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Fifth Generation (5G) and Its Role in Developing Modern Communication Networks

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Abstract— The explosion of mobile data traffic and emerging application scenarios (e.g., IoT, immersive multimedia/application, tactile internet) has propelled a drastic evolution from traditional 4G(long-term evolution(LTE)) networks. 5G) mobile system, is believed as no longer an evolution of 4G but a revolutionary industry driven and massively expanded service ecosystem that will enable us to connect the entire crowded world for more than 7 billion peopl world without any limitations and can constitute a "World Wide Wireless Web" (WWWW). The purpose of this paper is to give a well systematic overview of the 5G contributing in application areas for future communication networks. We analyze this transition, from 1G to 4G, with respect to the dynamics of RA technical systems settings, data rate and network technology. The essence of this paper is in depicting the enablers of 5G which include new network structures(hence reconfigurable multi technology cores and cognitive terminals)and game -changer physical layer technologies(hence Full- Duplex communication, Filter Bank Multi-Carrier crisis(FBMC), Non Orthogonal Multiple Access Noma).Sparce Code Multiple Access(Scma). We also comment on major enablers and supporting key technologies including SDR, CR,nanotech-nology, cloud computing to realize the 5G vision.. The study concludes that 5G is the preeminent technology for a digital society and resulted from naturally evolving technical specifications such as higher capacity, lower latency, faster..

Keywords—5G, Network Architecture, Physical Layer, NOMA, SCMA, Full Duplex, FBMC, Cognitive Radio, Software Defined Radio, IoT.

I. INTRODUCTION

The recent decades have seen the mobile wireless technology experience an overwhelming development; four to five generations of revolution and evolution [1]. From 1G's analog voice-centric systems to 4G LTE's high-speed mobile broadband, the new technologies introduced with each generation have been readable and the improvements were easily measurable through KPIs like peak data rate, spectral efficiency and latency. The rollout of 4G LTE networks has successfully brought the internet to just about everyone, but things change and grow. Increasing number of connected devices, the emergence of data-hungry applications and development of the Internet-of-Things (IoT) is straining on 4G networks [2], [3]. 5G technology, the next generation (5G) also known as beyond 4G and enables a new kind of network that is designed to connect virtually everyone and everything together including machines, objects, and devices [4]. It is intended to be a smarter technology which connects everyone in the world together with everything else, realizing a true wireless world—the WWWW (the World Wide Wireless Web) [1], [5]. It's not just a faster smartphone — it's the platform for a network architecture that can support an ecosystem of applications from connected cars and smart cities to vast sensor networks to a completely immersive virtual reality [6], [7]. In the last few years, a tremendous amount of research papers have been proposed concerning 5th generation (5G) networks and this is an evidence to how much they are interesting for researchers and the great progress that has been made in this field. [8].

Table 1. 5G statistics published research papers [8].

Year	Number of Publications	Trend Indicator
2020	**264**	**High Activity**
2021	**285**	**Growth**
2022	**297**	**Peak (Post-deployment research)**
2023	**263**	**Stabilization**
2024	**305**	**(Advanced Optimization)**

In this article, we provide an overview of emerging generations of modern communication networks and highlight the significance of 5G. II BACKGROUND Mobile Technology evolution is discussed in section II. The detailed description about the 5G network is given in Section III, which includes its design principles. Section IV presents an overview of the advanced physical layer methodologies for 5G, Section V elaborates on the key enablers and challenges. The transformative applications are presented in Section VI, while future work is outlined in Section VII, and the conclusion is drawn in Section VIII.

II. EVOLUTION FROM 1G TO 4G: A PATH TO 5G

The journey to 5G is marked by distinct generational shifts in technology. Understanding this evolution is crucial to appreciating the revolutionary nature of 5G.

A. First Generation (1G) to Third Generation (3G)

The analog systemthe 1G (designate in the '80) that phone had a technologies-based Voice Used Frequency Division Multiple Access(FDMA) and had a low capacity and securit [1], [8]. The 2G digital systems such as GSM provided with TDMA/FDMA and circuit switching, which can support only limited data applications like SMS[9]. The next developmental stage in was 2.5G (e.g.:GPRS) and 2.75G (e.g.: EDGE) which saw the introduction of packet switching although it was oriented to packet switched services, freeing the mobile device from being a resources of calls. The data rate increase that enabled full motion video: Up until this point even at 5-6 Layer-PDA rates with high error-correction coding (or low rates involving circus acts or media tycoons by themselves stopping point was not acceptable for movies; certainly no fast action movies like kungfu, etc.) is not understood how people watched shows on their....... you know what, "childhood wonder." By upgrading the amount you could access League Pass immediately! Season tickets available – please check your local cable provider too! [9], [10]. the 3G era, or IMT-2000 (International Mobile Telecommunication 2000), represented by UMTS was rather characterised by broader bandwidths (5 MHz) and CDMA allowing mobile internet access at peak rates of up to 2 Mbps [8], [11]. Enhancements like HSDPA (3.5G) and HSPA+ raised downlink rate up to several Mb/s [12].

B. Fourth Generation (4G) and LTE

The 4G standards, such as LTE, the extension of Wimax, and others greatly facilitated this evolution. They deployed an all-IP, packet-only core and adopted Orthogonal Frequency Division Multiple Access (OFDMA) for higher spectral efficiency and scalability [8], [13]. Furthermore, MIMO was part of the LTE Release 8 standards (also referred to as "3.9G") and could achieve peak downlink rates of 326 Mbps [14]. The real 4G IMT-Advanced requirements for LTE-Advanced (Release 10) and WiMAX Advanced (802.16m) only included peak downlink data rates greater than 1Gbps, increased spectrum efficiency and support for carrier aggregation [8], [15], [16The current 4G technologies have achieved unprecedented achievements, but it still being confronted with an issue of that how to adapt well on a tensile-connective and URLLC （Ultra-Reliable Low Latency Communication） or QoS （Quality-of-Services） diverse requirements. future scenarios [3], [17].

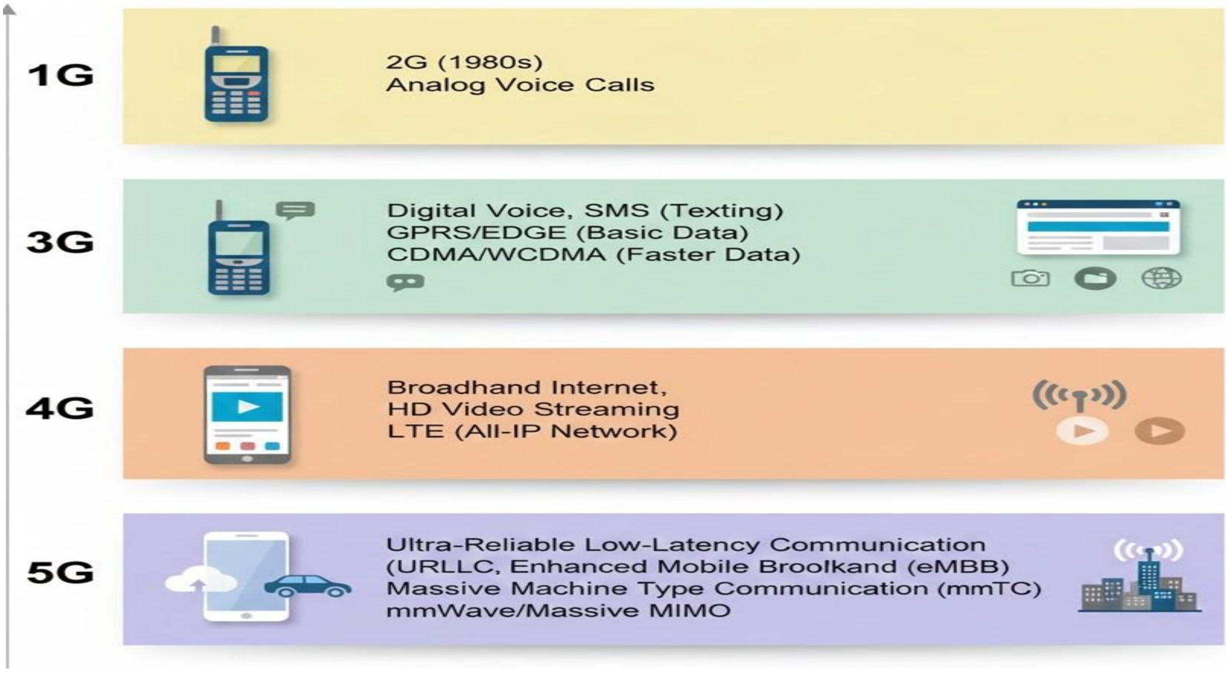

Figure 1. Network Evaluation [12],[17].

III. THE 5G NETWORK ARCHITECTURE: A RECONFIGURABLE FRAMEWORK

5G should not be considered just as a new radio interface, but networks are required to be rethought from the ground up for flexibility, efficiency and interoperability.

A. The All-IP Based Model and User Terminal

The 5G architecture proposed model is based on all-IP for interworking wireless and mobile networks [4], [18]. One of the pillars that holds this architecture is the user terminal, expected to be an absolutely reconfigurable multi-mode terminal able to act in an autonomous way upon any heterogeneous access network (e.g., 2G, 3G, 4G, WLANs and WMAN) [4], [19]. The RAT type of the terminal is dynamic with respect to user-defined policies, network status and services [1], [20].

B. The Policy Router and Virtual Network Layer

To interconnect this heterogeneity smoothly, a new architectural device: Policy Router is proposed [4]. This control system cooperates with the user terminal and provides network abstraction functionalities. It forms IP tunnels over the different RATs and acts as a virtual network layer. This layer provides client applications with a single, stable IP address, shielding the session from handovers between different technologies (vertical handover) [4]. To achieve this, the PR uses routing based on policies and sends the packets through an appropriate RAT at a specific time. [4], [21].

C. Reconfigurable Multi-Technology Core

The 5G core network is developed into a Reconfigurable Multi-Technology Core (RMTC), which merges cognitive radio, cloud computing and nanotechnology, that relies on All-IP Platform [4], [19]. This core is also a dynamically reconfigurable one, and it modifies the communication ranges according to different network conditions and system requests. Critical components, such as the RS-GW and RP-GW are reconfigurable entities empowered by a Reconfiguration Control and Management (RCM) engine accessing cloud resources [19]. This gives way to a software-defined reconfiguration of the network itself so it is possible for operators to efficiently roll out value added services and cope with shifting traffic patterns [4], [22].

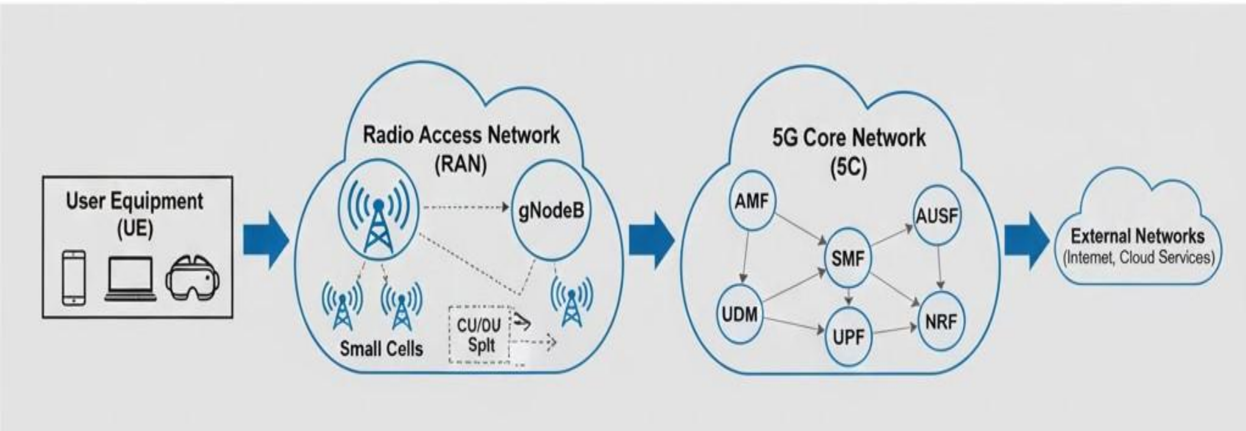

Figure 2. 5G NETWORK ARCHITECTURE

IV. ADVANCED PHYSICAL LAYER CONCEPTS FOR 5G

The physical (PHY) layer of 5G incorporates groundbreaking technologies to enhance spectral efficiency, support massive connectivity, and reduce latency.

A. Full-Duplex Communication

Typical previous wireless systems are based on either FDD or TDD. The full-duplex is a technology that enables the transceiver to transmit and receive simultaneously at the same frequency channel, potentially achieving double spectral efficiency [23], [24]. The biggest problem to be solved is the self-interference cancellation using both analog and digital cancellation method [25], [26]. Proof- of-concept implementations have shown its practicality and feasibility, and it constitutes a primary contender for 5G [27].

B. Filter Bank Multi-Carrier (FBMC)

While 4G uses Orthogonal Frequency Division Multiplexing (OFDM), it suffers from high out-of-band emission and strict synchronization requirements. Filter Bank Multi-Carrier (FBMC) is a strong alternative where subcarriers are shaped using a bank of well-designed filters [28], [29]. This results in a much lower out-of-band radiation, enabling better spectrum utilization, relaxed synchronization, and more efficient use of fragmented spectrum, which is crucial for dynamic spectrum access [30], [31].

C. Non-Orthogonal Multiple Access (NOMA) and Sparse Code Multiple Access (SCMA)

4G relies on orthogonal multiple access (OMA), which becomes inefficient with a massive number of devices. Non-Orthogonal Multiple Access (NOMA) schemes, particularly power-domain NOMA, allow multiple users to share the same time-frequency resource by superimposing their signals with different power levels [32], [33]. At the receiver, Successive Interference Cancellation (SIC) is used to decode the signals. NOMA can enhance system capacity and improve fairness, especially for users at the cell edge [34].

Sparse Code Multiple Access (SCMA) is a code-domain NOMA technique that directly maps data bits to multi-dimensional codewords from a predefined sparse codebook [35], [36]. The sparsity of the codebooks allows for low-complexity multi-user detection at the receiver using message passing algorithms (MPA) [37]. SCMA provides a performance gain over conventional OMA and other NOMA schemes by offering shaping gain and supporting massive connectivity with low latency [38], [39].

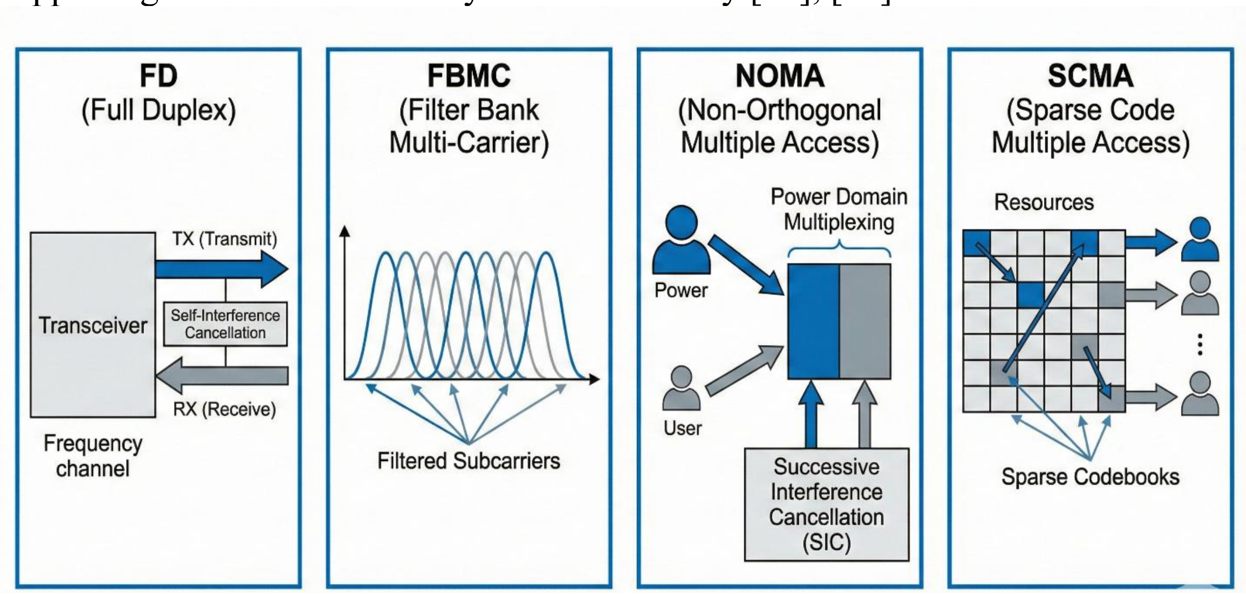

Figure 3. ADVANCED PHYSICAL LAYER

V. ENABLING TECHNOLOGIES AND DEVELOPMENT CHALLENGES

The realization of the 5G vision hinges on several enabling technologies and overcoming associated challenges.

A. Cognitive Radio (CR) and Software Defined Radio (SDR)

Cognitive Radio is the smart brain which provides dynamic spectrum access. A CR is capable of sensing the environment where it operates, and adjusting its transmission parameters according to that obtained from the spectrum holes or white spaces [4], [40]. HW flexibility is supported by the Software-Defined Radio (SDR) that can be understood as an underlying HW platform able to execute communication functionalities implemented in SW over programmable processors (DSPs, FPGAs) [4], [41]. SDR allows terminal and network reconfigurability through software downloads [19], [42].

B. Nanotechnology and Cloud Computing

Both devices and core network will be very affected by nanotechnology. It facilitates extremely efficient, small and low-power mobile devices able to act as smart sensors [19], [43]. In the core network, nanotechnology also advances Digital Signal Processing (DSP) manufacturing process for improved system rate and capacity [19]. Cloud Computing is coupled with the 5G core and users can access shared pool of configurable computing resources (e.g., storage, processing) on-demand [44]. This makes service placement very flexible and supports concepts like mobile edge computing (MEC) to decrease latency. [4], [45].

C. Key Challenges

The introduction of new 5G technology presents a number of challenges [4], [19]:

1. Spectrum Scarsity and CR Reality The aggressive utilization of spectrum by cognitive radio depends on researching how to apply it in actual use and its coexistence.
2. Energy efficiency: The energy consumption minimization is of great significance on battery- powered terminals as well as operational costs of network infrastructure.
3. M2-MAC will also be challenged to provide communication between the machines because a large number of low cost/low power M2 devices is expected in the MTC,which is difficult under network attachment and control signaling.
4. Security 5G is all IP based, open system and poses new challenges that need to overcome.
5. Interworking : Integration of Heterogeneous Technology Vertical handover between heterogeneous technologies has to be transparent so that a mobile terminal can switch to any technology with minimum service disruption in the network. [19], [46].

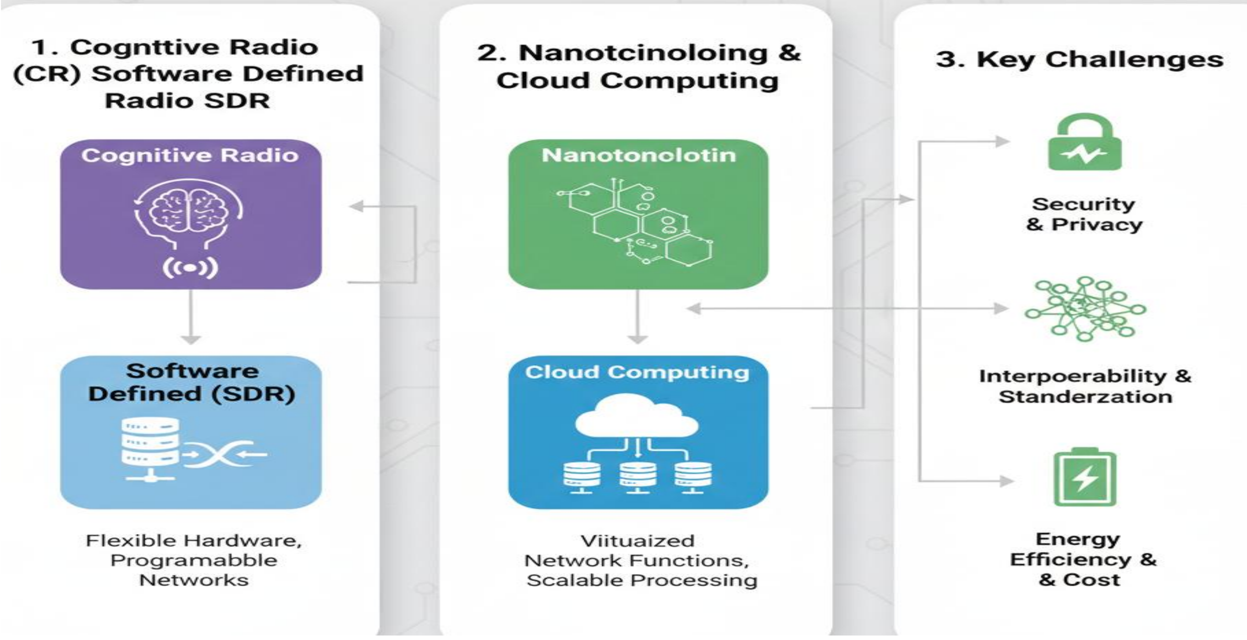

Figure 4. Networks Technologies keys [19],[46].

VI. APPLICATIONS OF 5G TECHNOLOGY

New forms of services and solutions The development of 5G will enable a series of new applications, which in turn will shape the future communication landscape:

Real World Wireless: All connected, all over the place and no access/ zoning worries [1]. II. IOT AND M2M COMMUNICATION Aggregation of various sensors and intelligent devices effectively [3], [19]. Tactile Internet/URRLC: It enables real-time control for applications such as remote surgery; autonomous driving and industrial automation [7], [47].

Enhanced Mobile Broad-band (eMBB): eMBB provides data rates beyond multi-gigabit to enable very immersive service classes such as 4K/8Kvideo streamingand virtual augmentation [2], [48].

AGI of Wearable devices In the proximity of Smart appliances and DBMS- environment like way sensors are widely spreaded [1], [4].

Context-Aware Computing: Smart traffic, grid and safety management [49].

VII. FUTURE DIRECTIONS: BEYOND 5G

Although 5G deployments are currently happening globally, research works in academia and industry are getting directed towards the next technological horizon known as beyond-5G or 6G [1], [7]. The early treatises on the harbingers aim at what technology can do beyond a 5G heralding based on its building blocks [1]. Key future directions include:

Rule of 6G and THz Communication: ‘The term, “6G “have been saved in web search [1], Online academe community It definitely refers to a new travel at all……. Next generation systems are expected to work at THz frequency band (0.1-10 THz) and can support Tb/s orders of connectivity, making possible hyper-connectivity / sub-ms delay applications [3], [50]. This would pave the way for such emerging applications as full-duplex high-fidelity holographic communication and integrated sensing-communication.

Deep AI Integration: Behind the scenes, 5G (as the AI-enabled network control plane) Next generation network will be programmed by deep learning-based skinning of their bones- to support cognitive and self-sustainable networks. [4], [19]. That involves using artificial intelligence for real-time network tuning, predictive resource allocation and to automatically spot and protect against security attacks.

Sustainability and Energy Neutral Networks: It will be one of the core objectives for future generations to attain energy neutrality, i.e. networks run on very large scales on renewable power (green), with only a minimum use of conventional resources (brown). This requires to design the appliances and the network with ultra-low-power features, eventually powered by an energy harvesting source in their ambient environment in order to reduce the environmental impact of the digital world [19].

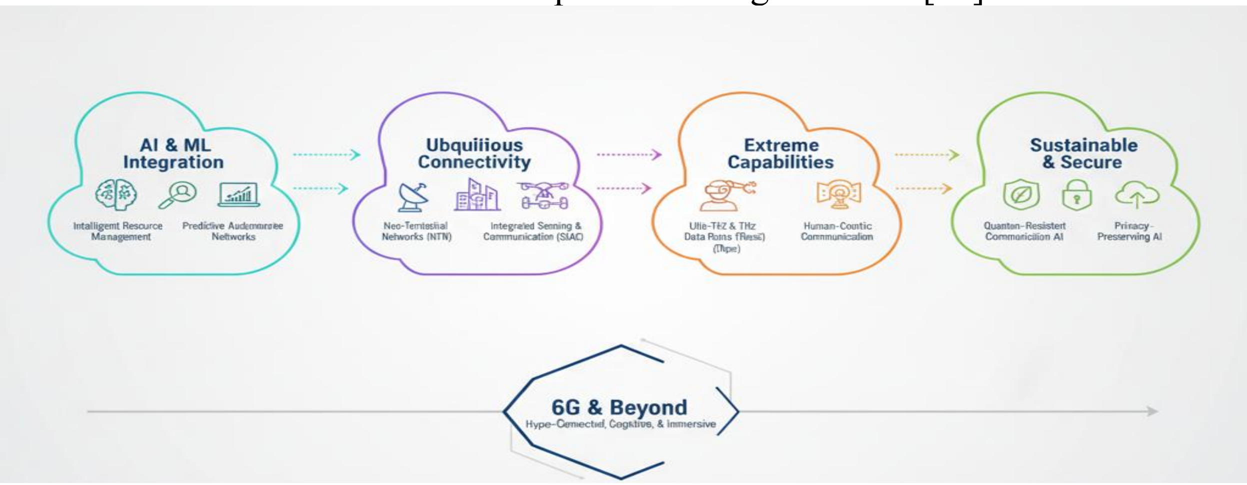

Figure 5. Future Direction [19].

VIII. CONCLUSION

The 5G era: reconfigurable intelligent surfaces may shape future networks The leap to fifth-generation (5G) mobile technology will be a transformation felt across the term "“a network designed for mobile broadband". With the supports from emerging architectural paradigms, such as RMT-core and PBR, and break-through physical layer technologies like FDD,FBMC,NOMA and SCMA etc., it is envisioned that 5G can meet the unmet demands for unprecedented data rate, number of connections with devices to be reached at massive scale simultaneously diversifying existing services in ultra low latency requirement. Triggered by catalysts such as cognitive radio, SDR, nano-technology & cloud computing to name a few enablers (not an exhaustive list), 5G is not just another communication service; it will become an infrastructure to steer innova tion in so many industries. While there are many open issues to be resolved, the joint international effort now in progress within the worldwide research community and by standard organizations gives real hopes that what we could offer in or after 2020 will at least open a new scope of life and life styles due to an inter- connected world without limits. The ongoing study of 6G concepts ensures that the development of wireless communications technology in the coming decades will continue to drive social transformation.

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