

TEXNİKA ELMLƏRİ TECHNICAL SCIENCES

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TECHNOLOGIES IN 5G CELLULAR SYSTEMS

Abstract

Starting with the first generation systems known as "Advanced Mobile Phone System", cellular communication systems have always been in development. Nowadays, the latest cellular communication system whose standardization is mature enough and which has been put on market by service providers is the fifth generation (5G) system. The aim of this study is to introduce emerging technologies to be used with 5G. These technologies include millimeter-wave technology, small cell technology, massive MIMO technology, beamforming technology and full duplex technology. To summarize these technologies; millimeter-wave technology ensures that the bandwidth is extended, but due to high frequency level used, the signals travel shorter distances and transmission losses increase in air and solid materials. So small cell technology has been suggested as a solution to this problem. In this technology, transmission range is extended by using base stations located at shorter proximity, but more antennas are needed. As a solution to the need for multiple antennas in question, massive MIMO technology has developed. With this technology, a base station can send and receive signals (data) from many more users at the same time, but installation of excess antennas causes interference between signals. In this case, beamforming technology is used. Additionally, the so-called full duplex technology attempts to achieve high efficiency and low latency. As a result, all these technologies used in 5G are supporting each other by eliminating the others' shortcomings, and an all-in-one 5G systems are promising technology.

Keywords: 5G, millimeter wave, small cell, Massive MIMO, Beamforming, Full Duplex

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5G seyrə sistemlərində texnologiyalar

Xülasə

"Qabaqcıl Mobil Telefon Sistemi" kimi tanınan birinci nəsil sistemlərdən başlayaraq mobil rabitə sistemləri daim inkişafda olmuşdur. Hal-hazırda, standartlaşdırması kifayət qədər yetkin olan və xidmət təminatçıları tərəfindən bazara çıxarılan ən son mobil rabitə sistemi beşinci nəsil (5G) sistemidir. Bu araşdırmanın məqsədi 5G ilə istifadə olunacaq yeni texnologiyaların təqdim edilməsidir. Bu texnologiyalara millimetr dalğa texnologiyası, kiçik hüceyrə texnologiyası, kütləvi MIMO texnologiyası, beamforming texnologiyası və tam dupleks texnologiyası daxildir. Bu texnologiyaları ümumiləşdirmək üçün; millimetr dalğa texnologiyası bant genişliyinin genişləndirilməsini təmin edir, lakin istifadə olunan yüksək tezlik səviyyəsinə görə siqnallar daha qısa məsafələrə gedir və havada və bərk materiallarda ötürmə itkiləri artır. Beləliklə, kiçik hüceyrə

texnologiyası bu problemin həlli kimi təklif edilmişdir. Bu texnologiyada ötürmə diapazonu daha qısa məsafədə yerləşən baza stansiyalarından istifadə etməklə genişləndirilir, lakin daha çox antena tələb olunur. Sözügedən çoxlu antena ehtiyacının həlli olaraq, kütləvi MIMO texnologiyası inkişaf etmişdir. Bu texnologiya ilə bir baza stansiyası eyni anda daha çox istifadəçidən signal (məlumat) göndərə və qəbul edə bilər, lakin artıq antenaların quraşdırılması siqnallar arasında müdaxiləyə səbəb olur. Bu vəziyyətdə şüa əmələ gətirmə texnologiyasından istifadə olunur. Bundan əlavə, tam dupleks texnologiyası yüksək effektivliyə və aşağı gecikməyə nail olmağa çalışır. Nəticədə, 5G-də istifadə edilən bütün bu texnologiyalar digərlərinin çatışmazlıqlarını aradan qaldıraraq bir-birini dəstəkləyir və hamısı bir yerdə 5G sistemləri perspektivli texnologiyadır.

Açar sözlər: 5G, milimetr dalğası, kiçik hüceyrə, Massive MIMO, Beamforming, Full Duplex

Introduction

When examining the evolution of cellular communication systems, the second generation primarily focused on voice transmission, while the third and fourth generations shifted towards transmitting broadband multimedia data. With the advent of the fifth generation (5G), new system requirements have emerged, including very high data traffic, numerous device connections, and high user mobility. The anticipated 5G technology is expected to address these requirements and find widespread application across various industries.

5G communication systems are primarily designed to increase capacity, facilitate extensive connectivity, and offer a diverse range of services. To address these objectives, the International Telecommunication Union (ITU) has classified 5G services into three main categories (Guizani, Hamdi, 2017). These categories include Enhanced Mobile Broadband (eMBB), Massive Machine Type Communication (mMTC), and Ultra-Reliable and Low Latency Communication (uRLLC).

Enhanced Mobile Broadband (eMBB) encompasses services that meet user needs such as high-bandwidth internet access, high-resolution video streaming, and augmented reality. On the other hand, Massive Machine Type Communication (mMTC) manages intensive data traffic in structures where a high number of devices are connected, such as smart cities, smart agriculture, and sensor networks. Lastly, Ultra-Reliable and Low Latency Communication (uRLLC) ensures the necessary delay limits in applications requiring millisecond-level latency and very low packet loss rates, such as autonomous driving systems and factory automation. Considering all these services together, it's conceivable that 5G communication technology will find application in various industries such as manufacturing, automotive, logistics, and energy. Research and development in 5G technology are on going. One commonly agreed-upon point among companies and industry groups is that as the number of mobile users and data demands increase, 5G must handle much higher traffic at significantly faster speeds than today's cellular networks formed by base stations (Agiwal, Roy, Saxena, 2016: 1617-1655). Alongside special technologies for 5G systems, compared to the approximately 70 ms latency in current 4G networks, 5G technology will deliver data with less than a millisecond delay and provide users with download speeds of up to 20 Gbps, compared to 1 Gbps in 4G. Prominent among 5G technologies are millimeter wave, small cells, massive multiple-input multiple-output (massive MIMO), beamforming, and full duplex technology (Nguyen, 2021). To understand the differences between today's 4G networks and 5G, it would be beneficial to explore these five technologies and evaluate what each means for wireless users.

Due to system requirements, changes are necessary in the 5G network architecture compared to previous generations. Essentially, the 5G network architecture consists of a core network performing control and transmission functions, and a high-performance access network. Different types of base stations and wireless devices are components of the access network, implementing advanced resource sharing and time scheduling. With 5G systems, various solutions for the radio access network (RAN) have been developed, such as cloud-based (CRAN), heterogeneous cloud-based (H-CRAN), and fog-based (Fog RAN) architectures. When examining the frequency bands to be used for 5G systems, they are divided into three separate categories: low band, mid band, and

high band. The low band covers frequencies below 1 GHz, the mid band covers the frequency range of 1 GHz to 6 GHz, and the high band includes frequencies above 24 GHz. Each band has its advantages as well as challenges. The low band, despite providing good transmission characteristics with a wider coverage area, can offer limited capacity due to bandwidth constraints. The mid band provides higher capacity compared to the low band and offers reasonable coverage for urban areas.

In the past, wireless communication networks were primarily focused on voice transmission, but in today's communication systems, efforts are made to provide high-quality, low-latency transmission, and multimedia applications for wireless devices. With the presence of a greater number of devices and users, there is higher data traffic than ever before. However, the licensed radio frequency spectrum allocated to mobile service providers is limited in bandwidth. This leads to low data rates alongside low bandwidth. Current applications are mostly confined to a carrier frequency between 700 MHz and 2.6 GHz. However, with the advancing technology used in unmanned aerial/sea/land vehicles, smart transportation systems, robots, smart grids, smart buildings, smart cities, augmented reality, mobile social services, and remotely controlled systems, this bandwidth is insufficient for new technological products (Nordrum, 2017: 1617-1655.)

As a solution, transmitting signals in a new band of the spectrum has emerged. Unlike the bands below 6 GHz traditionally used for mobile devices, millimeter waves are transmitted at frequencies ranging from 30 to 300 GHz Figure 1. This transmission technology in the frequency band is called millimeter wave technology and constitutes an important step for 5G systems. The wavelength in millimeter waves varies between 1 and 10 mm, which is larger than infrared waves or X-rays. However, compared to radio waves or microwaves, they have a smaller wavelength (Ozkaya, Seyfi 2015).

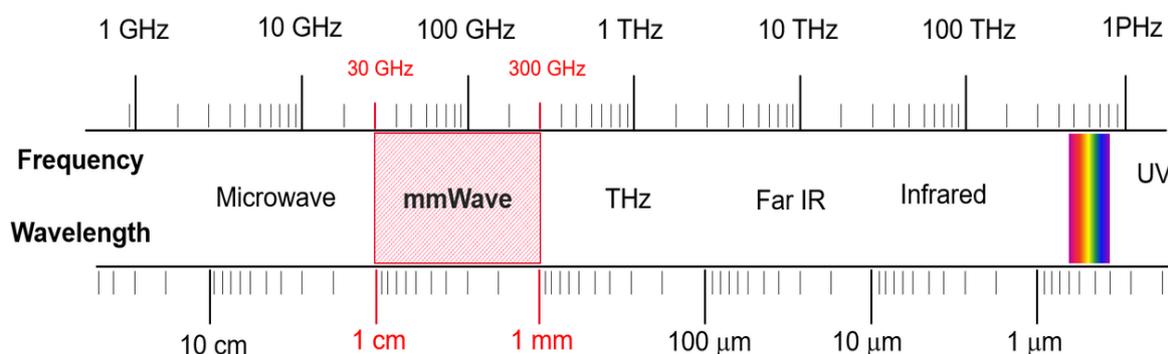


Figure 1: Frequency range in millimeter wave

There are several advantages to using millimeter wave technology in 5G systems. It provides a wide bandwidth at high frequencies, enabling high data rates. Additionally, it ensures high-security data transmission, enables efficient reuse of high frequencies, and offers high-speed internet, data, and voice communication by providing fiber optic data transfer rates (Jungnickel, 2014).

In addition to the advantages brought by millimeter wave technology, there are also some disadvantages. Firstly, due to smaller-sized components, the manufacturing of more sensitive hardware results in higher costs. Additionally, at very high frequencies, significant attenuation occurs, posing challenges for long-distance applications. It is known that millimeter waves have less penetration power into objects such as concrete walls. They also interact with oxygen and rain at higher frequencies. Due to these interactions, signal attenuation occurs between transmitters and receivers, and signals are prone to distortion as they cannot pass through obstacles. These challenges with millimeter waves have led to the development of small cell technology

To extend the coverage area between a base station and users, there is a need for small cell stations. This technology, known as small cell technology, is essentially a minimized version of a base station. It involves dividing a cell area into much smaller zones. Small cells are divided into pico cells, micro cells, and femto cells for indoor or outdoor use. Just like there is a transmission network between macro base stations and small cells, within small cells, there are multiple transmission channels specific to each cell. The main purpose of small cells is to enhance the end data capacity, speed, and overall network efficiency of macro cells. The primary use cases for small cells are locations with numerous users utilizing data at a specific point, such as shopping malls, gyms, stadiums, airports, and train or bus stations. When establishing stations, there are some points to consider. The number of small cell stations that can be installed in an area and the distance between them vary depending on the population in that area. For example, in a densely populated neighborhood, the distance between two small cells can range from 10 to 100 meters (Guizani, Hamdi, 2017).

Cells, ranked from smallest to largest in terms of coverage areas and number of users, have coverage areas and user numbers as follows: the coverage area of femto cells ranges from 10 to 100 meters with 1-30 users, the coverage areas of pico cells range from 100 to 200 meters with 30-100 users, and the coverage areas of micro cells range from 200 meters to 2000 meters with 1000-2000 users. Lastly, macro cells have coverage areas ranging from 8 to 30 kilometers with more than 2000 users. Considering these numbers, with sufficient distances and population, it will be possible to encounter such small cells in many areas in the near future. One of the main advantages of small cell technology used in 5G systems is the cost factor (Ngo, Larsson, Marzetta, 2011). Smaller-scale stations that reduce overall costs are being installed instead of the expensive rooftop systems currently used by service providers. It also increases data capacity. Wireless mobile devices transmit at lower power levels when closer to small cell base stations, effectively reducing power consumption in devices and significantly extending battery life, thereby improving the performance of mobile phones.

Another important technology that delivers significant performance in wireless communication with the advent of 5G is Massive MIMO (Multiple Input Multiple Output). Massive MIMO is a technique where a base station with hundreds of antenna arrays provides independent data streams to numerous user terminals, each equipped with a single antenna, within the same time or frequency interval (Larsson, Edfors, Tufvesson, Marzetta, 2014). The primary objective of this technology is to use a significantly larger number of antennas compared to previous generations of cellular systems. Increasing the number of antennas enables energy to be focused on a smaller area. This technology enables significant beamforming gains, allowing service to be provided to more users in parallel. However, the disadvantage of increasing the number of antennas is that it always leads to higher complexity and higher costs. Therefore, in Massive MIMO systems, time-division duplexing is often preferred over frequency-division duplexing to mitigate complexity related to channel estimation and channel sharing (SinghParihar, Saraswat, Maheshwari, 2015).

The utilization of Massive MIMO has become a promising technology that not only delivers high data rates but also enhances connection reliability, coverage, and energy efficiency in wireless communication systems. A comparison between small cells and Massive MIMO has been conducted in a publication. The result indicates that small cells exhibit greater energy efficiency than Massive MIMO. Additionally, having a Massive MIMO antenna array enables the support of millimeter-wave technology, which is suitable for high frequencies, as part of a 5G technology (Elijah, Leow, Rahman, Nunoo, Iliya, 2016).

During a time when operators are striving to obtain more spectrum for 5G, any technology that offers a way to utilize the existing spectrum more efficiently is worth further examination. Although full duplex technology is more than a decade old, it has regained the interest of some mobile operators and infrastructure providers because of its ability to use the spectrum more efficiently (Askar, Chung, Guo, Ko, Keusgen, Haustein, 2021). To understand why full duplex technology is

so intriguing, it is important to first understand how 3G and 4G networks handle user-to-base and base-to-user signals. There are two basic configurations:

- Frequency Division Duplexing (FDD): With FDD, the transmission and reception signals are in different spectrum bands. In other words, the signal transmitted from the user to the base station is sent in a certain spectrum block, while the signal transmitted from the base station to the user is sent in another spectrum block.

- Time Division Duplexing (TDD): With TDD, the signal transmitted between the user and the base station is separated from the signal transmitted between the base and the user using different time slots in the same frequency band. That is, after the user-to-base signals are transmitted, the base-to-user transmission takes place.

In full duplex technology, however, it is possible to transmit and receive wireless signals simultaneously over the same spectrum channel. Existing 4G wireless networks mainly use half-duplex FDD and TDD (Zhang, Cheng, Zhang, 2018). With 5G, a transceiver pair can send and receive data simultaneously at the same frequency. This technology is called a full duplex and allows doubling the capacity of wireless networks.

Conclusion

As we transitioned from first-generation systems to today's 4G systems, there has been an increasing trend in the frequency bands used in cellular systems. Signals in the low-frequency bands can propagate for kilometers and penetrate buildings easily. With the advancing 5G technology, the use of millimeter wave technology has greatly expanded the frequency band range to between 24 GHz and 40 GHz. However, there is significant attenuation in signal transmission, especially in the high-frequency band. Signals can only travel a few kilometers or even less distance. Additionally, there are high transmission losses when signals interact with oxygen or raindrops in the air or pass through objects like concrete walls. Therefore, along with millimeter wave technology, small cell technology has also been developed. 5G systems will require more antennas than today's base stations. To meet this requirement, another 5G technology called Massive MIMO technology has been developed. Unlike current 4G base stations, which support a limited number of connection points in their antennas, 5G base stations can support many more connection points. As a result, a single base station can serve many more users simultaneously, and the capacity of mobile networks can increase by orders of magnitude.

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