# REPUBLIC OF TURKEY ISTANBUL GELISIM UNIVERSITY INSTITUTE OF GRADUATE STUDIES

Department of Electrical and Electronics Engineering

# ENHANCEMENT OF BIT ERROR RATE IN LONG TERM EVALUATION SYSTEM OVER DIFFERENT CHANNELS BASED ON HYBRID TRANSFORM.

Master Thesis

### Sura Saadi Mohammed ABUHAMEED

Supervisor

Asst.Prof. Dr. Ercan AYKUT

Istanbul – 2024



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Signature

Asst. Prof. Dr. Ulvi BASPINAR

Signature

Member

Director

Asst. Prof. Dr. Ercan AYKUT (Supervisor)

Signature

Member

Asst. Prof. Dr. Halit YAHYA

### APPROVAL

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Director of the Institute

### ÖZET

LTE teknolojileri, hızlı veri iletimi ve kapsamlı bağlantı sunarak kablosuz iletişimi önemli ölçüde dönüştürdü. Bununla birlikte, LTE sistemlerinin bit hata oranı (BER) performansını olumsuz etkileyebilecek sönümleme kanalları ve parazitlerin varlığı, veri güvenilirliğinin azalmasına yol açmaktadır.

Bu çalışma, ayrık kosinüs dönüşümüne (DCT) ve bir QPSK haritalayıcı olan Walsh-Hadamard koduna (W-H) dayalı yeni bir sistem yapısı önererek LTE sistemini kapsamlı bir şekilde inceledi. Enerjiyi sıkıştırma ve frekans alanındaki sinyalleri temsil etme yeteneği ile tanınan Ayrık Kosinüs Dönüşümü (DCT), çok yollu sönümleme, girişim ve kanalın neden olduğu diğer bozulmaların etkilerini azaltmak için bir sinyal işleme yöntemi olarak önerilmektedir. Önerilen yaklaşımın döngüsel önek (CP) kullanımını gerektirmediğini, bunun sonucunda daha yüksek veri hızı ve daha geniş bant genişliği (BW) elde edildiğini belirtmek önemlidir.

Ana amaç, I/P verilerinin sembolleri ve çerçeveleri arasındaki çatışmayla mücadele etme yeteneğinden yararlanmak için Walsh-Hadamard kodunu ortogonal kodlayıcı olarak kullanmaktır. Sistem, hem ayrık kosinüs dönüşümü (DCT) hem de Walsh-Hadamard (WH) yaklaşımını kullanarak, alternatif tekniklerle karşılaştırıldığında tüm sistemin bit hata oranı (BER) performansını artırmayı amaçlamaktadır. Çeşitli Doppler kayma senaryolarında, özellikle 6, 60 ve 180'lik maksimum Doppler Frekanslarında (MDS) değiştirilmiş yapıların geliştirilmiş performansını sergilemek için çeşitli simülasyon deneyleri yapılmıştır. Bu tez, performansını aşağıdaki terimlerle değerlendirmek üzere LTE sistem senaryolarının simüle edilmesiyle başlar: bit hata oranı (BER). Simülasyon senaryolarında W-H-DCT-LTE stratejisi kullanıldı ve performansı standart FFT-LTE yöntemiyle karşılaştırıldı. Oluşturulan sistem, 1024 alt taşıyıcı boyutuna sahip Dörtlü Faz Kaydırmalı Anahtarlama (QPSK) ve Walsh-Hadamard'ın (WH) modülasyon şemalarını kullanmıştır. Ayrıca, iki iletişim kanalı modeli, AWGN (Katkılı Beyaz Gauss Gürültüsü) ve Rayleigh, Constar'dır. 2x2 çoklu giriş/çoklu çıkış yapılandırması. Sistem simülasyonunu MATLAB programını kullanarak dört kullanıcı üzerinde gerçekleştirdik.

Çeşitli kanal tipleri için yeni yapıların değerlendirilmesi, geleneksel LTE ile karşılaştırıldığında BER performansında yaklaşık 2,5 dB'lik önemli bir iyileşme olduğunu ortaya çıkardı. Bir LTE sisteminde W-H-DCT kullanıldığında, 1024 BPSK (5MDS) FFT-LTE ile 10<sup>-4</sup> bit hata oranına (BER) ulaşmak için gereken sinyalgürültü oranı (SNR) yaklaşık olarak şöyledir: 23 dB. Ancak W-H-DCT-LTE kullanıldığında gerekli SNR 12,8 dB'ye düşer. Önerilen sistem, bu spesifik kanal modeli için mevcut üç sistemden önemli ölçüde daha iyi performans göstermektedir.

Anahtar Kelimeler: LTE, BER, FFT, W-H, QPSK.

### **SUMMARY**

Long Term Evolution (LTE) technologies have significantly transformed wireless communication by offering rapid data transmission and extensive connectivity. However, the existence of deteriorating channels and interference can have a detrimental impact on the bit error rate (BER) performance of LTE systems, resulting in a reduction in data reliability.

This study extensively examined LTE system by proposing a novel system structure based on the discrete cosine transform (DCT) and Walsh-Hadamard code (W-H) a QPSK mapper. The (DCT), known for its capacity to compress energy and represent information in the frequency domain, is proposed as a signal processing technique to mitigate the impact of multipath fading, interference, and other distortions induced by the channel. It's important to note that the suggested method doesn't need to use a cyclic prefix (CP), which means that the data rate is higher and the bandwidth is bigger.

The main goal is to use the Walsh-Hadamard code as an orthogonal encoder to take advantage of its ability to fight the conflict between the symbols and the frames of the I/P data. By using both the (DCT) and the Walsh-Hadamard (W-H) approach, the system aims to enhance the (BER) performance of the entire system in comparison to alternative techniques. several simulation experiments are done to showcase the enhanced performance of the modified structures in various Doppler shift scenarios, particularly at maximum Doppler Frequencies (MDS) of 6, 60, and 180. This thesis begins with simulating LTE system scenarios to evaluate its performance in terms of (BER). A strategy called W-H-DCT-LTE was employed in the simulation scenarios, and its performance was compared to the standard Fast Fourier Transform- Long Term Evolution (FFT-LTE) method. The system was designed with the utilization of modulation schemes such as Quadrature Phase Shift Keying (QPSK) and Walsh-Hadamard (W-H), using a subcarrier size of 1024. In addition, there are two communication channel models: Additive White Gaussian Noise (AWGN) and Rayleigh. These models are used with a 2x2 multiple-input/multiple-output

configuration. We performed the system simulation on four users using the MATLAB program.

The evaluation of the new structures for various channel types revealed a considerable improvement of approximately 2.5 dB in BER performance when compared to conventional LTE. When employing W-H-DCT in an LTE system, the signal-to-noise ratio (SNR) needed to achieve a (BER) of 10<sup>-4</sup> with 1024 BPSK (5MDS) FFT-LTE is approximately 23 dB. However, when utilizing W-H-DCT-LTE, the required SNR drops to 12.8 dB. The proposed system significantly outperforms the three existing systems for this specific channel model.

Key Words: LTE, BER, FFT, W-H, QPSK.

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## **ABBREVIATIONS**

1G	:	First Generation
2G	:	Second Generation
3GPP	:	Third Generation Partnership Project.
4 <b>G</b>	:	Fourth Generation.
AWGN	:	Additive White Gaussian Noise.
BER	:	Bit Error Rate.
BPSK	:	Binary Shift Keying
CIR	:	Channel impulse response
СР	•	Cyclic Prefix
DF	:	Doppler Frequency
DFT	:	Discrete Fourier Transform.
DS	:	Doppler Shift
FDD	:	Frequency Division Duplexing
FFT	:	Fast Fourier Transform
FT	:	Fourier Transform
GI	:	Guard Interval
GSM	:	Global System for Mobile
ICI	:	Inter Carrier Interference.
IDFT	:	Inverse Discrete Fourier Transform
IEEE	:	Institute of Electrical and Electronics Engineers
IFFT	:	Inverse Fast Fourier Transform
ISI	:	Inter Symbol Interference.

LMMSE	:	Linear Minimum Mean Square Error
LMS	:	Least-Mean-Square
LS	:	Least Square
LTE	:	Long Term Evolution
LTE-A	:	LTE Advance
MCM	:	Multi-Carrier Modulation
FNN	:	Forward Neural Network
MDS	:	Maximum Doppler Shift
MIMO	:	Multiple-Input-Multiple-Output
MLSE	:	Maximum likelihood sequence estimation
OFDM	•	Orthogonal Frequency-Division Multiple
OFDMA	:	Orthogonal Frequency-Division Multiple Access
P/S	:	Parallel to Serial
PAPR	:	Peak-to-Average Power Ratio
PSK	:	Phase Shift Keying
QAM	:	Quadrature Amplitude Modulation
QPSK	:	Quadrature Phase Shift Keying
S/P	:	Serial to Parallel
SC-FDMA	:	Single-carrier-frequency-division multiple access
SISO	:	Single-Input-Single-Output
SNR	:	Signal-To-Noise Ratio
STBC	:	Space Time Block Code
TDD	:	Time Division Duplex
UE	:	User Equipment

WGN	:	White Gaussian Noise
W-H	:	Walsh-Hadamard code
WI-MAX	:	Worldwide Interoperability for Microwave Access
ZP	:	Zero Padded
DCT	:	Discrete Cosine Transform
IDCT	:	Inverse Discrete Cosine Transform



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#### INTRODUCTION

This study looked into the Long-Term Evolution (LTE) system in great detail by creating a new system architecture that uses the Discrete Cosine Transform (DCT) and the Walsh-Hadamard code (W-H) with a Quadrature Phase Shift Keying (QPSK) mapper. We suggest employing the Discrete Cosine Transform (DCT) as a signal processing method to alleviate the effects of multipath fading, interference, and other distortions in the channel. The Discrete Cosine Transform (DCT) is renowned for its ability to efficiently reduce the amount of energy required to represent data and encode it in the frequency domain. It is important to mention that the suggested approach does not necessitate the use of a cyclic prefix (CP), resulting in higher data rates and wider bandwidths (BW).

In the last two decades, wireless communications have undergone substantial advancements in terms of technological quality, data capacity, data speed, enhanced voice and video capabilities, conference calling, and 3D gaming. These skills progressed and improved throughout successive generations, starting with the initial generation that emerged in 1981(Gawas, 2015). Mobile phones could only make voice calls and use analogue communication systems prior to the second generation. However, the second generation introduced digital communication technology and added capabilities for text messaging. Subsequently, the third generation emerged, enabling rapid data transfer and capacity enhancement. Furthermore, this technology, based on Long Term Evolution (LTE), not only enables interactive social media usage until the fourth generation, but also provides even faster data transfer speeds than its predecessors. 4G technology allows users to participate in activities such as streaming high-definition videos, playing online games, and accessing cloud-based applications. It surpassed all issues encountered in previous generations in terms of cost reduction and bandwidth expansion(Cox, 2012). Table (1) show the evolution of generations from 1G to 4G.

Generation	period	Data Rate	Technology
1 <b>G</b>	1970-1984	2kbps	Analog
2G	1980-1999	14.4-64 kbps	Digital
3G	1990-2002	2Mbps	CDMA, EDGE, UMTS
4 <b>G</b>	2000-2010	1Gbps	CDMA, EDGE, UMTS

**Table 1.** Details of the Generations of Cellular Telecommunication Systems (Reyam

 Thair & Osama Althahab, 2024)

The initiation of the rollout of Long-Term Evolution (LTE) in 2004 was carried out by the Third Generation Partnership Project (3GPP), which is a partnership consisting of national and regional telecoms standards organizations. This program was initiated through research focused on the development of the Universal Mobile Telecommunications System (UMTS). LTE is a wireless communication technology that enhances the capabilities of the current GSM/EDGE and UMTS/HSPA network technologies. By integrating several radio interfaces and implementing basic network enhancements, it improves both speed and capacity (Ali & Barakabitze, 2015).

As a result of the incorporation of novel technologies, both data velocity and data throughput have increased. The utilization of Multiple-Input Multiple-Output (MIMO) technology has resulted in significant improvements in both data rate and channel capacity. Our main focus was on optimizing the communication system for velocities not exceeding 4 km/h. The system parameters encompass the capability to facilitate adaptability, attain velocities surpassing 350 km/h, and manage diverse scenarios of performance degradation.(R. T. Ahmed & AL-Thahab, 2022).

By utilizing a combination of subcarriers, Orthogonal Frequency-Division Multiple (OFDM) modulation technology divides a high-rate information stream into numerous lower-rate data streams, which are then transmitted. Orthogonal Frequency-Division Multiple (OFDM) is utilized by numerous technologies, such as Worldwide Interoperability for Microwave Access (WiMAX) and wireless LAN (WLAN). When designing the uplink, its capability to facilitate high-efficiency power transmission is among the most critical considerations.(Zyren & McCoy, 2007).

The LTE uplink utilizes Single Carrier Frequency Division Multiple Access (SC-FDMA) technology. Comparison able to the Orthogonal Frequency Division Multiple Access (OFDMA) system, SC-FDMA is founded on Discrete Fourier Transform (DFT). SC-FDMA differs primarily in that it incorporates a block DFT prior to mapping, rendering it essentially a DFT-mapped variant of OFDM (R. T. Ahmed & AL-Thahab, 2022).



### **CHAPTER ONE**

### INTRODUCTION

#### 1.1. Motivation

From the first generation of wireless communication, which used analog modulation, to the second generation, which used digital modulation, to the third generation, which used quicker data communications, and now we are transitioning to the fourth generation, which will use significantly greater data communications. However, excessive data traffic on few resources, such as the frequency spectrum, causes serious problems for wireless data transmission(Bakare & Bassey, 2021)

With faster access times, high data access rates, and packets that permit variable bandwidth deployment, Long Term Evolution (LTE) aims to deliver wireless access technologies. In line with this, the new system's architecture is built to allow package switching traffic with a smooth quality and service mobility with a low latency. Flexible ranges are supported by the system using Single Carrier Frequency Division Multiple Access (SC-FDMA) and Orthogonal Frequency-Division Multiple Access (OFDMA) as access techniques. The system's requirements provide for flexibility support for speeds up to 350 km/h, albeit there will be some performance deterioration. (SC-FDMA) is the technology used for uplink access, and it enhances uplink coverage in contrast to (OFDMA) and (PAPR)(Yonis & Abdullah, 2012).

In 2004, "Long Term Evolution" (LTE) technology was introduced. Leveraging existing and new frequency bands, facilitating flexible user capabilities, establishing an uncomplicated, low-cost network with transparent interfaces, and reducing network complexity while maintaining an appropriate energy footprint were all aspects of (LTE) that were driven by the imperative to reduce the cost per bit in addition to providing inexpensive services. Make use of wireless data connections. Additional LTE beliefs have resulted from these high-level objectives(Cao et al., 2014).

The communication technology for mobile must meet various demands in mobile multi-media operations, mobile data, and mobile calculations in addition to the rapidly expanding use of wireless communication and multimedia applications like streaming of audio and video, Internet browsing, mobile TV, and interactive gaming in order to support the growing number of innovative multimedia apps and mobile data consumption(Alaa Shakir et al., 2019). The Third Generation Partnership Project (3GPP) has officially selected (LTE) as the state-of-the-art mobile communication technology for future broadband mobile wireless networks. The packet-based design of the LTE system reduces the need for network components, boosts system capacity and coverage, and ensures efficient implementation with low access latency, high data rates, and adaptable bandwidth(Rumney, 2013). Fig (1) shows the Generations of mobile communication systems(Dahlman et al., 2014).



Figure 1. Generation of mobile communication systems(Mendelski & Juraj, 2019)

#### **1.2.** Historical Outline

The European Telecommunications Standards Institution's ("ETSI") Long Term Evolution recognized symbol for wireless data transmission technologies as well as the expansion of GSM/UMTS standards for the Universal Mobile Telecommunications System. On the other hand, other businesses and nations have a significant role to play in the growth of LTE. LTE's objectives were to increase wireless data networks' capacity and speed while utilizing DSP digital signal processing capabilities, which were a new breakthrough in technology around the turn of the century(Rankl & Effing, 2004).

The Japanese business "NTT DoCoMo" made the initial proposal for LTE in 2004, and the benchmark studies were formally launched in 2005. LSTI Trial Initiative LTE / SAE was introduced in May 2007 as an international partnership between operators and vendors to build and promote the innovative Basic in order to ensure that universal technology is offered to the greatest extent feasible. The finished LTE

standard was completed in December 2008. In December 2009, "Telia Sonera" made the first LTE service available to the general public in Oslo and Stockholm through a data connection via a USB modem. In North America, major providers have begun offering LTE. Samsung's "SCH-r900" was the first LTE mobile phone ever made(Parker, 2014).

The second LTE is marketed for sale and was available from "Verizon" in March with the HTC Metro and PCS Thunderbolts. Rogers Wireless launched LTE in Canada for the first time in July of 2011. In addition to Samsung mobile devices, the Sierra Wireless Mobile Broadband Modem provides a 313U USB of mobile card known as the LTE Skyrocket stick(*Verizon Launches Its First LTE Handset*, 2011)(tangertols, 2019). The prominent code-division multiple access (CDMA) operators, the network consists of the following carriers: Sprint and Metro PCS in the United States; Verizon; au by KDDI in Japan; Bell and TELUS in Canada; S-K Telecom in South Korea; and Telecom of China in China. Its primary objective was to improve the competitive standards for Ultra Mobile Broadband (UMB) and Worldwide Interoperability for Microwave Access (Wi-MAX). Instead, they want to transition to LTE. The LTE system was introduced for commercial use in 2011, and by 2013, it was operational in countries worldwide. In 2015, the future extension of the LTE system was approved, and this development continues until the current year(Fazel & Kaiser, 2008).

The LTE standard enables transmission times of less than 5 ms in the radio access network and maximum connection speeds of 300 Mbit/s in the downlink and 75 Mbit/s in the uplink, while ensuring quality of service. LTEs are capable of supporting both Time Division Duplex (TDD) and Frequency Division Duplexing (FDD) and can operate with carrier band widths ranging from 1.4 to 20 MHz, which can be adjusted to different sizes as needed. A network architecture based on IP; the "Evolved Packet Core" (EPC) facilitates data exchange with the GPRS network. It facilitates the effective transmission of data and speech to mobile towers via legacy networking protocols, including UMTS, CDMA2000, and GSM. Engineering outcomes with minimal operational expenses are attained through the implementation of E-UTRA cell determination, which has the capability to support up to four times the data and voice capacity of HSPA.(Dahlman Erik et al., 2008).

Higher data speeds should be provided by modern radio communication technologies. The usage of the transmission channel requires the application of new techniques since the use of larger bandwidth or high frequency modulation, for example, is constrained. (MIMO) significantly increases capacity of channel and data throughput. These programs give an introduction to the ideas and words of MIMO(Nagaradjane et al., 2012).

#### 1.3. The LTE-FDD In Addition LTE-TDD

The need for wireless networks is growing as advancements occur in many spheres of life. Utilizing contactless controls and communications with various applications is beneficial. Wireless networks are required, starting with the fourth generation and beyond, to meet capacity requirements and provide improved peer-topeer connections. Beamforming is one of the best ways to provide high throughput inside the wireless network while improving peer entity connections and bandwidth(Saxena, 2023). A worldwide coalition of businesses, including Huawei in addition to China Mobile and Solutions Networks of Nokia, Dating Telecom, ST-Ericsson, ZTE Samsung, and Qualcomm, share the 4th generation of communications technology and standard known as Long-Term Evolution Time-Division Duplex (LTE TDD). The as Long-Term Evolution Frequency Division Duplexing (LTE FDD) is the second of the mobile data transmission tools for the LTE standard. Even so, many businesses refer to LTE TDD (TD LTE). This acronym is not mentioned anywhere in the 3GPP terminology. Between LTE FDD and LTE TDD, there are two key changes in how data is downloaded and how the frequency spectrum networks are set up. LTE TDD employs a single frequency that continuously alternates between downloading data and loading data, in contrast to LTE FDD, which uses different frequencies for each(Nagaradjane et al., 2012).

LTE is capable of functioning in both (TDD) and (FDD) modes. By utilizing separate spectrum allocations for the uplink and downlink, FDD facilitates bidirectional communication simultaneously. TDD ensures that only one downlink and one uplink are active simultaneously due to the utilization of the same spectrum allocation for both the downlink and uplink. Typically, FDD employs paired spectrum

allocations, whereas TDD employs unpaired spectrum allocations.(Jason Brownand Jamil Y.Khan, 2020). Figure (2) shows the differences in idea between Time Division Duplex (TDD) and Frequency Division Duplexing (FDD)(Saxena, 2023).



Figure 2. TDD VS FDD(Micheli & Diamanti, 2019)

#### 1.4. LTE System

A worldwide consortium of businesses known as LTE TDD has created and tested technologies. China Mobile was a pioneer of LTE TDD, deploying LTE TDD networks and a more recent technology that enables LTE-TDD to function in white space, or the frequency spectrum between television stations, together with other businesses including Dating Telecom and Huawei. Additionally, Intel supported the development of core LTE-TDD stations, which increased coverage by 40% to 80% in China with Huawei and ST-Ericsson at the same time with Nokia solutions and networks. The first multi-mode chip incorporating LTE FDD, LTE TDD, EVDO, and HSPA Accelerant was also developed by Qualcomm, while a Belgian business created tiny cells for LTE TDD networks(Nagaradjane et al., 2012).

At the start of 2010, LTE TDD testing was done. In tests of LTE TDD conducted in India by Ericsson India and Reliance Industries, download rates of up to 20 Mbps and 80 Mbps were attained. 2011 saw the start of testing Chinese mobile phone technology in six cities.

Despite being first thought of as a technology employed exclusively by a few nations, like China and India, LTE TDD gained more attention in 2011 owing in part to decreased LTE TDD-like LTE rollout costs, particularly across Asia. There were 26 networks performing technological trials throughout the globe by the middle of the same year. With founding partners China Mobile, Bharti Airtel, Soft Bank Mobile, Clear wire Vodafone, Aero2, and E-Plus, the global initiative LTE TDD (GTI) was introduced in 2011.

In order to construct LTE-FDD and LTE-TDD networks in Poland, Huawei announced its cooperation with the Polish mobile phone carrier Aero2 in 2011. By April 2012, 33 operators across 19 countries had received LTE-TDD trial networks from ZTE Corporation. In order to create India's first multi-mode TDD LTE network, Bharti Airtel and Huawei partnered with Qualcomm to establish a commercial LTE-TDD network there in late 2012.

Under the moniker Advanced Extended Global Platform (AXGP), Soft Bank Mobile introduced LTE TDD services in Japan in 2012. The service was branded as Soft Bank 4th Generation. 2010 and after PHS's termination The PHS service made use of the same PHS domain that Willcom's AXGP service had previously used.

In order to produce clear wire frequency support chips with multi-mode LTE chipsets, LTE-TDD is preparing a clear wire line in the United States in collaboration with Qualcomm. 2013 saw Clare Wire Following Sprint's takeover of the carrier, these frequencies were used to support LTE on Nokia, Samsung, and Alcatel-Lucent networks.

In 2013, a cumulative count of 156 operational LTE 4G commercial networks existed, comprising 142 LTE FDD networks and 14 LTE TDD networks. The South Korean government declared its intention in 2013 to permit the fourth cellular provider to introduce LTE TDD services in 2014. LTE TDD licenses were granted to three LTE commercial carriers operating within China in 2013.

Nokia Solutions and Networks announced in January 2014 that multiple voice experiments utilizing LTE (VOLTE) calls from China Mobile via TD LTE had been completed successfully. Sprint, Nokia Solutions, and Nets unveiled LTE TDD speeds of 2.6 Gbps the following month, surpassing the previous 1.6 Gbps.

MIMO, short for multiple input/output systems, has demonstrated the ability to achieve remarkably high capacity without requiring more bandwidth or power. Research demonstrates that in scenarios with significant scattering and high levels of noise (SNR), the theoretical capacity of these channels with multiple inputs increases linearly with a slight increase in the number of transmitting and receiving antennas.

The OFDM method Its high spectrum efficiency and resistance to multipath fading have contributed to its widespread adoption in contemporary wireless communication systems. To significantly reduce ISI interference and ICI interference, the periodic cyclic prefix (CP) is employed as a time interval for each OFDM code. The draw design is substantially simplified by the OFDM system, which simultaneously employs the delay-time characteristics of the fading channel across several routes There is no text provided. You can combine OFDM technology with (MIMO) technology to enhance the capacity of a channel. The wireless channel plays a vital role in OFDM systems. Nevertheless, the presence of (AWGN) will disrupt the signal as it passes through the wireless medium, resulting in a deterioration of both the signal transmission quality and the system's overall efficacy(Tugnait, 2014).

For a very long time, MIMO has been manufactured for wireless frameworks. With the advancements made by Bell Laboratories' Jack Winters and Jack Saltz in the 1980s, MIMO was widely used for wireless correspondence [10]. They used many receiving wires on both the transmitter and recipient in an effort to transfer data from various customers on a comparable recurrence/time channel. Since then, a few academics and designers have made significant contributions to the MIMO sector. Currently, there is a growing buzz surrounding MIMO innovation and its wide range of applications in digital television, wireless LANs, urban areas, and mobile communication. The MIMO architecture utilizes multiple antennas in both the transmitter and the receiver to enhance the performance of the communication system by employing multiplexing and various technologies. The MIMO system provides greater spectrum efficiency, improved reliability, reduced signal degradation, and superior resistance to interference(Rawat et al., 2021).

OFDM is a kind of data transport that is used in several telecommunications protocols. Due to its resilience against specific frequency channels compared to carrier modification and the excellent spectral efficiency brought about by the use of orthogonal waveforms, OFDM has established its significance(Sesia et al., 2011). OFDM is a multi-carrier modulation (MCM) method that transforms a narrow-band parallel-fade channel into a selective broadband frequency channel. To reduce the ISI (interplay between symbols) brought on by a multi-channel wireless channel, a (CP) is appended to each code(N. Kaur & Kumar, 2019).

In order to construct the OFDM system, (FFT) and (IFFT) are employed since they require fewer computations. Due to the channel's temporal dispersion, many signal copies are picked up at the receiver's end. As a consequence, the interference guard interval, also known as the cyclic prefix, is decreased, and the frequency fading results are utilized for the frequency. The prefix of the loop duplicates the conclusion of the symbol. Orthogonal loss will not occur so long as the latency time of the channel remains within the parameters of the periodic prefix. The frequency transmission for LTE's downlink data for two separate users is known as OFDMA access technology. SC-FDMA is used in the LTE access node(Hasan, 2012).

When a signal remains in the frequency domain, wavelet analysis functions as an expeditious and effective technique. One may create waveforms with a varying time division and frequency by using a variable wavelet filter. The OFDM-based wavelet is simple to use, adaptable, and more orthogonal. In order to lessen the negative impacts of ISI and ICI, the loop prefix (CP) is no longer necessary in the waveletbased OFDM system but is still a crucial component in the DFT-based OFDM. To save costly bandwidth, separate wavelet switching (DWT) is a superior option. In the era of digital wireless communication, wavelet theory has proven effective in various domains including signal processing, data compression, source coding, channel coding, and channel modelling (Modi et al., 2018). Fig (3) shows the (LTE system)



Figure 3. LTE system(Jallouli et al., 2022)

### 1.5. Literature Review

In this introductory part, a few similar works are listed as follows:

- Jamal al-Din Zakaria and Muhammad Fadhli Muhammad Saleh presented this research in 2012 to examine how well (BER) and (PAPR) performed for wavelets based on OFDM by various waves. To determine the effectiveness of BER and PAPR features of the OFDM system using Haar, the author concentrated on the research of waves on certain wavelets of various kinds of wavelets(Jin & Hu, 2014).
- In 2020, Carolina Gijón et al. report the first study comparing time series analysis and SL methods for predicting monthly cell-by-cell data traffic during peak hours in an operational LTE network. In order to achieve this, a large dataset is gathered that includes the data traffic for each cell over a 30-month period for the entire nation. Several neural networks, such as additive Holt-Winters, seasonal auto-regressive integrated moving average, support vector regression, and random forest, are being evaluated as potential approaches. The

results suggest that SL models are more effective than time series approaches, even though they require less data storage. More crucially, non-deep SL techniques are computationally more efficient and competitive with deep learning, unlike short- and medium-term traffic forecasts(Gijón et al., 2021).

- Zhang Shupeng et al. (2022) Software radio peripherals are used in this paper as a platform for generating datasets. As a result, the user has the ability to alter the dataset's properties, including antenna gain, modulation style, and frequency band. Furthermore, the suggested dataset is produced using a variety of intricate channel settings in an effort to more accurately represent radio frequency waves in the real world. To imitate an actual Radio Frequency Fingerprint (RFF) dataset based on (LTE), they gather the dataset at transmitters and receivers. Additionally, they validate the dataset and affirm its dependability(Zhang et al., 2022).
- In 2018, Raabia Kausar et al. employed unique methodologies to conduct a comprehensive analysis of the (LTE) downward revision of the (3GPP). We have thoroughly reviewed the segment primarily focused on time, leading us to select the portion primarily focused on the stream. By decreasing the downward energy, this enhances the assessment of both favorable and undesirable signals. Additionally, we choose several strategies to transfer data related to the identification of signals, and apply a technique of element modification to the channel prior to the completion of data identification. The study and conclusions unequivocally demonstrate that the traditional procedures surpass the new ones in terms of cycle count and convenience of use.(Kausar et al., 2018)
- Shirish Joshi, Rohit Bodi, and others the authors carried out comparative research on OFDM with DWT and OFDM with FFT systems in 2012. To be noticed in OFDM, the OFDM DWT must satisfy the ideal reconstruction qualities and anomalous basis (Kumar, 2014).
- Rajashree A. Patil et al. (2018) explain that the LTE Advanced system uses OFDM and MIMO techniques to send data at a high speed. The maximum expected data rate for LTE transmission is 50 Mbps for uplink and 100 Mbps for downstream. MIMO-OFDM achieves the most data throughput and

capacity. This research project aims to investigate the execution performance based on the 3GPP standard release 10. Additionally, the study examines the performance of turbo-coded MIMO-OFDM in LTE-A networks. that use 256 subcarriers and 64-QAM modulation technology. There is a lot of noise in the downlink, so the MATLAB simulation checks the (BER) and downlink throughput of 16 x 16 MIMO configurations (Patil et al., 2018).

- Unfortunately, no text was provided for me to work with. Ali Jemmali, Jean Conan, and Muhammad Torabi conducted a study on the BER of MIMO techniques in the 3GPP LTE system, as outlined in their 2013 publication. We calculate analytical formulas for the average bit error rate (BER) of two different multiple-input multiple-output (MIMO) systems in Long-Term Evolution (LTE) networks, considering the utilization of M-quadrature amplitude modulation (M-QAM) techniques, over flat Rayleigh fading channels. Next, we assess these formulations using numerical methods. The addition of Monte-Carlo simulation data from the LTE system provides further validation for the mathematical analysis. (Jemmali et al., 2013).
- Currently, we rely on modern wireless communication systems that require improved efficiency in bandwidth and data speeds. Widely recognized as the leading 4G wireless standard, LTE technology incorporates OFDMA and MIMO technologies. The Long-Term Evolution (LTE) downlink employs these techniques. A (MIMO) system uses numerous antennas at both the transmitting and receiving ends to improve the communication system's performance through multiplexing and diversity techniques. The MIMO architecture offers enhanced phantom efficacy, improved reliability, reduced fading, and enhanced interference protection. This study by Akash et al. Provides a thorough examination of MIMO, OFDM, and MIMO-OFDM wireless communication systems (Rawat et al., 2021).
- In 2014, Anwarada and Narish Kumar. In this work, BER performance for waves and DFT based on OFDM are compared. (MIMO) and OFDM (multiple-frequency division) are important technologies utilized in the fourth generation of (LTE). Spectrum efficiency is boosted in the wavelet-based system since periodic prefixing is not necessary. Instead of OFDM Distributed

(DFT), OFDM-based wavelets are being suggested for LTE (N. Kaur & Kumar, 2019).

- In 2015, W. Saad, N. Al-Fishawi, S. Al-Rubaie, and M. Shakir. In their research, the authors discovered that orthogonal vectors were produced using OFDM and Fast Fourier Transforms (FFT) as a result of OFDM-FFT system flaws. Medium to High (PAR) Several methods have proposed an efficient OFDM approach employing wavelet conversion to replace the Fourier transform. Through AWGN, this system performs better than traditional OFDM-FFT systems. The (BER) is used to characterize system performance as a function of the (SNR) and (PAR)(Modi et al., 2018).
- Yehia G. War, Alistair C. Bohr, and Marwa Shafi collaborated in 2018. Scientists have shown significant interest in wavelets based on OFDM due to their fascinating properties. This research looks at the (PAPR) error rate for waveform performance when (OFDM) and (OFDM-IM) are used in various channels and equations (Sesia et al., 2011).
- 2019 will see Navdeep Kaur and Naresh Kumar. The writers of this article investigated the numerous self-cancellation techniques recommended in ICI literature. Waves based on OFDM are blended with these technologies. Simulink is used to compare the OFDM ICI self-cancellation algorithms to waves across various channels(Hasan, 2012).
- Alok Joshi, Apoorv Manas, and other researchers conducted this study in 2019 to compare the performance of FFT OFDM with OFDM using DWT. Because of its overlapping properties, the OFDM DWT has the potential to replace the (FFT), as it does not require prefix rotation. In a variety of critical aspects, (DWT OFDM) offers significant improvements over (FFT OFDM). The realization that replacing the FFT block in the existing OFDM system with DWT could improve performance led to the development of a new OFDM-based DWT system.(Jin & Hu, 2014).
- It is impossible to rewrite the user's text in a straightforward and precise manner. This research project aims to investigate the execution performance based on the 3GPP standard release 10. The study also looks at how well turbocoded MIMO-OFDM works in LTE-A networks that use 256 subcarriers and
64-QAM modulation technology. We evaluate the (BER) and downlink throughput of 16 x 16 MIMO configurations in the downlink based on the (SNR) using the MATLAB simulation. Rajashree and colleagues (2018)(Francis Xavier Engineering College & Institute of Electrical and Electronics Engineers, n.d.).

- ✤ This article suggests using hybrid approaches that take Quality of Service (QoS) into account when scheduling downlinks. This will help find a good balance between the QoS that is available and the system's performance when channel and bandwidth limits are in place. Moreover, this study presents a taxonomy that classifies scheduling algorithms into four primary categories: queue aware, target bit-rate aware, delay aware, and hybrid aware. This study introduces a scheduling class that belongs to the second group. It considers latency, queue, and channel characteristics while generating its scheduling metric. We employ simulations to examine and contrast various downlink scheduling policies. The simulations utilize network performance metrics such as average packet loss ratio, average throughput, average packet latency, system fairness, and system spectral efficiency. The simulation results suggest that the queue-aware and delay-aware scheduling rules are highly effective for video traffic classes. Additionally, the hybrid scheduling rules we proposed show promise for other types of traffic. To ensure effective QoS delivery for different traffic classes, it is recommended to use QoS balancing scheduling rules in an LTE downlink. Moustafa M. Nasralla (2020)(Nasralla, 2020)
- This study aims to provide a thorough overview of the various advanced time of arrival (TOA) estimators currently used for LTE signals. These estimators include the delay-lock loop (DLL), the super-resolution approach, information theoretic criteria, and first peak identification. Following that, the study will assess the efficiency of these techniques in estimating the time of arrival (TOA) using simulations, considering the impact of multipath propagation effects and different signal conditions. The DLL evaluates the multipath error envelope measure for various signal bandwidths. In order to assess appropriate TOA estimators in different contexts, we analyze the root mean square errors of the TOA estimations. Lastly, this essay also discusses additional performance

characteristics of these techniques. PaiWang and Y. Jade Morton, the authors, released the publication in 2020 (Wang & Morton, 2020).

- This study presents a novel MIMO antenna with the capability to dynamically modify its frequency, specifically tailored for 4G and preliminary 5G implementations. The MIMO antenna design incorporates a pair of radiating and receiving elements that are positioned diagonally opposite each other in order to produce improved isolation (>12 dB) and a broader range of patterns. Each antenna element in a MIMO array for 4G/LTE and early 5G/Sub-6 GHz wireless communication technologies is composed of a single module. This module features two meandering radiating arms that enable the electronic connection or disconnection to the 50-u feedline. This connection is achieved using two PIN diodes. The antenna has the capability to function in two selectable frequency bands or modes, either 2.4 GHz or 3.5 GHz. Arun Pant, Manish Singh, and Manoj Singh Parihar were all affiliated with the year 2020. (Pant et al., 2021).
- (Alaa Shakir et al., 2019)study the enhancement of BER performance of LTE system using DWT- OFDM with Neural Network as an adaptive equalizer, they found that by using DWT and FFNN Adaptive equalizer to improve the LTE system performance under different channel conditions will improve the LTE system and reduce BER. In addition, when compared to FFT, the DWT. The proposed system gives SNR= 17 at BER 10<sup>-4</sup> when using 5MDS flat fading with QPSK and 1024 subcarrier while LTE-DWT has SNR=20 db.
- (Reyam Thair & Osama Althahab, 2024)The LTE in this work studied widely and suggested a new system structure based Discrete Cosine Transform (DCT) and Fast Radon transforms (FRAT). DCT known for its energy compaction and frequency-domain representation properties, is proposed as a signal processing technique to mitigate the impact of multipath fading, interference, and other channel-induced distortions. By applying the DCT transform to LTE signals, the system can exploit the DCT's decorrelation capabilities to improve the system and process the transmitted data. The Purpose of using DCT was to achieve better performance of BER than traditional LTE system which using Fast Fourier Transform (FFT). It is worth noting that the proposed system does

not require cyclic prefix (CP), and thus the data rate will be faster and the BW will be larger.

There are many similarities and differences between the current study and the literature review whose details are listed above. Therefore, I will choose two studies from these studies and explain the similarities and differences with the current proposed system. These two studies are (Alaa Shakir et al., 2019) and (Reyam Thair & Osama Althahab, 2024), as the current study is similar to Alaa's study in that the two studies dealt with the system LTE, the aim of the study is to reduce BER and it differed from the current study in that it worked on the enhancement of BER performance of LTE system using DWT- OFDM with Neural Network as an adaptive equalizer. As for Reyam's study, it was similar to the current study by using DCT was to achieve better performance of BER, and it differed from the current study because it used Fast Radon transforms (FRAT).

All the studies mentioned in literature review focused on enhancing the BER by using one of the orthogonal algorithms like FFT, wavelet and DCT, while in this thesis, another idea is proposed, which depends on using one of a PN sequence code to increase the orthogonality and security. The idea is to XOR the input data with the proposed code then enter the result to the LTE system with the use of DCT as a modulator instead of FFT, then at the receiver, the received data XORed again with the proposed code to return the input data.

## 1.6. The Aims Of Study

- 1. Develop BER Performance.
- 2. Reduce The Effect of Multipath.
- 3. Increase Bandwidth Efficiency.
- 4. Increase Data Rate.
- 5. Devolve anew system to improve the BER.

## **1.7.** How to satisfy the aims of study

We propose two transceiver topologies to optimize bandwidth efficiency, enhance BER performance to achieve faster data speeds and minimize the impact of multipath in wireless communication networks:

- A proposed LTE structure based upon the (DCT) and Walsh-Hadamard code (W-H) and QPSK mapper.
- Simulate the proposed LTE system by using DCT as multicarrier with same Walsh-Hadamard code (W-H) via MATLAB program.
- 3. Evaluation and testing the new proposed LTE model W-H-DCT in several Doppler frequencies in all type of LTE channels.
- 4. The suggested method doesn't need to use a cyclic prefix (CP), which means that the data rate is higher and the bandwidth is improved.

## **CHAPTER TWO**

## THEOROTICAL BACKGROUND

#### 2.1. Introduction

We are currently experiencing a period of significant advancements in mobile data technology. The tablet market, smartphones, computers, and notebooks has grown significantly, and users now expect more from communications devices like mobile phones than simply voice and text. The growth of mobile apps, data, and social networking, which includes intensive the proliferation of services such as video, online surfing, and music streaming has driven the advancement of next-generation wireless standards. (Sesia et al., 2011). The use of mobile broadband has increased recently. Here, technologies are continuously enhanced to satisfy evolving customer requirements. The introduction of new software and services has aided in the fast progress of mobile technology, which has improved information and communication technology (ICTs)(Tanwar et al., 2022)

The main objective of (LTE) is to achieve increased data speeds for radio access. Additional objectives include expanded coverage and improved system capacity, such as heightened spectrum efficiency, adaptable bandwidth operations, reduced operational expenses, minimal latency, seamless connection with the Internet, support for multiple antennas, and compatibility with existing mobile communication systems. LTE and a fourth-generation wireless system demonstrate the potential progression of the ancestors of the third generation (Sesia et al., 2011)

#### 2.2. LTE Fundamental

LTE standards were created with the goal of achieving increased spectral efficiency, fast data rates, reduced latency, enhanced services, and a third-generation partnership project. Certain technological techniques are also used by the LTE system, such as OFDM access, MIMO transmission, or estimation techniques. This research focuses on the proposed system's LTE channel estimation and equalization Additionally, its performance can be evaluated in terms of (SNR) and (BER) (Jewel et al., 2021). The main LTE system can be shown in Fig (4).



Figure 4. LTE main block diagram system (Jewel et al., 2021)

## 2.3. OFDM System

OFDM has become a widely used air interface method in recent years. Discrete Multi-Tone (DMT) transmissions are an illustration of OFDM techniques in the context of wired systems, just like the ANSI, HDSL, ADSL, VDSL standards, VDSL applications, and ETSI do. Furthermore, the OFDM has been certified as or is regarded as a standard by several IEEE standardization committees, such as IEEE 802.11 and IEEE 802.16 Relatives of Standard(Madhav, n.d.).

Furthermore, it's necessary for transmission to be somewhat sophisticated, and implemented adaptability and acceptance, along with the excellent enactment that is possible, an extremely appealing option for OFDM-based high-quality data transfers over time, through varying radio-selective channels. These systems, which incorporate multi-path CP-introduced complicated equalizers in OFDM, exhibit remarkable flexibility against the ISI. However, it also has a small disadvantage in addition to its significant benefits, which is Increasing the (PAPR), in addition Because OFDM is susceptible to carrier frequency offset, it also causes ICI(Hanzo et al., 2010).

The OFDM technology modulation is to divide the high information stream at a higher rate into data summation streams. A combination of subcarriers is used to send these data streams. However, interference and other noise are a constant concern when there is a high data rate. Subchannels in the frequency range might interfere with one another, increasing the transmission rate. Many modulation techniques, including the (FFT) and (IFFT), are employed to both modulate and eliminate filter creation at transmitters and receivers(Modi et al., 2018). Here, contrast serves as a justification for the carrier to space closely, even when the node is nested without an ICI. Data with a high rate of transmission is generated using a single carrier frequency, and each signal efficiently utilizes the available bandwidth. Thus, ISI and ICI happen if a frequency is selected. The mild OFDM's primary benefit is its high spectrum efficiency (Modi et al., 2018).OFDM block diagram can be seen in Figure (5). a unique type of MCM, uses subcarriers that are closely spaced out and have overlapping ranges, enabling multiple accesses. One of the data transmission principles is MCM, which involves splitting the stream. Each bit stream in multiple streams of bits has a substantially lower bit rate due to these sub-fluxes changing of certain vectors(Jang et al., 2018a) ("BER for BPSK-OFDM" in "Frequency Selective Channel" | RAYmaps, n.d.-a).



**Figure 5.** OFDM main block diagram(*BER for BPSK-OFDM in Frequency Selective Channel* | *RAYmaps*, n.d.-b)

The production and identification of various orthogonal subcarrier transforms are typically employed in OFDM system implementations. Despite being more computationally efficient and requiring less work to construct, these transforms have a disadvantage in that they produce somewhat significant side lobes since they use a rectangular window as seen in Figure (5)(Dawood et al., 2015a).

One can define DFT of length N by looking at Equation (1).

$$X(K) = \sum_{n=0}^{N-1} x(n) W_N^{nk} \qquad K = 0,1 \text{ to } N-1 \dots \text{ Equation (1)}$$

Let x(n) and X(k) represent the input and output of the Discrete Fourier Transform (DFT) accordingly, in addition to  $W_N^{nk}$  denotes the  $N^{th}$  primitive root of unity(Jang et al., 2018b).

$$W_N^{nk} = e^{-j\left(\frac{2\pi nk}{N}\right)} = \cos\left(\frac{2\pi nk}{N}\right) - j\sin\left(\frac{2\pi nk}{N}\right) \dots$$
 Equation (2)

According to equation (3), The inverse fast Fourier transform (IFFT) is a mathematical operation that computes the N-point sequence for X(K).

X (n) = 
$$\frac{1}{N} \sum_{k=0}^{N-1} X(k) W^{-nk}$$
 .... Equation (3)

Where K ranges from 0 to N-1

Equation (4) can rewrite as follows to more effectively implement the IDFT algorithm:

X (n) = 
$$\frac{1}{N} \{ \sum_{k=0}^{N-1} X^* (W^{NK}) \dots$$
 Equation (4)



Figure 6. OFDM signal spectrum(Kochańska & Lasota, 2011)

Here, it is possible to prevent ISI by adding a guard interval between successive symbols. Limiting the guard period length to achieve bandwidth efficiency requires it to exceed the maximum delay caused by signal propagation across a multi-path channel (Misiti et al., 2009). There are two options for the guard interval:

Cyclic prefix (CP).

## Zero padded (ZP).

In order to minimize interference from ICI and ISI originating from multipath propagation, an acyclic prefix is introduced at the beginning of every OFDM transmission. Although the CP may be shorter than the length of the channel as a result of unexpected channel dynamics, the majority of these studies suggest that its length is equivalent to or greater than that of the channel.(Khlifi & Bouallegue, 2013). The duration of the original OFDM symbol is given  $T_{orginal}$  Furthermore, the cyclic prefix employed by the GI is depicted as  $T_{cp}$ , Afterwards, the equation (5) in Figure (6) determines the duration of the expanded OFDM signal through the cyclic prefix.(Kosanyakun & Kotchasarn, 2015).

 $T_{new}=T_{orginal}+T_{cp}$  .... Equation (5)

Zero-padding (ZP) is a convincing alternative to the usual cyclic prefix (CP) method in multi-wave systems like OFDM, as it guarantees precise code restoration.

The Zero Padding (ZP) strategy involves the insertion of zeros into the Guard Interval (GI). Indeed, the ZP technique use those zeros to populate the GI. The effective length of the OFDM code, including zero padding (ZP), is shorter than the length of the cyclic periodic OFDM code.

The duration of the original symbol of Orthogonal Frequency Division Multiplexing (OFDM) is represented as T\_{original}, whereas the Guard Interval (GI) filled with zeros is represented as  $T_{ZF}$ . The duration of the extended OFDM code with a periodic prefix is now defined by equations (6) and illustrated in Figure (7&8). (Oyerinde, 2017).

 $T_{new} = T_{orginal} + T_{ZF} \dots$  Equation (6)

It is assumed  $T_{cp}=T_{ZF}$ . If the number of zero-padded equals the CP length, the CP in OFDM and ZP in OFDM transmission spectral efficiency is the same(Misiti et al., 2009).



Figure 7. Cyclic Prefixed OFDM



Figure 8. Zero Padded in OFDM

## 2.4. The Estimation of Channel

In wireless communication, multipath propagation-induced channel fading is a primary challenge. Channel fading may result in significant ISI interferences, which severely distort the signal at the receiver. By giving the receiving signals, a suitable offset, the impact of channel fading can be greatly diminished. The channel equation is the name of this procedure. In the past, a well-known code sequence was sent to the receiver to make estimate to the channel, and the equivalent was derived using the channel information that was collected. In spite of how straightforward it is, this strategy consumes bandwidth and has low system productivity. Furthermore, several applications of the course, such as asynchronous wireless networks, will be impractical. The training sequence corresponds to the equation of the blind channel. should be avoided as a result(Chafii et al., 2016).

Due to the additional noise, the communication channel is often built as a linear system with a flawed shape. Equations are made to account for noise as well as channel distortions. The equivalent may be created directly from the received signal, or the equalizer can be created based on an estimation of the channel's pulse response. The channel models' mathematical complexity models and any possible information exchange (debugging) with the channel decoder are determined by the equation structure(Dai et al., 2012).

The receiver detects the attenuation in the signals caused by the environment to estimate of the channel. We then perform channel equalization by using the estimated channel data to adjust for the distortion in the received signal (Qin et al., 2010).



Figure 9. The Estimation of Channel (Qin et al., 2010)

Because it incorporates modern technology, Channel estimate is a crucial factor in enhancing the efficiency of the OFDM system (Tang et al., 2018). Channel estimation can be prepared in several ways, depending on whether a boundary model is used for assistance or not. The parameter estimate takes a model with a specified channel, defines the model's parameters, and derives the relevant values. To enhance grading quality, time-bound and frequency-spaced links—two distinct channel characteristics—can be integrated into the estimation process. The most popular approach, which is regarded as an evaluation method, relies on pilot training. In order to estimate the channel requirements, it takes into account a suitable technique where in the transmitter sends a predetermined signal to the receiver. However, the blind estimate method, which is frequently employed in operational OFDM systems, depends on specific signal features, such as periodic signal bending. Adaptive estimation techniques are typically applied to channels that undergo rapid and frequent changes. By injecting experimental tones or utilizing a set duration in each OFDM code, pilots can obtain the channel estimation in an experimental manner across all OFDM sub-carriers(Jiang et al., 2017).



Figure (10) shows A (MIMO) system consists of multiple transmission endpoints and multiple reception endpoints.

Figure 10. A MIMO system(T. Ahmed et al., 2015)

In a MIMO system, the method of channel estimation remains unchanged, except that there are now two signals received from a single source. This suggests that the medium employed two distinct pathways, each dedicated to a specific signal. Hence, in order to calculate the ultimate signal (f) for each frequency, it is necessary to take into account both received signals. This leads to the creation of the matrix of received signals.

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ n_{21} & h_{22} \end{bmatrix} + \begin{bmatrix} n & 1 \\ n & 2 \end{bmatrix} \dots \dots \dots \text{Equation (7)}$$

The channel of matrix h can be estimated by taking the Hermitian of the input matrix x, similar to a SISO system. The noise matrix n can also be computed using matrix operations in a similar way (https://www.hs-osnabrueck.de/fileadmin/HSOS/Forschung/Recherche/Laboreinrichtungen\_und\_Vers

uchsbetriebe/Labor\_fuer\_Hochfrequenztechnik\_und\_Mobilkommunikation/Forschun g/digitale\_Funksysteme/Channel-Estimation.pdf, n.d.).

#### 2.5. Equalizer

Properly equalizing the received signals can greatly reduce the impact of channel fading. Channel equalization is the term for this procedure. To estimate the channel, a known code arrangement is often sent to the receiver. The equalizer is then derived using the obtained channel information(Saad et al., 2010).

Usually, a communication of channel is represented as a linear system with additive noise tainting its output. Equalizers are made to compensate for noise and channel aberrations. By observing the received signal, a drawing can be created immediately(Chafii et al., 2016).

Equalizers are essential elements in bandlimited, high-data-rate digital communication systems. By mitigating or eliminating channel interference, they function to restore the sent information, or the information at the input of the channel. Over the past 70 years, researchers have devised many methods to coincide with the progress of communication networks. Initially, researchers created single-input/single-output (SISO) systems with the purpose of guaranteeing precise transmission of information between two locations. The principles of adaptive filtering and equalization were developed in this particular context. The received signal in a communication channel can be characterized as the result of mixing the output of a linear time-invariant (LTI) filter with noise.

 $x[n] = \sum_{k=-\infty}^{\infty} h[k]s[n-k] + v[n]'$  ..... Equation (8)

In this context, the channel impulse response (h[n]), the transmitted symbol (s[n]), and the additive white Gaussian noise (AWGN) denote v[n]. By rearranging terms, the symbol's presence is highlighted.

When discussing wireless transmission, it is important to note that the channel not only introduces interference between symbols (ISI), but also causes fading due to destructive interference from many routes. In this scenario, the movement of the user leads to a frequency deviation caused by the Doppler effect, which in turn generates variations in phase and power as time progresses. These inconsistencies in channels necessitate modifications using equalizers. Employing temporal and/or frequency diversity is crucial in order to provide superior transmission quality at higher data rates while maintaining a reduced signal-to-noise ratio (SNR). Soon after, scientists uncovered an additional technique to enhance quality: utilizing space variety. What are the advantages of using many antennas for transmission instead of a single one? Alternatively, why not employ many antennas for reception when only one is employed for transmission? The resulting systems are referred to as Single-Input Multiple-Output (SIMO) and Multiple-Input Single-Output (MISO). The implementation of the new equalization approaches resulted in substantial decreases in the bit-error rate seen at the receiver output. Exploring a wide range of antennas for both sending and receiving signals enhances the previously mentioned scenarios, leading to the implementation of (MIMO) systems.(Cavalcanti & Andersson, 2009). Figure (11) shows the process of linear equalization for a channel.



Figure 11. Demonstrating the process of linear equalization for a channel.

#### 2.5.1. Zero-forcing equalizer

Let's concentrate on symbol  $s_0$ , which is conveyed by the waveform h(t), without losing any generality. Shifted versions of the waveform h(t) that carry different symbols taint a portion of it. Orthogonal decomposition of h(t) is strongly related to zero-forcing equalization. As a result, we start with an orthogonal projection procedure.

Orthogonal projection.

ZFE.

Equivalent discrete ZFE receiver.

MMSE of linear equalizer

The ZFE is represented by an equivalent diagram consisting of a sampler and a discrete ZFE filter A(z) that is intended to completely eliminate ISI caused by the channel, even if it means amplifying noise. The receiver filter h \* (-t)matches the overall channel response. While maintaining the same structure, the MMSE equaliser uses the MMSE criterion to reduce the combined impact of ISI and the AWGN components. Let u(t) represent the output of the matched filter in response to x(t), After that, we can write(T Zhang, 2016):

 $u(t) = h(-t) * x(t) = h(-t) * \sum s_i h(t - it_s) + h(-t) * n(t) \qquad \dots \dots \dots$ Equation (9)

#### 2.5.2. Decision-Feedback Equalizer (DFE)

Using the ZF or MMSE criteria, we can completely or partially exclude the ISI component from the prior study. We can maximize the SNR by achieving the best possible trade-off between the ISI and noise components by applying the MMSE criterion. Furthermore, we note that this correlates with the noise-plus-ISI residue. So, it makes sense to ask: Is it possible to make use of this correlation to further minimize the remaining noise component? By exploiting the decision device's nonlinearity, we can produce a so-called DFE, which is depicted in Figure (12). For DFE and ZFE, the analogous channel model is the same. A DFE is comprised of a forward transversal

filter that provides a refined approximation of the current symbol and a decision-feedback filter that functions as a linear predictor of the current (Qureshi, 1985).



Figure 12. Block diagram for DFE(Nafie, n.d.)

## 2.6. The Wireless Channels Outlines

Any type of information transfer from one station to another without a physical wire connection which is referred to as wireless communications in general. A wireless communication system represents any form of airborne communication. Nowadays, the dispersion of electromagnetic waves is commonly used to transmit electronic information, and this is where the phrase "wireless communication" comes from(Zhao et al., 2019).

The electromagnetic medium that is trapped in the vicinity of the transmitter and receiver is referred to as the channel(Einolghozati et al., 2011) One path signal, or a perfect reconstruction with respect to the transmitted signal, comprises the complete signal received in an ideal radio channel. In contrast, the channel is regarded as genuine in our daily lives when the received signal is composed of a collection of replicas of the broadcast signal's deflection that have been refracted, reflected, and attenuated. Additionally, in a multi-path fading channel, related delayed paths of various signals can only be quantitatively described because they are unexpected. The channel adds noise to the transmission.

Furthermore, a phenomenon known as the Doppler Effect can cause a change in carrier frequency if the transmitter or receiver is moving. It is crucial to take into account these effects on the signal since the performance of the radio system is reliant on the radio channel's properties(Al-Thahab, 2006).

There are three common channels

1- AWGN

2- Attenuation

Attenuation can be classified as two kinds from channels

A- Flat fading

B- Selective fading

## 2.7. AWGN Channel

The Gaussian channel, also referred to as the (AWGN), is the most frequently used channel model. People commonly view a basic (AWGN) channel as a foundational stage for deriving essential system performance outcomes under specified conditions.(Khlifi & Bouallegue, 2013).

In this section, the focus is on the familiar (real) AWGN channel:

 $I[t] = s[t] + n[t] \dots$  Equation (10)

where I[t] and s[t] are real input and output at time m respectively and n[t] is

N (0, <T<sup>2</sup>) noise, independent over time.

Figure (13) shows the Block diagram of AWGN channel model.



Figure 13. Block diagram of AWGN channel model(Batsala et al., 2015)

## 2.8. Attenuation

The multipath effect and signal can affect the length of transmission pathways and obstacles. Some of the radio propagation effects that could result in attenuation are shown in Figure (14). Any object that blocks the Line of sight (LOS) From transmitter to receiver can cause attenuation(Wilson & Patwari, 2010).

Signal shading can happen when there we can obstacles between the transmitter and the receiver, like hills and buildings, are present. It is the most significant environmental attenuation factor. Radio waves propagate beyond the limits of impediments, completely obscuring signs behind hills and buildings. To solve the shade issue, the transmitters are set to a high level to minimize the number of obstructions(Althahab & Akkar, 2007).



Figure 14. Effects of Radio Propagation(ABDUL-SADE & Hasan, 2017)

One of the main channel representation models is the channel of Rayleigh fading, the statistical model in question is employed to investigate how the environment affects a radio signal's ability to propagate. The wireless system and devices use the Rayleigh fading channel model to cause the signal magnitude to fluctuate or fade in accordance with the Rayleigh method's distribution.

Here R consider this random variable and it will have a density function as in equation (11) (Khare et al., 2014)

$$P_R(r) = \frac{2\pi}{\Omega e^{\frac{-r^2}{\Omega}}} \qquad \dots \text{ Equation (11)}$$

Where  $r \ge 0$  and  $\Omega = E(R^2)$ 

The LTE system consists of three main channel types: (ETU), (EPA), and Extended Vehicular A model (EVA). Situations with high data rates and minimal mobility restrict its use. These models allow the system to calculate the reference to the suggested LTE configurations by assessing the transceiver's performance. Relative power vectors and associated delay profiles can define a model of any multi-channel channel for fading. A delay propagation environment with low, medium, and high values is determined by the multipoint distribution service (MDS) of the channels. Tabel (2) shows the profile of channel delay for each form with nanosecond tap delay values and decibel relative capacity values, indicates that 6, 60, and 180 Hz are the MDS (Abdul-Rahaim, 2015a).

Channel model	Excess tap delay (ns)	Relative power (dB)
Extended Pedestrian A(EPA)	[0, 30, 70, 90, 110, 190, 410]	[0, -1, -2, -3, -8, -17.2, -20.8]
Extended Vehicular A(EVA)	[0, 30, 150, 310, 370, 710, 1090,	[0, -1.5, -1.4, -3.6, -0.6, -9.1, -7,
	1730, 2510]	-12, -16.9]
Extended Typical Urban	[0, 50, 120, 200, 230, 500, 1600,	
(ETU)	2300, 5000]	

Table 2. EPA, EVA, and ETU profiles delay and power

## 2.9. Types of Rayleigh Fading

In wireless communications, the transmission of a signal from a transmitter to a receiver often encounters reflection, diffraction, and scattering due to the presence of surrounding structures, trees, mountains, and other obstacles. Multipath signals will therefore have varying amplitudes and phases when they reach a receiver. We call this phenomenon multipath fading. Two types of fading are depicted in Figure (15): small-scale fading and big-scale fading. The route loss resulting from motion over wide areas is represented by big-scale fading. The term "small-scale fading" describes significant alterations in a signal's phase and amplitude brought on by little shifts in the transmitter or receiver's positions. The signal experiences time spreading and the channel undergoes temporal fluctuation the two ways that small-scale fading might appear(Chau Vo, 2012).



Figure 15. Fading manifestations(S & p, 2017)

#### 2.9.1. Large scale fading

Obstacles like hills, woods, buildings, and so on between a transmitter and receiver cause large-scale fading, which is the attenuation of a signal's strength. This phenomenon, known as fast fading, occurs when a mobile transmitter or receiver moves over a considerable distance, leading to rapid variations in the amplitude of the received signal. Large-scale fading is a common occurrence in mobile communications, affecting different locations such as indoor, outdoor, and urban settings. Small scale fading

Small-scale fading refers to the phenomenon that is being described significant alterations in a signal's phase and amplitude brought about by a tiny shift in the transmitter's or receiver's location (about half a wavelength). The transmitted signal's constructive and destructive interference, which happens at extremely high carrier frequencies (900 MHz or 1.9 GHz for cellular), is the cause of this effect.



Figure 16. Multipath fading(Global System for Mobile Communications (GSM) Technology, n.d.)

The phenomenon of small-scale fading is represented by mathematical models that incorporate both Rayleigh and Rician fading. Figure (16) illustrates the occurrence of multipath fading between a transmitter and receiver. There are two categories of pathways: non-line of sight (NLOS), where obstacles cause the signal to bounce off, and line of sight (LOS), which refers to direct lines. The Rayleigh fading model is used when there are several pathways connecting a transmitter and receiver, but no direct line of sight link. Ricardian fading is utilized in scenarios when there is an unobstructed direct path between the transmitter and the receiver.

Small-scale fading is composed of two processes: time spreading, which occurs due to multipath delay, and time variation, also known as Doppler spread, which occurs due to motion between a transmitter and receiver. As depicted in Figure (17), these phenomena can be elucidated in either the frequency or time domain(Rappaport, 2010).

# Small scale fading based on multipath time delay spread Flat Fading **Frequency Selective Fading** 1. BW of signal < BW of channel 1. BW of signal > BW of channel 2. Delay spread < Symbol period 2. Delay spread > Symbol period Small scale fading based on Doppler spread **Fast Fading** Slow Fading 1. High Doppler spread 1. Low Doppler spread Coherence time < Symbol period</li> Coherence time > Symbol period Channel variations faster than 3. Channel variations slower than baseband signal variations baseband signal variations

**Figure 17.** Type of small-scale fading (*Unit 2 Mobile Radio Propagation: Types of Small-Scale Fading*, n.d.)

All of the frequency of components of the transmitted signal experience the same phase shift and attenuation as they pass across the channel in flat fading  $(f_0 > w)$ . Additionally, there is only one fading path via which the received signal reaches the receiver; The signal's multipath components cannot be distinguished or resolved. When a channel is slow to fade, it means that for at least one signaling interval, the signal that is being sent phase and amplitude are constant. The signal that has been received, assuming the broadcast signal is  $s_1(t)$ , includes noise within one symbol period(Chau Vo, 2012):

$$r_1(t) = a_n(t)e^{-j0n(t)}s_1(t) + n(t) \dots$$
 Equation (12)

n(t): the complex valued white Gaussian noise.

The system model for a flat-fading channel is represented by Figure (18) and can be expressed as follows:



Figure 18. System Model of a Fading Channel(Vahid Meghdadi, 2007)

$$v_t = \sqrt{A_t} exp(j\varphi)U_t + N_t \dots$$
 Equation (13)

where  $V_t$ ,  $U_t$ , and  $N_t$  correspond to the values defined. A complex channel gain with amplitude  $\sqrt{A_t}$  and phase  $\phi$  at time t is represented by  $\sqrt{A_t} exp(j\varphi)$ . The signal amplitude  $\sqrt{A_t}$  is a random variable with a Rayleigh probability density function, and the phase  $\phi$  is uniformly distributed in  $[0, 2\pi]$ . Referred to as the channel power gain with the time-varying feature, at can exhibit either independent or correlated behavior over time and is not reliant on the channel input Ut. The signal amplitude At is constant over T 1 symbol period time units, and after T time units, At is changed to an independent value according to some density function f. This means that a flat-fading channel has discrete-time and memo-rayless properties(Li et al., 2005).

#### 2.10. MIMO

The notion of MIMOs for many years, it has been considered a cost-effective solution for developing both wireless and wired systems. The year 1984 marked the inception of wireless communications. One of the initial applications of MIMO technology was transmitting data over a single frequency channel simultaneously Employing numerous antennas at both the transmitting and receiving ends, serving multiple customers. A MIMO system is a system that provides several concurrent data

streams, including a multitude of antennas for both the receiver and the transmitter. is seen in Figure (19) (Hussain & Audah, 2020) (Dawood et al., 2015b).



**Figure 19.** MIMO system with N receiver and M transmitter antennas(M. Kaur et al., 2017)

When information is being transmitted via various paths, The MIMO system can utilize the diversity of the transmitter and the receiver. preserving trustworthy links in this way. The two primary characteristics of MIMO systems are thought to be:

1. There has been a noticeable increase in system capacity and spectrum efficiency.

2. Lessen is fading significantly as a result of greater diversity. when the various channels are independently dimmed. This is deemed to be especially advantageous(Yuan et al., 2021).

Mobile communications systems like LTE utilize MIMO technology to provide high-speed mobile broadband. The LTE data rate can be accelerated with MIMO technology to reach 100 Mbps downlink and up to 50 Mbps uplink(Abdul-Rahaim, 2015a).

Diversity refers to the use of numerous send antennas. It is used to send the receiver several copies that are independent of the original signal. Frequency coding,

or space-space coding, is used in the most intricate transmission diversity algorithms. One method that offers significantly better performance in wireless communication networks with numerous antennas is space-time encryption. The Alamouti scheme's generic version is called Space time block coding (STBC). STBC is an intricately styled rendition of Alamouti's STC. Here, the decoding and encoding techniques are identical on the receiver and transmitter sides to provide the maximum diversity order for STBC, which is implemented for an appropriate number of transmitter and receiver antennas(Santumon & Sujatha, 2012).

The primary need for both broadcast and receive antennas is a distinct pilot sequence. In this case, data is created as a matrix, where columns represent the number of data transmission time intervals and rows represent the quantity of antennas. signals are initially assembled on receiver, and decision criteria are then applied via a maximum probability detector. Figure (20) shows transmitter scheme of Alamouti algorithm (Cho et al., 2010).



Figure 20. Alamouti encoder in space time(Jacob Sharony, 2006)

The encoding matrix X is composed of symbols x1 and x2, which are used in the equation (14) to illustrate the mathematical explanation of two sending schemes with one receiving scheme(Tse & Viswanath, 2005). So, two transmit antennas are mapped by these symbols x1 and x2.

$$\mathbf{X} = \begin{bmatrix} x1 & -x2^* \\ x2 & x1 \end{bmatrix} \dots \text{ Equation (14)}$$

The fading coefficients (h1(t), h2(t)) are displayed. As seen in equation (15), (16).

$$h1(t) = h1(t+T) = h1 = |h1|e^{j\theta_1} \dots \text{ Equation (15)}$$
$$h2(t) = h2(t+T) = h2 = |h2|e^{j\theta_2} \dots \text{ Equation (16)}$$

The signals at the receiver throughout the course of two successive symbols for t and t + T are denoted by y1 and y2, therefore the received signals can be expressed using equation (17), (18), and you can see the Alamoti algorithm at the receiver as seen in Figure (21).



Figure 21. The receiver with Alamoti algorithm(Jameel, 2010)

From y1 and y2, x1 and x2 must be extracted using an STBC encoder at the receiver. as shown by the subsequent equations (Islam et al., 2012)

$$\hat{x}_{1} = \bar{h}_{1}y_{1} + h_{2}\bar{y}_{2}...$$
 Equation (19)  

$$\hat{x}_{1} = \bar{h}_{1}h_{1}x_{1} + h_{1}h_{2}x_{2} + \bar{h}_{1}n_{1} - h_{2}\bar{h}_{1}x_{2} + h_{2}\bar{h}_{2}\overline{x_{1}} + h_{2}\overline{n_{2}}...$$
 Equation (20)  

$$\hat{x}_{1} = (|h_{1}|^{2}_{+}|h_{2}|^{2})x_{1} + \bar{h}_{1}n_{1} + h_{2}\overline{n_{2}}...$$
 Equation (21)

Similarly, for signal x2 we generate:

$$\hat{x}_{2} = \bar{h}_{2}y_{1} - h_{1}\bar{y}_{2}...$$
 Equation (22)  
$$\hat{x}_{2} = \bar{h}_{2}h_{1}x_{1} + \bar{h}_{2}h_{2}x_{2} + \bar{h}_{2}n_{1} + h_{1}\bar{h}_{1}x_{2} - h_{1}\bar{h}_{2}x_{1} - h_{1}\bar{n}_{2}...$$
 Equation (23)  
$$\hat{x}_{2} = (|h_{1}|^{2}_{+}|h_{2}|^{2})x_{2} + \bar{h}_{2}n_{1} - h_{1}\bar{n}_{2}...$$
 Equation (24)

The maximum probability detector receives both signals after which it determines which symbols are most likely to have been conveyed. In almost communication system the adaptive equalizer became an important brick such as optical, wire in addition to wireless communication.

## 2.11. "Discrete Cosine Transform" (DCT)

The (DCT) was initially introduced by Ahmed, Natarajan, and Rao in the early 1970s (Ahmed, Natarajan, & Rao, 1974). Following then, the (DCT) has been more and more popular, resulting in the creation of other variations, as recorded by Rao and Yip in 1990. In 1984, Wang categorized the (DCT) into four distinct transformations referred to as DCT-I, DCT-II, DCT-III, and DCT-IV (Hafed & Levine, 2001).

Nasir Ahmed, T. Natarajan, and K. R. Rao developed the first notion for the (DCT) while they were working at Kansas State University. The concept was suggested to the National Science Foundation in 1972. The main purpose of the DCT was to compress images. In 1973, Ahmed collaborated with his colleague Dr. K. R. Rao and his doctoral students T. Raj Natarajan, Wills Dietrich, and Jeremy Fries at the University of Texas in Arlington to develop an effective (DCT) method (N. Ahmed, 1991).

Their research results were documented in a scholarly article titled "Discrete Cosine Transform," which was published in January 1974 (RAO & YIP, 1990). The

text provided offers an explanation of both the type-III (IDCT) and the type-II (DCT-II) (Britanak et al., 2010). Since its inception in 1974, academics have undertaken thorough investigations on the (DCT). In a 1977 publication, Wen-Hsiung Chen, C. Harrison Smith, and Stanley C. Fralick presented a swift method for performing (DCT). The 1978 study conducted by A. M. Peterson and M. J. Narasimha, together with the 1984 research conducted by B. G. Lee, are two more significant contributions to the subject. In 1992, the Joint Photographic Experts Group recognized that these two studies, along with Ahmed's first research in 1974 and Chen's study in 1977, formed the foundation for the advancement of JPEG's lossy image compression technique (Wallace, 1992).

The (DST) was obtained by substituting the Neumann condition at x = 0 with a Dirichlet condition in the (DCT). The 1974 study authored by Ahmed, Natarajan, and Rao offered a comprehensive explanation of the (DST) (N. Ahmed et al., 1974).

Anil K. Jain introduced a type-I DST (DST-I) in 1976, while H.B. Kekra and J.K. Solanka introduced a type-II DST (DST-II) in 1978. In 1975, Guner S. Robinson and John A. Roese modified the (DCT) to enable inter-frame motion-compensated video coding. They developed inter-frame hybrid coders for both the (FFT) and the (DCT). The study conclusively showed that the (DCT), due to its simplified nature, is the most efficient technique for compressing image data. The system has the capability to generate image quality that is comparable to an intra-frame coder, requiring two bits per pixel for a videotelephone scene. In 1979, Anil K. Jain and Jaswant R. Jain further improved motion-compensated DCT video compression. (Cianci, 2014).

It is commonly referred to as a type of recompense for impeded mobility. In 1981, Chen created a video compression technique known as motion-compensated DCT, also referred to as adaptive scene coding. The motion-compensated (DCT) gained widespread acceptance as the preferred method for video compression starting in the late 1980s. John P. Princen, A.W. Johnson, and Alan B. Bradley, researchers from the University of Surrey, enhanced the (DCT) by creating a modified version called the modified DCT (MDCT) in 1987. This modification was based on their previous study conducted in 1986. Contemporary audio compression formats, including Advanced Audio Coding (AAC), Vorbis (Ogg), Dolby Digital (AC-3), and

MP3 (which employs a hybrid DCT-FFT algorithm), make use of the MDCT. (Mandyam et al., 1995).

In 1995, researchers Nasir Ahmed, Giridhar Mandyam, and Neeraj Magotra from the University of New Mexico collaborated to create a lossless (DCT) technique. Utilizing the DCT approach enables the compression of photos without compromising their quality. This is an enhanced iteration of the first (DCT) technology that incorporates delta modulation and inverse DCT components. In comparison to entropy coding, it is a more efficient technique for compressing data without any loss. LDCT is an abbreviation for lossless discrete cosine transform. The (DCT) are mathematical operations that convert a signal or image from the spatial domain to the frequency domain. Given the inherent and nearly inevitable nature of the discrete problem, it is somewhat noteworthy that the discovery of the DCT did not happen until 1974. This interval of waiting may illustrate a key principle. In the case of a continuous issue, such as a differential equation, there exist several discrete approximations, known as difference equations. The isolated instance frequently unveils a greater degree of intricacy and diversity in the boundary conditions. (Strang, 1999).

#### 2.12. Application of DCT

The (DCT) is extensively used in signal processing as the primary linear transformation for compressing data. The utilization of the DCT lossy compression method greatly reduces the memory and bandwidth requirements of uncompressed digital media and lossless compression, both of which have large demands. This method can achieve data compression ratios ranging from 8:1 to 14:1 for near-studio quality and up to 100:1 for content of acceptable quality. DCT compression standards are essential for various digital media formats such as digital pictures, digital photography, digital video, streaming media, digital television, video on demand (VOD), digital cinema, high-definition video (HD video), and high-definition television (HDTV). Signal and image processing commonly use the DCT, specifically the DCT-II, for lossy compression due to its notable energy compaction feature. Most applications concentrate the majority of the signal information in a limited number of the low-frequency components of the DCT. When there is a lot of correlation between

Markov processes, the discrete cosine transform (DCT) can get a level of decorrelation that is about the same as the Karhunen-Loève transform's best level of compaction. We deduce the boundary conditions from the cosine functions, as we will elaborate later. At both ends of the array, various discrete cosine transform (DCT) variations are associated with slightly different even and odd boundary conditions. Spectral approaches frequently employ Discrete Cosine Transforms (DCTs) to solve partial differential equations. Chebyshev polynomials and discrete cosine transforms (DCTs) have a strong connection. Crenshaw-Curti's quadrature employs efficient DCT methods (listed below) to estimate arbitrary functions using a sequence of Chebyshev polynomials (*Discrete Cosine Transform - Wikipedia*, n.d.).

#### 2.13. Property of DCT

The (DCT) is a widely acknowledged approach in the disciplines of image and signal processing. The (DCT) is more effective than the (DFT) at reducing high-frequency components in the converted domain. The reason for this is that the (DCT) does not need to handle the impact of edges, unlike the (DFT). The (DCT) outperforms the Fourier transform domain technique in terms of concentrating power on the low-frequency region, approximating the frequency response of the original channel impulse, and minimizing aliasing error. The estimators utilizing the (DCT) can offer an accurate approximation of the (MMSE) channel estimation. The mathematical formulation of the DCT method closely resembles that of the Fourier transform method, but with the key difference that it uses the DCT matrix instead of Fourier matrices. In the following sections, we will offer detailed explanations of the channel estimators that are based on the (DCT). (Zhou et al., 2009).

## 2.14. DCT-"Based Channel Estimation"

An effective approach to decrease noise in the time domain is utilizing DFTbased channel estimation. Channel power leakage occurs when the multipath time delays are not evenly spaced, which in turn influences the overall channel coefficient. The (DCT) mitigates the impact of the sharp edge caused by the (DFT) methodology by employing a mirror extension method to smooth out the data. Figure (22) largely identifies the leaking common intermediate frequency rejection (CIR) in the low-frequency range. Using the (DCT) for estimate minimizes the aliasing mistakes that arise from using the (DFT) technique. Below is a description of the algorithm used to estimate values using the (DCT). Following the execution of the (DCT), a pilot frequency response manifests in the transformed domain. (Du et al., 2013).

$$\hat{h}_d(m) = w(m) \sum_{k=0}^{N_b - 1} \hat{H}_p(k) \cos \frac{(2k+1)\pi m}{2N_b} \cdot m = 0.1 \dots N_b - 1 \dots$$
 Equation

(25)

Were

$$W(m) = \begin{cases} \frac{\sqrt{1/N_b}}{\sqrt{2/N_b}} m = 0 \\ m \neq 0 \end{cases}$$
 Equation (26)

Out of the Nb samples of the impulse response, a significant number of samples will have minimal or no energy, save for the presence of noise disruption.



Figure 22. DCT & DFT principle (Alaa Shakir et al., 2019)



**Figure 23.** Block diagram of the discrete cosine transform filtering(Alaa Shakir et al., 2019)

## 2.15. Turbo Encoder

The turbo code, comprising many system block icons, facilitates the transmission of data messages between inter-servers, serving as the first stage in the data flow. The implementation of decoding algorithms, like Turbo Code, has made significant progress. To obtain an estimate of the probability of transmitting icons, each decoding method relies on the received data action when decoding the encoder. Decoders use soft output. One encoder transmits the probabilities associated with the symbols, identifying them as external probabilities, to the other decoder, which uses them as assumptions. In this scenario, the decoders collaborate with each other, enabling them to combine evidence from past possibilities disclosed in the equivalency information of the code. Following After multiple iterations, the decoder makes an approximation of the given code word by utilizing the result obtained by the preceding decoder as the input for the succeeding decoder. Figure (24) Displays the schematic diagram of the turbo encoder (Moon, 2020)



Figure 24. Turbo encoder Block(Mursi et al., 2014)

After coding, the data go to the mapper or modulation block to modulate it in N-QAM (where N =2, 4, .64) then after mapping the data go to OFDM block.

#### 2.16. Walsh Code

The Walsh code is a linear code that converts binary strings of length n into binary codewords of length 2<sup>n</sup>. Moreover, these codes are mutually orthogonal. (Singhal, 2012).

Many applications, including (DS-CDMA) communications, have widely used the Walsh Transform (WT). The orthogonality attribute and the convenience of its binary-valued base sequences make it popular in implementations. Research has shown that in asynchronous multicarrier communications, binary gold codes, with their nonlinear phase and virtual orthogonality, and their extensions outperform Walsh sequences of the same length with their linear phase and orthogonality. However, the orthogonality property of Walsh sequences makes them more suitable for synchronous communications compared to the nearly orthogonal gold family (Akansu & Poluri, 2007).

#### 2.17. Encoding Walsh Code and Hadamard Matrices

"A Hadamard matrix H of order n is an  $n \times n$  matrix of 1s and -1s in which  $H^T = nI_n$ . ( $I_n$  is the  $n \times n$  identity matrix) For Walsh codes, we use an Hadamard matrix of the order  $2^{N}$ ". It is hypothesized that Hadamard matrices can be found for all orders that are divisible by 4. There exists a constructive proof for powers of 2. In 1867, J.J. Sylvester presented the subsequent recursive construction:

$$H_{1} = \begin{pmatrix} 1 \end{pmatrix} H_{2} = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

$$H_{2N} = \begin{pmatrix} H_{N} & H_{N} \\ H_{N} & -H_{N} \end{pmatrix}$$
For correctness, we see that,
$$H_{2N}H_{2N}^{T} = \begin{pmatrix} H_{N} & H_{N} \\ H_{N} & -H_{N} \end{pmatrix} \begin{pmatrix} H_{N}^{T} & H_{N}^{T} \\ H_{N}^{T} & -H_{N}^{T} \end{pmatrix}$$

$$= \begin{pmatrix} H_{N}H_{N}^{T} + H_{N}H_{N}^{T} & H_{N}H_{N}^{T} - H_{N}H_{N}^{T} \\ H_{N}H_{N}^{T} - H_{N}H_{N}^{T} & H_{N}H_{N}^{T} + H_{N}H_{N}^{T} \end{pmatrix}$$

$$= \begin{pmatrix} 2I_{N} & 0 \\ 0 & 2I_{N} \end{pmatrix} = 2I_{2N}$$

Equation (27)

"Hadamard matrices with orders that are a power of two can yield Walsh codes. The rows of the matrix of order  $2^N$  constitutes the Walsh codes which encodes N bit sequences. Now, instead of 1 and -1 consider 1 and 0". That is consider the matrix and the codes over the field F<sub>2</sub> or modulo 2. Since Walsh codes is a linear code, there exist a generator or a transformation matrix for the same. Consider the following n ×  $2^n$  generator matrix for encoding bit strings of length *n*:(Singhal, 2012)

. . . . . .
$$G_n = \begin{pmatrix} \uparrow & \uparrow & & \uparrow \\ g_0 & g_1 & \cdots & g_{2^n - 1} \\ \downarrow & \downarrow & & \downarrow \end{pmatrix}$$

where  $g_i \in \{0, 1\}^n$  is the binary representation of *i*. Walsh Code  $WC(x) = x \cdot G_n$  For instance, Generator matrix for n = 2 is given by

$$G_2 = \begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 \end{pmatrix}$$

Notice that. 
$$G_n$$
 is in fact a basis<sup>2</sup> for  $H_{2^n}$ .

.... Equation (28)

# 2.18. Hadamard code

The Hadamard code, discovered by Jacques Hadamard, is an error-correcting code designed to identify and fix errors that may occur when transmitting data through unreliable or noisy channels. In 1971, NASA's Mariner 9 successfully transmitted images of Mars back to Earth using the code. The Hadamard code has been extensively studied by researchers in the fields of coding theory, mathematics, and theoretical computer science. Engineers find it useful due to its mathematical functionality. The Hadamard code is sometimes referred to as the Walsh code, the Walsh family, or the Walsh-Hadamard code, in honor of the American scientist Joseph Leonard Walsh. The Hadamard code is an example of a  $2^m$  long linear code over a binary letter set. As a result, this term isn't completely clear. Some sources say that k = m, whereas others say that k = m + 1 is the message length. The Hadamard code refers to the first case in this paper, while the expanded Hadamard code refers to the second (*Hadamard Code - Wikipedia*, n.d.).

The Hadamard code is a particular example of a linear code that has a fixed length of  $2^m$  and utilises a set of two symbols. Unfortunately, this statement is ambiguous as some sources assume a certain length for the message, denoted as k = m, while others assume a message length of k = m + 1. The initial instance is referred to as the Hadamard code, but the subsequent example is known as the enhanced Hadamard code. The defining characteristic of the Hadamard code is that each nonzero codeword has a Hamming weight precisely equal to raise to the power of  $2^{k-1}$ , indicating that the code's distance is also raised to the power of  $2^{k-1}$ . The Hadamard code is a block code in traditional coding theory notation, specifically a  $[2^k, k, 2^{k-1}]$ 2 code. This indicates that the code is a linear code over a binary alphabet, where the length of each block is  $2^k$ , the length of the message (or dimension) is k, and the minimum distance is equal to half of  $2^k$ . Despite the block length being significantly greater than the message length, errors can still be corrected even in extremely noisy conditions. The augmented Hadamard code, denoted as a  $[2^k, k + 1, 2^{k-1}]$  code, is an improved version of the Hadamard code. It is more suitable for practical applications because it preserves a relative distance of 1/2. The code referred to in communication theory as the Hadamard code is identical to the first-order Reed-Muller code when using the binary alphabet (Guruswami, n.d.).

"Hadamard code" can also refer to codes made from any Hadamard matrix; they don't have to be of the Sylvester type. However, most Hadamard codes are based on Sylvester's combination of Hadamard matrices. In general, this kind of code isn't straight. The first set of these codes was made by Raj Chandra Bose and Sharadchandra Shankar Shrikhande in 1959. The code has parameters (n, 2n, n/2), indicating that it is a non-linear binary code with 2n codewords of block length n and minimal distance n/2 if n is the size of the Hadamard matrix. For any n, the following construction and decoding methods will work. However, n must be a power of two to meet the standards for linearity and identification with Reed-Muller codes, and the Hadamard matrix must be the same as the matrix made using Sylvester's method (Bose & Shrikhande, 1959).

The Hadamard code is a type of locally decodable code that enables the examination of a limited section of the received word, resulting in the recovery of parts of the original message with a high likelihood. This has implications in the field of computer complexity theory, particularly in the development of probabilistically verifiable arguments. The Hadamard code typically has a relative distance of 1/2, indicating that one can only anticipate recovering from a maximum of 1/4 percent of errors. However, if less than  $\frac{1}{2} - \epsilon$  of the bits in the received word have been corrupted, Through the use of list decoding, a limited number of potential candidate messages

can be generated. Walsh Code, also known as the Hadamard code, is utilized to designate distinct communication channels in (CDMA) communication. When discussing CDMA literature, codewords are frequently denoted as "codes." By modulating their signal with a distinct codeword, or "code," each individual user will do so. Theoretically orthogonal Walsh codewords render a Walsh-encoded signal as random noise unless a CDMA-capable mobile terminal employs the identical codeword utilized to encode the incoming signal (Langton, 2002).

### 2.19. Constructions

Although Hadamard matrices serve as the foundation for all Hadamard codes, the constructions vary slightly depending on the scientific discipline, author, and application. In general, the goal of coding theorists and engineers who examine the extreme qualities of codes and employ codes for data transmission are to maximize the code's rate, even if doing so results in a little less elegant mathematical formulation. However, in many theoretical computer science applications of Hadamard codes, achieving the optimal rate is not as crucial. As a result, simpler Hadamard code structures are preferred since they allow for more elegant analysis(*Hadamard Code - Wikipedia*, n.d.).

#### 2.19.1. Construction using inner products

When a binary message is provided  $\varkappa \in \{0,1\}^k$  of length k, The Hadamard code transforms the message into a codeword *Had* ( $\varkappa$ ) employing an encoding function *Had*:  $\{0,1\}^k \rightarrow \{0,1\}^{2^k}$ . This function utilizes the inner product ( $\varkappa, y$ ) of two vectors  $\varkappa, y \in \{0,1\}^k$ , It is described or outlined in the following manner:

 $\langle x, y \rangle = \sum_{i=1}^{k} xiyi \mod 2 \dots$  Equation (29)

The Hadamard encoding of x is defined as the series of inner products between x and all other vectors in the set

Had 
$$(x) = (\langle x, y \rangle)_{y \in \{0,1\}^k}$$
 .... Equation (30)

Real-world applications commonly employ the augmented Hadamard code because of its restricted usefulness. This occurs when the initial bit of y is zero, $y_1 = 0$ , The inner product does not provide any information concerning  $x_1$ , Consequently, it is not feasible to completely decipher x only based on those places of the codeword. Conversely, when the codeword is limited to specific spots where  $y_1 = 1$ It is still feasible to completely decipher x. Therefore, it is logical to limit the use of the Hadamard code to these specific locations, resulting in the creation of the augmented Hadamard encoding

*x*, *that is*, *pHad* 
$$(x) = \{(x, y)\}_{y \in \{1\} \times \{0,1\}^{k-1}} \dots$$
 Equation (31)

# 2.19.2. Construction using a generator matrix

The Hadamard code is a type of linear code, which means that it can be formed using a generator matrix G. In fact, all linear codes may be constructed in this way. This is a matrix with the following properties:Had(x) = x.G holds for all  $x \in \{0,1\}^k$ , The message x is considered as a row vector, and the vector-matrix product is interpreted within the vector space over the finite field  $F_2$ . Specifically, the inner product definition for the Hadamard code can be expressed equivalently by employing the generator matrix, wherein each column comprises a string y of lenth k, that is,

$$G = \begin{pmatrix} \uparrow & \uparrow & \uparrow \\ y_1 & y_2 & \dots & y_{2^k} \\ \downarrow & \downarrow & \downarrow \end{pmatrix}$$
..... Equation (32)

Where  $y_i \in \{0,1\}^k$  is the  $i_{th}$  vector of binary data in lexicographical order. As an illustration, consider the generator matrix of the Hadamard code of dimension k = 3 is:

$$G = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \end{bmatrix}$$
..... Equation (33)

The matrix G is a  $(k \times 2^k)$  The matrix in question generates the linear operator Had:  $\{0,1\}^k \rightarrow \{0,1\}^{2^k}$ . The generating matrix of the augmented Hadamard code is derived by selecting only the columns of matrix G that have an initial entry of one. As an illustration, the generator matrix for the augmented Hadamard code of a specific dimension is k = 3 is:

$$G' = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 \end{bmatrix}$$
..... Equation (34)

Then pHad:  $\{0,1\}^k \to \{0,1\}^{2^{k-1}}$  is a linear mapping with pHad $(x) = x \cdot G'$ .

Regarding a broad or overall context k, The generator matrix of the augmented Hadamard code serves as a parity-check matrix for the extended Hamming code with a specific length.  $2^{k-1}$  and dimension  $2^{k-1} - k$ , Consequently, the dual code of the extended Hamming code is the augmented Hadamard code. Therefore, the Hadamard code can also be defined with respect to its parity-check matrix. The generator matrix of the Hamming code is equivalent to the parity-check matrix of the Hadamard code.

### 2.19.3. Construction using general Hadamard matrices

A Hadamard matrix H with dimensions n-by-n is used as the foundation for Hadamard codes. More precisely, the 2n codewords of the code can be matched with both the rows and the negated rows of matrix H. The matrix elements undergo a transformation by applying the mapping  $-1 \mapsto 1$ ,  $1 \mapsto 0$ , or, equivalently,  $x \mapsto (1 - x)/2$ , to generate a code using the alphabet  $\{0,1\}$ . The defining property of Hadamard matrices, which specifies that their rows are mutually orthogonal, implies that the minimum distance of the code is equal to half of the matrix size (n/2). This implies that two distinct rows of a Hadamard matrix exhibit precisely n/2 distinct positions. Furthermore, it is worth noting that negating a row of matrix H does not affect its orthogonality. As a result, any row of H differs from any row of -H in exactly n/2points, unless the rows correspond, in which case they vary in all n positions. To obtain the expanded Hadamard code mentioned above  $n = 2^{k-1}$ , The selected Hadamard matrix H must be of Sylvester type, resulting in a message length of  $\log_2(2n) = k$ .

# 2.20. MDS

When there is relative motion between the source and receiver, the frequency of the received signal deviates from the frequency of the source signal. As the source signal and receiving signal converge, the frequency of the source signal is lower than that of the receiving signal. The phenomenon is referred to as a Doppler shift (DS). This impact is crucial for the advancement of mobile radio systems. DS states that both the velocity of the propagation wave and the relative motion between the source and the receiver have an impact on the rate at which the frequency changes. The following illustrates the distribution of the DS in terms of frequency (Al-Thahab, 2006).

$$f_d = f_c * \frac{v}{c}$$
 ..... Equation (35)

The symbol fc represents the frequency of the carrier, while v represents the speed of the source. The symbol c represents the speed of light.

 $f_d$  is (6Hz denoted as mobility of 2km/hr speed. 60Hz to 20 km/hr speed. and 180Hz to 80 km/hr speed.). For used models of LTE channels Path Loss. A DS of 5 Hz This simulation is used in accordance with the walking speed.

# CHAPTER THREE

# LTE PROPOSED SYSTEM

# 3.1. Introduction

This chapter will first focus on designing the LTE system and explaining the Discrete Cosine Transform (DCT) with conventional channel modulation (QPSK). Secondly, it will introduce a proposed Walsh-Hadamard code that used to encode the binary data input to LTE system. The simulation results of both systems will be analyzed and compared for three different values of MDS frequencies (6, 60, and 180 Hz). Each simulation utilized a subcarrier of (1024) and accommodated four users. Two multi-antenna (2x2) and communication channel models (AWGN and Rayleigh) have been integrated(Reyam Thair & Osama Althahab, 2024).

# 3.2. The Proposed LTE System

There are three different ways to implement the proposed system. The first method utilized the (IFFT) with the Quadrature phase shift key (QPSK) as a mapper constellation, as depicted in Figure (25). The second method employed the Inverse Discrete Cosine Transform (IDCT) instead of IFFT-OFDM, using QPSK, as shown in Figure (26). The third method, illustrated in Figure (27), utilized the Inverse Discrete Cosine Transform (IDCT) with the Walsh-Hadamard code based on QPSK Mapper, QPSK.



Figure 25. The proposed IFFT system with QPSK Mapper



Figure 26. The Proposed IDCT system



Figure 27. The proposed IDCT system block diagram with W-H code

In a traditional LTE system, The OFDM system utilize 1024 subcarriers, and the input data consists of 144 elements distributed across 10 frames. Randomly produce these input data. The QPSK mapping converts two bits binary data into a constellation. The modulation process transforms intricate symbols Converting from a sequential format to a concurrent format. Afterwards, the data is allocated to the subcarriers via either localized or interleaved subcarrier mapping. Next, a rapid inverse The Fourier transform is utilized for translate the mapped symbols into the time domain. Adding the final portion of the data to the beginning, known as the (CP), helps to mitigate (ISI). The system transforms the data back into serial format and then sends it across the channel.

Upon receiving the signal from the channel in the receiving section, the aforesaid operations are reversed, incorporating frequency domain equalization.

This study utilizes a Walsh-Hadamard code to encode the input binary data by anew way since the code insider an orthogonal one, so it will be help in forcing the confusing between the data input and the ISI mitigating. The modified data may display specific characteristics that are advantageous in specific channel situations, leading to improved signal reception and restoration. So, in the result the signal is enhanced in its quality and a decreased (BER) can be accomplished.

#### 3.3. The Proposed W-H Code

Our proposal involves including the W-H code in the LTE system on the transmitter side and W-H decoder on the receiver side. The system hopes to improved spectral efficiency and less interference. By utilizing the 1D-IFFT with the abilities of W-H code based on QPSK, it is found that the orthogonality is enhanced among the sub-carriers. The purpose of increasing the bits-per-hertz by increasing the bandwidth, since it removes the CP, which intern reduce No of transmitted Bits.

The proposed system, particularly reduce the effect of multiple distinct fading channels. The new LTE structure has reduced sensitivity compared to the classic LTE structure when it comes to fluctuations in maximum delay, path gain, and maximum Doppler shift (MDS) in selective fading channels.

#### **3.4. The OFDM Block**



Figure 28. The OFDMA system block diagram.

In a standard (OFDM) system, as depicted in Figure (28), the input data consists of 1024 subcarriers and is divided into 10 frames. People commonly use a cyclic prefix (CP) to lessen the impact of multipath propagation. This is achieved by including a guard interval (GI) that enables the receiver to disregard delayed replicas of the signal resulting from multipath echoes. It replicates the rear part of the OFDM signal and places it at the beginning of the symbol. Carrier phase modulation (CP) not only mitigates (ISI) but also enhances spectral efficiency by lowering the duration of guard gaps between symbols. Additionally, it streamlines the process of equalization at the receiver's end by transforming frequency-selective fading into a consistent and unchanging fading effect across time. We select the length of CP to exceed the expected maximum delay across the channel.

### 3.4.1. The Proposed W-H-DCT-LTE System

In the proposed system as seen in Figure (27), four user-equipment (UE) are used, the subcarriers size is used is 1024 with 10 frames.

### **3.4.2.** The LTE Transmitter

The ten processes that make up the LTE transmission portion, as depicted in Figure (27), will be discussed together with how they were implemented in the MATLAB program. Additionally, an example that serves as the foundation for all operations will be provided.

# 3.4.3. Input data (I/P)

Typically, to assess the effectiveness of a communication system, it is imperative to transmit a specific type of data and then analyze the system's reception capabilities. Random numbers are generated using a uniform distribution, with the added requirement that the number must be 2880. This can be accomplished, as demonstrated in equation (36).

# $x_3 = \text{randsrc} (288, 1, [0\ 1]) \dots (36)$

The produced random data constitutes a column vector of dimensions 144-by-1, comprising uniformly distributed samples from the interval [0, 1], as outlined in equation (37 and 38).

input data = 
$$\begin{bmatrix} bit_1 \\ \vdots \\ bit_{288} \end{bmatrix}_{288 \times 1}$$
 ..... Equation (37)

input data = 
$$\begin{bmatrix} 0\\1\\0\\1\\\vdots\\288\times 1 \end{bmatrix}_{288\times 1}$$
..... Equation (38)

### 3.4.4. Encoder

The encoder is an essential component of any system as it is responsible for preparing data for transmission. The primary purpose of the encoder is to convert incoming data into a format that is appropriate for modulation and subsequent transmission through the LTE system. In the proposed system, Turbo codes are utilized. The encoder adds redundancy to facilitate error correction. The introduced additional components serve the goal of error protection and correction, hence improving the system's resilience against channel impairments. The data input will consist of a column vector with dimensions of 2880- by 1, as indicated in equation (39).

Input data = 
$$\begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 1 \\ \vdots \end{bmatrix}_{2880 \times 1}$$
 ..... Equation (39)

#### **3.4.5.** W-H Coder

The proposed system used a code generated from Hadamard and Walsh code as follows:



As you know the Walsh and Hadamard code are sequence codes with ahigh orthogonality properties, so introducing a new code from them is a good idea. The generated code will then (XOR) with the I/P data (binary data that generated earlier), then the resulted one will enter to the rest of LTE stages.

Coded data = 
$$\begin{bmatrix} 0\\0\\0\\1\\0\\,\end{bmatrix}_{2880\times 1}$$

This study, which dealt with the subject of Hadamard-Walsh code, is considered the first and unique study around the world, as no researcher has previously dealt with the code that was adopted in this thesis.

### 3.4.6. S/P

The matrix reshaping function is utilized to do this procedure. The reshaping operation commences by manipulating the columns of the array, enabling the transformation of its structure while preserving the constituent elements.

### 3.4.7. QPSK Mapper

00	0.707+j0.707
01	0.707-j0.707
10	-0.707+j0.707
11	-0.707-j0.707

Here every two bites are mapped by the QPSK algorithm as depicted in table (3) **Table 3.** QPSK Algorithm

After the mapping process a zero padding is added to reduce the impact of (ISI).

#### 3.4.8. Pilot Symbols

The inclusion of 25 pilot symbols in an OFDM system with 1024 subcarriers is crucial for accurate channel estimation and correction. The deliberate selection of 25 pilot symbols from the entire set of subcarriers is a tactical decision made to guarantee extensive coverage across the frequency band. The main objective of these pilot symbols is to function as a frame of comparison for the receiver to assess the parameters of the channel. Through the analysis of the pilot symbols received, the system is able to evaluate fluctuations in the channel's response, encompassing both phase shifts and variations in magnitude. Subsequently, this data is used to modify and standardize the communicated data symbols, offsetting the impact of the communication route.

The arrangement of the 25 pilot symbols guarantees a precise channel estimate over the extensive bandwidth of 1024 subcarriers. The receiver can successfully mitigate channel defects, such as frequency-selective fading and multipath propagation, using this thorough estimation. Equation (40) displays the quantity of pilot symbols utilized.

$$pilot\_added = \begin{bmatrix} 1\\1\\1\\1\\1\\\vdots\\25 \times 1 \end{bmatrix}_{25 \times 1}$$
..... Equation (40)

### 3.4.9. 1D IDCT

The signal is partitioned into segments of size N. The IDCT is applied separately to each block of the signal. The IDCT coefficients are computed using the formula specified in equation (4) in chapter two.

In order to achieve compression, the IDCT coefficients undergo quantization, which involves setting some of the less significant coefficients to zero or representing them with fewer bits. This stage enables the signal to be encoded more efficiently. The results of the Inverse Discrete Cosine Transform (IDCT) can be observed in equation (42).

#### 3.4.10. P/S

The process of parallel-to-serial conversion entails organizing the modulated symbols from each subcarrier into a sequential format for transmission. It is a critical procedure that enables efficient use of the frequency spectrum and provides resilience against channel impairments, making it a widely preferred option for high-speed data transfer in various wireless communication technologies. This crucial process enables more efficient utilization of the frequency spectrum and provides resilience against channel impairments, which is why numerous wireless communication standards priorities it for high-speed data transmission.

#### 3.4.11. 2x2 Multiple Input-Multiple Output

We use a 2x2 MIMO system with (STBC) to improve the reliability and diversity of wireless communication systems. (STBC) is highly efficient in scenarios involving a significant number of transmitting and receiving antennas. A 2x2 (MIMO STBC) system utilizes two transmit antennas and two reception antennas. The incoming data stream is partitioned into symbol pairs, as seen in equations (43) and (44). These symbol pairs are encoded using space-time block coding to create numerous transmit symbols. The symbols are thereafter sent concurrently from the two antennas. The signals that are sent experience channel phenomena such as fading, reflections, and interference.

The signals received by the two antennas at the receiver are individually analyzed, and the received symbols are demodulated for each antenna individually. The signals received undergo space-time decoding, which is a process designed to retrieve the original symbols that were broadcast. Space-time block coding (STBC) achieves diversity gain by leveraging the spatial dimension of the many antennas. Upon decoding, the receiver has two distinct sequences of symbols that correspond to the original data that was transmitted.

It is crucial to acknowledge that although (STBC) offers diversity gain, it does not directly double the data rate as easily as certain other (MIMO) approaches. The extent of performance enhancement is dependent on variables such as the specific STBC scheme used, the prevailing channel conditions, and the presence of interference. The result of (STBC) is represented by equation (43).

$$STBS = \begin{bmatrix} -0.088 - 0.016i & 1.561 - 0.570i & \dots & \dots & -0.391 - 1.167i & -0.284 + 0.080i \\ \vdots & \vdots & \vdots & \dots & \vdots & \vdots \\ 0.711 - 0.679i & 1.125 + 0.309i & \dots & \dots & -0.346 - 0.101i & 0.1629 - 0.105i \end{bmatrix}_{1024*10*2}$$

$$\dots \dots \dots \text{Equation (43)}$$

$$St1 = \begin{bmatrix} 0.0000 & 0.0000 & \dots & \dots & 0.0000 & 0.0000 \\ \vdots & \vdots & \dots & \vdots & \vdots \\ 3.384 + 1.615i & -4.230 + 0.230i & \dots & \dots & 0.923 - 2.923i & -1.615 + 0.615i \\ \vdots & \vdots & \dots & \dots & \vdots & \vdots & 1_{1024*10} \\ \dots & \dots & \dots & \dots & \vdots & \dots & \dots \end{bmatrix}_{1024*10}$$

# 3.5. Channel Modelling

We broadcast the data across two channels to assess the system's performance under varying transmission conditions. The first stage involves adding white Gaussian noise to the data using a Gaussian channel(Reyam Thair & Osama Althahab, 2024).

The second channel has three taps and is a Rayleigh-fading channel. The specifications of this channel in the simulation are provided in Table (4) using the MATLAB function step (Rayleigh Chan (1/bitrate, MDS)). The data is generated randomly and is in the form of a 1024×1 row matrix when it reaches the channel after the previous step. Upon traversing the channel, the resultant signal will retain its original dimensions, measuring 1024×1.

Channels Model	MDS	Path Gains			
	6Hz	-0.1623 + 0.8654i			
Flat Fading	60Hz	1.0234 - 0.1735i			
Channel	180Hz	-0.9409 - 0.4535i			
	6Hz	[-0.3751 + 0.5520i -0.8815 - 0.0019i]			
Selective Fading	60Hz	[-0.2422 - 0.4835i -0.3180 - 0.8963i]			
Channel	180Hz	[-0.6320 + 0.5515i 0.2813 + 0.6892i]			

#### Table 4. Rayleigh Channel

# **3.6.** The LTE Receiver Section

As shown in Figure (27), the receiver section in LTE includes several operations. These receiver operations include terminating an example initiated by the transmitter.

# **3.6.1.** Discrete Cosine Transform (DCT)

The compressed coefficients are subjected to the inverse Discrete Cosine Transform (IDCT) in order to derive an approximation of the original signal. Quantization results in the loss of certain information, despite the fact that the reconstruction procedure is designed to minimize perceived discrepancies.

The resulting signal is a vector of 1024 elements, representing the initial block of the first iteration. Executing the DCT function within the same loop produces an output vector of 1024 symbols with the same length. Equation (46) displays the result of the Discrete Cosine Transform (DCT).

#### **3.6.2.** Channel Equalizer and Estimation

Channel equalization and estimation collaborate to guarantee resilient and dependable communication in the face of demanding channel circumstances. Equalization is the process of modifying the received signal to reduce distortions, whereas channel estimation involves obtaining the properties of essential information of the channel to enable efficient equalization. Collectively, these procedures are essential for attaining optimal performance in communication systems.

The pilot-aided method is utilized for channel estimation in the suggested system. The process includes the injection of predetermined pilot symbols, their retrieval at the receiver, and the use of this data to estimate and correct for distortions in the channel, guaranteeing precise recovery of data symbols even when the channel conditions change. The Rayleigh channel transmitted the pilot signal as an unprocessed series of ones (1), encountering the combined influence of Rayleigh fading and (AWGN). As a result, these circumstances cause the value of the pilot signal to fluctuate during the data transfer. Equation (47) displays the matrix that represents channel estimation.

# 3.6.3. QPSK decoder

In this process a QPSK mapper is applied to the received data but here in inverse way, so that, the received data are decoded to a binary number from the decimal numbers as the decoded words depicted in Table (3).

### 3.6.4. W\_H Decoder

Here in this step, the Walsh – Hadamard code word that that generated at the transmitters are XORed again with the received binary data to return them to original one. The main gain from that process is the number of bits that received in error way will decrease because the orthogonality of using code which can face the channel effect and noise.

### 3.6.5. Decoder

The decoder, the last component, retrieves the original data from the received signals by undoing the encoding process performed at the transmitter. The objective of the decoder is to precisely restore the transmitted data, even when there is noise and impairment in the channel. This is achieved through demodulation, channel decoding, and other processing stages. The data that has been deciphered is displayed in equation (48).

Then XOR the decoded data with the generated code to get the input data:

Input data = 
$$\begin{bmatrix} 0\\1\\0\\1\\\vdots\\2880\times 1 \end{bmatrix}_{2880\times 1}$$

After the decoding signal obtained the BER equation is apply as seen in equation (49).

This equation calculates the quantity of bit errors occurring between the decoded binary data and the original binary data. (u) represent the number of users.



# **CHAPTER FOUR**

# **RESULTS AND DISCUSSIONS**

### 4.1. Introduction

In this chapter, the general LTE system based on FFT is explained by using the pilot aided as channel estimation and compare it with the proposed LTE system based on DCT in the same channel estimations and using Walsh-Hadamard code based on QPSK Mapper.

Each simulation employed different MDS values (6, 60, 180) HZ. Three models of the communication channel have been simulated (AWGN, Rayleigh: Flat and Selective fading channel).

The proposed architecture can optimize the LTE system's efficacy under diverse channel conditions for high data rates and low BER. Each and every LTE-system Model is employed in MATLAB 2016a. These parameters of LTE system the data is presented in Table (5).

Parameter	Value
subcarriers size	1024
Modulations Types	QPSK
BW (MHz)	20 MHz
No. Users	4
Channel	AWGN, Rayleigh channels
Prefix Ratio for FFT system	1/4
No. Pilot	25
No. TX and Rx MIMO	2x2
No. Frame	10

 Table 5. System Characteristic

# 4.2. Performance of the Proposed LTE System in AWGN

In wireless environments, where communication signals experience varying degrees of noise, optimizing LTE systems is the paramount for sustaining reliable and

high-quality connections. This section presents the (BER) performance results of the (LTE) technology. the AWGN channel as a transmission channel are shown.

Figure (30) represent the comparative between the results. These figures encapsulate the BER performance under different scenarios, shedding light on the efficacy of each modulation technique in the presence of AWGN. The findings indicate that the proposed system has a lower BER than the implemented alternative methods.

Finally, to provide a comprehensive view, the proposed system analysis extends to two distinct cases involving 1024 subcarriers. The presence of diverse elements enables us to examine the capacity for growth and flexibility of the suggested system when faced with different amounts of data.



Figure 30. LTE systems with AWGN with 1024 subcarrier

The provided section compares the proposed LTE system algorithm with pilotbased channel estimation methods in a perfect case scenario. In this scenario the channel is AWGN, and the pilot length is 25. The comparison is based on the performance of different algorithms at various SNR.

It is observable Figure (30), for BER= $10^{-4}$  the SNR required for 1024 QPSK-FFT-LTE is about 23 dB and for DCT-LTE The Signal-to-Noise Ratio is about 14 dB, and for W-H-DCT-LER the SNR is about 12.8 dB. Therefore, the difference between DCT based LTE against W-H-DCT-LTE is 1.2 dB.

# 4.3. LTE Performance in Flat Fading Channel

In the proposed LTE system, an extensive study is conducted, considering both the AWGN model and the flat fading channel. The comparative analyses are depicted in Figures (31-33), extend to the use of DCT and its comparison with W-H-DCT mapping.

The system makes use of several antennas in transmitters to increase the system's effectiveness and spectral performance. This is carried out using several MDS frequencies, including 6, 60, and 180 Hz. Here, QPSK modulation schemes are employed to further diversify the evaluation. Table (6) shows the Flat Fading Channel parameters.

Flat Fading Channel						
MDS  (HZ) Channel parameters (Path gain						
6	0.5536+0.8112i					
60	-0.2764+0.4454i					
180	-0.3164+0.434i					

Table	6.	Flat	Fading	Channel
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**Figure 31.** The proposed LTE system with 1024 based on MDS=6Hz over flat fading channel.



**Figure 32.** The proposed LTE system with 1024 based on MDS=60Hz over flat fading channel.



Figure 33. The proposed LTE system with 1024 based on MDS=180Hz over flat fading channel

For instance, Figure (31) shows the (SNR) at (BER)  $10^{-4}$  for both the proposed system and DCT-LTE is 12.5 dB and 14.5 dB respectively, and there is a gain of 2 dB for the W-H-DCT-LTE against DCT-LTE and more than that gain for the other systems.

Table (7) presents a comparison, revealing that the W-H-DCT based LTE model outperforms FFT-LTE, DCT-LTE, in terms of performance. This superiority can be attributed to the strong orthogonality of the (W-H) codes and the exceptional orthogonality of DCT.

	AWGN 1024 bit	Flat Fading			
System name		MDS			
		6HZ	60HZ	180 HZ	
FFT-LTE	23	23.5	25	26.5	
DCT-LTE	14	14.5	18	20	
W-H-DCT-LTE	12.8	12.5	16.5	18	

**Table 7.** SNR values of  $10^{-4}$  BER\ for flat fading & AWGN channel based on 1024 bit with different DS values with QPSK

# 4.4. LTE Proposed System Performance via Selective Fading Channel

This particular portion employs the selective fading channel as the channel model for the proposed system. We will conduct the analysis under the same conditions as shown in Figures (34–36). Specifically, the specification of the channel is depicted in Table (8). In order to assess the effectiveness of the suggested system, tests are conducted over a Selective fading channel with MDS of 6 Hz, 60 Hz, and 180 Hz. The tests are performed using 1024 subcarriers. Here, it is also taking in to account the CP is removed from the main block of LTE system which intern gain a B.W.

	Selective Fading Channel									
MDS (HZ)	Path Delay	Average Path Period		Channel Parameter (Path gain)						
6	$0, 3.33 + 10^{-9}$	0, -8	4.166+10 <sup>-10</sup>	0.536-0.515i,0.0834-0.246i						
60	$0, 3.33 + 10^{-9}$	0, -8	4.166+10 <sup>-10</sup>	0.2082-0.5525i,0.186-0.335i						
180	$0, 3.33 + 10^{-9}$	0, -8	$4.166 + 10^{-10}$	0.0878+0.244i,0.299+0.4177i						

 Table 8. Selective Fading Channel



Figure 34. The LTE system with 1024 based on MDS=6Hz



Figure 35. The LTE system with 1024 based on MDS=60Hz



Figure 36. LTE system with 1024 based on MDS=180Hz

The results showcasing a better BER performance in an LTE system when using DCT in conjunction with Walsh-Hadamard code based on QPSK mapper compared to use an FFT with QPSK modulation, because the Walsh-Hadamard code itself is not inherently affected by changes in channel parameters.

From Figure (34), it can be shown that, for BER= $10^{-4}$  the SNR required for FFT-LTE is about 24.5 dB, while in W-H-DCT based on LTE the (SNR) is about 15 dB and for DCT-LTE the (SNR) is about 16 dB, Therefore, a gain of 1 dB for the Walsh-Hadamard code based on QPSK based LTE against DCT-LTE is more than the gain for the other systems. As shown in Figure (34), it is discovered that the suggested system gives performance Superior to the alternative systems for this channel model.

Furthermore, it can be shown from the results that when using 6 MDS in 1024 subcarrier, it will give better performance than MDS (60 and 180) as shown in Table

(9) because the effect of moving is very small (the device transmitter is moving slowly (walk)) While a smaller MDS value can potentially result in enhanced efficiency in LTE systems in Regarding spectral efficiency and frequency reuse.

	Selective Fading 1024 bit					
Svstem name	MDS					
	6HZ	60HZ	180 HZ			
FFT-LTE	24.5	25	27			
DCT-LTE	16	22	23			
W-H -DCT-LTE	15	18.5	21.5			

**Table 9.** System SNR achieving BER of  $10^{-4}$  across selective channel based on 1024 bit with different DS and QPSK

### 4.5. Discussion

The results of the LTE proposed system are shown in in Figures (30), (31,32,33) and Figures (34,35,36) are discusses in Tables (8,9), which provide BER-Enhancement of LTE proposed system in selective-channel over the three Doppler frequencies (MDS=6, 60, 180).

It's found that the LTE proposed system which uses the DCT with W-H code is superior to the three other systems that use the FFT and the FFT with W-H and DCT. It is also more important, in spite of removing the CP. As a result, the BER is significantly reduced when using the proposed system, leading to better overall system performance. Furthermore, the Walsh-Hadamard code also enables efficient utilization of available resources in LTE systems. By mapping the LTE signals onto different frequency components using this transform, it allows for better allocation and management of resources such as bandwidth and power. This leads to improved spectral efficiency and increased the B.W in LTE networks by removing the CP.

Numerous simulations and experiments have validated the effectiveness of DCT-W-H implementation in LTE systems. The tables illustrate the sensitivity of LTE

systems to Doppler frequency variations in selective fading channels. Table (10) shows the SNR value of  $10^{-4}$ BER\ for different channels with different DS and QPSK.

	Fla	t Fading 102	24 bit	Selective Fading 1024 bit			
System name	Max	. Doppler Sh	ift (Hz)	Max. Doppler Shift (Hz)			
	6	60	180	6	60	180	
FFT-LTE	23.5	25	26.5	24.5	25	27	
DCT-LTE	14.5	18	20	16	22	23	
W-H-DCT-LTE	12.5	16.5	18	15	18.5	21.5	

**Table 10.** SNR value of  $10^{-4}$ BER\ for different channels with different DS and QPSK

# 4.6. Comparison With Related Works

Many works are employed to lower the BER value of the LTE system. These works are carried out using different types of modulation, transmission channels, and subcarrier mapping methods, Furthermore, there is a consideration of the user count.

To show how the proposed system is different from what has been done before, an evaluation of the suggested system and the previous works is shown in Table (11). The comparison considered various factors, including the user count, The category of modulation, channel model, and channel estimation.

Ref.	Mappi ng	Modulat ion type	No. of Use rs	Chann el	Mult i- carri er size	Estimat ion	SNR 1024	BER 1024
(Qingch uan Zhang et al., 2013)	QAM	DFT	1	Raylei gh channe l	1024	MSE	24 dB	6x 10 <sup>-4</sup>
(Riyazud din & Sharma, 2016)	PSK, QPSK	FFT		Multip ath channe l	1024	Ideal	26.5 dB	10 <sup>-4</sup>
(Abdul- Rahaim, 2015b)	64 QPSK	DWT		AWGN and Raylei gh	256, 512, 1024 , 2048	pilot channel estimati on	21.4 dB	10 <sup>-4</sup>
(Nagarju na et al., 2020)	QPSK	DWT	4	AWGN and Raylei gh	1024	FFNN	21 dB	10 <sup>-4</sup>
Propose d System	QPSK, W-H	DCT	4	AWG N and Raylei gh	1024	pilot channel estimati on	15 dB W-H 5MD S selecti ve	<b>10</b> <sup>-4</sup>

Table 11. comparison of the proposed system and the previous works

# **CONCLUSIONS AND RECOMMENDATIONS**

The conclusions that can be drawn from the outcomes of testing various scenarios are listed below.

- The LTE method uses Walsh-Hadamard code used the same as modulation schemes like QPSK, in addition of it doesn't needing acyclic prefix (CP).
- The W-H demonstrated resilience to channel impairments and displaying a significant resistance to noise and interference.
- The results indicate that the Doppler frequency significantly affects the (BER) performance in LTE systems. As the frequency of the Doppler effect increases, the (BER) worsens. This is because higher Doppler frequencies lead to more rapid fluctuations in the channel, resulting in faster fading and making it more challenging for the receiver to accurately interpret the broadcast signals.
- Utilizing the DCT in an LTE system with Walsh-Hadamard (W-H) provides superior BER performance compared to using the FFT and DCT. The DCT-W-H system surpasses the standard LTE system in terms of signal quality, interference rejection, spectrum efficiency, and overall system performance. This system works with (QPSK) in a flat fading channel and has a (SNR) of 12.8 dB and a (BER) of 10<sup>-4</sup>. In contrast, FFT-LTE achieves an SNR of 23 dB at the same channel.
- The proposed system, which employs 1024 subcarriers, has excellent performance in low (SNR) scenarios. We reach this conclusion when confronted with difficult situations characterized by a low signal-to-noise ratio (SNR).
- The limitation of the proposed system perhaps the effect of Peak to Average Power Ratio (PAPR), since exceeding this factor may cut the input information and cause another error.

Several proposed ideas could help to create a more robust LTE system:

- Instead of just looking at the basic turbo code in these simulations, it would be helpful for future research to look into more complex coding schemes like Reed-Solomon, LDPC, or polar codes to get more reliable results and better performance.
- ✤ Using a deep learning (DL) method as an alternative to pilot-aided channel estimation.
- Consider utilizing a different channel, for example, using the Rician channel instead of the Rayleigh channel, to evaluate the system.
The use of Multi-Wavelet Algorithm instead of DCT may improve the BER performance, since it has an excellent behavior in modulating and analyzing signals.



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## RESUME

### **Personal Information**

Surname, name	: Sura Saadi Mohammed ABUHAMEEI	)
Nationality	: Iraqi	
Education		
Degree	Education Unit	Graduation Date
Master		
Bachelor	Babylon University/Electrical Engineering/college of Engineering	2007
High School	Alzarqaa High School	2002
Work Experience		
Year	Place	Title
16	Babylon Governorate Office	Assistant Chief Engineer
Foreign Language		

Arabic & English

# Publications

### Hobbies

My hobbies are travelling, reading and watching TV

