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5G and Advance Network Architecture Considering Challenges, Solutions and Future Perspectives: A Survey

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Abstract

In recent decades, the two most crucial and intelligent breakthroughs of IT in recent decades have been the categories represented by mobile and wireless communications, plus the Internet. These technologies are not only grown up fast but also make a revolution in human life. The near future targets of the goal of the higher capacity and high data rate Services beyond 4G, lower transmission delay, and better service performance. To accomplish such network objectives above, radical architectural changes of cellular networks are required the aim is to shed some light on what 5G is about: what are the building blocks of core 5G system concept, what the main challenges are and how to tackle them. This paper presents findings from a comprehensive study on fifth-generation (5G) cellular network architecture and emerging technologies that can enhance it to meet user demands. The primary focus of this extensive review is on 5G cellular network design, massive multiple input multiple output technologies, and device-to-device communication (D2D).

Keywords: Here are potential keywords for our research paper on 5G architecture: 5G Architecture, Mobile and Wireless Communications, Cellular Network Design, Massive MIMO (Multiple Input Multiple Output), Device-to-Device Communication (D2D), Ultra-Dense Networks, Full-Duplex Radios, Millimeter Wave Solutions, Cloud Technologies, Software-Defined Networks (SDN), 5G Radio Access Networks (RAN), Internet of Things (IoT), Network Clouds, Enhanced Capacity, Reduced Latency, High Data Rates

Introduction

To address the needs and challenges of the anticipated future, contemporary wireless networks must undergo substantial modifications both in the present and upcoming years. Forward-looking networking models incorporate novel technological components such as Long-Term Evolution (LTE) and High-Speed Packet Access (HSPA). Additionally, supplementary elements may encompass forthcoming wireless innovations capable of supporting cutting-edge technology.

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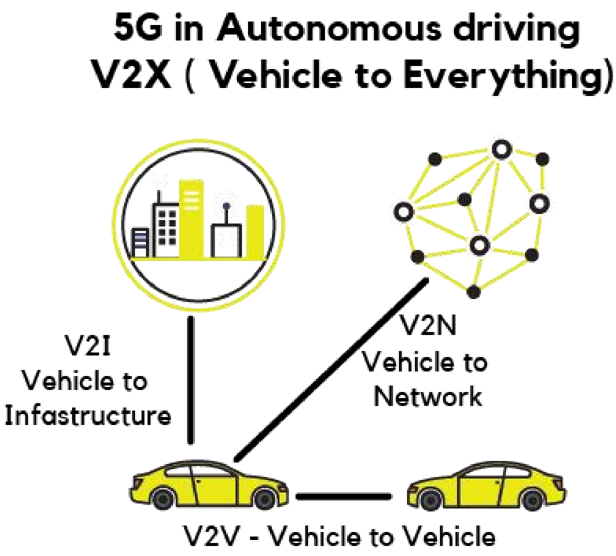

Figure 1: Image describing the V2X Communication across different systems

D2D represented in [Figure 1]and V2X as represented in [Figure 2] communication, crucial technologies in 4G and 5G networks, show promise for enhancing overall system efficiency, enhancing user experience, expanding the cellular communication applications, and has attracted widespread attention[1, 2] These new technological materials include various frequency access options, significantly higher frequency bands, promotion of large antenna configurations, and direct device-to-device connectivity.

This article presents our perspective on wireless communications beyond 2022, outlining the primary challenges that wireless communication in the Connected Society will encounter in the future. It also discusses several technical solutions to these issues. In a networked society, unrestricted access to information and data exchange should be available to anyone, anywhere, at any time. This concept necessitates research into new technological components to advance current radio technology.

To meet future demands, new technological elements are being incorporated into existing wireless technologies as described in [Figure 3] such as 5G, LTE, HSPA, and Wi-Fi from the 6th Generation Partnership Project. Wearable devices collect information, such as heart rate, amount of sleep, physical activities and send to the cloud server through the internet. 5G and

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IoT have the potential to boost the use of smart healthcare applications.[3] However, due to the ongoing evolution of current technologies, certain scenarios may not be adequately addressed.

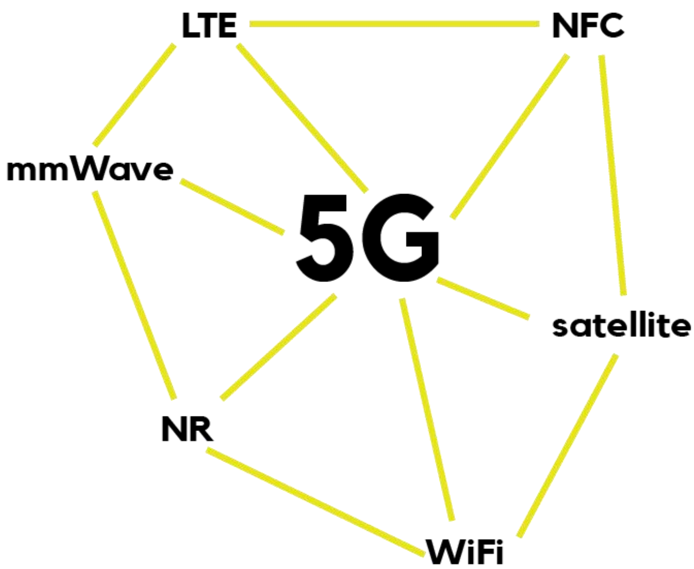

Figure 3: Describe the Combination of the 5G network.

Background and History

Since the 1970s, mobile radio systems have progressed from analog voice calls to cost-effective solutions providing high-quality coverage across extensive areas, with user data rates reaching tens of megabits per second. Presently, mobile broadband services can be delivered locally at rates of hundreds or thousands of megabits per second. The significant increase in the capacity of the mobile network and the new mobile devices like cellphones and t have led to a dramatic rise in the number of mobile communication applications, flow in resulting in network traffic.

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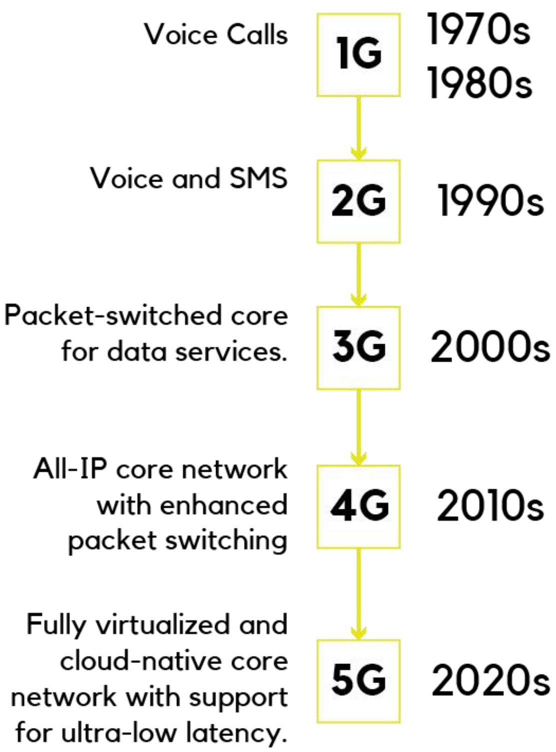

Figure 4: Visualizing the generations at each era and their functionalities.

1G (1970s-1980s)

In the begin, of portable communication connected analog innovation, voice calls of empowering simple without type in in code. In spite of the fact that it laid the basis for cellular systems, this period was tormented by inadequately security and restricted scope.

2G (1990s)

Second generation (2G) is a wireless technology that was introduced in 1990s.It utilize the circuit-switched network that divides into the several channels including like radio spectrum. In 2G there are three network architecture:

1.Mobile Station (MS)

2.Base Station Subsystem (BSS)

3.Network Switching Subsystem (NSS)

3G (2000s)

Third Generation (3G) is a wireless technology that was introduced in 2000s.It utilize the packet-switched network that validate faster data transport rates that include supports multimedia applications. In 3G there are three main components:

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1.User Equipment (UE)
2.Radio Access Network (RAN)
3.Core Network (CN)

4G (2010s)

Fourth Generation (4G) is a wireless technology that was introduced in the late 2000s.It utilize an all of the IP (internet protocol) network that validates faster data and high transfer rates, including supports high-bandwidth applications like video streaming and gaming purposes. In the 4G there are four main components:

1.User Equipment (UE)
2.Evolved Packet Core (EPC)
3.Radio Access Network (RAN)
4.Home Subscriber Server (HSS)

Rise of 5G Technology

After all these generations, the 5G Generation comes with so many features and performance upgrades that are so useful for the networking. The rise of the 5G technology is as follows:

Advancement Phase (2012-2018)

The push for quicker data transmission, reduced delay, and enhanced connection stability fueled 5G technology research. This period concentrated on crafting innovative network protocols and evaluating potential technologies to address these requirements.

1.2.2. Formalization and Experimentation (2015-2019)

Entities such as the 3rd Generation Partnership Project (3GPP) commenced establishing 5G standards, including the Release 15 specification that established the groundwork for 5G New Radio (NR).

Initial Deployment (2019-2020)

Early Deployment began in urban centers worldwide, emphasizing enhanced mobile broadband (eMBB) applications, utilizing new frequency ranges, such as millimeter wave (mmWave) and sub-6 GHz, to achieve faster data transmission.

Literature Review

This review section include literature related to the rising of 5G technology. Farris et.al [4]. Said that, The Internet of Things (IoT) ecosystem is evolving towards the deployment of integrated environments, wherein heterogeneous

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devices pool their capacities together to match wide-ranging user and service requirements. Many attempts and innovative ideas have been suggested and discussed around the world with the prediction of the arrival of 5G networks in the near future.

The advancement in technology that rebirth the wireless communication include virtualize network and software defined network. The advantage of 5G technology as illustrated in the [Figure 5] represents a fundamental improvement and meeting the increasing demand for faster data rates, enhanced connectivity and lower latency. The key innovation in 5G technology include Network Slicing, that allows for customize virtual networks, and Edge Computing which processed data closer end to the user by giving minimal latency. The Radio Access Network (RAN) has improved with the introduction of technologies like Massive MIMO to increase capacity, and mmWave for fast data transfer.

D2D communications, next generation technologies (such as cognitive radio), and the enhancement of 5G will play roles in cloud-based networks versatility and performance. Network Function Virtualization Security (NFVS) and Software-Defined Security (SDS) along with security protocols address the myriad of threats found in these virtualized environments.

Also, the potential of 5G will revolutionize applications in autonomous systems, smart cities and the internet of things (IOT) challenges in managing interference and guaranteed scalability. In order to Current research problems are directed towards solving these issues and explore possible potential advancements like AI-driven optimization and integration with satellite systems for future developments.

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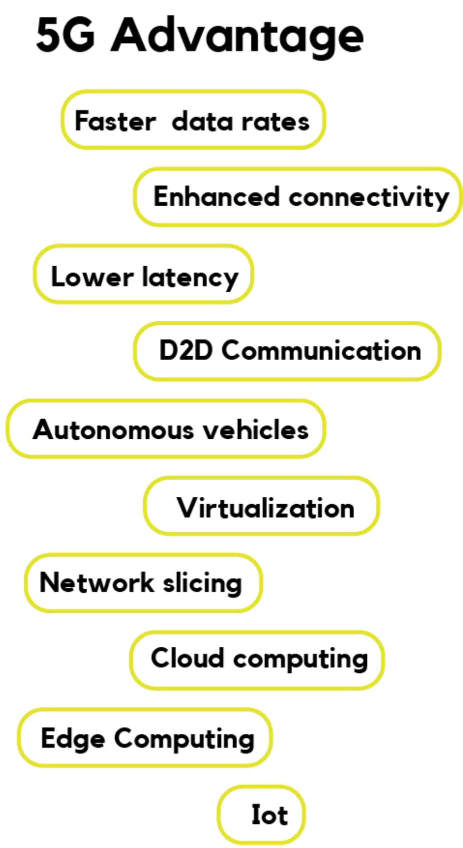

Figure 5: Describing the advantages of the 5G Technology.

5G Network Architecture and Design

The Primary goal of network architecture 5G marks a comprehensive development in wireless communication, the engineered need to address the extend needs for increased data speeds, comprehensive connectivity, and minimal latency. 5G has spread out this range to offer a range of wireless services delivered to multiple access platforms of the end user and multi-layer networks.

The design of 5G network architecture aims to provide swift and dependable connectivity while accommodating various applications and services. It allows for adaptable implementations through innovative concepts like network function (NF) virtualization, software-defined networking, and network slicing. Recent technology constituent like high-speed packet access (HSPA) and long-term evolution (LTE) will be launched as a segment of the advancement of current wireless based technologies.[4] The 5G system incorporates a service-oriented architecture with modular network services. This architecture is founded on the principle that 5G systems must cater to a

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broad spectrum of services with distinct characteristics and performance requirements. The service-oriented structure and interfaces in 5G systems enable future networks to be adaptable, customizable, and scalable.

By the end of this year, it is anticipated that the quantity of devices connected to networks will reach 7 trillion, with data traffic expected to increase tenfold in the next 8 years. It is expected that elements of 5G will be rolled out by early 2020s to meet business and consumer demands as well as requirements of the Internet of Things. China's Ministry of Industry and Information Technology announced in September 2016 that the government-led 5G Phase-1 tests of key wireless technologies for future 5G networks were completed with satisfactory results.[5]

1.Unlike its forerunners, 5G utilizes a service-oriented core network (5GC) enhanced by SDN and NFV, increasing flexibility and simplifying service management.

2.The radio access network (RAN) incorporates cutting-edge technologies such as massive MIMO and beamforming.

3.Functions on sub-6 GHz and mmWave frequencies to enhance spectral efficiency.

4.Network slicing allows for the establishment of tailored virtual networks for particular use cases.

5.Enables applications like enhanced mobile broadband (eMBB) and ultra-reliable low-latency communication (URLLC).

6.Edge computing supports real-time processing by decentralizing data storage and reducing response times.

7 .Essential for IoT applications and autonomous systems.

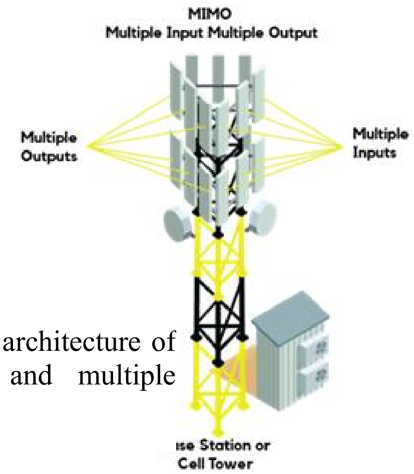

Figure 6: Representing the architecture of MIMO (Multiple Inputs and multiple Outputs.

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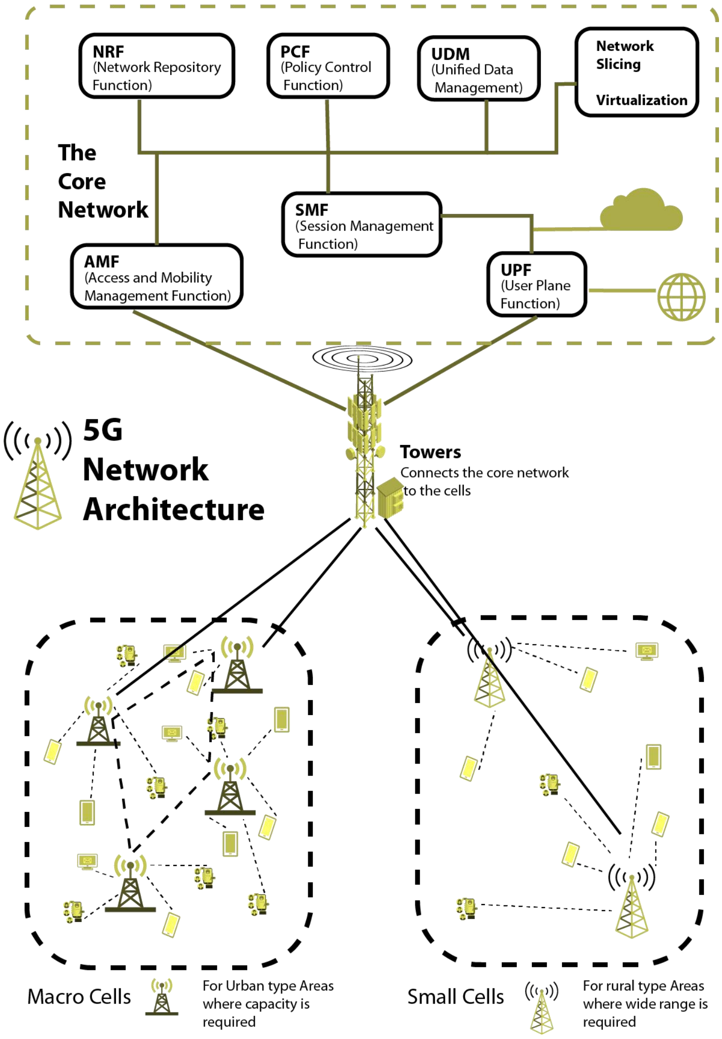
5G Architecture Diagram



5G Network Aim to Provide

The 5G Network build to provide the features that enhance the user experience and also add new features that are will be so useful in future. These qualities are as follows:

Enhanced Mobile Broadband (eMBB)

In the Key 5G Innovation this is undoubtedly going to improve the Quality of Service as well as Quality of Experience for end-users in using applications, especially those associate with very heavy data consumption by the end-user on their mobile devices.

Key characteristics of eMBB

The Key characteristics of the eMMB are as follows:

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Data rate

eMBB delivers higher data speed than previous generations of mobile networks.

More Bandwidth

eMBB offers more bandwidth, which can accommodate many more applications.

Latency

eMBB helps reduce latency which is vital for applications such as real time gaming.

Network Slicing

eMBB can be run on the same physical network infrastructure as other 5G services with no incremental cost.

Use Cases for 5G eMBB:

Video Streaming: This next-generation cellular network technology will allow people to view high-definition videos on their handheld mobile devices.

Massive IoT: The methods can deliver sufficient bandwidth and speed to guarantee stable connectivity for large-scale IoT deployments, therefore allowing smooth data collection and communication.

Connected Devices (IoT): The solution offers the speed required for constant connectivity, which gives IoT devices the capability to gather and transmit data reliably.

Virtual Reality (VR): With advanced cellular network technology, virtual reality experiences can be more enjoyable due to no lag.

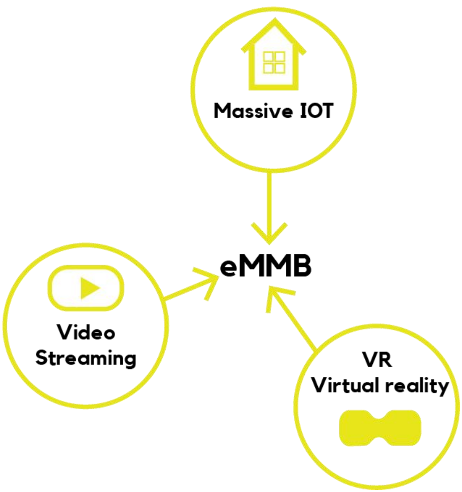

Figure 7: Representing the Qualities of the eMMB

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What are the financial implications?

Upgrading to a more sophisticated cell network service is, in most cases, free. Changing provider or equipment costs may not be covered by the price and will depend on the provider, it may also mean additional monthly charges.

Massive Internet of Things (mIoT)

Massive Machine type communication or Massive Internet of Things (mIoT) develops the idea of IoT that helps us to connect a vast number of number of devices with sensor through cellular network.

Essential Features of MIoT

Extensive Reach:

MIoT connects an immense quantity of devices, spanning from home appliances to industrial machinery and agricultural monitoring equipment.

Cheap, Power-saving Sensors

Cheap and power-efficient sensors are used in MIoT, so that they can be embedded into any objects to wirelessly transmit data over the internet.

Obstacles and Resolutions

Data Management

The amount of data that MIoT will create can be gargantuan, and challenging the decades old model of storage and processing systems; it will eventually conquer them.

Edge Computing

Data processing at its origin, with less time to respond, but also more security and less data being moved to a center.

Fog Computing

Distribution of computing and storage resources over a network pushes the location at which data could be processed closer to the source.

Applications:

Urban Intelligence

IoT can improve city architecture, traffic control, where devices like lights, street lamps and the parking sensors, waste handling, and public security.

Industrial Automation

MIoT can improve industrial automation, where machine can interconnect with each other without human disturbance. These allows companies to control large amount of data, driven maintenance, and organize management.

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Ecological Surveillance

MIoT aids in monitoring pollution, climate shifts, and natural resource administration.

Protection and Security

Data security given the extensive connectivity, ensuring security and privacy is crucial. Robust authentication, encryption, and access control systems are vital.

Ultra-Reliable Low-Latency Communications (URLLC)

Ultra-reliable low-latency communications (URLLC) is a new, but already well-developed, communication technology developed by 3GPP specifically to satisfy requirements presented in Industry 4.0 and the Internet of Things. This power provides high reliability with low latency, which allows for mission-critical applications to be supported.

Benefits of URLLC in 5G Networks

Being a key component of 5G Networks, URLLC caters multiple benefits. This allows for higher data rates and lower latency, providing immediate communication between users and their devices. In addition, the URLLC technology is supported by multiplexing of several users to utilize and share resources and enhancing there network efficiency.

Self-Driving Vehicles

The autonomous vehicles have a proper function that include high reliability and lower delay rates. URLLC technology facilitates dependable data transmission and enables real-time communication among vehicles, ensuring swift responses to environmental changes.

Manufacturing Automation

URLLC finds application in industrial automation as well. It provides dependable, trustable, low-latency communication between machines and enables real-time process control. This results in improved efficiency and precision in industrial operations.

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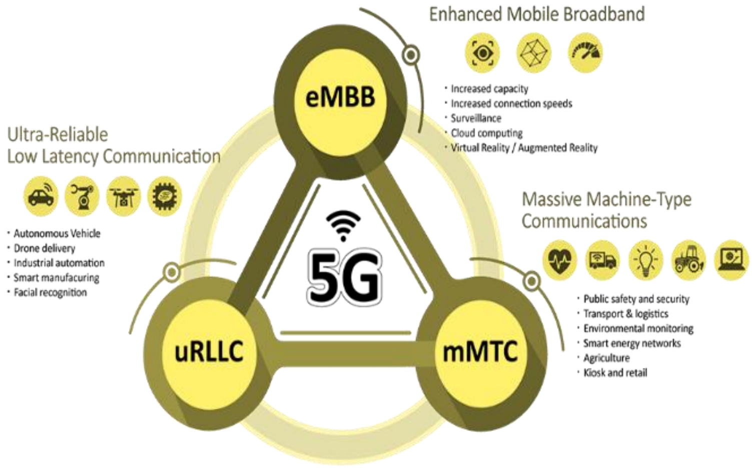

Figure 8: Representing the eMMB, mMTC and uRLLC in the 5G

Design Challenges

The design challenges of the 5G technology are as follows:

Network Slicing: Overall Resource Distribution and Separation

Network slicing can be pictured as integrating multiple distinct portions within one physical infrastructure. Each slice is made for a particular reason, like video streaming or facilitating IoT devices, and as such improves resource allocation and guarantees no service disturbance occurs. This type of a situation is not too different from launching a roadway with dedicative lanes for each type of vehicle thus ensuring all types of vehicles can have uninterrupted movements forward.

Edge Computing: Reduced Latency and Increased QoE

Edge computing pushes resource intensive computing tasks to the edge of the network closer to the consumer thus it's more like a street side coffee shop instead of a large warehouse. This makes the time required for data to travel form one point to another quite short, hence there is less time response (less latency) and hence satisfaction of the user experience is improved. This is very important for online gaming, self-driving cars, smart house applications, where anything more than a millisecond is too much.

RAN Evolution: Increased Volume and Adaptation

RAN (Radio Access Network) development entails the enhancement of the procedure of data delivery between the clients and the backbone of the network. Different technologies such as massive MIMO (Multiple Input, Multiple Output) allow networks to have lots of concurrent users and a large

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amount of data concurrently. This can be compared to a busy road and making it adaptable to change direction based on traffic patterns, enhancing both capacity and flexibility.

Security: Measures Improvement for Different Services

The provision of 5G technology allows the provision of a larger number of services and therefore the security measures become more complex. More advanced security strategies include establishing physical barriers and sophisticated surveillance techniques in order to mitigate the chances of a cyber-attack. This is like having a security system comprised of a high-grade lock, a guard dog, and even a camera, no matter what type of a person or package comes into your house.

Scalability: Successfully Deal with Multiple Patterns of Traffic

Scalability means that the increasing or decreasing amounts of traffic will not compromise the operability of the network in case of thousands of devices broadcasting videos or only a few devices send messages. This idea is similar to having a bridge that can be expanded or retracted thereby eliminating the congestion of extra vehicles crossing at the same time across a certain point.

Existing Solution

Network Slicing

SDN/NFV

Software-defined networking and virtualization of network functions to create scalable, software-managed network slices based on different needs.

Network Slice Orchestration

Automated allocation of resources so each section has the required resources dynamically (like highway lanes for a good flow of traffic).

Edge Computing

MEC (Mobile Edge Computing)

Places processing closer to the end-users with low latency and improved UI, especially great for high response AR/VR applications.

Fog Computing

Splits compute capacity over the edge of the network instead of keeping it in servers which is responsive and distributed.

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RAN Evolution

Massive MIMO

Adds many more antennas to base stations to make networks take on more users and data in real time for more capacity and effectiveness.

mmWave

Uses high frequency bands to send faster data, especially in densely populated locations that need high speed connection.

Security

NFV Security (NFVS)

Securing virtualized function level, digital traffic in the cloud network services.

Software-Defined Security (SDS)

Uses nimble, software-based protocols for enhanced security monitoring, responding as threats arise.

Scalability

NFV

Reliable Resource Allocation, enabling networks to scale up or down according to demand without hardware upgrade.

SDN

Centralizes network management for easier resource management and adaptation, and able to manage traffic spikes easily.

Conclusion

Mobile communication is undergoing constant evolution. On April 27, 3GPP officially named the 5G evolution "5G-Advanced," and the initial phase of 5G standards became available for commercial deployment. The 5G Advanced Network aims to provide enhanced social and business value by specifying additional objectives and capabilities. Industry collaborators will eventually release a white paper to guide the development of 5G-Advanced networks. This document represents the leading stage in future 5G network growth.

Technologically, "Artificial Intelligence, Convergence, and Enablement" will enhance 5G-Advanced network capabilities. This involves promoting intelligent technology adoption and integration into telecom networks, exploring distributed intelligent architecture, and fostering terminal-network cooperative intelligence. Convergence will drive the development of 5G networks across industrial, residential, and space-to-ground sectors. Enablement will benefit the 5G network for vertical industries.

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5G-Advanced will introduce interactive and broadcast communication alongside network slicing and edge computing, making network services "more versatile." Through scheme simplification and end-to-end quality assurance, the network will become "more certain." Time synchronization and location services will render the network "more open." Consequently, this white paper is expected to outline reference scenarios, requirements, and technological directions for developing advanced 5G networks.

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