

A Comparative Study of 5th Generation and Emerging 6th Generation Network Architectures

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Abstract-- In this paper I have analyzed that the rapid evolution of wireless communication networks has transitioned from a purely human-centric connectivity paradigm to an all-inclusive, strong, intelligent, and hyper-connected ecosystem. The fifth-Generation (5G) networks currently deployed and being used worldwide, successfully introduced groundbreaking architectural paradigms such as Service-Based Architecture (SBA), Network Function Virtualization (NFV), and Software-Defined Networking (SDN). These innovations enabled enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC), and massive Machine-Type Communications (mMTC). However, emerging applications—including holographic communications, multi-sensory extended reality (XR), pervasive artificial intelligence (AI), and autonomous global systems—demand performance metrics that exceed the intrinsic limits of 5G. This paper provides a comprehensive comparative study of 5G and the upcoming Sixth-Generation (6G) network architectures. It examines structural transitions, core technological enablers, spectrum utilization, performance metrics, and security frameworks to chart the trajectory of next-generation telecommunications.

Keywords-- 5G, 6G, SDN, NFV, IoT

I. INTRODUCTION

Modern telecommunication networks are no longer simple conduits for voice and data transmission; they have evolved into the foundational infrastructure of the global digital economy. The commercialization of 5G networks marked a major milestone by breaking away from rigid, hardware-centric architectures in favor of flexible, software-defined environments. Despite these advancements, the exponential explosion of data traffic, coupled with the proliferation of Internet-of-Things (IoT) devices and the demand for real-time intelligent automation, has pushed 5G to its theoretical boundaries. To address these limitations, academic and industrial consortia have initiated research into 6G wireless networks. Expected to reach commercial maturity around 2030, 6G aims to transform wireless networks from an infrastructure that merely connects intelligent engines to an architecture where the network itself acts as a massive, distributed intelligent entity.

This paper explores the architectural differences between 5G and 6G, analyzing how structural modifications will fulfill the ambitious performance requirements of the next decade.

II. ARCHITECTURAL PARADIGMS: 5G Vs. 6G

2.1 The 5G Network Architecture

The 5G Next Generation Core (5GC) introduced the Service-Based Architecture (SBA). In this model, Network Functions (NFs) exhibit modularity and exhibit self-containment, communicating via uniform application programming interfaces (APIs) over a shared bus interface. Key architectural innovations in 5G include:

- *User Plane and Control Plane Separation (CUPS)*: Decouples packet routing and forwarding from control policies, allowing independent scaling and flexible deployment of core functions.
- *Network Slicing*: Leverages NFV and SDN to create isolated, virtualized logical networks over a single physical infrastructure, tailoring slices to specific application profiles (e.g., URLLC or eMBB).
- *Multi-Access Edge Computing (MEC)*: Migrates cloud computing capabilities and storage resources closer to the network edge, significantly decreasing propagation latency.

2.2 The Envisioned 6G Network Architecture

While 5G succeeded in softwarizing the core network, 6G is projected to completely restructure the network topology into a cloud-native, AI-native, and space-air-ground-sea integrated network. The 6G architectural design relies on several core pillars:

- *Pervasive Native AI (AI-Native Architecture)*: Unlike 5G, where AI is applied as an optimization overlay, 6G embeds AI into the physical layer, link layer, and network management layers. This enables autonomous self-healing, zero-touch network management, and dynamic semantic communication.
- *Space-Air-Ground-Sea Integration (Three-Dimensional Topology)*: 6G expands the traditional terrestrial network into a comprehensive 3D architecture.

It integrates Low Earth Orbit (LEO) satellites, Medium Earth Orbit (MEO) satellites, Geostationary Earth Orbit (GEO) satellites, High-Altitude Platform Stations (HAPS), and unmanned aerial vehicles (UAVs) to guarantee seamless global coverage, even in remote oceanic and polar zones.

- *Cell-Free Massive MIMO Architecture*: 6G intends to move away from traditional cell-centric topologies. By coordinating vast numbers of distributed access points, the network eliminates cell boundaries, delivering a uniform, high-capacity user experience regardless of client location.

III. CORE TECHNOLOGICAL ENABLERS

The transition from 5G to 6G requires a fundamental shift in underlying hardware and software technologies.

3.1 Spectrum and Waveform Technologies

5G networks utilize two primary frequency ranges: Frequency Range 1 (FR1, sub-6 GHz) and Frequency Range 2 (FR2, millimetre-wave/mmWave, 24 GHz to 52 GHz). Although mmWave offers wide bandwidths, it suffers from severe atmospheric attenuation and poor penetration properties.

In contrast, 6G will access the sub-terahertz (sub-THz) and Terahertz (THz) spectrum (100 GHz to 10 THz),

alongside Optical Wireless Communications (OWC) and Visible Light Communication (VLC). The THz band unlocks tens of gigahertz of contiguous bandwidth, supporting ultra-high data rates. To mitigate the extreme propagation losses of THz signals, 6G relies on Ultra-Massive MIMO (UM-MIMO) systems with thousands of antenna elements, alongside reconfigurable intelligent surfaces (RIS) to dynamically redirect signal beams around physical obstacles.

3.2 Compute and Intelligence Overlays

The 5G core depends on centralized data centers and edge nodes running conventional virtualization platforms. 6G architectures will deploy a distributed, collaborative computing fabric. Through "Compute-First Networking" (CFN), network routing policies will consider not only network path state but also real-time computational load across federated edge nodes, ensuring optimal distribution for resource-heavy AI workflows.

IV. KEY PERFORMANCE INDICATORS (KPIs) COMPARISON

The architectural shifts directly translate into significant jumps across all primary Key Performance Indicators (KPIs). The table below highlights the performance improvements from 5G to the projected standards of 6G.

Key Performance Indicator (KPI)	5G Target Values	Envisioned 6G Target Values
Peak Data Rate	20 Gbps	1 Tbps (1000 Gbps)
User Experienced Data Rate	100 Mbps	1 Gbps to 10 Gbps
User-Plane Latency	1 millisecond (ms)	Less than 0.1 millisecond (100 microseconds)
Control-Plane Latency	10–20 ms	Less than 1 ms
Mobility Support	Up to 500 km/h	Up to 1000 km/h (Hyperloop & Supersonic Aircraft)
Connection Density	10 ⁶ to the sixth power 10 ⁶ devices / km ² km squared km ²	10 ⁷ to the seventh power 10 ⁷ devices / km ² km squared km ²
Traffic Capacity	10 Mbps/m ² Mbps/m squared Mbps/m ²	1–10 Gbps/m ³ Gbps/m cubed Gbps/m ³

		(Volumetric Capacity)
Energy Efficiency	1x Baseline	10x to 100x improvement over 5G
Reliability	99.999 % (Five Nines)	99.99999 % (Seven Nines)
Jitter	Not strictly bounded	Sub-microsecond bounds
Localization Accuracy	Centimetre-level	Millimetre-level

V. NETWORK INTELLIGENCE AND SEMANTIC COMMUNICATIONS

A key differentiator of 6G architecture is the shift from conventional Shannon-Hartley-driven data transmission to **semantic and goal-oriented communications**.

5G networks treat data as arbitrary bitstreams, optimizing for accurate delivery without considering the meaning or context of the information. This method becomes inefficient when dealing with high-bandwidth applications like real-time holographic rendering.

6G networks will use embedded AI models to extract the underlying meaning (semantics) of data before transmission. By sending only relevant features or knowledge abstractions rather than raw data, the system dramatically reduces required bandwidth while reconstructing the original intent at the receiver with high fidelity. Furthermore, 6G will introduce cognitive network slices that self-configure based on intent-based networking (IBN) principles, interpreting high-level user demands and automatically translating them into low-level network policies.

[6G Zero-Trust Architecture]

- | +---> Distributed Ledger Technology (DLT) ---> Decentralised Identity & Trust Validation
- | +---> Post-Quantum Cryptography (PQC) ---> Protection Against Quantum Decryption
- | +---> Physical Layer Security (PLS) ---> Secure THz Beamforming & Eavesdropping Defense

- *Distributed Ledger Technology (DLT)*: 6G architectures will deploy decentralized blockchains to handle access control, track network slicing agreements, and authenticate non-terrestrial network nodes without relying on a centralized clearinghouse.

VI. SECURITY, PRIVACY, AND TRUST ECOSYSTEMS

The softwarization of 5G opened up new attack surfaces. While network slicing provides logical isolation, vulnerability risks remain due to misconfigured software slices, shared physical hardware compromises, and DDoS vulnerabilities targeting the Service-Based Core. 5G addressed these issues by implementing advanced cryptographic keys, subscriber privacy protection via Subscription Concealed Identifiers (SUCI), and unified authentication protocols.

6G demands more robust security architecture. The integration of millions of untrusted edge devices, satellite links, and third-party AI models introduces unprecedented entry vectors for malicious actors. Consequently, 6G security is designed around a **Zero-Trust Architecture (ZTA)**, which assumes every access request is malicious until explicitly verified.

- *Post-Quantum Cryptography (PQC)*: Because the lifecycle of 6G networks will intersect with the practical emergence of quantum computing, the standard cryptographic primitives used in 5G (such as RSA and ECC) will be replaced with quantum-resistant lattice-based algorithms to protect long-term data privacy.

- *Physical Layer Security (PLS)*: Taking advantage of the narrow, highly directional properties of Terahertz beams, 6G introduces PLS techniques that disrupt eavesdropping at the radio frequency level, using random noise injection and cryptographic beamforming.

VII. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

The transition to a fully realized 6G architecture faces significant technical hurdles:

1. *Terahertz Hardware Limitations*: Developing semiconductor materials capable of operating at high power efficiencies within sub-THz bands remains an open engineering problem. Present silicon-based architectures face high thermal dissipation and low power efficiency at these frequencies.
2. *Computational Complexity of AI Integration*: Running deep neural networks across every node in the radio access network demands massive computational power, which directly conflicts with the strict green energy efficiency mandates of 6G.
3. *Complex Orbital Coordination*: Integrating multi-layered satellite constellations with ground-based networks introduces difficult handover challenges, high propagation delays from higher orbits, and complex Doppler effect compensations.

VIII. CONCLUSION

The transition from 5G to 6G represents a fundamental leap rather than a simple incremental upgrade. While 5G successfully introduced service virtualization, network slicing, and edge computing to decouple software from specialized hardware, it remains bounded by a terrestrial, cell-centric design optimized for raw bit delivery. 6G breaks these boundaries by deploying an AI-native, cell-free, three-dimensional network architecture operating across the Terahertz spectrum. By converting the telecommunications fabric into a distributed, intelligent sensor-and-compute platform, 6G will provide the foundation for next-generation systems, paving the way for a truly unified, hyper-connected intelligent world.

To further tailor this research paper, let me know if you would like to:

- Expand on a specific section, such as **Terahertz wave propagation** or **Reconfigurable Intelligent Surfaces (RIS)**.
- Adapt the document into a specific academic citation format like **IEEE** or **ACM**.

- Focus more deeply on the mathematical and architectural models behind **Cell-Free Massive MIMO**.

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