# Studies on Coding Methods in 5G Millimeter Wave Communication

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# Contents

# Abstract

5G wireless network is believed to be deployed as the next generation after the 4G. Nowadays, engineers use millimeter as 5G communication band because it can improve the speed of data transmission. At the same time, it also creates many new problems. Among these problems, how to realize comprehensive networking services with low BER performance degradation is a critical challenge. Several technologies have been chosen to solve this problem like OFDM, which is a significant technique for wireless communications, LDPC, which is an attractive coding method in 5G area and has been applied for mitigating performance degradation with BER.

In this thesis, we proposed coding methods like LDPC, polar code, turbo code, and other techniques such as massive MIMO and OFDM to reduce the signal loss during the data transmission process at millimeter wave standard. Also, in our experiment part, we explain the LDPC system can achieve better performance with lower bit error rate over 5G standards by comparing it with no-LDPC system and Turbo codes system. Finally, we design a system to combine LDPC codes with polar codes to realize better performance during the data transmission process.

Keywords: 5G Data Transmission; Millimeter Wave; LDPC; Polar Code; OFDM.

# Abbreviation

| | |
|---|---|
| 4G | Fourth Generation |
| 5G | The Fifth Generation |
| BER | Bit Error Rate |
| OFDM | Orthogonal Frequency Division Multiplexing |
| LDPC | Low-Density Parity-Check |
| LTE | Long Term Evolution |
| MIMO | Multiple-input Multiple-output |
| CDMA | Code Division Multiple Access |
| BDMA | Beam Division Multiple Access |
| WWWW | The Worldwide Wireless Web |
| 5GNR | 5G New Radio |
| MNOs | Mobile Network Operators |
| ECC | Envelope Correlation Coefficient |
| LTE-A | Long Term Evolution Advanced |
| SC | Successive Cancellation |
| SCL | Successive Cancellation List |
| CRC | Cyclic Redundancy Check |
| TBCC | Tail-Biting Convolutional Code |
| QPSK | Quadrature Phase Shift Keying |

| | |
|---|---|
| FFT | Fast Fourier transform |
| iFFT | Inverse fast Fourier transform |
| AWGN | Additive white Gaussian noise |
| FAR | False Alarm Rate |
| QAM | Quadrature Amplitude Modulation |
| SNR | Signal-to-Noise Ratio |
| IP | Internet Protocol |
| eMBB | Enhanced Mobile Broadband |
| mMTC | Massive Machine Type of Communication |
| uRLLC | Ultra Reliable and Low Latency Communication |
| RF | Radio Frequency |

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# Chapter 1

# Introduction

## 1.1 The Evolution of Wireless Communication Technology

Wireless communication is a fast-growing field, which has significantly enhanced the interactions between people in both daily life and business process. It also promotes the development of economy and society. As shown in Figure 1, communication technology has undergone many years of change. Nowadays, an increasing number of people pursue higher data transmission speed and better wireless internet access service. In that case, the fourth generation (4G) Long Term Evolution (LTE) mobile communication systems have been widely used. Due to its powerful techniques, for low mobility, 4G wireless networks can maximum offer 1Gbps data transmission rate for low mobility, like local wireless access. For high mobility, it can support 100Mbps data transmission rate[1].

4G has excellent performance in wireless communication, but the high energy consumption and spectrum crisis are inevitable problems. Communications companies always face various demands for higher transmission speed and better energy efficiency. Therefore, researches have begun to study on new mobile communication generation called The Fifth Generation (5G).

Scientists believed that compared with 4G, 5G network can achieve a thousand times system capacity, ten times the efficiency of spectral and data rates, and twenty-five times the average cell throughput[2].

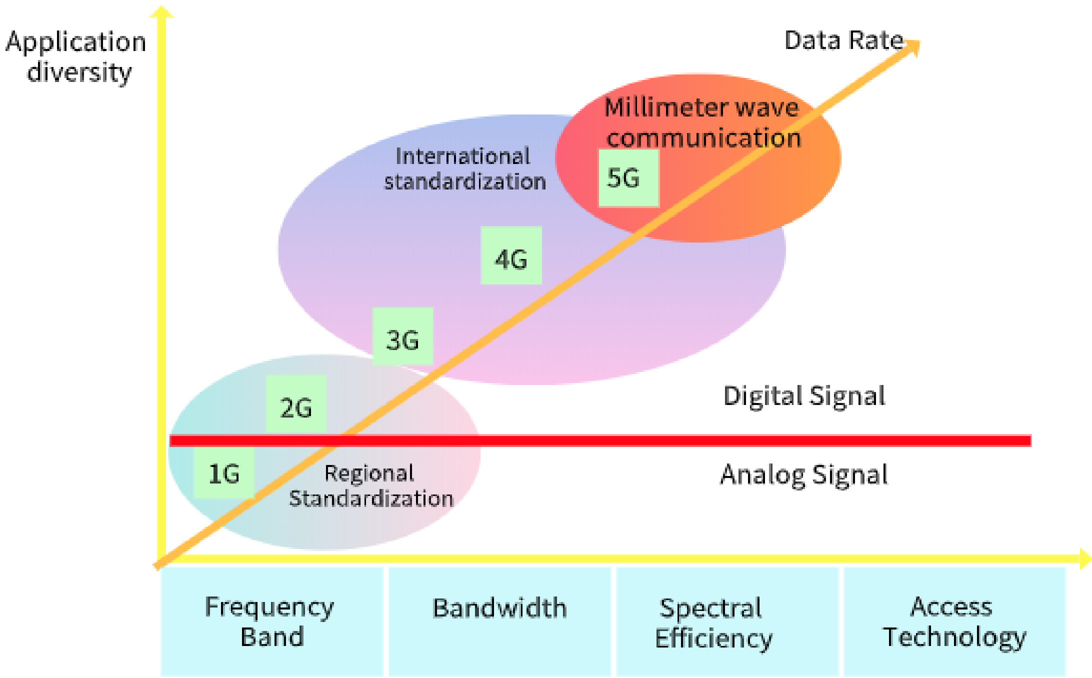


Fig.1. Evolution of wireless communication technology

## 1.2 Related Work about 5G

5G theory is based on the concept of an extraordinary high throughput speed network system[3].

Fig.1 shows the fundamental structure of 5G. In this figure, 5G devices have three essential servers which are Application Server, Data Server, and Cloud Server. Due to these three servers, 5G can realize very high resolution required by mobile phone and provide considerable bandwidth for wireless communication[4].

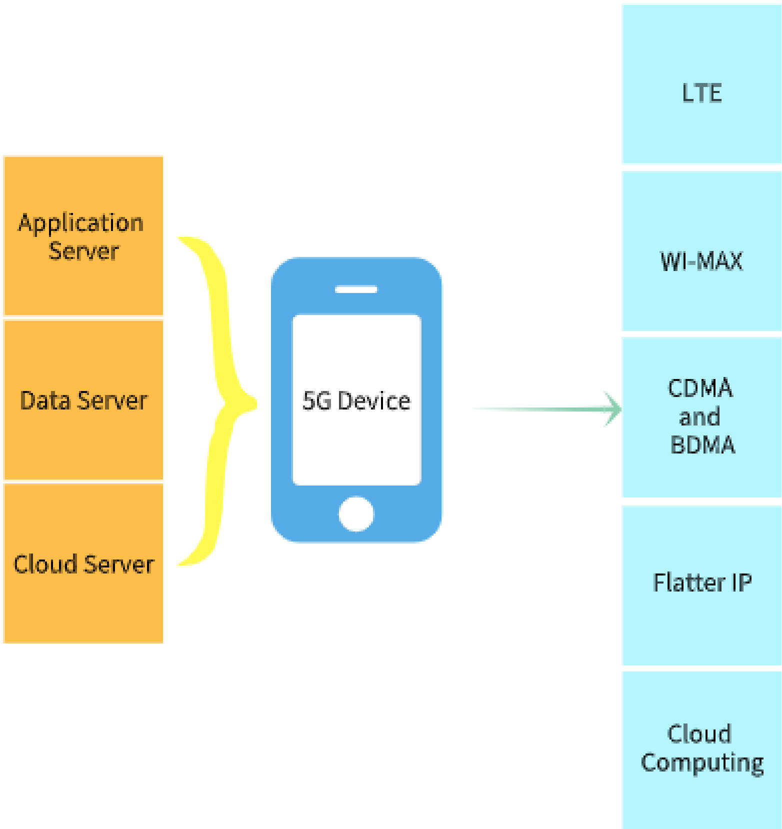


Fig.2. The server framework of 5G

The application server, data server, and cloud server could be connected to many functions like LTE, Wi-max, Code Division Multiple Access (CDMA) and Beam Division Multiple Access (BDMA), Flatter Internet Protocol (IP) network, and Cloud computing applications. These functions will achieve a very high transmission speed and resolution compared with 4G. Also, researchers believed that 5G could support massive multiple-input multiple-output (MIMO). Under this install version, both client and server can use antennas with multiple functions. In that way, massive MIMO can decrease the error rate and enhance the data speed relatively[5]. Table 2 shows the difference between 4G and 5G.

| | Deployment | MIMO | Multiplexing | Speed | Resolution |
|---|---|---|---|---|---|
| 4G | Deploy | Lower Order | CDMA | Medium/High | High |
| 5G | Expected by 2020 | Higher Order | CDMA and BDMA | Very High | Very High |

Table.1. General table of comparison of 4G and 5G

The rapid development of 5G wireless communication technology has brought opportunities for industry upgrade. For companies which are interested in wireless communication research and development, 5G technology brings fresh chances to enter the market, but it also brings many technical challenges[6].

### 1.2.1 The Development of 5G

Wireless communication system is the future of telecommunication technology, and 5G is the most critical technology is wireless communication. After several years of development, 5G technology can offer high resolution and advanced billing interfaces. 5G provides a large amount of data broadcast and supports nearly 65,000 connections. Users can get better and faster solutions through remote management provided by techniques in 5G. It offers connection speeds of up to 25 Mbps. At the same time, private networks can be settled in 5G system. Because of the high uploading and downloading speed in 5G, it can realize excellent performance in software and router technology. Other key characteristics of 5G are shown in Fig.2.

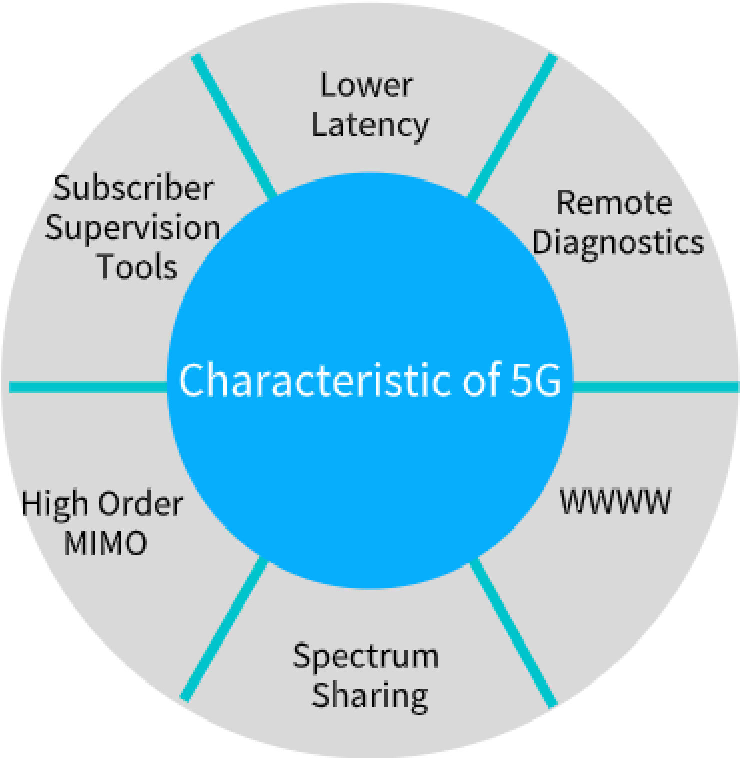


Fig.3. Characteristic of 5G

Low latency is one of the most considerable features of 5G. It makes 5G become an ideal technology for remote vehicle control and other quick response required applications. Under ideal conditions, the latency of 5G networks is less than milliseconds[7].

Remote diagnostics in wireless communication technology could reduce the cost of monitoring and maintenance obviously. Because it is possible to do remote error handling.

The worldwide wireless web (WWWW) is a commitment to provide a desktop experience to the mobile community. It is a promise of seamless connectivity and multimedia interaction during the moving time. This commitment drives the convergence of fast-speed wireless data needs which are better convenience and more intuitive and dynamic content.

This kind of convergence caused by WWWW will not affect our expectation of wired network: security, high speed, and excellent bit error rate performance[8].

With the popularity of 5G, the demand for spectrum is getting much more complicated. Different 5G services and applications need individually unique spectrum bands and different characteristics. They have different requirements and require both low and high frequency spectrum bands. However, spectrum is a limit resource. In that case, spectrum sharing could be very vital. 5G offers several techniques like beamforming to achieve better spectrum sharing.

MIMO arrays is a major technology in 5G. In a high order MIMO circumstance, a MIMO system could achieve high transmission speed and functional channel capacity without using extra frequency spectrum and transmitted power. Also, MIMO-antenna communication structure could improve the quality of communication when it has sound isolation and envelope correlation coefficient (ECC). At the same time, the antenna elements are still existing[9].

Nowadays, based on these characteristics, there are three significant application scenarios in 5G technology which are Enhanced Mobile Broadband (eMBB), Massive Machine Type of Communication (mMTC), and Ultra Reliable and Low Latency Communication (uRLLC).

The most intuitive performance of eMBB is the doubling of the network speed and the ultra-high transmission data rate. Under the 5G standard, people can easily watch the online 2K/4K video and AR/VR with peak speeds up to 10Gbps.

mMTC is an application that combines multiple industries with 5G powerful connectivity. 5G enables people to build a smartphone life by relying on various sensors and terminals around them. In this scenario, the data rate is lower, and the delay requirements are not too strict, the terminal cost of the layout is lower, and long battery life and reliability are required.

uRLLC has a high requirement for the delay and often reaches the 1ms level. It is used in special industries such as car networking, industrial control, telemedicine, and the market potential of car networking is generally favored by the outside world.

After introduced these applications, we also present the main challenges in the development of wireless communication for 5G.

### 1.2.2 The crucial challenges in 5G data transmission

In theory, the signal frequency for 5G is very high because of the millimeter wave technology. Compared with 4G LTE which the frequency is around 2.6GHz, the frequency of 5G millimeter wave can be extended to 300 GHz. In this situation, the cost of data transmission is very high. Millimeter wave was mostly used in the aerospace field in the past. And there is no relevant usage data in the civilian field, so the popularity of millimeter wave communication could cost a tremendous amount of money in the process of design and testing of millimeter wave products due to its high frequency. Other costs include faster application processors, basebands, and RF (Radio Frequency) devices of base stations which will increase the load on the economy. To realize high-speed data transmission, the cost of millimeter wave communication must be reduced.

On the other hand, although the high frequency allows signals to take more information and have more frequency resources, it makes the signal easier to interference from weather conditions and objects such as mountains and buildings. Also, it is difficult for millimeter waves to cover the room entirely. The unpredictability of signals and the distance it can reach are the main challenges.

This thesis mainly shows a coding method for signal loss in millimeter wave communication and carry out a series of experiments to propose a method to reduce signal loss.

Here is the organization of the thesis. Chapter 1 makes a brief introduction about wireless communication. In chapter 2, some techniques of 5G wireless communication and their explanations are provided. In chapter 3, an overview on the research structure is presented. We then discuss the key features of our experiment in chapter 4 and do simulation. In chapter 5, evolution of 5G wireless communication and future research areas are explored, with concluding remarks summarized in chapter 6.

# Chapter 2

# Techniques in 5G

In this chapter, we will introduce several standard and techniques in 5G technology.

## 2.1 5G NR

5G New Radio (NR) is a reliable and unified global standard of 5G wireless communication. It can provide significantly faster and more responsive experiences of mobile communications. To meet the requirements of various new fields, 5G NR also improves its ability of cellular connection.

5G NR introduces several core technologies that will dramatically enhance performance and efficiency such as mobilization of millimeter wave, massive MIMO, shared spectrum, advanced coding, and unlicensed transmission.

In order to achieve higher speeds and lower latency, 5G plans to use larger bandwidth signals and higher spectrum. The first version of the 5GNR standard will support eMBB and also intends to support partial URLLC functions. At the same time, the 5GNR defines a global spectrum range of 52.6 GHz and seeks more spectrum in the 100 GHz range, and the subcarrier bandwidth has reached 400 MHz, and can also achieve greater bandwidth through carrier aggregation. At the same time, the degradation of signal quality due to problems such as path loss, flatness, phase noise, linearity is a difficulty and challenge that 5G must correct.

## 2.2 Millimeter Wave

By the increasing demand for mobile communication, eMBB becomes the most significant driving force in the development of 5G. The rising demand lies in two part, one is the soaring demands for transmission data because more and more people begin to use high-speed mobile devices. The other is data transmission devices get more functions, like higher-resolution video, 4K camera, virtual reality, and augmented reality. This environment needs more spectrum resources to improve the power of network capacity and realize faster transmission speed and better user experiences.

In 5G, researchers can use new higher spectrum band which is not suitable for 4G wireless communications. As we said in 2.1, in the standard of 5G NR, new spectrum band has been decided to employ in 5G. These spectrum bands include mid-frequency band (3.3GHz to 6GHz) and high-frequency band (more than 24GHz) which is normally called as millimeter wave[10]. These new spectrum bands are very noticeable because of the large bandwidths they can offer, which could greatly improve data transfer speed and increase data capacity[11].

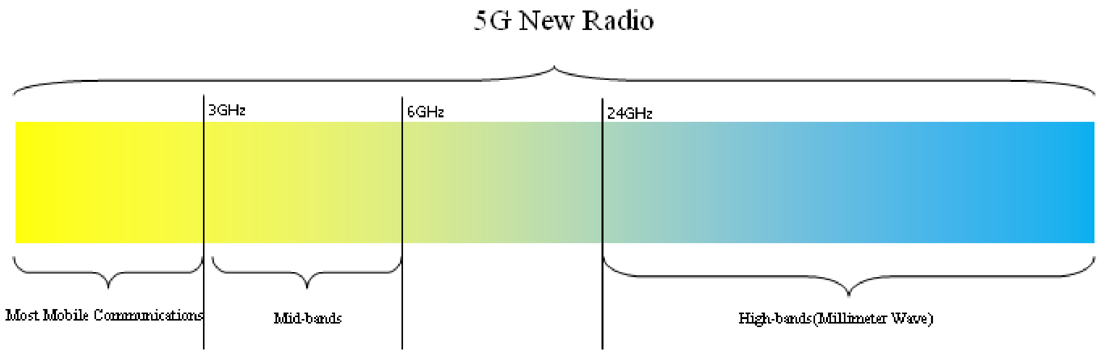


Fig.4. Spectrum bands of 5G New Radio

Nowadays, by using massive MIMO and OFDM, millimeter wave technology can overcome high attenuation caused by free space path loss and shadow during the communication process. Compared with 4G whose frequency below 6 GHz, 5G millimeter wave can support the situation of wireless communications better and it can reach multi-gigabit data rate at the same time. Although millimeter wave has so many advantages and great potential of future communications, it has several problems to be solved[12].

The disadvantage of millimeter waves in wireless communication is that it has a limited propagation distance. The data shows that the signal loss of a 70 Hz millimeter wave will reach as 89.3dB after a 10 meters propagation. Also, Millimeter wave is susceptible to the weather condition and can be blocked by buildings or human bodies. This can be a huge problem in public communications. At the same time compared to fiber-optic communication, signals in the air may be eavesdropped or grabbed, so the communication security cannot be guaranteed.

OFDM technology can be extended to the millimeter band better at 5G. In millimeter wave communication process, we use OFDM, MIMO and other techniques to guarantee the speed of transmission. Also, we use coding method like LDPC code and Turbo code to reduce the error rate in the data transmission process and enhance security.

## 2.3 OFDM

In 5G wireless network, providing high data transmission speed and extensive network service performance degradation are key challenges. Orthogonal Frequency Division Multiplexing (OFDM) is one of the implementation methods of multi-carrier transmission method. It uses

IFFT in the modulation process and FFT in the demodulation process. OFDM is the lowest complexity and the widest application multi-carrier transmission method. It divides the main transmission data into several sub-channel to achieve parallel transmission. In that case, under multipath scenario, OFDM can increase the transmission speed of the system and eliminate interference between subchannels.

In that case, we choose OFDM as a vital technique in our experiment. Fig.4 shows the structure of OFDM. In the communication system, after the data is sampled, a continuous stream of data such as F0, F1, F2, F3, F4, F5, ... is formed.

FDM is to transmit the elements in this sequence to the specified frequency and send them out. OFDM is to divide the sequence into four sub-sequences such as F0, F4, F8, F1, F5, F9, F2, F6, F10, ..., F3, F7, F11, etc. (The number of subsequences here is only an example, not Representing the actual number), then modulating the elements of the first subsequence to the frequency F1 and transmitting them, the elements of the second subsequence are sequentially modulated onto the frequency F2 and sent out, and the elements of the third subsequence are sequentially modulated to At frequency F3 and transmitted, the elements of the fourth subsequence are sequentially modulated onto frequency F4 and transmitted. The four frequencies F1, F2, F3, and F4 satisfy the orthogonal relationship between the two.

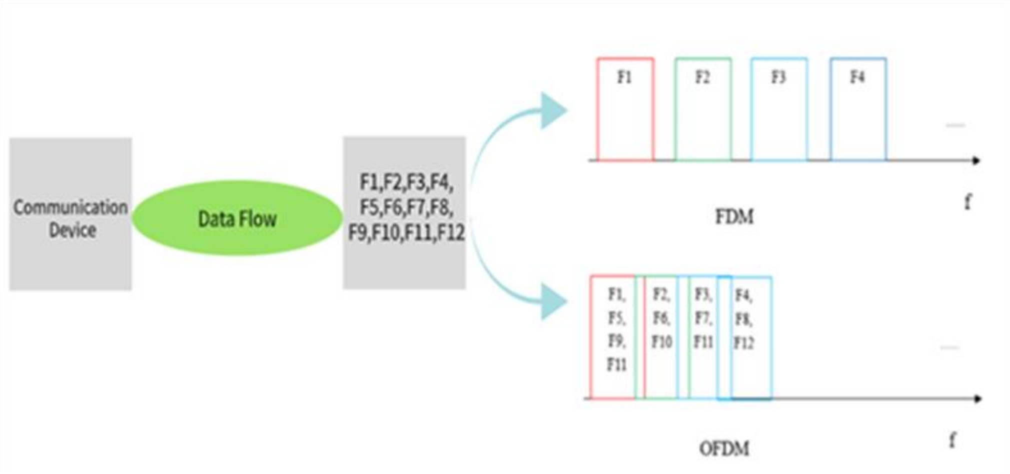


Fig.5.  Structure of OFDM

## 2.4 MIMO

MIMO and massive MIMO research have always been the core research field of wireless communication. In 4G Long Term Evolution Advanced (LTE-A), engineers use MIMO technology to develop spatial resources fully, use multiple antennas to achieve multiple transmissions and multiple receptions, and achieve a multiplication of channel capacity without using extra resources of spectrum and extra energy of antenna transmission[13]. While in 5G, Massive MIMO is getting attention to the requirements of higher transmission speed and better services.

MIMO technology refers to the structure of using multiple antennas at both transmitter and receiver, thereby improving communication quality. It can make full use of space resources, achieve multiple transmission and multiple receptions through multiple antennas, and can increase the system channel capacity by multiple times. It shows distinct advantages and being regarded as the future communication area. Figure 5 shows the structure of MIMO system. The transmitter sends the signal to multiple antennas, and the receiver decodes and recovers signal received by transmitter.

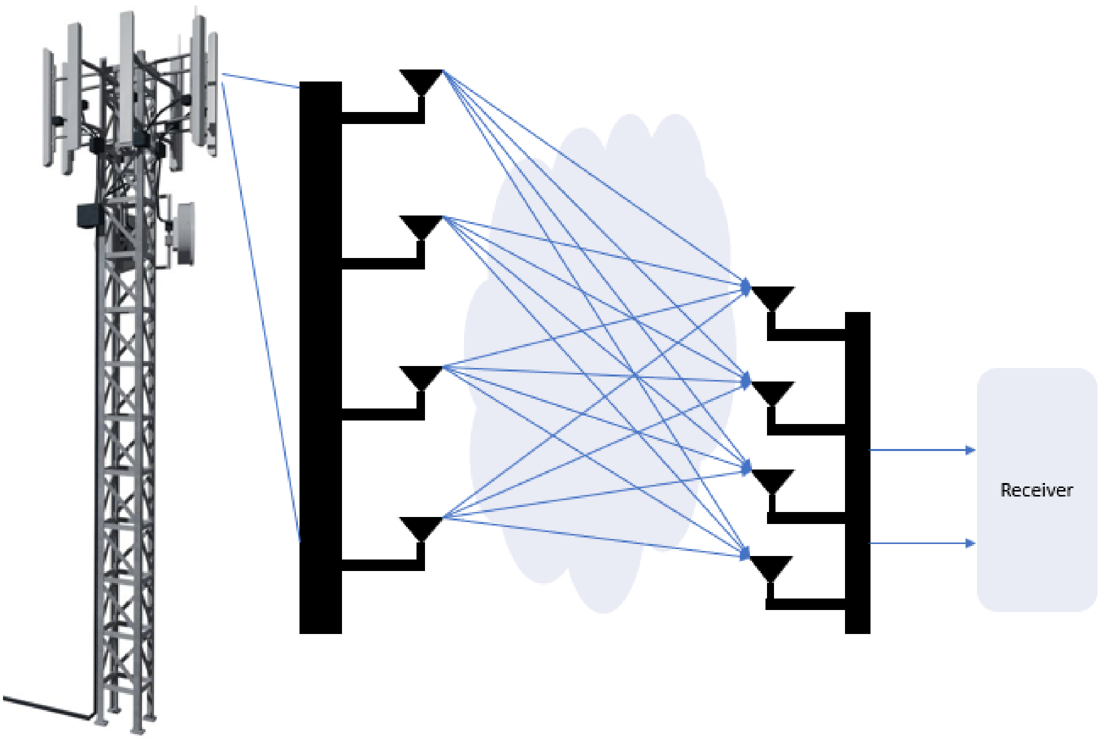


Fig.6. The structure of MIMO

Compare with traditional MIMO system, massive MIMO uses more antennas for better data transfer efficiency. It is a version of beamforming. This kind of system will provide higher transmission speed for terminals. Besides, this technique is able to make up the signal loss caused by the characteristics of millimeter wave transmission during the transmission process. Its transmitter creates narrow beams to receiver to solve the signal loss problem and offer the speed of data transmission at Gigabit standard in millimeter frequency[14].

Active antenna is deployed in Massive MIMO transmitter to give MIMO transmitter several features like lightweight and the ability to set in large size equipment. Fig.6 shows the detail information of massive MIMO system. Besides active antenna, active component technologies and passive component technologies are also core technologies in this system. At the same time, researchers need to create a method to keep the reliability of the system and find a way to simplify the installation process and to realize the low cost of the whole system.

| Requirements | Core Technologies | Technical Issues |
|---|---|---|
| Easy Installation | Active Component Technologies | Low Power Consumption |
| Low Cost | Passive Component Technologies | Beam Steering |
| Reliability | Array antenna Technologies | Redundancy |

Table.2. Information of massive MIMO system

## 2.5 Coding Method

People believe that 5GNR can realize low-latency, fast data transmission, and better reliability connections in the service process and meet new communication requirements. In 4G LTE, TBCC (Tail-Biting Convolutional Code) and Turbo codes are main coding methods. Convolutional codes also used in some fields. While in 5GNR, new coding methods like LDPC codes and polar codes have been used in many communication scenarios. In this part, we will describe these new coding methods including LDPC codes in 5G data channel and Polar codes in 5G control channel. We will also explain the critical technologies in these coding methods. After that, we will introduce Turbo, TBCC, and Convolutional Codes as part of the comparison with the codes we are interested in.

### 2.5.1 LDPC code

The discoverer of Low-density parity-check (LDPC) codes is a doctor Gallager[15]. Although LDPC codes have not been valued for a long time, in the mid-1990s it began to enter the field of wireless communication research. Nowadays it has been incorporated into many international standards and has become one of the significant error correction codes. Compare with Turbo codes, LDPC codes have better performance in throughput efficiency and peak throughput. LDPC has lower decoding complexity, it can achieve higher throughput and low latency communication, which are essential standards for 5G.

LDPC codes make use of particular parity bits in its encoding process. are encodings that use specific parity bits. In LDPC codes, every bit is acting equivalently. Each codeword has the same set of distances as other codewords. Therefore, the minimum distance from anyone codeword to another is the same for all codewords. On the other hand, LDPC is an efficient coding method. Its efficiency is reflected in its decoding algorithm. LDPC has two more convenient decoding algorithms. It can check every number and its parity operator. If most of them contradict this position, then it will be flipped. Repeat this process until all bits are static. All other bits can also be considered to calculate the probability that a bit is 1. It then iterates until it reaches a static position. In both, the result depends on the order in which the elements are checked.

We show the LDPC coding process in Figure 7. In Figure 7, LDPC codes are implemented by block segmentation, two encoder parts and an interleaver part.

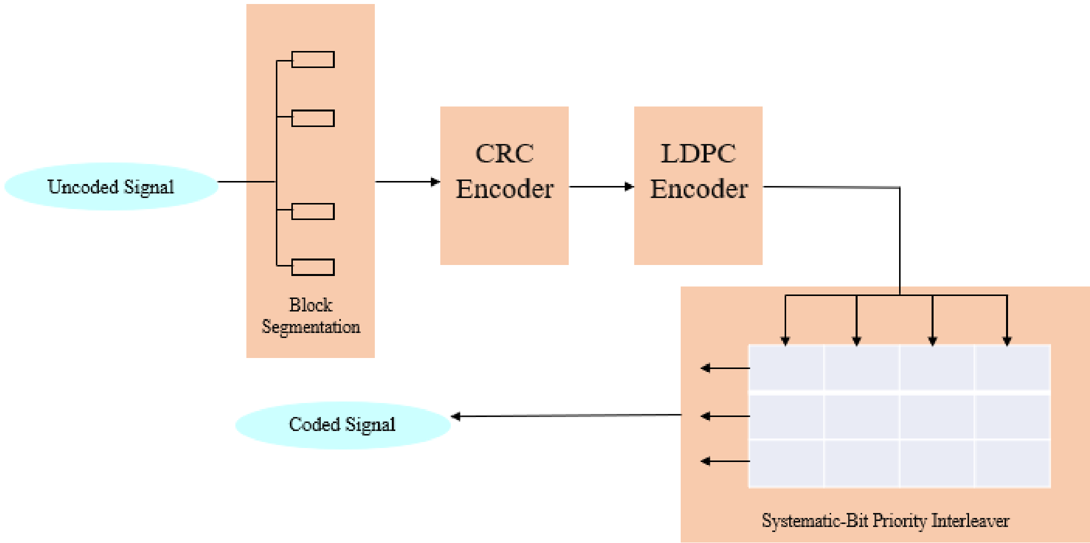


Fig.7. The LDPC coding process

The block segmentation decomposes the larger signal blocks into a number of small signal blocks suitable for encoding. LDPC coding method can encode small signal blocks at a extremely high speed. The CRC part is the module used for error detection, it can reduce the error probability to a deficient standard. In the transmission process, Systematic Bit Priority Interleaver increases the coding gain by eliminating the correlation of the symbol bits. Compared with the Turbo coding system, this system has lower decoding complexity and less waiting time.

### 2.5.2 Polar code

As we know, 4G LTE uses TBCC in the control channel, but in 5G NR, Polar code is used in the control channel due to excellent encoding and decoding algorithm processing power and high reliability. Arıkan first proposed polar code in his paper[16].

Polar code is based on the channel polarization theory and is a linear block code. Compared with TBCC, the Polar code can theoretically reach the Shannon limit. And has a lower complexity of the encoding and decoding algorithm. Its core theory is called channel polarization. The channel polarization process includes two parts: channel combination and channel decomposition. When the size of the coding block is large enough, the Polar Coding technique obtains the theoretical Shannon limit capacity through a simple encoder and a simple continuous interference cancellation decoder. When the coding block is small, in terms of coding performance, polar coding and cyclic redundancy coding, as well as adaptive continuous interference cancellation table decoder cascade, can surpass Turbo or LDPC. The disadvantage is that the code length is normal (<2000), the minimum Hamming distance is too small (only 16 when 1024 code length), the problem to be solved: due to the characteristics of the encoding, its parallelization is very difficult, so even the "complexity" It's low, but its throughput is lower than other encodings, which is the biggest problem in polar codes. In addition, the Polar code appeared later, and there is no standard before 5G. In this respect, the maturity of the Polar code is low.

### 2.5.3 Turbo code

The Turbo code is a reasonably innovation recorded for the first time in 1993. They use a mix of many previously discovered code. The research on Turbo code initially focused on the research of its decoding algorithm, performance boundary and unique coding structure. After more than ten years of development, it has achieved great results and has been in use in all aspects. The Turbo code obtains the decoding performance close to

Shannon's theoretical limit due to the good application of the random coding and coding conditions in the Shannon channel coding theorem. In high noise situation, Turbo codes can realize great performance by the ability of powerful anti-fading and anti-interference. At present, Turbo codes study mainly focuses on the coding and decoding technology, the design and analysis of Turbo codes and the combination of Turbo codes and other communication technologies.

However, one of the reasons for choosing to abandon the Turbo code used in the 3G and 4G eras is that the maximum rate of 4G is only 1 Gbps. The conventional Turbo code is iteratively decoded. An important feature of the Turbo code is that its decoding is more complicated than the conventional convolutional code. To be more complicated, this complexity is not only due to the iterative process of its decoding, but also the algorithm itself is more complicated. The key to these algorithms is not only the ability to decode each bit, but also the reliability information that is decoded per bit with decoding. With this information, the iteration can proceed. Essentially stems from the internal structure of the serial, so some people think that Turbo encountered a bottleneck when it encountered a higher rate of 5G. For example, the LDPC decoder is based on the parallel internal structure, which means that the decoding can be processed in parallel at the same time, which can not only handle a large amount of data but also reduce the processing delay. Although the Turbo coding system can adopt an external parallel approach, it also introduces a delay problem.

### 2.5.4 Convolutional code

P. Elias put forward convolutional code in 1955. Because the data is related to the binary polynomial sliding, it is called the convolutional code. Convolutional codes are widely used in communication systems, such as IS-95, TD-SCDMA, WCDMA, IEEE 802.11, and satellite systems.

The convolutional code is represented by (n, k, L). n is the output code word; k is the input bit information; L is the constraint length, also known as the memory depth. R (code rate) is expressed as R = k/n.

The convolutional code is a memory-corrected error code. The encoding rule is to encode k information bits into n bits. The encoded n symbols are not only related to the current input k information, but also the previous L- The information of a group is related, and its structure is shown in Figure 8 below. Figure 8 is from the work of Goldsmith.

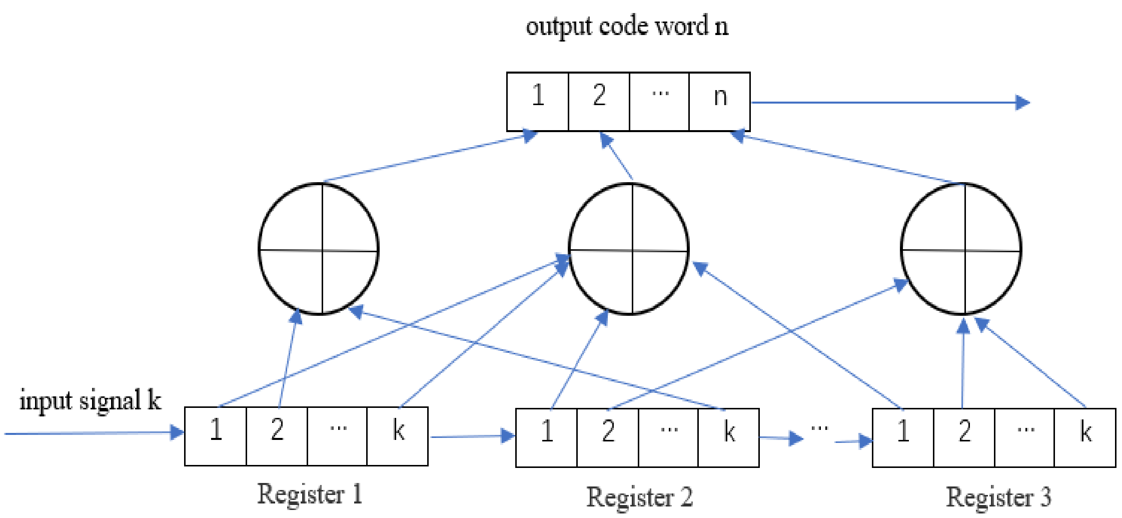


Fig.8. (n, k, L) convolutional code encoder

# Chapter 3

## Research structure

In this section, we describe several structures of our experiment. Including the main structure and coding structure.

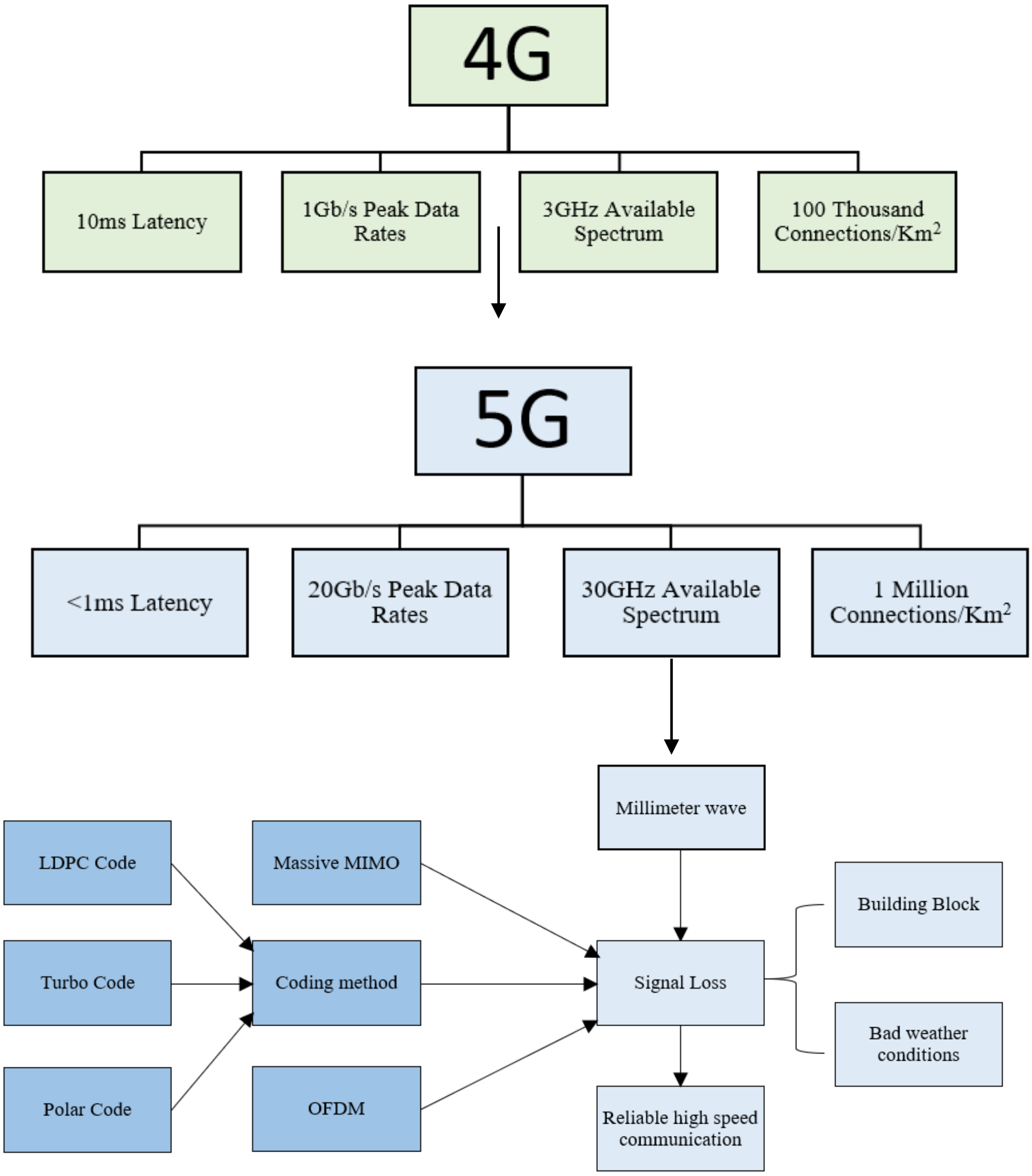


Fig.9. Research Structure

Our research is coding methods in 5G wireless communication which based on millimeter wave standard. To tackle the barrier in millimeter wave communication we proposed in the previous chapters, we combine OFDM and MIMO techniques with coding system. In our research, OFDM and MIMO are based on 5G standards. And in coding system, we mainly talk about LDPC, polar codes, and some modulation methods.

## 3.1 5G Specifications of experiment

In chapter 3.1, we introduce the parameter standard of the experiment which is come from Verizon 5g Technology Forum[17]. The parameter standard is shown in Table 3.

| Parameters | Values |
|---|---|
| Frequency Band | 28GHz |
| Bandwidth | 100MHz |
| Subcarrier Spacing | 75KHz |
| Modulation Method | QPSK, 16QAM, 64QAM |
| Channel Model | AWGN |
| Access Method | OFDM |
| Error Correction | LDPC |

Table.3. 5G Specifications

As Table 3 shows, we choose Additive White Gaussian Noise (AWGN) as the channel model. The power spectral density of Gaussian white noise follows a uniform distribution, and the amplitude distribution obeys a

Gaussian distribution. Gaussian white noise is not only irrelevant but also statistically independent between random variables at any two different moments. The size of the FFT is determined by the input signal and the code rate.

## 3.2 LDPC coded OFDM System

Fig.10 is an OFDM signal transmission structure with LDPC coding method. We choose AWGN as our channel model because it can represent the characteristics of channel noise. The input signal first enter the LDPC coding part. Then the encoded signal block will enter the modulation part, we choose Quadrature Phase Shift Keying (QPSK) as our modulation method. To convert the signal from frequency domain to time domain, we use Inverse fast Fourier transform (iFFT) technique. In the receiving end, the time domain signal is restored by Fast Fourier transform (FFT). During the propagation process, we use AWGN mentioned in 3.1 as our channel.  After FFT, the received signal will enter the QPSK demodulation part. Finally, the original signal will output in the receiving end.

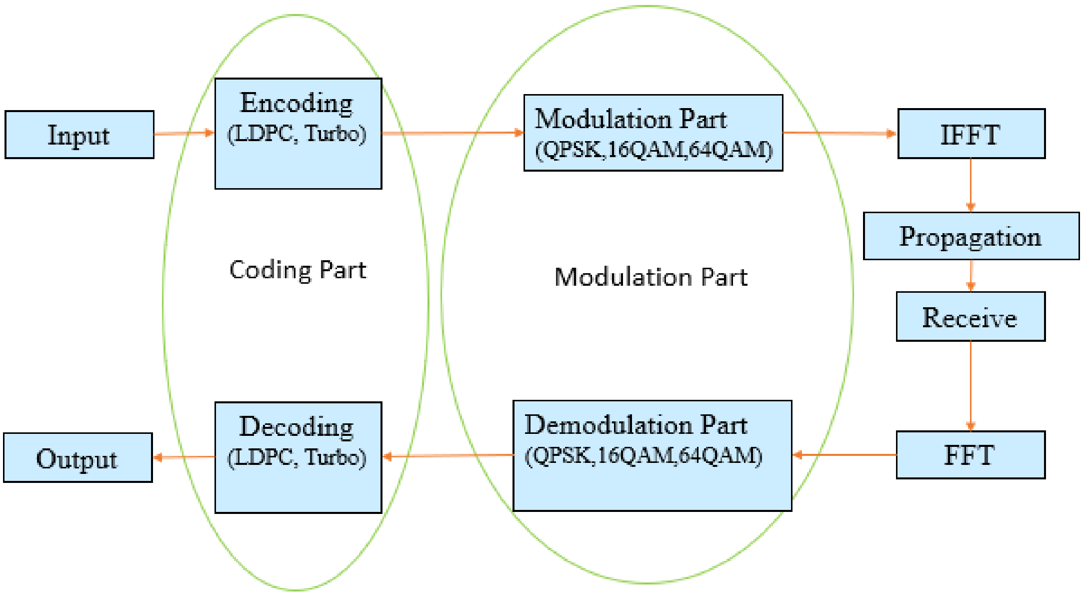


Fig.10. LDPC coded OFDM system

## 3.3 Polar codes system

In order to achieve cascaded LDPC encoding and Polar encoding system, we have studied the structure of the polar coding system. Figure 11 shows the whole coding process of NR polar codes. In this system, segmentation block and parity check encoder only exist in uplink, CRC interleaver only exist in downlink. Several important part like encode and rate matcher are applied in uplink and downlink process[18]. The CRC encoder and polar encoding kernel is the basic part of the Polar coding system. The rate matcher has two functions, one is it can make coded bits in a certain order to enter next step by the subblock interleaver in it. The other is the rate matcher can change the signal size to be suitable for transmission.

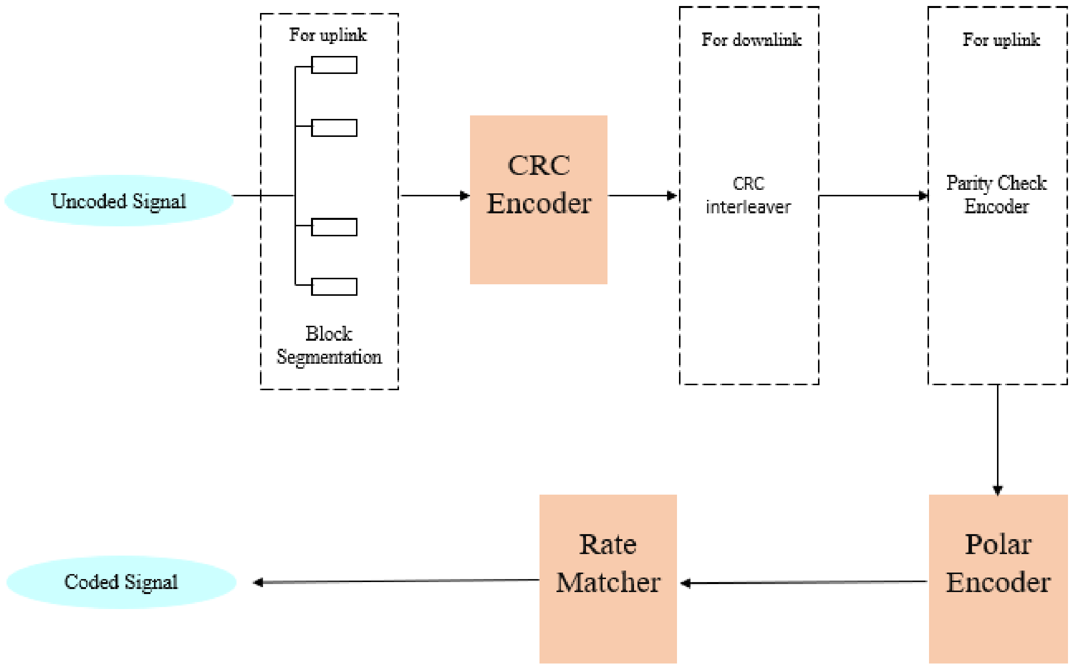


Fig.11. The NR polar coding chain

The Polar code essentially constructs a situation that the transmitter knows the channel state and obtains the code by constructing the generator matrix. As long as the given code length N, the code structure is uniquely determined. The polarization code is based on the channel polarization phenomenon, so that the message bits are transmitted on the most reliable subchannel, and at the same time, the frozen bits are transmitted on the least reliable subchannel.

# Chapter 4
# Experiment

We divide the chapter 4 into three parts. Firstly, we compare and select the modulation method that is most suitable for the experimental environment from three modulation methods which are Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (QAM), and 64QAM. Then we show our coding method. At last, we propose LDPC and Polar cascaded coding system.

## 4.1 Evaluation of modulation method

In wireless communication, modulation part is a very essential part which exploit QPSK, QAM, and other modulation methods to change input signal to the mapping of the subcarrier's amplitude and phase. In our experiment, we performed the experimentations on QPSK, 16QAM, 64QAM over our 5G OFDM simulations.

Both QPSK and QAM are digital modulation methods. QPSK (quaternary phase shift keying) uses four different phase differences of the carrier to characterize the input digital information. It specifies four carrier phases, 45°, 135°, 225°, 315°, respectively, and the data input to the modulator is a sequence of binary digits. QAM uses two independent baseband signals to suppress two adjacent frequency carriers to suppress the carrier sideband amplitude modulation and realize the two parallel digital information by using the orthogonality of the spectrum of the modulated signal in the same bandwidth. Transmission. The modulation method usually has binary QAM (4QAM), quaternary QAM (16QAM), and hexadecimal QAM (64QAM), and their corresponding spatial signal vector endpoint distribution map is called constellation diagram, which has 4, 16, and 64 respectively. Vector endpoint. Typically, if the channel quality is good, it does not require too high protection. QAM is chosen for the modulation method because QAM is more efficient than QPSK, but fault tolerance is not as satisfied as QPSK. If the quality of the wireless channel is not good, a bit error will occur. It is necessary to select a QPSK with good fault tolerance but low coding efficiency to perform modulation.

For the purpose of achieving a certain transmission quality, the BER must maintain a fixed value. The SNR required for QPSK, 16QAM, and 64QAM increases in turn. This indicates that QPSK is suitable for low-rate communication environments, in which it can reduce BER, while 64QAM is suitable for a better communication environment. In high-SNR communication environment, 64QAM can increase data transmission rate. Fig. 12 shows the data analysis of modulation method experiment, QPSK performed the lowest bit error rate over two other modulations techniques over SNR between 10 dB to 30 dB due to the low data transmission rate in our experiment. In that case, we decided QPSK is the most suitable modulation methods.

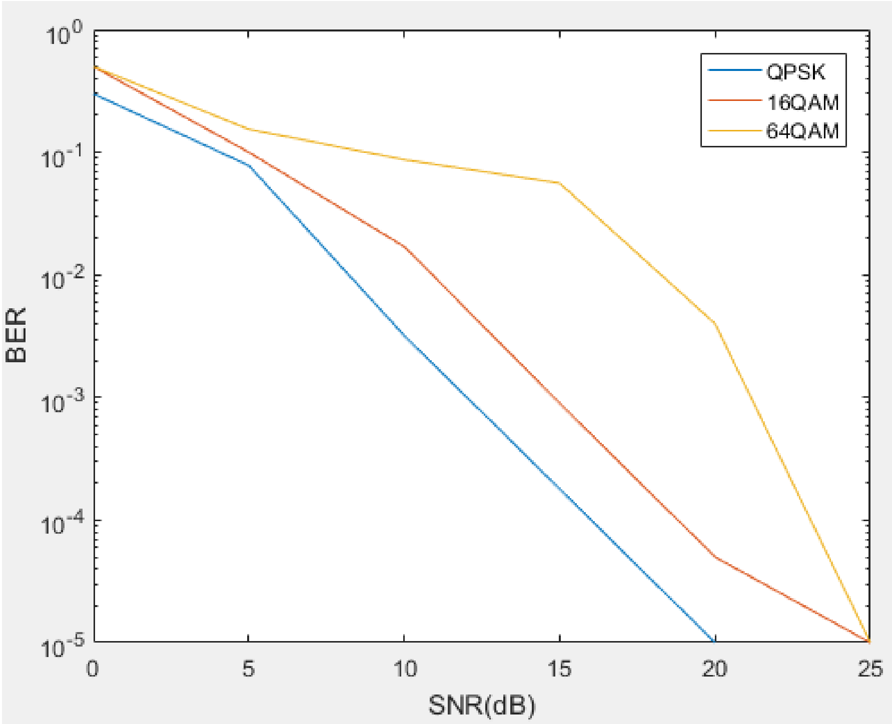


Fig.12. Comparison of three modulation methods

## 4.2 Evaluation of coding method in 5G data channel

Chapter 4.1 is the evaluation of modulation method and we propose QPSK as our modulation method. In chapter 4.2 and 4.3, we introduce the coding method is 5G data channel and 5G control channel. In chapter 4.2, we compare LDPC code and Turbo code to choose 5G data channel coding methods. And chapter 4.3 will decide the coding method of 5G control channel.

### 4.2.1 LDPC and no-LDPC

In this part, we compare LDPC system with no-LDPC system. Both coded and uncoded OFDM simulation are conducted by conforming 5G pacifications parameter as shown in Table.3 in chapter 3.1. OFDM propagation conducted the signaling process over AWGN channel in multipath fading condition. We designed two simulation situations shown in Table.4. One case formed same input length 600 bites for both coded and uncoded OFDM with different FFT sizes and the other case is formed on the same input length 2400 with different FFT sizes. Therefore, we can compare the BER performance on coded and uncoded OFDM systems over different FFT sizes in different situation of input signal size. For 600 bits input size, FFT size in no-LDPC system is 512 and in LDPC system is 1024. For 2400 bits input size, FFT size is no-LDPC system is 2048 and in LDPC system is 4096.

| Modulation Methods | Input Size | FFT Size of Uncoded LDPC | FFT size of Coded LDPC |
|---|---|---|---|
| QPSK | 600bits | 512 | 1024 |
| QPSK | 2400bits | 2048 | 4096 |

Table.4. Simulation situations of LDPC

Fig.13 and Fig.14 demonstrate the simulation results of these two situations, the differences of Bit Error Rate (BER) become larger as the increase of Signal to Noise Ratio (SNR) values.

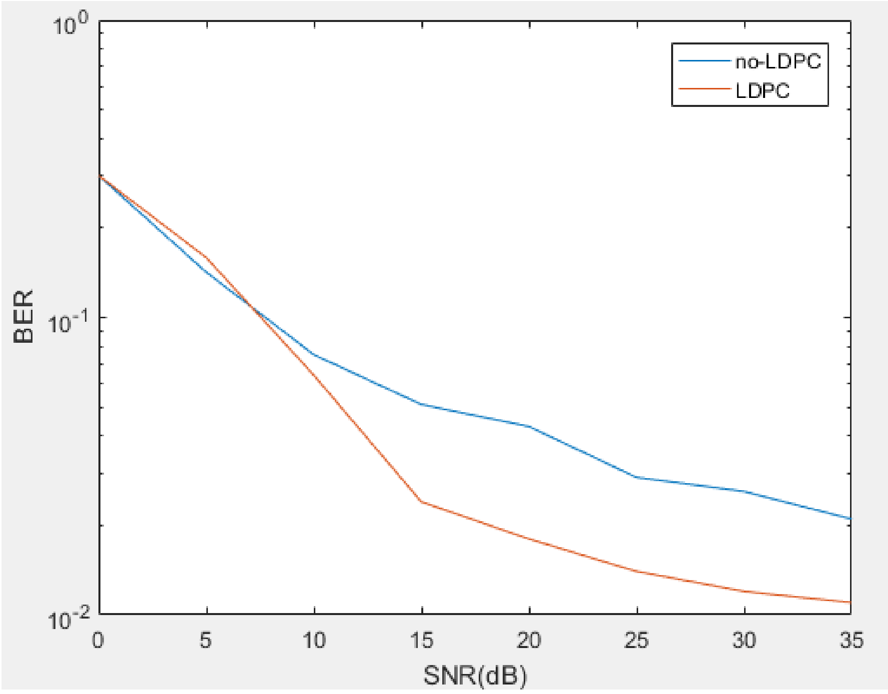


Fig.13. BER performance in LDPC and No-LDPC (data bits=600bits)

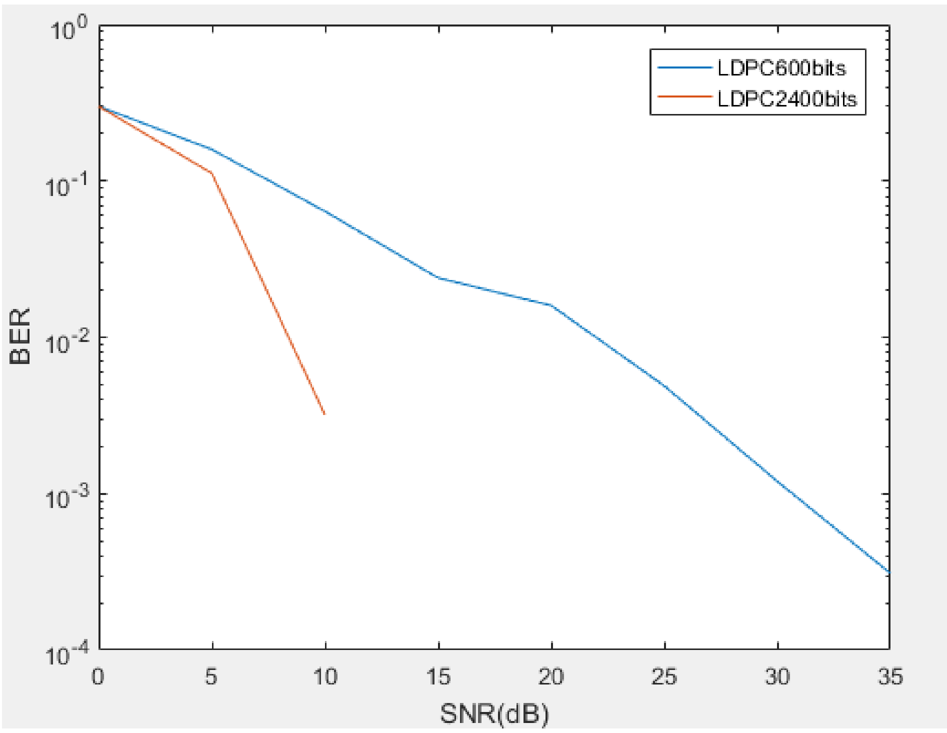


Fig.14. BER performance of LDPC system with different input signal sizes

According to the simulation result, we can see at the scenario which the input size is 600 bits, when the SNR exceeds 5 dB, the BER of the LDPC system become better than no-LDPC system in Fig.13. However, BER capability between no-LDPC system and LDPC system is quite same. That is because the input size is small, so the result cannot show too much difference.

Then we improve the input signal size to 2400bits to investigate the influence of input signal size on BER of LDPC coding system. In Fig.14, We compare the BER performance of the LDPC system with 600bits input signal size and 2400bits input signal size. Experiment results indicate that BER rate of 2400bits LDPC system is revealingly decreased at SNR 7 dB while the BER remained over 0.021197 dBs. BER rate is dramatically down at 0 dBs at SNR 10 dB and then it is remained the same 0dBs as shown in Fig.14. From Fig.13 we can conclude that LDPC plays a vital role in the reduction of BER in the coding system. While Figure 14 illustrates as the input signal increases, that is, as the FFT size increases, the bit error rate of the LDPC system will become smaller. In chapter 4.2.2, we compare LDPC code with Turbo code.

### 4.2.2 LDPC and Turbo

This section shows the comparison of Turbo codes and LDPC codes. We choose same input signal size = 2048 and the code rate = 1/2 to make this comparison fairly.

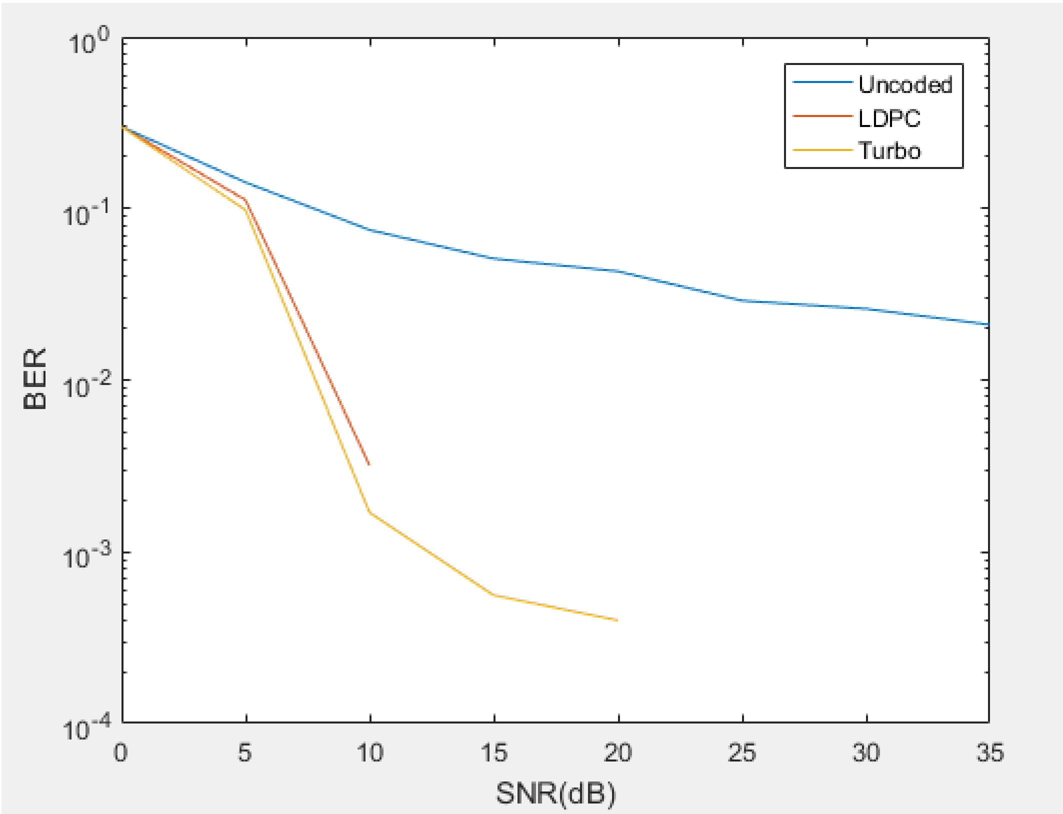


Fig.15. BER comparison between LDPC and Turbo

In Figure 15, Turbo code performance has always been better than LDPC before SNR reaches 10dB. Fig.15 also shows with the increase of SNR, the Turbo code shows the bottom line of the error rate. When the BER drops to a certain level, even if the SNR is increased, the BER will not decrease significantly, and the LDPC code does not exist this performance.

Due to the sparsity of the LDPC codes check matrix, LDPC codes can be decoded in linear time. Its decoding is a parallel algorithm with a short decoding delay which allows LDPC codes to achieve near or even better performance than the Turbo codes in the case of low decoding complexity. Meanwhile, Turbo code has the bit error rate bottom line which the LDPC code does not exist.

### 4.2.3 Polar codes

Polar code obtains the control channel of in 5G eMBB scene. The evaluation of Polar Codes was shown in 4.2.3.

Tail-Biting Convolutional Codes is 4G standard, and Polar codes applied to 5G has low computational complexity and low spatial complexity. Figure 16 shows the comparison of polar codes and TBCC. In figure 16, the code rate is 1/2, signal size is 512, modulation method is QPSK. At the standard of low code rate, the performance of 5G polar code is better than 4G TBCC.

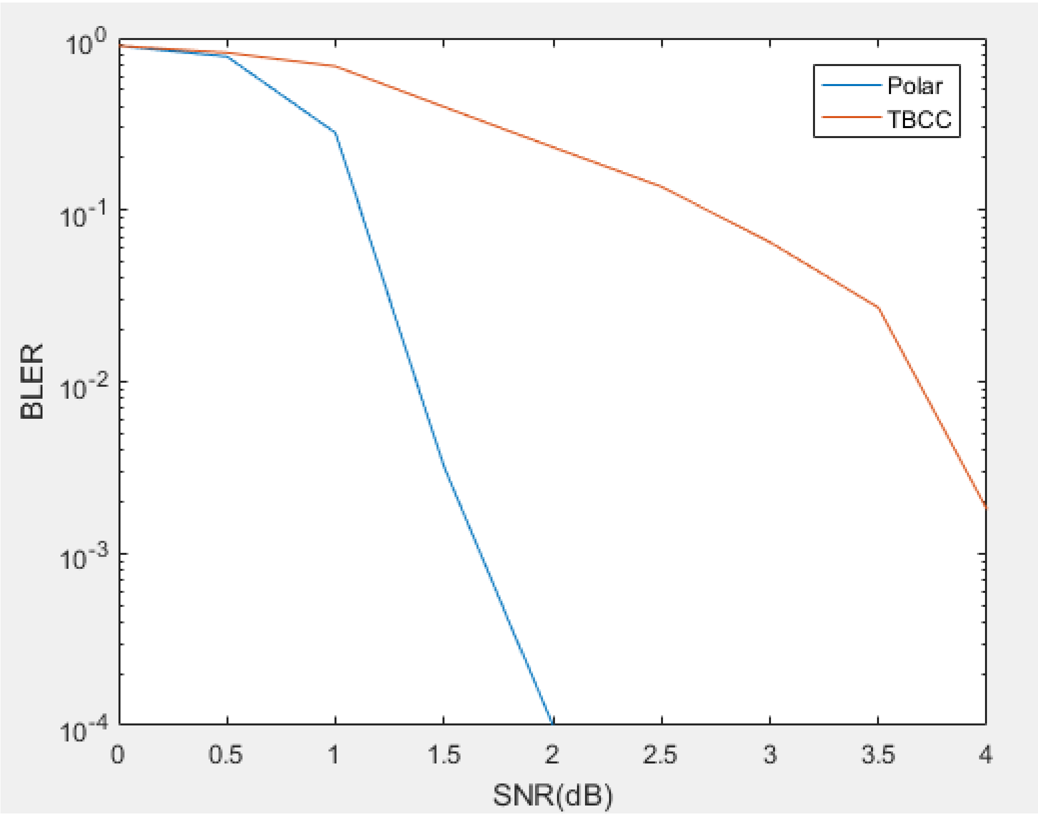


Fig.16. Comparison between Polar and TBCC

## 4.3 LDPC and Polar cascading system

LDPC and Polar cascading system are shown in this chapter. Through the analysis of chapter 4.2, we can also find in LDPC coding method, when the SNR is very high, the improvement effect of BER performance is not apparent. To realize better transmission performance, people have proposed the combination of two coding methods in many papers. For example, in[19] the LDPC code-Reed–Solomon code was proposed. In[20] the LDPC code-polar code was proposed.

Because Polar code can theoretically reach the Shannon limit. And has a lower complexity of the encoding and decoding algorithm. We evaluate the BER performance of Polar-LDPC system and single LDPC coding system. Fig.17 is the structure of our experiment.

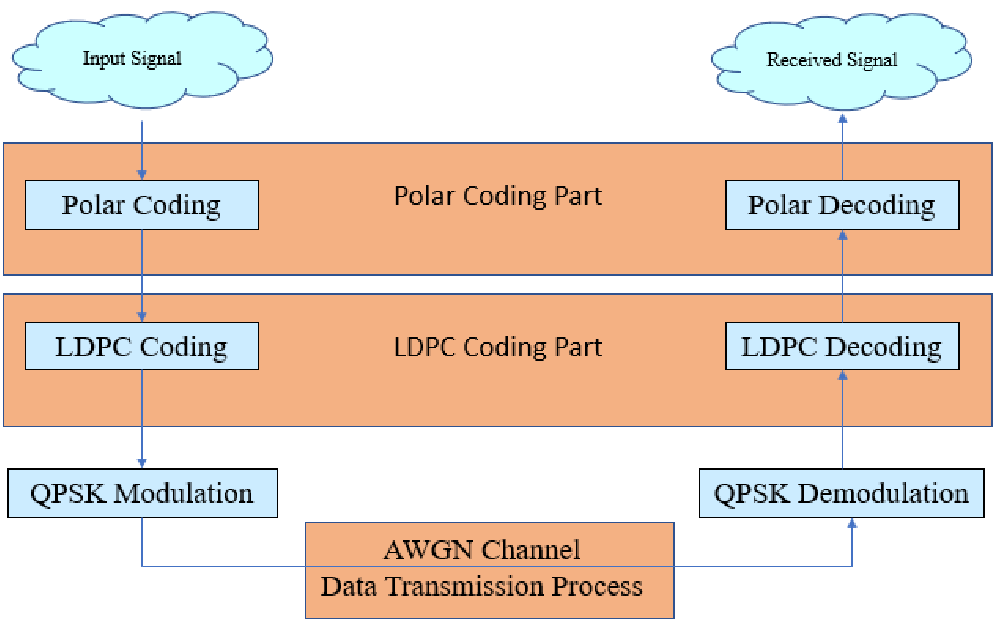


Fig.17. Structure of Polar-LDPC coding system

Fig.18 is the simulation result of the comparison between Polar-LDPC coding system and original LDPC coding system. According to Fig.18, The whole experiment can be divided into two stages. In stage 1, the SNR is low, so the BER performance of LDPC is better. In stage 2, when the SNR is between 15dB and 20dB, the concatenated system can reduce BER from $10^{-2}$ to $10^{-4}$, while original LDPC coding system reduces BER from $10^{-2}$ to $10^{-3}$. When SNR is 25dB, the concatenated system achieves the BER of $2.4\times10^{-7}$, while the original LDPC coding method gets the BER of $6.9\times10^{-6}$. The result shows that the concatenated system could realize superior BER performance than the original LDPC when the SNR is high.

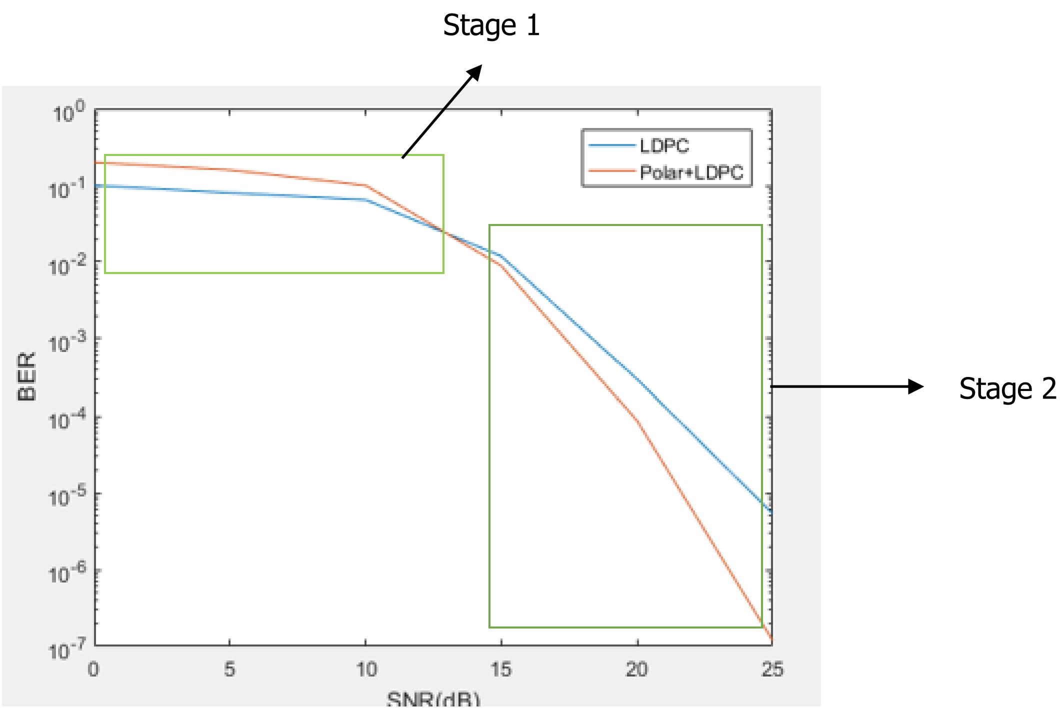


Fig.18. The comparison of Polar-LDPC and original LDPC

# Chapter 5
# Conclusion and Future work

## 5.1 Conclusion

In the thesis, we put forward several key techniques in 5G wireless communication, such as millimeter wave, OFDM and MIMO. Then, we showed introduced coding methods and modulation methods in the communication process.  Also, several experiments on 5G wireless communication have been proposed. In our experiment, in order to get the best option of modulation method, we analyze QPSK, 16QAM, and 64QAM. In coding method part, we compare LDPC codes with turbo codes in 5G data channel, evaluate the performance of polar codes and TBCC in 5G control channel. At last, we design a system to combine LDPC codes with Polar codes to realize the best performance of BER.

## 5.2 Future work

In the future, the data transmission system still needs to be improved, and BER also needs to be reduced at the same time. However, 5G technology is fully developed, we would like to improve our theory of coding method next generation wireless communication. Mobile communication has always been extended to more spectrum and higher frequency bands. 5G extends from less than 6 GHz to millimeter wave band. Perhaps next generation will enter the era of terahertz. As the network becomes denser, blockchain-based dynamic spectrum sharing technology will become a trend.

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