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ERROR CORRETION ENHANCEMENT FOR OFDM COMMUNICATION SYSTEM

BY

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ERROR CORRETION ENHANCEMENT FOR OFDM COMMUNICATION SYSTEM

THESIS

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BY

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بِسْمِ اللّهِ الرَّحْمَنِ الرَّحِيمِ

اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ ﴿١﴾ خَلَقَ الْإِنسَانَ مِنْ عَلَقٍ ﴿٢﴾
اقْرَأْ وَرَبُّكَ الْأَكْرَمُ ﴿٣﴾ الَّذِي عَلَّمَ بِالْقَلَمِ ﴿٤﴾
عَلَّمَ الْإِنسَانَ مَا لَمْ يَعْلَمْ ﴿٥﴾

صدق الله العظيم

سورة العلق الآيات (1-5)

Dedication

To my father and mother who taught me the value of studying and persevering and gave me continuous support.

To my children "Rada" and "Mostafa"

To my sister "Aouns"

To my husband

Supervisor Certification

I certify that this thesis titled " **MODELLING AND PRACTICAL IMPLEMENTATION TO OFDM TRANSCEIVER COMMUNICATION SYSTEM** " which is being submitted by **Mays Alreem Ameer Mahmood** was prepared under my/our supervision at the Communication Techniques Engineering Department, Engineering Technical College-Najaf, ALFurat Al-Awsat Technical University, as a partial fulfillment of the requirements for the degree of Master of Technical in Communication Engineering.

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Date: Oct. 2022

In view of the available recommendation, we forward this thesis for debate by the examining committee.

Signature:

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(Head of Communication Tech. Eng. Dept.)

Date:

LINGUISTIC CERTIFICATION

This is to certify that this thesis entitled " **Error Correction Enhancement For OFDM Communication System**" was reviewed linguistically. Its language was amended to meet the style of the English language.

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Abstract

Communication systems are playing a major role in modern societies by connecting people around the world. Therefore, reliable stable, and dependable links are required. The access demands for higher bit-rates have given birth to the new technology in communication which is called 5G (fifth Generation). This generation is promised to provide, theoretically, huge data transport to loads with minimum delays and power requirements.

In this research , RS code was used as it is a non-binary code and performs well in serial systems, it is help to detect and correct error. It is considered the best among the types of codes and this made it used in many previous researches.

Two types of interlever have been added the first type is Block interlever. This is the most common and used type and helps the Reed-Solomon RS-code to spread one-dimensional 1D errors but its performance is limited. So it is necessary to use another type of Interleaver is Chaotic interleaver, its ability to spread two-dimensional errors 2D and thus it is considered It is better than the Block and it is to add a security character to the system by encrypting the data (the image) sent using a secret key $S_{encoder}$ during transmission and that any change in the secret key $S_{decoder}$ will prevent the data from being received, thus ensuring data access with confidentiality and high efficiency and an improvement in the value of BER. The plan created for data transmission via the RS OFDM system is described together with the Block and Chaotic interleaves.

By using Matlab 2018, the model is constructed to work on the data rate of Total data = 13485 Mbps, Number of sub-carriers=52, Reed-Solomon coding RS(23,31), (Inverse Fast Fourier Transform/Fast Fourier Transform IFFT/FFT points Size=64, Cyclic prefix=16 bits (rate=1/4), Berlek map-Massey decoding, Block Interleaver, The performances were evaluated by applying (B-PSK) binary phase-shift keying modulation,(QPSK) Quadrature amplitude modulation scheme in the AWGN channel, fading selective channels. Performances in terms of bit rate error (BER) and signal energy to noise power density ratio (Eb/No).

The results shown BPSK modulation technique in AWGN channel better compare to fading selective channel the improvement rate will be obtained at BER= 10^{-3}. BER of RS code =6.5dB, Block interleaver=5dB, and chaotic interleaver=3dB.

ACKNOWLEDGMENT

In the name of Allah, the Most Gracious and the Most Merciful

All praises to Allah for the strengths and His blessing in completing this work and pleased me the science way, and prayers and peace be upon His Prophet Muhammad and his family (my great teachers).

First of all, I would like to express my warm thanks to my supervisor assistant Prof. Dr. Mazen Makki Ali AlIbraheemi. This thesis allowed me to have a good insight into the development of the OFDM system while gaining a lot of knowledge and skills in the area of the communication system.

Sincere thanks go to all the professors at Al-Furat Al-Awsat Technical University for all this considerable basis of information in the academic. All thanks to my great parents and all my wonderful family members for giving me a lot of support, love, and advice, Special thanks to my children for their love and support, and their prayers for my success.

DECLARATION

I hereby declare that the thesis is my original work except for quotations and citation which have been duly acknowledged.

Date: /   /2022   Mays Alreem Amer Mahmood

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List of Abbreviations

Abbrevaed	Details
1D	1 one dimension
2D	two dimensions
4G	Fourth generation
5G	Fifth Generation of Wireless Mobile System
ADC	Analog of digital converter
AWGN	Additive White Gaussian Noise
BCH	Bose–Chaudhuri–Hocquenghem codes
BER	Bit Error Rate
BPSK	Binary phase-shift keying
BW	Band width
CP	cyclic prefix
COFDM	coded Orthogonal Frequency Division Multiplexing
CCDF	Complementary Cumulative Distribution Function
CDF	Cumulative Distribution Function
DAB	Digital Audio Broadcasting
DAC	Digital to Analog Converter
DVB	digital video broadcasting
DWMT	Discrete Wavelet Multi-Tone
DSP	Digital Signal Processing
DVB	Digital Video Broadcast
ECC	Error-Correcting Codes
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
GF	Galois Field
HPA	High Power Amplifier
ISI	Inter-Symbol-Interference
ICI	Inter-carrier-Interference
IDFT	Inverse Discrete Fourier transform
IFFT	Inverse Fast Fourier Transform

LAN	Local Area Network
LoS	Line-Of-Sight
MCM	Multicarrier Modulation
MSE	Mean Squared Error
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak to Average Power Ratio
PSK	Phase Shift Keying
PSNR	Peak Signal to Noise Ratio
QAM	Quad Amplitude Modulation
QPSK	Quad Phase Shift Keying
RS	Reed Solomon
RF	Radio frequency
SNR	Signal-to-noise ratio
SSIM	Structural Similarity Index
SC	Signal Carrier
TETRA	Terrestrial Trunked Radio
Tsym	Time symbol
TX	Transmitter
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity Alliance
ZP	Zero Padding

List of Symbols

Symbol	Detail
$Fk\ (t), Fl\ (t)$	two signals spanning a period
T	signal time
$[t1, t1 + T]$	time interval
$x(n)$	discrete OFDM signal
T_P	length of the adding cyclic prefix
T_{sym}	cyclic prefix extends OFDM symbols
$x(t)ext$	extends equation cyclic prefix
P	total number of CP symbols
$h(\tau,t\ )$	multipath fading channel
y(t)	received signal
Hk	frequency response of the multipath fading channel
wk	AWGN component in the frequency domain
Xk	complex data symbol
F_k	gain of a single tap frequency domain
$w(t)$	additive white gaussian noise
$x(t)$	continuous-time baseband OFDM transmitted signal
Δf	Frequency offset
$max\ [x(t)]$	maximum instantaneous power
$E\{\|x(t)\|\}$	average power
$E\{.\}$	Expectation operator
Z	magnitude of complex samples
$F(Z)$	amplitude of a signal sample
w(n)	Gaussian noise with a mean of zero
N_0	complex noise with total noise variance
σ	standard deviation
r	a random variable
A	finite set of elements
q	an alphabet size of Reed–Solomon code
n	block length Reed–Solomon code
k	message length Reed–Solomon code
2t	Number of parity check elements
dmin	Minimum distance
$P(x)$	**parity polynomial**
n−k	parity symbols in the codeword
$p\ (x)$	***parity polynomial***
m(x)	message word
c (x)	codeword polynomial
g(x)	generator polynomial

S	Syndromes
a^i	roots of each transmitted codeword
x^j	error location
e_j	error magnitudes
B_i	error locator numbers
S_{key}	secret key
N	number of data in one row of interleaver

Chapter One

1.1 Introduction

With technological advancements and the growth of electronic technologies, Several constraints to physical wireless communication network connection have emerged, to meet the growing need for better data transmission speeds for new multimedia applications. Wireless communication networks have critical difficulties such as restricted bandwidth availability, mobility, and multipath fading, all of which must be addressed right now to overcome these limitations[1].

The concept of OFDM was introduced by R.W. Chang in 1966[2] and in 1971 the researcher Weinstein [3] found the possibility of using IFFT / FFT circuits for modulation signal to convert time domain to frequency domain, The system just got easier to modulation.

OFDM is the suitable method that can overcome fading and inter symbol interference (ISI) induced by multi-path propagation, and also obtain best spectrum efficiency. OFDM divides the frequency spectrum into multiple orthogonal sub-channels and converts frequency-selective channels into non-selective sub-channels. [4]Cyclic prefix (CP) is use to overcome ISI. To take an advantage of the characteristics of OFDM system in the broadband channels.

Several uses of the system such as DAB and DVB (Digital Audio and Video Broadcasting).WLAN (Local Area Wireless Networks) like HIPERLAN (Local Area Network with High Performance) and IEEE 802.11 (Wi-Fi) Digital television IEEE 802.16 (wifi Metropolitan Area Networks) (Wi-Max) ADSL (Asymmetric Digital Subscriber Line) [5]

Channel coding is a technology utilized to detect and correct errors through signal transmission, It can also make the performance information more reliable without changing the hardware or increasing the overall system cost. In this thesis, we study Reed Solomon code(RS), Which codes have aroused great interest in many communication systems channel coding is considered a solution for high data rates and reliable transmission[6]

In fact, the environment of mobile communications suffers from long burst errors. In the fast fading case, these burst errors are due to the multipath effect, and they reduce the quality of communication. An error control technique communication is not enough with long burst errors. In the effect of block interleaved coding with RS code on data and image transmission over a wireless channel was studied coding was presented but with little improvement. In fact, there is a need for an effective error spreading tool to enhance the quality of communication[7].

This technique achieve a lower error probability with the RS encoder. This technique depends on the data interleaving or randomization. So, long burst errors can be separated into single random or short burst errors. Computer simulations have been carried out on the proposed chaotic interleaver for the AWGN and Rayleigh channel. The simulation results have revealed that the proposed technique is efficient for reduce BER in medium and high SNR and with image communication over the OFDM system[8].

1.2 Why OFDM

OFDM is very effective for communication over channels with frequency selective fading (different frequency components of the signal experience different fading). It is very difficult to handle frequency selective fading in the receiver, in which case, the design of the receiver is hugely complex.

Instead of trying to mitigate frequency selective fading as a whole (which occurs when a huge bandwidth is allocated for the data transmission over a frequency selective fading channel), OFDM mitigates the problem by converting the entire frequency selective fading channel into small flat fading channels (as seen by the individual subcarriers). Flat fading is easier to combat (when compared to frequency selective fading) by employing simple error correction and equalization schemes[9].

However, OFDM has some drawbacks: OFDM has a higher sensitivity to phase noise and frequency offset. Because OFDM has a high Peak to Average Power Ratio it tends to lower power efficiency.

1.3 The Purpose of Research

1.3.1 Research Problem

OFDM overcomes the problem of inter-symbol interference by transmitting a number of narrow band subcarriers together with a guard interval. But this gives rise to another problem that all subcarriers will arrive at the receiver with different amplitudes. Some carriers may be detected without error but the errors will be distributed among the few subcarriers with small amplitude. Channel coding can be used across the subcarriers to correct the errors of weak subcarriers.

1.3.2 Contribution

The main contributions of this project were done to solve problems mentioned previously in the above paragraph are the following:

- To achieve high data rate and overcome the problem of multipath effects reduction of ISI.
- To detect and correct errors without re-transmission. Channel coding is a technique utilized for detecting and correcting errors during transmission, combination of Reed-Solomon (RS) code is ability to correct random errors were considered as a solution for achieve reliable communication. When using efficient simulation methods for using BPSK modulation, it improved the performance significantly with less errors.
- Burst errors of one-dimensional errors 1D are corrected by using an Block Interlever, where an interleaved distributes burst errors that the code is unable to correct, by randomly distributing errors to create a more reliable, effective, and faster system
- Burst errors of two-dimensional errors 2D are corrected by using an chaotic Interlever, where an interleaved distributes burst errors of two-dimensional that the block interleaver is unable to spread it, in addition to publishing images confidentially through a secret key

1.4 Literature Review

OFDM systems and coding have witnessed great interest by many of researchers since the end of the last century and the beginning of the current century due to the capabilities of these systems to meet the development requirements in the field of communications. Many researchers have published important results in the field of OFDM coding below is a presentation of some of the distinguished works in this field.

In2014 Soliman [10] The authors studied this paper presents technique for progressive image transmission over block and chaotic interleaver and low-density parity-check coded (LDPC-OFDM)system over AWGN and Rayleigh. The gap of this paper did not study encryption image during transmission.

Qazi, 2015 [11] The authors systematically studied the performance of several different codes using linear bloke code convolution code reed solomon code through AWGN channel. The gap in this paper, the system not use in effect of multipath of Rayleigh fading channel.

Abdeltwab, **2016** [12] This study discusses the performance improvement by use coding techniques include Reed Solomon coding, Convolutional coding, and Interleaved concatenated coding techniques through AWGN channel model. The gap not use the effect of multipath in Rayleigh channel.

A. Agarwal, 2017 [13]The paper have studied the performance three error correction codes convolutional code , Reed-Solomon code , low density parity check and three channel models AWGN, Rayleigh, Rician, They proved that RS code configurations exhibits better performance. The gap in this paper did not use interleaver to overlap the effect of fading channel.

Wirastuti 2018 [14] The authors made acomparison system between with RS-code and without RS-code in two channal AWGN and Rayleih channel. The gap in this paper not use interleaver for burst error and not use different type of modulation.

Kaur, 2019 [15] The authors have proved that system performance can be enhanced by use Reed Solomon code and block interleaver over AWGN. The gap in this paper not use Rayleigh channel to calculate the effect fading channel and not use different type of modulation.

Kizawa, 2020 [16] The authors have proved that system performance can be enhanced with a small number of iterations and evaluate the performance of LDPC coded OFDM system with iterative cancellation receiver under the long-delay multipath channel. The gap in this paper The effect of different code rates value and modulation on the system was not studied.

Okorie, 2020 [17] This paper evaluated the performance of convolutional, Reed-Solomon, and Concatenated Convolutional with Reed-Solomon (CC-RS) coding schemes over AWGN and Rayleigh fading channels in order to improve the spectral efficiency at higher subcarriers. The gap of this not use interleaver technique to spread the burst error.

Raouia Ghodhbane, 2021 [18] The researcher made a comparison between the system when adding RS and between adding the parallel Hamming code. The results show that the Hamming code is higher capacity, but the RS code is more efficient in identifying and correcting errors. The gap of this paper idea of parallel Hamming code is complex, expensive method and not effective.

Mehallel Elhadi, **2022** [19] The authors have proved the system performance can be enhanced by use Convolutional code with the Chaotic baker map encryption algorithm has been used to encrypt images to enhance their security during transmission via SC-FDMA based systems. The gap of this paper use single-carrier frequency division multiple access (SC-FDMA) specified the system lowe values of the SNR and the value of PSNR is not high.

1.5 Structure of Thesis

Chapter 2 Gives overview of OFDM system, and FEC technique that are illustrated too .In this chapter explain the background and principle of OFDM system, Shannon theorem, Reed Solomon coding (RS), Block Interleaver ,Chaotic Interleaver.

Chapter 3 Presents an illustration of the system model written using the (MATLAB) language to calculate the BER and in terms of the SNR. This chapter also explains structure of system. It also provides frequency selective channel and, bit error rate, signal to noise ratio and, additive white Gaussian noise.

Chapter 4 This chapter presents the simulation results and discussion.

Chapter 5 This chapter gives the conclusions of the thesis and suggestions for future work.

Chapter Two
OFDM System Theoretical Background

2.1 Introduction

OFDM is a type of multicarrier modulation in which a single data stream is sent over several lower-rate subcarriers. In OFDM, a high-speed bit stream is divided into N lower-speed parallel bit streams, each modulated by one of N orthogonal sub-carriers. OFDM improves immunity to narrowband interference and frequency selective fading [20].

In a single carrier system, a single fade causes the entire connection to fail, however, in a multicarrier system like OFDM, just a few subcarriers are affected. Error correction coding can then be used to correct those few errors. The frequency band is split into N non-overlapping frequency sub-channels in a parallel data system like OFDM to prevent spectral overlap of channels to avoid inter-channel interference, which leads to inefficient utilization of the available spectrum[21].

To accomplish the overlapping multicarrier approach, the notion is presented using parallel data and FDM with overlapping sub-channels. However, it is necessary to reduce crosstalk between subcarriers, which necessitates orthogonally between the different modulated carriers[22].

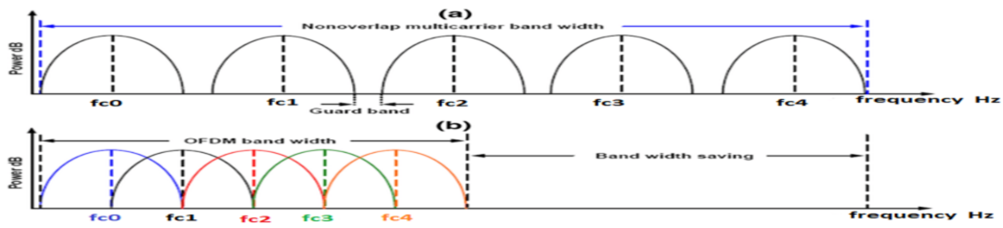


Figure 2.1 A comparison of single carriers and multicarrier techniques

(A) Non-overlapping, (B) Overlapping (OFDM)

In Figure 1, single carriers, non-overlapping multicarrier modulation, and overlapping orthogonal multicarrier modulation are compared. The signal can be received in a normal frequency-division multiplex system using Guard bands, which are introduced between various carriers in the frequency domain reduce spectrum efficiency. OFDM's multi-path delay spread tolerance,[23] resilience against frequency selective fading, and efficient spectrum consumption by permitting overlapping of two or more signals in the frequency domain, as well as its robustness against frequency selective fading, are some of its primary features. Additionally, IFFT and FFT techniques are used to modulate and demodulate an OFDM system, which is computationally efficient [24]

2.2 OFDM Implementation

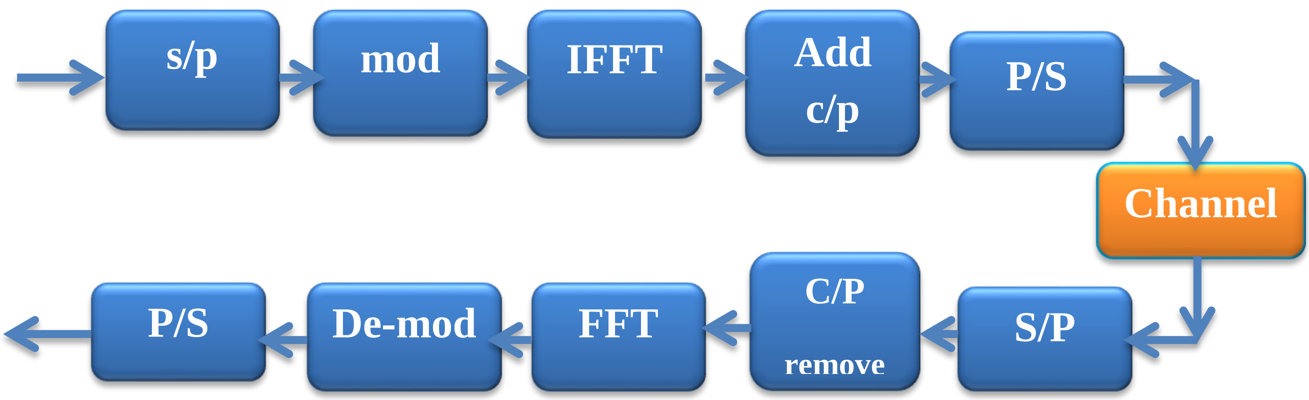


Figure2.2 Basic OFDM Transmitter and Receiver

The key example or concept that may best demonstrate the operations of a multi-carrier system is orthogonal frequency division. In OFDM broadcasts, the frequency spectra of each sub channel overlap, as in figure2, allowing for more efficient use of the frequency spectrum. Furthermore, because of the superposition process performed during the IFFT step in the transmitter, the output symbol of OFDM has a large dynamic envelope range[25]

OFDM signals have the ability and feature to optimally use the available spectrum by properly organizing the subcarriers in the channel together by the concept of orthogonally, which reduces interference between the closely spaced subcarriers. The method of overlapping multicarrier modulation differs from that of non-overlapping multicarrier modulation[26].

2.3 Mathematical concept in OFDM

2.3.1 Principle of Orthogonally

In a multi-carrier system, the frequency required by the channel is kept to a minimum, The frequency gap between carriers is narrowed to achieve minimization. When the carriers are orthogonal to each other, a smaller space is created The time-averaged integral product of two signals must be zero to be orthogonal as supplied by [27] in equation 2.1:

$$\frac{1}{T}\int_{t1}^{t1+T} F_k(t) \times \frac{1}{T}\int_{t1}^{t1+T} F_l(t)\, dt = 0 \;\; if\ k \neq l \qquad \ldots 2.1$$

Where $Fk\ (t)$ and $F_l\ (t)$ are any two signals spanning a period [t1] and [t1 + T]. T denotes the signal time. N denotes the number of subcarrier. The discrete-time domain of orthogonally of two signals is stated as with the additional reduction of equation2.1

$$\frac{1}{N}\sum_{n=0}^{N-1} e^{\frac{j2k\pi}{T}nTs} \times e^{\frac{-j2l\pi}{T}nTs} = 0 \qquad 2.2$$

$$\frac{1}{N}\sum_{n=0}^{N-1} e^{\frac{j2\pi(k-l)}{N}n} = \begin{cases} 0 & \forall\ k \neq l \\ 1 & \forall\ k = l \end{cases} \qquad 2.3$$

An OFDM-based communication system optimally uses the frequency spectrum by using overlapping subcarriers.

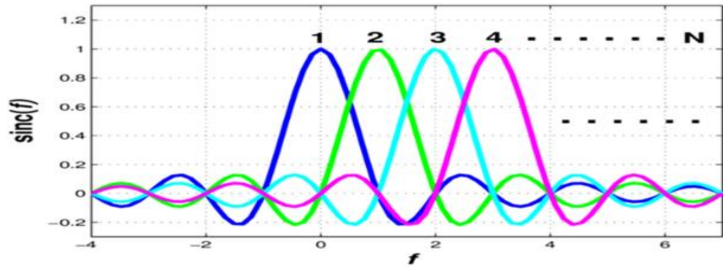


Figure 2.3 Frequency response of 4 subcarriers of OFDM signal

Because the maximum power of each subcarrier is exactly equal to the minimum power of its surrounding channels Figure 2.3 displays four subcarriers that are significantly overlapping while not interfering with surrounding subcarriers. In addition, each subcarrier is orthogonal to and distinct from the others[28].

2.4 Conceptual Model of OFDM System

According to OFDM is a kind of multicarrier modulation (MCM) with closely spaced subcarriers and overlapping spectra that enables multiple access created an OFDM transceiver model that displays the whole OFDM transceiver system, including FEC coding and interleaving, to offer the necessary power to combat burst failures. An OFDM system with interleaving and channel coding is referred to as coded OFDM (COFDM) [29].

OFDM's main principle is to divide an incoming data symbol into several bits of streams. Each substream has a much lower data rate and must modulate a large number of carriers. To provide variety, the incoming data is FEC coded before being interleaved. FEC codes input data before interleaving it to gain the benefit of variety. The data is converted into constellation point symbols (QPSK, BPSK, QAM), Which are disseminated and broadcast over the N sub-channels. The pilot symbol is contained in a complex data symbol as a consequence of the symbol mapping as shown in figure 2.4 [30]

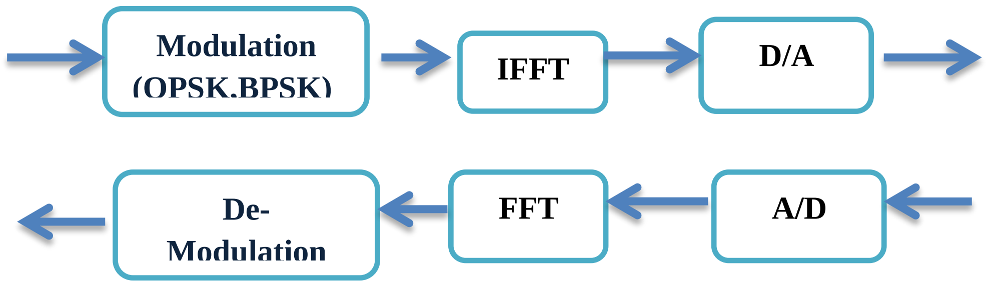


Figure 2.4 Basic model OFDM transmitter and receiver

The serial to parallel converter (s/p) receives the complex data symbol and executes the IFFT operation on the parallel complex data symbol. The relevant transmission subcarriers are then segmented from the transform data symbol. Each data block has a cyclic prefix, cyclic suffix, or zero paddings as a safety net. In the OFDM system, a guard interval is required to reduce the amount of ISI produced between successive OFDM signals

Carrier frequency synchronization takes place during receiver down conversion, whereas symbol timing synchronization takes place after ADC conversion. a description of The OFDM signal is demodulated using the FFT Symbol, The transmission constellation diagram is employed to do de-mapping and get significant received data[38-39]. FEC decoding and de-interleaving are now used to reconstruct the originally transmitted stream of bits[31]

2.4.1 Model of the Transmitter

The use of orthogonal subcarriers allows more subcarriers per bandwidth increasing spectral efficiency. In a perfect OFDM signal, Orthogonally prevents interference between overlapping carriers. In FDM systems, any overlap in the spectrums of adjacent signals will result in interference[32].

In OFDM systems, the subcarriers will interfere with each other only if there is a loss of orthogonally. Depending on the system requirements, independent M-ary modulators conduct modulation or mapping on a sequential number of input data symbols in OFDM systems (BPSK, QPSK, or QAM) The serial to parallel converter is then used to connect and send the N complex data symbol[33].

To connect the parallel data, the inverse fast Fourier transform is performed (IFFT). The reason for using IFFT is to produce orthogonal data subcarriers. Let, data block of length N represent by vector X = X(0), $X(1), \dots X(N-1)\ T$. Duration of any symbol X_K in the set X is T and represents one of the sub-carriers set. Hence, the transmitted samples are $\{x(0), x(1), \dots\ x(N-1)\}$ which are IFFT of samples of information symbols of X. As the N sub-carriers chosen to transmit the signal are orthogonal, so we can have, $fn = n\Delta f$, where $n\Delta f = 1/\,NT$ and NT is the duration of the OFDM data block X. The complex data block for the OFDM signal to be transmitted is given by as presented in equation 2.4 [43]:

$$x_{(t)} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, e^{j2\pi n\Delta ft} \quad 0 \le t \le NT \quad 2.4$$

Where N is the total number of subcarriers X_k , $k = (0,1 \ldots , N - 1)$ block of N input bits (symbol) is the mapped (QAM, PSK, QPSK) to be transmitted $e^{j2\pi n\Delta ft}$is the k^th^ subcarrier, $j = \sqrt{-1}$, Δf is the subcarrier spacing, NT denotes the useful data block period, T is the total time of the transmit symbol. In OFDM, the subcarriers are chosen to be orthogonal (i.e., $\Delta f = 1/ NT$). However, OFDM output symbols typically have a large dynamic envelope range due to the superposition process performed at the IFFT stage in the transmitter. [44].The discrete form of OFDM signal $x(n)$ is presented in equation 2.5

$$x(\mathrm{t}) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_K \, e^{\frac{j2\pi kn}{N}} \quad for\ n = 0,1,2,3.\ \ N-1 \qquad 2.5$$

The transmitted signal x(n) is produced via the inverse discrete Fourier transform (IFFT) of modulated input data symbols, as illustrated in Equation 2.5. IFFT may be completed rapidly and thoroughly using the Inverse Fast Fourier transform (IFFT)

2.4.2 Addition of a Guard band in OFDM

The delay spread or delay dispersion of a multipath transmission causes ISI in OFDM signals. In the OFDM system, the guard interval is utilized to reduce ISI, which is typically introduced between successive OFDM signals. The guard interval can be used in two ways to protect OFDM against ISI. There is no padding and the extension is cyclic. There are two techniques to prolong the cyclic extension: prefixes and suffixes with cyclic prefixes and suffixes[45]

Prefix that is cyclic In an OFDM system, a cyclic prefix (CP) is a type of guard interval that extends the duration of the OFDM symbol to decrease ISI caused by multipath propagation time dispersion. [46]. The cyclic prefix has two functions. First, it acts as a guard interval, preventing inter symbol interference from the prior symbol. It repeats the symbol's termination, allowing the linear convolution of a frequency selective Circular convolution may be used to represent a multipath channel, which can then be translated to the frequency domain using a discrete Fourier transform

To serve its purpose, the cyclic prefix must have a length that is at least equal to the length of the multipath channel. the notion of a cyclic prefix is commonly used. After a multipath OFDM symbol, a CP of length Tp is utilized, which is a copy of the final component of an OFDM transmit block connected to the front before transmission, as seen in Figure 2.5.

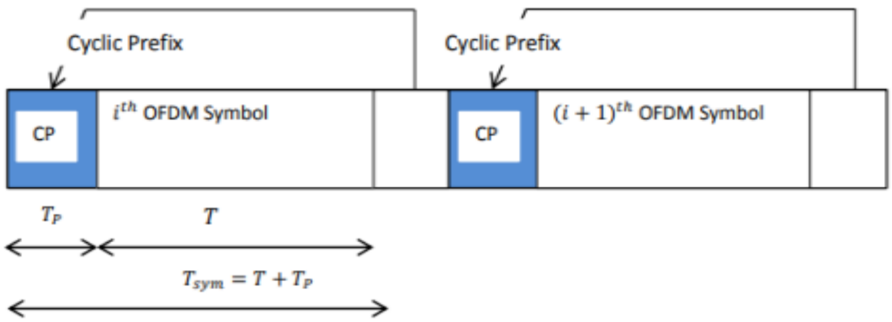


Figure 2.5 OFDM symbols with the cyclic prefix [21]

As a result, the supplied signal is made up of T + TP samples. OFDM symbols will be free of ISI if the selected path is longer than the longest anticipated delay path and the CP length is sufficient. If the CP is smaller than the multipath channel's delay spread, the tail component of the preceding OFDM signal will impact the head portion of the subsequent OFDM symbol, resulting in ISI[47].

The subcarriers' orthogonality is preserved by utilizing a cyclic prefix that is higher than the multipath channel's delay spread. Head portion of If the CP is smaller than the multipath channel's delay spread, the tail part of a previous OFDM signal will impact the following OFDM symbol. ISI is the outcome. A cyclic prefix bigger than the latency of the subcarriers maintains the multipath channel's orthogonally. [48] OFDM symbols are expanded to Tsym = T + TP when a cyclic prefix is added, as seen in the equation. 2.6

$$x(t)_{ext} = \begin{cases} x(n+N) \text{ for } n = 0,1,2,3 \ , \dots . p-1 \\ \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{\frac{j2\pi k(n-p)}{N}} \quad \text{for } n = p, p+1, \dots, p+N-1 \end{cases} \qquad 2.6$$

Where N signifies the total number of subcarriers in the OFDM signal and P denotes the total number of CP symbols.

2.4.3 Model of the Receiver

At the receiver,[49] the guard band is removed, and the OFDM data streams are converted from serial to parallel before being analyzed by an FFT block. The FFT is used to convert these simultaneous data streams from the time domain to the frequency domain. The receiver performs the opposite function as the transmitter.

The guard interval of an OFDM symbol is initially deleted in this case. The unprotected OFDM symbol is then transformed from serial to parallel before being transmitted to the FFT block. To translate these simultaneous OFDM data streams into the frequency domain, the FFT is utilized. An FFT operation's result can be written down.

$$X_k = H_k x(k) + w(k), \text{for } 0 \leq k \leq N-1 \qquad 2.7$$

Where H_k is the multipath fading channel's frequency response at the k^{th} sub-channel and is defined as:

$$H_k = \sum_{l=0}^{L-1} h_l(t) e^{\frac{j2\pi k\tau l}{N}} \qquad 2.8$$

The frequency domain is denoted by the symbol wk. The AWGN's component is Equation demonstrates this, The complex data symbol X_k accurately recovered using a single complex multiplication of factor F_k, where F_k is the gain of a single tap frequency domain equalizer)[51]

After multipath fading channel h, the received signal is represented as y(t)

$$(yt) = \sum_{l=0}^{L-1} h_l(t) x_{ext}(t-\tau) + w(t) \qquad 2.9$$

w(t) stands for white Gaussian additive noise (AWGN). The recovered data bits are then restored to the sequential streams and demodulated using a baseband demodulation method such as (M-PSK, MQAM) [50].

2.5 High Peak-to-Average Power Ratio (PAPR)

The OFDM system's high peak-to-average power ratio has been one of the technology's major flaws (PAPR). The high PAPR is owing to the data symbol waveforms' wide dynamic range. An OFDM signal (IFFT) is created when an Inverse Fast Fourier Transform is applied to data symbols (a sequence of bits arranged in the form of a set of subcarriers), with a high probability that a subset of these symbols adds up coherently, resulting in the generation of some large peaks at the output. The peak to average power ratio (PAPR) is a phenomenon that is directly proportional to the number of subcarriers N. This can produce a large PAPR when all subcarriers are added up coherently as shown in Figure 2.6 at the time (t=0.23). When N signals are added with the same phase, they produce a peak power that is N times the average power [51].

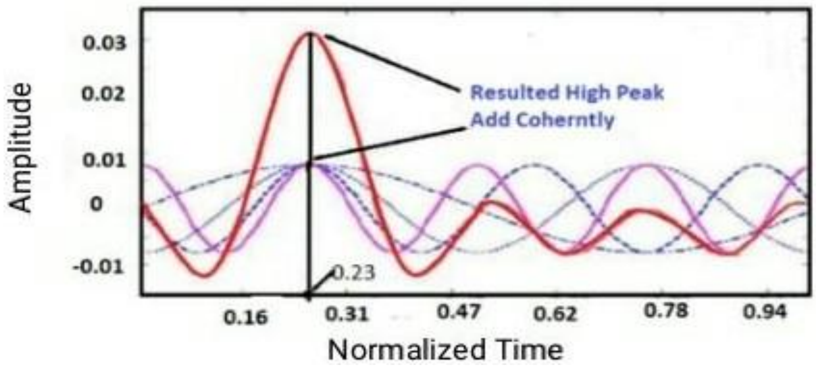


Figure 2.6: High Peak on OFDM System [44].

As a result, In OFDM-based systems, PAPR reduction is crucial. The ratio of Peak power to Average power is described mathematically as PAPR

$$\text{PAPR} = \frac{\text{Peak Power}}{\text{Average power}} \qquad 2.10$$

The ratio of maximum instantaneous power to average power is the PAPR of a continuous-time baseband OFDM transmitted signal x(t). As a consequence.

$$\text{PAPR} = \frac{\max[x(t)]^2}{E\{|x(t)|\}^2} \quad \text{for } 0 \leq t \leq NT \qquad 2.11$$

Where $E\{.\}$ denotes the Expectation operator, $\max[x(t)]^2$ is the signal's peak power, and $E\{|x(t)|\}$ T is an original symbol period, the average power of x(t).

2.6 Multipath Propagation

In any wireless communication multipath propagation occurs. Microwave signals do not travel in a straight line between the transmitter and the receiver, but rather in multiple directions. If there are adjacent interfering objects, the sent signal may be reflected. As a result, the receiver can receive several copies of the broadcast signal with varying delays. The propagation delay can distort or even eliminate the incoming signal. [52]

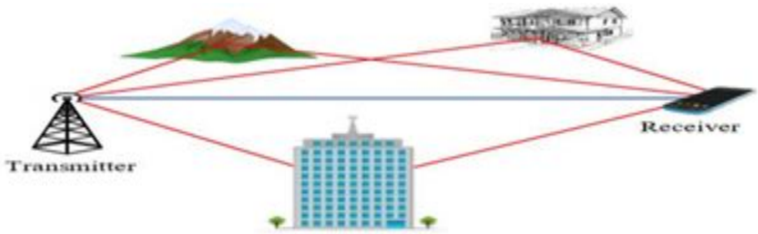


Figure 2.7 Multipath propagation. The blue line represents the Los while the red one represents the NLOS[38]

2.6.1 Mechanisms of Multipath Propagation

Three propagation mechanisms are critical in multipath propagation.

2.6.1.1 Reflection

When a signal reaches a smooth surface with unusually large dimensions in comparison to the wavelength of the propagating signal, reflection occurs as shown in Figure 2.8 [53].

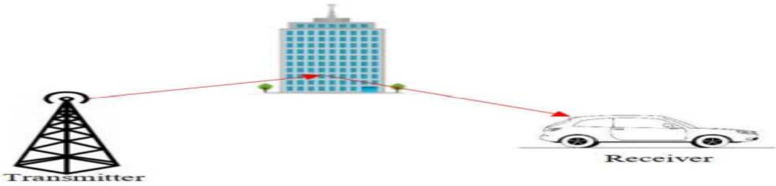


Figure 2.8: Reflection of the traveling signal[38]

2.6.1.2 Diffraction of light (Shadowing)

Diffraction is a phenomenon that occurs when traveling signals bend or diverge in the vicinity of barriers. It is caused by the edge of the impermeable substance that is big in comparison to the wavelength of the propagating signal as shown in Figure 2.9 as, mountains, houses, and walls[53]

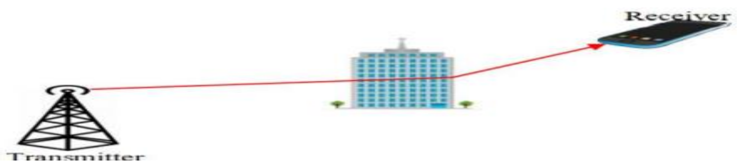


Figure 2.9: Diffraction of the transmitted signal[38]

2.6.1.3 Scattering

Scattering occurs when a propagating signal jumps off an obstacle that is the same size or narrower than the wavelength of the touring signal as in Figure 2.10. The signal is dispersed in all directions, rather than being reflected in a single path[53].

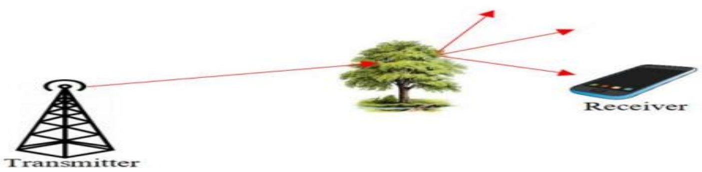


Figure 2.10: Scattering of the propagated signal.

2.6.2 The Effects of Multipath Propagation

The effects of multipath propagation include the following [54].

- Data Corruption: If the multipath is bad enough, the recipient is unable to detect the received information
- Signal cancellation: The Los signal is completely canceled when the reflected signals (NLOS) arrive precisely out of phase with the LOS
- Signal Amplitude Increase: The signal intensity is increased when the reflected NLOS signals arrive in phase with the LOS and contribute to the primary signal
- Decreasing Signal Amplitude: The signal amplitude is reduced when the reflected NLOS signals are out of phase with the LOS signal to some amount. Communication across such channels necessitates the development of strategies to avoid multipath effects.

2.7 Channel Models

The channel is referred to as electromagnetic medium stuck between the transmitter and the receiver. In an ideal radio channel, the received signal will compose of one path signal only which consider as a perfect transmitted signal reconstruction. While, in our life the channel is consider as a real channel so that the received signal is made of a set of deflection replicas for the transmitted signal, refracted, reflected, and attenuated. In addition Associated delays paths of Different signal in multi-path fading channel Change is unpredictable and can only be statistically characterized. Noise is added by the channel to the signal.

On top of all this and if the receiver or transmitter is moving it can make a shift in the frequency of carrier which known as the Doppler Effect. Since the performance of the radio system rely on the characteristics of the radio channel, therefore it is important to consider these effects on the signal [55]

There are two common channels

1. AWGN Channel
2. Rayleigh Fading Channel

Rayleigh Fading can be classified as two kinds of channels

A. Flat fading.
B. Selective fading.

2.7.1 Additive White Gaussian Noise (AWGN)

AWGN channel is the simplest channel type, it has noise distribution with a constant power spectral density and the channel bandwidth. The source of Gaussian noise may be coming from natural sources such as shot noise, black body radiation from the warm objects or thermal vibrations of atoms in antennas, and etc. With impulse response h = 1, the channel is assumed to be perfect. Only white Gaussian noise from the recipient front end is got to add to the signal,[56] as follows:

$$\mathbf{Y}(n) = \mathbf{x}(n) + \mathbf{w}(n) \quad \ldots \quad \mathbf{2.12}$$

Where $w(n)$ denotes Gaussian noise with a mean of zero.

2.7.2 Rayleigh Fading Channel

The Rayleigh fading channel is a way to gather information concepts for radio transmissions that are used to estimate the dissemination conditions that wireless signals occur during transmission. According to the framework, Any signal passing through this channel is assumed to be subject to a random magnitude transformation according to the Rayleigh distribution or simply fades.[57] The Rayleigh fading channel is thought to be an exact model for radio signals in densely populated areas. This channel will be most powerful when there is no direct line of sight between the transmitter and the receiver and many obstacles between them. The radio signals are dispersed by the barriers until they arrive at the destination Rayleigh channel has an amplitude with Rayleigh distribution, the probability density function of Rayleigh channel can be given by:

$$P_{Rayleigh}(r) = \frac{r}{\sigma^2}\exp(-\frac{r^2}{2\sigma^2}) \quad \ldots \quad 2.13$$

where, **σ** is the standard deviation and **r** is a random variable. The main source of the Rayleigh noise is the multipath propagation of the signal due to the indirect paths of the received signal at the receiver and no line of sight path exists between transmitter and receiver[58].

2.7.3 Bit Error Rate

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been changed by interference, noise, bit synchronization errors, and distortion. BER is normally used for determining the performance of the OFDM system. [59]The BER can be calculated as:

$$\text{BER} = \frac{\text{Number of received bits with error}}{\text{Total number of transmitted bit ribution}} \quad \text{....2.14}$$

BER is affected by many factors such as noise, quantization errors, wireless multipath fading, bit synchronization channel noise, attenuation, interference, distortion, etc. The BER is inversely proportional to the SNR because the noise in the transmission medium may disturb the information signal and causes data corruption[60].

The BER is improved by selecting strong signal strength, selecting robust and slow modulation schemes or line coding techniques, and applying channel coding techniques such as redundant forward error correction codes[61].

2.8 Coded channels

A kind of signal enhancement is channel coding that is used to improve communication performance by allowing the transmitted signal to withstand the impacts of different channel impairments such as noise fading and jamming. By adding redundancy to the transmitted data, channel coding aims to enhance the bit error rate (BER) performance of power-restricted and/or band-limited channels[62].

Already discussed how OFDM solves the problem of inter-symbol interference by broadcasting some narrowband subcarriers and employing a guard period. This leads to another issue, which is that in multipath fading channels, all subcarriers arrive at the receiver with varying amplitudes. Certain subcarriers may be lost entirely.Because of the severe fades, certain subcarriers may be lost. Even though most subcarriers may be recognized without errors, the total BER will be dominated by a few subcarriers with the lowest amplitudes[63].

To avoid this dominance of the weakest subcarriers, forward-error correction coding is required. Errors in the weak subcarriers can be repaired by coding across the subcarriers up to a particular limit determined by the error control code and the channel.

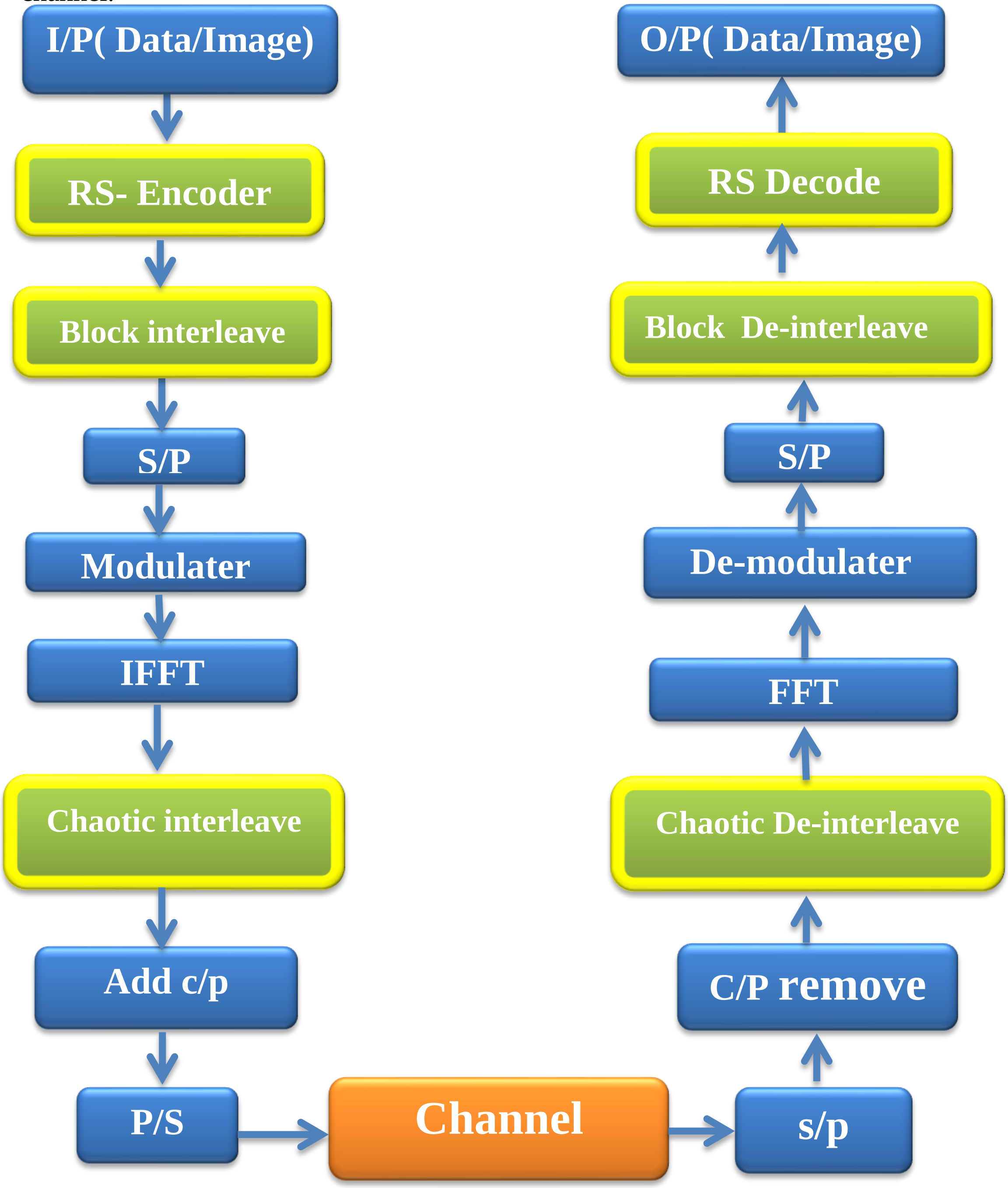


Figure 2.11 shows the improvement added to the system (OFDM)

The bursts error the process of interleaving can improve the performance of codes the explore Reed-Solomon codes with two types of interleaver in the following.

Figure 2.11 shows the improvement added to the system (OFDM), where the parts in blue represent the basic components of the system, and the parts in green represent the added improvement, RS- code was ability to identify and correct individual random and single errors but the code is limit in burst error

The add new technique that makes the system more reliable, fast and efficient is interleaving as well as the ability of interleaving to correct the accumulated burst errors that the messenger was unable to correct as well as interleaving adds a degree of security to the communication system by saving data during transmission through the use of an encrypted key between the sender and recipient .

Additionally its ability The interleaving is employed in the system to break the long correlation patterns of the in-phase and the in-quadrature components leading to a reduction in the PAPR. On the other hand, the errors are better distributed to different places after de-interleaving at the receiver. As a result, a better BER performance can be achieved with this proposed mechanism.

2.8.1 Fundamentals of Channel Coding Shannon's Theorem

By selectively incorporating redundancies in the transmitted data, channel coding protects digital data against mistakes. Error correction codes are codes that can detect and fix faults[64]. Shannon found in 1948 that by properly encoding the information, mistakes caused by a noisy channel may be minimized to any desired level without losing the pace of information flow. Shannon's channel capacity formula, which is provided by applies to the AWGN channel

$$C = B\log_2 \left(1+P/N_0B\right) = B\log_2 \left(1+\frac{S}{N}\right) \dots \quad 2.15$$

Where C represents the channel capacity (bits per second), B represents the transmission bandwidth (Hz), P represents the received signal power (watts) and N0 is the single-sided noise power density (watts/Hz).

Where Eb is the average bit energy and Rb is the bit rate of transmission The transmission bandwidth may be used to normalize E. equation 2.16 which is obtained by

$$\frac{C}{B} = \log_2 \left(1+\frac{E_b R_b}{N_0\ B}\right) \quad \dots \quad 2.16$$

Where C/B stands for bandwidth efficiency. The fundamental goal of error detection and correction algorithms is to establish redundancies in data to improve wireless network performance. The addition of redundant bits raises the raw data rate utilized in the network, therefore raising the bandwidth needed for a fixed source data rate. This decreases the link's bandwidth efficiency in high SNR circumstances while providing great BER performance in low SNR conditions[65].

The use of orthogonal signaling allows the chance of error to become arbitrarily minimal by increasing the signal set, and Shannon's discovery suggests that extremely wideband signals might be used to achieve error-free communications as long as adequate SNR exists.

2.8.2 Block Codes

A block code is defined as an (n, k) code and is defined as a code in which k symbols are input and n symbols are output. There are unique messages if the input is k symbols. For each k input symbol, the output is a codeword of n symbols where n is bigger than k [66]

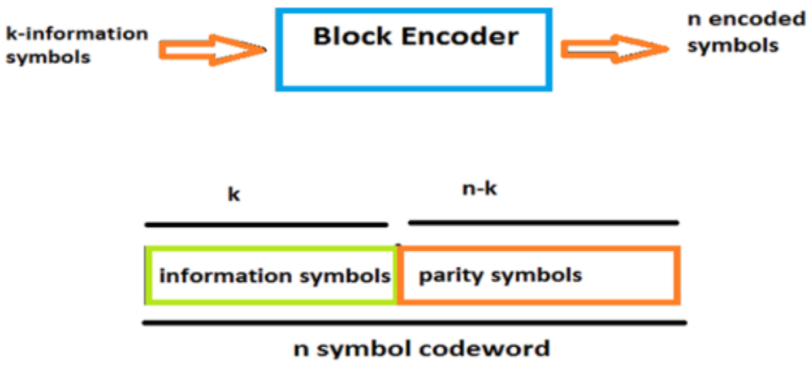


Figure 2.12: A block encoder and coding codeword

Note the usage of the word “symbols” instead of “bits” when referring to RS Codes. The word “symbol” is used to refer to a group of bits. For example, if using a (7, 3) RS Code with 5-bit symbols, it implies that each symbol is a collection of 5-bits, and the RS Codeword is made up of 7 such symbols, of which 3 symbols represent data, and the remaining 4 symbols represent parity symbols as show in figure 2.12 [67].

2.8.3. Reed–Solomon code

Reed-Solomon codes remedy faults by having the encoder add redundant data Bits are added to the digital input data. The decoder makes effort to repair and restore the original data by eliminating mistakes produced during transmission, which might be caused by a variety of factors noise in the channel as scratches. Reed-Solomon codes are classified into many families and each has its unique set of talents for reducing the amount and kind of mistakes. The encoder adds parity bits to the k data symbols of s bits each to form an n-symbol codeword. Errors in a codeword can be repaired by the decoder up to a maximum of t symbols, where $2t = n - k$. A RS code able to correct any error pattern of size t or less.as show in figure 13 [68].

Code length $n = q - 1$

Number of parity check elements $n - k = 2t$

Minimum distance $d_{min} = 2t + 1$

Error-correction capability t element errors per code vector

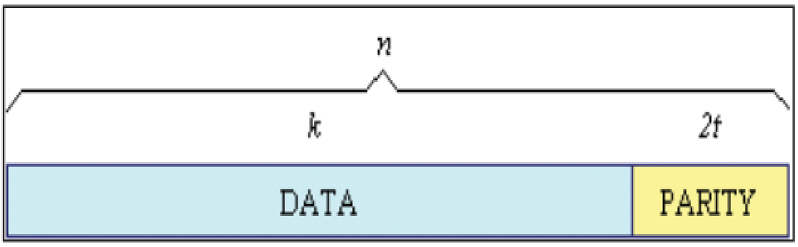


Figure 2.13: A typical Reed-Solomon Codeword

2.8.4 Encoding and Decoding Process of RS code

In order to realize the encoding and decoding principles of RS codes, it is necessary to know the area of finite fields. The enormous mathematical calculations and arithmetical operations involves in the RS encoding and decoding process. Such, arithmetical calculations over a finite field with certain properties are known as Galois fields [69]. Galois Field is a set that contains a finite number of elements and the miscellaneous operations of addition and multiplication for such sets are defined. Symbols from the extension field are used in the construction of Reed-Solomon codes. Besides the binary number 0 and 1, there are additional unique elements in the extension field that denotes the variable a. A finite set of elements, say (A) is formed by the element {0, 1, a} and generating additional elements by multiplying the last entry by a which yields as in

A = {0, a 0 , a 1 , a 2 ,a 3 , ……., a j } … 2.17

Thus, to obtain the finite set of elements from S, a condition must be imposed on A so that it may contain only 2 elements and is closed under multiplication. Therefore, the elements of the finite field GF are given in

GF (2m) = {0, a 0 , a 1 , a 2 ,a 3 ,..,a 2m-2 } 2.18

A set of polynomials called field generator polynomial is used to define the finite fields of Galois field (GF). It is a polynomial of degree m which is irreducible, also known as polynomial without any factor. For a Galois field of a particular size, there is sometimes a choice of suitable polynomials[70]. The RS encoding process for the message word m(x), involves the following steps:

1. Generate the generating polynomial:

$$\mathbf{G(x)} = \boldsymbol{g0} + \boldsymbol{g_1 x^1} + \boldsymbol{g_2 x^2} + \cdots \qquad \mathbf{2.19}$$

2. Generate the parity polynomial:

$$\boldsymbol{P(x) = x^{n-k}\, m(x) modulo\, G(x)} \qquad \mathbf{2.20}$$

3. The required codeword polynomial will be:

$$\boldsymbol{C(x) = P(x) + x^{n-k}\, m(x)} \qquad \mathbf{2.21}$$

Any valid code polynomial must be a multiple of the generator polynomial. It follows that any valid code polynomial must have as roots the same 2t consecutive powers of that form the roots of g(x). This provides to with a very convenient means for determining whether a received word is a valid code word the simply make sure that the corresponding polynomial has the necessary roots.

Reed Solomon code is non-binary block code. In the encoder redundant symbols are generated using a “generator polynomial” and appended to the information symbols. In decoder error location and magnitude are calculated using the same “generator polynomial”. Then the correction is applied on the received code. Reed Solomon code has very high coding rate and low complexity.

Designers are not required to use the "natural" sizes of Reed–Solomon code blocks. A technique known as "shortening" can produce a smaller code of any desired size from a larger code. [71] For example, the widely used (255,223) code can be converted to a (160,128) code by padding the unused portion of the source block with 95 binary zeroes and not transmitting them. At the decoder, the same portion of the block is loaded locally with binary zeroes. The Delsarte– Goethals–Seidel . theorem illustrates an example of an application of shortened Reed–Solomon codes. In parallel to shortening, a technique known as puncturing allows omitting some of the encoded parity symbols[72].

2.8.5 Syndrome

This error position is called Syndrome and the method is called Syndrome Decoding. Let the error magnitude at each location x^j denoted as e_j Then e (x) has the form: $e(x) = e_{j1}x^{j1} + e_{j2}x^{j2} \dots\dots + e_{jk}x^{jk}$

Define the set of error locator numbers $B_i = a^j$,j=1,2…k . Then the set of syndromes yields the following system of equation 2.22:

$$S_1 = e_{j1}B_1 + e_{j2}B_2 + \cdots + e_{jk}B_k \quad 2.22$$

Any algorithm which solves this system of equations is a Reed Solomon decoding algorithm. The error magnitudes e_j are found directly and the error locations $\mathbf{x}^j$ can be determined from B_k . If the error pattern is the all-zero vector then the syndrome vector will also be an all-zero vector, and thus the received vector is a valid codeword [73]. When the syndrome vector contains at least one non-zero component it will be detecting the presence of errors in the received vector.

2.9 Bursty Channels & Interleavers

Bursts (or clusters) of errors are defined as a group of consecutive error bits. A bursty channel is defined as a channel over which errors tend to occur in bunches, or "bursts," Therefore, a random error correction code, when applied, may not be powerful enough to correct the bursts of errors, in many channels of practical interest, the channel errors tend to be clustered together in "bursts." wireless channel may experience fading over several symbol times, or a stroke of lightning might affect multiple digits, a single incorrect decoding decision might give rise to a burst of decoding errors. Using a conventional random error-correcting block code in a bursty channel leads to inefficiencies[74].

In general, error-correcting codes are not efficient for correcting bursts, special burst error-correcting codes are used for this purpose introducing techniques for dealing with errors on burst channels is interleaving.

2.9.1 Interleaving

A process or methodology of rearranging the data in a non-contiguous manner to make the system more reliable, efficient, and fast based on predefined rules An interleaver, employed at the transmitter, essentially spreads out the burst errors (by shuffling the bits across the codeword) and distributes the errors across the entire code word. Since the burst errors are now distributed across the codeword, the codeword becomes more reliable for recovery[75]. This is because; the maximum length of a burst error in the codeword is reduced. Now the Reed Solomon code can operate more efficiently and will aid in recovering the codeword correctly. A de-interleaver used at the received to reorder or restore the bits to their original position. If the expected burst lengths less than or equal to t (the number of correctable symbol errors by RS coding), the code can be used as it is. However, if bursts length longer, the error-correcting code will fail. This is where interleaving comes to our rescue[76].

2.9.2 Block Interleaver Construction

Without repeating or omitting any elements the block Interleaver rearranges the elements of the input. The input to the block interleaver can be any number (real or imaginary). This type are efficacious in dealing with bursts of errors because an interleaver, employed at the transmitter, essentially spreads out the burst errors (by shuffling the bits across the codeword) and distributes the errors across the entire codeword now the Reed Solomon code can operate more efficiently and will aid in recovering the codeword correctly. A de-interleaver used in the receiver to reorder or restore the bits to their original position[77].

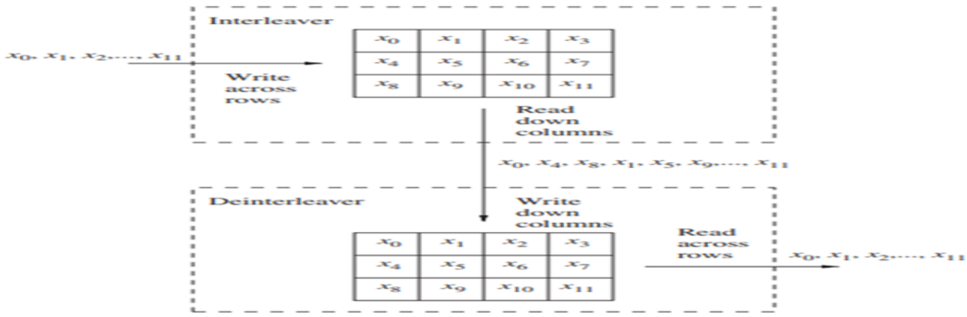


Figure 2.14: Block Matrix interleaver 3 × 4 interleaver and deinterleaver.

A block interleaver also called Matrix interleaver as shown in figure 2.14. This is simply an N × M array that can be read and written in different orders. Typically the incoming sequence of symbols is written into the interleaver in row order and read out in column order interleaver in row order and read out in column order. Figure 2.14 shows a 3 × 4 interleaver. The input sequence x0, x1, ..., x11 is read into the rows of array, as shown, and read off as the sequence x0, x4, x8, x1, x5, x9, x2, x6, x10, x3, x7, x11. Frequently, the width M is chosen to be the length of a codeword.

2.9.3 The block interleaving mechanism

Assume a burst of errors affecting four consecutive samples (1-D error burst) as shown in Figure 2.15-b with shades. After de-interleaving as shown in Figure 2.15-c the error burst is effectively spread among four different rows, resulting in a small effect for the 1-D error burst. With a single error correction capability it is obvious that no decoding error will result from the presence of such a 1-D error burst. This simple example demonstrates the effectiveness of the block interleaving mechanism in combating 1-D bursts of errors. [78]

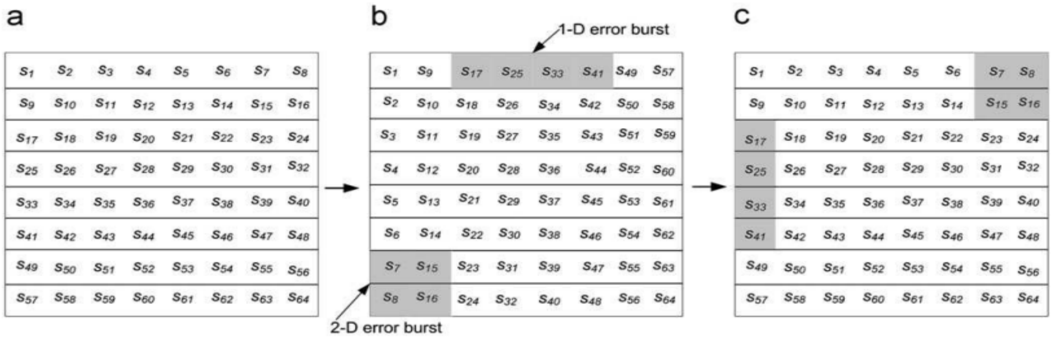


Figure 2.15 Block interleaving of an 8X 8 matrix.

The performance of the block interleaving mechanism when a 2-D (2 X 2) error burst occurs as shown in Figure 2.15-b with shades. Figure 2.15-c indicates that this 2 X 2 error burst has not been spread, effectively, there are adjacent samples in error in the first and second rows. As a result, this error burst cannot be corrected using a single error correction mechanism. That is, the block interleaving mechanism cannot combat the 2 X 2 bursts of errors.

2.9.4 The proposed chaotic interleaving mechanism

As mentioned in the previous sub-section, the block interleaver is not efficient with 2-D bursts of errors. As a result, there is a need for advanced interleavers for this task. The 2-D chaotic Baker map in its discretized version is a good candidate for this purpose. Due to the inherent strong randomization ability of these maps, they can be efficiently used for data interleaving[79].

The signal samples can be arranged into a 2-D format and then randomized using the chaotic Baker map. The chaotic interleaver generates permuted sequences with a lower correlation between their samples and adds a degree of encryption to the transmitted signal the discretized Baker map is an efficient tool to randomize the items in a square matrix. [80] Let B(n1, …, nk), denote the discretized map, where the vector, [n1, …, nk], represents the secret key, S_{key} Defining N as the number of data items in one row, the secret key is chosen such that each integer ni divides N, and $n_1 + \cdots + n_k = N$. Let $N_i = n_1 + \cdots + n_{i-1}$. In steps, the chaotic permutation is performed as follows:

1) An N X N square matrix is divided into k rectangles of width ni and number of elements N.
2) The elements in each rectangle are rearranged to a row in the permuted rectangle. Rectangles are taken from left to right beginning with upper rectangles and then lower ones.
3) Inside each rectangle, the scan begins from the bottom left corner towards the upper elements.

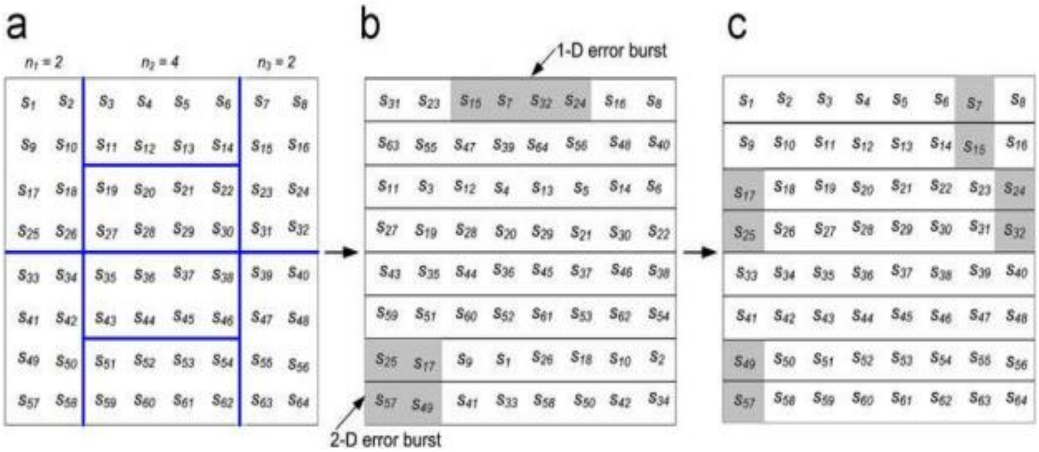


Figure 2.16 shows an example of the chaotic interleaving of an (8 X 8) square matrix (i.e. N=8). The secret key, Skey=[n1 , n2 , n3]=[2,4,2].

In figure 2.16, Note that the chaotic interleaving mechanism has a better treatment for both 1-D and 2-D bursts of errors than the block interleaving. Errors are better distributed to samples after de-interleaving in the proposed chaotic interleaving mechanism. As a result, a better BER performance can be achieved with the proposed interleaving mechanism. Moreover, it adds a degree of security to the communication system.

2.10 Image Transmission Over OFDM System

The figure 2.17 show the image transmission over the OFDM the processing steps of the image transmission in detail.

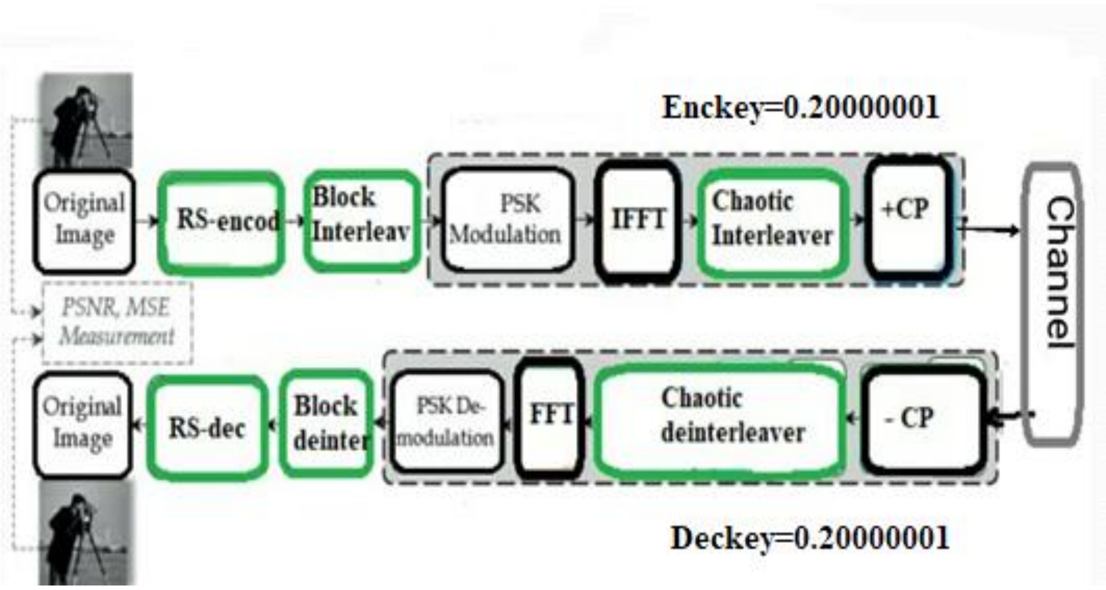


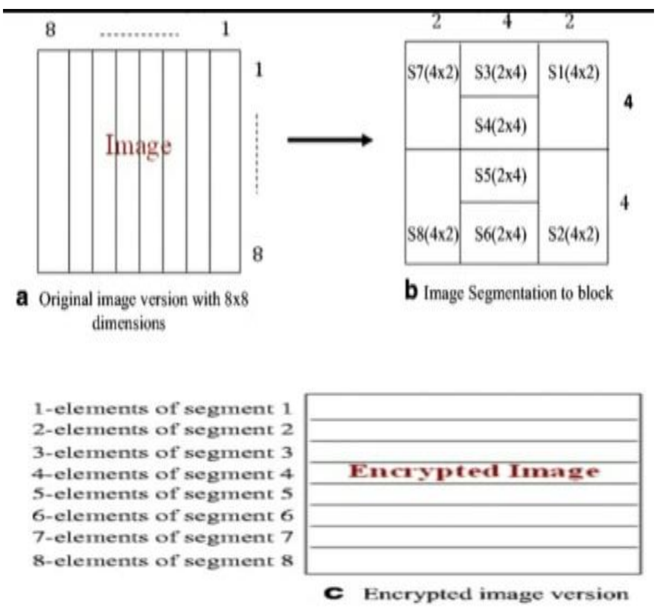
Figure 2.17 Show sent image in RS-OFDM with two interleaver

At the transmitter,[81] Firstly the image has been segmented into small packets as show in figure 2.17. Then encoding techniques have been applied. The encoding stage has been followed by the interleaving process the modulated data in (BPSK). The Inverse Fast Fourier Transform (IFFT) has been performed in converting the modulated data from the frequency domain into the time domain then encryption image by using the encryption key of chaotic interleaver. Finally add CP transmitted through the channels[82].

At the receiver, the inverse stages of transmission have been performed and in the steps, the received image is reconstructed by the success received and decoded packets collection[83]. The quality of the received image is measured with the peak signal-to-noise ratio (PSNR)[84] which is usually expressed in terms of the logarithmic decibel scale. It can be defined as follows in equation 2.23:

$$PSNR = 10\ Log\ \left(\frac{peak^2}{MSE}\right) \qquad 2.23$$

Where *MSE* is the mean squared error between the original and the reconstructed image, and *Peak* is the maximum possible amplitude of an image pixel. The peak value is 255 for 8 bits/pixel images.To better depict the performance of the proposed schemes, each simulation configuration is repeated for two different channel profiles AWGN channel and frequency selective fading channel[84].



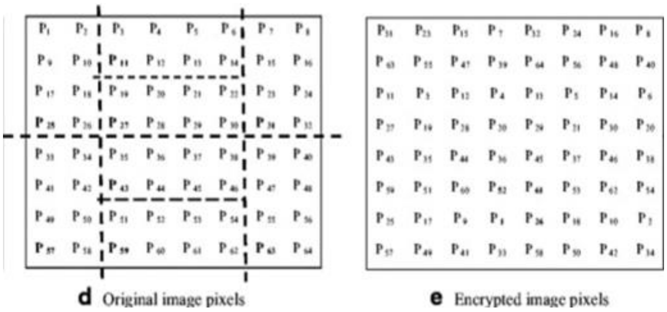


Figure 2.18 shows the chaotic interleaving of an (8 X 8) square matrix (i.e. N=8).

Chapter Three

Simulation of OFDM

3.1 Introduction

In this chapter explores how this study was conducted and how it was impleme nted.The implementation and modeling of the transmitter and receiver of theOFDM s ystem for random data and picture transmission are completed in this chapter. Transm ission distortions in conventional fixed.This chapter will go through the work done in this thesis,Beginning
with the methodological framework and then continuingto the execution
primary goal was to test OFDM systems for channel coding and assess performance b ased on BER improvement.

3.2 Research methodology

In this study, MATLAB was used as a tool to implement the OFDM system, and also an error correction code for the OFDM system, and then compare the performance of these techniques.

At various SNR, the behavior of all three techniques (Block interleaver, Chaotic interleaver and Reed-Solomon code) will be revealed. The analysis of the performance of the three methods schemes in conjunction with OFDM will be aided by the evaluation. The outcomes of this study could help OFDM system designers choose error-correcting codes that are appropriate for their purposes.

An interleaver, employed at the transmitter, essentially spreads out the burst errors (by shuffling the bits) across the entire codeword. Since the burst error length is distributed across the whole world it becomes more reliable for recovery. Frequency (sub-carrier) interleaving increases the resistance for fading. For example, when part of the channel bandwidth fades, frequency interleaving ensures that bit errors that might be caused by those sub-carriers in the faded portion of the bandwidth are propagated into the bitstream rather than into focus. Likewise, interleaving ensures sent from each other in the bitstream at intervals thus mitigating the severe fading that occurs when traveling at high speed.

3.3 Implementation

In the transmitter part shown in figure 3.1coding involves changing the message source to a suitable code to be transmitted through the channel the data from the source is randomized firstly and then passed through the Reed Solomon code, An appropriate amount of control redundancy is added to these source bits to protect them against the errors in the channel and to control redundancy into the transmitted or stored information (data) to increase the reliability of transmission and lower transmission requirements.

Then using the block Interleaver, where it randomly distributes the input data and corrects the errors with 1D, then transforms the data from serial to parallel and modulated them with PSK (BPSK or QPSK) and, then using IFFT it will be kept sub-carriers orthogonal with each other to prevent ISI occurs.

The data interleaving leads to performance enhancement of data transmission in wireless communication systems. It is known that data transmission over wireless channels may face severe adverse conditions, especially, burst errors, thus interleaving becomes an effective means to combat error bursts by converting bursts of errors into random errors. The Baker map is used for generating sequences of pseudo-random numbers, which can be used as time pads for the randomization process.

Moreover, the chaotic Baker map is an encryption tool that provides an additional degree of security to the transmitted signal over the wireless link finally is added Cyclic Prefix (CP) to make the system robust to inter-symbol interference (ISI). The data will be summed in a narrow bandwidth and sent through the channel. Two channels were used: additive white Gaussian noise (AWGN) and Rayleigh fading

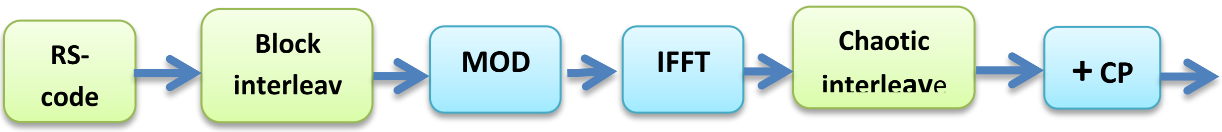


Figure 3.1 Transmitted side of OFDM system

at the receiving side in figure 3.2 after removing CP the data will be decrypted with Chaotic De-Interleaver, It will use the decryption key, which must be identical to the encrypted key. Then it will pass through the FFT. The data will be De-modulated, then block errors are identified and corrected by using 1D and RS-Decode to correct the single error to get the original data.

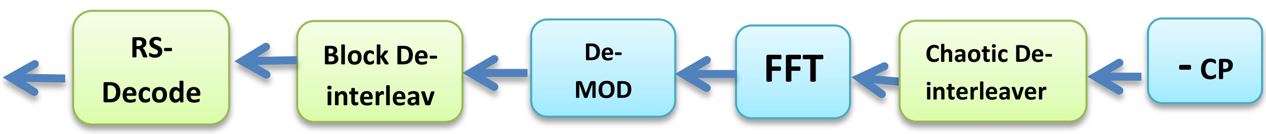


Figure 3.2 receiving side of OFDM system

3.4 Modeling RS-Code Performance

A complete RS-coded communication system PSK modulation over AWGN and fading channels have been constructed to evaluate the Bit-Error-Rate performance of the Reed-Solomon error-correcting code. It is a cyclic symbol error-correcting code and functions at the block level rather than the bit level. Such symbols can either be comprised of one bit (binary code) or, several bits (symbol codes). Reed-Solomon code belongs to a block codes family and is capable of working up to symbols level. The performance of RS codes can be evaluated from a different point of view like Redundancy, Code length, Code Rate, and error correction capability.

3.5 Transmitter

The transmitter of the OFDM system consists of four basic stages. first convert from serial to parallel the data is modulated and IFFT the addition of the cyclic prefix, then it is transmitted through the channel and then explain technics addition to enhance the system.

3.5.1. Data

To show the features and characteristics of the proposed system, two types of data were sent, random data and image data. Random data was generated by using the rand function. The rand function generates arrays of random numbers whose elements are uniformly distributed in the interval (0, 1). Y = rand (n, m) returns an n-by-m matrix of random entries. Image data is converted to a stream of binary bits before sending data over the system. The source block produces frame-based, 16-array random integers with 1280 samples/frame as seen in figure 3.3

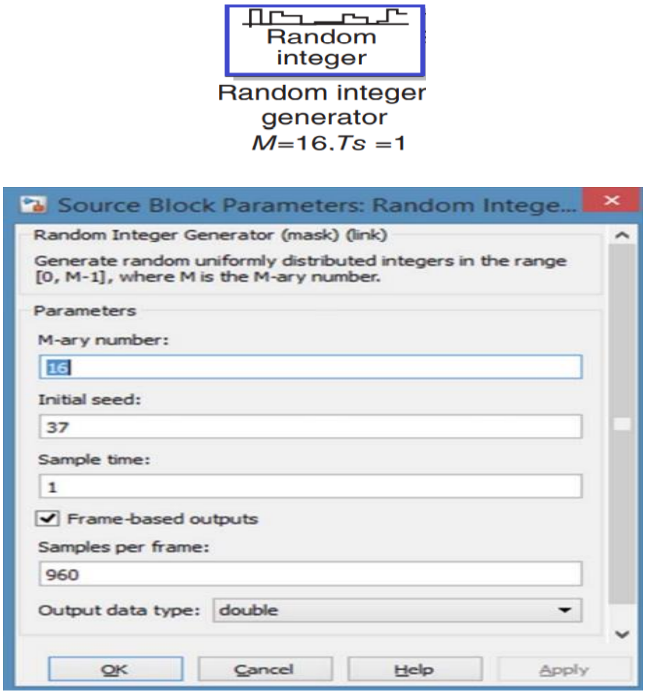


Figure 3.3 Source Block Generation of 16-arry Random Integers.

3.5.2 Block of RS-Encoder.

As shown in figure 3.4, the encoder takes k data symbols and adds check symbols to make an n symbol codeword. RS codes correct up to t errors in a codeword where 2t=n-k. For a symbol size m, the maximum codeword length (n) is n=2m -1. Because RS codes correct byte errors, they can potentially correct many bit errors. This makes RS code very good at correcting large clusters of errors. The amount of processing "power" required to encode and decode RS codes is related to the number of parity symbols per codeword. A large value of t means that a large number of errors can be corrected but requires more computational power than a small value of t

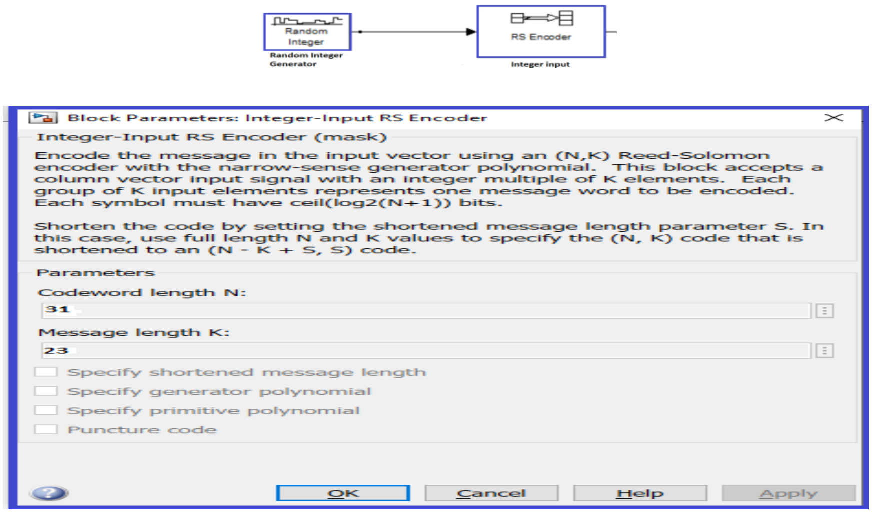


Figure 3.4 Setting of the RS encoder block

3.5.3 Block of Interleaver:

On the interleaver side, pseudo-random permutation is generated of available memory addresses. The data symbols are rearranged according to these generated pseudo-random orders of memory addresses, Block Interleaver may be basic and simple and should execute over different systems. Shown in figure 3.5 the setting of the Block Interleaving.

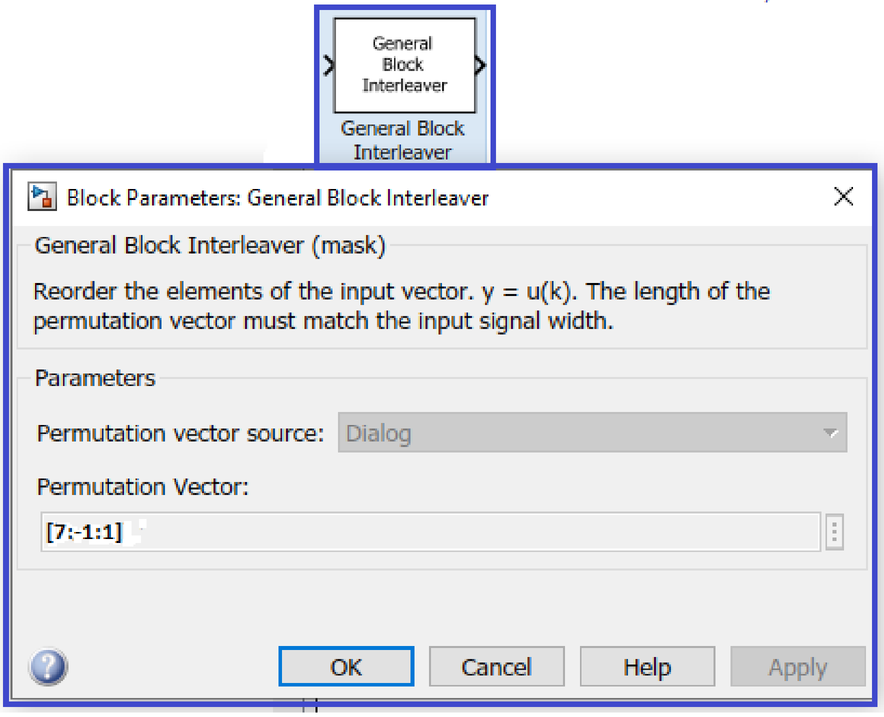


Figure 3.5 Block Interleaving

3.5.4 Block of Modulation

Modulation is a process of mapping the code bits in a format that is effectively sent over the communication channel. A modulation scheme converts the digital data signal into a signal which can be transmitted through the communication channel. The main aim of the modulation is to compress the data as much as possible into the spectrum or bandwidth available MATLAB functions and tools support several solutions for modulation and demodulation.

In our developed application, the modem. Psk mod (M) function was used from Communication Toolbox. This function also enables the setup that which symbols are to be mapped. Figure3.6 displays the shaping of OFDM symbols, found by looking under the mask, where it is seen that the 1280 samples/frame is converted into a 64 × 20 array.

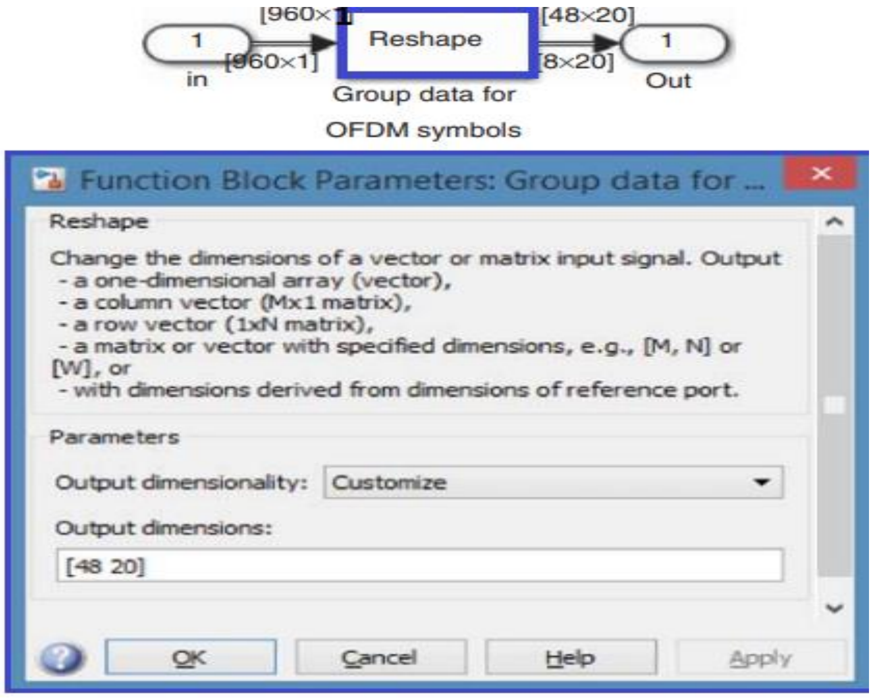


Figure 3.6 OFDM Symbol Shaping and Block Parameters.

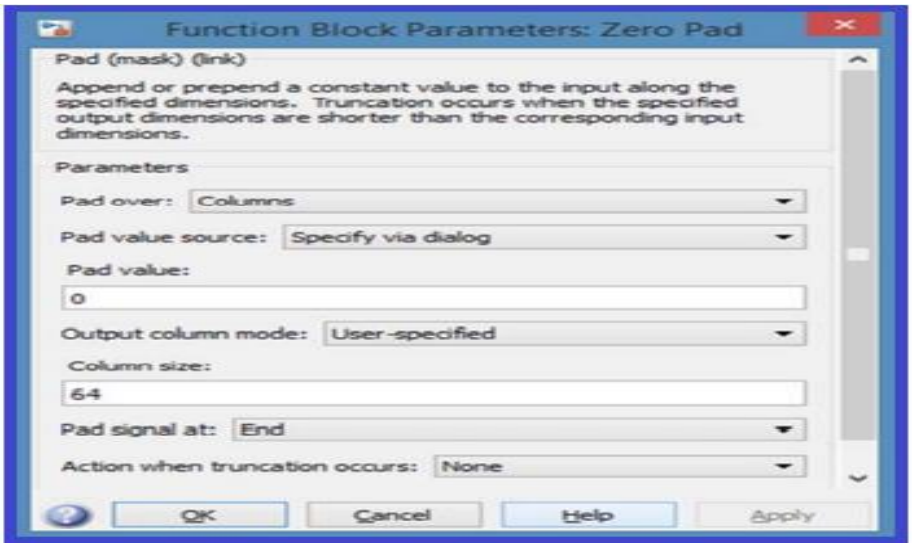


Figure 3:7 Zero Pad

To create an efficient IFFT size shown in Figure 3:7 appends zeroes to increase the column size to 64. The OFDM modulation is implemented using a 64-point IFFT block depicted in the selector block, labeled “shift for IFFT” as shown in figure 3.8 modifies the indices of the array for input to the Inverse Fast Fourier transform (IFFT).

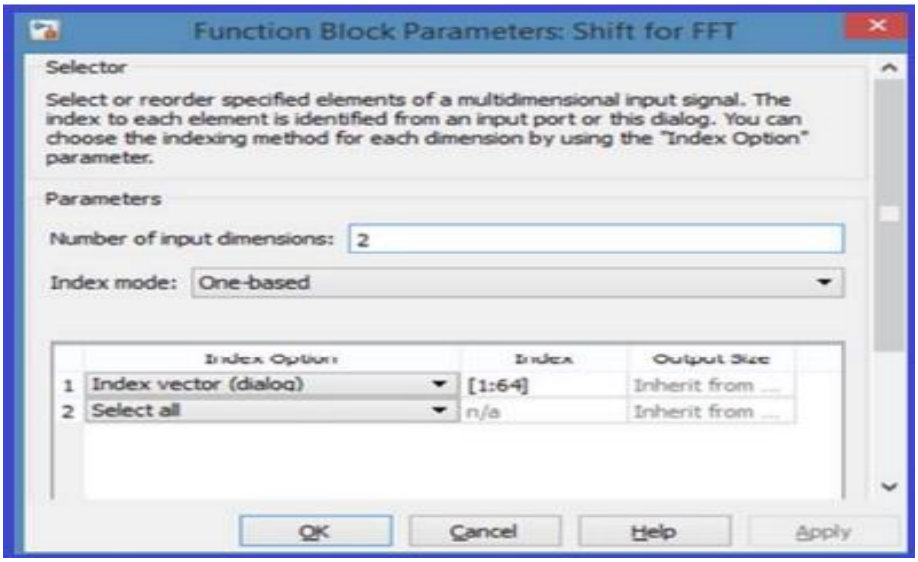


Figure 3.8 Selector Block, Shift for IFFT

3.5.5 IFFT

After converting serial to parallel spreading data, the inverse discrete Matlab's Fourier transform function was used to do the Inverse Fast Fourier transform. X = ifft(Y) returns the inverse.

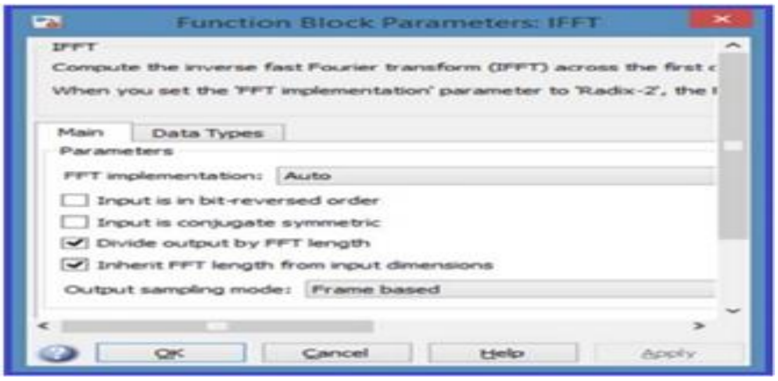


Figure 3.9 IFFT for OFDM Implementation

A rapid Fourier transform technique is used to compute the discrete Fourier tran sform of Y. The letter X is the same size as Y if Y is a matrix, the ifft(Y) returns the inverse transform of each matrix element. The use of Discrete Fourier Transform (DFT) in the parallel transmission of data using frequency division multiplexing was investigated in 1971 by Weinstein and Ebert used IFFT for the multiplexing of data for OFDM as shown in figure 3.9

3.5.6 The chaotic interleaving mechanism

In the system model after (IFFT) the signal samples can be arranged into a square matrix and then randomized using the chaotic Baker map. The discretized Baker map is required to transfer each element in a square matrix into a new position according to this map, then by using secret-key encryption data. For example, when used to send any image by Enc key = 0.20000001, the Dec key must have the same value Dec key=0.20000001, any small change in Dec key if an increase or decrease in Dec key the image not appear in the receiver. So, in this work use, Chaotic interleaved to save the data security between sender and receiver.

3.5.7 Add CP

The cyclic prefix is applied to symbols when the data stream is transformed fr om parallel to serialbits.

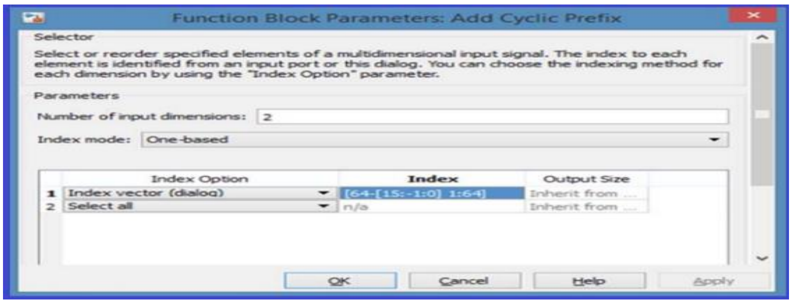


Figure 3.10 “Add Cyclic Prefix” Block Parameters

The cyclic prefix is designed in such a way that each symbol is preceded by a duplicate of the last section of the same symbol.In the suggested system a cyclic prefi x is addedby reshaping thebits of the symbol with a Matlab bits were added to this jo b as a cyclic prefix as shown in figure 3.10.

3.5.8 The channel

To test the efficiency of the system under different transmission conditions, two channels were used to send the data through it. The first is a Gaussian channel that adds white Gaussian noise to the data. The representation of a Gaussian channel in the proposed system was done using the Matlab function y = awgn (x, SNR).

The input x is assumed to be a real or complex voltage signal. The returned value y will be the same form and size as x but with Gaussian noise added. By the second channel the data was sent through the Rayleigh fading channel.

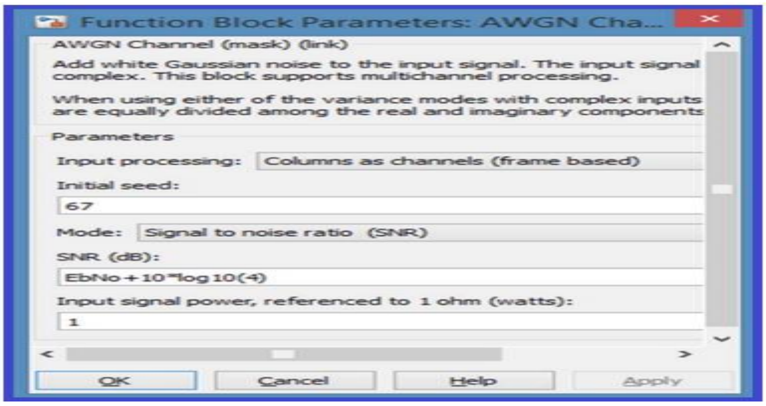


Figure 3.11 AWGN Parameters for OFDM Simulation

The Rayleigh fading channel was implemented assuming 4 taps with different gains and a delay of 1 second between taps. The setting of the AWGN block parameters for this simulation is shown in figure 3.11 where Eb/No =10 is specified in the MATLAB command window.

3.6 Receiver

When data is received from the channel, it moves through various steps before reaching the final data. The cyclic prefix is first deleted from the data, then it is input into the FFT section and finally, the disabling procedure is performed to separate the data of each user to extract the final data.

3.6.1 Remove CP

After receiving data from the channel The cyclic prefix is removed from symbols. In the suggested approach eliminating the cyclic prefix is done by reshaping the bits of the symbol with a Matlab function. The receive path converts the single-dimensional vector back to an 80 × 20 array displayed in figure 3.12.

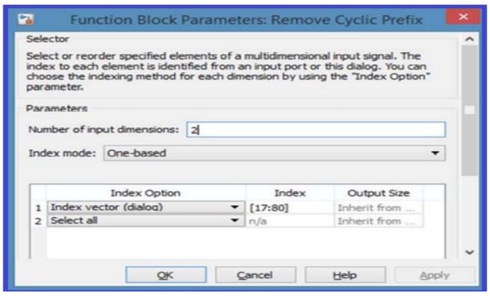


Figure 3.12 “Remove Cyclic Prefix” Block Parameters

3.6.2 The chaotic De- interleaving

At the receiver, The process is reversed. Since the data is processed to the chaotic de-interleaving the receiver is assumed to have an ideal knowledge of the secret key of the chaotic map. The data can be received and de-interleaved at the de-interleaver side only if it knows the exact order of the permuter-indices. The de-interleaver should know the order of pseudo-codes exactly like that in the interleaver. The piece de-interleaver performs the opposite operation of the interleaver

3.6.3 FFT

After removing the cyclic prefix from received data the data is converted from serial to parallel data. The discrete Fourier transform, done by using Matlab the function X = fft(Y) computes a discrete Fourier transform of Y using a fast Fourier transform algorithm. then fft(Y) returns the transform of each column of the matrix. shown in figure 3.14

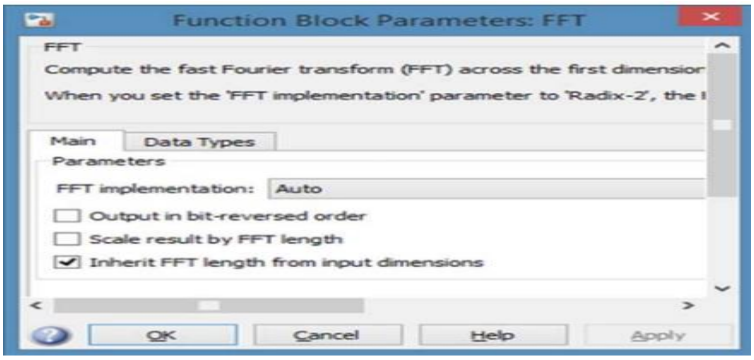


Figure 3.13 Parameters for 64-Point FFT

A serial syndrome is used to check if this codeword is valid or not.

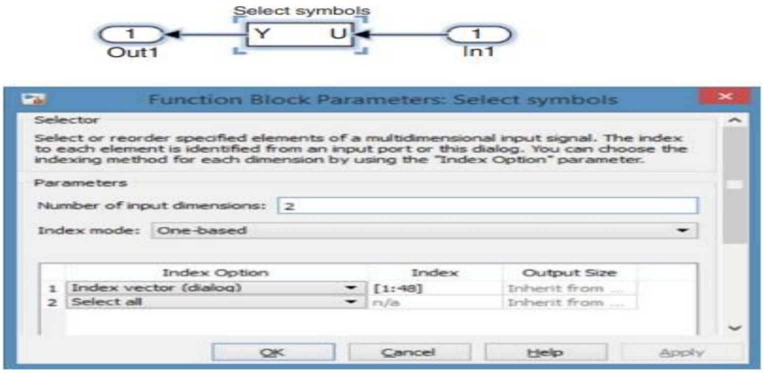


Figure 3.14 Remove Zeros Block and Associated Parameters

The “Remove Zeros” block, shown in figure 3.15 along with its parameters, produces a 64 × 20 array and its parameters used to convert the 64 × 20 arrays back to a 1280-sample frame for insertion into the 16-QAM demodulator

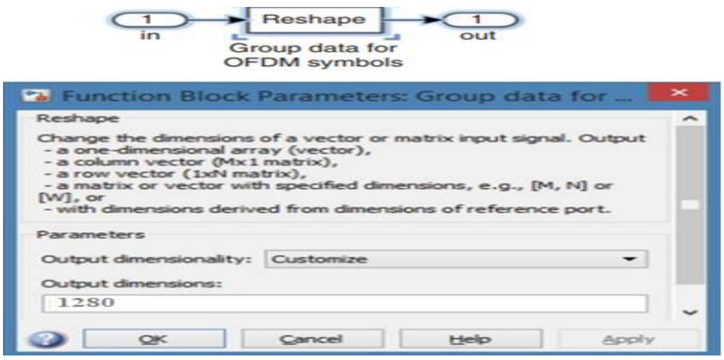


Figure 3.15 OFDM Symbols Block and Associated Parameters

3.6.4 Demodulation Block

The block parameters are the same that are used with the modulator in the transmitter side are shown in figure 3.16 displays the “OFDM Symbols” block the parameter settings.

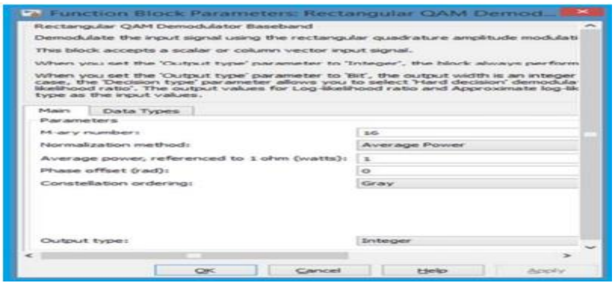


Figure 3.16 Rectangular 16-QAM Demodulator Parameters.

3.6.5 Block of De- Interleaver

The data can be received at the deinterleaver side only if it knows the exact order of permuter-indices. The de-interleaver should know the order of pseudo-codes exactly like that in the interleaver. The piece de-interleaver performs the opposite operation of the interleaver over which the data is composed of the RxC row-column grid section insightful Also perused over to column insightful.

3.6.6 Block of RS- Decoding

The RS decoder is more complex and consists of main stages; the error detection stage, and the error correction stage . If errors occurred during transmission, the decoder carried out error detection, then tries to correct these errors. then used to find the values of the errors. Finally, after getting the values and locations of the error, the received codeword can be corrected by XORing the received vector with the error vector as shown in figure 3.17

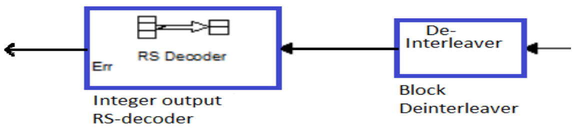


Figure 3.17 RS-decoder with Block de-interleaver

A summary of the principal OFDM Simulink model parameters used

M =16, k=4

- Gray coding
- Sample time=1 s
- Average signal power=1 W
- Frame-based with 1280 samples/frame
- OFDM array 20 × 64
- pad of zeroes 16
- 64-point IFFT and FFT
- 16- symbol cyclic prefix
- Receive and computation delay=0

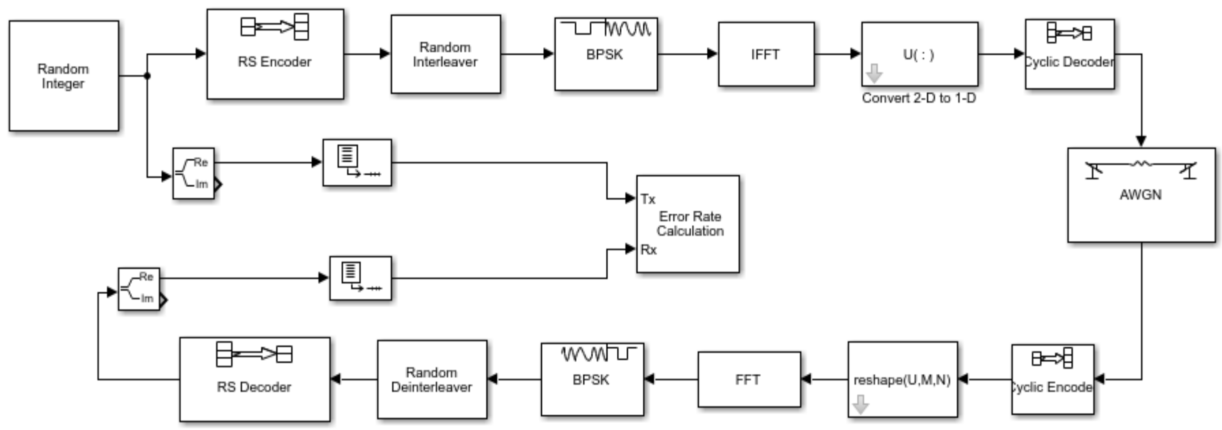


Figure 3.18 Simulink RS code OFDM with two interleaver

Chapter Four

Results and Discussion

4.1 Introduction

This chapter presents and discusses all of the results obtained by the computer simulation programs written in Matlab 2018b. It shows the analytical approach of a wireless communication system considering AWGN and Fading channel. BER calculations are accomplished using the Error Rate Calculation block. Simply this block compares the received data bits with the transmitted bits and counts the error bits. Then dividing the number of error bits by the total number of transmitted bits gives the BER. In more detail, the value of Eb/No in AWGN and Rayleigh select fading channels was changed from 10 dB to 50 dB, and at each time the value of BER was recorded. In the next steps, the performance of the data and image transmission and the image quality are measured with the different coding, interleaving and diffrent modulation have been carried out.

4.2 Component of Data Transmission in OFDM System

The results of simulating the OFDM system when random data is supplied will be shown later in this chapter. The outcomes of four scenarios will be shown, including system uncode, RS-code, and two interleavers. Different types of modulation techniques are utilized with two different types of channels in each situation

The system was tested by delivering data on two types of channels, AWGN and Selective Rayleigh fading channels, in order to understand and assess its behavior and efficiency. In the following paragraphs, the results will be presented into two groups, one using AWGN and the other using the Rayleigh fading Channel. The parameters used in the system modeling are shown in table1

Table 4.1 Simulation factors for communications system OFDM coded

OFDM system factors	Depiction
Scheme Coding	Reed-Solomon coding
Total data	13485 bit
Encoder RS	(31, 23)
Number of sub-carriers	52
IFFT/FFT point’s Size	64
Cyclic prefix	16 bits (rate=1/4)
Modulation	QPSK,BPSK,16PSK,32PSK,64PSK
Channel	AWGN-Rayleigh Fading
Interleaver	Block, Chaotic
Number of bits in symbol (m)	5 bits
Data length (k)	23 bits
Code length (n)	2^m-1 = 2^5-1 = 31 bits
Primitive polynomial	37 = [1 0 0 1 0 1] = D^5+D^2+1

4.3 RS- code Performance as the Function of Redundancy

The Reed-Solomon code (n, k) for several coding rates are: $CR1$ = (4/7), $CR2$ = (11/15), $CR3$ = (23/31), where each coding rate $CR = k/n$ represents the ratio between k the code dimension and the code length $n = q - 1$, to study its influence on the system’s performance. It decreases the BER when the Eb/No is increased in BPSK modulation .

Similarly while comparing the BER before and after channel coding as shown in table 4.2, It is noticed an improvement in the system performance.

Table 4.2: Code Rate of RS code.

Codeword Symbol	Assumed RS Code	Code Rate (CR=k/n)
4	RS (4,7)	0.517
15	RS (11,15)	0.738
31	RS (23, 31)	0.742

It is a trade-off between performance and complexity with different coding rates: the most effective coding is the highest complexity the Reed-Solomon curve with the highest coding rate $CR3$ manages to converge to no errors for $Eb\ N0$ = 8dB.

The redundancy increases (that is lowering code rate), and the BER performance improved. The BER performance improves as the redundancy (n-k) increases from $\frac{E_b}{N_o}$= 8 symbols thereby lowering the code rate,the high error correction capacity (Reed-Solomon being the most effective). So, this research used RS (31,23) to obtain better enhancement in the OFDM system . Figure 4.1 shows these cases.

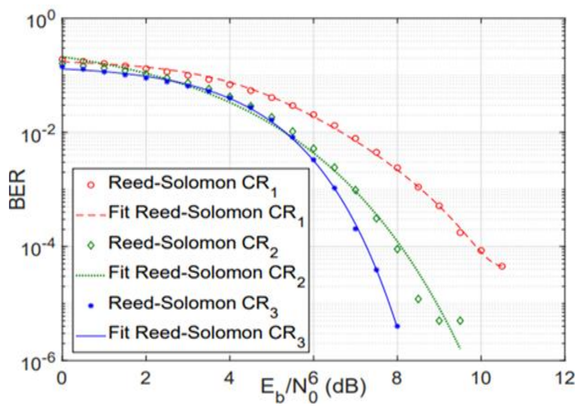


Figure 4.1 BER performance of the Reed-Solomon code for different coding rates $CR1$, $CR2$, $CR3$

4.4 RS- OFDM system with Block Interleaver in Rayleigh Fading channel

The results will be presented in the next paragraph. They can be classified into two groups. The first group is for the BER when sent data by using BPSK, QPSK, 16-PSK,16 QAM in the figures 4.2 to 4.5. The second group is for the figures 4.6a- 4.6b- 4.6c when sent image data by using BPSK.

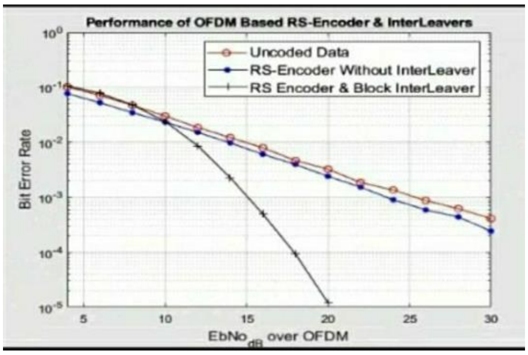


Figure 4.2. BER & SNR Interliver with RS-OFDM in 16-psk

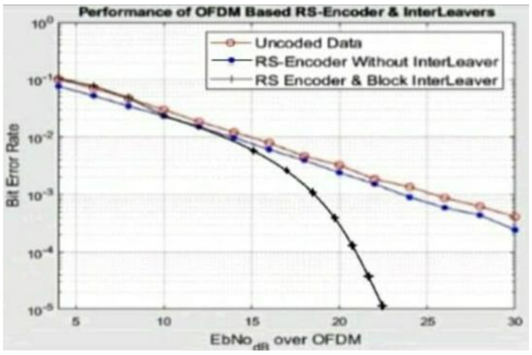


Figure 4.3 BER & SNR Interliver with RS-OFDM in 16-QAM

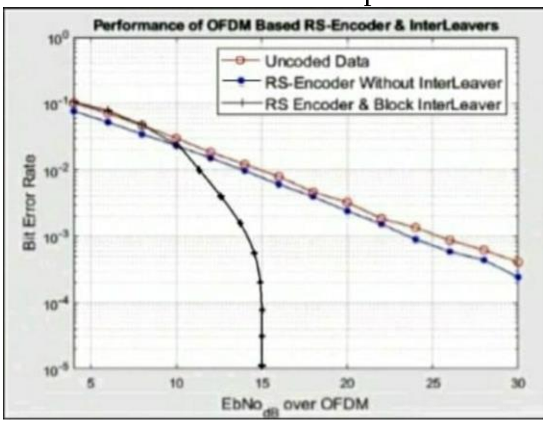


Figure 4.4 BER & SNR Interliver with RS-OFDM in QPSK

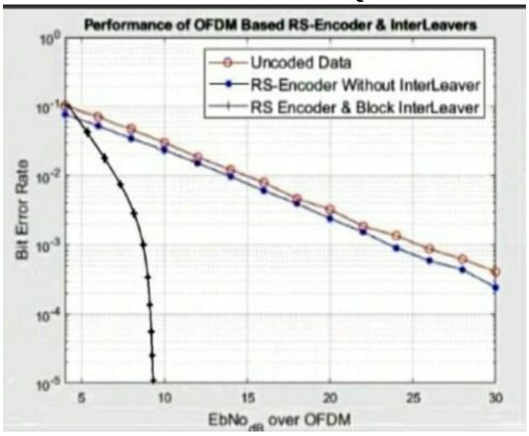


Figure 4.5 BER & SNR Interliver with RS-OFDM in BPSK

The BER probability performance of OFDM communication system with RS encoder at different four code rate for BPSK, QPSK and 16-QAM modulation schemes. The same set of inputs and RS encoder The results showed in figure 4.2 to figure 4.5 that RS coded with block interliver OFDM system performance was better than both uncoded OFDM and RS-OFDM systems. So, RS-coded with Block interleaver OFDM system performance outperformance both RS-coded of OFDM and uncode systems. The results showed a significant improvement had been noted when using block Interliver with RS-OFDM system. It may be concluded that the BER probability performance in OFDM communication system with RS encoder improves as using the BPSK modulation scheme. So, proposing block interliver and RS codes OFDM contributes to enhancing the BER performance of the system.

Figure 4.6 Sent cameraman image in 18 db in RSOFDM with Block Interleaver

The second part , Use Interlever to send images. Figure (4.6) a shows sending an image at 18db. After passing the image through the encode a group of errors was observed, since the ability of Encoder to correct single errors only as in Figure 4.6b. Therefore, it is necessary to use Interlever to distribute the apparent accumulated errors, where the image 4.8c is show Interlever overcomes the accumulated and clustered errors, and the image appears more clearly compared to without Interlever. Where the image 4.6c shows the efficiency of Interlever by sending images clearly.

4.5 RS-OFDM System with Chaotic Interleaver

The results will be presented in the next paragraph. It be classified into two groups, The first group is the BER improvement observed from these all figures 4.7 to 4.16 are tabulated in Table 3.

The second group is for the Encrypted image by using secreat key Encoder Chaotic Interleaver in the sent side and used the same Deccoder in the receiver side This adds a security aspect to the system

4.5.1 Bit Error Rate with Chaotic Interleaver in RS-OFDM for AWGN channel

It can be seen from the following BER curves that inclusion of bit interleaver from the figures 4.7 to 4.11. They show results achieved with the BPSK,QPSK and (16,32,64) PSK schemes for the AWGN channel utilizing RS-code with chaotic Interleaver.

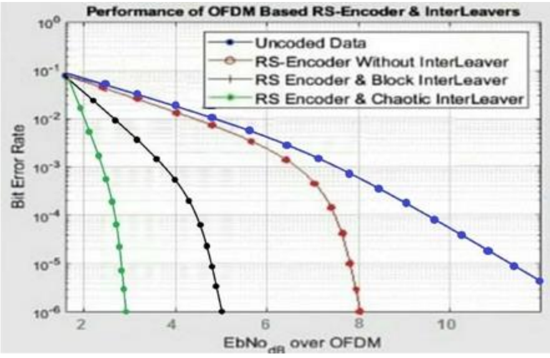


Figure 4.7 BPSK RS-code OFDM with and without interleaver

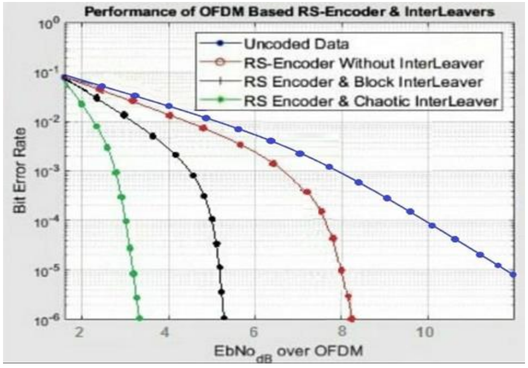


Figure 4.8 QPSK RS-code OFDM with and without interleaver

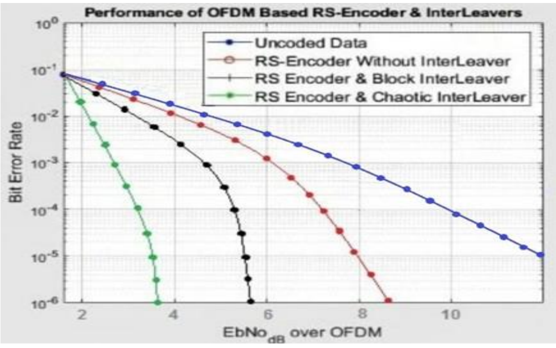


Figure 4.9 16PSK RS-code OFDM with and without interleaver

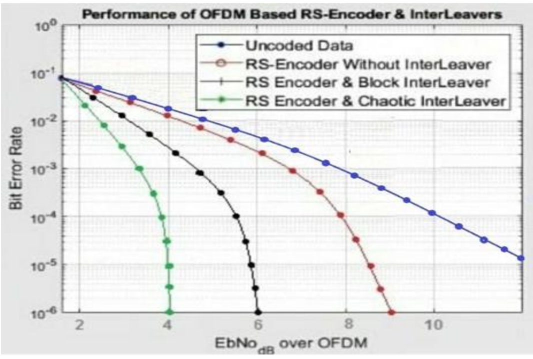


Figure 4.10 32 PSK RS-code OFDM with and without interleaver

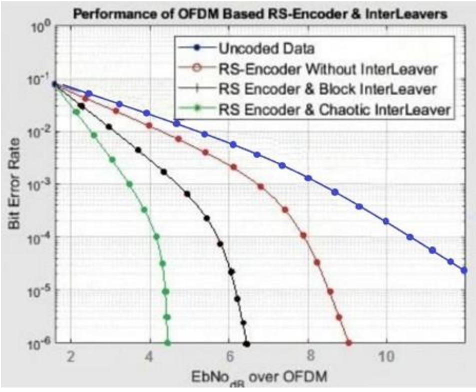


Figure 4.11 64 RS-code OFDM with and without interleaver

In Figure 4.11 that illustrate BER=10^{-3} the un-code=9.5dB, RS-code =6.5dB, Block Interleaver= 5 dB, Chaotic Interleaver=3dB ,The gain will be obtained between code and uncode

$$\text{Gain} = \frac{uncode - RS\ Code}{uncode} * 100\% = \frac{9.5-6.5}{9.5} * 100\% = 30\%$$

The gain between RS-code with and without Interleavers

$$\text{Gain} = \frac{without\ interleaver - with\ interleaver}{without\ interleaver} * 100\% = \frac{9.5-3}{9.5} * 100\% = 68\%$$

The results of the BPSK, QPSK, and (16, 32, 64)PSK schemes for the AWGN channel using RS-code with and without Interleaver the result show BPSK is the better can see in fig 4.7. The BER curves from The un-code Eb/No=9.5dB, RS-code Eb/No =6.5dB, Block Interleaver Eb/No=5dB, Chaotic interleaver Eb/No=3dB are shown in figure 4.7 to illustrate BER=10^{-3}. The goal is to maintain the transmission quality while using less power. All shapes BER and SNR gains are determined in the same way.

The BER improvement observed from these all figures are tabulated in Table 4.3 shows a comparison between the value of BER at the 10^{-3} obtained when without use Interleaver and the improvement when using the Chaotic interlever to the system.

Table 4.3. Performance improvement due to RS code AWGN channel

Modulation	BER –RS code without Interleaver 10^{-3}	BER-with Interleaver 10^{-3}
BPSK	6.5	3
QPSK	7	3.5
16- psk	7.3	3.9
32-psk	8.2	4
64-psk	8.5	4.5

The following table 4 shows a comparison between the three techniques added to the system update (RS-code, Block Interleaver, Chaotic Interleaver) where note the value BER at 10^{-3}

Table 4.4. Performance improvement when use (RS-code,Block Interleaver, Chatioc Interleaver) in AWGN channel

		BER–RS code 10^{-3}	BER- Block Interleaver10^{-3}	BER-Chaotic Interleaver 10^{-3}
Modulation	BPSK	6.5	5	3
	QPSK	7	5.5	3.5
	16- psk	7.3	5.8	3.9
	32-psk	8.2	6	4
	64-psk	8.5	6.5	4.5

4.5.2 RS-OFDM with chatioc interleaver in Rayleigh Fading channel

The results of simulation the system simulation with the Rayleigh channel shown in figures 4.12 to 4.16. It is shown using Reed Solomon without Interleaver (the red lines in the figures) gives a weak performance than having it in the system during sending data in the fading channel. This is because the fading channel makes burst errors that are grouped in one area without the other and it is difficult for the RS encoder to correct these errors.

To improve the performance of the RS encoder Interleaver was added after the RS encoder (the black lines in the figures). So the interleaver will hash the encoded data and send it through the Rayleigh fading channel and then rearrange encoded data through the de-interleaver thus the burst errors will be ungrouped or unburst errors and that makes it easier for the RS encoder to correct the bit errors. From figure 4.12 at SNR = 18 dB, the BER in RS encoder decaded by ten times from 10^{-3} to 10^{-4} because the Interleaver, figures show the BER performance of a Wireless Communication System under different modulation schemes under Rayleigh fading channels.

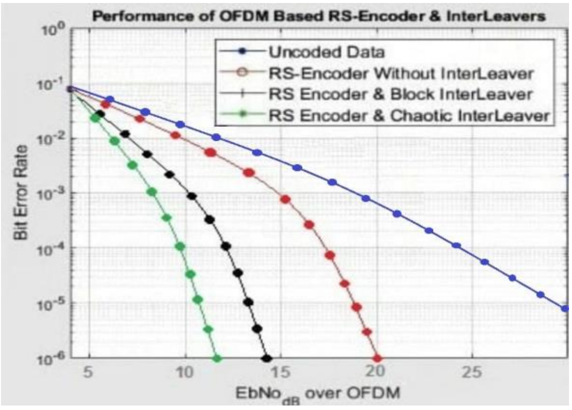


Figure 4.12 BPSK – RS OFDM with and without interleaver

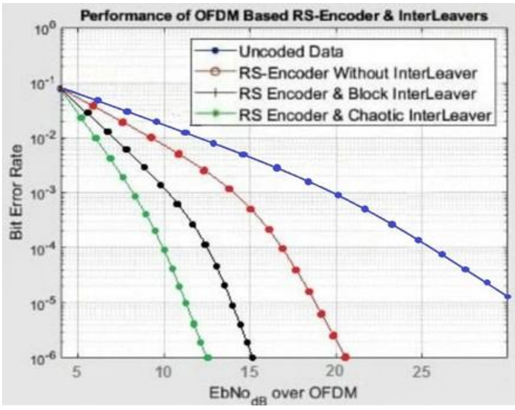


Figure 4.13 QPSK RS OFDM with and without interleaver

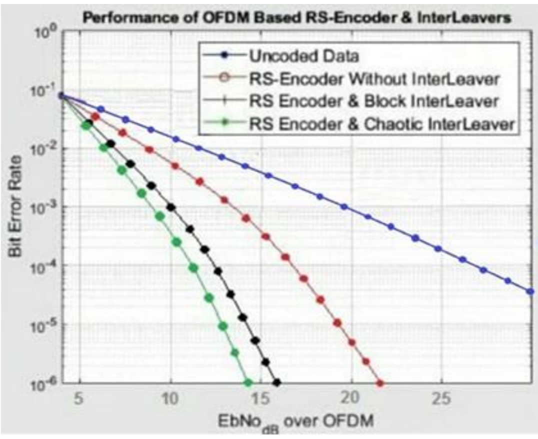


Figure 4.14 16-PSK RScode OFDM with

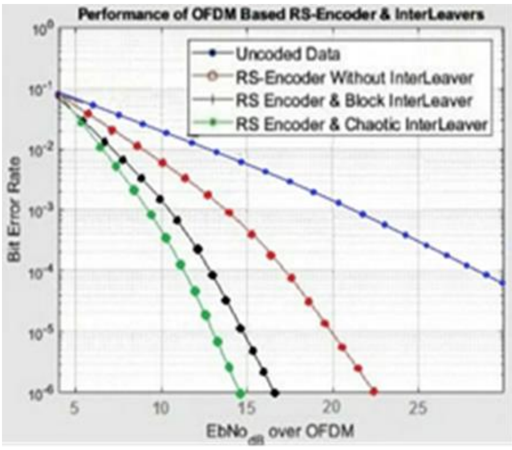


Figure 4.15 32-PSK RScode OFDM with

and without interleaver and without interleaver

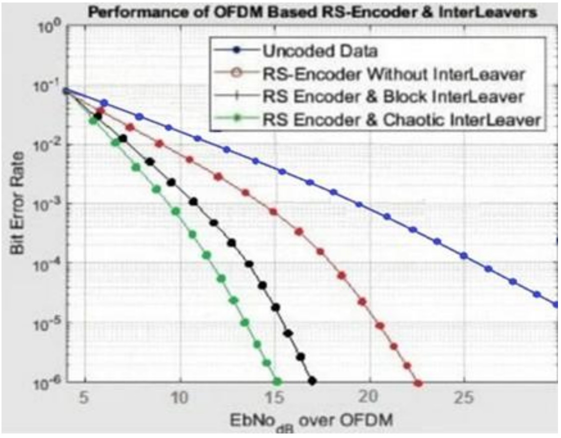


Figure 4.16 64-PSK RS OFDM RS-code OFDM with and without interleaver

From figure 4.14 At BPSK, BER= 10^{-3}. The BER RS-code=15dB, Block interleave=10db, chaotic interleave=8Db. To calculate the gain with interleave

$$\text{Gain} = \frac{without\ interleaver 15\text{dB} - with\ interleaver 8\text{dB}}{without\ interleaver 15\text{dB}} * 100\% \ = 46 \text{ dB}$$

Figures 4.12 to 4.16 display the simulation's findings for the Rayleigh channel system. It is evident that utilizing Reed Solomon without Interleaver (shown by the red lines in the figures) performs worse than using it while transferring data over a fading channel. This is because it is challenging for the RS encoder to repair burst mistakes made by the fading channel, which cluster in one area without the other.

An interleaver was added following the RS encoder to enhance performance (the black lines in the figures). Since the de-interleaver rearranges the encoded data after the interleaver hashes it and sends it over the Rayleigh fading channel, the burst mistakes become ungrouped or unburst errors, which makes it simpler for the RS encoder to rectify the bit errors. Also take note of the chaotic interleaving, which is superior than the Interlever block in terms of its capacity to distribute two-dimensional faults, represented by the green lines in the pictures It is also noticeable that the system performance degrades with increase of order of modulation, The SNR of uncode =23dB, RS-code=15dB, Block interleaver=10dB . At BER= 10^{-3} The chaotic interleaver=8Db to calculate the gain with interleaver gain = 23dB-8dB=15dB,the system will earn again of 15dB with interleaver the BER, SNR, gain for each figures are calculates shown in the following table 4.5

Table 4.5. Performance improvement due to RS code with and without interleaving in Rayleigh Select Fading channel

Modulation	BER RS code without Interleaver 10^{-3}	BER with Interleaver 10^{-3}
BPSK	15	8
QPSK	16	8.5
16- psk	16.5	9
32-psk	20.5	9.5
64-psk	23	10

The following table 6 shows a comparison between the three techniques added to the system update(RS-code, Block Interleaver, Chaotic Interleaver) where note the value BER when 10^{-3}

Table 4. 6. Performance improvement when use (RS-code, Block Interleaver, Chaotic Interleaver) in Rayleigh fading channel

		BER		
		BER –RS code 10^{-3}	BER- Block Interleaver 10^{-3}	BER-Chaotic Interleaver 10^{-3}
Modulation	BPSK	15	10	8
	QPSK	16	10.5	8.5
	16- psk	16.5	11	9
	32-psk	20.5	11.5	9.5

	64-psk	23	12	10

4.6 Encrypted lmage

The Camera operator picture with the dimensions 256×256 in this part, the simulation framework is fed a two-dimensional Chaotic Chaos mapping that is encoded and sent across a fading wireless channel using the RS-OFDM protocol the sent and encrypted image to receive the image as show in figure 4.17

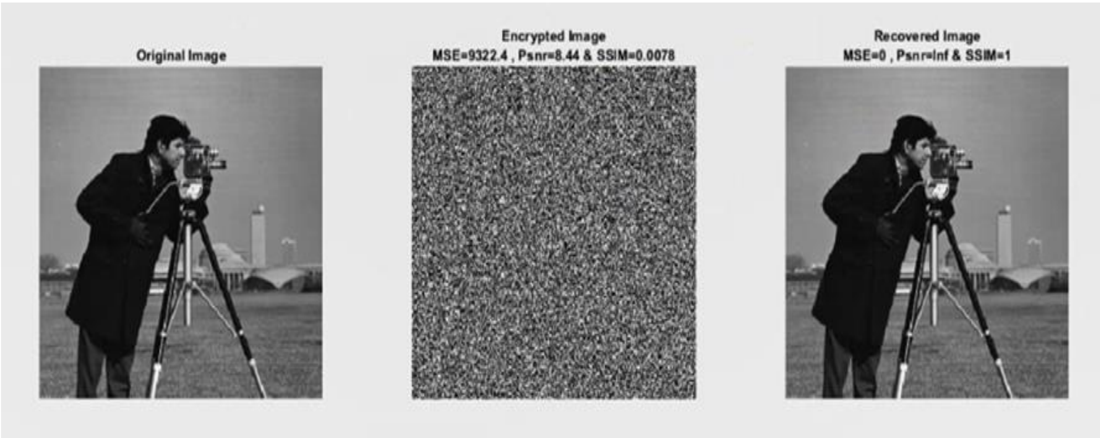


Figure 4.17 sent cameraman encrypted image by used 2D Chaotic Interleaver

Any change in encryption key The encrypted image does not appear for examble when used Deckey=0.2000000. The image will not appear at the recever side or used Deckey=0.200000001 also the encrypted image does not appear. Thus added another benefit for chaotic interleaver in addition to improving BER, as it added a protection and security aspect to the system as show in figure 4.18

Figure 4.18 Sent cameraman image by Chaotic interleaver used Deckey=0.2000000

4.7 Image transmission by two type of interleaver in RS-OFDM System

The results of simulating the OFDM system will be shown when image data is sent in the case use the type of modulation is BPSK in two types of channels used white Gaussian noise channel and Rayleigh fading channel.

4.7.1 Image Transmission in AWGN channel with BPSK

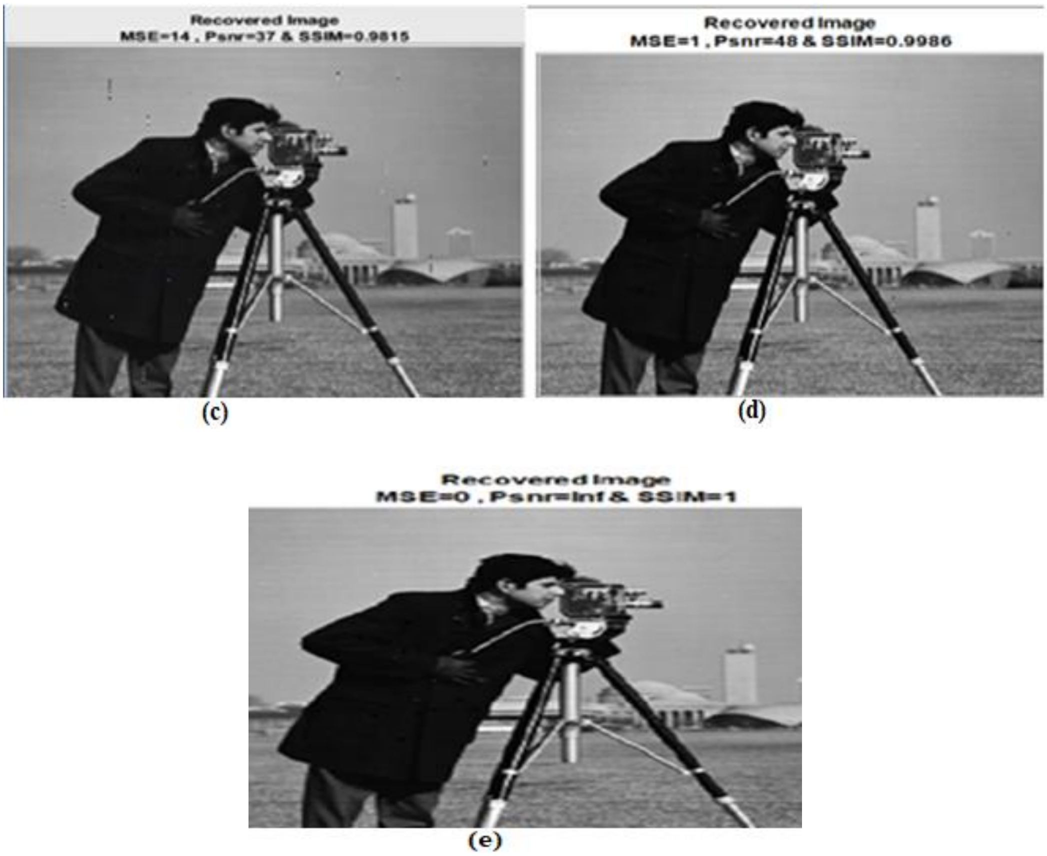


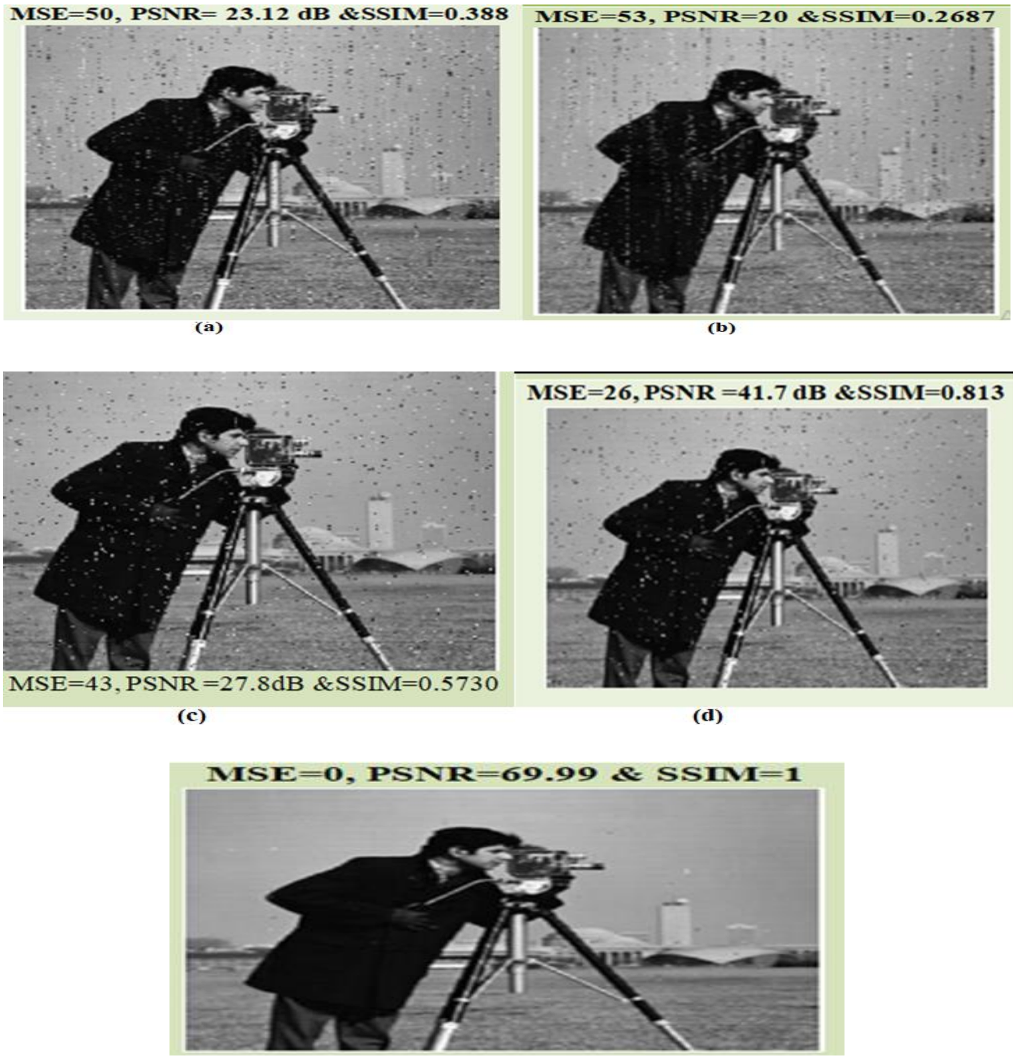
Figure 4.19 Sent Cameraman Image by Chaotic & Block Interleaver in RS-OFDM AWGNchannel (a)SNR=10 db (b)SNR=20 db (c)SNR=30db (d)SNR=40db (e) SNR=50db

The figure 4.19 shows four groups of images. Figure 4.19 (a) represents the image that sent from the SNR=10 db system notes that more errors appers in image and figure 4.19 (b) represents the image where SNR=20 db notice that there are many errors appears also. The figure 4.19 (c) represents the image when SNR=30 db and the figure 4.19(d) represents the image when SNR=40db notice a little of errors and notice that the received image is somewhat similar to that of the sent image. There is an improvement in the received image at SNR =50 where notice an increase in the clarity of the image it is considered the best performance was in the figure 4.21(e) for the ability of the Interleaving to spread the errors, and thus get a received image that identical the image original.

Table 4.7: Result Image of OFDM system in case RS- code, with and without Interleaving in AWGN channel.

Modulation type	(SNR)	MSE	PSNR	SSIM
BPSK	10	48	21	0.55462
	20	44	32	0.93461
	30	5	41	0. 9927
	40	1	48	0. 986
	50	0	Info	1

4.7.2 Rayleigh channel with BPSK



(e)

Figure 4.20 Sent Cameraman Image by Chaotic Interleaver in RS-OFDM Rayleigh fading channel (a)SNR=10 db (b)SNR=20 db (c) SNR=30db (d)SNR=40db (e) SNR=50db

The figure 4.20 shows four groups of images where figure 4.20 (a) represents the image that sent from the SNR=10 db system notes that more errors appers in image and figure 4.20 (b) represents the image where SNR=20 db notice that there are many errors appears also. The figure 4.20 (c) represents the image when SNR=30 db and the figure 4.20(d) represents the image when SNR=40db notice a little of errors and notice that the received image is somewhat similar to that of the sent image. There is an improvement in the received image at SNR =50 where notice an increase in the clarity of the image it is considered the best performance was in the figure 4.20(e) for the ability of the Interleaving to spread the burst errors, and thus get a received image that identical the image original.

Table4. 8 Result of OFDM system in case RS- code, Block Interleaving and Chaotic Interleaving with Rayleigh channel

Modulation type	(SNR)	MSE	PSNR	SSIM
BPSK	10	53	20	0.26877
	20	50	23.12	0.388
	30	43	27	0. 5730
	40	26	41	0.813
	50	0	69.99	0.9991

4.8 Comparison with related works

	Code	Interleaver	Mod	Channel	Improve At BER=10^{-3}
My thesis	Reed solomon	Chaotic & Block	QPSK& (M-PSK)	AWGN, Rayleigh	Gain(AWGN)=68db, PSNR= Inf Gain(Rayleigh)=50db ,PSNR=69.99
Abdonli[17]	Reed solomon&	No Interleaver	QPSK	AWGN	BER=10^{-3} SNR=13

	convolution				
Raouia[18]	Reed solomon& Hamming	No Interleaver	QPSK4	AWGN	BER=10^{-3} SNR=10
Elhadi[19]	Convolution	Chaotic Interleaved	QPSK	AWGN, SUI-3	SNR=10 PSNR=Inf PSNR=60

Chapter Five

Conclusions and Recommended Future Work

This chapter presents the concluded facts collected throughout the work of this thesis along with suggested future work for further improvements and implementations.

5.1 Conclusion

From this work, the following conclusions

1. The BER probability performance of coded OFDM communication system with interleaver provides better performance than without interleaver system.
2. The performance of coded OFDM communication system with interleaver provides better performance than without interleaver system.
3. The algorithm used has improved the error resilient capability and transmission efficiency for progressive image transmission over wireless noisy as well as frequency selective fading channels

5.2 Future Suggested Developments Upgrades and Case Studies

After completing the current work, the following areas and cases are left for future work and investigations .

1. Use the simulation of the OFDM system to calculate the PAPR
2. Implementation of the complete chain OFDM Tx-Rx on an FPGA
3. Implement MIMO or MISO for multi antenna transmission.

4. Enhancement of the BER performance in coded OFDM communication system by using particular channel encoding decoding IFFT/ FFT and modulation schemes.
5. Use the simulation of the OFDM system to transmit the video.

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ICEAT 2022

The 2nd International Conference on Engineering and Advanced Technology

28-29 March 2022, Turkey- Istanbul

Paper ID: 341 **March 15, 2022**

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Dear Authors,

Herewith, we are happy to inform you that the peer-reviewed paper entitled: **"Performance Improvement Of OFDM System Based On Reed-Solomon Encoder And Block Interleaver In fading Channel"** has been accepted for oral presentation as well as inclusion in the conference proceedings in the *2nd International Conference on Engineering and Advanced Technology* (**ICEAT 2022**) which is organized by Al-Qadisiyah University, Mustansiriyah University and the University of Warith Al-Anbiyaa, Iraq in collaboration with the University of Birmingham, UK, Hacettepe Ünivesity -Turkey and Taras Shevchenko National University of Kyiv-Ukraine.

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As this is an International Conference, we request you to present your paper and take part in the oral discussion.

We look forward to meeting you at the **ICEAT 2022** Conference.

Yours sincerely,

Prof. Dr. Salih A. Rushdi
Conference Organizing Committee Chairman
Al-Qadisiyah University

Assist. Prof. Dr. Zainab T.Al-Sharify
Conference Organizing Committee Chairman
Mustansiriyah University

SOLID STATE PHENOMENA

Academic Paper Acceptance Letter

Date: 30-09-2022.
Title : Encryption Image Of RS-code In OFDM System With Chaotic Interleaver Over AWGN & Rayleigh fading channels.

Dear Author: Mays Al-reem Ameer Chabouk [1-a]. Mazin Makkei Al-Ibraheemi [2-b]

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الخلاصة:

تلعب أنظمة الاتصالات دورًا رئيسيًا في المجتمعات الحديثة من خلال تامين الاتصالات بين الناس حول العالم. لذلك ، هناك حاجة إلى اتصالات موثوقة ومستقرة ويمكن الاعتماد عليها. ادت زيادة الطلب على معدلات ارسال أعلى إلى ولادة التكنولوجيا الجديدة في الاتصال والتي تسمى G5 (الجيل الخامس).

الغرض من هذا العمل هو نمذجة نظام OFDM مع شفرة Reed-Solomon لتصحيح الأخطاء واستعادة البيانات الأصلية المستخدمة لتشفير دفق البيانات شفرات Reed-Solomon هي الأفضل لتصحيح أخطاء الاندفاع وإيجاد مجموعة واسعة من التطبيقات في الاتصالات الرقمية وتخزين البيانات. لكن كفاءة كود Reed Solomon تقتصر على الأخطاء الفردية

تمت إضافة نوعين من interlever ، النوع الأول هو Block interlever. هذا النوع هو الأكثر شيوعًا واستخدامًا ويساعد كود Reed Solomon RS على نشر أخطاء أحادية البعد ، لكن أدائه محدود ، لذلك من الضروري استخدام نوع آخر من Interleaver وهو Chaotic Interleaver ، سببان رئيسيان لاستخدام Chaotic الأول قدرته على نشر الأخطاء ثنائية الأبعاد ، وبالتالي فهو يعتبر أفضل من Block Interlever ، والسبب الثاني لاستخدامه هو إضافة طابع أمني للنظام عن طريق تشفير البيانات (الصورة) المرسلة باستخدام مفتاح سري $S_{encoder}$ أثناء الإرسال ، وأن أي تغيير في المفتاح السري $S_{decoder}$ سيمنع استلام البيانات ، وبالتالي ضمان الوصول إلى البيانات بسرية وكفاءة عالية وتحسين في قيمة BER.

باستخدام Matlab 2018 ، تم إنشاء النموذج للعمل على معدل بيانات إجمالي البيانات = 13485 ميغابت في الثانية ، عدد الناقلات الفرعية = 52 ، ترميز Reed-Solomon RS (31،23) ، حجم نقطة IFFT / FFT = 64 ، تجريبي رقم الإدخال = 12 ، بادئة دورية ، 16

بت (المعدل = 4/1) ،مع استخدام التشذير والمشفر في الارسال و فك التشذير وفك التشفير عند الاستلام .تم تطبيق خمسة انواع من التضمين منها المفتاح ثنائي إزاحة الطور (B-PSK) ، مخطط (QPSK-16QPSK-32QPSK-64QPSK) في قناة AWGN، Fading .وتم تقييم الأداء من حيث معدل خطأ البت (BER) ونسبة طاقة الإشارة إلى نسبة كثافة قدرة الضوضاء (Eb / No). تم تقييم الأداء من خلال تطبيق تشكيل مفتاح إزاحة مرحلتين (B-PSK) ، مخطط (QPSK) في قناة WGN المضافة ،وقنوات الخبو الانتقائية. الأداء من حيث خطأ معدل البتات (BER) وقدرة الإشارة إلى نسبة كثافة قدرة الضوضاء (Eb / No).

أظهرت النتائج تقنية تعديل BPSK في قناة AWGN أفضل مقارنة بقناة frequency selective fading channel عند $BER = 10^{-3}$، SNR ونسبة الإشارة إلى الضوضاء الخاص بـ RScode =6.5 ديسيبل، تشذير الكتلة = 5 ديسيبل ، التشذير الفوضوي = 3 ديسيبل

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تحسين اداء وتصحيح الاخطاء لنظام الارسال مضاعفة التقسيم الترددي المتعامد(OFDM)

رسالة مقدمة الى قسم هندسة تقنيات الاتصالات كجزء من متطلبات نيل درجة ماجستير تقني في هندسة الاتصالات

تقدمت بها

ميس الريم عامر محمود جابك

بكالوريوس في هندسة تقنيات الاتصالات

إشراف

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