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A Comprehensive Review of 5G Wireless Network Evolution

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Abstract. Due to the demand for faster connections, the world's telecommunications companies are working together to improve fast connectivity. Thanks to fifth-generation (5G) wireless technology, devices such as smartphones, smart watches, smart homes and connected cars are increasingly connected to the internet. This is an exploration of a rapidly changing world. The cellular architecture of the industry must adapt to accommodate these changes. This study focuses on the design of 5G mobile networks and explores potential strategies that can improve infrastructure and meet customer needs. More importantly, this article highlights the importance of two key concepts in 5G: device-to-data (D2D) communications and multiple input multiplexing (MIMO) technology. Thanks to extensive research and the use of reliable online sources, the use of 5G c9 mobile networks is well established and developed.

Keywords: 5G Wireless Technology, Cellular Architecture, Connectivity Demand.

1 Introduction

The latest news in January 2022 says that 5G technology is a major breakthrough in wireless communications, providing faster speeds, lower latency and better connectivity than the pre-4G/LTE era. The emergence of new technology is not only interesting, but also important for understanding what will happen in the future. This research is part of the early development of the fifth generation of wireless communications equipment and technology known as 5G. 5G technology is gaining prominence in new applications and industries due to better, deeper and more powerful access. The main purpose of this article is to trace the development of this technology over the years and provide good and consistent evidence of its progress. We are exploring the field of technology development to update data analysis and mining techniques. This approach has proven useful in analyzing numerous published international reviews focusing on 5G.

5G-based telecommunication systems are designed to address challenges more effectively by leveraging the foundations laid by widespread use of 4G prototypes. While no single organization owns 5G, various companies within the mobile phone industry have made significant contributions to its development. Qualcomm, in particular, has played a pivotal role in introducing the foundational technologies that have propelled the industry forward, setting the stage for 5G as the next wireless standard.

South Korea is anticipated to lead the global deployment of 5G networks, positioning itself at the forefront of this technological advancement. Projections suggest that by 2025, 60% of mobile phone users in South Korea will be utilizing 5G networks. Notably, Huawei Technologies Co. has been identified in a recent study as holding essential rights to core aspects of next-generation 5G technology. Despite efforts by the Trump administration to exclude the technology from its supply chain, Huawei continues to provide financial support for the development of 5G.

Wireless systems employing broadband Orthogonal Frequency Division Multiplexing (OFDM) in the millimeter-wave spectrum (10mm to 1mm) ranging from 30 GHz to 300 GHz have the potential to deliver speeds of up to 20 Mbit/s at a distance of 2 km from the data source. The millimeter-wave band emerges as a promising solution that could support global network usage for wireless internet. Fig.1. below represents an introduction to 5G technology.

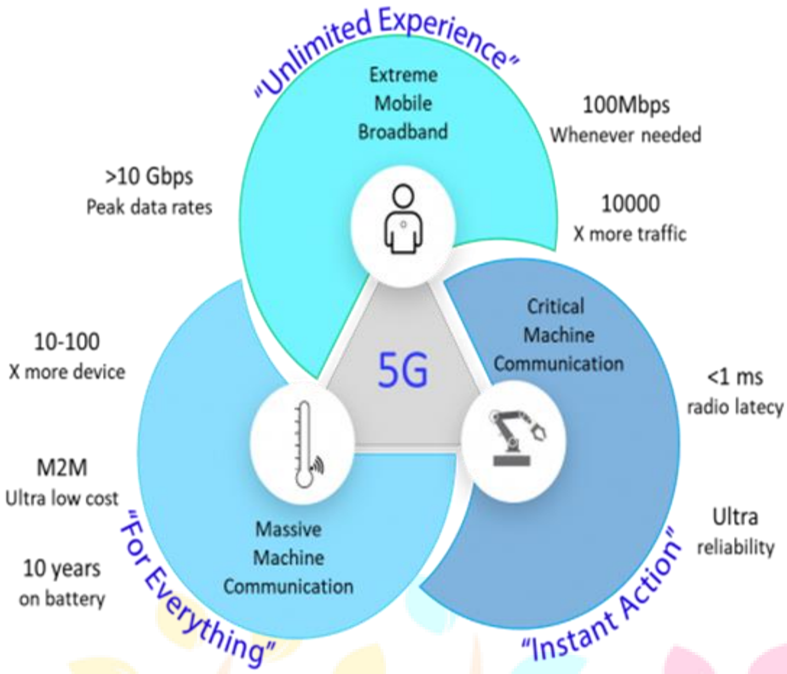

Fig.1. Introduction to 5G technology

2 Evolution from 1G to 5G

The evolution of wireless communications has crossed many milestones determined by technological advances and changes in communication patterns. A brief summary of the major stages in the development of wireless networks:

First Generation (1G)

Analog Cellular Networks (1980): The first generation of wireless networks introduced analog cellular technology. This network supports voice calls and is characterized by low capacity and limited range. The main standard for 1G is the Advanced Mobile Phone System (AMPS).

Second Generation (2G)

Digital Cellular Networks (1990s): 2G's transition from analog to digital communications. Digital networks offer better voice, more capacity, and services like text messaging (SMS). GSM (Global System for Mobile Communications) and CDMA (Code Division Multiple Access) are the main 2G technologies.

Third Generation (3G)

Mobile Broadband (Early 2000s): 3G networks were designed to deliver more data by providing mobile broadband services. Standards such as WCDMA (Wideband Code Division Multiple Access) and CDMA2000 have emerged. Its main features are video calls, mobile internet and higher data.

Fourth Generation (4G)

LTE and WiMAX (Late 2000s - Early 2010s): 4G networks represent a huge leap forward in data speed and network efficiency. 4G technologies include LTE (Long Term Evolution) and WiMAX (Worldwide Joint Venture for Microwave Access). 4G enables faster network access, better video streaming, and more widespread smartphone usage.

Fifth Generation (5G)

Next Generation Connectivity (2010): 5G is the next generation wireless technology focused on ultra-high speed, low latency and large device connectivity. The millimeter wave spectrum enables new technologies such as massive MIMO and networking. 5G is engineered to facilitate emerging applications like augmented reality (AR), virtual reality (VR), the Internet of Things (IoT), and autonomous vehicles. During this evolution, wireless networks have evolved from simple analog voice services to high-speed data centers supporting a variety of applications. This transformation is propelled by progress in communications technology, the proliferation of mobile devices, and the escalating need for swifter and more dependable wireless connections. Advances in 5G and beyond continue to define the future of wireless communications, focusing on connecting people and devices more efficiently and innovatively.

Key features of 5G include more data, lower latency and more connections

Advanced data: High precision: 5G should provide more flexible data compared to 4G/LTE. The maximum data rate of 5G reaches several gigabits per second (Gbit/s), providing users with high speeds and fast downloads. Increasing spectral efficiency: Advanced modulation techniques, wide frequency bands and advanced antenna technologies help increase spectral efficiency, allowing more information to be transmitted in the available spectrum.

Low Latency: Ultra-Reliable Low Latency Communications (URLLC): The goal of 5G is ultra-low latency by reducing the travel time required to and from places. Latency below 1 ms enables instant communication for applications such as augmented reality (AR), virtual reality (VR) and critical manufacturing processes.

Massive Device Connectivity: Massive Machine Type Communications (mMTC): The purpose of 5G is to facilitate a diverse array of interconnected devices, ranging from IoT sensors to smart cities. This capability is critical for the growing Internet of Things (IoT) ecosystem. Connection speed: 5G networks can maintain higher connected device speeds per square kilometer than previous generations. This feature is important for situations in smart cities or dense cities where many devices are connected simultaneously.

Network Slicing: Customizable Virtual Networks: Network slicing allows you to create virtual networks based on a specific usage, job, or application. Each form can have characteristics such as latency, throughput and reliability that enable it to meet different needs simultaneously. Millimeter Wave Technology: High Frequency Bands: 5G uses the millimeter wave (mmWave) spectrum at frequencies of 24 GHz and higher. These higher frequencies provide more bandwidth, supporting faster data transfer. However, millimeter wave signals are shorter and more susceptible to interference, requiring smaller stations to transmit effectively.

Massive MIMO (Multiple Input, Multiple Output): Increasing the number of antennas: Massive MIMO involves the use of multiple antennas in a base station network. The receiver increases spectral efficiency and capacity. This technology allows communication with many devices, improving the overall performance of the device.

Beamforming: Concentrated signal transmission: Beamforming technology allows radio waves to be directed by focusing the signal on a specific device without scattering throughout the instructions. This improves signal quality, coverage and network performance. The below Fig.2. represents the 5G usage design triangle.

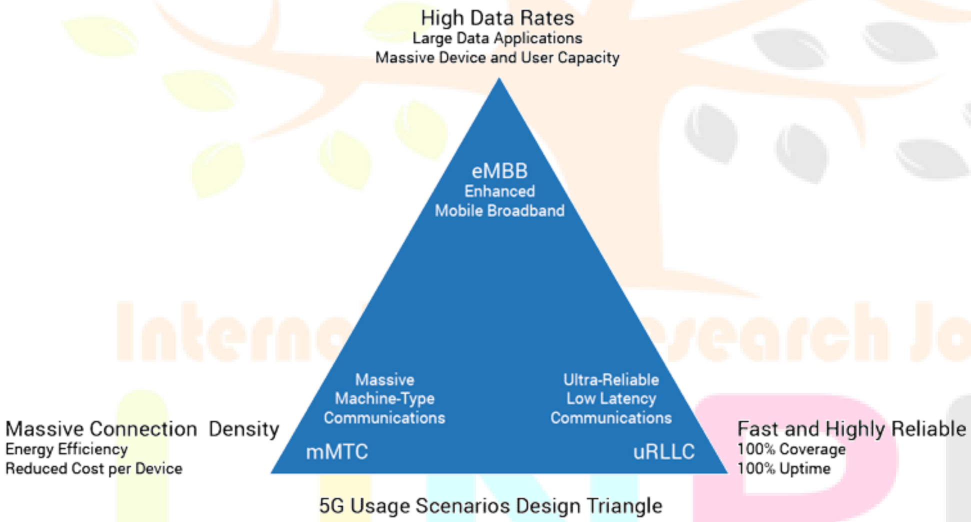

Fig.2. 5G Usage Design Triangle

Dual connection and multi-connection: Unrivaled transmission: 5G supports dual connection, allowing users to connect to 4G and 5G networks simultaneously. This allows for flexibility and the use of existing resources. Aggregation of various networks: Aggregation allows aggregation of various wireless applications to increase reliability and efficiency using different resources. Together, these initiatives enable the transformational potential of 5G, enabling a variety of applications and services beyond mobile broadband, such as smart cities, business automation, and more.

3 Overview of 5G architecture and standardization

Seven telecommunications standard development organizations, namely ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, and TTC, collectively referred to as organizational partners, play a crucial role in the third-generation partnership project (3GPP). Working collaboratively, these organizations generate reports and specifications that define 3GPP technologies. In the realm of cellular telecommunications technology, the project provides a comprehensive overview of mobile telecommunications systems, encompassing aspects such as radio access, core networks, and service capabilities. The 3GPP specifications extend to nonradio connectivity with the core network and interoperability with non-3GPP networks. Various contributors, including the Technical Specification Group (TSG), member businesses, and working groups, actively participate in 3GPP studies and the development of specifications. Over the course of multiple generations ("G's") in commercial cellular and mobile systems, 3GPP technologies, including LTE, LTE-Advanced, LTE-Advanced Pro, and the ongoing development of 5G, have positioned 3GPP as a central hub for advancing mobile systems beyond 3G (3GPP, 2021).

Even while these generations are now a suitable way to describe the kind of network that is being discussed, the actual advancement of 3GPP standards is decided by the milestones attained in particular releases. New features are functionally frozen and prepared for implementation after a release. 3GPP works on multiple releases at once, starting work on upcoming releases far in advance of the current release's completion. Although this gives the groups' work an extra degree of uncertainty, it guarantees steady and regular progress.

Fig.3. illustrates the timetable for the latest and forthcoming 3GPP releases. The 3GPP Technical Specification Group Radio Access Network (TSG RAN) is responsible for managing functions, specifications, physical layer, radio performance, and the definition of operation and maintenance requirements for conformance testing related to user equipment and base stations.

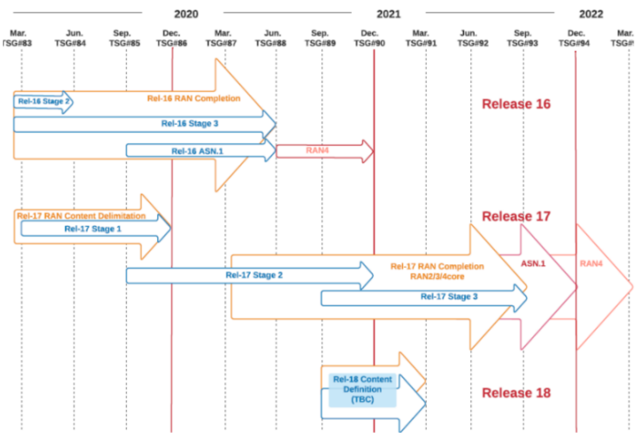

Fig.3. 5G Timeline

The initial deployment of 5G/New Radio (NR) technology, along with several new features as part of the LTE evolution, was encompassed in Release 15, concluded in June 2018. Serving as the inaugural phase of NR evolution, Release 16 introduces numerous significant enhancements and extensions to NR, along with additional improvements to LTE. The finalization of physical layer specifications occurred in December 2020, and the completion of Release 16 was scheduled for June 2020. The primary focus of 3GPP activities in 2020 and 2021 centers on Release 17, targeted for finalization in September 2021. In December 2019, decisions were made on various study/work items for 3GPP Release 17, aiming to improve network mobility, latency, capacity, coverage, and power efficiency.

4 5G system architecture

The overall system architectures of the core network (CN) and radio-access network (RAN), including the functionality divided between the two networks, were reviewed in tandem with 3GPP's work on NR radio-access technology. The radio-related aspects of the network as a whole, including scheduling, radio-resource management, coding, retransmission protocols, and different multi-antenna schemes, are managed by the RAN. In order to provide a complete network, the 5G core network manages operations that are not directly related to radio access. This includes configuring end-to-end connections, billing, and authentication.

Opting to manage these functions independently rather than integrating them into the Radio Access Network (RAN) is advantageous, as it allows a single core network to accommodate multiple radio-access technologies. In the context of non-standalone mode, where LTE and the evolved packet core (EPC) manage functions such as link setup and paging, it is feasible to connect the evolved packet core (EPC), a legacy long-term evolution (LTE) core network, to the New Radio (NR) radio-access network. The standalone operation is anticipated to be introduced in upcoming releases. The 5G core is connected to both LTE and NR networks, forming a cohesive system. Unlike the transition from 3G to 4G, where the 4G LTE radio-access technology couldn't link to a 3G core network, the LTE and NR radio-access schemes, along with their respective core networks, are closely intertwined (Dahlman, Parkyall, & Skold, 2020).

Core Network

The 5G core network introduces three new features—namely, a control-plane/user-plane split, NS support, and service-based architecture—aimed at enhancing the capabilities of the Evolved Packet Core (EPC). The architecture of the 5G core is service-based, signifying a shift from traditional node-centric approaches to a focus on the resources and functionalities within the core network.

This approach aligns with the existing trend of highly virtualized core networks that rely on commodity computer hardware for essential functions.

In the context of 5G, the term "NS" is commonly used, referring to a Network Slice—a logical network that amalgamates essential features from the service-based architecture to address specific customer or business requirements. For instance, a single network slice could be configured to provide mobile broadband applications with optimal mobility support, resembling what LTE offers. On the other hand, an industry automation program that prioritizes low latency and is non-mobile may have a distinct slice. Despite appearing as separate networks to end-user applications, all these slices operate on the same underlying physical core and radio networks, similar to setting up multiple virtual machines on a single physical machine.

This concept of a network slice can leverage edge computing, allowing sections of end-user applications to operate in close proximity to the core network edge to minimize latency. The network slice approach enhances flexibility and customization in catering to diverse application requirements within the 5G core network.

The control-plane/user-plane divide is emphasized in the 5G core network architecture, with different bandwidth scaling for the two. Let's say, for example, that more control plane capacity is required. If so, adding it should be straightforward and won't interfere with the network's user plane. A high-level service-based representation of the 5G core, similar to the one shown in Fig.4., can be used to highlight its functionalities and services. Fig.4. does not depict the reference-point definition found in the requirements, which focuses on the point-to-point interaction between the functions.

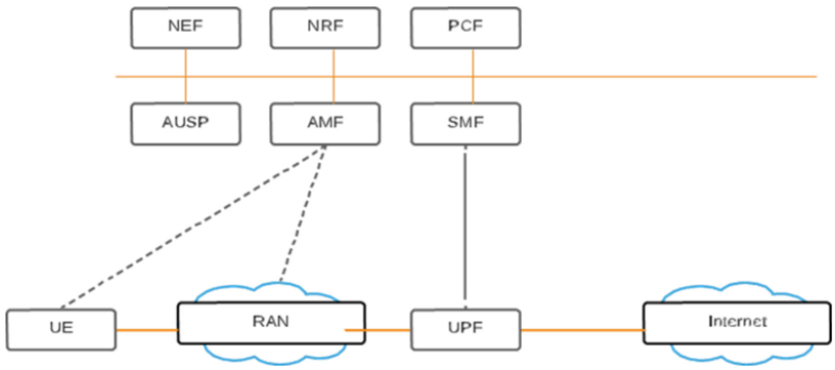

Fig.4. 5G service-based representation

The user-plane function consists of the user-plane function (UPF) and the gateway that connects the RAN to outside networks like the Internet. Its responsibilities include traffic measurements, packet filtering, packet routing and forwarding, packet verification, and QoS management. It also serves as an anchor point for (inter-RAT) mobility when needed. The control-plane functions are made up of numerous parts, including the session management function (SMF). The SMF is in charge of general session management, policy compliance control, and IP address allocation for the system (also referred to as user equipment, or UE). Control signaling between the device and the core network, user data security, idle-state mobility, and authentication are all handled by the access and mobility management function (AMF). Sometimes used to distinguish it from the access stratum (AS), which manages functionality between the device and the radio access network, the non-access stratum (NAS) refers to the functionality operating between the device and the core network, more especially the AMF. In addition, other kinds of functions can also be handled by the core network, such as the application function (AF), network exposure function (NEF), NR repository function (NRF), authentication server function (AUSF) handling authentication functionality, and policy control function (PCF) handling policy rules.

It is important to remember that there are numerous applications for the fundamental features of the network. For instance, many of the features can be distributed across multiple physical nodes, operated on a cloud platform, or implemented on a single node. The new 5G core network, which is being deployed alongside NR radio access and is capable of handling both NR and LTE radio accesses, is the subject of the definition given above. To enable the early deployment of NR in networks that are already in place, it is also feasible to connect NR to EPC, the LTE core network. LTE is used for "non-standalone service," or control-plane functions like paging, versatility, and first access. eNB and gNB can be thought of as base stations for LTE and NR, respectively.

Radio Access Network

The radio access network (RAN) within the 5G core network encompasses two types of nodes: a gNB, serving NR devices using NR user-plane and control-plane protocols, and an ng-eNB, serving LTE devices using LTE user-plane and control-plane protocols. For simplicity, the term RAN will be used, based on a 5G core network and an NR-based RAN. The gNB, responsible for radio-related functions in one or more cells, includes tasks like radio resource management, admission control, connection establishment, and routing of user-plane data to the UPF. It's crucial to note that a gNB is a logical node, not a physical implementation. The standard implementation is a three-sector site, where a base station manages transmissions in three cells, though alternative configurations exist.

The gNB connects to the 5G core network through the NG interface, specifically to the UPF through the NG user-plane part (NG-u) and to the AMF through the NG control-plane part (NG-c). The gNB may be connected to multiple UPFs/AMFs for load sharing and redundancy via the Xn interface, which supports active-mode mobility and dual connectivity. The F1 interface can divide the gNB into a central unit (gNB-CU) and one or more distributed units (gNB-DU), distributing specific protocols between them.

The Uu interface establishes a connection between the gNB (or gNB-DU) and the device, requiring at least one link for device communication. Initially, a device connects to a single controlling cell, managing both uplink and downlink transmissions. However, the advantages of connecting to multiple cells include user-plane aggregation and control-plane/user-plane separation. Dual connectivity presents another scenario where a device links to two cells, crucial for non-standalone service, enhancing data speeds by distributing control-plane and user-plane signaling between LTE and NR cells. Dual connectivity involves the eNB and gNB, serving as base stations for LTE and NR, respectively. Connection establishment and routing of user-plane data to the UPF are integral aspects of this process. The ability to establish connections between NR cells became feasible in the final version of release 15, as of July 2018. Fig.5. below illustrates the implementation of the 5G network.

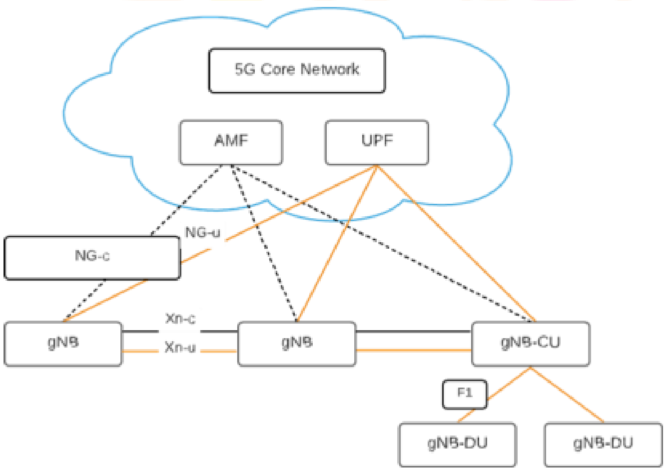

Fig.5. 5G network implementation

5 Spectrum Allocation and Frequency Bands

To deliver 5G services, Communication Service Providers (CSPs) must employ a mix of different spectrum bands, given the transformative impact of connectivity on our world. The advent of 5G introduces new challenges for CSPs. On one hand, 5G networks offer lower latency and faster mobile broadband speeds, unlocking possibilities for emerging applications such as the Internet of Things (IoT), artificial intelligence (AI), and the metaverse. However, realizing these innovative services hinges on CSPs having access to substantial amounts of spectrum.

According to the Global System for Mobile Communications Association (GSMA), a global trade association representing the mobile communications industry, 515 operators worldwide were investing in 5G as of the beginning of 2023, with 243 commercial 5G launches. The GSMA recommends that governments and regulatory bodies, responsible for allocating 5G spectrum, allocate 80–100 MHz of contiguous spectrum per operator in prime 5G bands and approximately 1 GHz of millimeter-wave spectrum per operator. Fig.6. provides a visual representation of the frequency bands designated for each generation.

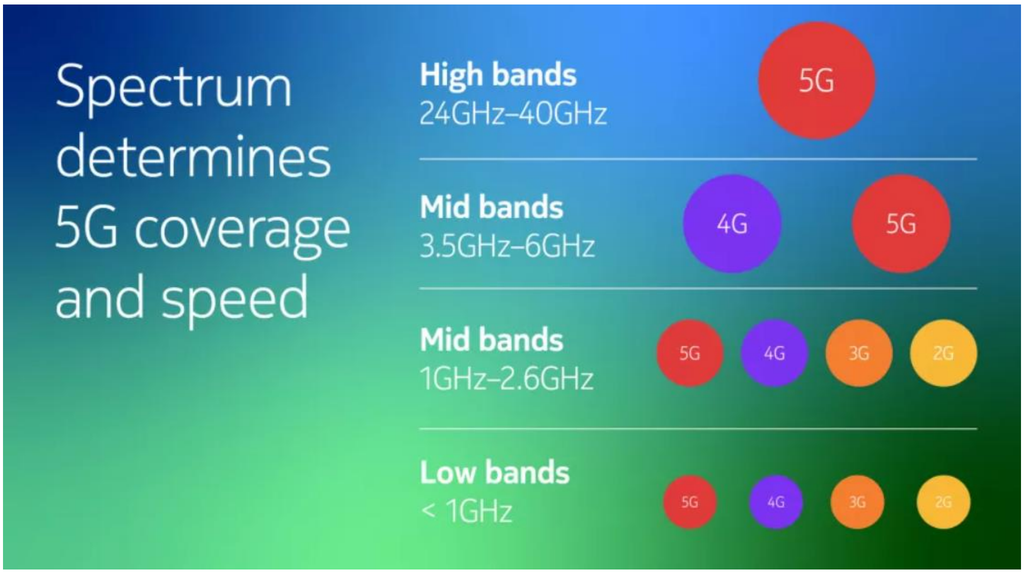

Fig.6. Frequency band Spectrum

Any spectrum on the spectrum chart below 1 GHz is considered low-band spectrum. Analog cellular networks, or low-band 800 MHz spectrum, were used for the deployment of early wireless networks. Because low-band spectrum was desirable at the time, CSPs referred to it as "beachfront property" frequently. With just one tower, wireless carriers could cover hundreds of square miles and thousands of customers. In the future 5G world, CSPs will be able to offer extensive coverage thanks to low-band spectrum. However, because 5G networks have smaller bandwidths than 4G networks, their speed and latency will only be marginally better. The closeness of your cell site will affect how well the 5G network performs. Low-band spectrum does, however, facilitate wireless signal penetration of walls and windows.

Over the course of seven days and forty rounds, bids totaling over $19 billion (Rs 1.5 lakh crore) were placed in India's largest spectrum auction. The biggest purchase was made by Reliance Jio. It held more than half of the shares in both the Indian 5G spectrum bands and the entire auction. Reliance Jio paid $11 billion (approximately Rs 88,078 crore) for spectrum in the 700MHz, 800MHz, 1800MHz, and 3300MHz bands. Bharti Airtel purchased spectrum in the 900 MHz, 1800 MHz, 2100 MHz, and 3300 MHz bands for $5.4 billion (Rs 43,084 crore). While 5G Plus, which is operating in the 36 GHz band millimeter wave spectrum owned by the company, is operational in portions of over 50 cities, AT&T has already implemented 5G in about 100 US cities. 5G Plus is designed for high-traffic locations like arenas and campuses and provides additional speed and capacity. In other places, Telefónica Deutschland (O2) CEO Markus Haas reaffirmed his demand for additional spectrum, like 600MHz, to facilitate the rollout of 5G in Germany and other parts of Europe.

Most recently, more than 60% of all assigned frequencies were in the mid-band spectrum. There will be more of this trend. In order to meet the demand for 5G and 5G-Advanced, governments are searching for solutions as pressure on mid-band spectrum grows. Since mid-band spectrum (1 GHz - 6 GHz) can transmit large amounts of data over long distances, it is thought to be ideal for 5G. The 3.3 GHz to 3.8 GHz range is ideal, according to the GSMA, because many nations have already designated it for 5G. Other mid-band spectrum is being utilized, though. In terms of consumer uptake and the scope of deployments, China has emerged as the world's most significant 5G market. In order to address issues with capacity and coverage, it awarded mid-band frequencies for 5G in the 2.6 GHz and 3.5 GHz bands. China has demonstrated a strong interest in leveraging the 6 GHz band to meet the rapidly increasing demand for 5G as it looks to the next phase of 5G expansion.

The deployment of 5G across mid-band spectrum has resulted in significantly increased mobile network speeds, as reported by network monitoring companies such as Ookla. The last few years have been devoted to the installation of mid-band radios on the cell towers that operators like AT&T, T-Mobile, and Verizon lease. With its mid-band 5G network, T-Mobile serves about 260 million people in the US, and it plans to grow to 300 million. Verizon, meanwhile, serves 200 million people and plans to grow to 250 million by the end of 2024. Additionally, a few US operators intend to utilize mid-band spectrum (like 1800 MHz), which is presently in use for 3G services, for 5G by refarming or reusing it. In February 2022, AT&T discontinued its 3G service. A month later, T-Mobile terminated Sprint's 3G network. T-Mobile's 3G network was eventually discontinued in the summer of 2022. Verizon decided to extend the deadline for its 3G shutdown until the end of the year in order to maximize the capacity of their expanding 5G networks.

The millimeter wave spectrum, or 24 GHz band and higher on the spectrum chart, is the third spectrum bucket where CSPs are deploying 5G. For mobile services, the GSMA advises CSPs to support millimeter wave spectrum in the 26 GHz, 40 GHz, 50 GHz, and 66 GHz bands. The association does point out that CSPs are gaining significant traction in the 26 and 28 GHz spectrum. They also mentioned that because these bands are close together, handset support for them is simpler. Because signals in the millimeter wave (high-band) spectrum cannot travel as far as those in the mid- and low-bands, they are limited. The signal can occasionally travel less than a mile and is more vulnerable to interference from objects like glass, buildings, and trees. However, the advantage of millimeter wave spectrum is that users can achieve connection speeds of up to 3 Gbps or more if the signal is unimpeded. AT&T has high-band 5G installed in its 36 GHz band millimeter wave spectrum in addition to its low-band 5G offering. For busy places like arenas, campuses, and transit hubs, it provides additional speed and capacity. Verizon possesses 1,741 MHz of high band millimeter wave spectrum, which is part of a sizable spectrum portfolio spanning low, mid, and high bands. With further mmWave footprint expansion, Verizon aims to provide transformative experiences for the network's busiest areas. Verizon executives have stated during earnings calls with investors that millimeter wave spectrum performs better than many experts had predicted. To increase coverage, the company combines 5G small cells with beam-forming technology.

To assist local businesses in entering the new high-speed network service industry, the Korean government is granting three years of exclusive rights to a new operator over an additional 5G network frequency band. One of the two 28 GHz wavelength frequency bands will be used first by the new operator. The Ministry of Science and ICT, on the other hand, states that the second band will be allotted three years after the first operator launches the service. For the first three years, the operator will have the exclusive right to use the 28 GHz spectrum, giving them ample time to secure the market. There will also be financial advantages, such as new loans and tax breaks. The global rollout of 5G technology can continue to thrive with the appropriate spectrum, enabling universal access to 5G capabilities. By reducing network density and increasing access to mobile spectrum, it is possible to achieve scale and provide everyone on the planet with low-cost, next-generation mobile services.

Spectrum will be essential to the 5G services that carriers can offer their clients. Although high-band spectrum has a smaller coverage area, it may offer you high speeds and lots of capacity. Although low-band networks may offer superior coverage, their performance may not significantly surpass that of 4G due to their smaller spectrum bandwidths. You can be sure that CSPs will keep improving their 5G networks in the upcoming years by utilizing new technologies, acquiring more spectrum, and extending their current coverage. Innovation is not limited, despite spectrum being a limited resource.

6 Technological Enablers

Some of the 5G technological enablers are mmWave, Massive MIMO, and NOMA.

6.1 5G Massive MIMO

Multiple-Input Multiple-Output (MIMO) technology plays a crucial role in wireless systems, enabling the simultaneous transmission and reception of multiple signals over a single radio channel. While MIMO has been integral to technologies like WI-FI, 3G, 4G, and 4G LTE-A networks, its limitations in throughput and connectivity led to the development of various MIMO technologies, including network MIMO, multiuser MIMO, and single-user MIMO (SU-MIMO). However, these fell short of meeting user demands. The advent of Massive MIMO in the 5G network marked a significant improvement, utilizing thousands or even hundreds of thousands of antennas connected to base stations to enhance throughput and spectral efficiency. Massive MIMO employs additional antennas to concentrate energy in more confined spaces, boosting spectral efficiency and transmission rates.

This technology accommodates multiple user equipment (UE) generating downlink traffic simultaneously, thereby increasing capacity. Additionally, Massive MIMO, when combined with beamforming and multiplexing techniques, addresses challenges in smart sensor data collection, offering low latency, high data rates, and enhanced reliability. This capability is pivotal for real-time transmission of data from various sensors to central monitoring points in applications such as intelligent vehicles, medical facilities, smart grids, smart cities, smart highways, smart homes, and smart businesses.

Salient features of 5G Massive MIMO technology are as follows:

1. **Data rate:** It is recommended that massive MIMO be used as one of the leading technologies to deliver gigabit-per-second wireless data rates at high speeds.
2. **The relationship between wave frequency and antenna size:** Both have an inverse relationship with one another. Larger antennas are therefore required for lower frequency signals and vice versa.
3. **Number of user:** A single cell in 1G and 4G technology has ten antennas. However, a single cell in 5G technologies has more than 100 antennas. Thus, several users can be served by a single small cell at once. as depicted in Fig.7.

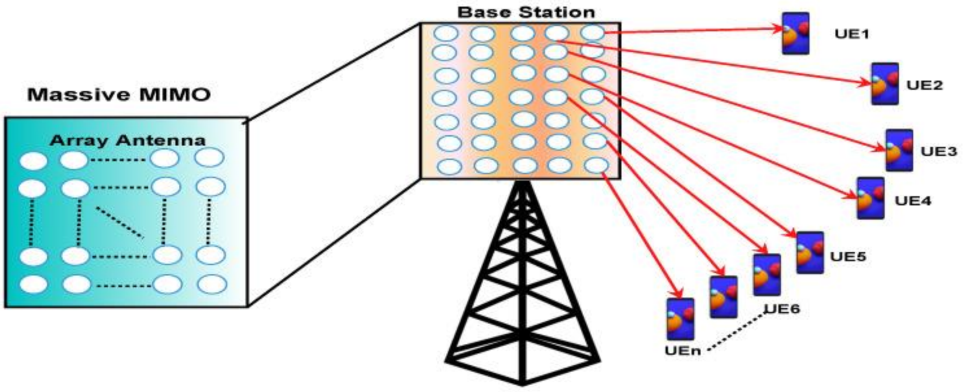

Fig.7. Pictorial representation of multi-input and multi-output (MIMO).

6.2 5G Non-Orthogonal Multiple Access (NOMA)

Next-generation wireless communication relies on Non-Orthogonal Multiple Access (NOMA) as a pivotal radio access technology, presenting advantages over preceding orthogonal multiple access methods. NOMA operates on a baseline to distribute resources such as time, space, and frequency to multiple users, falling into two broad categories: power domain NOMA and code domain NOMA. Power-domain NOMA is extensively employed in 5G networks, accommodating various wireless communication techniques and addressing the low spectral efficiency of traditional orthogonal frequency-division multiple access (OFDMA) for users with limited channel state information. On the other hand, code-domain NOMA enhances spectral efficiency, particularly in mMIMO, and encompasses multiple access strategies like sparse code multiple access, lattice-partition multiple access, multi-user shared access, and pattern-division multiple access.

Despite its benefits, NOMA has drawbacks, such as the need for substantial processing power for successive interference cancellation (SIC) algorithms in high-data-rate scenarios and challenges in managing power allocation optimization when users leave the network. To address these issues, Hybrid NOMA (HNOMA) combines both power-domain and code-domain NOMA, achieving higher spectral efficiency than individual NOMA techniques. NOMA, in its various forms, finds applications in scenarios like massive machine-type communication (mMTC), machine-to-machine (M2M) communication, and ultra-dense networks (UDN).

Salient features of 5G NOMA technology are as follows:

i NOMA increases data rates and closes all of OMA's shortcomings, making the 5G mobile network more dependable and scalable.

ii The network performs better as a whole when multiple users use the same frequency band at once.

iii Nonorthogonal transmission is provided by NOMA on the transmitter end in order to set up intracellular and intercellular interference.

iv The main goal of NOMA is to increase spectrum efficiency by fortifying the receiver's ramifications.

v NOMA is not the same as any of the earlier orthogonal access protocols, including FDMA, CDMA, and TDMA. Multiple users operate concurrently in the same band at varying power levels in NOMA. as depicted in Fig.8.

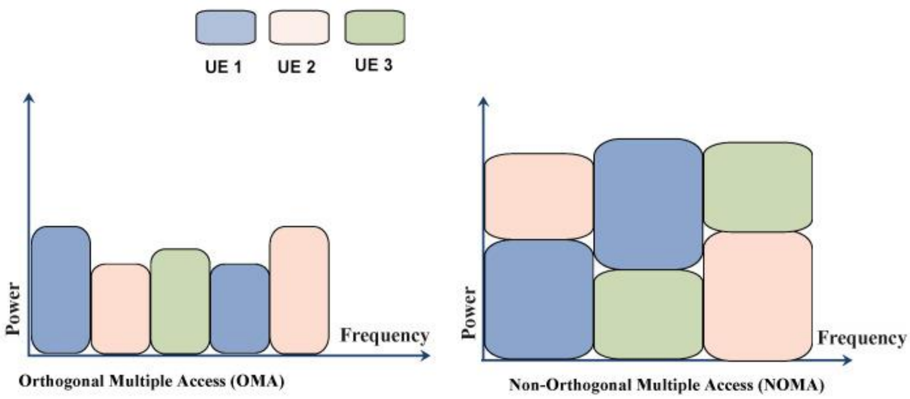

Fig.8. Pictorial representation of orthogonal and Non-Orthogonal Multiple Access (NOMA).

6.3 5G Millimeter Wave (mmWave)

Millimeter wave (mmWave) technology in the 5G wireless network utilizes the 30 GHz to 300 GHz spectrum band with wavelengths between 1 to 10 mm. This high-frequency band enables very fast wireless communication, and it is being increasingly adopted by radar systems, satellites, and mobile network providers for transmitting data between base stations. Unlike the crowded frequency band below 5 GHz, mmWave technology focuses on increasing spectrum bandwidth rather than utilization. By leveraging frequencies between 28 GHz to 60 GHz, 5G achieves significant improvements, offering up to 2 GHz spectrum bandwidth compared to 4G LTE's 100 MHz. This increase in bandwidth, facilitated by mmWave, results in substantially enhanced transmission speeds.

Salient features of 5G mmWave are as follows:

i. Three benefits come with 5G millimeter wave technology: (1) it is a relatively underutilized new band; (2) millimeter wave signals are more data-carrying than lower frequency waves; and (3) it can be combined with MIMO antennas to potentially provide a higher magnitude capacity than existing communication systems.

ii. In today's technologically advanced world, everyone communicates via WiMax, GPS, wifi, 4G, 3G, L-Band, S-Band, C-Band satellites, etc. These technologies operate in a very small radio frequency spectrum, ranging from 1 GHz to 6 GHz. As a result, it is packed. The millimeter-wave (mmWave) spectrum, which spans from 30 GHz to 300 GHz, is not as widely used as other communication technologies. Finally, after much waiting, 5G is assigned the frequency range of 24 GHz to 100 GHz. as depicted in Fig.9.

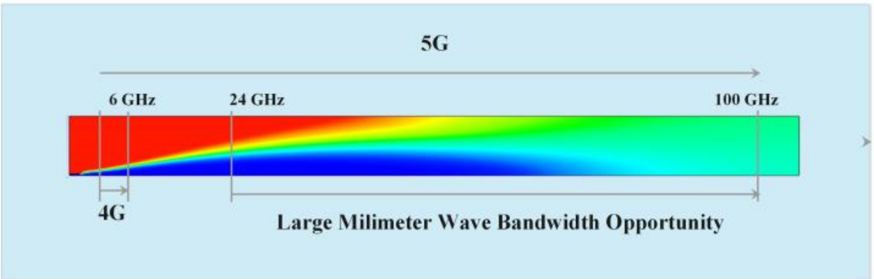

Fig.9. Pictorial representation of millimeter wave.

7 5G Technology data and applications

5G is the fifth generation of mobile technology that promises to revolutionize the way we connect and interact with the world around us. It has higher speed, lower latency and more capacity than previous models. But these advancements go beyond downloading videos in seconds or making ringtones sound better. 5G opens the doors to a whole new world of possibilities in many areas, with three main applications:

7.1 Enhanced Mobile Broadband (eMBB)

Imagine downloading long videos or connecting to streaming virtual reality content in less than 10 seconds. That's the power of eMBB. This application focuses on delivering ultra-fast data speeds, catering to users who demand high bandwidth for:

Ultra-high-definition (UHD) video streaming and gaming: Immerse yourself in hyper-realistic experiences with near-instantaneous loading and lag-free gameplay.

Augmented reality (AR) and virtual reality (VR) applications: 5G's speed and reliability will enable seamless integration of AR/VR into everyday life, from interactive education to remote surgery.

Cloud computing and remote access: Access powerful computing resources and massive data centers from anywhere, facilitating real-time collaboration and on-demand services.

7.2 Massive Machine-type Communications (mMTC)

mMTC envisions a world where billions of devices are connected and communicating with each other, creating the "Internet of Things" (IoT). This application focuses on:

Smart cities: Imagine traffic lights that optimize flow in real-time, sensors that monitor air quality and energy usage, and connected infrastructure that self-diagnoses and repairs.

Industrial automation and remote monitoring: Factories can optimize production lines with real-time data from connected machines, and critical infrastructure like pipelines and power grids can be monitored remotely for preventive maintenance.

Wearables and connected health: Track your health vitals with unprecedented accuracy, receive real-time medical advice from remote specialists, and enable remote patient monitoring for improved healthcare accessibility.

7.3 Ultra-Reliable Low-Latency Communications (URLLC)

For applications where even a millisecond delay can have disastrous consequences, URLLC ensures near-instantaneous data transmission and high reliability. This application is crucial for:

Autonomous vehicles: Self-driving cars rely on real-time communication with sensors, traffic signals, and other vehicles for safe and efficient navigation.

Remote surgery and robotic applications: Surgeons can operate complex procedures remotely with precise, real-time control over robotic instruments.

Industrial control and automation: Critical industrial processes requiring split-second decision-making and synchronized operation will benefit from URLLC's reliability and minimal latency.

These are just a glimpse into the vast potential of 5G technology. As the infrastructure continues to develop and applications evolve, we can expect even more transformative use cases to emerge, blurring the lines between the physical and digital worlds and shaping our future in ways we can only begin to imagine.

7.4 5G across industries transforming the landscape

5G, with its blazing-fast speeds, ultra-low latency, and massive capacity, is not just a technological upgrade; it's an industrial revolution waiting to happen. Its impact is already being felt across various sectors, each unlocking a new wave of possibilities:

Manufacturing

Smart factories: 5G-powered sensors monitor production lines in real-time, optimizing processes, predicting equipment failures, and enabling predictive maintenance.

Industrial automation and robotics: Collaborative robots seamlessly interact with humans on the factory floor, powered by real-time data and remote control capabilities.

Augmented reality (AR) training and maintenance: Workers receive on-site, interactive guidance through AR overlays, improving efficiency and safety.

Healthcare

Remote surgery and robotic applications: Surgeons remotely operate with precise control over robotic instruments, expanding access to specialized care even in remote areas.

Real-time patient monitoring: Wearables and sensors continuously track vital signs, enabling early detection of health issues and personalized medicine.

Telemedicine and virtual consultations: Patients receive high-quality medical care remotely, overcoming geographical barriers and increasing accessibility.

Transportation and logistics

Autonomous vehicles: 5G's ultra-reliable communication enables self-driving cars to navigate safely and efficiently, revolutionizing transportation and logistics.

Connected vehicles and traffic management: Real-time data exchange between vehicles and infrastructure optimizes traffic flow, reduces congestion, and improves road safety.

Drone delivery and fleet management: Track and manage fleets of drones in real-time for efficient deliveries, search and rescue operations, and infrastructure inspection.

Entertainment and media

Immersive AR/VR experiences: 5G's low latency unlocks seamless AR/VR experiences for gaming, live events, and interactive storytelling.

Ultra-high-definition (UHD) video streaming and gaming: Enjoy lag-free, crystal-clear content, blurring the lines between reality and virtual worlds.

Cloud gaming and remote access: Access powerful computing resources for high-end gaming and creative applications from any device, anywhere.

Smart cities

Connected infrastructure: Sensors monitor air quality, noise levels, and energy usage, enabling data-driven urban planning and resource optimization.

Public safety and emergency response: Real-time data from cameras, sensors, and connected devices streamlines emergency response and improves public safety.

Citizen engagement and personalized services: Interactive platforms and apps empower citizens to participate in decision-making and receive personalized services based on their needs.

8 Challenges and Limitations

While 5G promises immense potential, challenges remain:

Infrastructure development: Building and maintaining a nationwide 5G network requires significant investment and coordination.

Device compatibility: Not all devices are 5G-ready, creating a gap between potential and accessibility.

Cybersecurity concerns: The vast amount of data generated and transmitted raises concerns about data privacy and security breaches.

Regulatory hurdles: Varying regulations and spectrum allocation across countries can hinder widespread adoption and standardization.

Cost and affordability: Access to 5G technology might exacerbate existing digital divides if not addressed through affordable plans and equitable access initiatives.

5G challenges on the road to ubiquity:

While 5G promises to be a game-changer, its journey to widespread adoption is paved with challenges. These hurdles can be categorized into three key areas:

Security and Privacy

Increased attack surface: 5G's complex network architecture and reliance on a vast number of devices create more entry points for cyberattacks.

Data explosion and privacy concerns: The sheer volume of data generated by billions of connected devices raises serious questions about data collection, storage, and potential misuse.

Vulnerability of critical infrastructure: Integrating 5G with power grids and other critical infrastructure exposes them to cyber disruptions with potentially devastating consequences.

Infrastructure and Cost

High spectrum costs and limited availability: Securing and allocating sufficient spectrum for 5G rollout is expensive and complex, potentially hindering widespread access.

Dense network deployment: The need for numerous small cell towers to achieve 5G's promised coverage and capacity requires significant investment and infrastructure development.

Digital divide risk: The high cost of infrastructure and devices might exacerbate existing digital divides, leaving marginalized communities behind in the 5G era.

Regulation and Standardization

Varying regulations across countries: Inconsistent regulatory frameworks can create confusion, delay deployment, and hinder cross-border connectivity.

Standardization challenges: The evolving nature of 5G technology and competing interests from different stakeholders make standardization a complex and ongoing process.

Concerns over health impacts: Despite scientific evidence, unfounded fears regarding the health effects of 5G radiation can lead to public resistance and hinder deployment efforts.

Comparison with Previous Generations

Compared to previous generations, 5G's challenges are amplified due to its:

Greater complexity: The intricate network architecture, diverse device ecosystem, and reliance on new technologies like mmWave introduce new vulnerabilities and complexities.

Increased data dependency: The sheer volume of data generated and transmitted creates an entirely new set of privacy concerns and security risks.

Integration with critical infrastructure: The deeper integration with power grids, transportation systems, and other vital infrastructure raises the stakes of potential cyberattacks and disruptions. Wireless networking technology has evolved from the humble beginnings of 1G to the rapid pace of 5G. Each generation has brought significant improvements, but 5G represents a leap forward in performance, capacity and availability. Let's deepen the comparison:

Generation	Peak Data Speed	Latency
1G (Analog)	2.4 kbps	N/A
2G (Digital)	56 kbps	N/A
3G (Mobile Broadband)	2 Mbps	100 ms
4G (LTE)	1 Gbps	50 ms
5G (eMBB)	10 Gbps	1 ms

Fig.10. 5G vs previous generation peak data speed and latency

According to the guidelines, 5G provides ten times higher data speeds and less latency compared to 4G. This means near-instant downloads, lag-free streaming and instant response; It's a game-changer for everything from mobile gaming to remote surgery. While

1G and 2G laid the foundation for basic communications, 3G ushered in the era of mobile Internet and smartphones. 4G continues to change the way we consume content through high-speed data and streaming services. But 5G is breaking the mold and not just faster; This is the difference.

Generation	Key Capabilities	Use Cases
1G	Basic voice calls	Analog phones
2G	SMS, MMS, basic internet access	Texting, basic web browsing
3G	Mobile web browsing, email, video calling	Smartphones, mobile internet
4G	High-speed data, mobile video streaming, online gaming	Smartphones, tablets, mobile hotspots
5G	eMBB, mMTC, URLLC	Enhanced mobile broadband, massive machine-type communication, ultra-reliable low-latency communication

Fig.11. 5G vs previous generation key capabilities and use cases

eMBB strives for applications such as ultra-high-definition video streaming, augmented reality and cloud gaming, blurring the lines between the physical and digital worlds.

mMTC connects millions of devices to enable the Internet of Things (IoT), enabling smart cities, automation and connected healthcare.

URLLC allows close communication for important purposes such as automotive, remote surgery and business management.

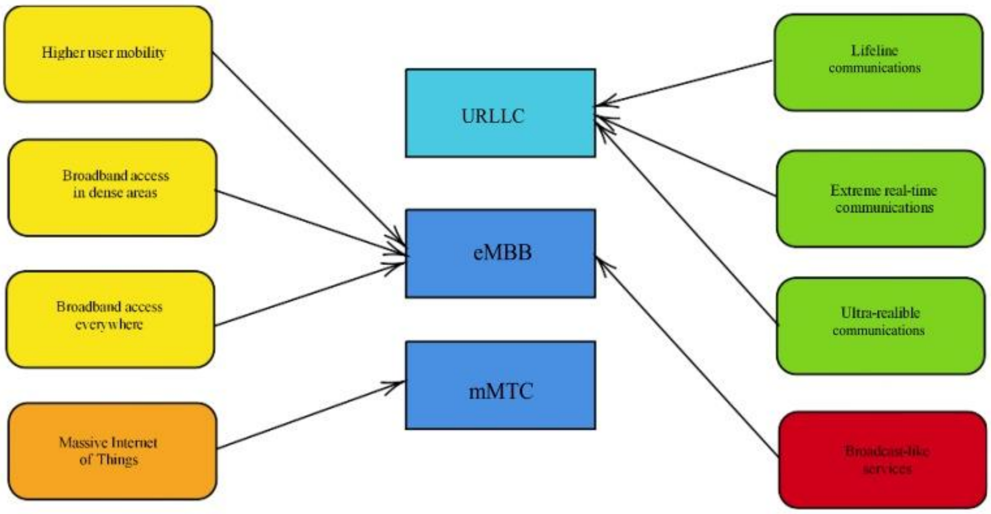

Fig.12. mapping from the usage scenarios

Fig.12. illustrates the mapping between the usage scenarios defined by ITU-R and the proposed use case families by NGMN. In this representation, URLLC encompasses extreme real-time communications, lifeline communications, and ultra-reliable communications. Meanwhile, mMTC aligns with the massive Internet of Things (IoT). The eMBB usage scenario comprises broadband access in dense areas, broadband access everywhere, increased user mobility, and services resembling broadcast transmissions.

9 Standardization Bodies

The development of 5G relies heavily on two key standardization bodies

i **International Telecommunication Union (ITU):** Information and communications technology (ICT) is under the supervision of the International Telecommunication Union (ITU), a specialized agency of the United Nations. The International Telecommunication Union (ITU) is the main player in determining the global vision and needs for 5G technology through its Radiocommunication project (ITU-R), particularly Working Group 5 (SG5).ITU-R SG5 is what defines all the performance and requirements of IMT-2020: this includes spectral performance, latency, data rate and reliability, and other key performance indicators (KPIs).See 5G applications and use cases. This will help ensure that the design is appropriate and meets the needs of various stakeholders. Promote cooperation and information sharing between countries and relevant organizations. This will lead to global harmonization of 5G standards.

Establish guidelines and recommendations for 5G spectrum allocation: This ensures sufficient spectrum to support the deployment and operation of 5G networks

ii **3rd Generation Partnership Project (3GPP):** This international organization is responsible for developing and maintaining mobile communications specifications. It consists of suppliers, network operators, research centres and others involved in communication.

3GPP activities include: developing and updating specifications for 5G Radio Access Networks (RAN), including radio protocols, air interfaces and radio control. Provide and manage specifications for the 5G Core Network (CN), including implications for service delivery, network architecture, and core network functions.

Ensure that various 5G networks and devices are compatible: This is done by creating comprehensive and clear guidelines. Make sure 5G technology is tested and implemented. This will help ensure that 5G networks meet the requirements needed to be efficient and effective.

Dialogue between 3GPP and ITU: ITU and 3GPP are working closely together to ensure that the global vision for 5G technology is translated into specific guidelines. 3GPP creates the specifications needed to implement the rules, while ITU provides all the standards and specifications.

Other important 5G initiatives include: The global mobile phone community finds representation through the GSM Association, committed to advancing the 5G environment and emphasizing its dedication to security and privacy concerns. The European Telecommunications Standards Institute (ETSI) is also actively engaged in the intricacies of 5G standards. Additionally, a regional entity known as the Alliance for Telecommunications Industry Solutions (ATIS) is dedicated to the development of 5G technology, with a specific focus on North American telecommunications standards.

Governance and issues: Governments are actively involved in overseeing many aspects of the 5G environment.

Spectrum allocation: Governments allocate specific frequencies for 5G services through sales or other regulatory processes. The performance and deployment of 5G networks are greatly affected by this.

Licensing and authorization: The country has created laws regarding allowing businesses to operate 5G networks. They are also authorized for certain activities, such as building infrastructure or providing services.

Technical regulations: Government-mandated regulations to ensure the security and efficiency of 5G networks.

Security and privacy: Governments around the world have enacted laws to protect user privacy and data security in the 5G era.

Some important controls on 5G deployment are:

Spectrum availability: 5G services will be more difficult if there is no available spectrum.

Regulatory: If international regulations are inconsistent, problems may arise with cross-border services and international travel. 5G's ability to collect and process data has raised concerns about privacy and data protection.

Cybersecurity Risks: Considering that 5G networks bring new targets for cybercriminals, security measures are important. Impact on existing systems there may be concerns that the development of 5G infrastructure may disrupt existing services. Collaboration of senior management, company leaders and other stakeholders is needed to solve these problems. Investments in this area include spectrum use, cyber security and improving personal security.

Promoting global collaboration: Policies and guidelines to facilitate global deployment of 5G.

Public Awareness and Education: Address concerns and build trust about the benefits and risks of 5G. Build strong cybersecurity: Protect 5G networks against cyber-attacks. By solving these problems and promoting collaboration, we can make full use of 5G technology to create a smart and integrated future.

10 The regulatory aspects and challenges related to 5G

Leveraging 5G network technology for substantial and rapid development is not without challenges. Security and privacy have become increasingly critical concerns for both businesses and individuals with the advancement of technology. Government regulations, costs, international design, and technological expertise pose significant obstacles. According to a recent study by Ericsson, the industry is actively working to address the challenges associated with the deployment of 5G technology. Key challenges include peer-to-peer competition, lack of standards, and concerns regarding data security and privacy (Ericsson, 2018).

The speed of 5G is expected to lead to more incidents, especially with the addition of small cells, which may result in malfunctioning equipment. The emergence of open design and technology is considered a benefit of 5G, allowing for faster collaboration and innovation, but it may also lead to concerns about quality. Technical standards across various domains are currently scattered and inconsistent, and certain aspects of technology still face constraints and restrictions. Fully utilizing 5G networks will require an innovative business model, the adoption of new technology, and investments in new resources and expertise.

Despite the potential benefits, a majority of companies have yet to provide their employees with 5G-capable computers, scanners, smartphones, or, in the case of manufacturers, smart factory floor devices. Upgrading business infrastructure is essential to capitalize on 5G's connectivity, necessitating the replacement or update of outdated equipment with new 5G-capable devices. This transition will incur additional expenses and adjustments for companies.

Important 5G characteristics including increased spectrum efficiency, low latency, high throughput, and extension possibilities have been made possible via optimisation algorithms. The application of artificial intelligence-based optimisation algorithms still faces various challenges and issues. Future discussions will centre on the following subjects:

i Machine Learning (ML) and Reinforcement Learning (RL): These algorithms play a crucial role in enhancing 5G network coverage and capacity. Improvements in these algorithms are essential to bridge the gap between intelligent algorithms and the capabilities of 5G networks.

ii Scheduling Algorithms: The implementation of scheduling algorithms is imperative for optimizing throughput and enhancing the capacity of cellular networks in the context of 5G.

iii Antenna parameter optimization: To enhance coverage and capacity, minimize mobile phone interference, and alleviate delivery costs and challenges, adjustments such as optimizing antenna tilt angles, varying antenna heights, and increasing the number of antennas are necessary in 5G networks.

Various algorithmic variations and approaches documented in the literature can be employed to enhance fundamental metrics in 5G, including coverage, delay, throughput, spectrum efficiency, data rate, outage probability, interference control, and power consumption. The following encompasses a compilation of crucial performance evaluation measures and elements. Fig.13. illustrates a statistical study of key properties in 5G.

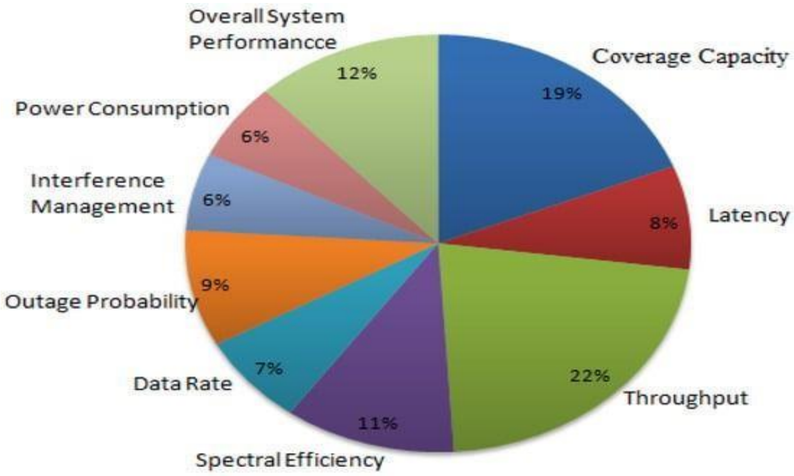

Fig.13. Statistical analysis of 5G key parameters.

11 Potential advantages and their impact on technology

This article provides a comprehensive overview of the key components, benefits, drawbacks, and impending challenges associated with technological advancements, with a primary focus on the introduction of 5G. Chapter 3 delves into the overall development of 5G technology, discussing its benefits, limitations, and upcoming challenges. In practice, the utilization of small cells, Carrier Aggregation (CA), Device-to-Device (D2D) communication, Non-Orthogonal Multiple Access (NOMA), Multiple Input Multiple Output (MIMO), and optimization technologies is crucial for the advancement of 5G. Each of these technologies is examined in terms of their advantages, disadvantages, and anticipated challenges. The article suggests that the use of deep learning, artificial intelligence, and machine learning in creating models for small cells can address future issues. This approach can enhance protection by mitigating loss patterns that impact mobility, transmission, and power consumption.

To tackle upcoming challenges in Carrier Aggregation (CA), the development of integrated electronic devices and optimization strategies aimed at extending battery life is recommended. Device-to-Device (D2D) communication faces challenges related to device detection, synchronization, and mode selection, which can be addressed through algorithmic recommendations based on artificial intelligence and machine learning. For Non-Orthogonal Multiple Access (NOMA), the optimization process should focus on improving receiver complexity, security, user integration, and overall performance. Multiple Input Multiple Output (MIMO) can benefit from the application of Artificial Neural Network (ANN) and Convolutional Neural Network (CNN) algorithms to analyze signals and predict data.

12 Conclusion

Over the coming years, 5G networks and services will be gradually implemented, offering a platform for the development of new digital services and business models. With 5G, high-performance connections will be available to billions of devices, ushering in a revolution in communications technology. Through the routing of nearly infinite services, it will make communication systems possible in the Internet of Things. IoT data consumption is rising along with the number of devices connecting to the internet. Because 5G networks can reliably connect patients and doctors worldwide, they will improve healthcare and transform transportation. 5G cellular technology will enable the user experience to shift from text, images, and video to virtual reality and augmented reality (VR and AR) by providing fast, dependable, high-bandwidth, and low latency.

This article examines how 5G will be crucial to the advancement of several industries, such as the Internet of Things, smart grids, smart cities, manufacturing, automobiles, and healthcare. The significance of 5G for the digitalization of developing markets and the resolution of numerous issues that the various manufacturing sectors were facing in a setting that was changing quickly. The article concludes by outlining the significant contribution that 5G makes in offering a strong platform to enable the broad use of essential communications services as well as the digitization and automation of Business 4.0 operations.

13 Future trends and developments in the field of 5G

Although it will take some time for 5G networks to be fully deployed and used, 5G will continue to develop as businesses strive towards its next phase. After its 2020 launch, 5G is predicted to grow quickly, with coverage expected to reach slightly more than one-third of the world's population in just five years. The emergence of autonomous electric vehicles has profound effects on society, the auto industry, and the transportation sector. The development of autonomous ride-sharing and electric vehicles will be significantly aided by 5G. 5G will make it possible for networks of self-driving cars to exchange data in milliseconds and interact with other vehicles, traffic lights, road sensors, aerial drones, and other devices. Self-driving trucks, trains, and even planes will also appear soon.

The use of an increasing number of electronic companies and products will also be significantly impacted by 5G wireless, which will alter the business market's mainstream. Businesses will be able to ride the growth wave and satisfy investors, clients, and staff thanks to 5G wireless. As a result, the future holds great promise for business and will be brimming with opportunities, risks, and challenges like never before.
Users require more network capacity, bandwidth, data speed, spectrum efficiency, lower latency, and more services than they did with 5G networks, in addition to 5G and 6G network applications. The nation will attain automation, or smart design, smart society, and smart life, by 2030.

Extensive research in the literature has focused on 6G networks, conducting a comprehensive evaluation covering technology standards and topics related to coverage, capacity, user data speeds, and mobility in telecommunications. This analysis builds upon the advancements made in 5G. To meet the demands of highly immersive applications such as virtual reality, digital twins, and 3D communication, the capabilities of 6G must be scaled up. Discussions have explored how real-time applications on edge networks can leverage the upcoming 6G technology. The trajectory and challenges of 6G-based edge computing have been deliberated, addressing the future hurdles and potential directions. The future challenges of 6G networks include the implementation of quantum machine learning for communications, ensuring ultra-reliable communications for edge computing, exploring energy harvesting techniques for prolonged battery life, and addressing various other emerging issues. These considerations represent the forefront of the challenges that must be tackled in the evolution of 6G networks.

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