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An Overview of the Wireless Key Technologies of 5G

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Abstract. With the accelerate growth of mobile communication technology, 5G emerges at a historic moment, has been developing at high speed and devotes itself to open the curtain of the information age. This paper summarizes the wireless key technologies of 5G including technology trials. Finally, progress on implementation issue of these techniques are also reviewed.

1. Introduction

Driven by services and technology and to achieve a true 'Internet of everything', the 5th-generation (5G) mobile communication system has become the hottest topic and will be used in the next ten years. A great many countries, organizations, and units are keeping investing in 5G in order to bring new development opportunities and new economic growth. For example, the 5G Industry Association (5GIA) from Europe, IMT-2020(5G) [1] Promotion Group from China, and 5G Mobile Forum (5GMF) from Japan are official 5G organizations. To push forward the global unified 5G standard and to promote the 5G industry, these organizations emphasize international cooperation by initiating global 5G summits which discuss topics including spectrum collaboration, technology and standards trends for 5G. With the promotions of the summits, 5G has been moving forward rapidly. Different from the former generations of mobile communication, 5G will serve not only the telecommunication industry, but also the whole information society. The two typical kinds of services of 5G are the Internet of Things and Mobile Internet. From the standards aspect, we have a complete 5G standard in 2019 and even an approved 5G version from the ITU around 2020. The International Standards Organization of the 3rd Generation Partnership Project (3GPP) has officially released an enhanced 5G version for commercial using, which makes 5G become more mature and competitive. We can expect 5G pre-commercial and even a commercial network towards 2020.

In this paper, we give an overview of the wireless key technologies of 5G including technology trials.

2. 5G Wireless Key Technologies

To realize 5G user requirements of the system capacity, spectrum efficiency, and operational efficiency, many innovative wireless technologies have been invented and adopted, including main MIMO (massive multiple-input multiple-output) [2], NOMA (non-orthogonal multiple access), UDN (ultra dense networking), advanced coding and modulation and flexible spectrum access.

2.1. Massive MIMO

MIMO will be further enhanced in 5G and massive MIMO has been approved to be the most efficient technology for enhancing spectrum efficiency. The 'traditional' MIMO techniques have been researched extensively and deeply in 4G and the previous communication systems before 4G. There was an agreement on that there is a linear interrelationship between the MIMO capacity and the scale

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of antennas array. However, in recent years, by the reason of the antennas size and the terminal complexity problems, the antennas number in practice is less than or equal to 8 even with latest upgrades of 5G standard. It is obviously impractical to boost the communication capacity by increasing the antenna number. Nevertheless based on the research conclusions of [3], if the antenna number increases greatly, in other words, orders of magnitude exceeds former configuration, even the simplest MIMO system would get excellent performance, which is the so-called massive MIMO.

Because one base station can be configured dozens of antenna ports and hundreds antennas, it can be used for distributed or centralized massive MIMO. In different cases, technology needs to be improved and optimized including the design of channel estimation, reference signals, multi-user scheduling mechanism, receiving algorithms, and channel information feedback. Therefore, TDD is a more promising candidate for 5G systems with large antenna arrays.

The massive MIMO technique will bring benefit to the 5G communication systems in the following respects:

Capacity: The base stations in cellular system can be equipped with hundreds antennas but the antenna number of user equipments (UEs) is limited, e.g. less than 8. The capacity of MIMO communication system would be improved greatly in both uplink and downlink transmission.

Latency: Fading affects the transmission latency of wireless communication deeply. By adopting massive MIMO technique, MIMO signal processing and space diversity would give benefit to the receiving signal, for example precoding and beamforming, which compensate fading.

Cost and power: Although in the massive MIMO application, there is up to hundreds antennas, the energy efficiency is increased dramatically [3]. Massive MIMO could get a higher transmission gain with a lower emitting power consuming per antenna by sharping the signal in a very small region. In fact, the total power consuming of massive MIMO is much less than the traditional one.

2.2. NOMA

In former generations of mobile communication systems, orthogonal multiple access techniques in the frequency, time, and code domain have been utilized mainly. For a 5G system, connecting 1 million devices per square kilometer requires much evolved hardware capability. Non-orthogonal multiple access (NOMA) [4] has been regarded as a prospective technique to reach the objectives in terms of service latency, user connectivity, and system capacity.

Non-orthogonal multiple access, which multiplexes multiple users in the power domain, is the newest multiple access technique to meet the demand of 5G communication system for wireless broadband spectrum. By adopting NOMA technique, multiple users could be allocated at different power levels, according to their channel conditions, where it needs to be emphasized that the communication among these users is occurring at the same time, frequency and code channels.

Pilot researches in the way of system-level simulation and analysis on NOMA have been implemented in recent years [4,5]. The results of these researches prove that NOMA technique could attain higher spectral efficiency than other mainstream orthogonal multiple access techniques, for example, frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA) and orthogonal frequency division multiple access (OFDMA). The primarily reason why there exists such a performance improvement is because that NOMA can choose the right chance to utilize the wireless channel conditions, however, other existing mainstream orthogonal multiple access techniques, such as FDMA, TDMA, CDMA, OFDMA, could not consider channel conditions.

A more strict and comprehensive method to assess NOMA performance is to take not only the randomly distributed small scale fading gains, but also the random distances between users to the base station into consideration. Stochastic geometry can be used as an ideal mathematical method to acquire the random geospatial location of the mobile user equipments (UEs), which was adopted to NOMA in [5], which proves that even if mobile UEs are randomly distributed, NOMA could also reach higher performance than other existing conventional mainstream orthogonal multiple access techniques.

2.3. Ultra Dense Networking (UDN)
UDN is aimed at supplying a very high transmission rate to different users for hotspot or indoor scenarios, for example, offices, stadiums, and dense residential areas. Typical supports of UDN are for very high traffic, user, and access point (AP) density.

Key challenges of UDN include interference management, cell virtualization, integrated access, wireless backhaul, and user-centric design.

2.4. Advanced Coding and Modulation
In addition to traditional binary Turbo code and quadrature amplitude modulation (QAM), 5G needs to support advanced coding and modulation methods for wider services. Novel signal constellation mapping and de-mapping, faster-than-Nyquist (FTN) signaling, and low density parity check (LDPC) could be adopted to further boost spectrum efficiency in physical layer for high speed rate transmission services. In some low signal-noise-ratio (SNR) and short code-length conditions, low code rate convolution codes and polar codes could be adopted to approach the theoretical Shannon limit for small packet and low speed rate transmission services. Fast encoding and decoding schemes are chosen for low delay services. The 'error floor' effect should be removed from decoding algorithms for high reliability services. Besides, network coding could improve the backhaul system capacity in a dense network where exists a lot of wireless backhaul links.

In 3GPP, LDPC coding was accepted for the NR data channel, while polar coding was accepted for the NR control channel.

2.5. Flexible Spectrum Access
Different from former generations, 5G operates at not only high-frequency (HF) bands of 6–100 GHz but also low-frequency (LF) bands of below 6 GHz. The HF bands are the new supplementary bands which are used to reach high transmission rates in hotspot areas, for example, in the dense urban area. The LF bands are the core bands which are used for seamless coverage. To fully exploit the advantages of different frequencies, 5G needs to support hybrid networks with LF and HF bands to simultaneously meet the requirements of seamless coverage, ultra-high data rates, and ultrahigh capacity.

Considering the big differences between HF bands and traditional LF bands, research on 5G spectrum access focuses mainly on key technologies including channel measurement and modeling, new air interface design, networking technology, and radio frequency components for HF mobile communications.

Besides technologies discussed for HF bands and other traditional methods for spectrum efficiency, innovative spectrum utilization methods are also efficient ways to extend the usable frequency for 5G systems. Potential flexible spectrum sharing schemes include intra-operator inter-RAT, inter-operator, in secondary access, and spectrum sharing in unlicensed band.

3. 5G Technology Trial
Different from former generations, the 5G technology trial was conducted early in the same period as 5G standardization to serve as a guide to the standard. As shown in Table 1, major organizations have issued their 5G testing or commercial plan, making a huge investment to invite international vendors and operators to attend. Among them, China led the fastest and first 5G scale tests, and started 5G communication network commercialization in early 2019.

Table 1. 5G test and commercial plans from major organizations in different countries and regions.

Country/Region	Test and commercial plans
EU	Investing €1.4 billion on 5GPPP projects Conduct small scale tests to verify 5G standards in 2018
USA	A local 5G standard was led by Verizon in mid-2016 Released frequency in 2016 and started to cost more than $400 million in the next several years to establish a pilot 5G communication network
Japan	Carrying out 5G technology trials with leading operator NTT DoCoMo Planning to offer formal 5G commercial services ahead of the 2020 Summer Olympics
South Korea	Released national 5G strategy Launched a pre-commercial 5G trial at the 2018 Winter Olympics and then commercialize by the end of 2020
China	Dominated the 5G trial since the plan was issued in 2016 Started 5G network commercialization in early 2019

4. Conclusions

Thanks to a new opportunity offered by economic growth, 5G has gained wide attention and is developing very fast. As expected, 5G will bring unprecedented changes to people’s daily life and even to the whole society. The 5G industrial ecosystem is at a building phase, and the involvement of and cooperation with industry need to be strengthened. 5G is finally expected to be large-scale commercial in 2020. It could be predicted that the next 10-year mobile communications will come.

5. References

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