Research on the Coverage Optimization of 5G mmWave

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Abstract. This article introduces the evolution of 5G millimeter wave (mmWave) standard, analyzes the major technical advantages and summarizes three typical application scenarios, then puts forward the optimization strategy of 5G mmWave coverage capability, and finally forecasts the evolution direction of technology and products.

1. Introduction
5G, widely recognized as a universal enabling technology in the Industry 4.0 era, will bring revolutionary improvement of user experience and digital transformation of thousands of industries, and inject new vitality and energy into digital entertainment, health care, energy, manufacturing, transportation, etc. 5G mmWave, with rich frequency resource, high speed and large capacity, can contribute to the realization of all the original promise and initial visions of 5G. Moreover, it will bring huge social and economic benefits. It is expected to contribute $565 billion to global GDP by 2035, accounting for 25% of the total contribution of 5G, while the economic benefits from the use of mmWave spectrum in China will reach about $104 billion by 2034[1].

2. Standard evolution
5G mmWave, as one of the main components of 5G, is an important guarantee of 5G performance index. Its standardization work is carried out synchronously with the low and medium frequency. At present, 3GPP has completed two versions of 5G standard, i.e., Rel-15 and Rel-16.

In the first version of 5G technology, namely Rel-15, 3GPP standardized the millimeter-wave frequency band, carried out modelling research, and provided the basic functional version.

In Rel-16, frozen in June 2020, 3GPP further optimized mmWave, focusing on the improving work efficiency and reducing delay and cost. In addition, a number of 5G NR enhancement feature supporting mmWave were introduced, such as integrated access backhaul (IAB), enhanced beam management, dual connection optimization, etc.

Rel-17, currently in progress, will enhance mmWave and accommodate more scenarios. Besides, 3GPP will make further efforts to expand the spectrum, support from 52.6GHz to 71GHz band and 60GHz unlicensed band, contributing to the expansion of millimeter-wave spectrum utilization.

3. Technical advantages

3.1. Rich frequency resources
Compared to Sub-6GHz frequency band (FR1), 5G mmWave is valued for its rich spectrum resources, which it is the main way for 5G network to provide Gigabit connectivity and a strong guarantee for realizing the initial vision of 5G. The peak rate of mmWave network can be achieved up to several Gbps. Take 26 GHz band for example, allocating continuous 800MHz spectrum into four single
carrier 200MHz (4*200MHz) or eight single carrier 100MHz (8*100MHz) to realize carrier aggregation transmission, the peak data throughput of Gbps can be obtained by combining with advanced antenna design and RF processing technology. In short, 5G mmWave significantly improves the peak rate, compared with Sub-6GHz band.

3.2. High beamforming gain
With high frequency band and short wavelength, mmWave has space superiority in design and deployment, making it quite suitable for combining with beamforming technology, so as to enhance performance and reduce interference. Due to the short wavelength of mmWave, more antenna arrays can be placed in limited space. In particular, the number of antenna arrays can reach 256, 512 or even more.

3.3. Low latency
Compared with the Mid-Low frequency system, mmWave system significantly reduces the NR delay with low latency of less than 1ms, supporting for URLLC (Ultra-reliable and Low Latency Communication) business such as industrial Internet, AR/VR, cloud games, real-time cloud computing, etc. For instance, AR/VR requires millisecond delay to ensure multi-sensory coordinated experience and interaction ability. Higher requirements for NR delay is also put forward in the industrial internet such as industrial robot network, remote real-time control and intelligent manufacturing, etc.

3.4. High precision positioning
With the characteristics of narrow beam, good directivity and extremely high spatial resolution, mmWave signal transmission features low cycle and high time accuracy, which is expected to achieve high precision positioning of centimeter level. In particular, in the indoor environment where satellite navigation signals are weak, mmWave will play a more important role in providing fast and high precision positioning services in industrial internetworking, logistics and transportation, transportation hubs, etc.

3.5. High equipment integration
Compared to Sub-6GHz, the size of 5G mmWave components is much smaller, and the device is much easier to be miniaturized and miniaturized. The cost of related components will be gradually reduced after its large-scale commercialization. In the field of professional equipment, wearable devices, intelligent components and so on, the advantage of high equipment integration means much broader application prospect. In addition, 5G mmWave base station features small size, light weight and easy installation, which is conducive to creating a green, efficient and convenient deployment of 5G network.

4. Application scenarios
In view of its characteristics of large bandwidth, low delay and weak coverage, three main application scenarios of mmWave are summarized as follows.

4.1. Hotspot areas
The first category is hotspot areas with dense population and large business flow, i.e., shopping malls, concert halls, sports fields, and transportation hubs such as airport and railway station, etc. For these scenarios with large numbers of users and high demand for data traffic during peak hours, 5G mmWave technology can give full play to its advantages of large bandwidth, high instantaneous rate and large system capacity to carry out accurate coverage diversion and solve the hotspot flow problem.

4.2. Industry application
The industry application of 5G mmWave is mainly aimed at large bandwidth, low delay service and high reliability service, that is 5G uRLLC scenarios, such as mobile video surveillance, industrial
vision, UAV control and graphics transmission, collaborative robot production line control, etc. 5G mmWave can well meet the strict demand and realize the industrial intelligence and network interconnection. Moreover, combining with MEC and AI technologies, 5G mmWave can provide intelligent solutions of large capacity, high rate and localization as well as customized campus private network services for the coverage area.

4.3. Fixed wireless access
Due to its property of high frequency point and short wavelength, more antenna arrays can be placed in the same area, thus the beam energy is more concentrated. Besides, 5G mmWave is capable of providing up to 800MHz large bandwidth and several Gbps peak rate, so that it can be served as a wireless backlink to solve the problem that optical fiber cannot be laid or the cost is too high in some scenarios, thus as a supplement to the conventional access of the last kilometer.

5. Coverage optimization scheme
High propagation loss, weak diffraction, and relatively limited coverage are the biggest challenge faced by mmWave communication system. How to reasonably deploy mmWave to improve its coverage capability is the prerequisite for the successful commercial implementation. Three solutions to the signal attenuation and blocking of mmWave are put forward as follows.

5.1. Beamforming
First of all, mmWave increases EIRP (equivalent omnidirectional radiation power) through beamforming technology to improve coverage capability, which can easily realize signal transmission of hundreds of meters and alleviate the path loss. It has been verified not only by simulation experiments, but also in field testing and commercial deployment. Moreover, in the standardization of mmWave, beam management is one of the key tasks, including beam search, beam tracking and beam switching, etc. Therefore, mmWave system can capture the new beam quickly and implement beam switching dynamically when signals in some directions are blocked[2]. On the other hand, advances in semiconductor technology have promoted the rapid development of mmWave technology, which integrates large-scale array antenna and RF link into phase array with higher cost performance, and successfully implements intelligent beam forming, beam searching and beam tracking technologies, thus providing powerful support for mmWave system in terms of hardware.

These advanced technologies not only enable mmWave to make up for its shortage in propagation through beam forming, but also make good use of multi-path and reflection, and switch freely between different connections and paths through beam management. If the line-of-sight transmission path is blocked, mmWave system can still quickly find and identify the non-line-of-sight path (such as reflection) through intelligent beam searching and quickly switch to the corresponding transmission path, so as to solve the problem of line-of-sight transmission blocking of mmWave signal.

5.2. IAB

Figure 1. IAB expands coverage and capacity
In Rel-16, IAB technology is supported to enhance the coverage capability of mmWave. Especially in places where fiber deployment is difficult or expensive, such as in high-rise buildings, isolated islands, or mountainous areas where fiber laying is problematic, the ultra-large millimeter-wave bandwidth can be used to provide backhaul links to facilitate seamless coverage of 5G networks. As shown in Figure 1, on the one hand, IAB technology can expand the coverage of mmWave network through wireless backhaul. On the other hand, it improves the capacity by sharing spectrum resources over access and backhaul links[3]. In addition, IAB technology supports the functions of multi-hop connections and network topology self-adaptive, so that the network coverage can be flexibly extended, while inter-station connections are more flexible and the network topology is less restricted. It also supports OTA synchronization and node discovery, making the synchronization between mmWave base station much easier, the interface more intelligent and the deployment more convenient. Moreover, the coordination of access link and backhaul link is supported, which realize the integration of physical layer resource allocation, beam management, interference management, etc., fully integrate different link resources and improve overall efficiency. In MAC layer, mobility management, fast link recovery, QoS management, load balancing and other aspects of 5G network is enhanced to improve its robustness, which enables 5G mmWave network can quickly respond to network faults, dynamic adjustment and recovery.

5.3. Small cell
Small Cell technology is another solution to the coverage problem of mmWave. In the 5G era, it is difficult for a single base station to meet all communication requirements and deployment scenarios. Compared to medium and low frequency macro station technology, Small Cell base station has smaller coverage radius and larger deployment density, which ensures high throughput by reducing communication distance and fully guarantee coverage effect by increasing deployment density. Small Cell base station can be deployed in both indoors and outdoors. In order to match various deployment scenarios and meet differentiated usage demand, it presents multiple network architecture forms ranging from distributed to centralized.

The typical deployment scenario of Small Cell base station is various hot spots, such as conference rooms, large stadiums, concert halls, as well as transportation hubs (e.g., airports, railway stations, and subway stations). On the one hand, these scenarios usually have higher demand for 5G connection and higher load pressure. If only 5G medium and low frequency macro stations are deployed, it is easy to cause base station traffic overload, user access failures, and so on, resulting in the decline of user experience. The high-capacity feature of the Small Cell base station can effectively shunt the load of macro station, increase the success probability of user access, and ensure the stability of user connection and the consistency of user experience. On the other hand, in these scenarios, the high-density deployment of Small Cell base station can usually compensate for the loss of signal penetration through walls, and can work around the clock with no concern about the impact of rain and leaves blocking. As results, the signal quality can be guaranteed and the communication rate can be maintained stably at a very high level. In addition, compared to macro base station, Small Cell base stations are easier to achieve low power consumption, low cost and lightweight, as well as compatibility and controllability.

In short, 5G mmWave Small Cell base station can simplify high-density network department, realize plug-and-play, intelligent networking and flexible ultra-dense network, effectively reduce the installation requirements of base station and alleviate the location problem of macro base station.

6. Future Prospect
- Promote the industrialization of 5G mmWave high-frequency devices
The capability indicators of high-frequency devices determine the equipment capability power consumption and energy efficiency of 5G mmWave system. The industrialization maturity of high-frequency devices determines the equipment cost, which has an important impact on future deployment plans and application landing. It is necessary to gather industrial-academic-research
cooperation to jointly promote the industrial development of high frequency devices, building a mature industrial chain of high-frequency RF devices and chips.

- Improve OTA test
  
  As the OTA RF index standardization of 5G mmWave base station equipment evolves, the feasibility, reliability, accuracy, cost and efficiency of indicator testing scheme are facing new problems and challenges. The cost of test site, test efficiency and accuracy are all issues that need to be considered and provide solutions. At present, relevant institutions and manufacturers in the industry are exploring and researching around this technical direction.

  It requires the joint efforts of the whole industry in aspects of test environment, instrumentation devices and algorithm design to overcome obstacles, promoting breakthroughs and progress in OTA RF index testing technology[4].

- Support higher frequency band
  
  The millimeter wave high frequency band has rich spectrum resources, which can meet the demand of large-capacity communication in the future. 5G mmWave frequency band, i.e., FR2, defined in Rel-15 ranges from 24.25 GHz to 52.6 GHz. At present, Rel-17 has carried out research on the 52.6 GHz-71 GHz band, and will give priority to developing 5G NR standards for the newly expanded 60 GHz band. Recently, and 60 GHz has been identified as the International Mobile Communication band (IMT) in some countries and regions by the World Radiocommunication Conferences. In Rel-18 and beyond, it will first consider supporting the mmWave band near 100 GHz, including NR characteristics will be designed to support the frequency band up to 114.25GHz. Compared to the existing FR2 band, 5G mmWave bands are much abundant and will provide higher peak throughput.

  It is expected that the future development of 5G mmWave will inevitably expand to above 100 GHz and even reach 300 GHz. Higher frequency 5G mmWave communications is believed to bring changes in various aspects, such as mobile data streaming, short-range machine communication, broadband distribution network, IAB networking, industrial Internet, AR/VR, intelligent transportation, wireless connectivity of data centers, etc. However, it will also face complex technical problems, such as stronger phase noise, more serious path loss, more serious air absorption, lower power amplifier efficiency, etc.

7. Conclusion

At present, the development of 5G mmWave in China presents both opportunities and challenges. In terms of opportunities, the industry of 5G mmWave will develop rapidly along with new infrastructure construction. While, there are still some tricky issues to be addressed. As a whole, China's 5G mmWave industry chain lags slightly behind that of the United States, Japan, South Korea. The key technologies, core devices and chips need to be improved. International cooperation will help to complement each other's strengths. However, China still has several advantages such as strong policy support, large market space, and high demand for industry applications. In addition, the productization progress of the network side and the terminal side is basically in line with the international market. Given the dominance of manufacturing in China's economy, the industrial application of 5G mmWave will provide an excellent opportunity to drive China's economic growth.

With the acceleration of 5G construction and the increasing abundance of application terminals, the 5G mmWave market will usher in a broad space for development. In a word, the future prospect of 5G is very exciting. 5G mmWave will enable continuous technological breakthroughs in the next decade and beyond.

Acknowledgments

Funding supported by Research Project of Academy of Broadcasting Science, NRTA, Project No. : JBKY20210260.

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