A Survey on 5G/6G Radio Access Networks: Technologies, Protocols, and Performance Metrics

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Abstract

There will be revolutionary improvements to data throughput, latency, dependability and device connectivity with 6G next generation of mobile networks, which will replace 5G. Utilizing millimeter-wave (mmWave) frequencies, network slicing, software-defined networking (SDN/NFV), and massively multiple-input multiple-output (MIMO) 5G networks deliver low-latency, dependable, and peak data rates of up to 10 Gbps. The creation of 6G networks, however, is required by new uses, including holographic communication, tactile internet, and autonomous systems powered by artificial intelligence. By combining terrestrial, satellite, and underwater networks, 6G aspires to achieve microsecond-level latency, the lowest possible latency, accomplish peak data speeds of 1 Tbps, and provide ubiquitous global coverage. Enabling technologies such as terahertz communications, beamforming, reconfigurable intelligent surfaces, full-duplex transmission, Open/Cloud RAN, and edge computing are central to meeting these ambitious targets. Furthermore, AI-driven protocols, predictive resource management, and sustainable network practices will enhance Quality of Experience (QoE), Quality of Service (QoS), and Quality of Life (QoL) while maintaining cost efficiency, scalability, and energy optimization. This review presents a comprehensive examination of the fundamentals, protocols, architectures, next-generation wireless systems, paving the way with enabling technologies and performance measures of 5G and 6G RAN.

Keywords: *5G, 6G, RAN, New Radio, Massive MIMO, Network Slicing, Edge Computing, Ultra-Low Latency, Open RAN, Cloud RAN.*

I. Introduction

The exponential growth of mobile traffic can be attributed to the fast development of new applications like virtual reality (VR), 3D media, artificial intelligence (AI), and Internet of Everything (IoE) [1]. This increase highlights the paramount importance of dependable, low-latency communication networks with high data rates. Autonomous technologies are proliferating in many modern societal domains, including logistics, healthcare, transportation, the oceans, and space, all of which are trending towards completely automated and remotely managed systems [2]. With the proliferation of millions of sensors, smart environments and automated services are becoming a reality in their cities, cars, homes, and businesses [3]. Although 5G networks have been put into operation in a number of areas, the need for sixth-generation (6G) networks to meet requirements of new applications like holographic communications, tactile internet, autonomous vehicles, and ubiquitous sensing has prompted their development.

The evolution of mobile networks has significantly transformed human interaction, information access, and business operations. Early generations (1G and 2G) primarily supported voice communication, while 3G and 4G introduced mobile internet and high-speed data services. Today, 5G networks deliver ultra-high data rates, enhanced reliability , ultra-low latency, massive device connectivity, and supporting emerging applications such as IoT and immersive media [4]. RAN technologies have progressed from GSM and UMTS to LTE and 5G New Radio, incorporating innovations like software-defined networking (SDN), beamforming, millimeter-wave communications, and massive MIMO. These technologies link end-users to the core network.

Now that 5G connection technology has advanced, the Internet of Things can be used in more places than ever before. Main research on a 6G access network has started at the same time as 5G technology is being employed; this network will operate at frequencies ranging from 3 THz (sub-millimeter waves) to above 100 GHz [5]. For example, close to a thousand publications have been recorded documenting a succession of investigations and recommendations pertaining to 6G communications.

This survey provides a complete overview of 5G RAN technologies, emerging 6G concepts, enabling protocols, and performance evaluation metrics. It examines architectural evolution, key enabling technologies, and network performance measures, including throughput, latency, reliability, energy efficiency, and sustainability. By offering a structured perspective, this work guides researchers, practitioners, and policymakers in understanding and advancing next-generation mobile communication networks.

A. Organisation of the Paper

The study is organized in Section I introduces 5G and 6G networks, including their objectives and scope. Section II covers the fundamentals of 5G/6G RAN, while Section III presents key enabling technologies in 5G/6G. Section IV discusses protocols of RAN. Section V examines performance metrics. Section VI reviews recent literature, and Section VII concludes with important results and areas for further study.

II. FUNDAMENTALS OF 5G AND 6G RAN

The standardization, hardware deployment, and initial testing phases of 5th-generation (5G) mobile communication network are almost complete, and the network is becoming ready for commercial deployment. Data rate, latency, network dependability, energy economy, and enormous device connectivity are some of 5G's key goals. 5G leverages the new microwave spectrum (3.3–4.2 GHz) and, for the first time, utilizes the millimeter-wave (mmWave) band, enabling significantly higher data rates of up to 10 Gbps [6]. As 5G moves into commercial operation, global research efforts have begun focusing on the sixth-generation (6G) network, anticipated for deployment around 2030. Green 6G is an initiative with the aim of greatly improving data transmission, with peak data rates of 1 Tbps and ultra-low latency in the microsecond range. Utilizing spatial multiplexing and terahertz (THz) frequency communications, it provides capacities that are up to a thousand times greater than 5G. By combining land-based, satellite, and underwater communication networks, 6G aims to accomplish ubiquitous connection and guarantee coverage all over the world.

A. 5G RAN Architecture (gNodeB, C-RAN, O-RAN)

The 3GPP standard describes the 5G radio architecture, which is as illustrated in Figure 1 up top. The development of 5G New Radio is aimed at assisting various administrations, deployments, and gadgets. The 5G Core network's AMF/UPF is accessible through the NG interface by 5G devices, and the g-NodeB terminates the User Plane and Control Plane radio signals for the User Equipment [7]. The capabilities of AMF are integrated into Mobility Management Equipment and include features like access control and portability, connection and reachability management, and access authentication and authorization. 5G NR UPF manages quality of service, inspects packets, and routes and sends them.

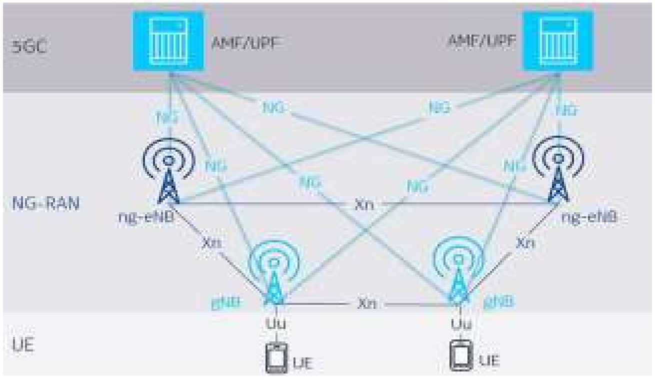

Fig. 1. 5G NR Architecture

Through its NG interface, the ng-eNodeB communicates with the 5G Core Network and sends LTE UP and CP termination signals to the User Equipment. Xn, Ng, E1, and F1 are only a few of the interfaces included in the new 5G radio architecture. The 5G Core Network is contacted by 5G-RAN when 5G devices establish a radio interface with 5G-RAN. The PDU Session service, which transports user data, is implemented using user plane protocols. On the basis of factors such as managing various transmission resources, handovers, etc., CP protocols regulate PDU Sessions, connections among User Equipments, and the network. The components of a g-NodeB are g-NodeB-CU. The architecture and logical interfaces of 5G RANs are both very adaptable and scalable. Technologies like as network function virtualization (NFV), software-defined networking (SDN), network slicing, and cloud computing underpin 5G radio design.

B. 6G Vision and Next-Generation RAN

An significant question emerges in light of the anticipated expansion of 5G wireless networks and its enormous capabilities: Is there a concrete justification for 6G networks? The answer lies in identifying the limitations of LTE and 5G that remain unresolved, such as spectrum scarcity, ultra-low latency beyond current limits, ubiquitous coverage, and seamless human–machine interaction and envisioning how 6G can overcome them. Academics, businesses, and government agencies have therefore been working tirelessly to define "beyond 5G" or 6G, establish design principles, and develop enabling technologies [8]. This section reviews the vision, expected applications, and defining features of 6G RAN, as identified in recently published works. The applications serve as a foundation for determining the architectural, protocol, as depicted in Figure 2 for 6G, and the performance standards for subsequent generations of systems:

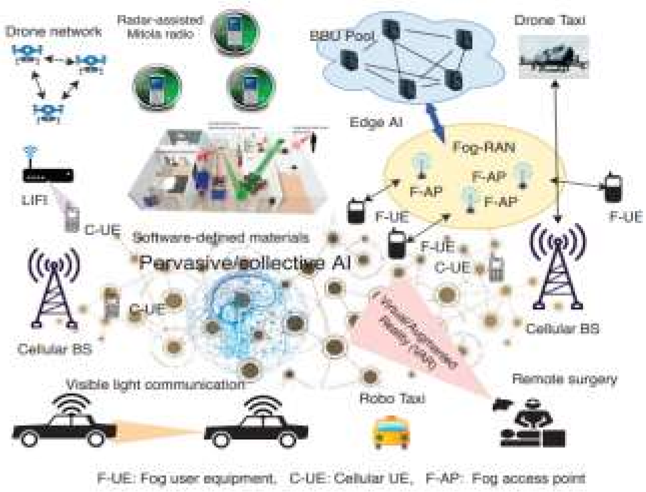

Fig. 2. The vision of 6G

1) Expected Scenarios of 6G Applications

Several futuristic applications are projected to define the capabilities of 6G RAN. These scenarios go beyond the traditional eMBB, URLLC, and mMTC use cases of 5G and represent enhanced or entirely new paradigms.

2) Enhanced Mobile Broadband Plus (eMBB-Plus)

In contrast to 5G's eMBB, eMBB-Plus aims to deliver significantly improved Quality of Experience (QoE) by integrating big data-driven optimization for handover, interference management, and network utilization. It also targets indoor positioning accuracy, seamless global connectivity, and affordability. Importantly, eMBB-Plus services must ensure security, privacy, and secrecy without compromising performance.

3) Big Communications (BigCom)

The concept of BigCom emphasizes global coverage including dense urban, rural, and remote regions supported by extremely large bandwidths (e.g., terahertz spectrum) and AI-driven optimization. BigCom envisions truly ubiquitous connectivity with high throughput regardless of geography, ensuring communication "anywhere, anytime."

4) Secure Ultra-Reliable Low-Latency

Communications (SURLLC) 6G will extend the URLLC and mMTC features of 5G into SURLLC, characterized by latency below 0.1 ms and reliability exceeding 99.9999999%. SURLLC integrates a security-first framework, making it essential for vehicular networks, mission-critical services, and cyber-physical systems where failures are unacceptable.

5) Three-Dimensional Integrated Communications (3D-InteCom).

Unlike 5G, which primarily supports 2D terrestrial communications, 3D-InteCom incorporates satellite, UAV, and underwater communications into a unified framework. By considering device altitude and enabling elevation beamforming with full-dimensional MIMO, 6G aims to achieve seamless 3D coverage. This requires revisiting analytical frameworks originally designed for 2D environments.

6) Unconventional Data Communications (UCDC)

UCDC is an umbrella category that covers emerging paradigms such as holographic, tactile, and human-bond communications, which demand unprecedented network capabilities:

- Holographic Communications: Support the real-time transmission of 3D holograms with synchronized stereo audio, requiring ultra-high bandwidth and reliable connections.
- Tactile Communications: Empower teleoperation, cooperative driving, and real-time haptic interactions for communication and interpersonal purposes. Such systems may necessitate over-the-air fibre communication networks, innovative physical-layer (PHY) techniques, and cross-layer system design.
- Human-Bond Communications: A human-centric paradigm where all five senses are digitally transmitted. Applications include disease diagnosis, emotion detection, and remote bio-interaction. These applications demand interdisciplinary research in communication, biology, and computing.

C. Key Differences Between 5G and 6G RAN

Higher data rates, huge connection, ultra-low latency, and intelligence driven by AI are driving the progression from 5G to 6G RAN. While 5G focuses on eMBB, mMTC, and URLLC, 6G aims to support extreme mobile broadband, holographic communications, tactile internet, and fully autonomous systems. 6G networks will leverage AI for adaptive resource management, predictive handovers, and self-optimizing protocols, enabling higher reliability, spectral efficiency, and energy efficiency compared to 5G. Table I summarizes the key differences between 5G and 6G RAN.

TABLE I. COMPARISON BETWEEN 5G AND 6G RAN

Aspect	**5G**	**6G**
Year	2020	2030
Peak data rate (per device)	10 Gbps	1 Tbps
Maximum frequency	300 GHz	10 THz
Downlink data rate	20 Gbps	1 Tbps
Uplink data rate	10 Gbps	1 Tbps
Latency	1 ms	100 µs
Jitter	–	1 µs
Mobility	500 km/h	1000 km/h
Maximum bandwidth	1 GHz	100 GHz
Device density	10^6 devices/km²	10^7 devices/km²
Area traffic capacity	10 Mb/s/m²	1 Gb/s/m²
Peak spectral efficiency	30 b/s/Hz	100 b/s/Hz
Reliability	>99.999%	>99.9999%

III. ENABLING TECHNOLOGIES FOR 5G/6G RAN

The success of 5G and the evolution toward 6G largely depend on a set of empowering technologies which enhance spectrum utilization, antenna design, network architecture, and edge–cloud integration. Achieving the lofty performance goals of extremely low latency, great dependability, and massive data rates is impossible without these technologies. Integrating a slew of new, revolutionary technologies into 6G is essential for enabling and guaranteeing the performance of the aforementioned services.

A. *Spectrum and Frequency Bands*

Consequently, mmWave bands are seen as potential solutions to the problems of spectrum availability and utilisation. Due to the limited availability of radio spectrum, mmWave bands provide an ample solution. The line-of-sight (LOS) components predominate in the propagating signals due to the quasi-optical propagation properties of mmWave systems. One of the most noticeable features of these systems is this. It is possible to achieve a high data rate of 1-100 Gbps in a pure LOS mmWave channel. In addition, service providers can enhance data rates by using the mmWave spectrum to increase channel bandwidth beyond the 20 MHz used in 4G networks [9].

The manufacturing of multiple micro antennas in regions as small as 1 or 2 cm2 can achieve extraordinarily high gain, thanks to improvements in low-power complementary metal-oxide-semiconductor (CMOS) radio-frequency circuits and incredibly short wavelengths. In order to provide path variety in the case that human obstacles are obstructed, these antennas can be either integrated into the base station (BS) or embedded into the skin of a mobile device. Please be aware that although the mmWave spectrum is officially designated as the underutilized frequency range of 30 GHz to 300 GHz, any frequency beyond 10 GHz can be broadly referred to as mmWave. In addition, the mmWave spectrum allocations are somewhat closer than the ones below 3 GHz. As a result, the propagation properties of various mmWave bands are comparable, in contrast to bands below 3 GHz where the cell coverage varies significantly due to poor spectral allocations.

B. *Antenna and Transmission Techniques*

5G and 6G RAN are centered around advanced concepts such as massive MIMO, beamforming, reconfigurable intelligent surfaces (RIS), and full-duplex communication, which collectively enhance spectrum utilization, coverage, and security. Massive MIMO employs large antenna arrays at base stations to serve multiple users simultaneously while leveraging beamforming for precise signal direction, thereby improving spectrum efficiency, minimizing interference, and boosting energy efficiency [10], the integration of massive MIMO introduces new security challenges, including vulnerabilities to eavesdropping and active attacks, which have been addressed through secrecy rate analysis, eavesdropper detection, and hierarchical security models using NOMA, RIS technology enables smart reconfiguration of the wireless environment by reflecting and refracting signals through programmable meta-surfaces [11]. At the same time, full-duplex communication allows for both sending and receiving data on the same frequency range, which significantly reduces latency and doubles the efficiency of the spectrum [12]. Together, these antenna and transmission innovations form the backbone of high-capacity, secure, and energy-efficient 5G/6G RANs, paving the way for scalable and intelligent next-generation wireless systems.

C. *Network Architectures*

Network Architectures in 5G and beyond have evolved toward openness, flexibility, and efficiency through concepts such as Open RAN (O-RAN), Cell-Free Massive MIMO (see in Figure 3) (CFmMM), and Cloud-RAN (C-RAN). O-RAN introduces a modular and configurable approach that contrasts with traditional proprietary and monolithic RAN solutions, which often lead to vendor lock-in (as shown in Figure 3), limited interoperability, and increased costs for service providers. By enabling openness and interoperability across different vendors, O-RAN enhances flexibility in addressing diverse requirements across geographical regions and customer applications. Similarly, C-RAN has emerged as a next-generation strong candidate architectures by centralizing baseband units (BBUs) into a virtualized pool shared across base stations, thereby improving resource utilization, scalability, and cost efficiency compared to traditional RAN deployments [13].

In parallel, the concept of CFmMM eliminates the limitations of cell-based wireless topologies, where devices at the cell edge often suffer from weak signals. Instead of being connected to a single base station, devices in CFmMM are coherently served by multiple distributed base stations, ensuring more uniform coverage, enhanced spectral efficiency, and improved reliability across the entire service area. Together, these architectural innovations aim to deliver highly flexible, scalable, and performance-optimized RANs for 5G and future 6G networks.

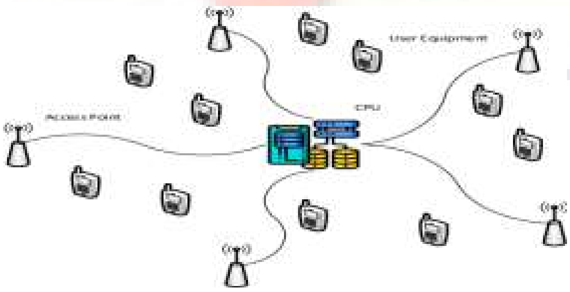

Fig. 3. Cell-free massive MIMO

D. *Edge and Cloud Integration*

Future networks are expected to be able to manage a connection density of one million devices per square kilometer. The proliferation of such a massive number of devices introduces numerous endpoints, making it challenging to process enormous volumes of data while maintaining a round-trip time of less than 1 ms. The 6G network must have improved dependability, ultra-low latency, and very high data speeds to support new applications like haptic internet services [14]. To support these requirements, Edge Computing (EC) is utilized to reduce computational complexity by processing the majority of data at network edge instead of sending it to distant cloud servers. This approach offers a local source for data storage and processing, thereby minimizing access time and significantly reducing latency. Edge computing provides several key advantages with respect to:

- Making the network more computationally powerful. Speeds up computation for real-time applications that deal with complicated jobs.
- Decreases the time it takes to access data and reduces latency.
- Decreases the amount of bandwidth that is required.
- Improve the efficiency of the data processing for computer layers that are higher. Functions as a supplement to fog computing.

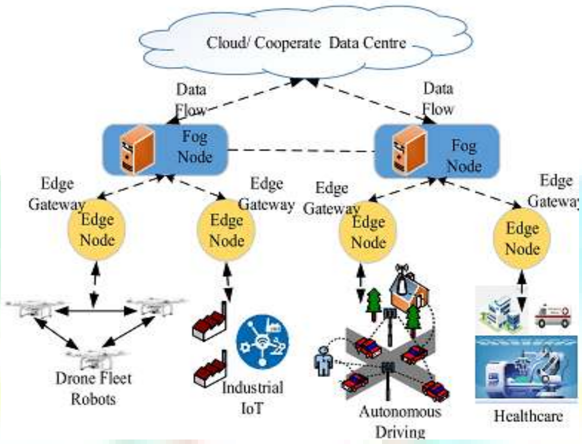

Fig. 4. Edge computing with different applications

As shown in Figure 4, the approach of edge computing makes possible a plethora of next-generation applications. The network contains a multitude of Edge nodes. Through the edge gateways found in every node, the local edge processor is linked to the centralized network/Cloud, and the edge devices are linked to the local edge processor. Sensors, cellphones, actuators, smart devices, cameras, haptic devices, and other Internet of Things (IoT) components make up edge devices. Reduced bandwidth utilisation and improved performance are the results of local edge processing, which is done close to the network. Only data that is absolutely required is buffered and sent to cloud network for processing. In real-time applications, this data is sent back to edge device.

IV. PROTOCOLS IN 5G/6G RAN.

6G protocols need to be flexible, in contrast to the traditional 5G protocols that depend on set frame structures and strict parameters, learning from real-time and predicted wireless conditions. This includes dynamic multiple access protocols that adjust based on application and network demands, as well as advanced handover mechanisms that support the 3D nature of 6G with heterogeneous devices. To achieve this, all 6G protocols must be inherently distributed, capable of leveraging datasets across the edge to ensure intelligent, seamless, and secure operations.

A. PHY and MAC Layer Enhancements.

The physical (PHY) layer forms the foundation of communication by generating and interpreting electrical signals and must be standardized to ensure consistent user experience. In 5G, the PHY layer incorporates advanced technologies to deliver lower latency, higher data rates, and support for massive device connectivity, providing a superior experience compared to previous generations. Security is a key consideration at this layer, with techniques such as Physical Layer Security (PLS) utilizing specialized channel coding and the inherent randomness of wireless channels to protect information confidentiality. The MAC (Medium Access Control) layer complements the PHY layer by managing access to the shared wireless medium, scheduling transmissions, and coordinating resource allocation among multiple users. Enhancements in the MAC layer for 5G include dynamic scheduling, flexible frame structures, and QoS-aware mechanisms that optimize throughput, minimize delays and boost dependability for a wide range of uses, and very reliable low-latency connections, as well as enhanced mobile broadband.

B. *Resource Management Protocols*

Intelligent, context-aware protocols are the main emphasis of 5G/6G RAN resource management, which aims to optimize both network performance and user experience [15]. A social-aware load balancing system uses fuzzy logic and social event data to distribute traffic across cells during crowded events, improving load sharing while maintaining acceptable SINR levels in 5G networks [16]. To improve average user capacity and handover performance, context-aware handover policies (CAHP) for HetNets optimize handover decisions based on UE speed, transmit power, route loss, and cell load. A Markov Chain model is employed to estimate the appropriate Time-to-Trigger (TTT) [17], An MIH-based QoS-aware predictive method for managing radio resources incorporates scheduling, user categorization, and vertical handover decisions [18], predicting handovers and managing interference to ensure efficient bandwidth usage and improved QoS across heterogeneous networks.

C. *Security and Privacy Protocols*

Data transmissions via networks rely on these protocols as cornerstones to keep sensitive information private and secure. To begin with, encryption algorithms ensure data secrecy by encoding it in a way that no one other than authorized parties may decode it [19]. This safeguards all types of sensitive information from private conversations to financial dealings and secret company records, making sure they are not accessible to unauthorized parties. In addition, encryption measures are vital for ensuring that transferred data remains intact. Cryptographic techniques are used by encryption protocols to ensure that data packets remain intact during transmission. This prevents any tampering or alteration that could compromise the trustworthiness and reliability of the transferred information. In addition, data interception, packet sniffing, and man-in-the-middle assaults are just a few of the cyber dangers that encryption effectively protects against. To improve 5G network security, encryption technologies make intercepted data unintelligible to outside parties, making successful intrusions much more difficult.

D. *Network Slicing*

5G must include a system to manage and monitor various user demands in order to keep the network fair and provide quality of service, since it can manage a wide range of use cases. "Network slicing" describes this approach. A network slice is a self-contained virtual network that follows a predetermined quality of service standard and separates resources, data flows, security measures, and the overall network architecture. The following is a brief overview of network slicing, one of its core concepts, and how it works to separate and distribute resources to different users:

- Performance: Each slice is tailored to fulfil particular service specifications. There should be safeguards to make sure that needs are satisfied as best as possible regardless of the state of the network, so that one slice's performance is not negatively impacted by other concerns.
- Security and Privacy: If an assault or fault affects one slice, it must not affect any other slices. As a result, each slice needs to have its own security features that prevent unauthorized people from reading or writing to the configuration, management, or accounting data.
- Management: To achieve isolation, it is necessary to create uniform policies and methods at the virtualization layer. Each slice is considered as a different network. The policies outline the necessary separation of manageable entities, while the system's mechanisms carry out the protocols and enforce the regulations.

V. PERFORMANCE METRICS IN 5G/6G RAN.

Evaluating the performance of 5G and 6G RAN requires a comprehensive set of metrics that capture network efficiency, user experience, and sustainability considerations. These metrics not only provide insights into the operational effectiveness of the network but also guide the design and optimization of emerging RAN architectures and protocols.

A. Network-Level Metrics.

Network-level metrics form the backbone of performance evaluation in 5G and emerging 6G RANs, with latency, reliability, energy efficiency, and spectral efficiency being the most critical. Autonomous driving and telemedicine are two examples of mission-critical applications that must have minimal latency; yet, considerable delays still occur due to signaling overheads in the air interface [20], studies have proposed access control policies in H-CRAN that reduce backhaul latency and delay-aware techniques leveraging preemptive networking with Coordinated Multi-Point Reliability, defined by outage probability and packet delivery success, has been enhanced through KPI-driven monitoring in O-RAN, where AI-assisted predictive analytics enable early anomaly detection and more stable operations [21].

Energy efficiency has been improved through architectural shifts from C-RAN to F-RAN, which reduces fronthaul bottlenecks and optimizes energy use by bringing computation closer to the edge [22], where user equipment (UE) connects to nearby groups of remote radio heads (RRHs). Spectral efficiency, another core metric, benefits from such clustering approaches, with disjoint clustering reducing inter-cell interference and user-centric clustering dynamically adapting based on received power thresholds to optimize individual user performance.

B. User-Centric Metrics.

User-Centric Metrics in 6G communication encompass Quality of Experience (QoE), Quality of Service (QoS), and Quality of Life (QoL), all of which are increasingly AI-driven and mobility support is included:

- **Quality of Service (QoS):** The entire performance of 6G communication technology is measured by quality of service in a specified network area. 6G communication relies on AI to drive quality of service (QoS) [23]. Artificial intelligence allows 6G connectivity to provide a high level of service. high-mobility communications,
- **The Quality of Experiences (QoE):** QoE extends beyond QoS by focusing on user satisfaction and client-centric interactions through AI-assisted services. Immersive applications such as holographic communication, AR, VR, and the tactile internet will improve 6G's quality of experience [24]. These services require incredibly fast data transfer speeds with almost no latency at all.
- **Quality of Lives (QOL):** QoL improvements in 6G stem from the combined impact of QoS and QoE. By enabling innovations such as holographic communication, AR, VR, and the tactile web, 6G will significantly influence everyday lifestyles, societal interactions, and business operations [25]. Achieving high QoL requires AI-driven 6G technologies, as artificial intelligence is indispensable for maintaining the seamless delivery of services with high performance, reliability, and user satisfaction.
- **Mobility:** With 6G communication technology, AI is essential for delivering high quality of service, quality of experience, and quality of life. This is especially true when it comes to the network's capacity to keep users connected even when they're on the go [26], and this is essential for uses like vehicle communication and high-speed rail.

C. Sustainability Metrics

Energy Consumption, Green Networking, Cost Efficiency, and Scalability are central considerations in evaluating the sustainability of modern ICT infrastructures. Data centres' (DCs') and communication network devices' energy consumption is just a fraction of the total energy consumption of ICT, with user-related devices accounting for the other significant share [27]. Importantly, the consumption patterns of user devices present distinct challenges and therefore require tailored strategies for energy reduction, differing from those applied to network and DC equipment [28]. The projected increase in energy demand is unsustainable, making it essential to design approaches that specifically address the unique characteristics of user-side devices.

The volatility and time-varying nature of global energy markets, prices may fluctuate sharply and can even become negative during periods of surplus production when demand is low. Since energy storage remains inefficient and production forecasts, although relatively accurate, cannot fully eliminate the risk of overproduction, these market dynamics can be strategically leveraged [29]. By relocating computational workloads to regions where energy is cheaper, operational expenditures can be significantly reduced. Companies such as Amazon already exploit this strategy, demonstrating how service delocalization can mitigate energy costs while supporting sustainability goals. In 5G/6G RAN, cost efficiency stems from energy-aware resource utilization and virtualization, while scalability enables green networking in the face of massive connectivity and data growth.

VI. Literature of Review

This review highlights key trends, findings, and enabling technologies from existing studies on 5G and 6G networks, providing insights that inform future research directions and practical implementations.

Dogra, Jha and Jain (2020) present a high-level summary of 5G NR's new capabilities and KPIs. In this study, the problems of synchronizing inter-RAT handovers and adapting higher-level modulation methods are thoroughly discussed. To address these problems, a suggested architecture for next-generation wireless communication is presented. This design provides the groundwork for upgrading to networks that go beyond 5G/6G. Along with this, the article also reviews a number of 6G network technologies and their potential uses. Optical wireless communication, haptic services, edge computing, quantum computing, artificial intelligence (AI) based services, and hybrid access would all be a part of the 6G network. A 6G architecture based on virtualized network slicing is suggested to make these various services possible [14].

Huang et al. (2019) provide an in-depth analysis of the development of wireless networks leading up to 6G networks. With the advent of ubiquitous AI, an improved network protocol stack, and ubiquitous 3D coverage, 6G networks are the major topic of this survey's new architectural modifications. This study aspires to shed light on future research on green 6G by discussing relevant potential technologies that aid in the formation of socially seamless and sustainable networks. These technologies include blockchain, symbiotic radio, a new communication paradigm, and terahertz and visible light communication [30].

Saad, Bennis and Chen (2019) present a comprehensive, future-oriented plan outlining the foundations of a 6G network. 6G, in their view, will represent more than just the expansion of high-frequency band spectrum; it will be the meeting point of new technical trends propelled by intriguing underlying services. Here, they begin by cataloguing the main uses and related technological developments that are propelling the adoption of 6G systems. Afterwards, they reveal the intended 6G performance specifications for a new set of service classes that they have proposed. After that, they lay out a thorough research plan that takes advantage of the technologies that will allow the introduced 6G services to function. Finally, they offer specific suggestions for the 6G road map. The ultimate goal of this piece is to lay the groundwork for more creative 6G research [31].

Parvez et al. (2018) give a comprehensive overview of the new technologies that are coming out to accomplish low-latency communications, taking into account three distinct areas of solution: 1) radio access networks (RANs), 2) core networks, and 3) caching. In addition, they provide a high-level summary of the key components of 5G cellular networks, such as SDNs, Mobile edge computing, caching, and NFDs that can manage latency and other 5G requirements. The major objectives of the 5th-generation (5G) wireless network standard are to increase connection density, decrease latency, and improve capacity, dependability, and energy efficiency; by 2020, these aims should have been accomplished. With the help of appropriate robotics and haptics hardware at the network's periphery, 5G will be able to send real-time communication of a touch perception type [32].

Ankarali, Pekoz and Arslan (2017) discuss the possible ways to get more leeway in RATs after 5G, as with the next 5G and 6G releases. Here, they offer a framework and some sample methods for creating strategies for flexible waveforms, numerology, and frame design. In addition, they go over their possible function in dealing with a wide range of system-level problems, such as those in cellular networks, non-orthogonal and orthogonal multiple-access schemes, and more. Their goal is to help shape the future of flexible RAT design while also highlighting any gaps in related research [33]

Table II summarizes recent studies on SDN, highlighting approaches, key findings, challenges, and future directions for 5G/6G Radio Access Networks.

TABLE II. LITERATURE SUMMARY ON 5G/6G RADIO ACCESS NETWORKS

Reference	Study On	Approaches	Findings/Insights	Objectives	Challenges
Dogra, Jha & Jain (2020)	Features and KPIs of 5G NR; transition towards B5G/6G	Overview of modulation schemes, inter-RAT handover, virtualization, and architecture design	Proposed a virtualized, network-slicing-based 6G architecture with AI, edge, quantum, optical wireless, and tactile services	To address 5G NR adaptation issues and propose a migration platform toward 6G	Handling higher modulation, inter-RAT synchronization, and integration of diverse 6G technologies
Huang et al. (2019)	6G architectural evolution and sustainable technologies	Survey of 6G design elements: 3D coverage, AI, blockchain, terahertz, visible light, symbiotic radio	Identified architectural trends for sustainable 6G; proposed socially seamless and green networking vision	To guide future 6G research through architectural, technological, and protocol insights	Achieving ubiquitous 3D coverage, integrating AI pervasively, sustainable implementation
Saad, Bennis & Chen (2019)	Vision and roadmap for 6G systems	Analysis of drivers, service classes, enabling technologies; research agenda proposal	Defined 6G services and target KPIs; convergence of spectrum and emerging technologies	To provide a forward-looking vision and stimulate 6G research directions	Mapping services to enabling technologies; handling convergence of multiple tech trends
Parvez et al. (2018)	Low-latency communication in 5G	Survey of latency solutions in RAN, core, and caching; overview of SDN, NFV, MEC	Identified enabling technologies for URLLC; 5G roadmap towards improved latency and reliability	To analyze latency-reduction strategies and present 5G capabilities	Maintaining ultra-low latency under massive connectivity; edge integration challenges
Ankarali, Pekoz & Arslan (2017)	Flexible waveform and RAT design for B5G/6G	Proposed frameworks for waveforms, numerology, frame design;	Introduced flexible RAT framework for beyond-5G systems	To contribute to vision of flexible RATs and explore	Complexity of flexible RAT design; handling interference in

		methods for OMA/NOMA schemes		design strategies	multiple access schemes

VII. Conclusion and Future Work

Higher data speeds, ultra-low latency, huge interconnectedness, and AI-enabled intelligence are driving the move from 5G to 6G, which constitutes a paradigm leap in wireless communication. 5G networks have successfully addressed many challenges of earlier generations through innovations such as Massive MIMO, mmWave spectrum utilization, network slicing, and edge/cloud integration. However, reconfigurable intelligent surfaces, Sustainability, energy efficiency, and cost-effective deployment remain central design considerations.

Future Work in 6G research involves the experimental validation of terahertz communication systems, the development of secure and adaptive AI-driven protocols, the implementation of fully integrated 3D networks, and research into incredibly dependable, low-latency applications including autonomous transportation, holographic telepresence, and remote surgery. In addition, to fully utilize 6G, research spanning disciplines is crucial, particularly in the areas of communication, computing, and human-centric technology. The evolution of 6G networks from theoretical models to commercially deployable systems will be guided by ongoing standardization initiatives, field experiments, and performance evaluations based on simulation analysis.

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