many users as possible. This will increase the channel utilization and reduce the service costs. Therefore, the free space is a luring choice for transmission of these systems. Nevertheless, the signals will fly around in the free space boundlessly. When these signals fall on an obstacle such as buildings, houses, forests or mountains the will be reflected back to the receiver as shown in Fig. 3. At the receiver, these reflected signals will collide with the incoming signals. Unfortunately, the reflected signals normally follow a longer path. Hence, they will arrive with a time delay τ_i. This means, the receiver will detect the current data plus copies from previously arrived data. This is what is called the Inter-Symbol Interference (ISI).

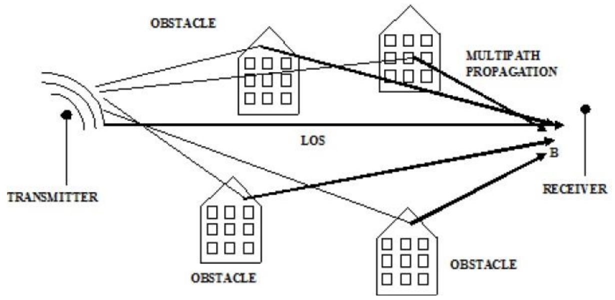


Fig. 3: The Multipath Model of a Transmitted Signal.

The multipath channel are modeled using the delay line model as shown in Fig. 4

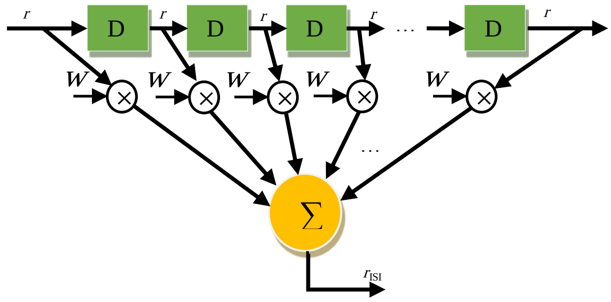


Fig. 4: The Delay Line Model of a Multipath Channel.

The model in Fig. 4, suggests that the received signal r_{ISI} is the sum of the current incoming signal r_0 and the previously stored signals r_i by the delay banks D_i. The weights w_i represent the attenuation in the signal power due to absorption, scatter or refraction along their paths.
There are two main types of the ISI channel which are the Rayleigh and Rician types. When the transmitter is not in the line of sight of the receiver, then the model used for this kind of link is the Rayleigh model. When the transmitter is in the line of sigh of the receiver the Rician model is used. Practically, the fastest reaching signal is considered the reference for the other trailing signals.
The characterization of the ISI channels is not an easy and straight forward task due to many parameter that affect the response of the channel. These parameters are relative motion, the relative heights, the weather, the heat and the type of the reflective material. The ITU published a recommendation describing the different types of widely used standard channels [21]. The characterization of the channel is accomplished by transmitting a probe reference signal and detect its arrival to the destination with the delayed version of it. The probing is done with a constant time period that is called the differential delay. The differential delay is a description for the test resolution for the channel response. The ITU have chosen the 50 nS ad a differential delay for the In-Door and Out-Door channels and 100 nS for the GSM long haul channel. These three channels are simulated and used in this research.

4. Modulation technique

The modulation technique describes the method by which the incoming data are translated to their equivalent carrier version. The mapping should ensure that each data message has its unique carrier version. This mapping is called a point to point mapping. The sinusoidal signal is characterized by its amplitude, phase and frequency. When one of these parameter is varied according to the incoming information level then this is called mapping or modulation. Basically, there are three types of modulation which are Amplitude Modulation (AM), Phase Modulation (PM), and Frequency modulation (FM). A hybrid type of modulation that is Quadrature Amplitude Modulation (QAM) combines two parameters to modulate the input data that are the amplitude and phase. Fig. 5 shows an example of QAM modulation for the 16 level constellation.

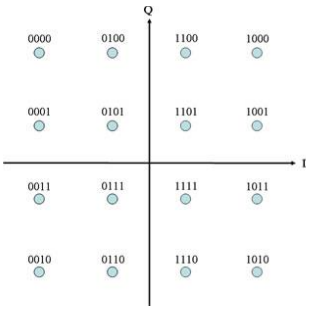


Fig. 5: 16 Level QAM Map.

Fig. 5 shows that each symbol contain 4 bits and each symbol has its unique phase and amplitude. The incoming symbol will select one of the levels according to its bit pattern. After that, the symbol is projected to the I-Q (real, imaginary) axes to set the carrier in phase and quadrature phase amplitudes [cos(ωt), sin(ωt)] pair. This pair has orthogonal components thus we can transmit both of them at the same simultaneously without interference.
At the receiver, the de-mapping circuit will compare the amplitudes of the incoming carrier pair to the map of Fig. 5 to choose their corresponding symbol.
The QAM modulation is the primary choice for the dense high rate data transmitters because the QAM has the highest spectral efficiency among the other techniques. Therefore, we shall simulate the data using the QAM technique because it is the most practically used scheme [1].

5. Simulation model

The OFDM system is developed, simulated and analyzed using MATLAB Simulink environment. The BER is calculated for different modulation QAM levels and for different subcarriers systems over an AWGN and Rayleigh Fading channel models.
We focused on 3 different issues regarding analysis. Those are the signal constellation, the number of subcarriers and the level of ISI. The number of transmitted bits are 10^6 bit to calculate the BER for the 10^{-6}. The delay line model is used to simulate the response of the multipath channels in this research.

6. Results and discussion

The simulation is set to test the OFDM for various subcarriers (16, 32, 64, 128 and 256). Figure 6 shows the used OFDM system for the 16 carriers FFT OFDM system. The same system and its internal settings are expanded according to the requirements of the higher number of the subcarriers. This section will discuss the system design criteria and how it is created

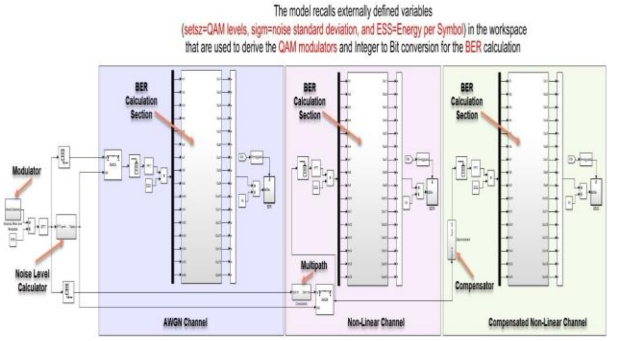


Fig. 6: The Simulation System for the 16 Carriers OFDM.

The system of Fig. 6, consists of 3 main sections which are, the OFDM subjected only to AWGN in the first section, the second section has the multipath channel without compensation and the last section is the same as the second section but with channel compensation for the multipath channel. The modulator of the system is shown in Fig. 7.

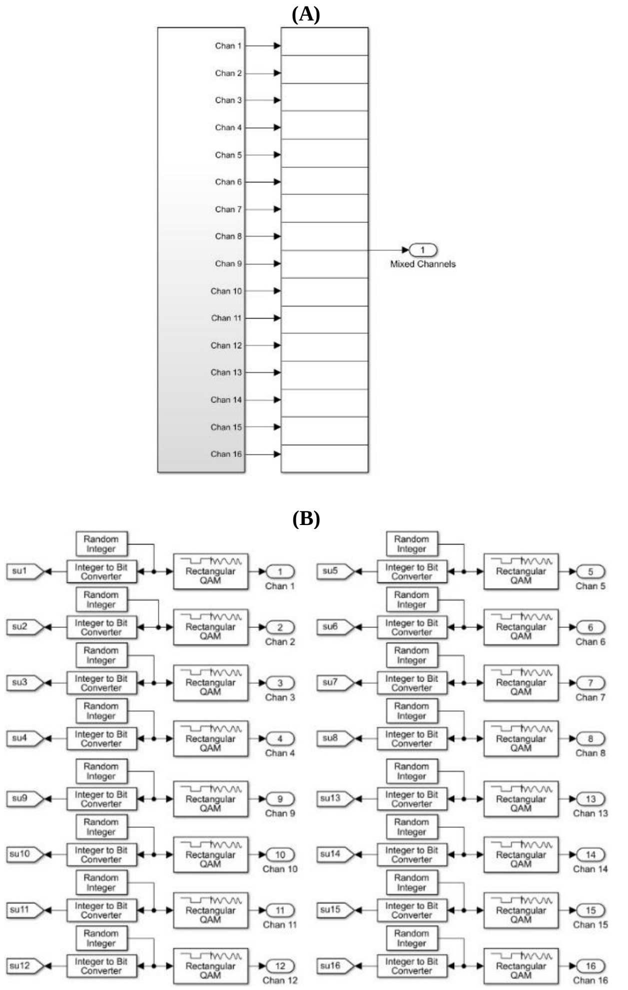


Fig. 7: The OFDM Modulator. A) the Transmitter Main Sections, B) the Symbol Generator inside Settings.

This modulator has two main parts, which are the symbol generator and the symbol concatenate. The Symbol generator comprises of 16 uniform random number generators connected to the integer to bit converter to analyze the system according to the BER. The generated symbols are then modulated using QAM modulator. The generated modulated symbols are then concatenated to generate the OFDM symbol of length 16. After generating the OFDM symbol, its power should be normalized by dividing the whole symbol by its maximum power of the QAM symbol ESS. The maximum power for the QAM are, ESS= [2, 10, 20, 42] for the 4, 16, 32 and 64 levels respectively. After normalizing the power, the symbols are sent serially through the AWGN channel. The AWGN channel noise power are calculated instantaneously for each OFDM symbol using the block shown in Fig. 8

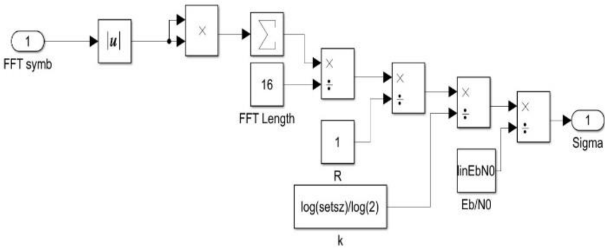
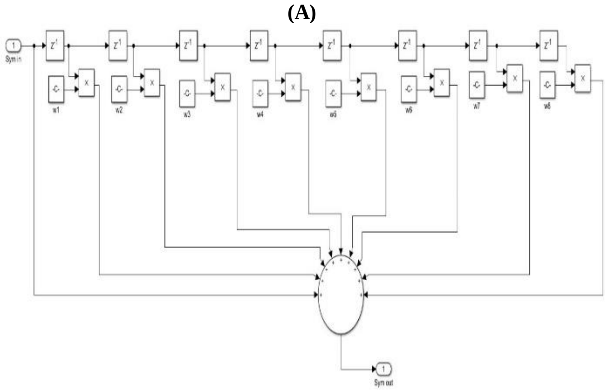


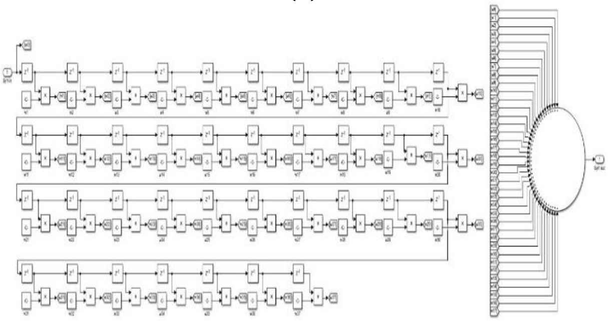
Fig. 8: Noise Power Calculator.

The power of the incoming OFDM symbol is first calculated then divided by the number of subcarriers to ensure each carrier has an equal power. Then, the effect of guard bands and nulls are also included with the coding symbols using the value of R. Here these nulls, guard bands and coding are not considered therefore, the value of R=1. To distribute the power evenly for all the bits of the transmitted bits, the normalized power of the OFDM symbol is divided by the by the number of bits per symbol of the QAM symbol. When this operation is complete, the value of σ is calculated using the defined linear value for $\frac{E_b}{N_0}$. The calculated σ is then used to set the noise power level in the AWGN block. When this step is completed, the symbols are fed to the multipath channels. In this research, we simulated 3 practical ITU-R channel for slight, moderate and high distorting multipath channels that are the In-Door, Out –Door, and GSM channels. The models of these channels are shown in Fig. 9, a, b, c respectively. The taps of the In-door and Out-Door channels are calculated using differential delay of 50 nS while the GSM channel differential delay is 0.1 μS. The modulation carrier is 15 MHz.

(A)



(B)



(C)

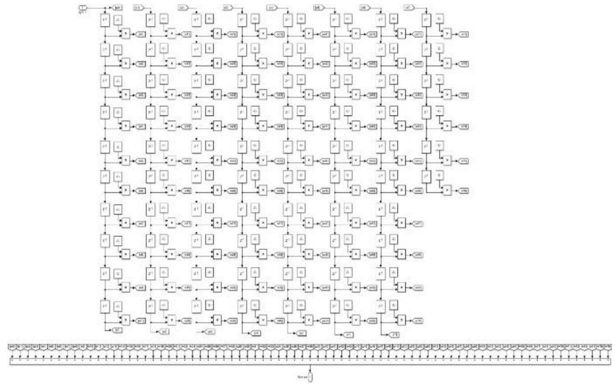
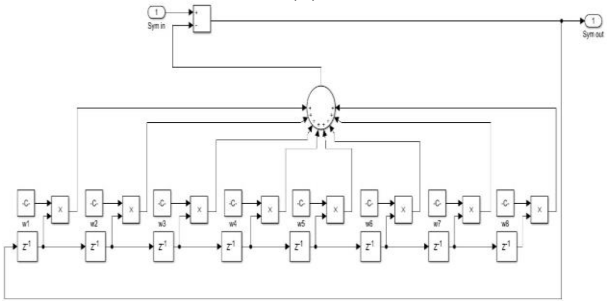


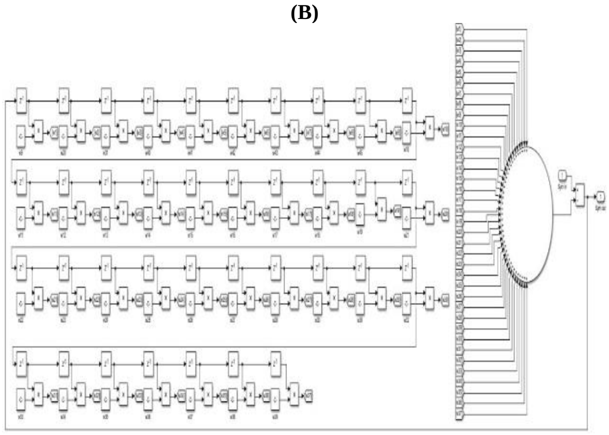
Fig. 9: The Multipath Channels. A) the in-Door, B) the Out-Door, C) the GSM Channels.

The final part in each section is the receiver. The last section in Fig. 6 uses compensation to counteract the effect of the multipath. The compensation for the above channels are shown in Fig. 10

(A)



(B)



(C)

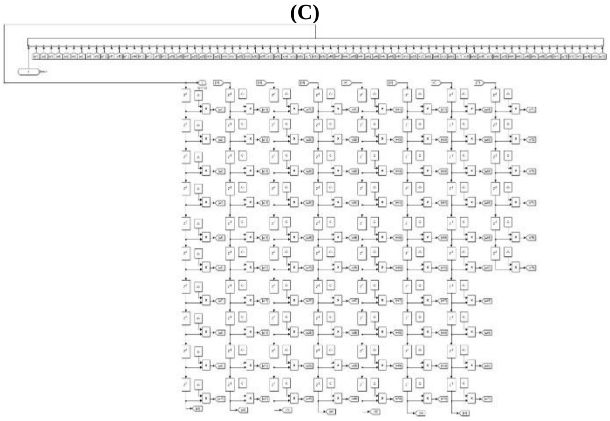
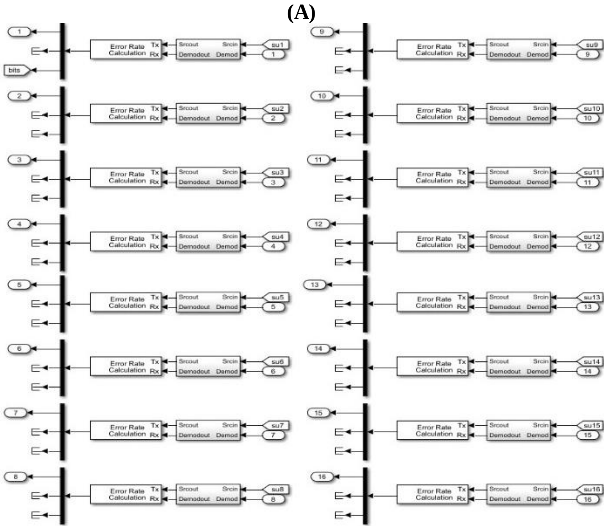


Fig. 10: The Compensation Circuits for the Multipath Channels. A) the in-Door, B) the Out-Door, C) the GSM Channels.

These compensators acts as deconvolutions circuits of the distorted OFDM symbols. The final stage in the receiver is shown in Fig. 11.

(A)



(B)

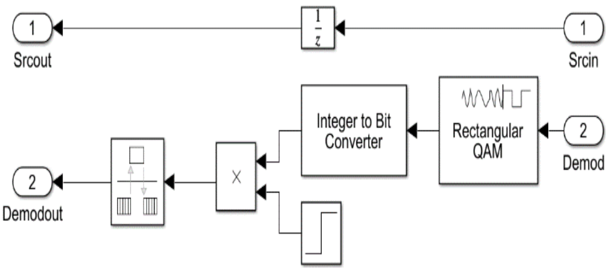
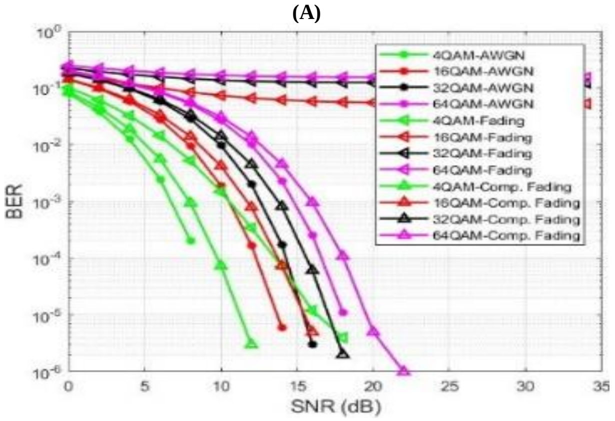


Fig. 11: The Final Part of the Receiver. A) the Complete Receiver, B) the QAM Demodulator.

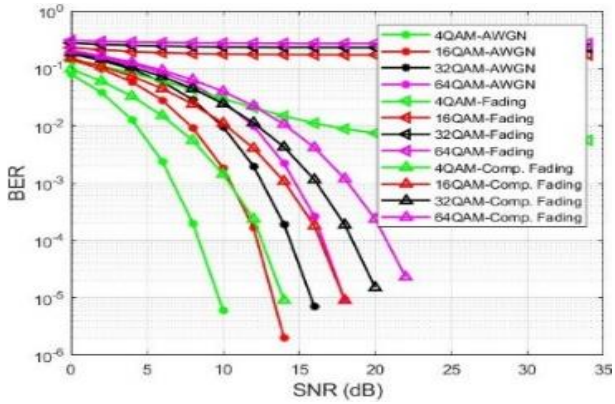
After demodulating the QAM symbol, the resulting value is converted to bits and XORed with the actual bits to calculate the BER. The total transmitted bit. The simulation is carried out for the following settings which are, the QAM levels are, 4, 16, 32 and 64, the subcarriers 16, 32, 64, 128 and 256 and finally the SNR ranges from 0 to 34 step 2. The following results represent the output of the simulation according to the channels.

1) The In-door channel. The Fig. 12 is the performance of the OFDM for various settings over the In-Door channel

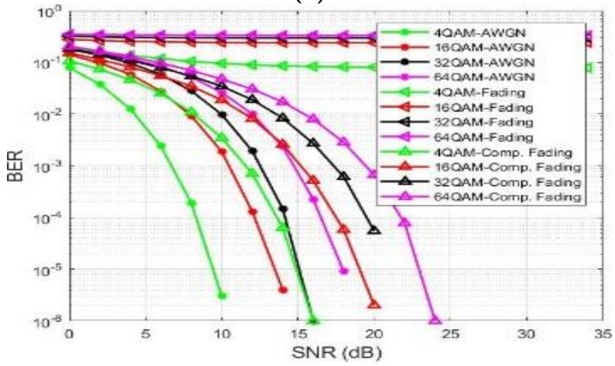
(A)



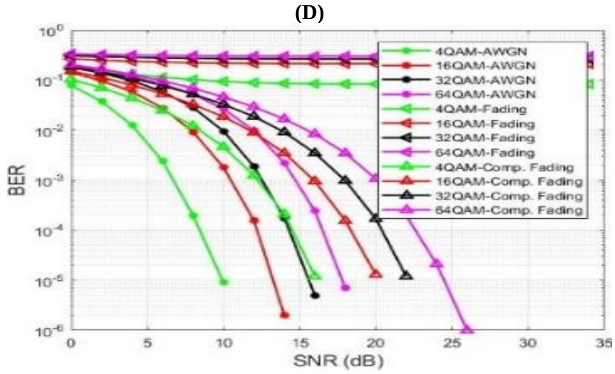
(B)



(C)



(D)



(E)

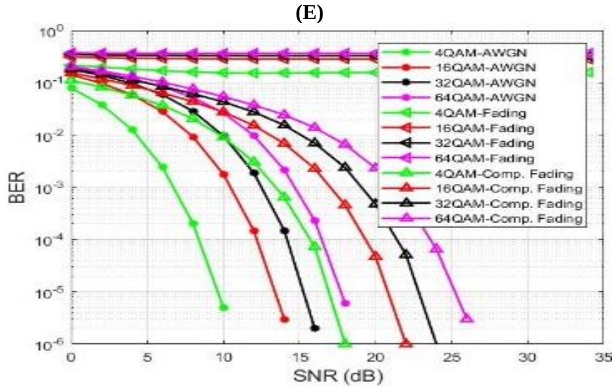
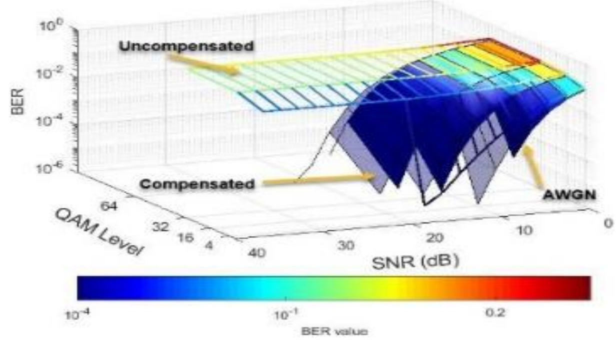


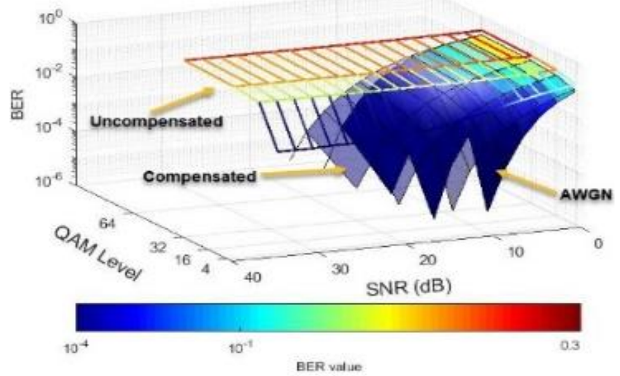
Fig. 12: The OFDM Performance over the in-Door Channel. A), 16 Subcarrier FFT, B), 32 Subcarrier FFT, C), 64 Subcarrier FFT, D), 128 Subcarrier FFT, E), 256 Subcarrier FFT.

Figure 13 represents the connection between the BER with the subcarriers and the QAM levels. The relation creates a three dimensional surface. As it can be seen the uncompensated BER is almost the same for all figures which means all the symbols are in error. The maximum possible error is 0.5 which is a reasonable result due to the collision between the original symbol and the reflected copies. The difference between the AWGN BER and the multipath BER represents the channel power

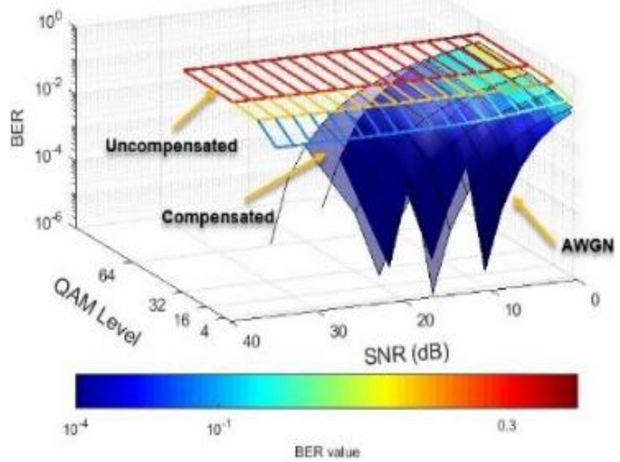
(A)



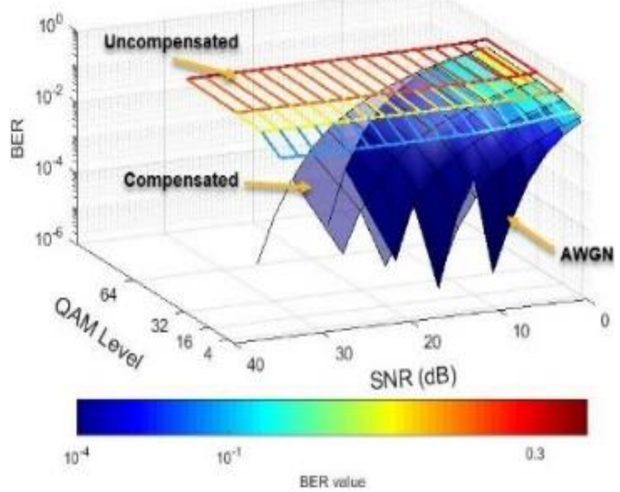
(B)



(C)



(D)



(E)

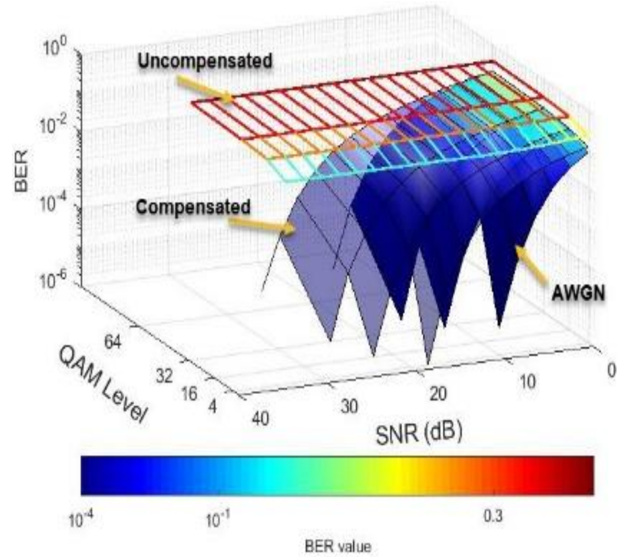
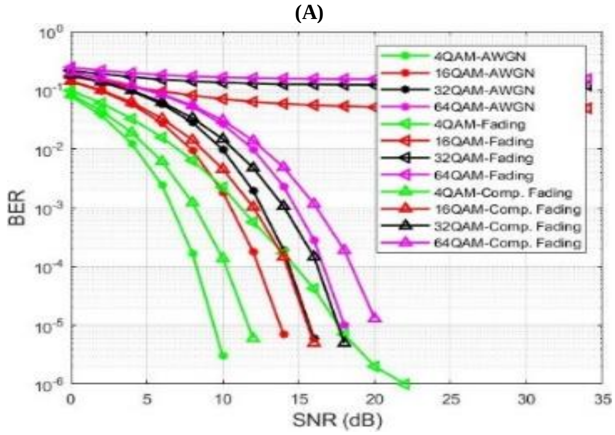


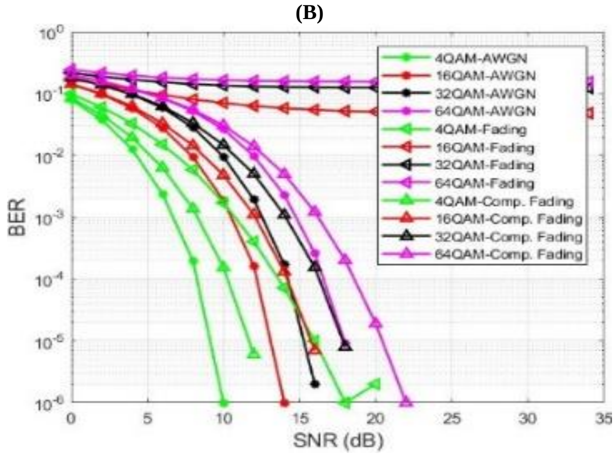
Fig. 13: The OFDM BER Relation with QAM Levels and the OFDM Subcarriers In-Door Channel. A), 16 Subcarrier FFT, B), 32 Subcarrier FFT, C), 64 Subcarrier FFT, D), 128 Subcarrier FFT, E), 256 Subcarrier FFT,

2) The Out-Door channel. The Out-Door channel is used to test the moderate effect of the multipath channel. The effect of the multipath increases with the increase of the reflection points distances. The Out-Door channel has longer distances, therefore; its effect is worse than the indoor channel. The OFDM performance is shown in Fig. 14

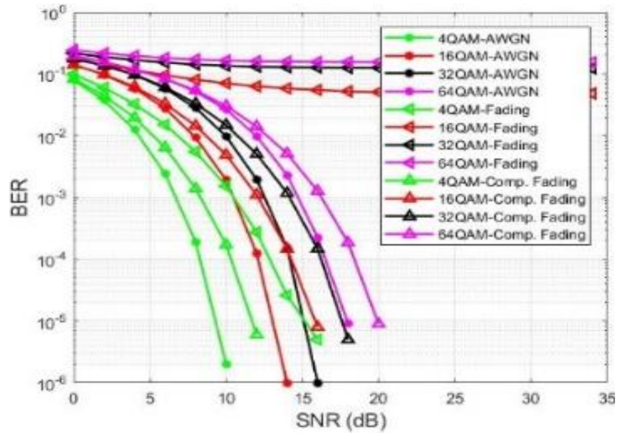
(A)



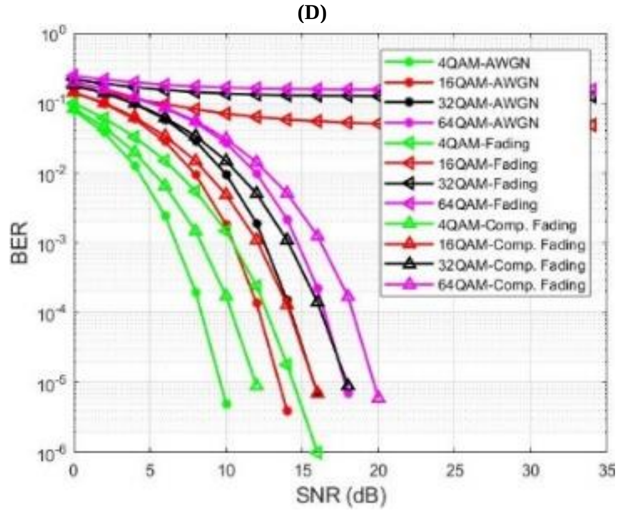
(B)



(C)



(D)



(E)

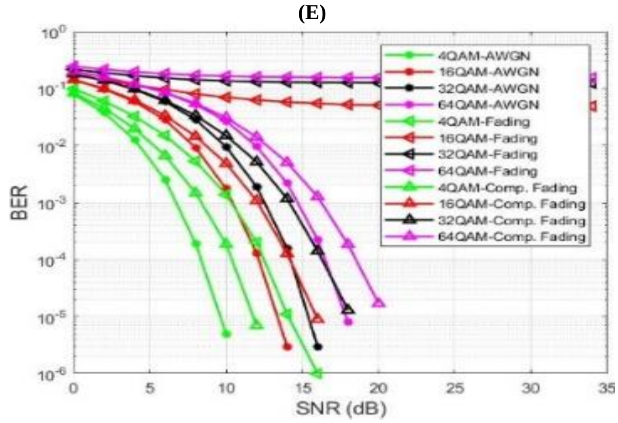
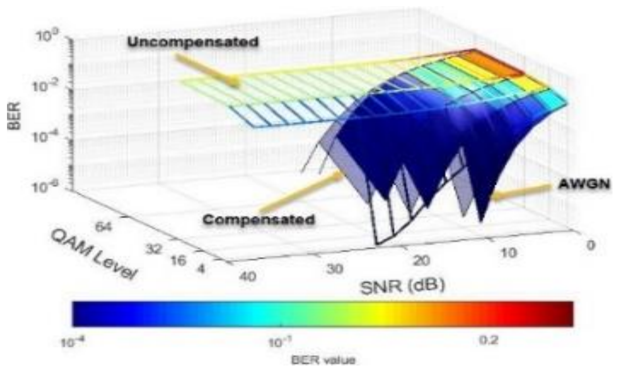


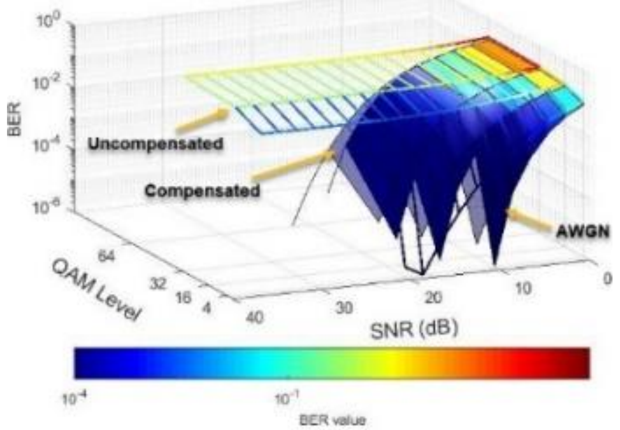
Fig. 14: The OFDM Performance over the Out-Door Channel. A), 16 Subcarrier FFT, B), 32 Subcarrier FFT, C), 64 Subcarrier FFT, D), 128 Subcarrier FFT, E), 256 Subcarrier FFT.

The relation between the BER and the other parameters that are the QAM levels and the subcarriers are shown n Fig. 15

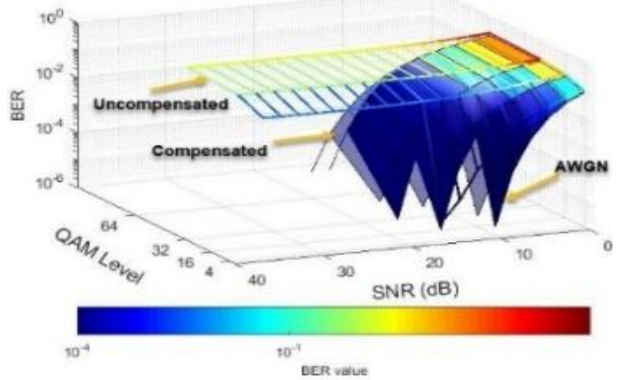
(A)



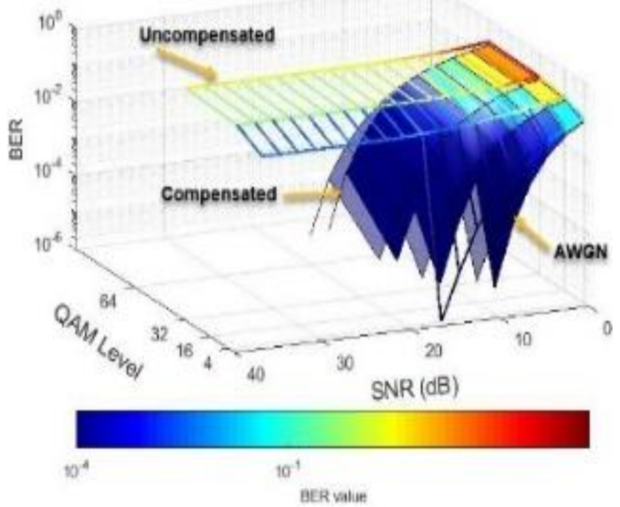
(B)



(C)



(D)



(E)

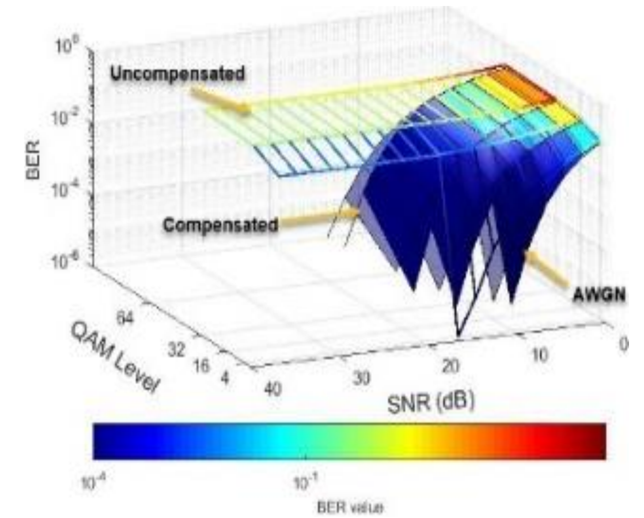
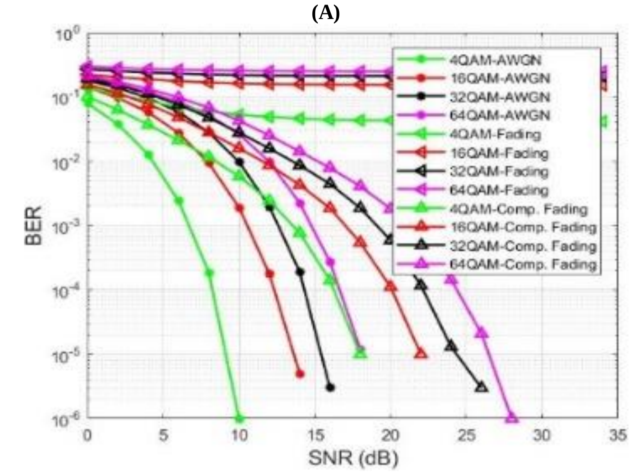


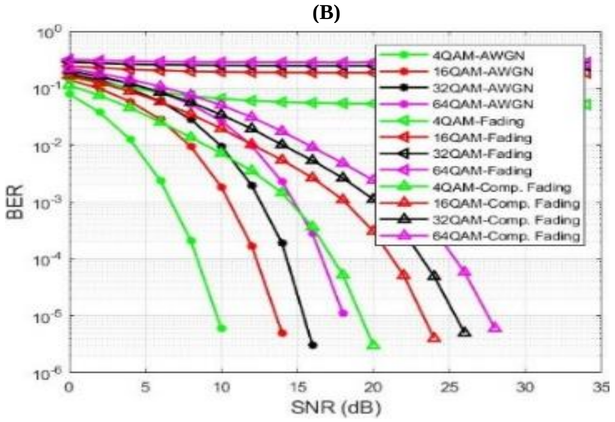
Fig. 15: The OFDM BER Relation with QAM Levels and the OFDM Subcarriers Out-Door Channel. A), 16 Subcarrier FFT, B), 32 Subcarrier FFT, C), 64 Subcarrier FFT, D), 128 Subcarrier FFT, E), 256 Subcarrier FFT.

3) The GSM Channel. The severest channel simulated here is the GSM channel. The GSM towers usually placed far away from each other to cover a wide area. Therefore, the multi-path will have a significant effect on the BER of the received symbol. Therefore, the GSM station are equipped with sophisticated equipment to neutralize the multipath channels effect. The simulation of the OFDM performance over the GSM channel is shown in Fig. 16.

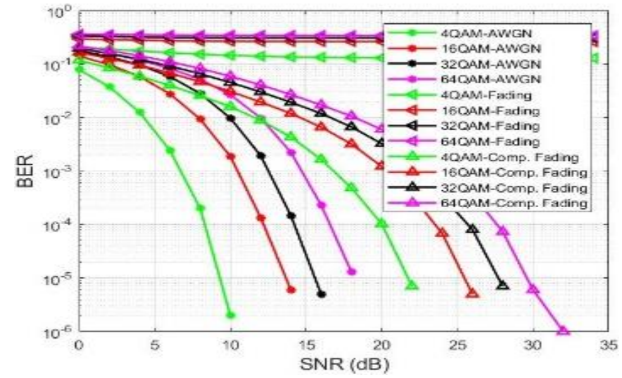
(A)



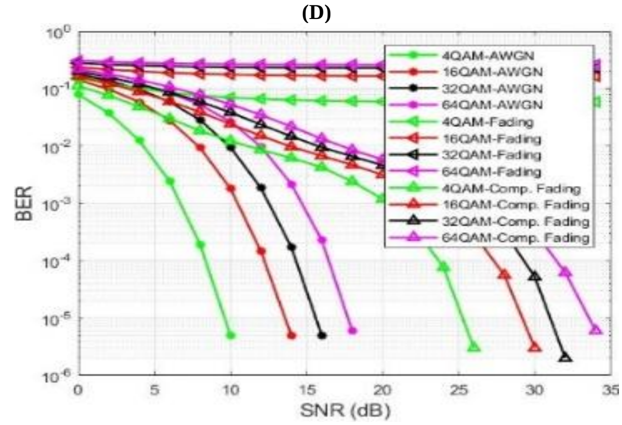
(B)



(C)



(D)



(E)

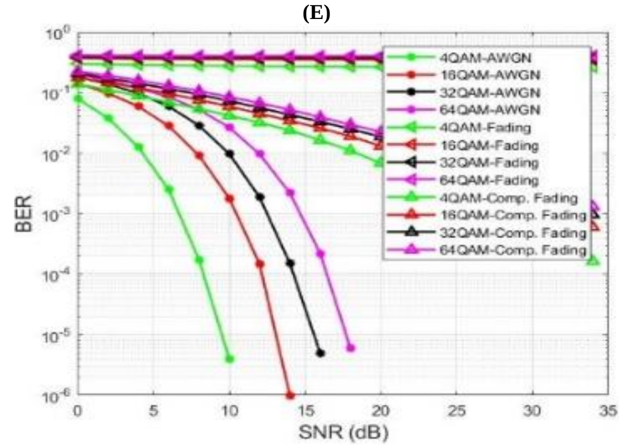
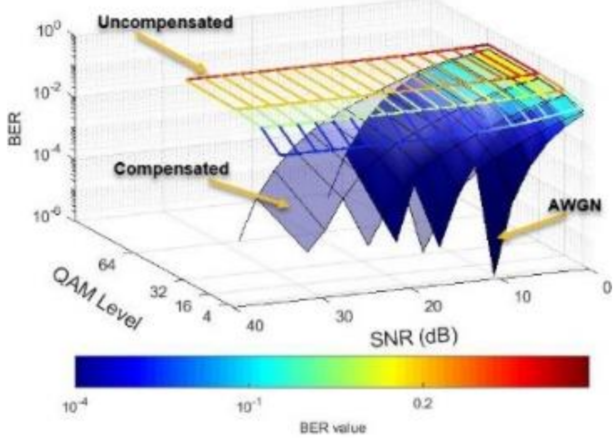


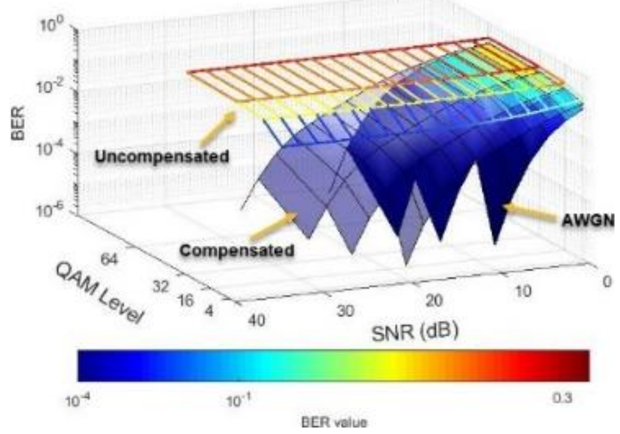
Fig. 16: The OFDM Performance over the GSM Channel. A), 16 Subcarrier FFT, B), 32 Subcarrier FFT, C), 64 Subcarrier FFT, D), 128 Subcarrier FFT, E), 256 Subcarrier FFT.

The relation between the QAM levels and the SNR is shown in Fig. 17

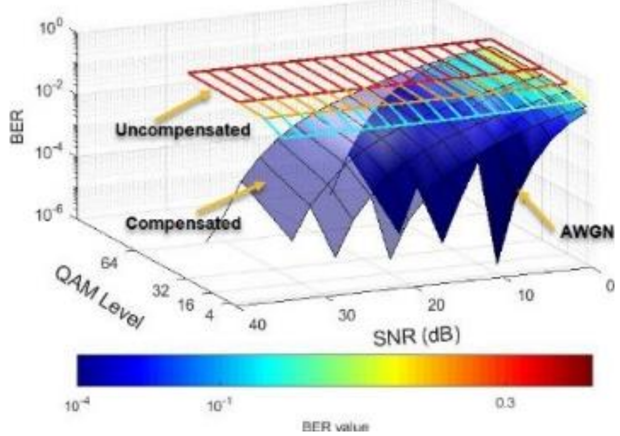
(A)



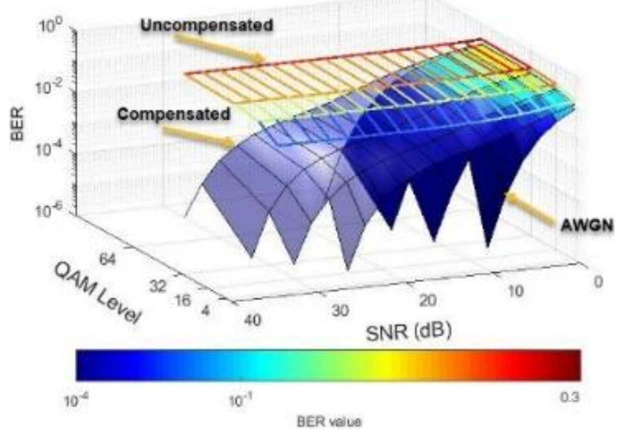
(B)



(C)



(D)



(E)

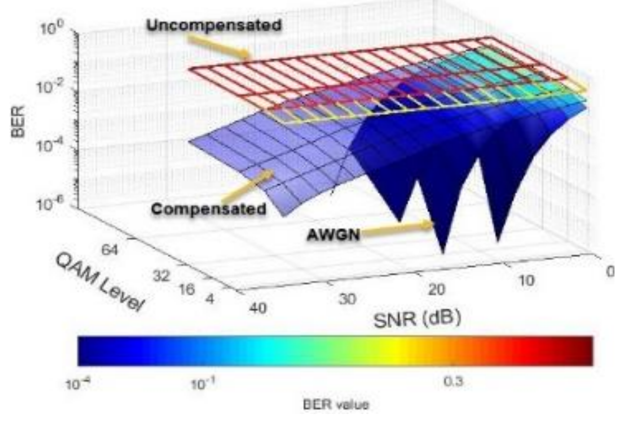


Fig. 17: The OFDM BER Relation with QAM Levels and the OFDM Subcarriers GSM Channel. A), 16 Subcarrier FFT, B), 32 Subcarrier FFT, C), 64 Subcarrier FFT, D), 128 Subcarrier FFT, E), 256 Subcarrier FFT,

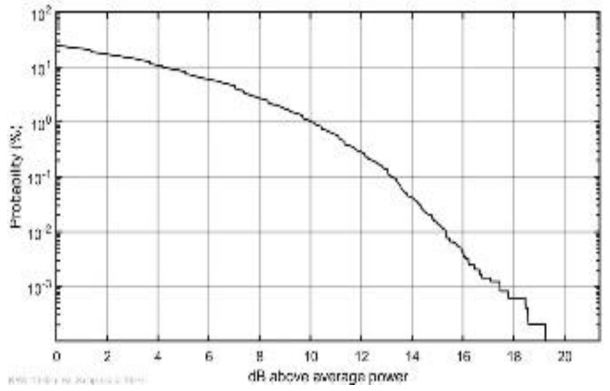
The used channel responses, the In-Door and Out Door with differential delay of 50 nS and the GSM channel with differential delay of 0.1 µS for OFDM carrier of 15 MHz are shown in Table 1

Table 1: The Multipath Channels Response

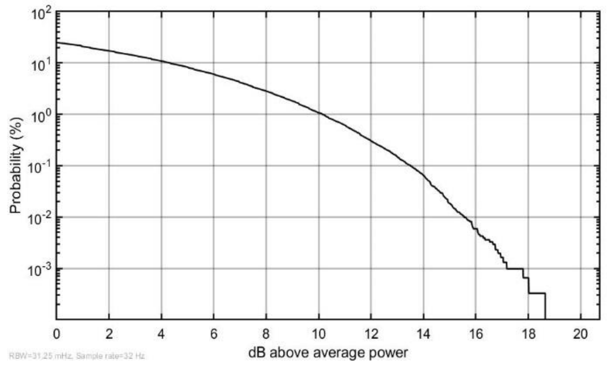
In Door	Delay	[0, 50, 110, 170, 290, 310]
	Gain	[0, -3, -10, -18, -26, -32]
Out Door	Delay	[0, 10, 90, 135, 230, 275, 310, 420, 630, 635, 745, 815, 830, 1430, 1790, 20]
	Gain	[-2.6, -8.5, -14.8, -17.5, -19.2, -18.8, -14.9, -14.9, -22.1, -10.3, -22.2, -19.2, -16, -22.9, -20.3, -27.4]
GSM	Delay	[0, 200, 500, 1600, 2300, 5000]
	Gain	[-3, 0, -2, -6, -8, -10]

A more elaborate test is the received symbol spectrum and PAPR. The PAPR is a very important measure for how much power we lose in the transmitter and the receiver to accommodate the power fluctuations of the OFDM symbol safely. Fig. 18 shows the PAPR of the different subcarriers OFDM systems used in this simulation.

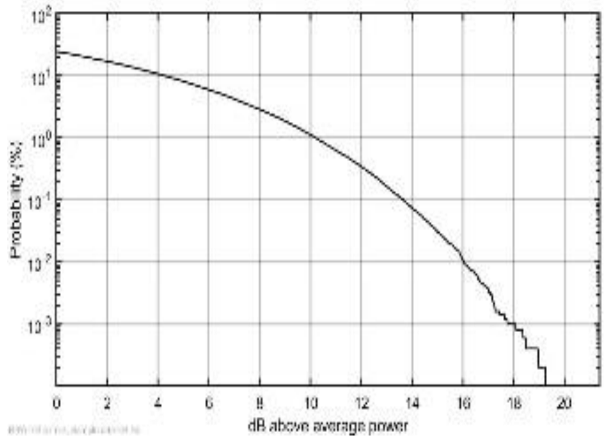
(A)



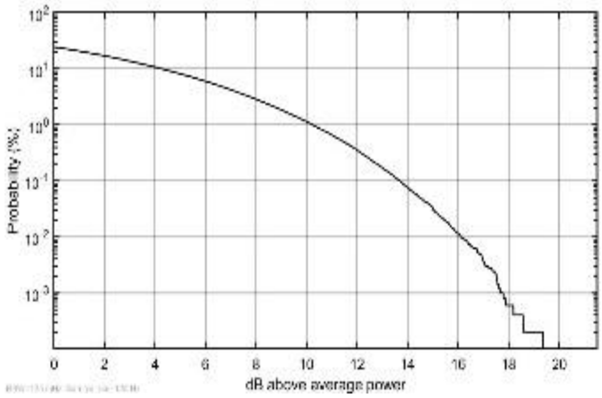
(B)



(C)



(D)



(E)

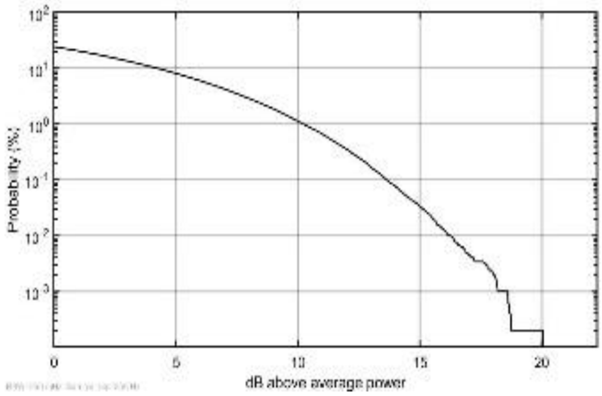
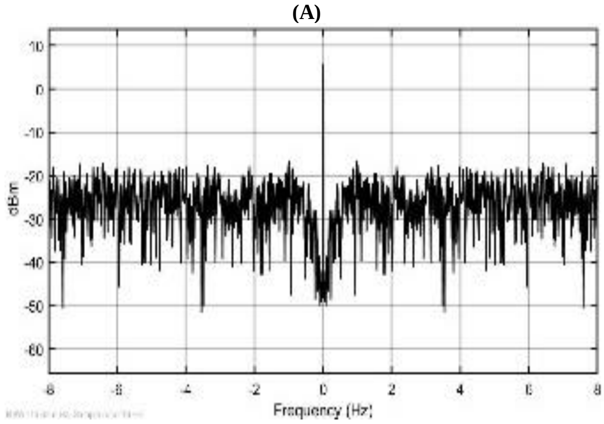


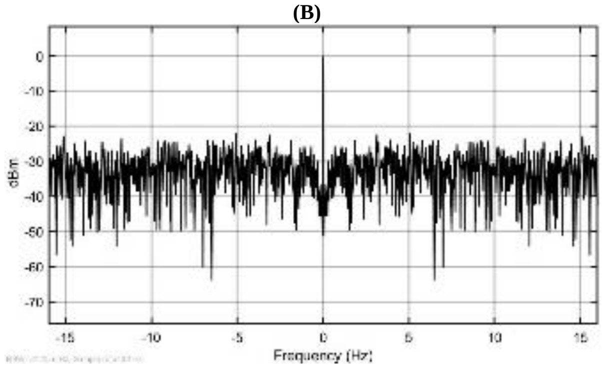
Fig. 18: The PAPR Curves for the OFDM Subcarriers. A) 16, B) 32, C) 64, D) 128, E) 256 Subcarriers.

Fig. 19 show the spectrum of the received OFDM signal for 16 subcarrier systems using different constellation sizes.

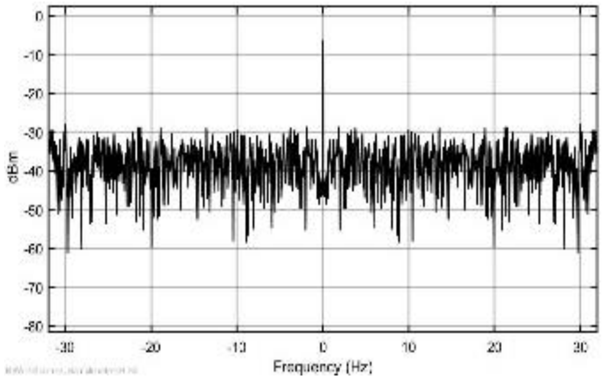
(A)



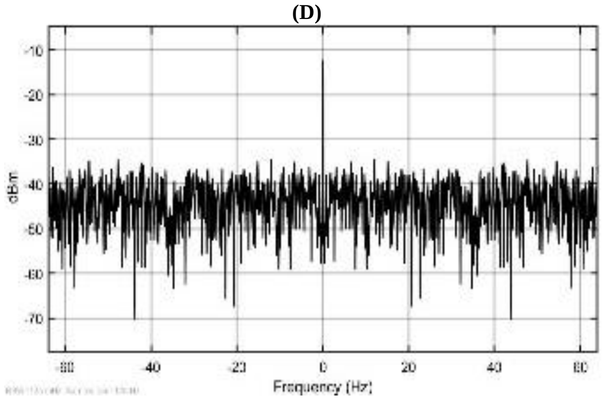
(B)



(C)



(D)



(E)

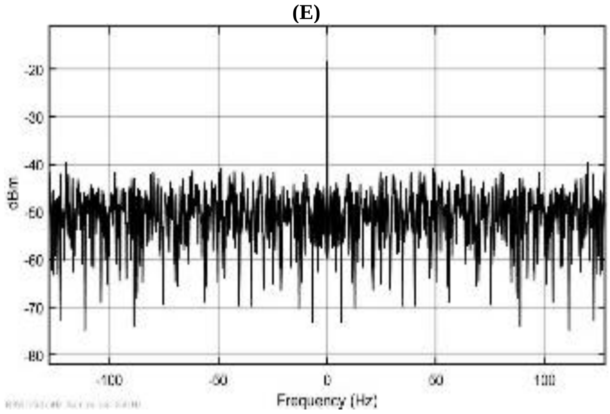


Fig. 19: The OFDM Symbol Spectrum. A) 16, B) 32, C) 64, D) 128, E) 256 Subcarriers.

7. Conclusions

In this paper we evaluated and analyzed the performance of the OFDM system over multipath Rayleigh AWGN suing the BER as a measurement for different constellation sizes and number of subcarriers. It is obvious that the multipath has a dramatic impact on the system performance. The effective parameter in the multi-path channel that increases its deformation is the amount of delay between successive delay banks. As we see from Table 1, the Out-Door has the highest number of delay banks. Nevertheless, the GSM has the worst performance because the time difference among the taps are the highest. Also, the number of taps increases with the increase of the carrier or the data rate. Therefore, their effect will increase substantially. We conclude that the power of the OFDM appears in the multipath channels because it can down convert the data rate significantly leading to a much less effect of the multipath. In a pure AWGN the performance of the OFDM is the same as a single carrier FDM. The BER result figures shows the importance of the compensation stage or equalization in the presence of ISI because it can de-convolve the received data over the ISI channel.
The presented 3D surface figures that relates these different parameters, constellation size and SNR, with the BER can give a

clear picture for how to choose a constellation over a certain channel to meet the specific BER level.

An important conclusion can be drawn from Figs. 18 and 19. From Fig. 18, we can see that the CCDF of the PAPR is independent of the number of subcarriers. However, Fig. 19 shows that the peak power level can be considerably reduced by increasing the constellation size. As it can be seen, the peak level is reduced from 5 dB in Fig. 19.a to −18 dB in Fig. 19.e. This observation can justify the choice of dense QAM constellation despite the increase in the BER because these dense constellation not only increase the bit rate but also increase the power efficiency of the OFDM system. Increasing the power efficiency leads to a more stable, low cost and provide the ability to increase the subcarrier without deteriorating its performance. This also leads to the decrease of the ISI effect on the received signals.

References

[1] Proakis, J. G. and Salehi, M., *Digital Communications*, Fifth Edition, McGraw-Hill, USA, 2008.

[2] Haykin S., *Digital Communication Systems*, John Wiley, USA, 2014.

[3] Simon, M. K. and Alouini, M.-S., *Digital Communication over Fading Channels: A Unified Approach to Performance Analysis*, Wiley & Sons, Inc., USA, 2000. https://doi.org/10.1002/0471200697.

[4] Hanzo, L. and Keller, T., *OFDM and MC-CDMA A Primer*, IEEE press, USA, 2006. https://doi.org/10.1002/9780470031384.

[5] Glisic, S., *Advanced Wireless Communications 4G Technologies*, John Wiley, USA, 2004. https://doi.org/10.1002/0470867787.

[6] Zhang, K.T., *Wireless Communications Principles, Theory and Methodology*, John Wiley, USA, 2016.

[7] Moaveni, S. M., Rajabzadeh M. and Koshbin H., "A Study on the PAPR of Systematic UW-OFDM", *Iranian Conference on Electrical Engineering (ICEE)*, 2018, pp. 688-692.

[8] Gupta, P. ET. al., "PAPR Performance Analysis of SLM with Hadamard Matrix Based Phase Sequence under M-PSK Modulation for Diminishing PAPR of OFDM System," *International Conference on Intelligent Circuits and Systems (ICICS)*, Phagwara, India, 2018, pp. 46-51. https://doi.org/10.1109/ICICS.2018.00022.

[9] Wang, L., "Additive Scrambling PAPR Reduction Scheme in BPSK-OFDM Systems," *eighth International Conference on Electronics Information and Emergency Communication (ICEIEC)*, China, 2018, pp. 211-214. https://doi.org/10.1109/ICEIEC.2018.8473541.

[10] K. Tani, ET. al., "PAPR reduction of post-OFDM waveforms contenders for 5G & Beyond using SLM and TR algorithms," *25th International Conference on Telecommunications (ICT)*, St. Malo, 2018, pp. 104-109. https://doi.org/10.1109/ICT.2018.8464904.

[11] H. Boche and U. J. Mönich, "Tone Reservation and Solvability Concepts for the Papr Problem in General Orthonormal Transmission Systems," *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Calgary, AB, 2018, pp. 3669-3673.

[12] Timoshenko, A. G. ET. al., "5G Communication Systems Signal Processing PAPR Reduction Technique," *Systems of Signal Synchronization, Generating and Processing in Telecommunications (SYNCHROINFO)*, Minsk, 2018, pp. 1-4.

[13] Akdeniz, B. C. ET. al., "Molecular Signal Modeling of a Partially Counting Absorbing Spherical Receiver," *IEEE Transactions on Communications*.

[14] Olanrewaju, H. G., Thompson, J. and Popoola, W. O., "Performance of Optical Spatial Modulation in Indoor Multipath Channel," *IEEE Transactions on Wireless Communications*, vol. 17, no. 9, pp. 6042-6052, Sept. 2018. https://doi.org/10.1109/TWC.2018.2854573.

[15] Lian, J., Noshad, M. and Brandt-Pearce, M., "M-PAM Joint Optimal Waveform Design for Multiuser VLC Systems Over ISI Channels," *Journal of Lightwave Technology*, vol. 36, no. 16, pp. 3472-3480, 15 Aug.15, 2018.

[16] Mutangana, J. de Dieu, Kumar, D. and Tandon, R., "MIMO wiretap channel with ISI heterogeneity — Achieving secure DoF with no CSI," *51st Asilomar Conference on Signals, Systems, and Computers*, Pacific Grove, CA, 2017, pp. 1687-1691. https://doi.org/10.1109/ACSSC.2017.8335647.

[17] Giordano A. A. and Levesque A. H., *Modeling Of Digital Communication Systems Using Simulink*, John Wiley, USA, 2015. https://doi.org/10.1002/9781119009511.

[18] Proakis, J. G., Salehi, M. and Bauch, G., *Contemporary Communication Systems Using MATLAB*, Cengage Learning, USA, 2013.

[19] Poikonen, J., *Efficient Channel Modeling Methods for Mobile Communication Systems*, Turun Yliopiston Julkaisuja Annales Universitatis Turkuensis, 2008.

[20] Jeruchim, M. C., Balaban, P. and Shanmugan, K. S., *Simulation of Communication Systems*, 2nd Edition, Kluwer Academic Publishers, USA, 2002.

[21] Recommendation ITU-R M.1225, *Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000, Annex 2* (1997).