ISSN No:-2456-2165

An Extensive Study of Evolution in 5G

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Abstract:- The evolution of 5G technology promises to bring about significant improvements in the performance and capabilities of wireless networks. In this paper, the evolution of 5G, which is advancement in 5G, with higher data rates, lower latency, and increased capacity are examined. 5G networks will enable a wide range of new applications and use cases, from autonomous vehicles and smart cities to advanced healthcare and immersive entertainment. To achieve these improvements, 5G networks are being designed with advanced technologies such as massive MIMO, millimeter wave technology, and network slicing. These technologies will enable faster data transfer rates, improved coverage and capacity, and more customized services tailored to specific use cases. Overall, the evolution of 5G technology represents a significant step forward in the evolution of wireless networks, and will enable a wide range of new use cases and services that were previously impossible. As the technology continues to evolve, we can expect to see even more advanced capabilities and applications emerge, transforming the way we live, work and communicate.

Keyword:- *5G, Cognitive Radio (CR), MIMO, Critical IoT, RATs, XR.*

I. INTRODUCTION

Over the past few years, we have observed significant changes in the field of telecommunications. In the present and the near future, mobile communication networks will need to evolve in various ways to meet the demands and challenges of the coming era. With the ongoing deployment of 4G mobile networks, some telecommunications companies are considering further advancements towards future 5G services and technologies. The upcoming 5G wireless technology, which includes BDMA and FBMC, will replace 4G wireless technology. 5G's initial rollout has been swift across many regions globally, but it's just the initial phase of its ongoing development. Building on the foundation of 5G Standalone (SA) deployment, communication service providers (CSPs) will experience continuous enhancements in the coming years, offering novel use cases, improved performance, and more efficient networks. To facilitate this progress, 3GPP has initiated the specification of 5G Advanced starting from Release 18. The concept of beam division multiple access is explained by considering the communication between the base station and the mobile station. In this type of transmission, each mobile station is assigned on orthogonal beam from the antenna, which is split according to the mobile station, thereby improving the networks capacity. The decision to transition of 5G is based on current trends, and it is believed that 5G mobile networks must address six problems that have not been adequately resolved by 4G mobile communication networks. The evolution is not just about faster download speeds or smoother streaming. It is about unlocking the full potential of emerging technologies such as the Internet of Things (IOT), Artificial Intelligence (AI), Virtual reality (VR), and autonomous vehicles. 5G evolution will enable seamless connectivity between billions of devices, creating a truly interconnected world.

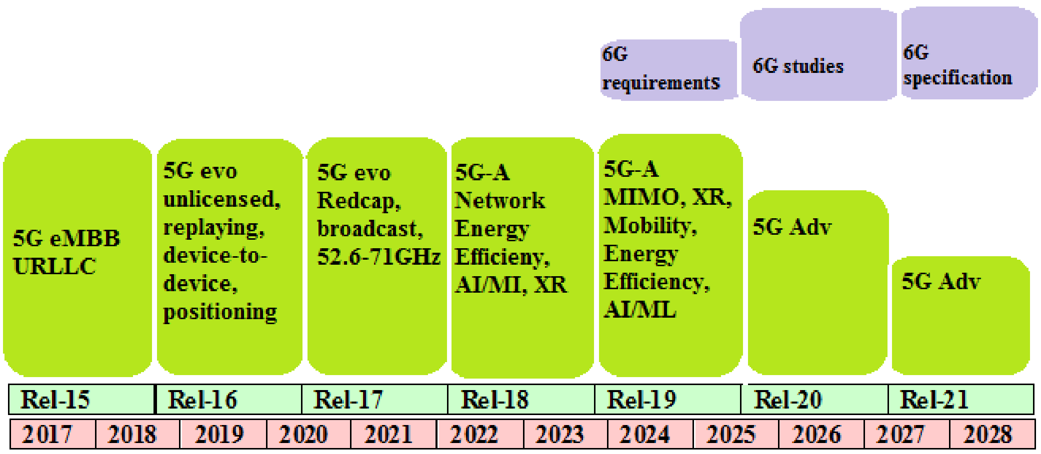

Fig. 1: View of 5G Advanced and 6G timeline of 3GPP (dates beyond 2023 are indicative)

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II. 3GPP TECHNOLOGY EVOLUTION

Since its debut in Release 15, 5G has focused on three primary use case families: enhanced Mobile Broadband (eMBB), critical Internet of Things (IoT), and massive IoT. With the addition of support for new verticals in subsequent releases, 5G enables numerous novel use cases, surpassing previous 3GPP systems. It delivers exceptional network performance, offering greater capacity and coverage while prioritizing sustainability. Enhancing network energy efficiency to minimize the 5G system's carbon footprint is of utmost significance. Currently, the 5G system requires additional optimization due to emerging use cases like extended Reality (XR) and insights gained from existing commercial 5G deployments. The next phase of 5G, known as 5G Advanced, begins with Release 18 and involves extra features for new market segments, along with architecture enhancements for 5GS. This evolutionary process continues in Release 19. 5G NR caters to eMBB use cases through its support for various duplex schemes, frequency ranges, MIMO, and multi-carrier operations. 5G Advanced will bring further improvements to eMBB performance. Release 18 introduces NR and LTE dynamic spectrum sharing (DSS) enhancements, making the transition from LTE to NR smoother and more efficient. Mobile devices benefit from MIMO enhancements, resulting in enhanced capacity and performance. Looking ahead to Release 19, massive antennas are expected to take the spotlight, further enhancing performance Critical IoT (cIoT) pertains to use cases that have strict requirements regarding latency and reliability.

III. EVOLUTION OF 5G NETWORK

Due to significant increase in the number of mobile users, it is anticipated that global mobile data traffic will grow more than 200 times between 2010 and 2020, and nearly 20000 times between 2020 and 2020 as result, the development of 5G networks is necessary to meet the demand for mobile data. The 5G standard is expected to have 2 key features: increased network capacity and higher peak data rates. The network capacity of 5G cellular systems should be 1000 times that of 4G networks, and 5G will employ advanced technology such as massive MIMO to achieve this. The peak data rate for 5G networks will be 1 GBPs for mobile users and 10 GBps for stationary users, providing internet services comparable to fibre optic connections. In the near future it is estimated that there will be 100 billion devices connected to the global mobile communication network.

The current round trip latency for the LTE-A advanced 4G network is 20 ms, but it is anticipated that the 5G standard will offer a much lower latency of less than 1ms for a one-way uplink or downlink delay. This is known as user plane latency and is a significant improvement that will enable real-time applications such as remote surgery, autonomous vehicles, and industrial automation to function more effectively. In addition to new spectrum allocation, it is crucial to efficiently use the available spectrum. To achieve this, 5G cellular networks will incorporate smart radio technologies such as cognitive radios. These technologies will enable the efficient utilization of both licensed and under-utilized spectrum, resulting in better spectrum sharing overall.

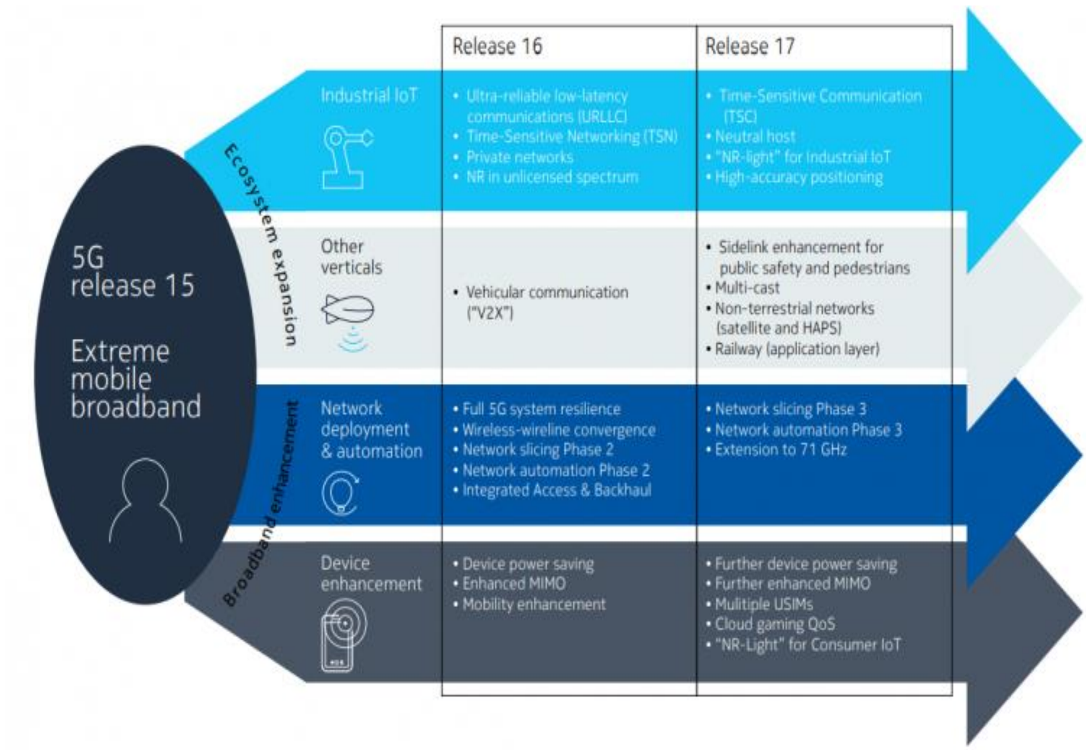

Fig. 2: 5G Evolution

IV. 5G ADVANCED PILLARS

5G Advanced is set to improve network performance and introduce support for novel applications and use cases. This paper emphasizes four crucial feature areas, where 5G Advanced is anticipated to bring substantial enhancements:

- 5G Performance
- Support for new market segments
- Sustainable networks
- Intelligent Network Automation

A. MIMO

Advanced antenna systems and MIMO support are integral to 5G technology. Release 18 enhances MIMO capacity in both uplink and downlink through improved demodulation reference symbols. Additionally, to better cater to high data rates for mobile users, the MIMO beam forming framework is refined to adaptively switch between various beam forming methods based on the user's speed. In Release 19, to accommodate the growing trend of larger antennas, an extension of supported antenna ports is required, allowing for more radiating elements. MIMO-related improvements for uplink coverage and capacity are crucial for XR, mobile broadband, and fixed wireless access (FWA) scenarios. Additionally, Release 19 aims to enable coherent-joint transmissions across multiple transmission and reception points (mTRP) on a larger scale, moving towards a more distributed MIMO system. To enhance current coarse link adaptation (LA) procedures, channel quality reporting needs improvements to ensure more accurate LA. For reciprocity-based massive MIMO, predicting the noise and interference level experienced by the UE, which is currently not accurately available to the gNB, leads to inefficient MIMO operation. Therefore, Release 19 should specify enhancements related to CSI acquisition for reciprocity-based downlink single-user/multi-user MIMO (SU/MU-MIMO).

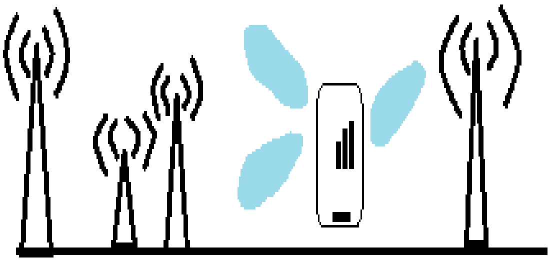

Fig. 3: Multi-antenna transmission and receptions

B. MOBILITY

Similar to MIMO, mobility is an essential element of 5G. In 5G Advanced, there is an opportunity to enhance service continuity for mobile users. The introduction of the new L1/L2 triggered mobility (LTM) handover procedure aims to reduce handover interrupt time. LTM integrates the beam managing and mobility frameworks, introducing a low-latency mobility procedure for NR that supports carrier aggregation (CA) and applies to both FR1 and FR2 frequency ranges.

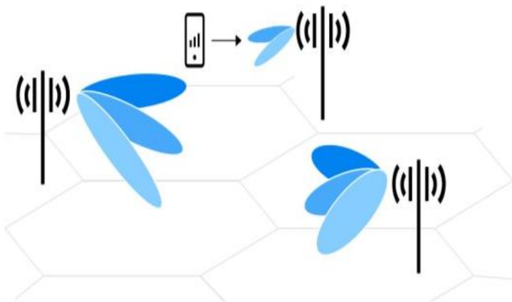

Fig. 4: Beam based mobility in cellular networks

V. TECHNOLOGIES THAT FACILITATE THE IMPLEMENTATION OF 5G

"This section provides an overview of the technologies that are being researched and developed to achieve the expected performance mentioned in the previous section."

- **Multiple Radio Access Technologies (RATs):** To achieve the thousand times network capacity of 4G networks, the upcoming 5G network will utilize multiple radio access technologies. These RATs will include advanced WLAN and Wi-Fi technologies, which will increase coverage and provide seamless handovers over 5G cellular networks. For instance, the latest wifi technologies, IEEE 802.1lac , can offer wireless broadband connection with data rates up to Gbps, and it can be integrated into the network. Telecom companies are planning to merge 3G/4G/wifi transceivers into a single base station and make mobile stations intelligent enough to connect to the appropriate radio access network based on the quality of service requirement.
- **Small Cell Deployment:** The 5G small cells network consists of micro-, pico-, or femto-cells, which together form a heterogeneous network (Het Net). This Het Net can be created by overlaying small cells of the same technology, forming a multi-tier Het Net, or by combining small cells of different technologies forming a multi- RAT Het Net.
- **Self Organising Network:** The idea of Self-Organising Networks (SON) particularly valuable when deploying hyper-dense small cells. It enables small cells to synchronize with the network autonomously and intelligently adapt their radio coverage which reduces inter cell interference. As a result, SON helps to improve the overall performance and efficiency of the small cell network.
- **Machine Type Communication (MTC):** MTC is conducted within a small cell area that is outside the cellular standards. This is achieved through the use of either Bluetooth or WLAN in ad-hoc mode. MTC requires slow latency and real-time remote control of mobile devices.
- **Millimeter Wave Technology:** As the sub 3GHz band is becoming more crowded, researchers are exploring the use of millimeter wave band for mobile communication. This band extends from 30 to 300 GHz and offers a vast bandwidth for communication. However, due to high operating frequencies, Omni directional path loss is higher in the mm Wave band compared to the conventional sub 3 GHz band. This can be addressed through directional transmission and appropriate beam forming strategies. Nonetheless, mm Wave signals are highly susceptible to

shadowing, which can cause outages and reduce channel quality. Additionally, channel fluctuations are more significant in the mm Wave band, as the channel coherence time is very short for given velocity, and the channel changes at a much faster rate. Furthermore, device power consumption increases as the mobile station has to support a large number of antennas. Consequently, mm Wave cellular networks are currently an area of active research, with numerous experiments being conducted to analyze their coverage and capacity and determine ways to make them suitable for cellular communications.

- **Cognitive Radio:** It is a type of radio that can adjust its transmission parameters based on the environment in which it operates. This technology enables the more effective use of licensed frequency bands in an opportunistic manner. Networks based on Cognitive Radio result in a more efficient utilization of radio resources, improved interference coordination in HetNets, and increased network capacity and coverage.
- **Cognitive Radio Based Architectures:** There are two types of architectures for cognitive radio networks (CRNs): non-cooperative and cooperative. In a non-cooperative CRN, there are two radio interfaces - one for licensed channels and the other for temporary unoccupied channels known as cognitive channels. On the other hand, in a cooperative CRN, the licensed channel is accessed opportunistically, meaning it is used only when the primary user is not accessing it
- **Device to Device Communication Based Architectures:** The technology enables direct communication between two mobile stations without the involvement of the IBS, OBS, or core network. This approach provides several benefits like improved link reliability, faster data transfer rates, instantaneous communication, peer-to-peer file sharing, online gaming, energy efficiency, and traffic offloading from IBSs. However, interference can be a significant challenge, but it can be mitigated by using cognitive radio networks (CRNs) in device-to-device (D2D) communication.
- **Energy Efficient Architectures:** The primary focus for next-generation networks is energy consumption. This objective is based on the "no more cells" principle, which aims to separate the uplink (UL) and downlink (DL) channels as well as the signaling and data.

VI. OVERVIEW OF KEY AREAS OF 5G EVOLUTION

The 15th release of 5G technology delivers exceptional results in critical performance indicators such as data rate, spectral efficiency, and latency, which are essential for high-speed mobile broadband services. It outperforms the capabilities of 4G technology in those areas. Meanwhile, Releases 16 and 17 are geared towards broadening the 5G ecosystem to enable a diverse range of industries to benefit from it. These releases offer a wide range of features that cover all aspects of 5G development, including industrial IoT, various vertical industries, network deployment and automation and device evolution.

- **Industrial IOT**: Achieving comprehensive support for factory automation and other essential Industrial Internet of Things (IoT) applications is a complex task that spans across several 3GPP releases. In certain markets, the term "Industrial 5G" is used to encompass the features included in Releases 16 and 17, which provide the necessary support for IoT applications. These are URLLC and TSC.
- **Vertical Industries**: Although Releases 16 and 17 primarily focus on expanding the 3GPP technology ecosystem to support Industrial Internet of Things (IIoT) applications, they also introduce features that enable 5G to cater to various specialized markets where the network operator's role may extend beyond that of traditional communication service providers (CSPs). These markets are commonly referred to as "vertical industries" in the context of 3GPP technology.
- **Network Deployment and Automation**: This area of 5G development is primarily focused on introducing features that enable communication service providers (CSPs) to deploy the technology more efficiently or reduce their operating costs. A key feature introduced in Release 16 is Network Slicing (NS), which allows operators to outsource the management of network slice subscriptions to third parties who are using the operator's networks to provide services to their own customers. This release also introduces Network Slice-Specific Authentication and Authorization (NSSAA), which allows a third party to manage a user's subscription to a particular slice without requiring the intervention of the operator in managing transitions such as adding or removing end-users to/from a slice. An example of this is BMW, who can manage its end-users (e.g., owners of BMW 5 Series and 7 Series cars) who access its slice to use V2X services. Release 17 will further enhance the overall operability and automation of network slice deployments.
- **Device Evolution**: As 5G technology becomes more widespread and mature, Releases 16 and 17 introduce improvements to the basic mobile broadband experience provided by 5G. The battery life of devices is a crucial aspect of the user experience. Although many factors that affect battery life depend on the design of the implementation and tend to improve naturally as the technology advances, there are certain aspects of the 5G standards that directly impact the energy efficiency of devices. Release 16 introduces signaling from the network to the devices, specifically designed to help reduce their power consumption during "connected mode" when conditions allow, resulting in optimized device power consumption during periods of active transmission and reception. Release 17 enhancements will focus on power-saving improvements for devices that are in "inactive" or "idle" modes, thus improving standby battery life.

VII. BLUEPRINT FOR FURTHER 5G EVOLUTIONS

- **Ubiquitous Coverage:** The expansion of both IoT and Extreme Mobile Broadband use cases will continue to extend from population to geographic and volumetric coverage. These use case domains include connectivity for both humans and machines, such as higher data rates for IoT to support video as a sensor, and basic MBB services that use fixed wireless access to reach more people. NR Light will introduce efficiencies for services with throughput speeds of up to 100Mbps and down to 100ms delay requirements.

- **Fusion of New Service Profiles:** There is a rapid growth in the use cases that require high-speed, reliable data services with strictly limited latency. Combining the characteristics of Extreme Mobile Broadband (eMBB) and Ultra-Reliable and Low Latency Communications (URLLC) can lead to the creation of new service profiles.
- **Time and Space Accuracy:** Offering precise time information via the network without relying on a GNSS satellite link can enhance application reliability and simplify their implementation. This can be beneficial for various applications, including digital financial transfers, multimedia synchronization, synchronization of industrial production units, and real-time digital twin solutions.
- **The Next Level of Automation**: The potential for AI/ML in the 5G network platform is vast, enabling the enhancement and streamlining of various functionalities. These include optimizing RF power amplifiers, automating the network, and improving the radio network with open RAN integration.

VIII. BARRIER TO IMPLEMENTATION

Implementing 5G networking technology faces numerous challenges that hinder its rapid growth. The primary concerns are security and privacy, especially as devices become more interconnected. Major obstacles include technological maturity, global standardization, government regulations, and cost. A recent Ericsson study highlighted companies' struggles in using 5G technology due to barriers like data security and privacy, lack of standards, and challenges in end-to-end implementation. 5G's speed can lead to faster breaches, and the proliferation of small cells introduces more vulnerable hardware. Additionally, 5G's adoption brings an increase in open-source designs and technologies, which, while fostering innovation and collaboration, also raise security concerns due to potential vulnerabilities.

IX. CONCLUSION

To recapitulate, this paper examined that the advancement in 5G technology has been remarkable, revolutionizing the way we communicate and access information. With faster data speeds, lower latency, and increased capacity, 5G enables seamless connectivity for a wide range of applications. Additionally, this paper explored the vital functions of 5G in driving success across various industries, such as IoT, the automotive sector. Also, as 5G deployment continues to expand worldwide, it has the potential to fuel economic growth, enhance productivity, and drive technological advancements across various industries. However, addressing challenges such as infrastructure development and security concerns will be crucial to fully harness the transformative potential of 5G and ensure a seamless digital future for everyone.

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