Studies on Evaluation of Error Correction Coding Methodologies on 5G Wireless Communication

5G 無線通信における誤り訂正符号化方式の評価に関する研究

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Abstract

In fifth generation wireless network, it becomes the critical challenge to offer high-bit rate data transmission and extensive networking services with low bit error rate (BER) performance. To achieve the requirements of 5G services, Orthogonal Frequency Division Multiplexing (OFDM) is a considerable technique for high quality communications. In addition, many channel coding schemes have been applied for mitigating performance degradation in terms of BER. Among them, LDPC and Turbo coding methods become the standard specification for high-bit rate data transmission in 5G network. There are so many difficulties and challenges how to apply this coding methods in OFDM with 5G standard specifications.

In fifth generation wireless communications, data transmission is challenging due to the occurrence of burst errors and packet losses that are caused by multipath fading in multipath transmissions. To acquire more efficient and reliable data transmissions and to mitigate transmission medium degradation in 5G networks, it is important to study the error patterns or burst error sequences that can provide insights into the behavior of 5G wireless data transmissions.

In this study, we conducted the study on channel coding methods and error modeling in 5G environment. We proposed two states Markov based generative error model for improving performance of 5G simulation by saving execution time and cause effectively. In our proposed system, we can divide two parts, coded OFDM 5G simulation frame work and two states Markov based generative error model. In first part of this research, we proposed coded OFDM 5G simulation frame work by implementing two 5g standard coding methods in 5GTF specification. Then, we conduct the analysis on two standard channel coding methods in multipath fading environment of 5G network. In this research, we consider LDPC and turbo code as a backward compatibility of LTE, 4G and 3G according to 5G specifications of Verizon 5G Technology Forum released test plan. This proposed simulation frame work provides two reference error sequences for error generation process. For experiment and evaluation, three modulation methods are implemented including, including QPSK, 16QAM and 64QAM.Moreover, we do the analysis the abilities of coded OFDM 5G simulation over different sizes. According to our experimental results, we found that our coded OFDM in 5G network outperforms uncoded OFDM in 5G network. Moreover, Turbo coded OFDM with 5G specification achieve better performance with smaller BER than the LDPC coded Multipath OFDM in 5G network. Finally, we approve that the coded OFDM simulation have better results in both coding methods by comparing standard Monte Carlo and theatrical simulations results.

That finding motivates to select Turbo codes as 5G channel coding resulting in cost savings because of backward compatibility to 3G and 4G.

In second part of this research, we proposed a two-state Markov-based 5G error generative model for modeling the different statistical characteristics of the underlying error process in the 5G network. The underlying 5G reference error sequences are obtained from our 5G wireless simulation. The binary error sequences are generated by referencing two reference error sequences and using two-state Markov model. For estimating the error model, the Baum-Welch algorithm is used. Then the error probability and run-length distribution, error gap and error burst, of the generated error sequences are compared with original error sequence. By comparing the burst or gap error statistics of the reference error sequences from the 5G wireless simulations and those of the generated error sequences from the two-state Markov error model, we show that the error behaviors of coded OFDM 5G simulations can be adequately modeled by using the two-state Markov error model. Finally, we can approve that proposed two-state Markov-based generative error model have the accurate estimated channel model and generate exact error sequences that is mostly symmetric with original sequences by comparing theoretical Gilbert Elliot model. Our proposed two-state Markov-based generative error model can help to provide a more thorough understanding of the error process in 5G wireless communications and to evaluate the error control strategies with less computational complexity and shorter simulation times.

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CHAPTER 1

INTRODUCTION

For new era of wireless communications technology, fifth generation (5G) has evolved for filling the requirements of foregoing wireless network technologies and providing satisfactions of new mobile users. Providing very high data rates (typically of Gbps order) and extremely low latency is significant characteristic of 5G technology. By comparing the existing generation technologies, the facilities of 5^{th} generation technologies can offer best quality services to the end users in terms of latency, bit error rate, data transmission rate, capacity, energy consumption, coverage and cost. Fifth generation technology is necessary to enhance in the area of other important factors, such as signaling efficiencies, bandwidth, cost per bit, energy and spectral and so on. For back ward compatibility, 5G need to take responsibility of challenges of foregoing generation technologies, such as fourth generation (4G).

In fifth generation wireless network, it becomes the critical challenge to offer high-bit rate data transmission and extensive networking services with low bit error rate (BER) performance. To achieve the requirements of 5G services, Orthogonal Frequency Division Multiplexing (OFDM) is a considerable technique for high quality communications. OFDM is able to mitigate the detrimental effects of multipath fading by partitioning a wideband fading channel into flat narrowband channels. Large peak to average power ratio (PAPR) is still unrecoverable weak point of OFDM systems.

As long as emerging of new applications of fifth generation wireless technology as well as Device to Device (D2D) communications, Machine to Machine (M2M), Internet of Things (IoT), Internet of Vehicles (IoV) and so on, achieving efficient and reliable high-bit rate data transmission and mitigating performance degradation becomes a critical challenge in 5G networks. These problems are evaluated in terms of error. Between the transmitter and receiver, information losses may be occurred because of some of causes, such as attenuation, intersymbol interference (ISI), Doppler shift, multipath fading, Internal processing of symbols and so on.

Therefore, researchers have been finding the optimal solution for the above mentioned problems. Firstly, error control scheme is considered as a vital part of modern digital wireless systems, enabling reliable transmission to be achieved over noisy channels. An also a combination of high rate data transmission with forward error correction techniques becomes a critical solution for future wireless environment.

Since foregoing generation technologies, mitigating performance degradation has been challenged and finding the solution has been a major research area for this challenges. Owning to this, channel coding methodologies becomes a major solution and has been explored. For evaluatingthe performance of channel coding schemes are performed in terms of block error rate (BLER) or bit error rate (BER). Some technical organization, such as 3GPP and 5GTF, proposed candidate methods for5G data transmission.Polar code was defined as 5G standard from 3GPP and Turbo, low density parity check-code (LDPC), are standard schemes of V5GTF. For evaluating the performance of these candidate schemes, code rates and block lengths are measuring parameters.

According to logical thinking, it is a better way to understand the facts of causes or to understand the sources or the causes. In order to achieve efficient and reliable data transmissions and mitigate performance degradation, it is very important to study these errors from different perspectives. By studying the sources of causing errors, we can gain the knowledge of error patterns in terms of burst error sequences and the statistical properties of these errors in terms of numbers and distributions that can provide insights into the behavior of 5G wireless data transmissions. Modeling the error process is one of the best ways to find the optimal data transmission in future wireless technology by saving cost and time effectively.

1.1 Evolution of Wireless Technologies

In wireless generation technologies, the trends of generation technologies have been evolved from the first generation (1G) to the fourth generation (4G) by enhancing new advanced services.

In 19890, first generation emerged which include Analog System, obviously smart phonetechnologies have been developing by adding text messaging services. It uses analog radio signal which have frequency 150 MHz, voice call modulation is done using a technique called Frequency-Division Multiple Access (FDMA).

2G emerged in late 1980s. In 2G era, voice message has been innovated as services of digital signals with 64 kbps.Short Message Service was also popular new services of 2G which use the bandwidth of 30 to 200 KHz. Beyond 2Gpacketsswitching and circuit switching technologies has been evolved as a significant mark of 2.5G with 144 kbps data rate. E.g. GPRS, CDMA and EDGE.

The third generation (3G) added mobile internet services to 2G. Wide Band technologies have been evolved with increasing clarity. This way of data sending technology is called PacketSwitching. By using circuit switching technology, voice calls are interpreted. Voice call services and data services, both are included for accessing to television/video which is called new services like Global Roaming. These services are operating with 2100MHz and 15-20MHz bandwidth for High-speed data service, video processing. Wide Band Voice Channel isimplementing in 3G.

Currently 4G offers high capacity mobile multimedia service at 1 Gbps data rate when stationary and 100 Mbps rate when mobile, making it 250 times better than the 3G services. LTE (Long Term Evolution) is considered as 4G technology. 4G is being developed to accommodate the QoS and rate requirements set by forthcoming applications like wireless broadband access, Multimedia Messaging Service (MMS), video chat, mobile TV, HDTV content, Digital Video Broadcasting (DVB), minimal services like voice and data, and other services that utilize bandwidth.

5G New Radio (NR) is the forthcoming evolution of mobile technology expected to be in use by the year 2020 with a wide range of usability beyond the uses of 4G [1]. Performance parameters of 5G technologies are expected to be tens and thousands times better than in 4G.

1.2 Challenges in Fifth Generation Wireless Technology

Fifth generation network have been developed during this years, we are facing with my potential challenges in such areas and trying to resolve the problems and challenges. For a complete and fair assessment of 5G wireless systems, performance evaluation and metrics are considerable factors. These metrics include spectral efficiency, energy efficiency, delay, reliability, fairness of users, QoS, implementation complexity, and so on.

For evaluating performance of 5G wireless technology, a general framework should be developed, taking into account as many performance metrics as possible from different perspectives. There should be a trade-off among all performance metrics. This requires high-complexity joint optimization algorithms and long simulation times.

Realistic channel models with proper accuracy-complexity trade-off are indispensable for some typical 5G scenarios, such as massive MIMO channels and high-mobility channels (e.g., high-speed train channels and vehicle-to vehicle channels). On the other hand, statistics channel models with good accuracy are needed for analyzing the 5G frame work by reducing complexity and saving time.

1.3 OFDM: Principles and Challenges

In next generation wireless era, enormous demanding of high bit data rate, demanding advanced multimedia capabilities and mobility requirement of new wireless applications and users has been continuously increased. The wireless designers have been facing the challenges that cannot be accommodated even by 4G and foregoing wireless generation including performance degradation because of multipath fading. In order to fulfill these requirements, Orthogonal Frequency Division Multiplexing (OFDM) becomes the one requirement of the promising multicarrier modulation schemes for data transmission with high bit rate.

For reducing the multipath fading and impulsive noise, OFDM system is a good solution and robust techniques. Guard band is a good point for removing some interferences, such as inter symbol interference (ISI) which was occurred by multipath effect of multi paths propagations.The technique is guard intervals are inserted between sub carrier channels and added the cyclic prefix in OFDM symbol. In the later generation sof 5th generation network technologies, OFDM becomes as a useful standard access technology. In the OFDM process, total available bandwidth is splited into narrowband orthogonal subcarrier channels. Therefore, frequency flat fading will have resulted and can make the effects on the individual subcarriers corresponding to their position in the frequency domain. As consequences, fading factors of all subcarriers are not affected equally. But the impact of fading will be occurred in some subcarrier channels. As a drawback, a few subcarriers can be lost in the data transmission process. On the other hand, it can recover for information lost and error as main advantages. By evaluating with Bit error rate (BER), OFDM can remain the BER at the low level. In advance consideration, Coded OFDM is a good solution for improving BER. In OFDM infrastructure, the design parameters are an important factor for making improve BER performance. Error correction schemes, modulation methods, frequency band, Subcarrier spacing, etc, are important parameters of COFDM framework.

1.4 Error Modeling

In digital signal propagation of next generation wireless technologies, Errors are not occurred randomly. The forms of error occurring have been changed to error distribution, such as bursts or clusters. For analyzing and characterizing the statistical behavior of bursty error sequences, error models become a critical point in digital data transmission. For error generating process, error models are very useful by exploring the characterized statistics of real error sequences.

Error Models can generally be divided into two categories, such as descriptive and generative model. We can know that description model is a reference model and generative model is a simulation [11, 12].

In descriptive models, reference error sequences are used for identifying statistical characteristics of error sequences. The reference error sequences are obtainedfrom simulation model and real environments of wireless channel.

Generative models can generate similar error sequences which have approximate similar burst error behavior and characteristic of reference error sequences. In this model, we can implement the updated error generating procedure and methodology for improving the error generating model.

The error models can provide the efficient reliable design for error control mechanism and higher layer protocols by learning the burst error statistics effectively. The generated error sequences can be implementing in the real wireless channel and simulation process. As sequences, we can greatly reduce the execution time and communicational complexity effectively, especially for the analysis and experimentation on different error models [13–16] and different communication protocols [17–20]. As an advantage, we don't need to simulate the whole communication process for new test of error models and protocols. We can substitute the digital wireless channel with the generated error sequences effectively.

1.5 Problem Statement or Motivation of Thesis

Although the new generations of wireless have been improved now a day, there are so many problems which cannot be avoided because of the nature of wireless communications. In any kinds of wireless propagation technologies, the main sources of causing impairments are the design of wireless propagation system.

In the propagation channel, all impairments are occurred because of the two reasons. The first reason is the impact on the design of a wireless receiver and the second reason is the multipath fading which is caused by reflections, diffraction, and scattering.

In wireless propagation process, the problem is losing received signal power and receiving wrong information which is different from the original transmitted sequences at the receiver side. Therefore, one conclusion is due to the errors which are occurring in data transmission process because of the above mention problems [142].

By consideration these factors, the three main factors have to understand for getting optimal data transmission system with low bit error rate. Firstly, we need to understand how the errors are occurring in the transmission channel, cause of errors. As a second factor, it is very important to study the behavior of the error patterns and nature from different perspectives. Qne of the most important factors is the knowledge about the statistical characteristics of these errors and their distributions as a measure of evaluation. The goal of consideration is to handle the errors by controlling and reducing performance degradations.

Some of the reasons of error occurrence are [141]:

Attenuation: Attenuation is the electromagnetic energy decreasing at the receiver. It can be occurred because of the distanceand some obstructions in the propagation process.

Intersymbol interference (ISI):ISI can be occurred by interfering the transmitted symbols each other. As a consequence, some symbols can be cancelled partially because of delays.

Doppler shift: Between the transmitter and receiver, the velocity of moving objectives can make the frequency shipping in received signals which are call Doppler shift.

Multipath fading: At the receiver part, the received signal can be fluctuated in the phase, angle and amplitude because of reflection, diffraction, and scattering.

Internal processing of symbols: In the transceiver part, the errors can be occurred in the symbol which are processing internal part of transceiver. For example, in the demodulation process, the errors can be occurred because of the decision scheme.

Quality of Services (QoS) becomes a critical factor for future user they have high expectation for high bit data rate, low latency and low bit error rate for fifth generation wireless technology.

In order to provide the good quality of services in 5G environment, awareness of errors in received signals have to encountered in the wireless channels. Designing appropriate signal processing components and other channel components in wireless propagation can achieve better communications.

For better understanding the impairments inside the digital wireless channels, studying and analyzing the error patterns and generating such errors is one of the best solution for improving the received signal by reducing the occurrences of error.Error models can identify such error accurately and reproducing the error for making reliable communication.

Such error model can assist the error control strategies with less computational complexity and shorter simulation times instead of executing a whole wireless communication system. Therefore, researches can replaced the proposed error model to the existing physical wireless channel model for generating error sequences in different lengths of data profile in a few seconds. In high demand for elastic error profile for various channel conditions different from existing error profile at fixed channel conditions. The entire error model can save time and cost by mitigating computational complexity and execution time.

In this thesis, designing accurate error models was emphasized while maintaining the computation complexity acceptable. Since the parameterization is very effective on the accuracy of the error model, applying the Baum-Welch forward-backward algorithm is the one of the factors that can make improvement of the accuracy. Moreover, some models were designed for the restricted error sequences in limited propagation areas. Since their production ability is very limited and fixed channel conditions, the appropriate solution have proposed for overcoming these problems.

1.6 Contribution of Thesis

- Analysis simulation framework for coding methods in 5G environments was proposed.
- Analysis model for difference error patterns over three different kinds of modulation methods, including QPSK, 16QAM and 64QAM was proposed.
- Two state Markov based error generative model, two reference error model, is proposed by using two different error sequences form different coding schemes in 5G environment
- Studying the error patterns and the statistical characteristics of burst error sequences that can provide insights into the behavior of 5G wireless data transmissions and model of the underlying error process in the 5G network.

- Finally proposed a robust generative error models aim to be a robust generative model for generating different which can represent symmetrically the any reference error sequences form any different background scenarios simulation.

1.7 Objective of Thesis

- There are so many difficulties and challenges how to implement coding methods in OFDM with 5G standard specifications.
- In order to save the cost because of backward compatibility to 3G and 4G.
- The statistical characteristics of the underlying error process in the 5G network
- Assist the finding the optimal solution for reliable and effective high bit data transmission
- To provide a more thorough understanding of the error process in 5G wireless communications and
- To evaluate the error control strategies with less computational complexity and shorter simulation times.

1.8 Overview of Thesis

Among them, LDPC and Turbo coding methods become the standard specification for high-bit rate data transmission in 5G network. There are so many difficulties and challenges how to apply this coding methods in OFDM with 5G standard specifications. Therefore, firstly we conducted the analysis on two channel coding methods in multipath fading environment of 5G network: LDPC according to 5G specifications of Verizon 5G Technology Forum and Turbo codes by considering backward compatibility. According to our experimental results, we found that our coded OFDM in 5G network outperforms uncoded OFDM in 5G network. Moreover, Turbo coded OFDM with 5G specification achieve better performance with smaller BER than the LDPC coded Multipath OFDM in 5G network. That finding motivates to select Turbo codes as 5G channels coding resulting in cost savings because of backward compatibility to 3G and 4G.

As a second part of thesis, a two-state Markov-based 5G error model is investigated and developed to model the statistical characteristics of the underlying error process in the

5G network. The underlying 5G error process was obtained from our 5G wireless simulation, which was implemented based on three different kinds of modulation methods, including QPSK, 16QAM and 64QAM and was employed using the LDPC and TURBO coding methods. By comparing the burst or gap error statistics of the reference error sequences from the 5G wireless simulations and those of the generated error sequences from the two-state Markov error model, we show that the error behaviors of coded OFDM 5G simulations can be adequately modelled by using the two-state Markov error model. Our proposed two-state Markov-based wireless error model can help to provide a more thorough understanding of the error process in 5G wireless communications and to evaluate the error control strategies with less computational complexity and shorter simulation times.

1.9 Organization of Thesis

This thesis is structured as follows: Chapter 1 introduces problem issues in 5G data transmission system and error modeling, motivating factors of the research, contributions and objectives of the proposed system. Next, literature review, state of the art and the related theory are presented in Chapter 2. The next chapter, Chapter 3, proposed how to design and implement coding method in 5G environments, and analyzes Turbo and LDPC coding in 5G simulation. In Chapter 4, the proposed two state Markov based error model are presented. Finally, Chapter 5 summarizes the proposed system and sets some conclusions and future research directions.

CHAPTER 2

RESEARCH BACKGROUND

In this Chapter, we present about the Research background and Literature Review. In wireless communication systems, 5G is the one of the most expectation for fulfill the user requirements by providing extremely high data transmission rate, very low latency and low bit error rate. In this research, bit error is focused as main aspect of 5G facilities. According to our focus, firstly we tried to reduce BER by implementing coding methods in 5G simulation, secondly we analysis the error process in terms of burst error, finally we proposed the statistical error model based on two state Markov chain.

2.1 Requirements for Fifth Generation Wireless Technology

In the new era of communication technology, 5G is a significant mile stone of new generation wireless history. In recent rapid changing process of technology access form, “Extreme Flexibility” is the key contribution of 5G in order to satisfy the new advance users’ requirements, such as Cloud Access and IoT access. In order to fulfill the requirements is an important in 5G research area. The requirement of 5G can be divided in two categories, network requirements and wireless transmission requirements [58,63143]. In our focus, High Throughput, Low Latency, Low Error Rate, High Spectral Efficiency, Flexibility, and Energy Efficiency are significant requirements of 5G which are related to channel coding issue.

Throughput: Extra high transmission speed and large band width are most expected throughput form 5G new generation technology. Comparing with 4G, transmission speed of 5G is much higher than 4G, while 20 Gbps is targeted for the 5G, the 1 Gbps achieved by 4G. Band width of 5G is 100 MHz while the band width of 4G is 20 MHz [62]. For significant improve, forward buffering can get high ability in video streaming process. Since all transmitted and received data have to pass through the encoder and decoder of channel, it is very important for achieving a high encoded and decoded throughput. Otherwise, the role of channel coding process becomes a critical issue in new generation era.

Latency: Less than 1 ms is the target achievement of 5G's latency. Comparing with 4G, the latency is lower than the10 ms. For 5G radio propagation, 0.5 is the entire ms for end-to-end communication, which is much lower than the10 ms achieved in 4G[63,67]. Latency can be defined as a delay time between the transmission process and receiving process including encoding and decoding time [60,66]. Therefore, significant improve of latency depends on the flexibility of propagation mechanism. In order to confirming the requirements, guaranteeing the ultra-low latencies is a critical issue in recent research area.

Error correction capability: The occurrence of communication error is only 1 block in every 100,000 is the target of 5G high speed data transmission that cannot capable by the channel coding scheme when the data transmission of propagation is of appropriate quality. Comparing occurrence of communication error 1 block in every 10,000 in 4G data communications, it is obviously improved in 5G[65,66,67].

Since the main objective of error correction mechanism is error-free communication, improving the error correction iscan make the lower latency as a 5G requirements.

Flexibility: As a backward compatibility of foregoing generation wireless communication technologies, Flexibility is still remaining in essential role until 5G wireless communication technology which owes themuch wider range of properties better than the previous generations.

Alongside improving of enhance services radio access technologies and advance user experiences, the new paradigm of accessing emerged as such applications, vehicular communications, cloud computing and theInternet of Things (IoT). In order to support those high demand requirements, the coding schemes are enhancing for supporting a wide variety of coding ratesR= K/N with a wide variety of data block lengthsK [60,66,67]. For example, high code rate and low code rate are appropriate in rural and urban areas respectively. While cloud computing requires long block length, IoT is enough with short block lengths for favorable data transmission process. The impacts of the drawback of channel coding methods effect on the degradation of other requirements, such as throughput, latency andperformance of error correction of 5Genvironment. According to this reason, the flexibility is standing up as a key requirementin order to fulfill the challenges of other significant requirements of 5G.

Implementation complexity: For new 5G communication technology, new expectation is emerged for the implementation complexity of a channel coding methods, since those requirements of previous generation technologies are having not beenagreed with the 5G [62,65]. As long as expectation of abilities of channel coding methodologies for 5G communication system is higher, the complexity of implementing channel coding methods is significantly larger. However,theexpectation of the ability and efficiency of channel coding methods in 5G is higher than foregoing wireless technology as well as other requirements of 5G. Owing to this, new enhance coding methods may be developing for optimal communication system as well.

2.1.1 Technical Objectives and Standardization

In recent years, there have been significant developments in the research on 5th Generation (5G) networks. Several enabling technologies are being explored for the 5G mobile system era. The aim is to evolve a cellular network that is intrinsically flexible and remarkably pushes forward the limits of legacy mobile systems across all dimensions of performance metrics. All the stakeholders, such as regulatory bodies, standardization authorities, industrial fora, mobile operators and vendors, must work in unison to bring 5G to fruition. Therefore, many standard technological organizations, such as 3GPP and Verizon Technology Forum, are trying to propose the standardization of 5G specifications in various scenarios and back ground technologies [66,67].

One main characteristic of 5G and Beyond (B5G) mobile networks is the huge amount of data, which requires very high throughput per device (multiple Gbps) and per area efficiency (bps/km2). Based on the several existing research observations and experiment, the main technical objectives for 5G systems can be defined as follow;

- Extremely high data rates per device (multiple tens of Gbps).

• High data rates per area and massive a large number of connected devices. Thus, the interference among transmitters should be minimized.

• Ultra-low latency (round time of less than a microsecond), especially for multimedia and interactive 3D video/VR applications.

• Ultra-reliable support for various critical applications such as Vehicle-to-Vehicle (V2V) communications, industrial control, and healthcare.

Table .2.1. The V5G Specifications (Up link)

Item	**Specification**
Access	OFDM
MAP	QPSK, 16 QAM, 64 QAM
Frequency Band, Bandwidth	28 GHz,100 MHz
Sub frame length (Slot)	0.2ms (0.1ms)
No of OFDM Symbols	7 in time domain
Physical Resource Block	100 in Frequency Domain
Resource Block (RB)	12 sub-carrier
Number of subcarrier	1200 in a Resource grid
Sub-carrier duration	75KHz
CP (Cyclic Prefix) length	First OFDM Symbol (160 Ts) Remaining OFDM Symbol (144 Ts)
Symbol length, Block length	13.3 µs

The trial version of 5G deployments are come out based on these specifications. These trial version test plan provide the test-bed for evaluating process of wireless industry. In United States, Verizon is trying to engage testing 5G in several different areas. The objective of Verizon is to speed up the innovative technologies and get the backward compatibility of the benefits of fiber to wireless. On the other hand, for user experiences, gigabits-per-second; extra high throughputs and extra low latency with single-millisecond are critical point. The evaluating results of key 5G wireless components show that we can have incomparable services to 4G technologies. Moreover, millimeter wave technologies are validating and studying on this platform over several locations. The underlying Verison Test Plan released 1's 5G specifications are presented in Table 2.1, 2.2 and 2.3 respectively.

For simulation framework, we used Version 5th Generation Radio Access; Test Plan release 1 [13]. In 2015, the research partners formed the Verizon 5G Technology Forum (V5GTF). The cooperation partners of V5GTF are listed as follow Nokia, Samsung, LG, Cisco, Samsung, Intel, Ericsson and Qualcomm. The Verizon's 28/39 GHz V5GTF common platform was created for fixing wireless access trials and deployments. As an outcome of technical forum, the 5G specifications are released for 5G radio assessment of OSI upper three layers. And also the user inter faces design and network design were defined in this forum. The manufactures of UE, chipset and network designer can promote their interoperability by using these standard specifications. For layer 1, the V5G.200 release is available and for the Layer 2 and 3, V5G.300 release is appropriated.

Table.2.2. The V5G Specifications (Down link)

Item	**Specification**
Access	OFDM
MAP	QPSK, 16 QAM, 64 QAM
Frequency Band, Bandwidth	28 GHz,100 MHz
Sub frame length (Slot)	0.2ms (0.1ms)
Number of sub-carrier	1200
Sub-carrier duration	75KHz
Resource Block (RB)	12 sub-carrier
CP (Cyclic Prefix) length	First OFDM Symbol (160 Ts) Remaining OFDM Symbol (144 Ts)
Symbol length, Block length	13.3 μs
MIMO	8
Error Correction	LDPC, Turbo coding (optional)

Table.2.3. The V5G Specifications

Item	Specification
Peak Data rate downlink	20 Gbps
Peak Data rate uplink	10 Gbps
Max. frequency reuse factor for downlink	30 bps/Hz
Max. frequency reuse factor for uplink	15 bps/Hz
Average frequency reuse factor for downlink	7.8 bps/Hz Dense Urban
Average frequency reuse factor for uplink	5.4 bps/Hz Dense Urban
Number of MIMO Antenna for downlink	8
Number of MIMO Antenna for uplink	4
Carrier aggregation	up to 8 CC (1 Pcell + 7cell)

2.2 Error Correctionin 5G Data Transmission

In 5G data transmissions system, the receiver received the transmitted bits with errors. Corresponding to this point, communication errors is occurred by some interference, channel noise and attenuation. Generally, for mitigation and with some errors correction these communication errors, channel coding is the one of the best solution in 5G propagation as well as foregoing wireless communication technologies. According to the 3G UMTS and 4G LTE cellular standards [64,68], the turbo code [70] is the main channel code in data transmission process.

In recent year, the Low Density Parity Check (LDPC) coding methods and the turbo coding methods are debatable issue in the 3GPP standardization group [65], as the apply areas including WiFi, WiMAX, G.hn, Ethernet and DVB-S2 standards [69]–[59], while the new polar code is one of the considerable and debatable issue as well[60]. The main goals of 5th generation technology are to invent the advanced next generations technologies for offering exponentially greater user experience and more diverse applications, these debatable issue becomes one the requirement of 5G research era. Specifically, 28 Gbps is one of the main target for 5G data transmission as a high throughput which is much higher than 4G facilities, such as 1 Gbps data transmission rate.

For approving the high thought put of 5G data transmission, video streaming is very significant and one of the good examples of improving throughput. Even when the channel conditions become unfavorable,thiscapable to maintain the efficiency and reliability of streaming process in a good condition.

For new accessible form of fifth generation technology, such as cloud computing, Internet of Things (IoT) and vehicular communications, a much higher degree of flexibility, including extra high bit data transfer rate, low bit error rate and extra low latency, becomes a main objective by consideration backward compatibilities to previous generations beyond the foregoing facilities and services.

2.3 OFDM: Principles and Challenges

The principal and challenges of the OFDM aredescribed in the following sub-sections.

2.3.1 OFDM Principles

Since the future wireless applications demands high data rate transmission, multi-carrier transmission and multiplexing are key properties of high speed data transmission system.OFDM can promise the users with a high data rate transmissioncapability at a reasonable complexity and precision.OFDM can be defined as a special form of multi-carrier transmission system where all the subcarriersare orthogonal to each other for transmitting the information in parallel piece streams and is a form of combination of both and multiplexing and modulation schemes [71, 73]. It has a wide transmission capacity transporter is separated into small transfer speed subcarriers. Generally basic OFDM system can be divided into three principles, transmission, channel and receiving.

In OFDM data transmission, initially the input data symbols are converting to from serial-to-parallel by dividing the big block of input data is divided into small blocks. Since the input sources are binary sequences of digital signal, digital modulation scheme is implemented for modulating the input signals. BPSK, QPSK and QAM are standard modulation methods with differentbehaviors.The modulation is performed on each parallel sub-streams.After that, these small sized information streams are exchanged on the diverse N subcarriers parallel [73]. The required amplitude and phase of the carrier is calculated based on the modulation scheme (typically BPSK, QPSK, or QAM). The N subcarriers, $Xi=[X1,X2,X_{N-1}]T$, which represents the information in each OFDM symbol is converted in to time domain from frequency domain by passing through Inverse Fast Fourier Transform(IFFT) block. A cyclic prefix is inserted in order to eliminate the inter-symbol. and inter-block interference (IBI). This cyclic prefix of length L is a circularextension of the IFFT-modulated symbol, obtained by copying the last L samples of thesymbol in front of it. The data are back-serial converted, forming an OFDM symbol thatwill modulate a high-frequency carrier before its transmission through the channel. Theradio channel is generally referred as a linear time-variant system. The channel is modeled as a time-domain complex-baseband transfer function, which may then be convolved with the transmitted signal to determine the signal at the receiver side.

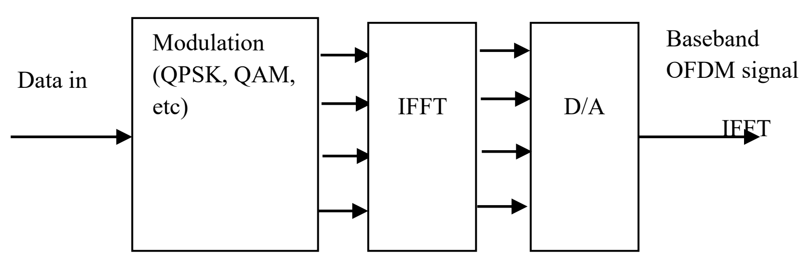


Figure.2.1. Basic OFDM Flow Diagram

To the receiver, theinverse operations are performed: the data are down-converted to the baseband and thecyclic prefix is removed. The coherent FFT demodulator will ideally retrieve the exactform of transmitted symbols. The data are serial converted and the appropriateddemodulation scheme will be used to estimate the transmitted symbols.In this section, the key points of OFDM are presented: the principles of a multicarrier (parallel) transmission, the usage of FFT and the cyclic prefix.

The receiver basically does the reverse operation to the transmitter to retrieve the information transmitted. The guard period is removed. The FF To feach symbolist then taken to find the original transmitted spectrum. The phase angle of each transmission carrier is then evaluated and converted back to the data word by demodulating the received phase. The data words are then combined back to the same word size as the original data.

2.3.2 OFDM Challenges

Orthogonal frequency division multiplexing is a wideband modulation scheme which is used in wireless next technologies for transferring the data at high rate and eliminate the inter symbol interference. Various advantages are provided in cognitive radio such as ease in spectrum sensing and provide interoperability to other wireless technologies such as Wi-Fi, 4G, and Digital Audio Broadcasting.On the other hand, there are number of challenges to implement the OFDM at the physical layer of the wireless data transmission systems. Peak-to-Average Power Ratio reduction,inter symbol interference(ISI) reduction and maintaining synchronization with the primary users etc. [75,76,77,78,79,80]Various major challenges of OFDM implementation in the wireless networks are expressed as below;

- Minimize the high PAPR
- Challenges in sensing the radio Spectrum
- Trade-off between size of Cyclic Prefix and Spectral Efficiency
- Synchronization
- Designing Effective Pruning Algorithm

- Signaling Transmission Parameters

2.4 Channel Coding Methods in OFDM

In recent years, OFDM has been popular in high bit data transmission system because of it's abilities. It can eliminate the interferences like cause intersymbol interference (ISI) which are occurred in frequency selective fading environments. This is the one reason. For removing such interferences, a guard interval is added in between the sub carrier bands. Therefore, we can avoid the using of complicated equalizer in propagation process. As advantages, OFDM can provide the diversity for critical needed, such as, the multi-path fading, appropriate frequency interleaving and coding is necessary. Owing to this, channel coding plus OFDM becomes a good solution for mitigating the performance degradations in term of BER. The researchers emphasized the coding schemes to be an optimum solution for correcting error and recovering the information loss. The designing interleaver and check matrixes become a research area in COFDM [81]. Among the error correction schemes, Forward error correction is very useful schemes which introduce the concept of redundant data transmission by adding delay time [82]. The obvious mechanism is parity check matrix which is constructed by adding extra bits to the last portion of code word. For the low error occurrence probability, it works well. Coding Methodologies can reduce the BER while maintain the data transmission rate to close to Shannon's limitation.

2.5 Burst Error Correction Techniques

In error correction producers, they are performing in block code. For each code ward, a limited number of bit errors can be recover by using added parity bits. The block error sequences are defined as error clusters which are called burst error. The significant solution for recovering burst error is interleaver.

In the data transmission process, the input data sequences are passing to the interleaving process of error correction at first. And then they are transmitted over channel. In the receiving process, the transmitted datasequences are decoded by using decoder.For burst error correction, the significant error correction schemes are express as follow;

1. Convolutional Coding
2. Reed Solomon Coding
3. Turbo coding
4. Polar Coding
5. Low Density Parity Check coding

2.6 Coded OFDM System

Coded OFDM system conforming with 5G specifications is presented as in figure 2. We consider OFDM propagation in AWGN channel with multi paths fading. The block of input signals, k information bits, are encoded by the encoder. Coded information (k bits) plus extra bits (x bits) are modulated by three kinds of modulation methods, QPSK, 16 QAM and 64 QAM and serial to parallel conversion are performed for mapping with N subcarrier channels. Inverse fast Fourier transform (iFFT) is carried out to convert from frequency domain to time domain. In a multipath environment, OFDM transmission process is performed over AWGN channel. After converting received time domain signals to frequency domain signals by using FFT, the information bits are demodulated employing demodulation methods. The original bits are restored after decoding the demodulated signals [8].

2.7 5G Standard Channel Coding Techniques and Challenges

According to 3GPP TS 38.212 version 15.2.0 Release 15, LDPC and Polar code are potential candidate channel coding methods for 5G. Polar coding is used for PBCH (Physical Broadcast Channel), PDCCH (Physical Downlink Control Channel) and PUCCH (Physical Uplink Control Channel) and LDPC (Low Density Parity Check) is used for PDSCH (Physical Downlink Shared Channel) and PUSCH (Physical Downlink Shared Channel). These channel coding techniques are applied for different types of 5G New Radio Channels. 3G and 4G cellular systems selected the Turbo code as the main channel code The turbo code which is used in PDSCH channel. But the 3GPP standardization group is currently debating whether it should be replaced by the Low Density Parity Check (LDPC) code in 5G [18, 67]. On the other hand, Verizon 5G Technology Forum (Verison 5th Generation Radio Access; Test Plan release 1) [84] published the 5G specifications including LDPC and Turbo coding as a potential candidate channel coding methods. In 5th generation standardization, there are many standardizing organization including V5GTF and 3GPP. The organizations defined the convolutional codes, turbo codes, LDPCcodes and polar codes as the candidates for 5G.However, we followed the Verizon 5G Technology Forum (Version 5th Generation Radio Access; Test Plan release 1) in this work.

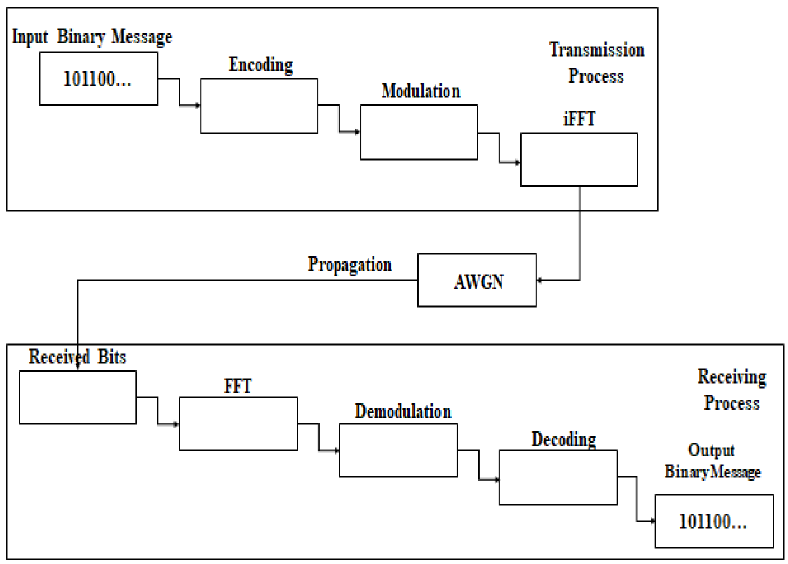


Figure.2.2. Coded OFDM System Flow Diagram

2.7.1 Turbo coding and challenges

C. Berrou, A.Glavieux and P. Thitimajshimaexplored Turbo coding techniques and publish in 1993 IEEE conference proceeding. Turbo channel coding technique is a powerful error correction technique and a potential for future wireless technology. Turbo code technique is composed of two two convolutional code in parallel manner via interleaver. Firstly, all convolutional coded bit sequences are converted in to the recursive symmetric convolutional codes. In decoding process, two soft-in-soft-out (SISO) decoders are used and exchanging extrinsic information iteratively base on soft input Viterbi algorithm [86,67]. Two decoder can be separated by deinterleaver. Owing to this, turbo technique can reduce computational complexity especially for long message length.The principle of interleaving [83] is illustrated in Figure 2.2:

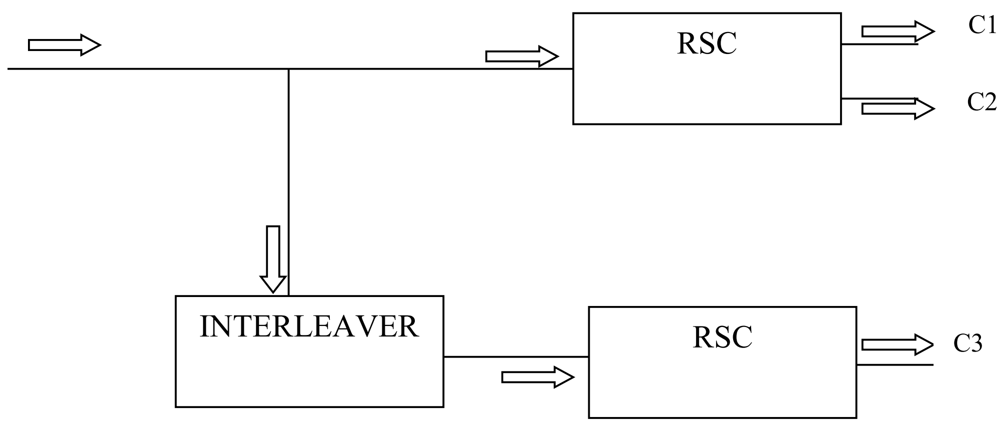


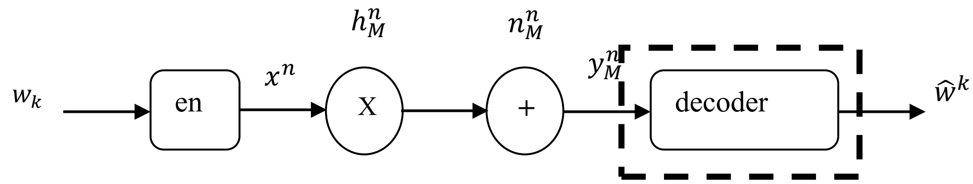
Figure.2.3. The principle of interleavingof Turbo Coding

As a back ward compatibility of 3G and 4G technologies, Turbo coding is significant in mobile communication standards. It's advantages are low complexity iterative decoding schemes, as low complexity encoders and suitability to simple rate adaptation.Their error correction performance can make the BER evaluation very close to Shannon limitation.

On the other hand, turbo coding technique are still facing with some drawbacks now a day.The iterative decoding methods of Turbo technique is suitable for long messages. Alongside the decreasing of message length, the performance of Turbo code loses their effectiveness and is still comparable with other advance coding schemes. One of the significant challenge regarded as the $\max*(x,y) = \max(x,y) + fc(x,y)$ function in the BCJR algorithm, where $fc(x,y)$ is a non-linear correction function.In [2.28]. The researcher proposed different schemes for reducingcomplexity.

2.7.2 LDPC Coding and Challenges

In 1960 [87], R. Gallagerfirstly introduce LDPC codes as a sparsity low complexity encoding and decoding scheme. LDPC coding aimed especially for longcodeword length. Nowadays, LDPC coding technique becomes popular for future wireless technology and was adopted by 10 Gigabit Ethernet (10GBASE-T), digital video broadcasting (DVB-S2), WiMAX,DVB-S2, 60 GHz WPAN (802.15.3c)etc[86].



$$H = \begin{pmatrix} 1 & 1 & 0 & 11 & 1 & 0 & 1 \\ 1 & 0 & 1 & 10 & 1 & 1 & 1 \\ 1 & 1 & 1 & 01 & 1 & 1 & 0 \\ 0 & 1 & 1 & 11 & 0 & 1 & 1 \end{pmatrix}$$

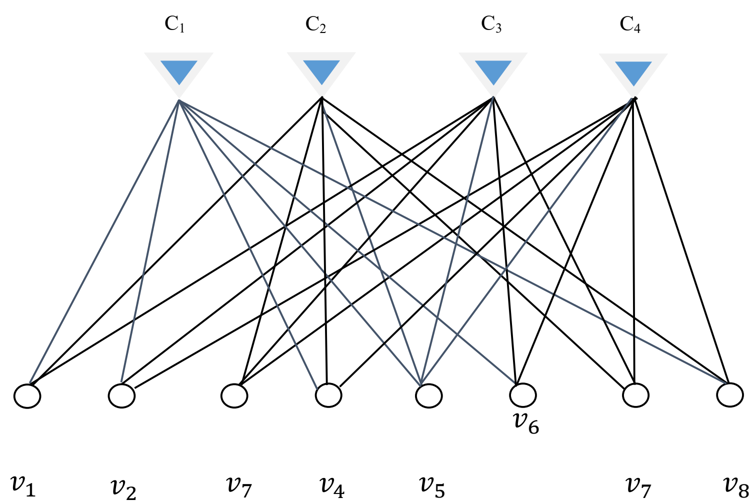


Figure.2.4. LDPC Coding Procedure

An LDPC code is characterized by its sparse parity checkmatrix$H$ of size $(n-k) \times n$. LDPC codes can be represented by a bipartitegraph[87]. The bipartitegraph is composed of two types of nodes,a Check Node (c-nodes) which delegate each rows in thetanner graph and Variable Node (v-nodes) which delegatesearch column respectively.

The connections between the c-nodes and v-nodes can be represented by “1” s in the matrix. Check node fi is connected to variable node cj if theelement hij of H is a 1. By using Sum-Product decoding algorithm, the sparse paritycheck matrix can reduce decoding complexity effectively.

Corresponding to the parity check matrix, the decoding process of LDPC are performed by usingbelief propagationon a bipartite graph given.Sum-Product Algorithm is avery significant in decoding of LDPC 87]. Based on message passing procedure between the connected nodesand variablenodes of the Tanner graph, this algorithm is established.

Although LDPC codes have recently received a lot of attention because of their superior error correction performance, many researches have been focused on many difficulties such as LDPC decoders and their VLSI implementations for achieving achieve such requirements as lower error floors, reduced interconnect complexities, smaller die areas, lower power dissipation, and design re-configurability (run-time) to support multiple code lengths and code rates. Current research trends of LDPC are Error Floor Reduction, Efficient Reconfigurable Decoder Design, Routing Congestion Reduction,

2.7.3 Polar Coding and Challenges

In 2009, the Polar codes were introduced by Arikanas new coding methods. According to the concept of polarization, polar codes are constructed. The polarization mechanism can convertthe transmission channel into virtual bit channels.Base on the polarization, the code is constructed. In code construction process, symmetric ordinary channelsCh1 and Ch2 are transformed into two virtual bit channels. These channels may either be error free channel or error channel. We show the basic channel polarization and channel combination in figure.2.5. The two channels, Ch1 and Ch2 are combined to produce a new channel with inputs 1, 2 and outputs 1, 2 and transition probabilities.

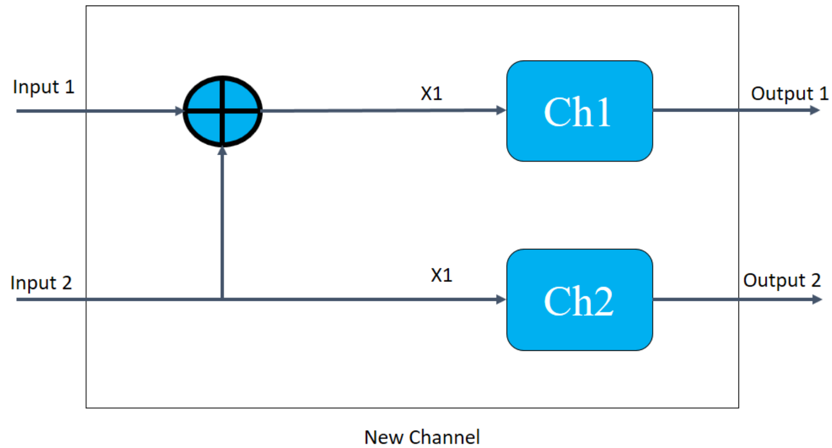


Figure.2.5 Polarization Based Polar Coding

In encoding part, by freezing all other bits to know their values, it can assign the input bits into the noiselessbit channels. In decoding part, Successive cancellation (SC) decoding methods are every obvious and useful mechanism. In SC decoding process, the transformed virtual bits are either completely noisy or noiseless. In [89], they presented achieving the symmetric capacity of underlying channelas main goals of polar coding methods. SC decoding is one solution for that objective. In [89, 91, and 92], the researchers emphasized the polar coding as an extensive research trends and proposed the different mechanism of polar coding. Contract with foregoing coding technologies, such as LDPC and Turbo, polar coding ability can give the best performance for finite length by using SC decoding. In [93,94], the researchers tried to improve the polar coding performance by inventing successive cancellation list(SCL) decoding scheme andCRC-aided SCL decoding scheme. The basic polar coding procedure are expressed as follow;

2.8 Characteristics of Digital Wireless Channel

In wireless communication systems, wireless channel can generally be divided into two categories, such as analog channel and digital channel [95]. For the analog channel, the receive signal strength indicator (RSSI), signal-to-noise ratio (SNR) or carrier-to-interference ratio (CIR), and mobile speed are important parameters [96]. Digital wireless channel is composed of three main components, transmitter, physical channel, and receiver.

For digital wireless channels, error distribution and number of error occurrences within a specific interval of error sequences or packets are common parameters. The entire error sequences can be acquired by calculating the input and output of digital channel.

For the error distribution, error sequences are characterized by two error terms, error burst and error gap (EG). Correct bit is defined as zero (‘0’) and Error Bit is defined as one (‘1’). An error gap is defined as a series of consecutive zeros between two ones and the error gap length is the number of zeros.A series of consecutive ones is defined as an error cluster (EC) and the length of error cluster is defined by the number of ones.

An error-gap or error-free burst (EFB)is a consecutive zeros of error sequences which have a finite length although the length of error gap has no limitation. Also, error gap does not need to be defined between two ones. A sequence of consecutiveones can be defined as an errorburst(EB) over different finite lengths.

2.9 Error Model

In digital wireless channels, errors are occurred in the formed of bursts or clusters, such that long error-free bursts are followed by error bursts or clusters. The statistical behavior of bursty error sequences can be characterized by developing a model which we can basically called error model. The main objective of developing an error model is to characterize the statistics of error sequences and to study the behavior of error patterns of wireless channel. In advance, error model generates the entire error sequences by learning experiences in references error sequences [15, 16].

Applying areas of descriptive and generative modeling are design, optimization, and performance evaluation of error control methodologies and high-layer protocols of wireless technologies [99,100]. The advantages of generative models are significant reduction of computational load and complexity and simulation.

Generally, error models can be divided into two categories, such as descriptive model (reference model) and generative model (simulation model). The reference error is obtained from situation model in descriptive models. Corresponding to this reference sequences, burst error sequences are analysis.Therefore, we can consider as reference models.

Generative model defined canmechanisms with bursty error statistics to generate error sequences at first and generate similar error sequences that are approximately similar to target reference error sequences.

The advantages of error models are as follow;

- The designing and evaluating of error control methodscan acquire the benefice of learning burst error behavior
- The generated error sequences can be replaced in the underlying digital wireless
- As consequences, it can effectively reduce the computational complexity and simulation time, especially for evaluation and analyzing new test of experiment wireless technologiesover different error correction methods and error models [101,102] and different higher level protocols [103,104].
- The input data sequence is no need to transmit again for testing new error schemes or protocols.
- The generated error sequences can conduct well as well as real data transmission model of wireless system channel as the main part of the wireless communication system.

2.9.1 Burst Error Statistics

For analyzing a generative error model, burst error statistics are playing as a crucial row in error modeling mechanism and basic performance matrix for comparison between different generative mechanisms. For designing and evaluating the performance of wireless channel, generative model can effectively support. Furthermore, they can express the behavior of different error patterns [105].

The burst error statistics are defined in specific conditionsfor observingthe burst error statistics, Therefore, the error sequences are producing front coded OFDM wireless simulation. The simulation was built to conform the specifications of 5G standards which was released from Verizon 5G technical forum, 2007 including LDPC coding and turbo coding mechanisms and three modulations techniques in different scenarios [16].

The binary burst error statistics are:

- Gap Distribution (GD): the cumulative distribution function (CDF) with gap lengths m is defined as G(m). The mean of this statistic can represent the randomness of the channel [107].
- Error-free run distribution (EFRD), otherwise, error gap (Pr $(0^m|1)$) is the probability of an occurrence of non-error (correct) bit with length m, m number of '0' error-free bits [93]. The EFRD can be defined as Pr $(0^m|1)$ and calculated from the GD [2-50]. $Pr(0^m|1)$ is a monotonically decreasing function of m0 such that $P(0^0|1) = 1$ and $Pr(0^m|1) \rightarrow 0$ as $m0 \rightarrow \infty$. The minimum error-free burst length η can be determined by this statistic.
- The error cluster distribution (ECD), otherwise, error burst (Pr $(1^m|0)$) is the probability of error bit with length m [51], m number of '1' error bits. Random and bursty channels are two types of channel derived from this statistic.
- The error burst distribution (EBD), otherwise, P_{EB} (m) is the CDF of error burst with lengths m. The designing the error bursts' correcting codes apply this statistic [107].
- The error-free burst distribution (EFBD), otherwise, PEFB ($m_{\bar{e}}$) is the cumulative distribution function of error-free burst with lengths $m_{\bar{e}}$. Owning to this, we can understand how to determineoptimum degree of interleaving with the specific code [107].
- The block error probability distribution (BEPD), otherwise, P (m, n) is the probability the occurrence of at least m out of n error bit. For evaluating the performance of Hybrid Automatic Repeat Request (HARQ) protocols, this statistic is useful [106].
- For understanding the burst error statistics od entire channel, we need know that the bit error correlation function (BECF), otherwise ρ(Δk) is the conditional probability that the Δk^{th} bit following a bit in error is also in error [52], [53].

In studying structural behavior of error sequences, burst error statistics are very useful. As consequences, those statistics can aid for designing and evaluating of error control schemes and higher layer protocols. Specifically error burst (Pr (1^m |0)) and error gap (Pr (0^m |1)) are important metrics for this work. By comparing with other generative models and descriptive models, burst error statistics are very useful for judging the relative merits of different generative models.

2.10 Modeling and Simulation in Wireless Channel

Basically the wireless communication system composed of appropriate modulation, access methods, channel coding scheme, and digital signal-processing elements, etc. In order to provide an optimal data transmission withhigher throughput, quality of service to meet high expectations of user, it is indispensable to meet the constraints on important parameters, such as power, bandwidth, complexity, and cost. For achieving an optimal wireless system design, it is very important to well characterize the wireless channel behavior. For future wireless propagation and next generation wireless communication system, characterizing and designing the wireless channel becomes a critical challenge because of advance wireless mobile channels become multipath fading channel and they might occur significant levels of interference, distortion, and noise. Therefore, it is very difficult to characterize the multipath channels [111].

A number of candidate designs are necessary to explored for designing the system. Creating new design prototypes is very expensive and consumes time too much for implementing the equipment. Owing to this, considering creating appropriate models and building simulation is the best way for cost and time saving effectively. Owing to this reason, most of researchers are trying to proposed deterministic or statistical models for wireless communications channels for evaluating and analysis of proposed design by using analytical approach.

In this example, additive Gaussian noise and Rayleigh fading channel, in which amplitude probability density function is set up, are used. For a binary data transmission system, we can express the error occurrenceprobability as follow;

$$Pe = 1/2\gamma b \tag{2.1}$$

Where, at the receiver side, the "average" value of SNR can be defined as γb.

By understanding this clarification, the power of the transmitter necessary to meet a given error probability.We need to consider the effects of implementationin real system, for example, non-ideal filters and nonlinear amplifiers. The difficulties are analytically characterizing in such cases. One solution is a combination of simulation and analytical analysis. According to those reasons, modeling and simulation process becomes a critical point for designing wireless communication systems.

2.10.1 Models of Communication Channels

In modeling process, the input output relationship of propagation system can be representing in mathematical or algorithmic form by experience in the basic theory concept of the physical model of communication channel [112].

Measurement-based models: It includes statistical characteristics and explanation of the channels. These modelsare expressedin the form of random process or random variables. The parameter estimation is accomplished form the measured data. Measurement-based models are useful for designing and validating of the wireless channel models.

Mathematical models: For understanding the physical model of entire channel, we need to develop the mathematical model for the data transmission communication system. In channel modeling, the translation of a detailed physical propagation model into a suitable simulation form is challenging. In the physical point of view, mathematical models may not be a suitable form for simulation because it might often be extremely detailed. For a radio channel, the mathematical model is developing by operating in the form of Maxwell's equations. As a clear explanation, physical channel model is observed at first, and then translation is performed to simulation model. This is a straight forward procedure for modeling.

2.10.2 Simulation Model for Communication Channel

Physical communication channel is performed randomly in time varying manner. Generally, the simulation model can be divided into two types of channel models as follow[112,113];

Transfer function models: This model is a time-invariant channel model such as wired, free-space propagation, and optical fibers. Because of the internal relationship of time-invariant impulse responses, fixed delays, particular frequency responses are occurred in depending on the bandwidth saturations. In these models, there are two channels categories, including flat channel and frequency selective channel. The channel can be defined as flat channel which has the bandwidth with a constant gain response and The channel with the saturation which has bandwidtha significant gain variation with can be defined as frequency selective channel. The analytical expressions are easier to simulate using IIR techniques or the transfer function.

Tapped delay line (TDL) models: This model is a time-varying channel, includingwireless and mobile radio channel which is assumed to vary over time. In this model, the channels are divided as fast fading channel and slow fading channel. for an applied signal, the occurrences of fast fading channelare happened during a smallest period of time interval of interest and slow fading channel can occurs over the particular span of time of consecutive symbols of the applied source.

There are two types of techniques, such as or infinite impulse response (IIR) or finite impulse response (FIR) for simulation. While Transfer function models can simulate using both, tapped delay line (TDL) model is appropriated for infinite impulse response (IIR) technique. Empirical models are usually simulated using FIR techniques based on measured impulse or frequency responses.

Transfer function model: It can be simulated by using infinite impulse response (IIR) filters or finite impulse response (FIR)in either the time domain or frequency domain by using FIR techniques.

Empirical models: these modelcan be simulated in the form of synthesized impulse or measured or frequency responses. For the underlying time variations channel model, tapped delay line (TDL) simulation models can be performed by taking the form of process model.

2.10.3 Discrete Channel Models for Communication Channel

The waveform is sampling with appropriate sampling frequency for waveform channel models. By processingsimulation model, we can get the sampling results.The channel can be represented bya finite number of states using another way. This way is often more efficient for some applications. Owing to this, according toa set of transition probabilities, the channel state can be changed [111,112,113]. Furthermore, by using a Markov chain, the channels can be defined. The resulting channel model most often is in the form of a hidden Markov model (HMM). the HMM can characterize a communication systemaccuratelywith minimum computational burden.

2.11 Overview of Channel Models

In channel modeling of wireless communication channels, generally channel models can be categories as physical channels and digital channels.

Firstly, physical channels also known as analog channel. The physical channel can be model by describing the fading characteristics of receive signals. Rayleigh and Rice channelsare well known physical channel model in designing, parameter optimization, evaluation and experimental environments of wireless data transmission system [114]. The important parameters are the interference power, received signal strength (RSS), mobile speed and signal to noise ratio (SNR), etc.

In modeling the digital channels, the error distribution and the number of error occurrence are described in the form of bits or cluster or packets. A digital is also known as time-discrete channel which are model by considering the complete transmission procedure, such as the transmitter, the physical channel, and the receiver in the complex baseband. In the digital wireless channels, the errors are occurred independently in the form of bursts or clusters. Error model can be defined as a Channel models for digital channels [115,117], for describing the statistical characteristics of the underlying burst error. Error model can be assisted for designing the error control schemes [117] and high layer wireless communication protocols [113,116].

2.11.1 Digital Channel Modeling

A digital channel can be known as a time-discrete channel which can represent the whole wireless propagation process, including the transmission process receiving process and analog channel. In digital channel, the input and output re express in digitized form. According to the nature of wireless environment, information lost is occurred in different forms or different manners because of impairments of wireless channel. Owning to these facts, digital signal processing methods becomes a good solution for error controlling process [114]. These errors are concurred in the formed of burst error sequences or error clusters.

Other important facts that we need to consider for digital modeling is the parameters, the number of error and error distribution in the form of bit pattern and sequences are important parameters for digital channel modeling.Modeling the digital channel can be represented by mathematical channel modelby experiencing the knowledge of statistical behavior of bursty error sequences[115]. These mathematical models are called error model. In error modeling process,descriptive and generative model are well known model[113,117].

Descriptive models: characterize the statistics of target (reference) burst error sequences. The references error sequences are obtained directly from the simulation or real environment of wireless communication. Therefore, the statistics of target error sequences can be analyzed directly from the wireless simulation or real digital channel.

Generative models: generate the target error sequences which are similar to the references error sequences [97]. Compared with a descriptive model, the main advantage of a generative model is that it can greatly reduce the computational effort for generating long error sequences and therefore speed up simulations. Therefore, the generative model is considered as a simulation models instead of real simulation of the whole system.

Both error modeling schemes are very useful for improving the error control schemes in advance and high-layer wireless communication protocols [113,116,118].

2.11.2 Generative Models

The generative model is constructed based on the fading processes. We can define the characteristics of error sequences as error gap (error free burst) and error burst. By using the second order statistics of fading envelope processes, those parameters can be estimated. Among them, the significant useful second order statistics are the level crossing rate (LCR) and the average duration of fades (ADF). These important parameters of error sequences are associated with the fading and inter-fading intervals. The entire error sequences can be generated by using fading processes. the error-generation mechanism can be described by discrete channel model probabilistically.

In the literature, the researchers have been proposed many generative models by addressing the objectives such accuracy and efficiency for error modeling. Generally,we can classify the generative models as followed;

Markov Models: In [117,119,120], the researchers show that the first generative model was developed byusing finite or infinite state Markov chains. Gilbert a two-state Markov model is significant. Gilbert model have one state two state such as good state and bad state in which a good state can be defined as a hard error-free sequence and bad state can be defined as a sequence of errors. In [118], Gilbert Elloit model has been improved in such a way that errors can also occur in the good state with a small probability. As a drawback of a two-state Markov model is limited capability for reproducing the desired burst error statistics. Enlarging the number of states is one of the solutions for this problem. Simplified Fritchman's model (SFMs) is a Finite state Markov models with a finite number K of states [121].

Hidden Markov models (HMMs): It is one of the generative model [122,123,124,125]. It can produce the desired burst error statistics by using a high number of HMM states. It can capable of parameterization problems, performance evaluation and experiment of high layer protocols increasingly difficult [116]. HMMs has some draw back, such as lacking a direct intuition between the channel behavior and the underlying Markov chain.

Stochastic Context-free Grammars: Stochastic context-free grammar based hard generative models are limited to model hard error sequences having the bell-shaped error-density behavior [123].

Chaotic Attractors Generative Models: In this model, the approximation of burst error statistics is failed by using Chaos equation based hard generative models [2-68,69]. Theimportantparameters, such as the block error probability distribution, need to estimate with high accuracy.

Deterministic Process Based Generative Models: In this model, the error generation is based on the It is a deterministic process [127,128]. The accurate entire error sequences of can be produced by meeting the target burst statistics by learning the reference error sequences. The reference error sequences are acquired by wireless simulations or real wireless environment.

2.11.3 Two State Markov Models

Generally, Markov modeling process is operating by using the well-known Markov property.Gilbert's model is the well-known Markov Model (MM) and also known as the first basic generative model [129]. As shown in figure 2.6, the model includes only good (G) and bad (B). The state in which the output digital sequences are always 0, is call good state, G state.And then, the state, in which the produced sequences can be 0 or 1, is called bad state, B state. For constructing the error sequences, the state transitions processis carried out according to transition probabilities. The state transition probabilities are less than the probabilities for persisting in the same state.

In both states, the error sequences can be generated by using Gilbert's model is suggested by Elliot [130]. In the error generation process, the good state probability has low for generated error sequences. In many application areas, the two-state Markov modelsis very useful and significantwith their simplicity. On the other hand, they have still some draw back. For example, when desire error sequences are generating approximately as close as the target error sequences, the estimation accuracy is low. The renewal natures limit the estimation accuracy. For the run length of the states, the parameterization is performed by using the assumption of having a geometric distribution.

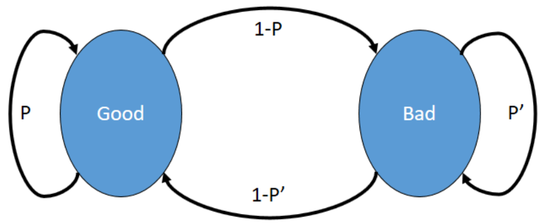


Figure .2.6 Two state Markov based Gilbert-Elliot model

For improving the performance of this model, there are some existing research which are trying to modify the simple MMs in different ways. Some of researchers modified the increasing the number of states[131,133], some imposed certain conditions on the transitions [94,100]. In [131], the researcher proposed a three state model which composed of one good state and two bad states. It can calculate the error gap distribution by the sum of three exponential terms for three state models. As a drawback of three state models, the accuracy of generated error sequences are not satisfied. The researchers proposed Markov Model with several states in [132]. As an assumption of this paper, in every state, the occurrence will be happenedwith different error rates. Moreover, the state can change to another state immediately following an error. The proposed model of the reference [134] is based on the same idea with the previous one. But the model construct by using only two states.In each state of this model, the transition probabilities will be occurred over sojourn times.

FritchmanModel is a significant Markovian model which has finite-state [138] and composed of N-states. In this model, the states are divided into two groups state which are the state with k error and the state with $N - k$ error free. Another version of Fritchman's model is the Simplified Fritchman's model (SFM). In [135], the researcher proposed an infinite states Markovian model which consists of two coupled renewal infinite state Markov chains.After the error is occurred, the stats can be change to another state, transition state.The transitions probability depends on the length of the previous gap. In [142], the researcher proposed a higher order N-state MM which composed of N-states.In this model, only one transition step is allowed. And also A conditional state transmission probability N-state model was proposed by Chein et al. [136] which has the same idea of [142]. Another researcher proposed extension MMwhich has additional memory and the model are incorporated for short gaps [138]. On the other hand, there is some weak point of infinite states MM. But the model has some equality of Fritchman's model like distribution of error free, gap, which are similar with conditional and unconditional gap distributions.

2.12 Chapter Summary

This chapter presented about related theory background of proposed coded OFDM 5G simulation frame work and two states Markov based generative error model. Firstly, we discussed about the Requirements for Fifth Generation Wireless Technology and Technical Objectives and Standardization for Fifth Generation Technology. After that we present about OFDM: Principles and Challenges. And then we present channel coding methods in 5G Data Transmission. In next section, we described Coded OFDM System including discussion about 5G standard coding methods, such as Turbo, LDPC, Polar and their challenges. And then we introduce Characteristics of Digital Wireless Channel and error modelling by following discussion about burst error characteristics in the next section. Furthermore, we present about Modeling and Simulation in Wireless Channel and overview of channel models including description model, generative model and two state Markov model as a final section of this chapter.

CHAPTER 3

ANALYSIS OF ERROR CORRECTION METHODS IN MULTIPATH OFDM 5G

3.1 Introduction

In next generation wireless communication, version of communication technology standards like 5G is still increasing until now. Fifth generation technology has evolved as a basic standard platform of next generation wireless communications with powerful high data rate transmission (hundreds of gigabits per second) and thousand times of channel capacity. OFDM becomes a reasonable multicarrier access method in order to sustain adverse channel conditions in 5G standard platform. Although OFDM transmission has been implemented in 5G communication as an unbeatable access method, there are performance degradation problems in terms of bit error rates (BER) and inter symbol interference (ISI) which are caused by multipath fading effects.

On the other hand, it becomes the critical challenge to offer high-bit rate data transmission and extensive networking services with low bit error rate (BER) performance. To achieve the requirements of 5G services, Orthogonal Frequency Division Multiplexing (OFDM) is a considerable technique for high quality communications. In addition, many channel coding schemes have been applied for mitigating performance degradation in terms of BER. Among them, LDPC and Turbo coding methods become the standard specification for high-bit rate data transmission in 5G network. There are so many difficulties and challenges how to apply this coding methods in OFDM with 5G standard specifications.

The existing researches have been trying to solve the performance degradation of OFDM such as high Peak-to-Average Power Ratio (PAPR) problem, sub carrier losing problem and information bit error due to multipath deep fades [32]. In order to correct the communication errors due to noise, interference and poor signal strength, coding techniques become a reasonable solution to compensate bit losses and bit errors. Many coding methods have been applied in OFDM, such as Turbo codes, convolutional code and LDPC etc.

Wireless cellular network implemented with the turbo code and LDPC code achieved good results in performance, complexity, and code rate [41,42]. These two coding methods provided a better performance in terms of good error correcting rate approximately 0.8 which is a 60% improvement in data rate compared with standard convolutional code.

In storage and retrieval of data for large clusters area, turbo codes got better performance compared with LDPC codes [42]. They theoretically and experimentally approved that turbo code is more accurate and faster for encoding and decoding for multiple error correction [39]. The turbo code is more promising than the LDPC codes for prioritizing the achievable performance and as the channel coding scheme R= 1/3 for the shared data channel in the E-UTRA.

Muaini et.al also compared Turbo codes and LDPC codes in terms of performance and complexity with same input length and code rate R=1/2 [32]. According to results,the computational complexity of LDPC codes are lower than at the code lengths, the simulation was performed over LDPC and Turbo codes with code word length I = 1784 and I = 3568 per iteration.

Comparing LDPC coding to continuous decoding of convolutional codes, convolutional codes outperform message passing decoding of block LDPC codes on an AWGN channel with BPSK modulation giving sufficiently low decoding latency [37]. Moreover, Costello et al made a comparison of LDPC block and convolutional codes based on several factors. According to the results, by comparing their block code counterparts, LDPC convolutional codes have a performance error [38]. By reviewing previous works [35,36, 37, 38, 39, 42], not all LDPC codes are better than all other coding schemes. It really depends on how the channel coding methods is designed and background scenario.

In this study, we follow the 5G specifications of Verizon 5G Technology Forum (Verizon 5^{th} Generation Radio Access; Test Plan release 1) [43]. Verizon has published LDPC coding as Downlink/ Uplink data coding. In 3G UMTS [32] and 4G LTE cellular standards [33], the turbo code [31] was selected as the main channel code. If we could apply

Turbo codes in 5G wireless network, we could get the benefit of backwards compatibility to 3G and 4G resulting in cost savings for the cellular communications industry. For these reasons, we chose not only LDPC but also Turbo codes to test in our coded OFDM 5G simulation by considering Verizon's 5G specifications and backward compatibility to 3G and 4G.

In this chapter, we conducted the analysis on two channel coding methods in multipath fading environment of 5G network: LDPC according to 5G specifications of Verizon 5G Technology Forum and Turbo codes by considering backward compatibility. According to our experimental results, we found that our coded OFDM in 5G network outperforms uncoded OFDM in 5G network. Moreover, Turbo coded OFDM with 5G specification achieve better performance with smaller BER than the LDPC coded Multipath OFDM in 5G network. That finding motivates to select Turbo codes as 5G channel coding resulting in cost savings because of backward compatibility to 3G and 4G.

This chapter is organized as follows. We describe the introduction in section 3.1. In Section 3.2, we discussed about existing researches which are related to channel coding methods in next generation wireless technologies.We present about simulation parameters and 5G specifications that we follow to construct the OFDM 5G simulation framework in section 3.3. In the next section, we describe the proposed coded OFDM system in 5G network. Then we briefly describe the theoretical backgrounds for the channel coding methodologies in section 3.5, including detail clarification LDPC encoding and decoding, and Turbo encoding and decoding. In section 3.6, we presented description of the Coded OFDM 5G simulation.And then, analysis of Channel Coding Methods on OFDM 5G simulation and the experimental result of channel coding methods are described in section 3.7. In section 3.8, we discussed and wrap up our findings in section 3.7 by confirming coded OFDM has better performance in BER than uncodedOFDM and approved that by comparing theoretically. Finally, we described the organization of this chapter in section 3.8.

3.2 Related Work

In [31], Shannon explored the possibility of error free communication. That was be possible with some limitations. These limitations are the channel Capacity bound,they mention that data rate should be less ten or equal the limitation.Owing to this finding, many researchers have been trying to explore for new transmission techniques. The objectives areto reach to the entire the channel capacity. Channel coding methods are very significant for filling this objective. They introduce the new advance mechanism for encoding and decoding, which proposed a structured redundancy concept for achieving wide possibilities of error detection and correction.

In [22,31], the researchers state the four kinds of channel coding methods: LDPC, Turbo, Polar and convolutional as standard methods for 5^{th} generation wireless Network (5G) because of low complexity and good performance of those methods.Elias introduced convolutional codes in 1955 as a class of linear coding methods. The input information bits are process bit by bit in the encoding process. In [33,34], the BCJR algorithm and the Viterbi algorithm are obvious for decoding of convolutional code.

In 1993, the Turbo code was introduced [35]. The researchers proposed the new code with the closet capacity limit. In the turbo coding process, two recursive convolutional encoders are implemented. After passing the first encoder, the input process is calculation by using permutations, and then passed to second encoder. On the other side, two decoders are implemented in receiving part. The two decoder are working by relating to each other by exchanging probabilistic information. LDPC is a another popular code. The Robert Gallager introduced in 1960 [36] which can make the capacity to close to Shannon limitation. But practical implementation is too complexed.

After a few decades, LDPC codes has been a popular and rediscovered around 1996. The concept of LDPC based on the block code and the codes are constructed by using sparse parity check matrix [38]. The construction of sparsity matrix can reduce the complexity of decoding by using Sum-Product Algorithm (SPA)[38]. In this infrastructure design, we can conduct low-complexity encoding process. In later years, Arıkanintroduced the polar code in 2008 [39]. It based on the concept of polarization and the channel polarization transform. The specialty of polar code is that can be achieved the channel capacity at infinite length. In the encoding process, encoder was operated by using Generator matrix which come out from the polarization transform. In the decoding process, Successive Cancellation (SC) mechanism is a good solution for decoder [39]. In [40]–[46], we can found the evaluation of those mechanisms and they found out a limited set of results can be provided. The researchers showed the performance analysis of those channel coding methodologies by comparing in term of BER for different code rates and block lengths over the different background scenarios. Moreover, performance evaluation of decoding algorithms was performed by using their convergence behaviors and decoding effects.

In this work,as an objective ofimproving the performance of fifth generation technologies and reliable data communications, two coding schemes are selected as standard methods of 5Gtechnologies by addressing their high performance and low complexity nature for improving the performance of fifth generation technologies and reliable data communications. We also do analysis the performance of the performance of channel coding schemes and evaluating with the key components of wireless technologies, such as modulation schemes and different FFT sizes.

3.3 Simulation Parameters and 5G Specificationsfor Simulation Testbed

In this work, simulation test-bed was implemented by conforming 5G specifications which was released by Verizon 5G Technology Forum (Version 5th Generation Radio Access; Test Plan release 1) [33]. The simulation parameters are as shown in Table 3.1.

Table.3.1. Specifications for 5G for Simulation

Parameters	Values
Frequency Band	28GHz
Bandwidth	100MHz
Subcarrier Spacing	75 KHz
Modulation Methods	QPSK,16QAM, 64QAM
Channel Model	AWGN
Access Method	OFDM
Error Correction	LDPC and Turbo codes
No of Frames/No of iterations	1000

In the data transmission process, the input bit sequences are binary sequences of digital signal. At first, the encoding process is performed by encoding the binary bit sequences are encoded by using underlying encoding mechanism, such as LDPC and Turbo. At the next step,theburst error which are occurred in frequency-selective fading channel are randomized by using bit interleaving. After that the sub carrier mapping process is performed by using appropriate modulation methods, such as QPSK, 16QAM and 64QAM.The modulated signals are transformed from serial to parallel for multiplexing. By using the inert Fast Fourier transform (FFT), the information signals are converted from frequency domain to time domain in which FFT size is set up by 1024 and 2048 for evaluation. Finally, a cyclic prefix (CP) is added in the transmitted bit sequences by using

160tsec.Seven OFDM symbols are included in each sub-frame by setting up 0.2 msec as a sub-frame duration.

In the receiving part, CP is eliminated form received signal sequences at first. The received signals are converted from time domain to frequency domain by using FFT. As an assumption, the channel approximation process is emphasized on the power of channel coding schemes. In each sub-carrier channel, the variation of OFDM symbol is compensated by estimating derivedchannels which are the form of combining and interleaving. Each sub-frame is decoded by using decoder to restore the original input signals.

We cannot fix the same subcarrier N and FFT size for both coded OFDM and uncoded OFDM in 5G simulation. For the OFDM 5G simulation without using coding methods, the values of subcarrier N and FFT size are mainly dependent on the number of input signals. On the other hand, when we implement the coding methods into OFDM 5G simulation, FFT size will be determined not only by the number of input signals but also by the code rate R of the channel coding because the number of encoded bits change according to R. The modulated bits are generated based on modulation factors. The relationship of encoder and modulator is explained in next section.

3.4 Implementation of OFDM in 5G environment

In near future, high data transmission rate is going to be an attractive feature of upcoming 5G network technology. On the other hand, multicarrier transmission and access methods are also the prominent issues in implementing 5G technology. OFDM which is the one of multicarrier modulation techniques can offer parallel transmission by dividing the wide signal bandwidth into many narrowband sub-channels to provide high bit data rate transmission in multipath environment [2]. The input data signals are modulated by a set of orthogonal sub-carriers. After that FFT is applied to offer maximized spectral efficiency for high data bit propagations in 5G [4]. With the above abilities, OFDM can conduct high data bit propagation by implementing the robust frequency selective fading channels and low complexity equalization in data receiving. By demodulating the received data bits, the original data bits are received.

To satisfy the requirements of 5G services, OFDM becomes an undebatable powerful technique for accessing high data rate multicarrier transmission. We implemented OFDM system for 5G wireless network following 5G specifications as described in Section 3.3.

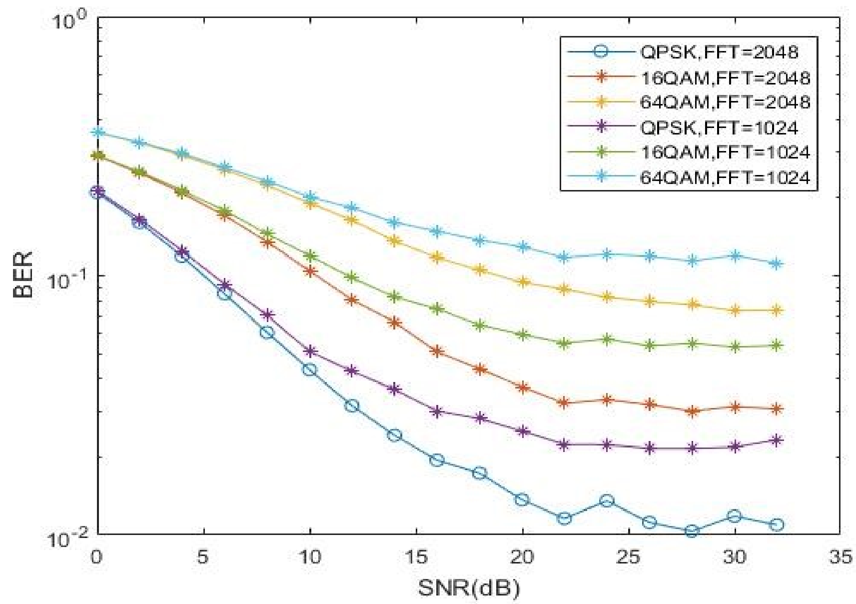


Figure.3.1. Uncoded OFDM for QPSK, 16QAM and 64 QAM (FFT size=2048 and 1024)

3.5 Related Theory Background for Channel Coding

Before explaining our coded OFDM obeying 5G specifications, we briefly explain about LDPC coding and Turbo codes in this section which were employed in our coded OFDM system.

3.5.1 LDPC Coding

Robert Gallager designed Low Density Parity Check Code (LDPC) in 1962. In noisy multipath fading communication channel, LDPC is a very useful coding scheme for error correction and reducing information loss and performance degradation in terms of BER. The probability of information loss can be reduced as closed as possible to Shannon's by using LDPC [48].

LDPC codes can be defined as sparse parity check matrix H and described as (m, n) m rows and n columns otherwise M check nodes and N variable nodes or bits nodes. The parity check matrix H is constructed by (n,k) n codeword and k information bits, k=n-m respectively. Code Rate R is defined as R=k/n. Row Weight wr and Column weight wc is defined as wr=6 and wc =3 for regular LDPC otherwise number of 1s per row and number of 1s per column.

For regular LDPC coding, we assume that all rows of the parity check matrix are linearly independent. (n,k) bits block code provides n code bits to protect the error for k information bits. With minimum hamming distance d, block code is represented as (n,k,d).

The characteristics of LDPC code can be expressed by using sparse parity checkmatrix. By using the sparsity matrix, the complexityof encoding anddecoding process can be reduced. The sparse parity check matrix can be expressed as the following;

$$H=\begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 \end{bmatrix}, \tag{3.1}$$

In the explanation of LDPC coding,Tanner graph can be represented for LDPC code [49]. A Check Node (ChN) is defined as each row of matrix and Variable Node (VaN) is defined each column. Theconnections between such nodes can be defined as “1” s in the matrix. TheTanner graph of the example code is shown in Figure.3.2.

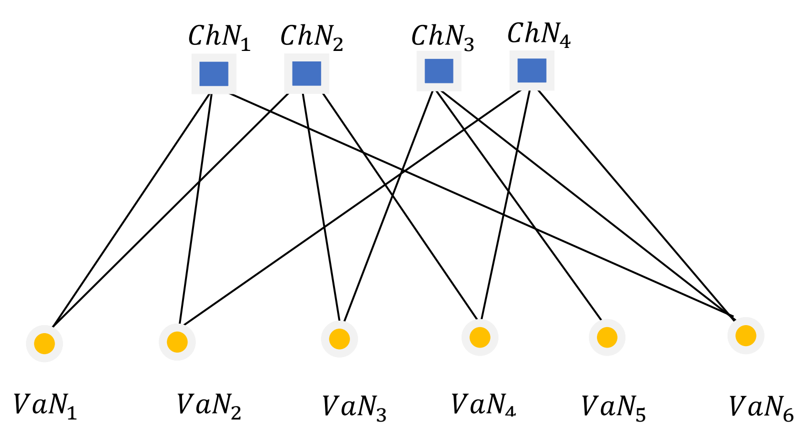


Figure.3.2. Tanner graph of the example code

3.5.1.1 LDPC Encoding

By the following formula, we can express the process of encoding as follow:

$$C_w = B_k G_x, \tag{3.2}$$

where the output codeword is defined as $\mathbf{C_w}$, the input block is defined as $\mathbf{B_k}$, and the generator matrix is defined as $\mathbf{G_x}$.The designparameter of LDPC coding schemes is parity check matrix H, and not the generator matrix $\mathbf{G_x}$. The given parity check matrix can produce the generator matrix. By using Gauss-Jordan Elimination, the matrix is putting into systematic form. In such way, we can generate the generator matrixes[49].

3.5.1.2 LDPC Decoding

The Sum-Product Algorithm (SPA) is very obvious for decoding process [53]. In the Tanner graph, the connection of the CNs, and VNs represent message passing between these nodes. Firstly, for connecting request to CNs, the VNs send the channel LLRs Lj. After that CNs conducts thecalculation process, andpass new messages to their connected VNs according to [49].

$$L_{i\to j} = 2tanh^{-1}\left[\prod_{j' \in N(i)-\{j\}} \tanh(L_{j' \to i}/2)\right], \tag{3.3}$$

where $L_{i\to j}$is the message passed from the i^{th} CN to $j$thVN, $L_{j\to i}$is the message passed from the j^{th} VN to the i^{th}CN, and $N(i)$ is the set of VNs connected to the i^{th} CN. These messages were received by VNs, after that VNs process the message. Finally, The CNs which connected to VNs can received the newmessages passing from VNs ;

$$L_{i\to j} = L_j + \sum_{i' \in N(j)-\{i\}} L_{j' \to i}, \tag{3.4}$$

where N(j) is the set of CNs connected to the j^{th} VN. Here, one iteration is completed, and we can becalculated the total LLR as follow;

$$L_{j(Total)} = L_j + \sum_{i\in N(j)} L_{i\to j}. \tag{3.5}$$

Those nodes are scheduled in the sequence, and the performance are effected by those sequences. The above node includes the CNs. After that the message areparallel updated by all the VNs. That kind of node is defined as the Flood schedule. By performing the serial schedules, we can improve the performance. Which is defined asLayered Belief Propagation (LBP) [55]. The properties of LBP arethe double the convergence which are expressed in terms of iterations,the flood schedule can be speed up.

We can express the approximation of (3.5)as follow;

$$L_{i\to j} = \left(\prod_{j'\in N(i)-\{j\}} \alpha_{j'\to i}\right) \cdot \min_{j'\in N9i)-\{j\}} \beta_{j'\in i} \ , \quad (3.6)$$

where _j0!i and _j0!i are the sign and magnitude of Lj0!i,respectively. According to [56], we can know that is the Min-Sum approximation. Even in some drawbacks as performance loss, they can offer lower complexity decoding.

3.5.2 Turbo Coding Methodology

Claude Berrou proposed Turbo Codes as a new class of convolutional code which is able to reach close to Shannon Limit in 1993[16]. Turbo codes are a recursive scheme for channel coding in wireless communication technologies. In encoding process of Turbo, two identical recursive systematic convolutional (RSC) coding is used with parallel concatenation [12].

3.5.2.1 Turbo Encoding

In encoding process of Turbo, Turbo codes can be constructed by using many different ways.By using two or more codes, the encoding process was performed. In [57], the researchers show the encoders which are operating recursively, that we can call systematic convolution (RSC) codes.A general implementation of the encoder is shown in Figure 3.3.

In this work, The number of information bits is K= $\{K_o, K_1, K2, \ldots, K_{n-1}\}$ and code word is C, $=\{C_o, C_1, C_2, \ldots, C_{n-1}\}$ where the code word C is varied with code rate R. In the encoder, the input bit sequences, K are sent directly to encoder, EC1 and through an interleaver to second encoder, EC2 such a RSC encoder. The first encoder, EC1 coded the input sequences K, and generate the coded bit sequences $CK1^2 = \{CK1_o, CK1_1, CK1_2, \ldots, CK1_{n-1}\}$. The copy of the input bit stream, K is interleaved by loading into a matrix order and taking out in Pseudo Random Order. And then interleaved data sequence is passed to the second encoder EC2 and generated second coded sequence $CK2^2 = \{CK2_o, CK2_1, CK2_2, \ldots, CK2_{n-1}\}$. In order to transmit the coded bit streams by passing the modulator, the code word consists of K as the systematic bit K and parity bit sequence CK which contain both CK1 and CK2 from the two encoders. The encoder has two output sequences, data sequences K and parity sequence CK. Finally, systematic code bits and parity bits are passed to the modulator in the form of Y= {K, CK}. The decoding process consists of two decoders DC1 and DC2. The decoder received the coded data sequences in the form of X= {K, CK}. The first decoder DC1 outputs a constituent of the transmitted data is K and the second decoder DC2 outputs the secondconstituent of the transmitted data is K which include de-interleaved values. The decoding process is conducted repeatedly in an iterative manner.

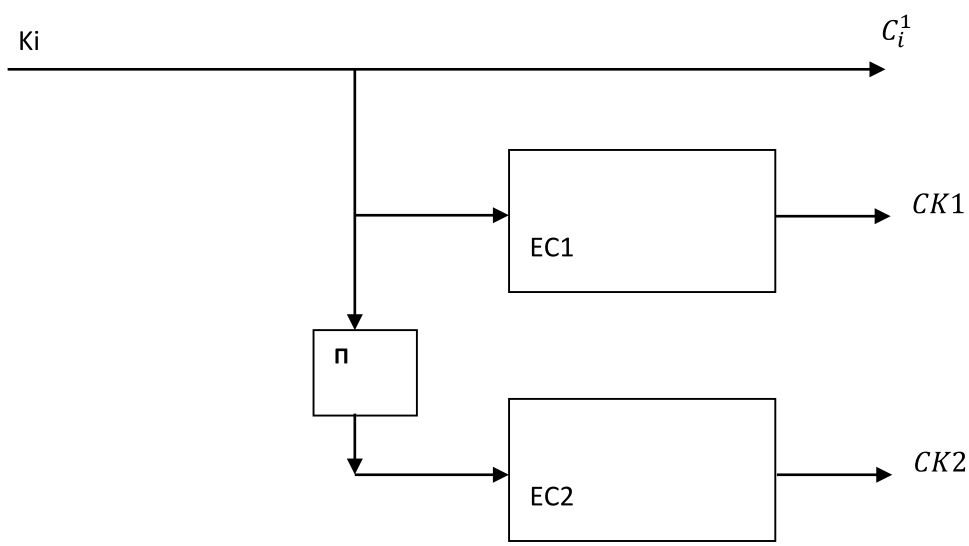


Figure.3.3. Block diagram of Turbo Encoding Process

In the code word, the number of bits arevaryingby code rate. Code rate of R = ½ is defined as overall code rate, it can be usedfor two RSC codes. The systematic bits can be transmitted in that places.A puncturing matrix is usedthe coded bits. In the transmitted symbol,only every second codebit are come out from each of the constituent codes. The systematic bits are permutated by using the permutation matrix Π. Therefore, by using the same information bits, we can have excitedthe two constituent codes in the different orders. For designing better codes, the permutation matrix is a critical design factor. $C_i^1$is included in the code word as the systematic bit (K_i) and $CK1_i^2$and $CK2_i^3$ are encoded bits vectors of the two convolution codes. One or more bits can be included in these vectors and the information bit is defined as K_i, the permutation matrix is defined as Π.

3.5.2.2 The BCJR algorithm

In [1], the researcher proposed an optimal decoding by using the BCJR for turbo coding methods. Based onLPDC's message passing procedure thealgorithm was developed. A symbol based decoder is implemented in BCJR algorithm. The decoder can deliver the correctness probabilities of the symbol and decoding is performed together with each decoded bit. In convolution coding, there are two different state transitions, one state was caused by an information bit, "1"and another state was caused by an information bit,"0". A state transition can denote the states linked together. The state transition occurs between time (i – 1) and time i Si−1 a1 and Sib1, if the transition is caused by a 1 as the information bit. If the transition is caused by a 0 as the information bit, the notation is Si−1 a0 and Sib0correspondingly. The vector of received channel can be denoted as symbols y, where y is perturbed by AWGN. The information bit can be denoted at time i di. For a state transition, the log likelihood ratio is associated with di = 1 and di = 0 can be expressed as follow;

$$\boldsymbol{\lambda_i} = \log \frac{\sum_{S_{i-1}^a, S_{i|di=1}^b} P(S_{i-1}^a, S_i^b, y)}{\sum_{S_{i-1}^a, S_{i|di=0}^b} P(S_{i-1}^a, S_i^b, y)} \tag{3.7}$$

The expression of much possible state transition is more complicated and can be expressed as follow:

$$\lambda_i = \log \frac{\sum_{S_{i-1}^a, S_{i|di=1}^b} P(S_{i-1}^a, S_i^b, y)}{\sum_{S_{i-1}^a, S_{i|di=0}^b} P(S_{i-1}^a, S_i^b, y)} \tag{3.8}$$

We can express the vector y as three parts:

$$y = \sum_{p=1}^{i=1} y_p + y_i + \sum_{k=i+1}^{N} y_k \tag{3.9}$$

$S_i^b$and$y_i$depend only on the state S_{i-1}^a and the bit d_i, whereas $\sum_{k=i+1}^{N} y_k$ depend only on $S_i^b$and the bit d_kk$\in \{i+1, N\}$. The probability of the state transition $S_{i-1}^a S_i^b$ is then given the expression in (4).

$$P\big(S_{i-1}^a, S_i^b \mathrm{Y},\big) = P(S_{i-1}^a, S_i^b, \sum_{p=1}^{i=1} y_p + y_i + \sum_{k=i+1}^{N} y_k \tag{3.10}$$

$$= P\big(S_{i-1}^a, S_i^b, \sum_{p=1}^{i=1} y_p)(y_i i + \sum_{k=i+1}^{N} y_k, S_i^b | S_{i-1}^a\big) \tag{3.11}$$

$$= P\big(S_{i-1}^a, S_i^b, \sum_{p=1}^{i=1} y_p)\big(y_i, S_i^b \big| S_{i-1}^a\big)(\sum_{k=i+1}^{N} y_k, |S_i^b\big) \tag{3.12}$$

Equation 3.12 can be written as

$$P\big(S_{i-1}^a, S_i^b \mathrm{y}\big) = \alpha(S_{i-1}^a)\gamma(S_{i-1}^a, S_i^b)\beta(S_i^b) \tag{3.13}$$

With the following definitions:

$$\gamma(S_{i-1}^a, S_i^b) \quad \triangleq \quad \mathrm{P}(y_i, S_{i-1}^a | S_i^b,) \tag{3.14}$$

$$= \mathrm{P}(y_i | S_{i-1}^a, S_i^b,)\ \mathrm{P}(S_{i-1}^a | S_i^b,) \tag{3.15}$$

$$\alpha(S_{i-1}^a,) \triangleq \mathrm{P}(S_{i-1}^a, \sum_{p=1}^{i=1} y_p) \tag{3.16}$$

$$\beta(S_i^b) \triangleq \sum_{k=i}^{N} y_k | S_i^b \tag{3.17}$$

Furthermore, we may express,

$$\alpha(S_{i-1}^a,) = \sum_{S_{i-2}^a} \alpha(S_{i-2}^a,)\ \gamma(S_{i-2}^a, S_{i-1}^b) \tag{3.18}$$

And

$$\beta(S_i^b) = \sum_{S_{i-1}^a} \beta(S_{i+1}^b)\ \gamma(S_i^a, S_{i+1}^b) \tag{3.19}$$

We substitute Equation (3.13) into Equation (3.8) and obtain Equation (3.20).

$$\lambda_i = \log \frac{\sum_{S_{i-1}^a, S_{i|di=1}^b} \alpha(S_{i-1}^a,)\gamma\left(S_{i-1}^a, S_i^b\right)\beta(S_i^b)}{\sum_{S_{i-1}^a, S_{i|di=0}^b} \alpha(S_{i-1}^a,)\gamma(S_{i-1}^a, S_i^b)\beta(S_i^b)} \tag{3.20}$$

As shown in Equation (3.14), we have:

$$\gamma\left(S_{i-1}^a, S_i^b\right) = \mathrm{P}(S_{i-1}^b | S_i^a,)\mathrm{P}(y_i | S_i^b, S_{i-1}^a,) \tag{3.21}$$

Through knowledge of the nature of AWGN, Equation (3.21) may be written as:

$$\gamma\left(S_{i-1}^a, S_i^b\right) = \mathrm{P}(S_{i-1}^b | S_i^a) \prod_{j=1}^{n} e^{-\frac{(\left(y_i^j\right)(2c_i^j-1)^2)}{2\sigma^2}} \tag{3.22}$$

We compute the logarithm of Equation (3.22) and obtain Equation (3.24).

$$\log \gamma(S_{i-1}^a, S_i^b) = \mathrm{P}(\log(S_{i-1}^b, S_i^a)) + \sum_{j=1}^{n} \frac{(y_i^j - a_i^j)^2}{2\sigma^2} - \log(\surd(2\sigma^2)) \tag{3.23}$$

In this situation, we assume an equal probability of 1's and 0's in the information sequence, P(S_{i-1}^{b}, S_i^{a})) is equal for all permissible states Sb. Therefore, In the decoding procedure, this category may be omitted. We can express the metric of a symbol n as follow;

$$M_u^{ab} = \sum_{j=1}^{n} \frac{(y_i^j)^2 + a_i^j + 2y_i^j a_i^j}{2\sigma^2} \quad (3.24)$$

3.5.2.3 Decoding of Turbo Codes

In this section, the decoding procedure of Turbo code is shown in Figure (3.4) including the constituent RSC decoders of turbo codes.

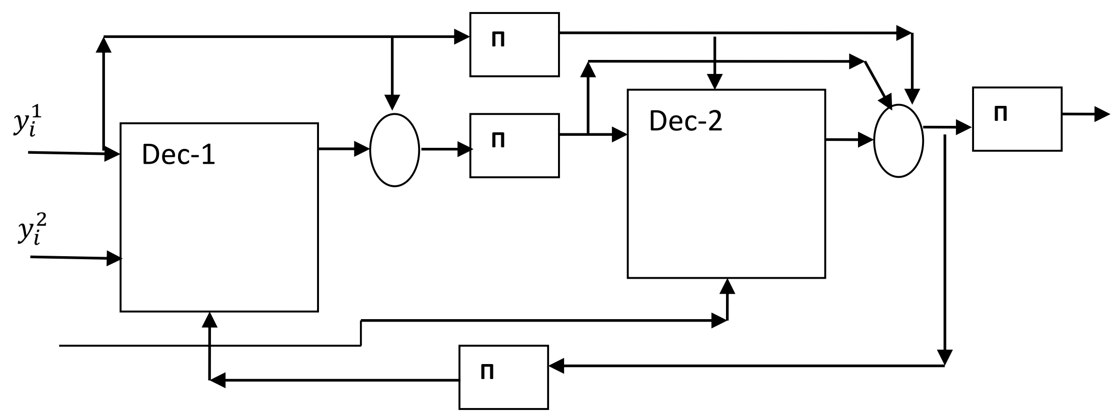


Figure.3.4. Block Diagram of Turbo Decoder, several iterations

In the preceding sections, the decoding algorithms wasdescribed as an algorithm for decoding of constituent RSC codes for turbo coding. The decoding algorithms of each of the constituent codes need to combined in same style, like a message passing process of LDPC for achieving the 'turbo structure'.A multiple iteration decoder isdescribed in Figure 3.4.

At first, the new information bit is fed by first decoder form the last decoder of the former iteration.A feedback loop can be found in this stage. γ^edenoted passed information to the next decoder. This step can be known as the extrinsic part of γ. In the given decoding process, this part can be generated. For ensuring that subsequent decoding stages operate only new information, the subtractions process is performed in this system.This procedure can say that the posteriori probability from one decoder is used as a priori information in the subsequent decoder.

3.6 Description of the Coded OFDM 5G simulation

In this section, coded OFDM system conforming with 5G specifications is presented as in figure 2. We consider OFDM propagation in AWGN channel with multi paths fading. The block of input signals, k information bits, are encoded by the encoder. Coded information (k bits) plus extra bits (x bits) are modulated by three kinds of modulation methods, QPSK, 16 QAM and 64 QAM and serial to parallel conversion are performed for mapping with N subcarrier channels. Inverse fast Fourier transform (iFFT) is carried out to convert from frequency domain to time domain. In a multipath environment, OFDM transmission process is performed over AWGN channel. After converting received time domain signals to frequency domain signals by using FFT, the information bits are demodulated employing demodulation methods. The original bits are restored after decoding the demodulated signals.

In proposed simulation test-bed, we consider code rate as R=k/n where n is variable nodes and m is check nodes for both coding methods. Parity check matrix H is constructed by code word length (m,n). K is information bits, K= {K0, K1, K2,…,Kn-1} and code word is C, ={Co,C1,C2,…,Cn-1}.The length of encoded bits is L=K*1/R and the encoded bits is E, E ={Eo,E1,E2,…,EL-1}. Modulation process is conducted to map the encoded bits with number of sub carrier, N. According to the modulation factor F, the length of modulated bits can be calculated as the following equation 1.

$$L(mod\ i) = {}^{E}/_{F_i} \tag{3.25}$$

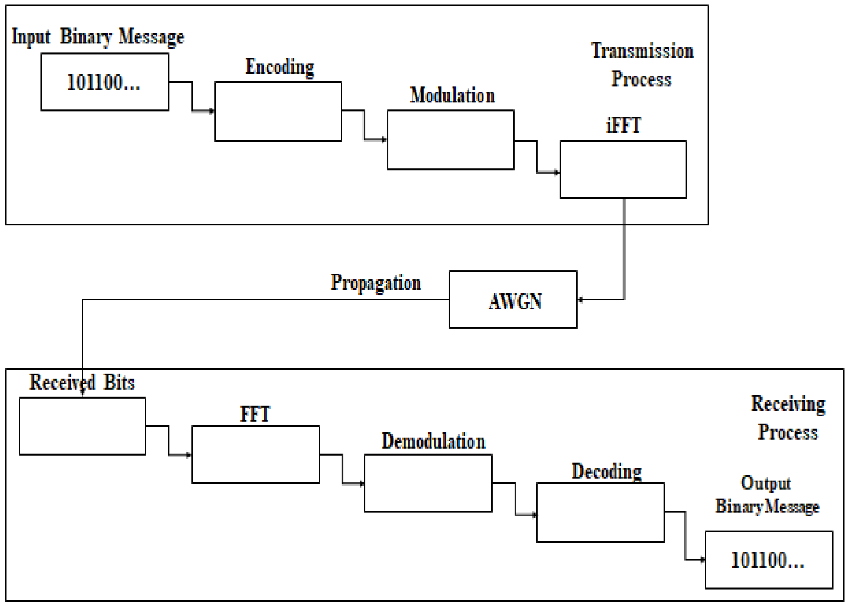


Figure.3.5. Coded OFDM System

Where i is the modulation Method of Fi= {F1, F2, F3} because three types of modulation methods such as QPSK, 16 QAM and 64 QAM are setting up in our simulation, Experiments is conducted with these modulation methods.

In 5G specifications, the actual number of subcarrier N does not map with the modulated bits and it has n bits less than the number of sub carrier N. To map with N sub carrier in OFDM 5G propagation,

$$L(mod\ i) = {}^{E}/_{F_i} + {}^{N}/_{2} \qquad (3.26)$$

In uncoded OFDM 5G communication, the number of input signal, information bits, is B, B= {Bo, B1, B2,…,Bn-1}. According the modulation factor, F, the length of modulated bits can be determined by equation 3.

$$Lu\ (mod\ i) = {}^{B}/_{F_i} \qquad (3.27)$$

Here Lc> Lu

After that, the modulated bits are converted to time domain by iFFT with FFT size. We use FFT=2048 as a 5G standard in this work.

In receiving process, we conduct reverse operation for bit sequences operations.

In coded OFDM, LDPC encoder generates the code word and parity check matrix H twice of original input signal length n if we use the code rate 1/2. For example, for input signal length 1200 bits, fft size is 2048 and encoded bits are 2400.

We design our simulation model by using LDPC and Turbo codes coding methods for coded OFDM 5G propagation as shown in figure 2. This observation presents the close relationship between the coding theory, modulation techniques and Fast Fourier Transform FFT.

3.7 Analysis of Channel Coding Methods on OFDM 5G simulation

Table.3.2. Simulation Parameters

Parameter		Values
Coding Schemes		LDPC & Turbo
Code Rate		1/2
Code length/FFT size		1200/2048
Decoding Methods	LDPC	Sum-product decoder
	Turbo	BCJR

In OFDM modulation, the input data bits are converted so that they can be mapped into the sub carrier's amplitude and phase using modulation techniques such as BPSK, QPSK or QAM. In this work, according to the Verizon 5GTF release 1, the three modulation schemes of QPSK, 64 QAM and 16 QAM are considered as the physical channels. The simulation parameters for the coding process are as given in Table.3.2. The LDPC-coded 5G OFDM simulation is compared with the uncoded 5G OFDM simulation based on the three modulation techniques and the results are shown in next sections.

3.7.1 Analysis on Turbo Coded OFDM in 5G

We performed the simulation on three modulation schemes for Turbo coded OFDM in 5G and analysis the obtaining result over different FFT sizes in figure.3.7.

By doing analysisTurbo coded OFDM simulation over different FFT sizes, we can clearly discover that analysis results obtains better performance for three modulation methods with FFT size=2048 than FFT size=1024. As usual QPSK has the lowest BER in both FFT sizesamong three modulation methods. By investigating in two different FFT sizes, Turbo coded OFDM simulation results have lower BER for FFT size 2048 than FFT size 1024. From this fact, we can approve that FFT size 2048 can be used as a standard for 5G specifications.

By comparing the Turbo-coded OFDM with the uncoded OFDM in 5G, it can be discovered that OFDM in 5G using the Turbo performs better for the three modulation methods than the OFDM in 5G without using the coding technique as shown in figure.3.8. We can conclude that QPSK gives the lowest BER for the three different modulation methods in both FFT sizes. With respect to the two different FFT sizes, the Turbo-coded OFDM simulation results have a lower BER for the FFT size of 2048 than the uncoded OFDM with same FFT size. From this observation, it can be concluded that both coding methods can give lower BER rates and better performance than the uncoded OFDM.

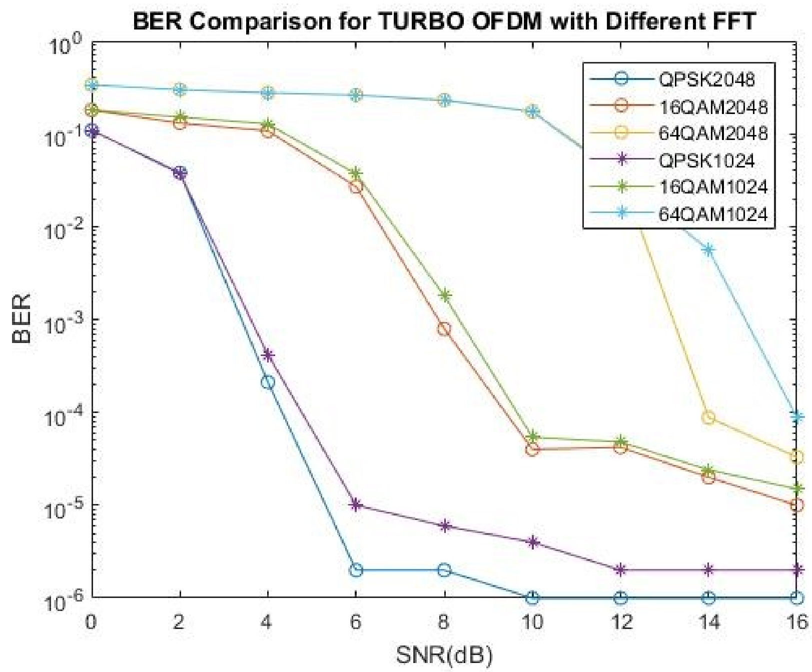


Figure.3.6. Turbo Coded OFDM Analysis Results in 5G for QPSK, 16QAM and 64 QAM (FFT size=1024 and 2048)

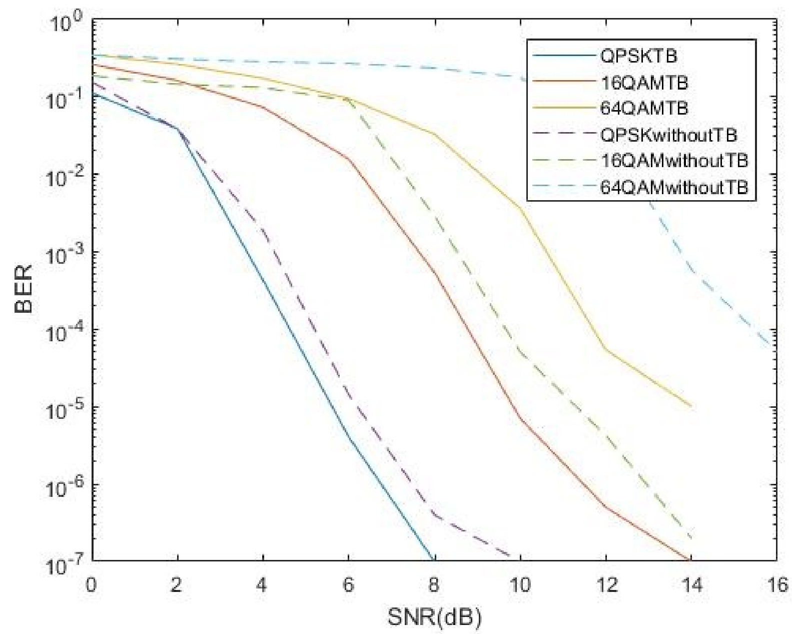


Figure.3.7. BER Comparison for the TURBO Coded OFDM and Uncoded OFDM (fft=1024).

3.7.2 Analysis on LDPC Coded OFDM in 5G

After carrying out the simulation for LDPC coded 5G OFDM using three modulation methods, we obtained and compared their results with uncoded 5G OFDM over different FFT sizes as shown in figure.3.9.The analysis results obtains better performance for three modulation methods with FFT size=2048 than FFT size=1024 in LDPC as well. QPSK also has the best performance with lowest BER in both FFT sizes among three modulation methods. LDPC coded OFDM simulation results have lower BER for FFT size 2048 than FFT size 1024. Owing to this fact, we can say that FFT size 2048 of LDPC can be used as a standard for 5G specifications.

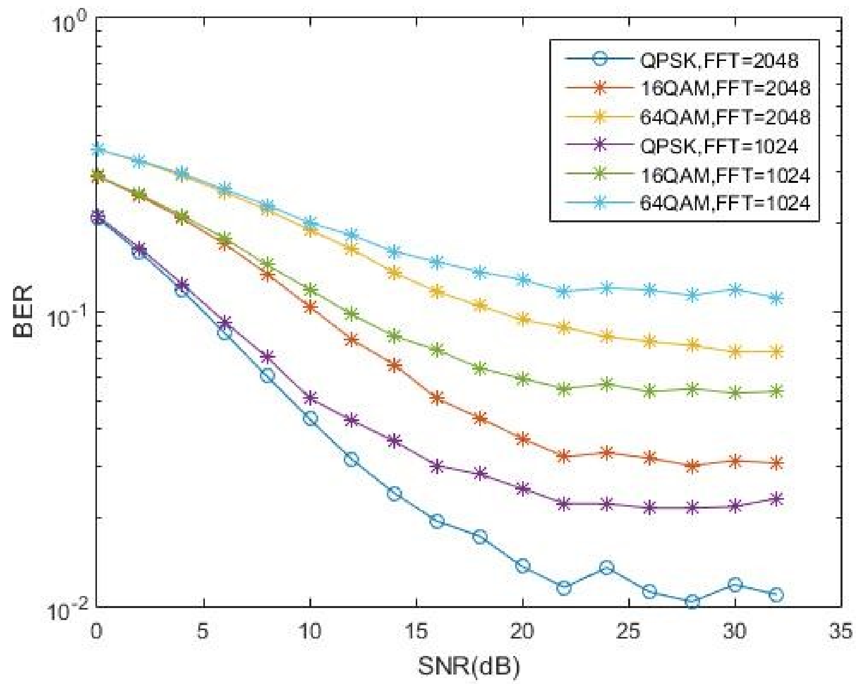


Figure.3.8. LDPC Coded OFDM Analysis Results in 5G for QPSK, 16QAM and 64 QAM(FFT = 1024 and 2048)

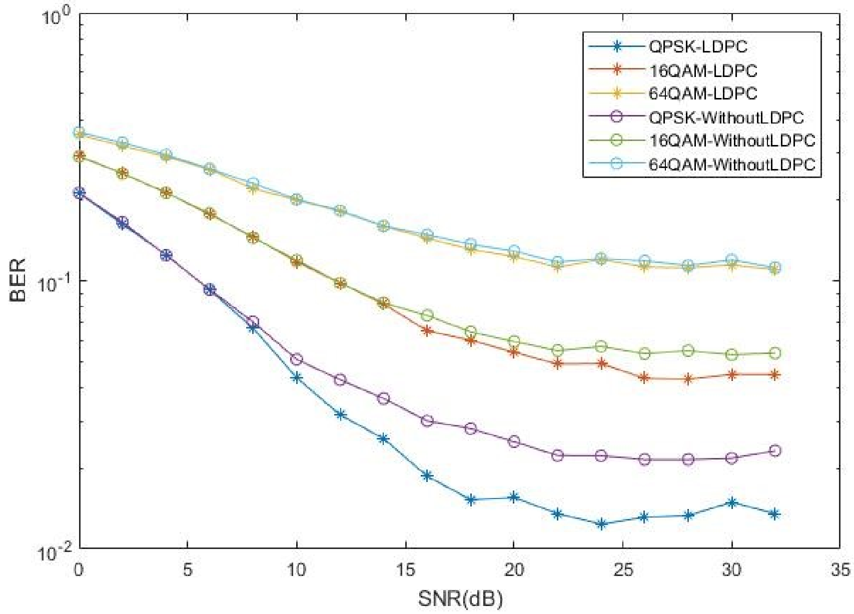


Figure.3.9. LDPC Coded vs. Uncoded OFDM in 5G for QPSK, 16QAM and 64 QAM (FFT size = 1024)

Similar to comparison between Turbo coded and uncoded OFDM in 5G, LDPC coded OFDM 5G produces better and lower BER results than uncoded OFDM 5G for all modulation methods as shown in figure.3.10. Moreover, QPSK of coded LDPC outperforms the two other modulation techniques. Although we have tested LDPC coded OFDM in 5G by using FFT size 1024, we can guess and expect the similar results for FFT size 2048 by observing the simulation results of Turbo coded and uncoded OFDM in 5G.

3.7.3 Comparison between LDPC Coded and Turbo coded OFDM in 5G

The result for comparing between LDPC coded OFDM and Turbo coded OFDM for 5G simulation is as shown in figure.3.11. The same as the findings in analysis of coding methods in OFDM simulations [14,15], we could find that turbo coding is better achievement than LDPC coding in 5G OFDM simulation. In the existing research that analyzed the coding methods in OFDM simulations [12,13], turbo coding achieved a better result than LDPC coding. In this simulation, the Turbo-coded OFDM has a lower bit error rate than the LDPC-coded OFDM.

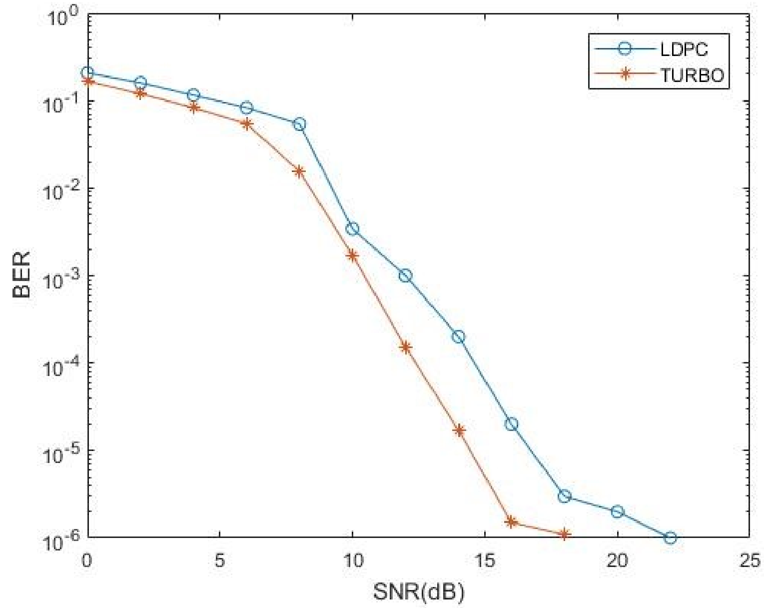


Figure.3.10. Turbo Coded vs. LDPC Coded OFDM in 5G

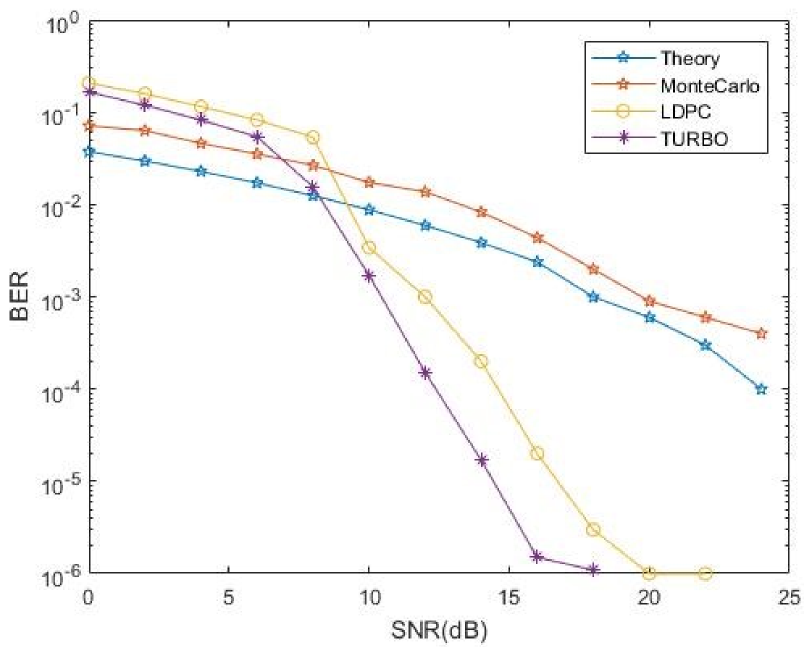


Figure.3.11. BER Comparison for the LDPC-coded OFDM Vs Turbo Coded OFDM (fft=2048).

Finally, the comparison of the simulation results for theLDPC-coded OFDM and the Turbo-coded OFDM for the 5G simulation is shown approved the simulation results by using Monte Carlo and theoretical BER Simulation Results in figure.3.12.According to the simulation results, the results of Turbo coding methods have started lower than Monte Carlo BER around SNR 5 dB and theoretical BER Simulation Results around SNR 6 dB. For LDPC coding methods, the results have lower BER than Monte Carlo BER around SNR 10 dB and theoretical BER Simulation Results around SNR 12 db.

From our simulation results, one is encouraged to select the Turbo codes for the channel coding in 5G wireless networks conforming to the 5G specifications that were released by the Verizon 5G Technology Forum (Version 5th Generation Radio Access; Test Plan release 1) [14]. By using Turbo codes for the 5G channel coding, it is possible to implement 5G wireless networkswitch lower costs because of the backwards compatibility with 3G and 4G technology.

3.8 Discussions

In this chapter, we conducted the experiments of coded OFDM system for 5G network employing two coding methods: LDPC and Turbo in order to correct the communication errors and improve the performance by lowering Bit Error Rate (BER) which is important to support the various services of 5G network. We performed our simulation by using three modulation techniques over AWGN channel with two different FFT sizes. From the experimental results, we can show that coded OFDM systems have better performance giving less BER than OFDM system without using coding methods by measuring BER performance over 5G specifications. The BER depends on the different FFT sizes or the number of subcarriers in 5G OFDM environment. Moreover, we can confirm that the differences between coded and uncoded OFDM in BERs has become larger over SNR values. The BER value is 0.001 less than uncoded OFDM at SNR values 30 dB. We can conclude that applying coding methods to correct communication errors is effective for OFDM system in 5G network.

Since three types of modulation methods such as QPSK, 16 QAM and 64 QAM are proposed in 5G specifications, we evaluated all these modulation methods with different FFT sizes over 5G OFDM simulations. Then, we compared Coded and Uncoded 5G OFDM simulations over three modulations with FFT size 1024 and FFT size 2048. Contrasted to others, QPSK is the best method for both 5G OFDM propagations.

Comparing the coding methods, Turbo coding can give better performance than LDPC coding methods by reducing BER rate effectively. This result motivates to select Turbo codes for 5G channel coding which can save costs for communications industry.

3.9 Chapter Summary

In this chapter, we presented the Coded 5G OFDM simulations Frame Work. Then we discuss two channel coded methods which are implemented in Coded 5G OFDM simulations Frame Work such as LDPC and Turbo Code. In the infrastructure design, we proposed simulation model by conforming 5G specifications which are released form Verizon 5G Technology Forum (V5GTF). The experimentations were conducted over three modulation methods. We evaluated the performance of two coding methods over different FFT sizes and discussed about the analysis results by comparing two channel coding methods. Finally, we approved that two channel coding methods are standard methods of 5G technologies, especially for the V5GTF specifications by comparing Monte Carlo simulation and theoretical simulation.

CHAPTER-4

MODELING AND ANALYSIS OF ERROR PROCESS IN 5G WIRELESS COMMUNICATION USING TWO-STATE MARKOV CHAIN

4.1 Introduction

The fifth generation of wireless technology promises to greatly enhance the speed, coverage and responsiveness of wireless networks [6]. Users have high expectations for future 5G mobile networks with respect to the technology being as simple as possible and providing more functions.In fifth generation wireless communications, data transmission is challenging due to the occurrence of burst errors and packet losses that are caused by multipath fading in multipath transmissions. To acquire more efficient and reliable data transmissions and to mitigate transmission medium degradation in 5G networks, it is important to study the error patterns or burst error sequences that can provide insights into the behavior of 5G wireless data transmissions.

To achieve improvements in network facilities with respect to bandwidth, spectral, energy and signaling efficiencies and reliability, fifth generation network technology needs to utilize an efficient waveform in order to meet the user demands [7]. Orthogonal frequency division multiplexing (OFDM) is obviously a powerful multiplexing technique that is a baseline standard technology of high performance wireless transmissions. Although OFDM can reduce the effects of multipath fading and inter-symbol interference (ISI) by inserting the cyclic prefix (CP), the intra-block OFDM symbol interference has remained as an important factor in degrading the error performance of OFDM systems [22]. A major solution is to combine a coding method with the OFDM system in order to improve the bit error rate (BER) performance of the data transmission system by recovering the data symbol losses. Another major drawback of OFDM systems is their large peak to average power ratio (PAPR), which causes nonlinear distortions in the transmission process. Performance degradation followed as a consequence. To reduce OFDM errors, such as subcarrier losses, large PAPRs, data symbol losses, inter-symbol interference (ISI), etc., channel coding methods become a major solution in this research area. Turbo-code, LDPC code and convolutional code are significant coding methods in the existing studies [20, 21, 22,23].

To evaluate the performance of channel coding methods in next generation wireless communications networks, it is important to explore the behavior of enhanced physical channels and the impacts of the errors in binary data transmissions. There are two types of channels in the wireless data transmission system: physical channels and binary channels. The performance of physical channel models, such as Rayleigh and Rice models, is evaluated using parameters such as the received signal strength, the signal to noise ratio, etc. [26]. For the binary channel models, the channel is characterized using error statistics in terms of burst errors or error clusters. The performance of binary channels is evaluated using the bit error rate (BER) or packet error rate (PER) [16,17,18]. For the performance evaluation of the binary data transmission system, the study of the underlying burst error process and the exploration of the statistical dependencies among errors are important prerequisites.

The statistical and deterministic approaches are employed to model the physical channel characteristics of 5G wireless channels and the statistical characteristics of the error patterns are investigated in order to model the binary channels in 5G wireless transmissions. Knowledge of the error patterns, such as single bit error patterns and burst error patterns, can promote the optimization of wireless data transmissions. For modelling the burst error sequence, the mathematical channel model, which can be divided into the descriptive and generative models, is needed [27]. The statistics of the burst error sequences, which are obtained directly from real digital wireless channels or from computer simulations implementing the entire communication link, can be expressed by using descriptive models. By assessing the error statistics of the descriptive model, the generative models can generate similar burst error sequences [28,29].

In this work, a simulation model was established and evaluated [8] in order to support the design of the coded OFDM 5G simulation. The statistical behaviors of the reference error sequences produced by this simulation model were studied in a descriptive way in order to achieve a better and more reliable communication model. Then, the precise generative error model was proposed using the discrete time, two-state Markov model in order to find more accurate burst error statistics and the optimal way to improve the bit error rate (BER) performance in 5G wireless communications. After comparing the error burst and error gap statistics of the descriptive model and those of the generative model and discovering similar characteristics, it could be concluded that the error process of the coded OFDM 5G simulation can be effectively modeled using a two-state Markov chain.

In this study, a two-state Markov-based 5G error model is investigated and developed to model the statistical characteristics of the underlying error process in the 5G network. The underlying 5G error process was obtained from our 5G wireless simulation, which was implemented based on three different kinds of modulation methods, including QPSK, 16QAM and 64QAM and was employed using the LDPC and TURBO coding methods. By comparing the burst or gap error statistics of the reference error sequences from the 5G wireless simulations and those of the generated error sequences from the two-state Markov error model, we show that the error behaviors of coded OFDM 5G simulations can be adequately modeled by using the two-state Markov error model. Our proposed two-state Markov-based wireless error model can help to provide a more thorough understanding of the error process in 5G wireless communications and to evaluate the error control strategies with less computational complexity and shorter simulation times.

The main motivation of this chapter is to investigate and model the errors in the coded OFDM 5G simulation model in order to achieve more accurate and better performance for the data transmissions of 5G networks. The contributions of this paper are the coded OFDM 5G simulation based on LDPC and Turbo coding [8], analyzing the error process in a descriptive manner based on the reference error sequences of 5G simulations and proposing the generative error model based on two-state Markov chains. The results show that our error models can accurately represent the errors of coded OFDM 5G networks. These error models can be applicable to evaluating and implementing error control mechanisms in order to save both costs and time because we don't need to execute the whole simulation and can generate the accurate error sequence by using proposed error model.

4.2 Literature Review

In next generation wireless communications, the fifth generation technology has evolved as a basic standard technology with prominent high performance characteristics such as a high data transmission rate, low latency, manifold increase in system capacity, energy savings and new, improved QoSs[24,25,30].Although the existing studies have assessed the developments of the above potential key technologies, many challenges still remain, such as interference management, channel modelling and the signal processing complexity in data transmissions [24].

Previous research has determined that the modulation constellation, coding scheme, and channel and resource allocation are key drivers for improving the transmission technology and the above research challenges depend on factors such as the transmission power, transmission time, channel conditions, coding and modulation [30]. To overcome these challenges, channel coding schemes and the combination of channel coding with the OFDM system in next generation wireless transmissions have beenanalyzed in the previous studies [8,20,21,22].

Likewise, channel modelling or error modelling and exploring the error statisticshave become promising research topics in this area. To improve the BER performance of digital wireless transmissions, the error patterns and their statistics have been explored and error models have proposed [15,16,17,18]. The influence of the bit error process on packets based on their length was analyzed by investigating the packet error process and establishing a 2-state Markov process over a 2-state Markov error channel [1]. The modelling of the performance of error correction codes was performed under random and burst errors. A closed form solution provided the parameterization for the 2-state Markov model.

C.Ling-Jyh and H. Hao-Hsiang[2] investigated the two error models for Bluetooth networks by using two FHSS kernels, the ordinary hopping kernel and the AFH hopping kernel. The Markov Chain Monte Carlo (MCMC) method was used to evaluate the proposed model and to prove the consistency of the simulation and analytical methods.

The BER analysis of the Digital Audio Broadcasting (DAB) system for convolutional coded and turbo coded OFDM in an Additive White Gaussian Channel (AWGN) was performed in [3].

The burst error behavior and error profile of Discrete Time simulations were studied for fading channels by applying a tristate memory-less Markov Model in [4], whichevaluated the performance of the error-correction code over the different packet sizes with the bit error rate. The research proved that the longer the data packets, the longer the burst errors and that the larger the packet size, the larger the Bit Error Rate (BER). The experiment was conducted using different packet sizes, such as 300 bits, 1200 bits, 4800 bits and 19200 bits.

The burst errors were modelled by using generative and descriptive (analytical) methods with real wireless transmitted packages in [5].To capture the error behavior of error bursts and error gaps, Elliot's model was applied for the generative and gamma distribution models and the Markov modulated Poisson process (MMPP-2) was applied for descriptive methods. According to the experimental result, the MMPP-2 model is closerto the channel trace and theoretically can be even more precise than Elliot's model.

The generative error models have proposed based on three widely used generative models, namely, the Simplified Fritchman Model (SFM), the Baum-Welch based Hidden Markov Model (BWHMM), and the Deterministic Process Based Generative Model (DPBGM), and by considering factors such as the detection threshold, parameterizations and parallel mapper [16,17,18]. They proved the effectiveness of their proposed models by showing the well-matched characteristics when comparing the reference error statistics of the underlying descriptive models with those of the generative models with respect to both the burst error statistics and BER performance of the coded digital wireless transmission system. According to the literature reviews, error modelling using the real simulation model is the most prominent research area for improving wireless data transmissions in future network technologies. For the purpose of assisting the error control schemes in order to reduce transmission errors and attain better performance in 5G networks, the two-state Markov error model is proposed and evaluated based on our coded OFDM 5G simulation in this paper.

4.3 Theoretical Background and Proposed Model

The following subsections described the theoretical background and proposed model.

4.3.1 Error Modeling

To assess the realistic error behaviors in the coded simulation, a statistical or deterministic precise error model is needed. By investigating the error process, useful knowledge will be gained for the error control and adjustment processes in specific situations of wireless communications. In this work, a discrete Markov model-based error analysis model is proposed, as shown in Fig. 5.

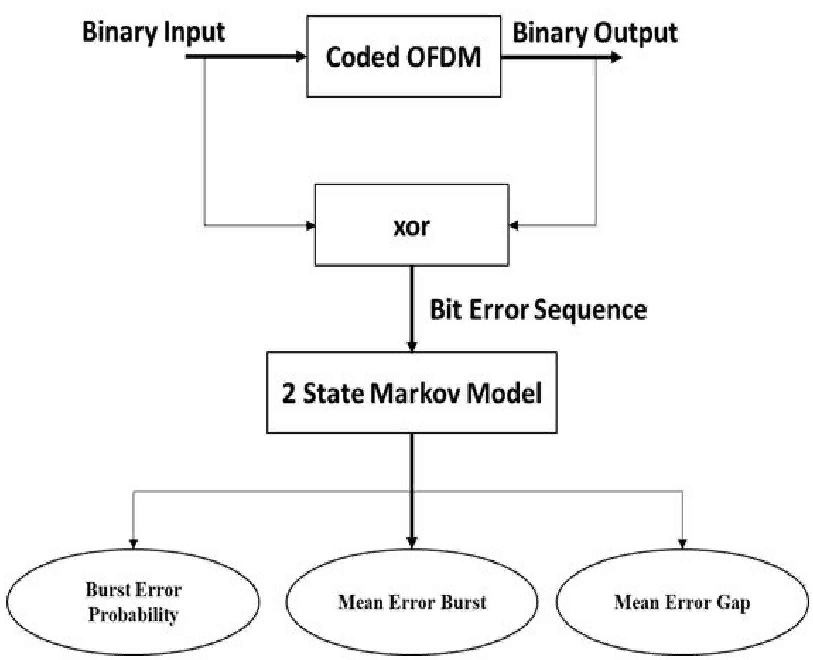


Figure.4.1. Two-State Markov-based Wireless Error Model.

In the data transmission process, X_i is the digital input sequence and Y_i is the corresponding output sequence. As an output sequence including error sequences, Y_i can be considered a binary discrete-time stochastic process and N_i can be considered the noise sequence representing the effect of the multipath channel on the data packets. Then,

$$Y = X + N \tag{4.1}$$

The error process of the data transmission is considered as a binary discrete time stochastic process. The binary input is the set of X,

$X = [x_1, x_2, \cdot\cdot\cdot, x_k, \cdot\cdot\cdot]$, where $X_k \triangleq k^{th}$ is the channel input.

The binary output is the set of Y,

$Y = [y_1, y_2, \cdot\cdot\cdot, y_k, \cdot\cdot\cdot]$, where $y_k \triangleq k^{th}$ is the channel output

The effective noise on the data packets is

$N = [n_1, n_2, \cdot\cdot\cdot, n_k, \cdot\cdot\cdot]$, where $n_k \triangleq k^{th}$ is the channel noise.

The probability of an error occurring in the data transmission is PE,

$PE = [PE_1, PE_2, \cdot\cdot\cdot, PE_k, \cdot\cdot\cdot]$, where

$P_k \triangleq$ is the probability of an error in the k^{th} symbol transmission.

For a binary data transmission channel, the input-output relationship can be expressed as

$$E = X \oplus Y \tag{4.2}$$

where $E = \{e_1, e_2, e_3, \cdot\cdot\cdot, e_k, \cdot\cdot\cdot\}$ is a binary vector or sequence having the elements {0, 1}. A correctly received bit is defined as “0”, and an incorrectly received bit is defined as “1’. Therefore,

$e_k = 0$ denotes that the k^{th} element of X, x_k, is received correctly ($y_k = x_k$) and $e_k = 1$ denotes that the k^{th} element of X that is received has an error ($y_k \neq x_k$). The error sequence can be generated randomly by threshold

$$e_k = \begin{cases} 1 & U_k \leq P_k \\ 0 & U_k \geq P_k \end{cases} \quad (4.3)$$

whereU_k= the number obtained from the k^{th} call to the random number generator.

For modelling the error sequences, the model parameters can be estimated and the expressions can be derived from the burst error statistics and the burst error distributions.

The burst error statistics can be calculated by using the second order statistics, which are extracted from small parts of that error sequences. According to the literature, error sequences are composed of the two classes of consecutive errors and error-free sequences, which are called error bursts and error gaps, respectively. An error gap is a sequence of consecutive zeros between two ones that has a length equal to the number of zeros. An error burst is a series of errors that includes ones and zeros and is restricted by "1" s at the edges. They are defined over the observable length, m.

In an error sequence, E = {e_1, e_2, e_3, · · ·, e_k, · · ·}, where e_k = 1 indicates that a transmission error occurred in the k^{th} transmitted bit, and e_k = 0 indicates that the k^{th} symbol is transmitted correctly. These two natures can be expressed as follows:

$(0^m|1)$ represents that error-free transmissions occurred following an error by observing m or more consecutive bits, and

$(1^m|0)$ represents that consecutive error transmissions occurred following an error-free transmission with m or more consecutive bits.

The probabilities of occurrence of these two events are given by the sum of weighted exponentials as follows:

$$Pr(0^m|1) = \sum_{i=1}^{k} f_i \lambda_i^{m-1} \quad (4.4)$$

$$Pr(1^m|0) = \sum_{i=k+1}^{N} f_i \lambda_i^{m-1} \quad (4.5)$$

whereλ_i, where i = 1, 2, · · ·, k, and λ_i, where i = k + 1, k + 2, · · ·, N, are the eigenvalues of the state transition probabilities A_{gg} and A_{bb}, respectively, and the corresponding values of f_i are functions of the a_{ij}, elements of the state transmission matrix.

4.3.2 Two State Markov Error Model

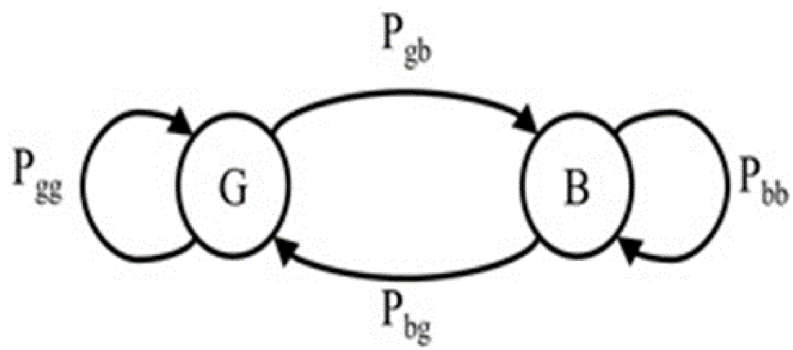


Figure.4.2. Two-State Markov model.

For modelling the error process of a coded OFDM data transmission, the discrete-time, two-state Markov model (MM) is applied, as shown in Fig. 6. In this work, wireless communication channels are considered as the discrete communication channels and the error process is a simple two-state Markov model. In this model, there are two-states: good states and bad states. If the data transmission is error free, it is assumed to be in the good state, and if an error occurs, it is considered to be in the bad state with the bit error probability of h. The state can be represented by the following set:

$$S= \{G, B\}. \tag{4.6}$$

Given that the data transmission started at the initial state St, since the time is continuous, the state will proceed to the next state S_{t+1} at time t+1. We can express the discrete time T as the set of times t

T = [t, t+1, t+2· · ·, t+k]

and the set of the states as

$S = [S_t, S_{t+1}, S_{t+2} \cdots, S_{t+k}]$

At the initial state, the channel might be in a good state or a bad state. At the transition of a new state for a new bit, it will change to a new state or remain in the same state. The state transition will occur with a set of transition probabilities, $P_{ij}(t)$. We expressed the four transition probabilities as follows:

$$P_{gg}(t) = Pr\{S_{t+1} = g \mid St = g\} \tag{4.7}$$

$$P_{gb}(t) = Pr\{S_{t+1} = b \mid St = g\} \tag{4.8}$$

$$P_{bb}(t) = Pr\{S_{t+1} = b \mid St = b\} \tag{4.9}$$

$$P_{bg}(t) = Pr\{S_{t+1} = g \mid St = b\} \tag{4.10}$$

This can be represented by the state transition matrix.

$$A(t) = \begin{vmatrix} P_{gg} & P_{gb} \\ P_{bg} & P_{bb} \end{vmatrix} \tag{4.11}$$

We define Π_t as the state probability distribution at time t. Specifically,

$$\Pi_t = [\ \pi_{t,g}\ \pi_{t,b}],$$

where π is the steady-state vector that expresses the total percentage of a state in a Markov chain. This vector can be computed by raising P to a large power:

$$P^n \rightarrow 1\pi$$

Here, the sum of πi must equal to one.

P is the probability transition matrix.

Π is the steady state probability vector.

1 is the column vector of ones: 1T = (1, 1,…).

Then, the error generation matrix is defined as

$$Er = \begin{vmatrix} \Pr\{c/g\} & \Pr c\{c/b\} \\ \Pr\{e/g\} & \Pr\{e/b\} \end{vmatrix} \tag{4.12}$$

Where “c” denotes that a correct decision is made and “e” denotes that an error is made.

By simple matrix multiplication, it follows that the unconditional probability of a correct decision Pc and an error Pe are given by

$$|P_c P_e| = \Pi_t Er^T \tag{4.13}$$

whereΠ_t is the steady-state state distribution matrix and Er^T is the transpose of the error generation matrix Er.

4.3.3 Estimation of Markov Model Parameters

In the parameter estimation of the Markov Model, the Baum-Welch forward-backward algorithm is a well-known and obvious method [9, 10]. It supports the mitigation of the computational complexity in the evaluation of all the states of the model using the training data. The Baum-Welch algorithm was established based on the computations of two different probabilities, the forward path probability and the backward path probability. By using these probabilities, the parameters of the proposed Markov model can be estimated.

The Markov model for a discrete channel is described using the N ×N state transition matrix A and the M × N error probability generation matrix E. An iterative procedure for estimating these parameters Γ = {A, Er} from a given error sequence is obtained using the coded OFDM 5G simulation

$E = \{e_1, e_2, e_3, \cdots, e_t, \cdots, e_T\}$, based on the Baum-Welch algorithm [11]. This iterative algorithm is designed to converge to the maximum likelihood estimator of Γ = {A, Er} that maximizes Pr(Er|Γ).

The parameters of BMW, which are the estimates of the elements of the state transmission matrix and the estimates of the elements of the error generation matrix, can be computed as follows:

$$A_{ij} = \frac{\text{expected number of transitions from i to j}}{\text{expected number of transitions from i}} \quad (4.14)$$

$$Er(e_k) = \frac{\text{expected number of times } e_k \text{ is occured in state j}}{\text{expected number of visit to state j}} \quad (4.15)$$

In the next steps, we described the calculations required to implement the Baum-Welch algorithm. We would like to express the simple procedure for theBaum-Welch algorithm as follow;

Step 0: Γ = {A,B} is defined as initiative model

Step 1: Firstly, the forward variables are computed with that model

$$\propto_t (i) = \Pr[O_1, O_2, \dots \dots . O_t s_t = i|\Gamma] \quad (4.16)$$

And then "backward variables" are calculated as followed;

$$\beta_t(i) = \Pr[O_{t+1}, O_{t+2}, \dots \dots . O_T|s_t = i|\Gamma] \quad (4.17)$$

For t=1,2,..,N. we expressed the details calculations as follow;

Forward variable: three steps of calculation are composed in the forward variables calculations: These are Initialization, induction, and termination as follow;

Initialization:

$$\propto_1 (i) = \pi_i b_i(O_i), i = 1,2, \dots . . N \quad (4.18)$$

Induction:

$$\propto_{t+1} (j) = \left|\sum_{i=1}^{N} \propto_t (i) a_{ij}\right| b_{\boldsymbol{j}}(\boldsymbol{O_{t+1}}), \quad (4.19)$$

$$1 \le t \le T - 1, 1 \le j \le N$$

Termination

$$\Pr[\bar{O}]\Gamma] = \sum_{i=1}^{N} \propto_T (i)\beta_T(i) \tag{4.20}$$

Note that

$$\sum_{i=1}^{N} \propto_T (i) = \sum_{i=1}^{N} \Pr[O_1, O_2, \dots \dots . O_T s_T = i|\,\Gamma] = Pr[\bar{O}|\,\Gamma] \tag{4.21}$$

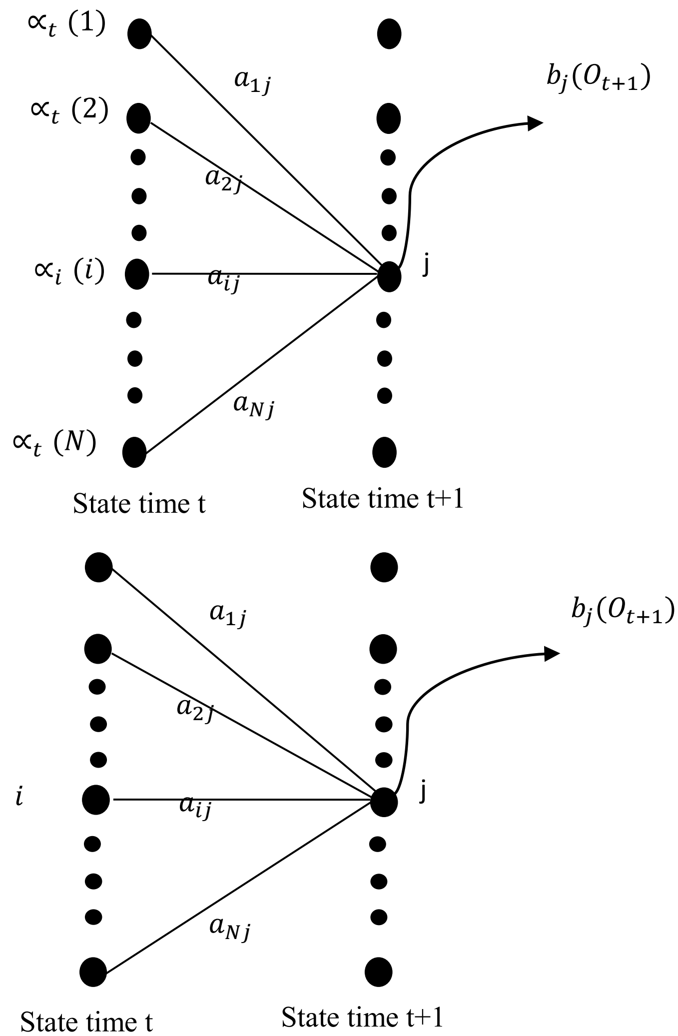


Figure.4.3. Parameter estimation for the HMM.

There are two steps in the calculation of Backward variables:

These are initialization and induction as follow;

Initialization:

$$\beta_T(i) = 1, i = 1,2, \dots, N \tag{4.22}$$

Induction:

$$\beta_t(i) = \sum_{j=1}^{N} \beta_{t+1}(j) b_j(O_{t+1}) a_{ij}, \tag{4.23}$$

$$1 \le t \le T-1, 1 \le j \le N$$

Figure 4.3 expressed the detail of this calculations.

Step 2: the next step is to compute

$$\gamma_t = \Pr[s_t = i \,|\bar{O}, \Gamma] = \frac{\alpha_t(i)\beta_t(i)}{\Pr[\bar{O}|\Gamma]}; i = 1,2, \dots \dots, N \tag{4.24}$$

The quantity $\xi_t(i,j)$ is defined by

$$\xi_t(i,j) = \Pr[s_t = i, s_{t+1} = j \,|\bar{O}, \Gamma] = \frac{\alpha_t(i) a_{ij} b_j(O_{t+1}) \beta_{t+1}(j)}{\Pr[\bar{O}|\Gamma]} \tag{4.25}$$

which can be calculated as follows:

According to equation (4.26), the new state of transition probability $\hat{a}_{ij}$ can be determined.

$$\hat{a}_{ij} = \frac{expected\ number\ of\ transition\ from\ i\ to\ j}{expected\ number\ of\ transition\ from\ i} = \frac{\sum_{t=1}^{T-1} \xi_t(i,j)}{\sum_{t=1}^{T-1} \gamma_t(i)} \tag{4.26}$$

Next $\hat{b}_j(e_k)$, defined by

$$\hat{b}_j(e_k) = \frac{expected\ number\ of\ times\ e_k\ is\ emitted\ from\ state\ j}{expected\ number\ of\ visit\ to\ state\ j} \tag{4.27}$$

$$= \frac{\sum_{t=1|O_t=e_k}^{T} \gamma_t(j)}{\sum_{t=1}^{T} \gamma_t(j)} \tag{4.28}$$

is computed.

We can also compute

$$\hat{\pi}_i = (expected\ number\ of\ times\ in\ state\ S_i at\ time\ t = 1)$$

$$= \alpha_1(1)\beta_1(1) \quad (4.29)$$

Step 3: with the new values of $\hat{\Gamma} = \{\hat{A}, \hat{B}, \hat{\pi}\}$, or equivalently $\hat{\Gamma} = \Gamma$, go back to step 1 and operate it repeatedlyreached up to the level of convergence.

4.3.3.1 Scaling

To prevent numerical underflow, the forward and backward variables of the Baum-Welch algorithm are scaled using the scaling constant vector Ct. We can define the scaling constant vectors for the forward variable αt and the backward variable βt as follows:

$$C_t = \sum_{i=1}^{N} \propto_t (i) \quad (4.30)$$

The scaled values of $\alpha_t(j)$, denoted $\alpha_t(j)$, are given by

$$\alpha_t(j) = \alpha_t(j)/ C_t \quad (4.31)$$

This, of course, implies that

$$\sum_{i=1}^{N} \propto_t (i) = 1 \quad (4.32)$$

For scaling the backward variables, we need to save the values of C_t and used it.We can express the scaledvalues of $\beta_t(i)$, denotedβ_t,are as follow;

$$\overline{\beta_T}(i) = \frac{\beta_i(i)}{C_t} \quad (4.33)$$

With the initialization;

$$\overline{\beta_T} = \frac{1}{C_T} \quad (4.34)$$

where the column vector containing all ones can be defined as '1'. If we wish, we can have normalized the gamma variable but we do not need to scale the gamma variables.

4.3.3.2 Convergence and Stopping Criteria

Defining the stopping criteria is a critical challenge for iterative methods. Since the Baum-Welch algorithm is an iterative method, it is necessary that the optimal level of the stopping criteria be met within the given accuracy. To accurately estimate the desired parameters of Baum-Welch algorithm, A and Er, the execution of the algorithm is allowed to continue until the elements of the parameters no longer change from iteration to iteration. For this reason, the maximum likelihood solution can support the determination of the convergence for continuing the iteration until the optimal value of Pr(Er|Γ) is reached. The optimal value of Pr(Er|Γ) can be express using the scaling constant vector Ct as follows:

$$\Pr(eR/\Gamma) = \prod_{t=1}^{T} C_T \tag{4.35}$$

Equation (4.36) express this small number for T large as follow;

$$\log_{10} \Pr\,[\bar{O}|\,\Gamma] = \sum_{t=1}^{T} \log_{10} C_t \tag{4.36}$$

Foragivensetofdata,the estimation of A and B arenot unique without the initial process of estimation of these parameters. After that Πarespecified. Corresponding to the initial conditions, various combination of A and B may generate statisticallyequivalent results and a specific result.

In this experiment, the log likelihood function is illustrated in Figure.4.4.shows the convergence of the absolute value of the log likelihood function for different iterations with Eb / No from (0 to 5) dBs. The Baum-Welch algorithm finds the local maxima and does not change considerably after the initial iterations. It can be seen that the log likelihood function reaches the optimal point for convergence in about two iterations. Note that this conclusion is consistent with the preceding computations of Ak and Bk for 20 iterations. Note also that, as discussed previously, the likelihood numbers are very small.

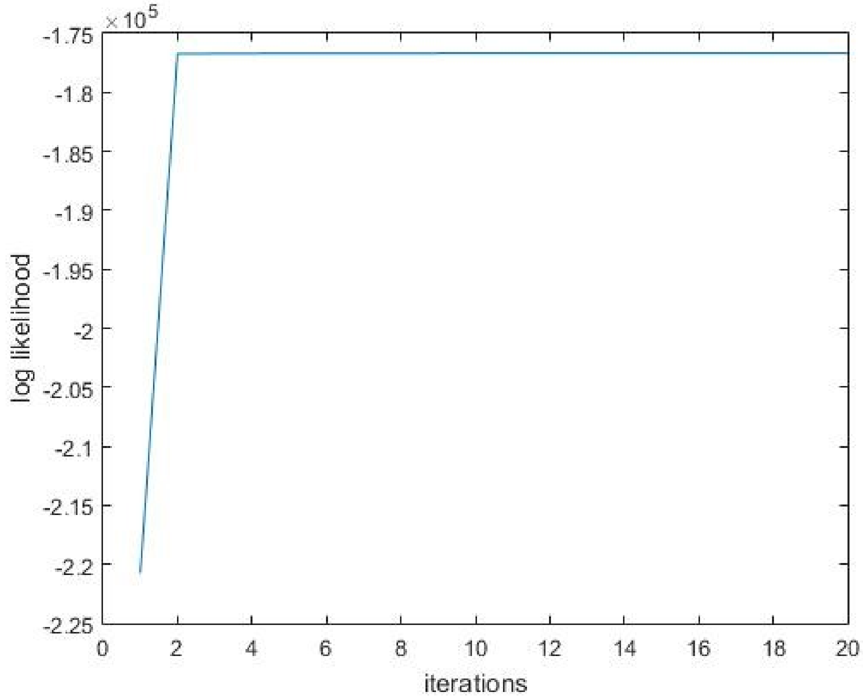


Figure.4.4. Log Likelihood Function for Parameters A and Er.

4.3.3.3 Block Equivalent Markov Models

Among many parameter estimation algorithms of mathematical models, the Baum-Welch algorithm is well known algorithm which based on an error vector. A huge amount of millions of symbols is included in this error sequence. Even for small values ofa_{ij}, it will take the long observation times for accurate estimated results.

For accurate estimation of performance of entire system, we need to care about these small values as an important factor. For the long error vector, the Baum-Welch algorithm can have big computational burden. In the given error sequence, thecalculation of the forward and backwardvariables was performed for each symbol. Sometimes, slow convergent calculation can be a computational burden. The error vector has long runs of zeros for lowerror probability applications,Furthermore,for defining accurately the error model,asignificant number of error events must be included in error vectors.The Baum-Welchalgorithm is especially inefficient for these situations, and it necessary for faster algorithms.For overcomingabove problems, the researcher proposed the mechanism that composed of the forward and backward variables. This mechanism can calculate by using a block matrix version as follow;

$$A = \begin{bmatrix} A_{00} & A_{01} \\ A_{10} & A_{11} \end{bmatrix} \tag{4.37}$$

By using (4.37), we can express the relationship between the terms of the matrix. The relationship can be express in the Figure (4.5).For reducing the computational burden, we can pre-compute the powers of submatrices which involved in the computationsand we can used it again.

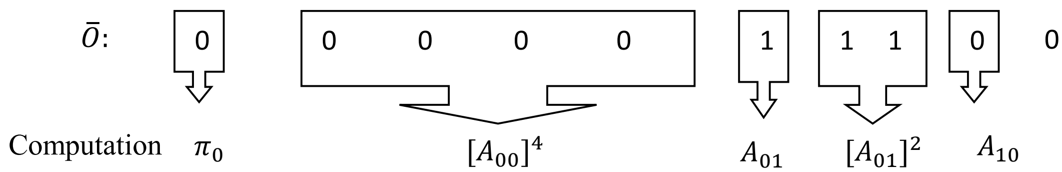


Figure.4.5. Computation for the sequence 00000111000 (Version 1).

In [6], the researcher proposed another modification which is based ona generalMarkov model. The model was developed by using k good states and N − k bad state. This model is similar to Fitchman Model. We can express in equations (4.38).

$$A = \begin{bmatrix} \Lambda_{00} & A_{01} \\ A_{10} & \Lambda_{11} \end{bmatrix} \tag{4.38}$$

We can see that Λ00 and Λ11 be as diagonal matrices. We can note that this models aslockdiagonal Markov models. Owning to this, in the error burst, the state can be changes state only at the last portion of a burst and the channel is remained the same. As a consequence, we can compute all variables during time stepsin which the error symbol are changing.Otherwise, we can compute variables at the initiative state of each error burst rather than calculating for every symbol. Owing to this, the calculation process isexpress in Figure 4.6. During long burstsof ones and zeros,increasing the diagonal matrix power are included rather than increasing arbitrary power matrices. Only atthe transition process, matrix multiplications occur from one burst to another. Therefore,this modification can achieve the efficient computations andwe can operate the long error bursts by reducing the computationalload and storage burden.

In this model, we focus on run length distribution as 1 and 0. Therefore, we can make the error vector in a very compact form. Error sequences can be expressed as follow;

$$E =[000001110000000000000011000000000000000000000100] \quad (4.39)$$

For the above error sequences, we can express the run-length vector as follow;

$$V=[0^5 1^3 0^{14} 10^2] \quad (4.40)$$

Equation (4.39) expressthe error vector and equation (4.40) describe the run-length vector.However, further studies were performed in [1, 14, 15]. Figure 4.6 expressed the use of modified algorithm;

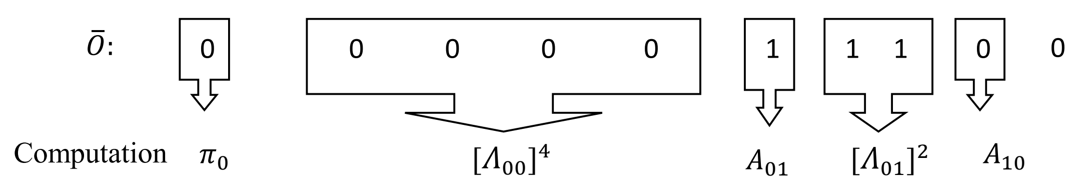


Figure.4.6 Computations for the se quence 0000011100 (Version 2).

The different parameter values of the physical wireless channel are needed to be calculated for Markov model as an Irrespective of this algorithms. The discretechannel model has to estimated again If the physical wireless l channel is changed in any way. In this kind of situation, the Markov model have to developed by using the measurements simulation. Therefore, for the design and analysis of errorcontrol coders and interleavers, we can developa two state Markov models for theunderlying channel.

4.3.4 Proposed Two State Markov Based Generative Error Model

In this study, we proposed two states Markov based generative error model for improving performance of 5G simulation by saving execution time and cause effectively. In our proposed system, we can divide two parts, coded OFDM 5G simulation frame work and two states Markov based generative error model. In first part of this research, we proposed coded OFDM 5G simulation frame work by implementing two 5g standard coding methods in 5GTF specification. Then, we conduct the analysis on two standard channel coding methods in multipath fading environment of 5G network. In this research, we consider LDPC and turbo code as a backward compatibility of LTE, 4G and 3G according to 5G specifications of Verizon 5G Technology Forum released test plan. This proposed simulation frame work provides two reference error sequences for error generation process. For experiment and evaluation, three modulation methods are implemented including, including QPSK, 16QAM and 64QAM.Moreover, we do the analysis the abilities of coded OFDM 5G simulation over different sizes.

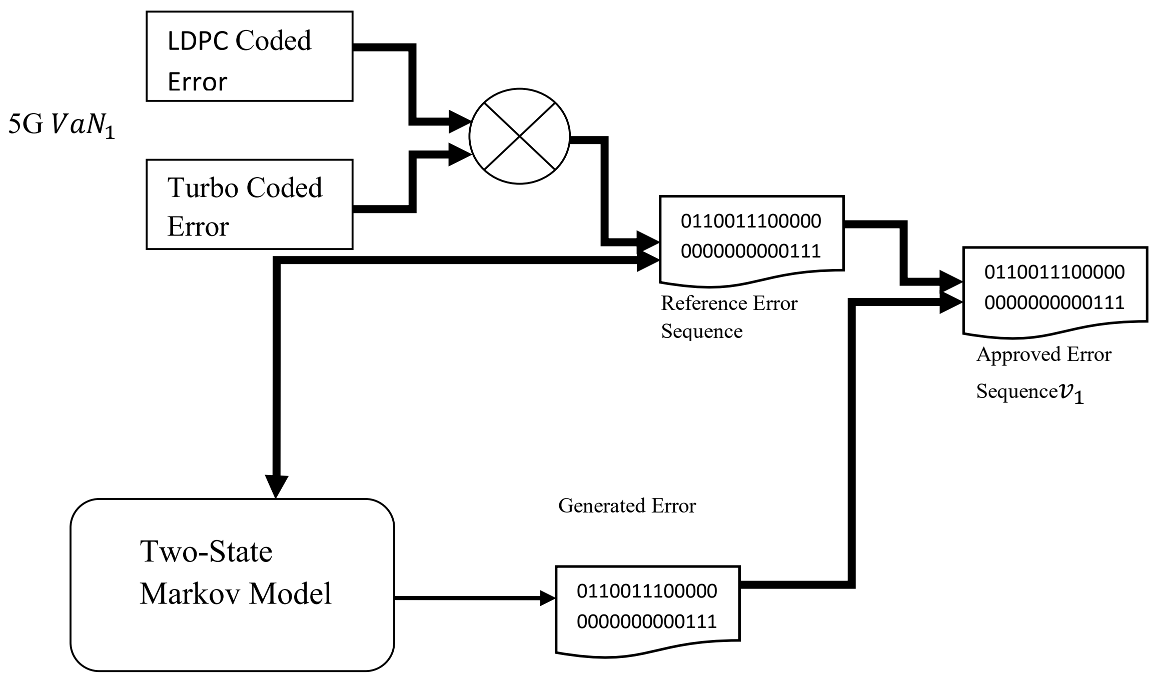


Figure.4.7 Proposed Two State Markov Based Generative Error Model

In second part of this research, we proposed a two-state Markov-based 5G error generative model for modeling the different statistical characteristics of the underlying error process in the 5G network. The underlying 5G reference error sequences are obtained from our 5G wireless simulation. The binary error sequences are generated by referencing two reference error sequences and using two-state Markov model.For estimating the error model, the Baum-Welch algorithm is used. Then the error probability and run-length distribution, error gap and error burst, of the generated error sequences are compared with original error sequence.

4.4 Simulation and Experiment of Proposed Two-State Markov Based Generative Model

In this simulation, two reference error sequences are produced by the coded OFDM 5G simulation based on the LDPC and Turbo coding and used. They are represented by a blue line and labelled as ‘experiment’. The error sequence generated by the simulation of the proposed Two-state Markov error model is expressed by the orange colour and labelled as ‘model’. The x axis represents the probabilities of error gaps, Pr{0m|1}, and error bursts, Pr{1m|0}, and the y axis represents the length of m observation intervals. The reference error sequence has 170400 bits for the training process for model simulation. The burst size is 3 for all modulation methods. The error free (gap) size changes depending on the error occurrences.

4.4.1 Simulation Model Description

In this section, Markov simulation model is established to demonstrate the determinationof a Markov error model. Based on this Markov Model, the error sequences are generated. The generate error sequences are binary sequences, the length of binary sequences, N=20,000. The symbol error sequences are represented by binary sequences. Since the error sequences are binary sequences, “1” can defined as symbol error and “0” can defined as correct bit.

As an assumption, the error can occur in both with different probabilities as follow;

$$\Pr\{E|S1\} = 0.05 \tag{4.41}$$

$$\Pr\{E|S2\} = 0.50 \tag{4.42}$$

The probabilities will occur according to the error probability matrix.

$$B = \begin{bmatrix} 0.95 & 0.50 \\ 0.05 & 0.50 \end{bmatrix} \tag{4.43}$$

Equation (4.44) expressed state transition matrix,

$$A = \begin{bmatrix} 0.95 & 0.05 \\ 0.10 & 0.90 \end{bmatrix} \tag{4.44}$$

The error sequences can be generated according to these two parameters. By using the Baum-Welch algorithm, these error sequences can be estimated. Corresponding to the estimated parameters, we can estimate the channel model. The estimated channel model can be determined by the run-length distribution and the error probability by comparing with thosefrom of the original sequence generated. By using the generatederror sequence,the parameters can be estimated based on the Baum-Welch algorithm. The estimated procedure is expressed in step by step as follow;

After 1thiteration, the results are as follow:

$$\hat{A} = \begin{bmatrix} 0.7348 & 0.2652 \\ 0.0031 & 0.9969 \end{bmatrix} B^{\hat{}} = \begin{bmatrix} 0.9974 & 0.6610 \\ 0.0026 & 0.3390 \end{bmatrix} \tag{4.45}$$

After 10thiteration, the results are as follow:

$$\hat{A} = \begin{bmatrix} 0.6310 & 0.3690 \\ 0.0022 & 0.9978 \end{bmatrix} B^{\hat{}} = \begin{bmatrix} 0.9953 & 0.6629 \\ 0.0047 & 0.3371 \end{bmatrix} \tag{4.46}$$

At the 20th iteration, which is the termination point, after 10thiteration, the results are as follow:

$$\hat{A} = \begin{bmatrix} 0.5563 & 0.4437 \\ 0.0017 & 0.9983 \end{bmatrix} B^{\hat{}} = \begin{bmatrix} 0.9926 & 0.6636 \\ 0.0074 & 0.3364 \end{bmatrix} \tag{4.47}$$

The log likelihood function is illustrated in Figure. 4.8. It can be seen that thelog likelihood function converges in about 2 iterations. Note that this conclusionis consistent with the preceding computations of Ak and Bk for k = 10 and k = 20. Note also that, as discussed previously, the likelihood numbers are very small.

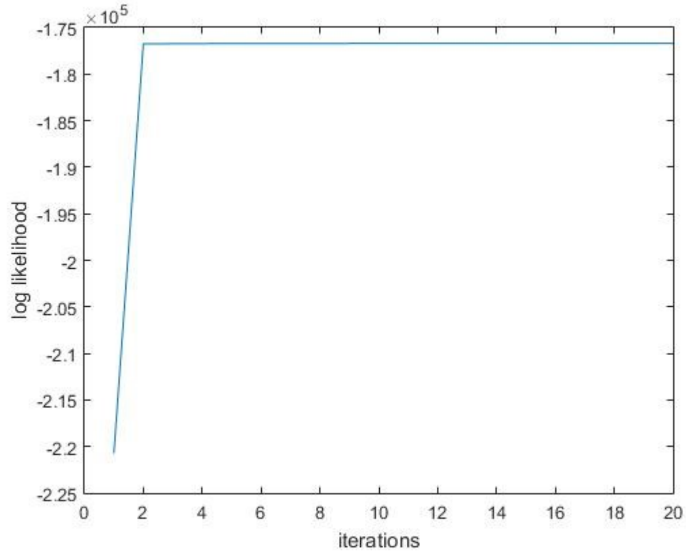


Figure.4.8. Log likelihood function for Proposed Simulation Framework

4.4.2 Simulation Results of the Estimated Markov Model Compared with LDPC Coded OFDM

The performance of the estimated two-state Markov model is also evaluated by comparing it with the LDPC-coded OFDM 5G simulation based on the parameters of the error gap probability Pr(0m|1), the error burst probability Pr(1m|0), and the burst error probability PE. All experiments were performed and evaluated over 20 iterations.

In Fig. 4.8, the comparison of the error gap Pr{0m|1} for the error sequences of the LDPC-coded OFDM 5G simulation and the error gap Pr{0m|1} of the error sequences generated by the Markov model using the Baum-Welch algorithm are expressed. From these simulation results, it can be clearly seen that the error gap probabilities of the estimated Markov model and the LDPC-coded OFDM 5G simulations are symmetrically identical for every interval for the 16QAM modulations, although there is a slight difference in the neighbourhood of m=10 for QPSK and between m=10 and m=20 for the 64QAM modulation.

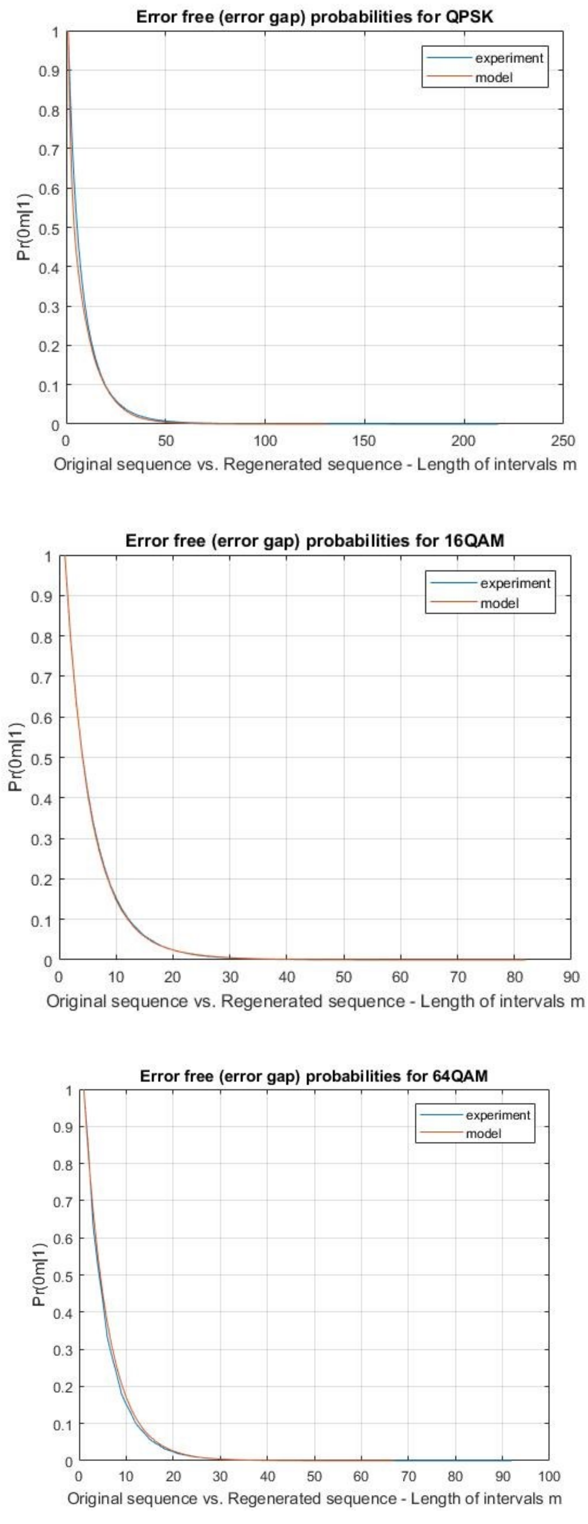


Figure.4.9. Error gap histograms for the error sequences of the LDPC-coded OFDM 5G simulation and the error sequence resulting from the 2 state Markov model.

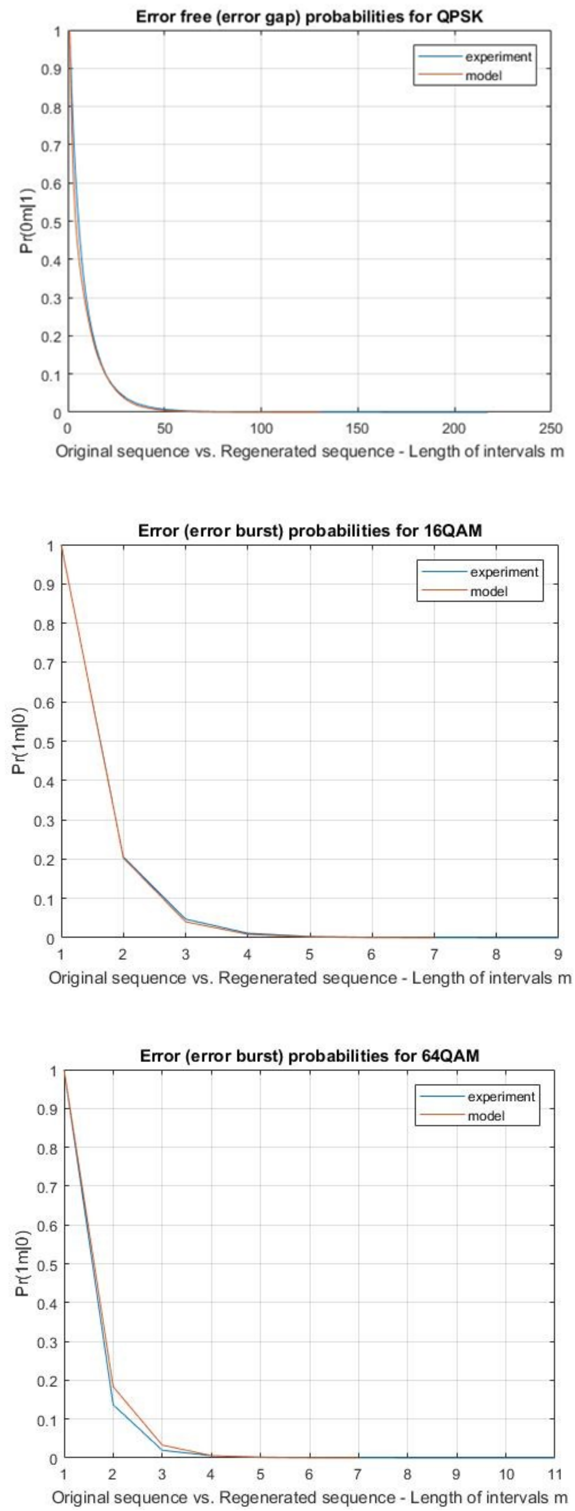


Figure.4.10. Burst error histograms for the error sequences of the LDPC-coded OFDM 5G simulation and the error sequences resulting from the 2 state Markov model.

The results of the error burst Pr{1m|0} for the error sequences of the LDPC-coded OFDM 5G simulation and the error burst Pr{1m|0} using the data generated by the model estimated by the Baum-Welch algorithm are also nearly the same as in Fig. 9. It can be clearly observed that the burst error probabilities of the estimated Markov model and the LDPC-coded OFDM 5G simulation are symmetrically identical for every interval for QPSK and 16QAM modulations although there is a few difference between m=2 and m=4 for 64QAM modulation.

4.4.3 Simulation Results of the Estimated Markov Model Compared with the Turbo Coded OFDM

The performance of the estimated two-state Markov model is also evaluated by comparing it with the Turbo-coded OFDM 5G simulation based on the parameters of the error gap probability Pr(0m|1), the error burst probability Pr(1m|0), and the burst error probability PE. All experiments were performed and evaluated over 20 iterations.

In Fig. 10, the curves are symmetrically close for the error gap Pr{0m|1} of the error sequences of the Turbo-coded OFDM 5G simulation and the error gap Pr{0m|1} obtained from the data generated by the model using the Baum-Welch algorithm. By comparing the estimated Markov model with the Turbo-coded OFDM 5G simulation, it can be clearly seen that the error gap probabilities are symmetrically identical for every interval for the QPSK and 16QAM modulation methods, but the results of 64QAM have slight differences in the interval lengths (m) of 2 and 6.

The best match of the error burst Pr{1m|0} for the error sequences of the Turbo-coded OFDM 5G simulation and the error burst Pr{1m|0} using the data generated by the model estimated by the Baum-Welch algorithm is presented in Fig. 11. From the figures, it can be seen that the error gap probabilities are symmetrically identical for every interval for the QPSK and 16QAM modulation methods, although there are slight differences around m=4 in 64QAM.

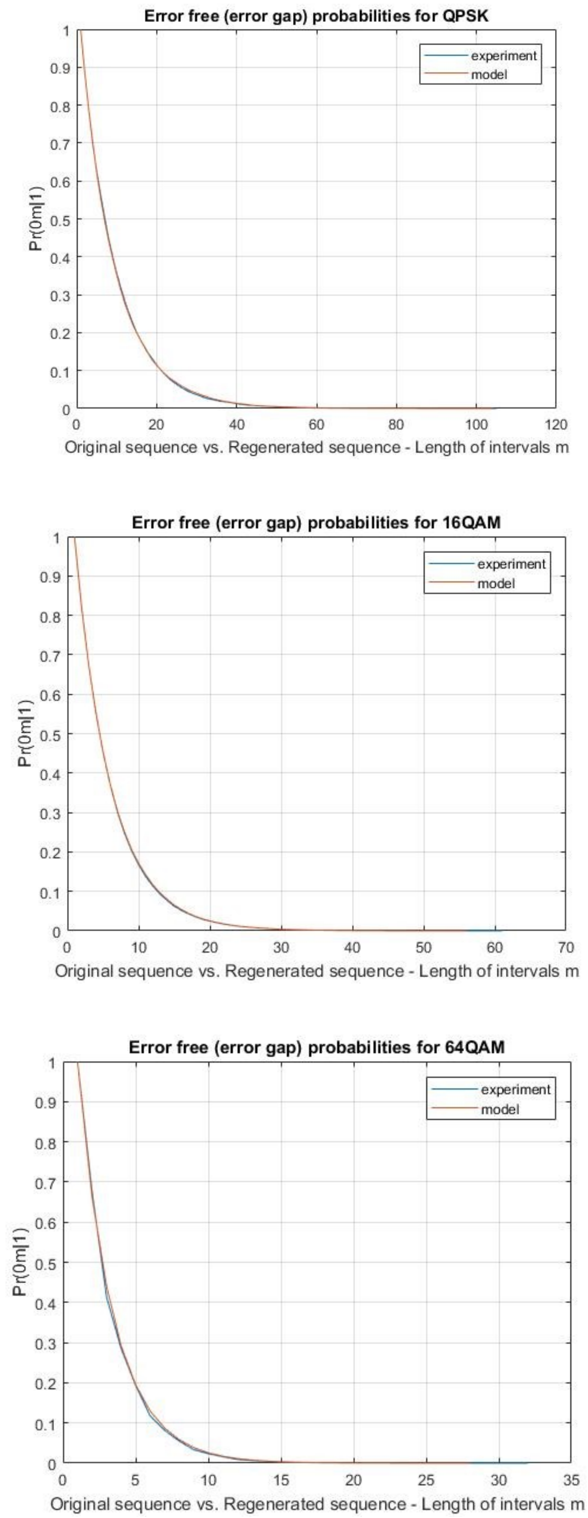


Figure.4.11 Error gap histograms for the error sequences of the Turbo-coded OFDM 5G simulation and the error sequence resulting from the 2 state Markov model.

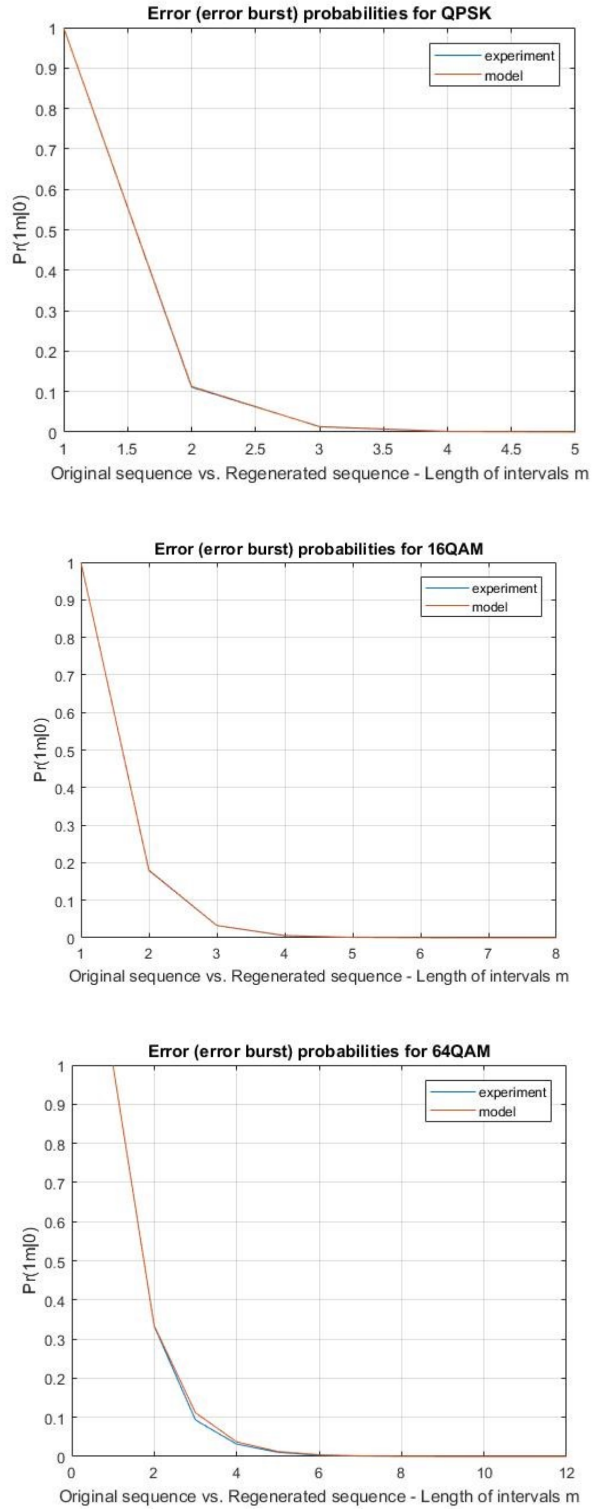


Figure.4.12. Burst error histograms for the error sequences of the Turbo-coded OFDM 5G simulation and the error sequences resulting from the 2 state Markov model.

4.4.4 Burst Error and Error Probability Analysis on LDPC and Turbo Coding in 5G

Burst error analysis was conducted for the estimated two-state Markov model and compared with the LDPC and Turbo-coded OFDM 5G simulations based on the three different modulation methods of QPSK,16QAM and 64 QAM, as shown in Fig. 12. The burst error probabilities of the estimated model are very close to those of the coded OFDM 5G simulation and there are very few differences over all modulation methods.

The probability of a burst error in the Turbo-coded OFDM 5G is 0.108374 and the burst error probability for the Markov model is 0.0.108539 using QPSK Modulation. Since the probabilities are nearly consistent, it can be said that our Markov model can well estimate the error process of the Turbo-coded OFDM. On the other hand, the burst error probability is 0.149563 with the LDPC-coded OFDM 5G and is 0.14879 with the Markov error model in the QPSK modulation. This nearly symmetrical result shows that our proposed Markov model can also effectively estimate the error process of the LDPC-coded OFDM 5G. The difference between the Turbo and the LDPC is 0.041189.

The experiments are performed for the error occurrence probability of the three modulations methods by comparing the LDPC and Turbo, as shown in Fig. 13. According to the figure, the error occurrence probabilities of our estimated model and the coded 5G simulations are nearly the same for all three modulation methods for both coding schemes. Among the three modulations, the error occurrence probability is the highest in 64QAM and the lowest in QPSK. In addition, the error occurrence probability of the Turbo-coded OFDM is lower than that of the LDPC-coded OFDM.

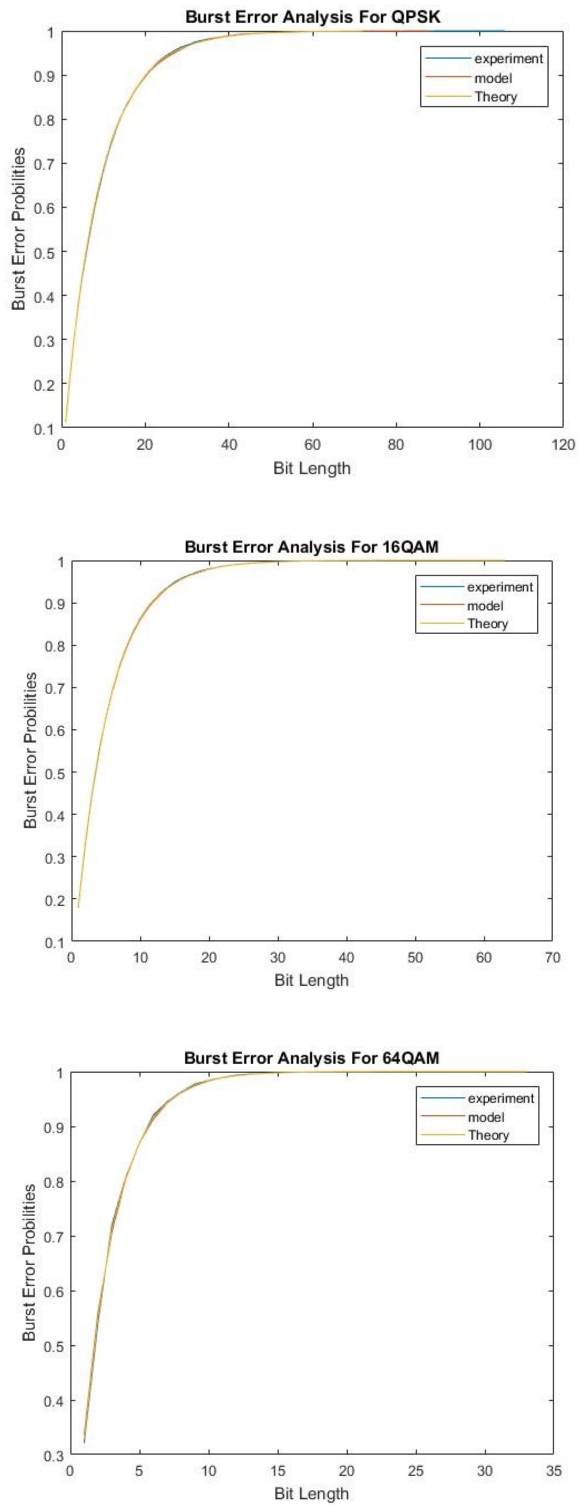


Figure.4.13. Burst error Analysis for the error sequences of the Turbo-coded OFDM 5G simulation and the error sequences resulting from the 2 state Markov model.

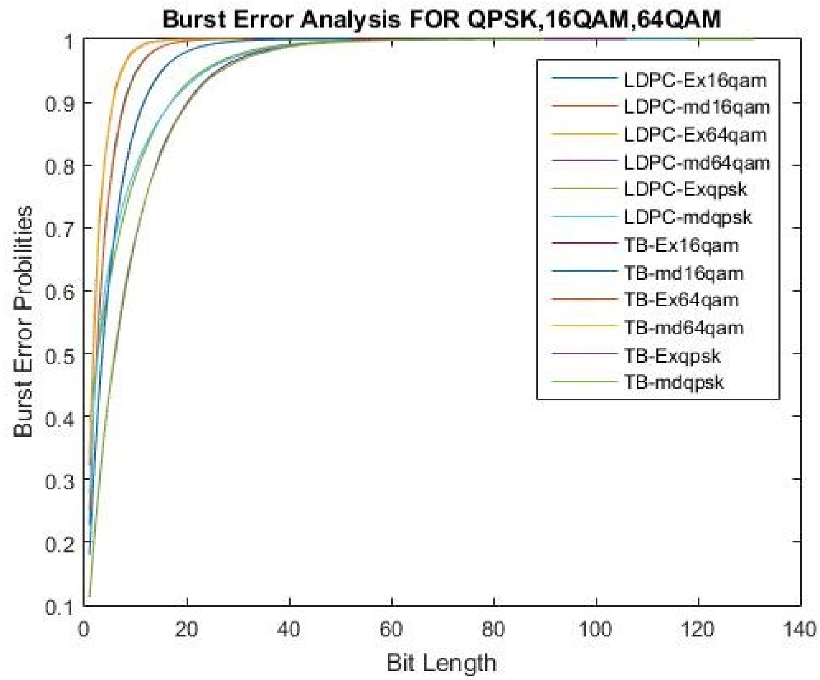


Figure.4.14. Burst error analysis for the estimated two-state Markov model compared with the LDPC- and Turbo-coded OFDM 5G simulations.

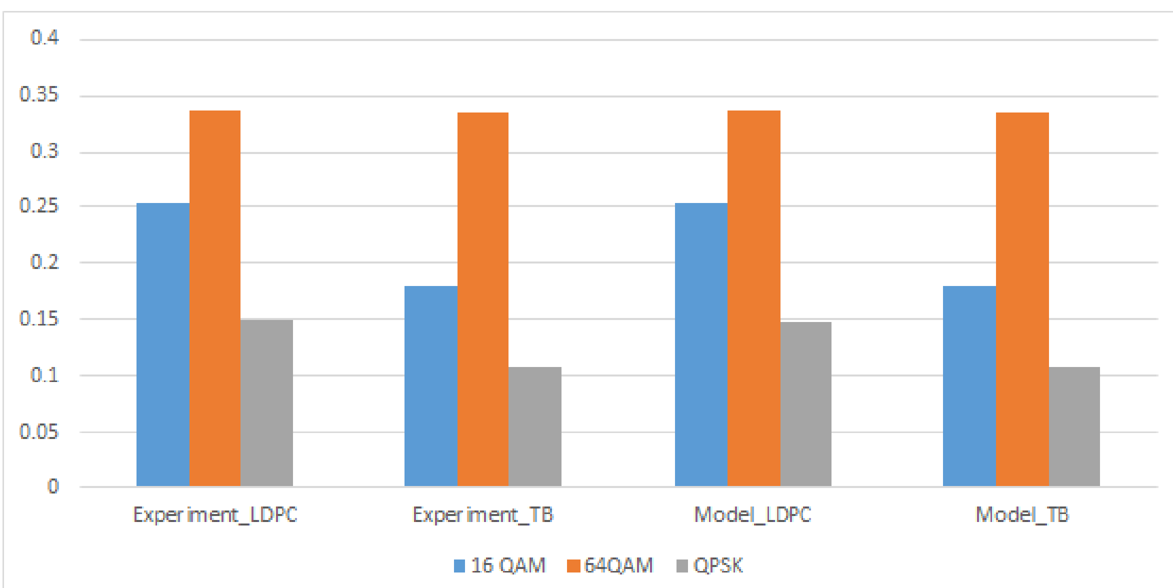


Figure.4.15. Error probabilities for the three modulation methods.

4.5 Discussions

In this study, the error behaviours, including the error gap and error burst statistics, of both LDPC-coded and Turbo-coded OFDM data transmissions in the 5G environment are investigated and modelled using two-state Markov chains. Moreover, the impacts of the three different kinds of modulation methods with respect to the error patterns and behaviour are studied by performing burst error analysis based on the proposed two-state Markov error model. From this analysis, it can be seen that the estimation of the Markov error process model performs better in Turbo coding than in LDPC coding in the OFDM 5G environments.

From the results of the error gap and error burst analyses, it can be concluded that the error gap $Pr\{0m|1\}$ and the error burst $Pr\{1m|0\}$ are closely symmetrical between the estimated model and the 5G simulations of both error coding methods. These results also show that our Markov error process model works well for coded OFDM 5G simulations. The bit error occurrence probabilities are the highest in 64QAM and the lowest in QPSK. By detailed examination of the estimation process of the proposed Markov error model on the three modulation methods, the burst error occurrence probabilities of the models based on 16QAM and 64QAM are almost identical to those of the coded 5G simulations, while the burst error probability of QPSK has slight changes and very few differences from those of the coded 5G simulations.

The proposed generative error models have the advantage of significantly reducing the simulation time because they do not need to simulate the entire communication system. The Baum-Welch (BW) algorithm was mostly used to tune the hidden parameters based on the available observations, which greatly improved the accuracy of the proposed model. The main advantage of the proposed generative error model is that it can greatly reduce the computational requirements for generating long error sequences and therefore accelerate the simulations. The results show that the proposed error model can provide the best estimation of the desired burst error statistics of the reference error sequences and the desired BER of coded 5G transmission systems.Our proposed generative Markov error model for the coded OFDM 5G network can assist in designing and investigating the digital components, error control schemes or protocols by reducing complexity and saving time. In future works, more prediction models could be considered for designing error control schemes and higher layer protocols.

4.6 Chapter Summary

In this chapter, we presented the Modelling and Analysis of Error Process in 5G Wireless Communication Using Two-state Markov Chain. In section 4.2, some work related to our studies is reviewed. Then we present proposed error model and related brief theoretical background. In section 4.4, wedescribe Simulation Results of proposed error generative model. We discussed about simulation results in section 4.5. As a final section, we present the chapter summary.

CHAPTER 5

CONCLUSION AND FURTHER EXTENSION

5.1 Summary of Thesis

In this research, we studied on 5G standard channel coding methods and we conducted two experiments as two parts of this research over proposed coded OFDM 5G simulation frame work and two states Markov based generative error model.

Firstly, we conducted the experiments of coded OFDM system for 5G network employing two coding methods: LDPC and Turbo in order to correct the communication errors and improve the performance by lowering Bit Error Rate (BER) which is important to support the various services of 5G network. We performed our simulation by using three modulation techniques over AWGN channel with different FFT sizes.

Secondly the error distribution, such as the error gap and error burst statistics, of both LDPC-coded and Turbo-coded OFDM data transmissions in the 5G environment are investigated and modelled the error process by using two-state Markov chains. Moreover, the impacts of the three different kinds of modulation methods with respect to the error patterns and behavior are studied by performing burst error analysis based on the proposed two-state Markov based error generative model. From this experiment, we can approve that the proposed error generative model can generate accurate error sequences symmetrically with error sequences which are directly come from real simulation by approving theoretically with Gilbert Elliot Model. Further More, we can approve that Turbo coding have better achievement than LDPC coding in the OFDM 5G environments.

5.2 Discussion of Proposed System

For the first part of this research, we can show that coded OFDM systems have better performance giving less BER than OFDM system without using coding methods by measuring BER performance over 5G specifications. The BER depends on the different FFT sizes or the number of subcarriers in 5G OFDM environment. Moreover, we can confirm that the differences between coded and uncoded OFDM in BERs has become larger over SNR values. The BER value is 0.001 less than uncoded OFDM at SNR values 30 dB. We can conclude that applying coding methods to correct communication errors is very effective for OFDM system in 5G network.

Since three types of modulation methods such as QPSK, 16 QAM and 64 QAM are defined as standard modulation methods in 5G specifications, we evaluated all these modulation methods with different FFT sizes over 5G OFDM simulations. Then, we compared Coded and Uncoded 5G OFDM simulations over three modulations with FFT size 1024 and FFT size 2048. Contrasted to others, QPSK has achieved better results with lowest BER rate over all experiments in 5G OFDM propagations. Comparing the coding methods, Turbo coding can give better performance than LDPC coding methods by reducing BER rate effectively. This result motivates to select Turbo codes for 5G channel coding which can save costs for communications industry.

For the second part of this research, we can conclude that the error gap distribution, $Pr\{0m|1\}$, and the error burst distribution, $Pr\{1m|0\}$, are closely symmetrical between the estimated model and the 5G simulations of both error coding methods. These results also show that our Markov error process model works well for coded OFDM 5G simulations. Furthermore, we can approve the result of our first part that the bit error occurrence probabilities are the highest in 64QAM and the lowest in QPSK. By detailed examination of the estimation process of the proposed Markov error model on the three modulation methods, the burst error occurrence probabilities of the models based on 16QAM and 64QAM are almost identical to those of the coded 5G simulations, while the burst error probability of QPSK has slight changes and very few differences from those of the coded 5G simulations as well.

The proposed generative error models have the advantage of significantly reducing the simulation time because they do not need to simulate the entire communication system. The Baum-Welch (BW) algorithm was mostly used to tune the hidden parameters based on the available observations, which greatly improved the accuracy of the proposed model. The main advantage of the proposed generative error model is that it can greatly reduce the computational requirements for generating long error sequences and therefore accelerate the simulations. The results show that the proposed error model can provide the best estimation of the desired burst error statistics of the reference error sequences and the desired BER of coded 5G transmission systems. Our proposed generative Markov error model for the coded OFDM 5G network can assist in designing and investigating the digital components, error control schemes or protocols by reducing complexity and saving time.

5.3 Further Extension

As future work, we can consider analyzing in error distributions of our coded OFDM in 5G network by using some machine learning technique like Markov theory that analysis will enhance the performance of the system by recognizing and correcting the errors. In future works, more prediction models could be considered for designing error control schemes and higher layer protocols.

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Applicant's Publications

Articles in Refereed Journals	[1] Modeling and Analysis of Error Process in 5G Wireless Communication Using Two-State Markov Chain, IEEE Access, 10.1109/ACCESS.2019.2892051, Vol.7, Jan 11 2019, **M. San Hlaing**, Keping YU and T.sato,
	[2] Overload Pattern Classification for Server Overload Detection, International Journal of Information & Network Security (IJINS), Vol.2, No.3, (ISSN: 2089-3299), June 2013, **M. San Hlaing**.
	[3] Data Center Resource Demand Prediction, Internal Journal of Information Engineering Research Institute IERI, lecture Notes in Information Technology (ISSN:2070-(1918)), December 2013, **M. San Hlaing** and Thandar Thein.
International Conferences	[1] Analysis of Channel Coding Methods in Multipath OFDM 5G, WPMC-2018, Chiang Rai Thailand, 25-28 Nov. 2018, **M.San Hlaing** and T.sato.
	[2] Machine Learning-based Advanced Localization Method in Wireless Communication, Future Technologies Conference (FTC) 2017, 29-30 November 2017, Vancouver, Canada, pp 82-88, **M.San Hlaing** and T.Sato.
	[3] AI Management System to Prevent Accidents in Construction Zones Using 4K Cameras Based on 5G Network, WPMC-2018, Chiang Rai Thailand, 25-28 Nov. 2018, Koki Okamoto, Daichi Nozaki, Toru Mochida, Xin Qi, Zheng Wen, **M. San Hlaing**, Kiyohito Tokuda , Takuro Sato, Kazuhiko Tamesue.
	[4] Resource Demand Prediction and Carbon Emission Estimation for Data Centers, Computer Science and Information Technology, Vol 2, No 2, doi: 10.13189/csit.2014.020203, 2014, **M. San Hlaing** and Thandar Thein.
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