5G: An overview of Technologies and use Cases

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***Abstract*—5G *NR* in a very popular technology since 2020. 5G is not just an incremental improvement. It has a revolutionary leap forward in terms of data rates, latency and massive connectively. These functions aim to realize high-speed connection, the Internet of Things, enhanced virtual reality, haptic Internet, etc. Due to the enormous technologies and use cases of 5G, it is necessary to give an overview. The 5G channel is encoded by polar code. In addition, massive MIMO technology is used to enhance the 5G signal. eMBB, uRLLC and mMTC are the three most important applications scenarios.**

Index Terms* – *5G, polar code, massive MIMO, eMBB, uRLLC, mMTC.

I. INTRODUCTION

THE fifth-generation mobile communication technology (5G) is a new generation of broadband mobile communication technology with high speed, low delay, and large connection characteristics. It is a network infrastructure to realize human-computer and object interconnection. Mobile communication technology has been developed for decades. In the 1980s, the first-generation mobile communication system (1G) using analog communication system was born. 1G use the technologies of AMPS and FDMA. However, theft and serial numbers often occur in analog communication systems. Then, the second-generation mobile communication (2G) was born in the 1990s. 2G use the technologies of GSM and FDMA/TDMA. Followed by the arrival of 3G era. 3G use the technologies of WCDMA. Higher bandwidth enables 3G to connect to the network. In 2014, 4G finally landed in China. 4G includes TD-LTE and FDD-LTE [17]. As a result, the era of the Internet is coming. However, there is a need for higher network speeds and lower latency. The fifth-generation mobile communication technology (5G) has been put into use in 2020.

5G uses New Radio (5G NR) technology. 5G has made great changes in channel coding, uplink and downlink frequency bands, networking, and network architecture. In addition, the application scope of 5G is also greatly increased. Since 5G has the characteristics of high bandwidth, low-latency and high connection density, its applications mainly include three aspects: eMBB, uRLLC and mMTC. In this paper, we provide an extensive discussion and summary of some key technologies and its applications of 5G. Section II outline two key technologies of 5G. Three application scenarios of 5G are discussed in Sec. III.

II. SOME KEY TECHNOLOGIES OF 5G MOBILE COMMUNICATION

A. Channel coding: Polar Code

In digital communication. All information, such as sound, image, and text, will become binary codes such as 0 and 1. The process of converting this information into binary numbers is called source coding. However, in the process of information transmission, information will be disturbed. Channel coding can solve the problem. Figure 1 shows a whole digital communication model.

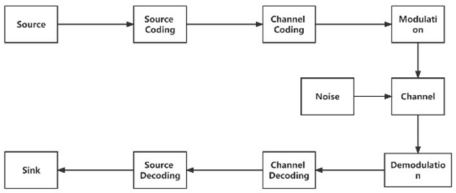

Fig. 1: Simple Digital Communication Model

In Shannon formula:

$$C = B \cdot log_2(1 + SNR) \quad (1)$$

SNR means signal-to-noise ratio, B means channel bandwidth and C means channel capacity. If B is increased, the

noise power will also increase accordingly. Thus, C can not be increased without limitation. Shannon believes that through correct coding, it is possible to transmit information at rate C through the channel, and the error frequency or equivocation can be as small as satisfactory. This statement is not valid for any rate greater than C [1]. This is called Shannon limit. In decades of communication development, many great channel coding methods have been born, such as Convolutional code and Turbo code. However, these channel coding cannot reach to Shannon limit.

Polar code is the first channel coding method that has been proved to reach Shannon limit. In the discussion of 5G short code scheme at 3GPP conference in 2016, Polar code has been determined as the coding scheme of 5G eMBB scene control channel.

The basic principle of Polar code is channel polarization [2-3]. Fig .2 shows the binary-input discrete memoryless channels (B-DMC) W in the case of $N = 2$. When N=2, assumed probability of being erased P=0.5, 1-P=0.5. After transmission, the probability of successful u_1 transmission is $(1-P)^2 = 0.25$, and the probability of successful u_2 transmission is $1-(1-P)^2 = 0.75$. Thus, the channel u_1 is called good channel, u_2 is called bad channel. When N is large enough, a polarization phenomenon will occur. That is, the channel capacity of some polarized channels ${W_{(N)}}^i$ tends to 1, at the same time, the channel capacity of the residual polarization channel tends to 0. Polarized channels with channel capacity approaching 1 are called noiseless channels, polarized channels with channel capacity approaching 0 are called noisy channel [4].

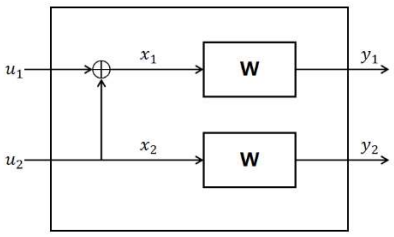

Fig. 2. N=2 polarization coding based on binary-input discrete memoryless channel

B. Massive MIMO technology

The main problem of ongoing wireless network development is that it depends on increasing bandwidth (spectrum) or densifying the cells to achieve the required regional throughput. However, these resources are very rare and will reach the saturation point within a few years. In addition, the increase of bandwidth and densify the cells will lead to the increase of cost. Another factor is improved area throughput, that is, spectral efficiency. However, the spectral efficiency is basically guaranteed to remain unchanged in the development of mobile communication. Thus, we need a wireless access technology to increase area throughput without increase bandwidth and densifying the cells [5].

Massive MIMO (multiple-input multiple-output) can realize the desire. For wireless communication, MIMO refers to the use of more antennas on the base station. This, of course, means increasing the channel capacity without increasing the frequency band and power. In MIMO technology, it can achieve three effects. Firstly, *Space Diversity*. Multiple antennas are used to transmit or receive a data stream to avoid the impact of a single channel on the entire link. Space diversity can improve acceptance quality. Figure 3 shows the space diversity. Secondly, *Space Multiplexing*. Use the non-correlation between large antenna array elements or beam forming to transmit multiple data streams to a terminal/base station in parallel to improve the link capacity. Figure 4 shows the space multiplexing. Thirdly, *Beam Forming (TDD format)*. Use the correlation between antenna elements with small spacing to form interference through the waves transmitted by the elements, concentrate energy in a specific direction, and form a beam, to achieve greater coverage and interference suppression effect [6].

The most important application of massive MIMO technology is beam forming. Beamforming is the ability of the base station to adapt to the radiation mode of the antenna [7]. Beamforming can help the base station find a suitable path to transmit data to users and reduce the interference to nearby users along the way [8]. In addition, beamforming can increase channel capacity. Radio wave is a kind of electromagnetic wave. Like water wave and sound wave, it has coherent phenomenon. If many antennas are used to transmit electromagnetic waves of the same frequency, and the phase of the transmitted wave is well controlled, the signal can be transmitted in one or several specific directions. This kind of signal not only has concentrated energy, but also can distinguish different spatial positions without sharp decrease in power when it is transmitted over a long distance. Using this discrimination is equivalent to establishing more channels.

$$C = min(m_R, m_T) \cdot B \cdot log_2(1 + SNR) \qquad (2)$$

m_T and m_R are the number of transmitting and

receiving antennas in the channel respectively. min is the minimum of m_T and m_R [9].

Massive MIMO systems will perform crucial role in 5G. It can be used for smart sensor applications, such as an autonomous vehicle, remote healthcare, smart grids, smart antennas, smart highways, smart building, and smart environmental monitoring [5].

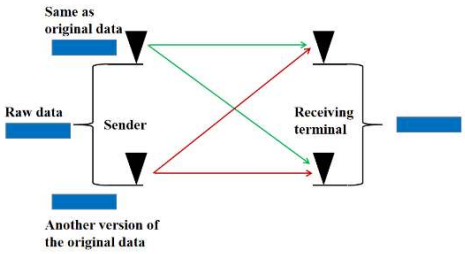

Fig. 3. Space diversity

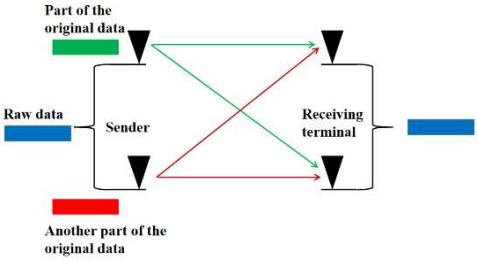

Fig. 4. Space multiplexing

III. 5G APPLICATION CASES

Compared with 4G, 5G has made great improvements in many aspects. Such as greater bandwidth and lower latency. Table 1 shows the theoretical comparison between 4G and 5G. In addition, Figure 5 shows the total use cases in 5G. This section will introduce three application scenarios of 5G: enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (uRLLCs), and massive machine - type communications (mMTCs) [10].

TABLE 1. THE THEORETICAL COMPARSION BETWEEN 4G AND 5G

Index name	4G reference value	5G reference value
Flux density	0.1 $Tbps/Km^2$	10 $Tbps/Km^2$
Connection number density	$10^5/Km^2$	$10^6/Km^2$
Time delay	Air interface 10ms	Air interface 1ms
Mobility	350 Km/h	500 Km/h
Energy efficiency	1 time	100 times
User experience rate	10 Mbps (urban)	0.1-1 Gbps
Spectral efficiency	1 time	3 times
Peak rate	1 Gbps	20 Gbps

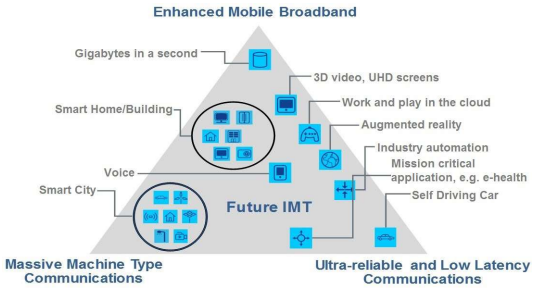

Fig. 5. IMT 2020 Use Case Categories

A. Enhanced mobile broadband (eMBB)

For the first 5G deployment in the world, the enhanced mobile broadband (eMBB) service is the main target. eMBB supports stable connections with very high peak data rates, as well as moderate rates for cell-edge users. eMBB traffic can be considered as a direct extension of 4G broadband services. The goal of eMBB is to maximize the data rate while ensuring moderate reliability, with packet error rate (PER) on the order of 10^{-3} [11]. Under eMBB, the user can receive data at a transmission rate of up to 1Gbps and a peak rate of up to 20Gbps. Thus, for eMBB, there are mainly the following applications in 5G.

1) 8k Cloud VR Live Broadcast

Ultra HD 8K VR live broadcast, exceeding 100Mbps uplink live video transmission rate.

2) VR Cloud Games

VR games are processed in edge computing unit real-time media and GPU image rendering. Users do not need to configure VR game consoles, but only VR display units. Connecting VR devices can support wireless connection with higher speed.

3) Smart Tourism/Exhibition

Face recognition cameras are deployed in exhibitions or tourist attractions to realize face recognition, authentication, and track tracking through 5G feedback.

4) AR Remote Collaboration

Head-mounted AR device, which realizes two-way communication of high-definition video through 5G and realizes AR cooperation assistance.

B. Ultra-reliable low-latency communications (uRLLCs)

uRLLC supports very reliable low latency transmission of small payloads from a limited group of terminals [11]. In this scenario, the connection delay should reach the level of 1 ms, and the high reliability link should be supported in the case of high-speed mobile (500 Km/h).

1) 5G in healthcare in COVID-19.

As of December 12, 2022, there will be 650 million COVID-19 cases in the world, including 6.6 million deaths [12]. As a core technology, 5G has a positive impact on the treatment of COVID-19. URLLC makes it possible to exchange a large number of data sets and track contacts in real time in the fangcang (cabin) hospital, while low latency enhances robot-assisted tele-ultrasound, and telementoring during ophthalmic surgery. In other instances, 5G provided a supportive technology for applications related to COVID-19, e.g., patient monitoring [13].

2) Automatic driving technology

Automatic driving is a product of artificial intelligence. However, 5G low latency and large bandwidth technology can make it come true. The goal of automatic driving is to replace human vision and perception.

At present, Tesla's automatic driving relies on multiple radars and laser detectors, which requires extremely high reaction speed. The current 5G low latency technology is the best way to solve this problem.

C. Massive machine -type communications (mMTCs)

mMTC supports a massive number of Internet of Things (IoT) devices, which are only sporadically active and send small data payloads [11]. The strong connectivity of 5G can quickly promote the deep integration of various vertical industries (smart cities, smart homes, environmental monitoring, etc.). With the interconnection of all things, people's lifestyle will also undergo disruptive changes. Its characteristics are low data rate and insensitive delay, connection covering all aspects of life, lower terminal cost, longer battery life and higher reliability.

1) Internet of everything

“Internet of Everything” (loE) is defined as the combination of people, processes, data, and things to make network connectivity more relevant and valuable. loE not only provides links between things, but also links between data, people and (business) processes. Strengthening the links between people and things, things, and things, will have a huge impact on urban planning, personnel first aid, military and health and other aspects. In addition, several Internet and connection-based paradigms fall under the loE umbrella, such as Internet of Things (loT), Internet of People (loP), and Industrial Internet [14]. These devices usually do not require good network conditions. However, the increase of networking devices makes 4G networks incompetent, while the high connection density of 5G networks can support this situation

2) Automatic driving technology

As mentioned above, uRLLC technology is applied to automatic driving. In addition, mMTC technology is also very helpful for automatic driving. C-V2X (Cellular Vehicle-to-Everything) is the V2X communication technology developed based on the cellular systems. It makes use of and enhances the characteristics and elements of the current cellular network, enabling low latency and high reliability communication between nodes in the vehicle network, including vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I), and vehicle-to-network (V2N) communications [15-16]. The Internet of Vehicles can guarantee the safety of automatic driving to a greater extent.

REFERENCES

[1] Shannon, "A mathematical theory of communication," *Mobile Computing and Communications Review,* vol. 5, *(1),* pp. 3-55, 2001.

[2] Arikan, E. (2009;2008;). Channel polarization: A method for constructing capacity-achieving codes for symmetric binary-input memoryless channels. *IEEE Transactions on Information Theory, 55*(7), 3051-3073. doi:10.1109/TIT.2009.2021379

[3] Bioglio, C. Condo and I. Land, "Design of Polar Codes in 5G New Radio," 2018.

[4] 于清苹, 史治平. 5G 信道编码技术研究综述[J]. 无线电通信技术, 2018, 44(01):1-8.

[5] R. Chataut and R. Akl, "Massive MIMO Systems for 5G and Beyond Networks-Overview, Recent Trends, Challenges, and Future Research Direction," *Sensors (Basel, Switzerland),* vol. 20, *(10),* pp. 2753, 2020.

[6] T. L. Marzetta, "Massive MIMO: An Introduction," *Bell Labs Technical Journal,* vol. 20, pp. 11-22, 2015.

[7] A. F. Molisch *et al*, "Hybrid Beamforming for Massive MIMO - A Survey," 2016.

[8] B. Yang *et al*, "Digital Beamforming-Based Massive MIMO Transceiver for 5G Millimeter-Wave Communications," *IEEE Transactions on Microwave Theory and Techniques,* vol. 66, *(7),* pp. 3403-3418, 2018.

[9] A. van Zelst, R. van Nee and G. A. Awater, "Space division multiplexing (SDM) for OFDM systems," in 2000, . DOI: 10.1109/VETECS.2000.851289.

[10] M. Shafi *et al*, "5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice," *IEEE Journal on Selected Areas in Communications,* vol. 35, *(6),* pp. 1201-1221, 2017.

[11] P. Popovski *et al*, "5G Wireless Network Slicing for eMBB, URLLC, and mMTC: A Communication-Theoretic View," *IEEE Access,* vol. 6, pp. 55765-55779, 2018.

[12] “COVID-19 Coronavirus pandemic,” Accessed: Dec. 12, 2022. [Online]. Available: https://www.worldometers.info/coronavirus/#countries

[13] A. Moglia *et al*, "5G in Healthcare: From COVID-19 to Future Challenges," *IEEE Journal of Biomedical and Health Informatics,* vol. 26, *(8),* pp. 4187-4196, 2022.

[14] L. T. Yang, B. Di Martino and Q. Zhang, "Internet of Everything," *Mobile Information Systems,* vol. 2017, pp. 1-3, 2017.

[15] S. Chen *et al*, "A Vision of C-V2X: Technologies, Field Testing, and Challenges With Chinese Development," *IEEE Internet of Things Journal,* vol. 7, *(5),* pp. 3872-3881, 2020.

[16] S. Chen *et al*, "Vehicle-to-Everything (v2x) Services Supported by LTE-

Based Systems and 5G," *IEEE Communications Standards Magazine,* vol. 1, *(2),* pp. 70-76, 2017. . DOI: 10.1109/MCOMSTD.2017.1700015.

[17] H. Chen, "Research on 5G Key Technologies and Challenges," *Journal of Physics. Conference Series,* vol. 1920, *(1),* pp. 12097, 2021.