The Transition from 4G to 5G: Design, Challenges, and Future Prospects

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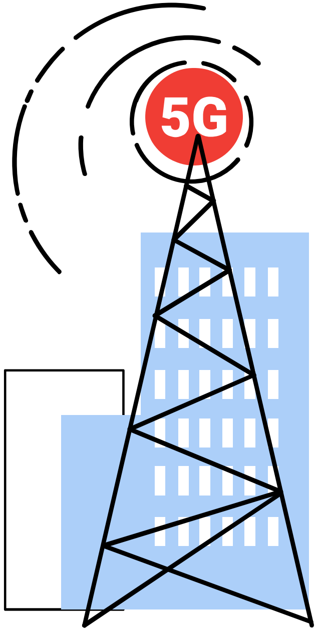


Motivation

The transition from 4G to 5G is more than a technological upgrade—it's a step toward a more connected, intelligent world. As 5G continues to evolve, understanding its challenges and potential is key to unlocking innovations that will shape how we live, work, and communicate in the years ahead.

More Than Faster Speeds:

📶 5G enables massive connectivity, low latency, and advanced applications like autonomous driving and remote healthcare.

New Design, New Challenges:

⚙️ 5G introduces SBA and Network Slicing, but spectrum scarcity, network densification, and 4G integration pose challenges.

Global Deployment Still Ongoing:

🌐 Despite the 2020 standard release, 5G adoption remains uneven, with many regions still building infrastructure.

A Gateway to Future Innovation:

🚀 5G lays the groundwork for 6G, smart cities, and IoT ecosystems, reshaping industries and global connectivity.

Objectives:

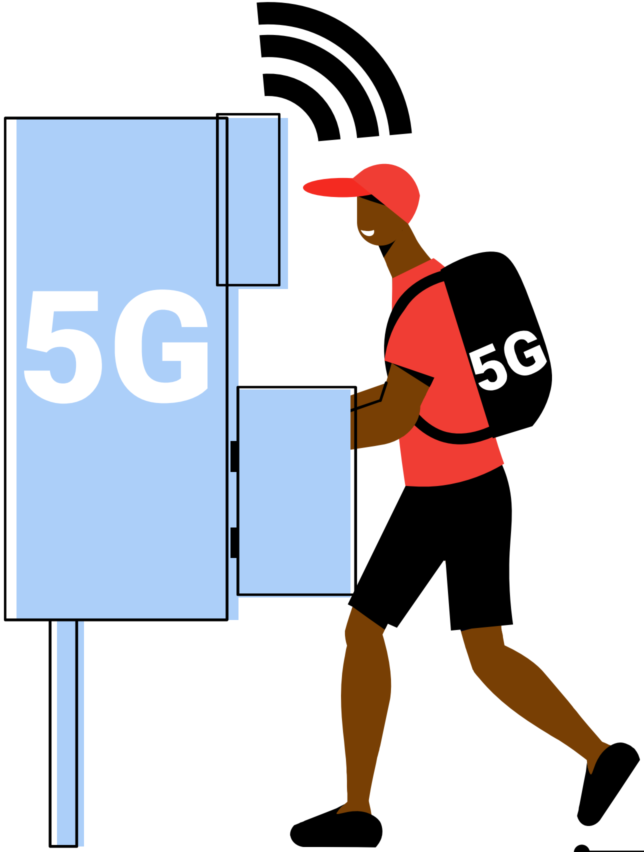
This presentation will give you a clear picture of how mobile networks are evolving and why 5G matters. From this presentation, you will be able to:

- Learn how network evolved: From 4G to 5G
- Understand why 5G is different: Faster, smarter, and more connected.
- Discover the challenges: What makes the transition difficult.
- Look toward future innovations: The role of 5G in enabling next-generation networks.

By the end, you'll see how this technology impacts everyday life and shapes the future of communication.

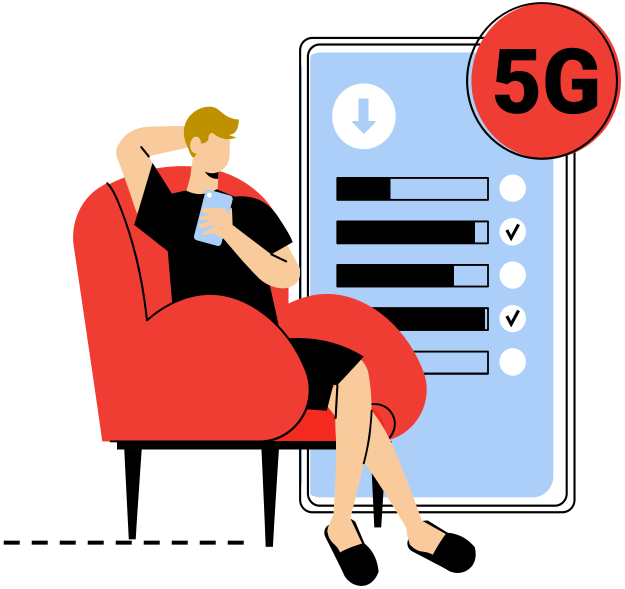
01

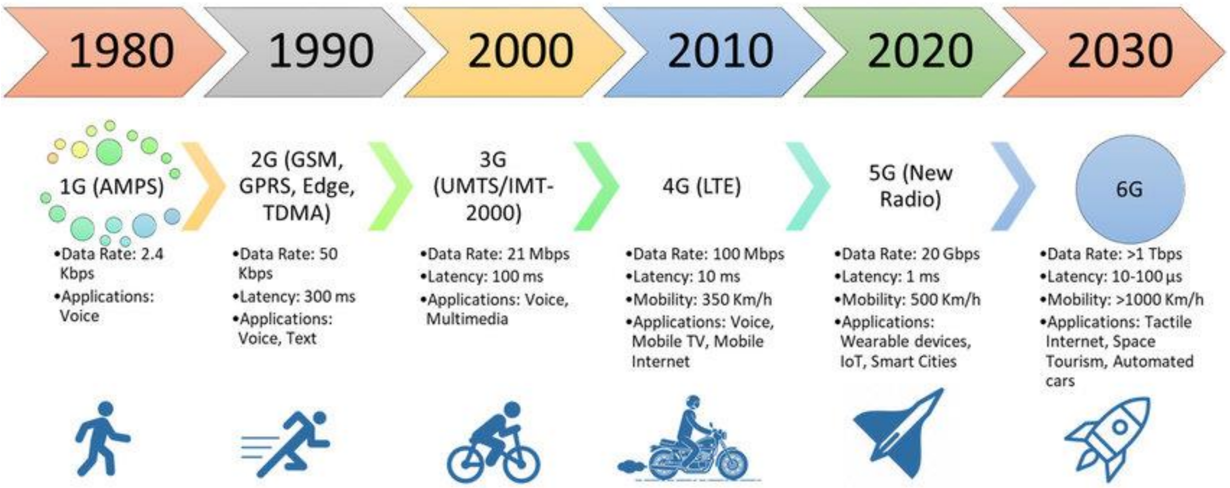
Network Insight and Evolution



3GPP Mobile Network Timeline

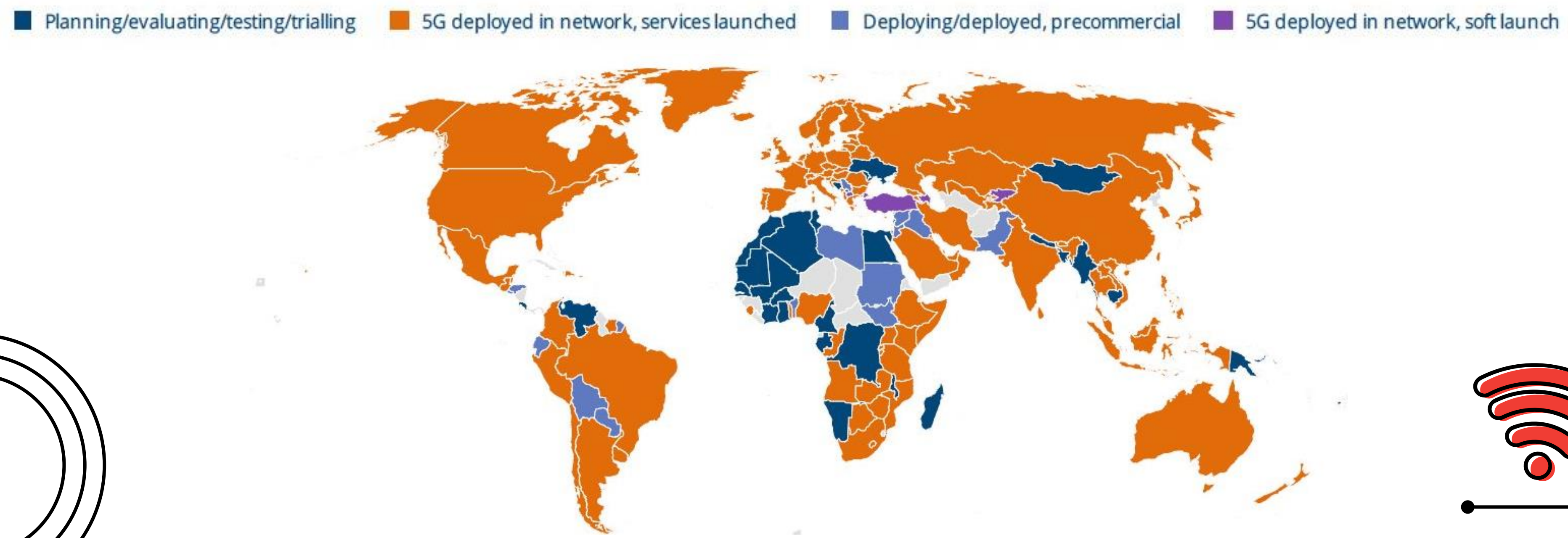
Since the 1980s, mobile networks have evolved every decade, driven by 3GPP standards. Each generation introduced new capabilities, from voice calls to ultra-fast, low-latency 5G, with 6G research now underway.





Map of operator investments in 5G

By October 2024: 619 operators in 184 countries invested in 5G through trials, licenses, and deployments.
3,125 5G devices announced (72% increase from 2023), with over 2,000 models supporting band n78.



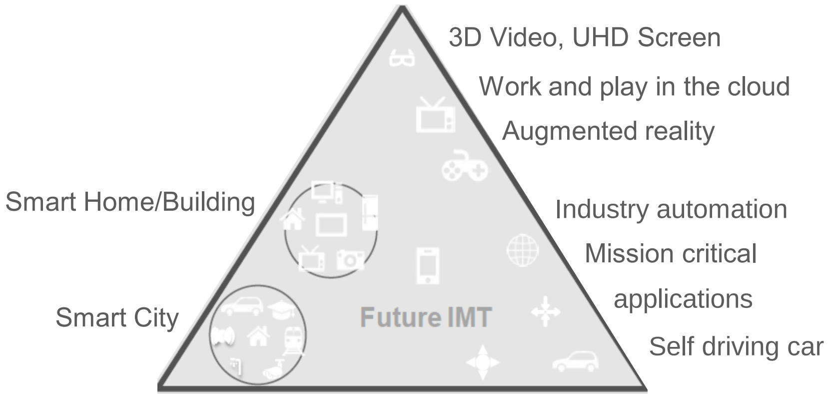
Source: GSA 5G-Market Snapshot November 2024-2

5G: Three Key Features

$10Gbps$

Enhance Mobile Broadband

eMBB



mMTC

Massive Machine Type Communications

$1million/km^2$

uRLLC

Ultra-reliable and Low-latency Communications

$1ms$

5G

Diversified Challenges and Gaps to Reach 5G

	Latency	Throughput	Connections	Mobility	Network Architecture
5G	**1ms** E2E Latency	**10Gbps** Per Connection	**1M** Connection Per km^2	**500km/h** High Speed Railway	**Slicing** Ability Required
GAP	**30~50x**	**100x**	**100x**	**1.5x**	**NFV/SDN**
4G	30~50ms	100Mbps	10K	350km/h	Inflexible

Key Concerns for Reaching 5G

Spectrum:

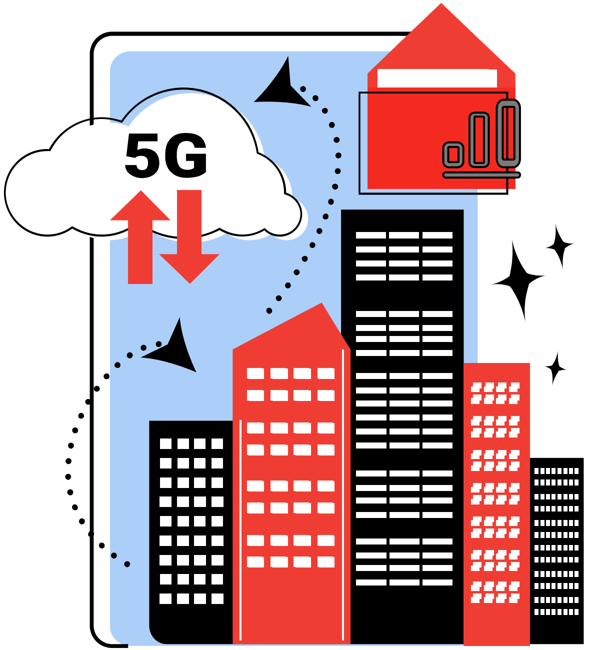
Aggregating All Available Bands: 5G requires access to a wide range of spectrum across low, mid, and high bands (mmWave) to deliver its full potential.

New Architecture:

One Physical Network Serving Multiple Industries: 5G introduces a more flexible, software-defined core network using technologies like Network Slicing.

New Air Interface:

Flexibility and Spectrum Efficiency: 5G New Radio (NR) is designed to handle various deployment scenarios and spectrum bands with greater efficiency.



Scope of Report

This report focuses on analyzing the key aspects of the 4G to 5G network transition, with an emphasis on architectural design, transition challenges, and future possibilities.

Network Architecture:

- 4G and 5G Core Network Overview
- Radio Access Network Technologies
- Spectrum Utilization

Challenges in the Transition:

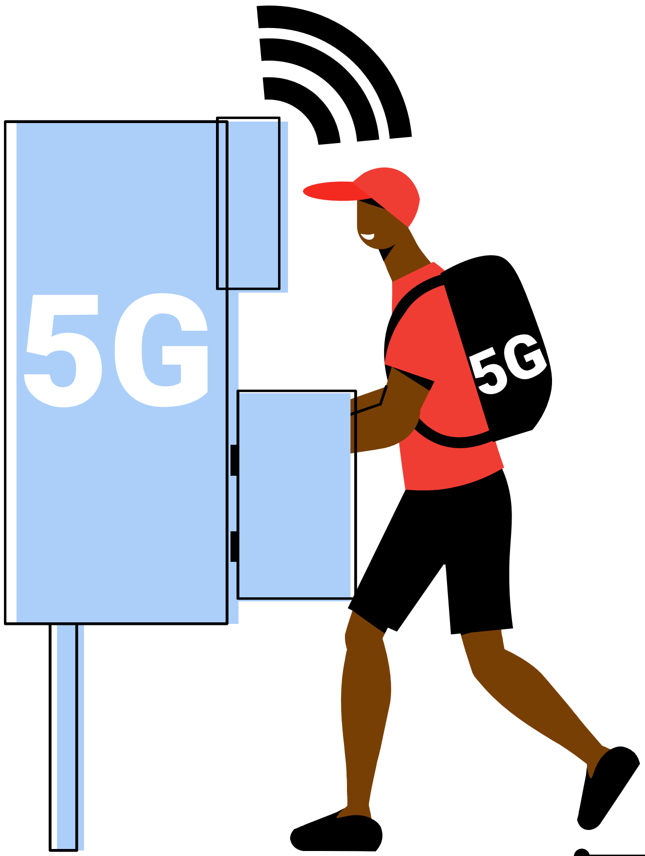
- Technical Challenges
- Industry Challenges

Future Prospects:

- AI-Driven Network Optimization
- Non-Terrestrial Networks (NTNs)
- Mission-critical Applications
- Key Technologies for 6G
- Sustainability and Green Networks

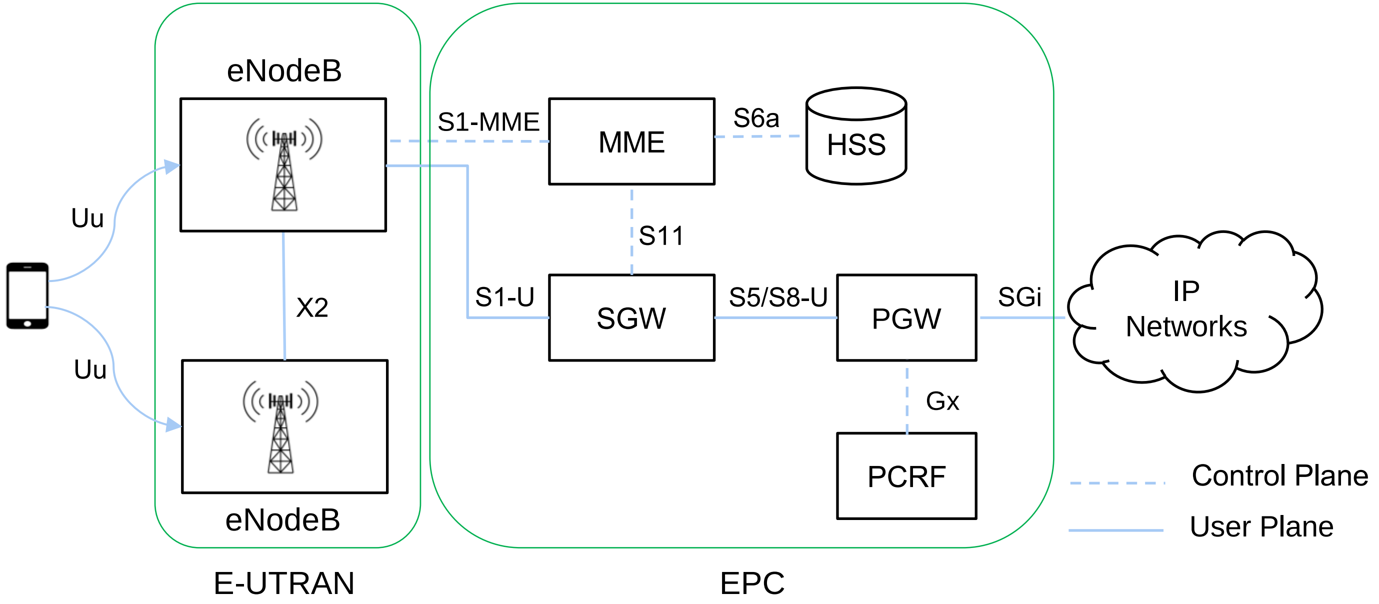
02

Design Evolution in the Transition



4G Evolved Packet Core

The conventional 4G Evolved Packet Core (EPC) is a centralized system where the control plane and user plane are integrated for network management. It is designed for efficient data flow.



MME:
Mobility Management Entity

SGW: Serving Gateway

PGW:
Packet Data Network Gateway

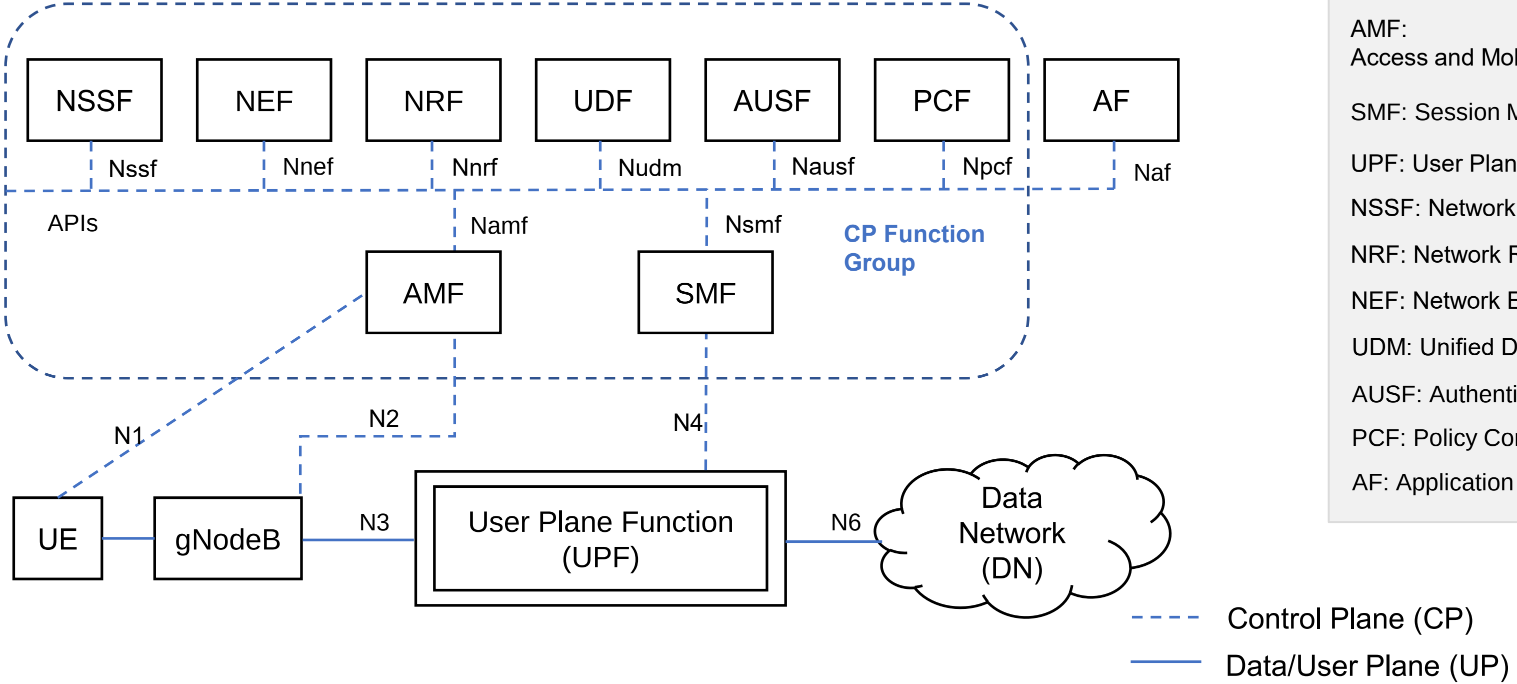
HSS: Home Subscriber Server

PCRF:
Policy and Charging Rules Function

Note: EPC supports partial decentralization with CUPS, but this report focuses on its centralized architecture as 4G's foundation before transitioning to 5G.

5G Core

5GC overcomes the limitations of EPC by adopting a modular, cloud-native architecture with service-based design. It fully separates the control and user planes (CUPS) for greater scalability, flexibility, and operational efficiency.



AMF: Access and Mobility Management Function

SMF: Session Management Function

UPF: User Plane Function

NSSF: Network Slice Selection Function

NRF: Network Repository Function

NEF: Network Exposure Function

UDM: Unified Data Management

AUSF: Authentication Server Function

PCF: Policy Control Function

AF: Application Function

Why EPC is different from 5GC?

Service-Based Architecture:
Unlike 4G's more rigid design, 5G adopts a Service-Based Architecture (SBA), allowing different network functions to access services from other functions.

Separation of Control and User Planes:
5G further decouples the control and user planes, enabling scalability and flexibility in network deployment and management.

Stateless NFs:
Network functions in 5GC are designed to be stateless, meaning they don't store session state. This improves reliability and fault tolerance.

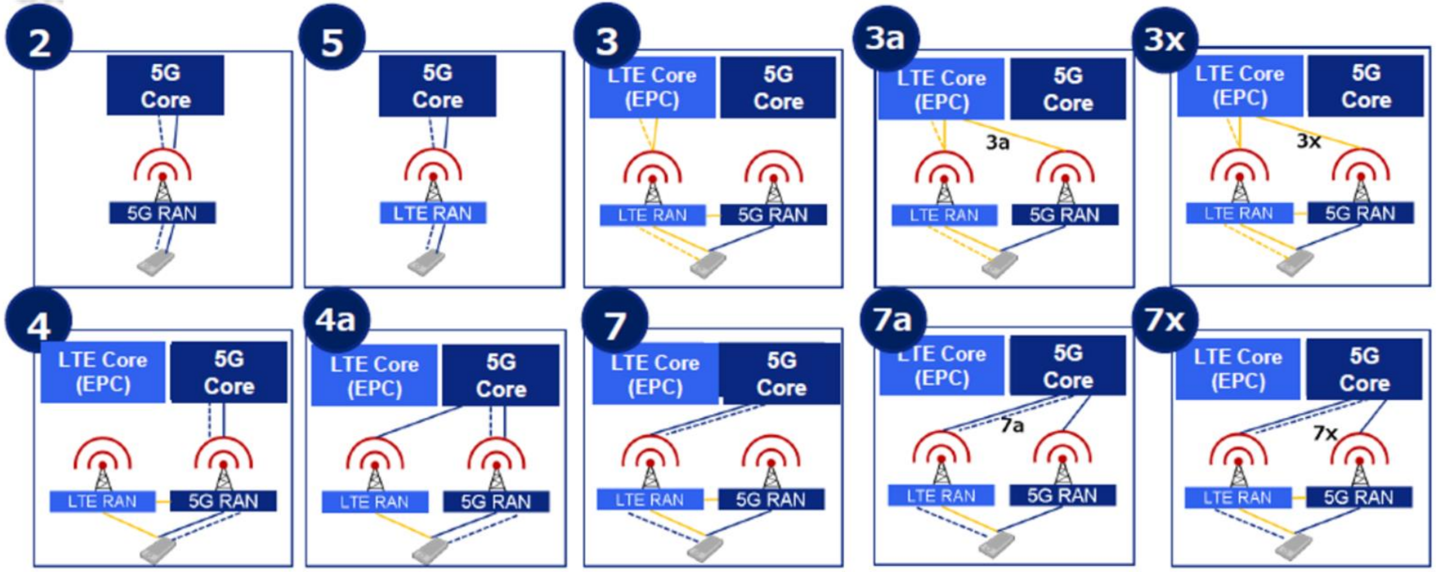
Network Slicing:
5G introduces network slicing, allowing operators to create multiple virtual networks with varied performance characteristics on a single physical infrastructure.

EPC vs 5GC Architecture Difference

Feature/Component	4G (EPC)	5G (5GC)
Architecture Type	Monolithic	Service-Based Architecture (SBA)
Mobility Management	MME	AMF
Session Management	Combined with MME & SGW	SMF
User Data Management	HSS	UDM and UDR
Authentication	Integrated with MME	AUSF
Policy Control	PCRF	PCF
Service Discovery	Not Explicitly Defined	NRF
Exposure to Third Parties	Limited	NEF provides extensive capabilities
User Plane Function	SGW & PGW	UPF (User Plane Function)
Network Flexibility	Less Flexible	High flexibility due to decoupling of control and user planes
State Handling	Stateful components	Mostly stateless functions
Network Slicing	Not Native (Can be emulated)	Native support with end-to-end slicing

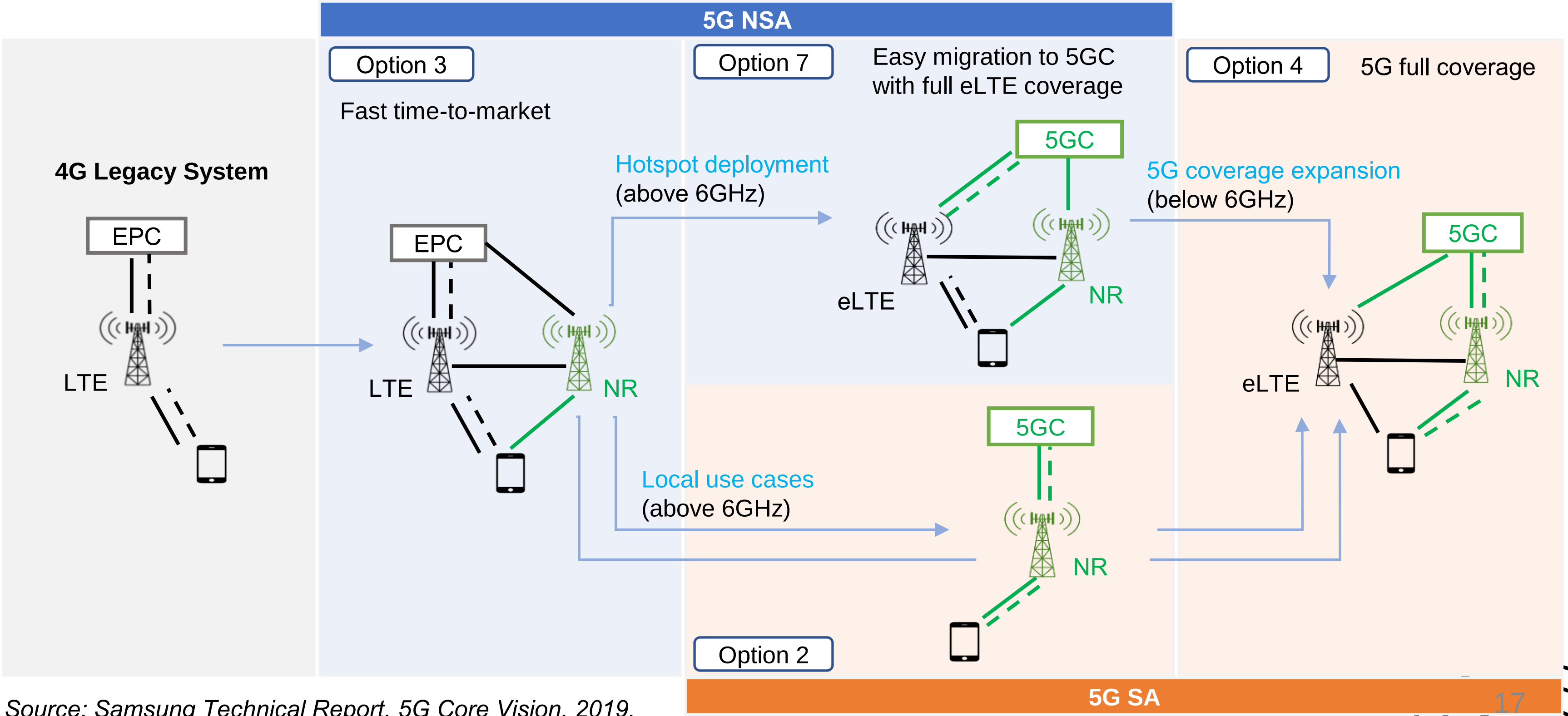
3GPP 5G Deployment Options

3GPP-defined 5G deployment options that guide the evolution from 4G LTE to 5G networks. These options demonstrate how 5G RAN and 5G Core (5GC) can be introduced alongside existing LTE RAN and EPC infrastructure, ensuring a smooth transition.

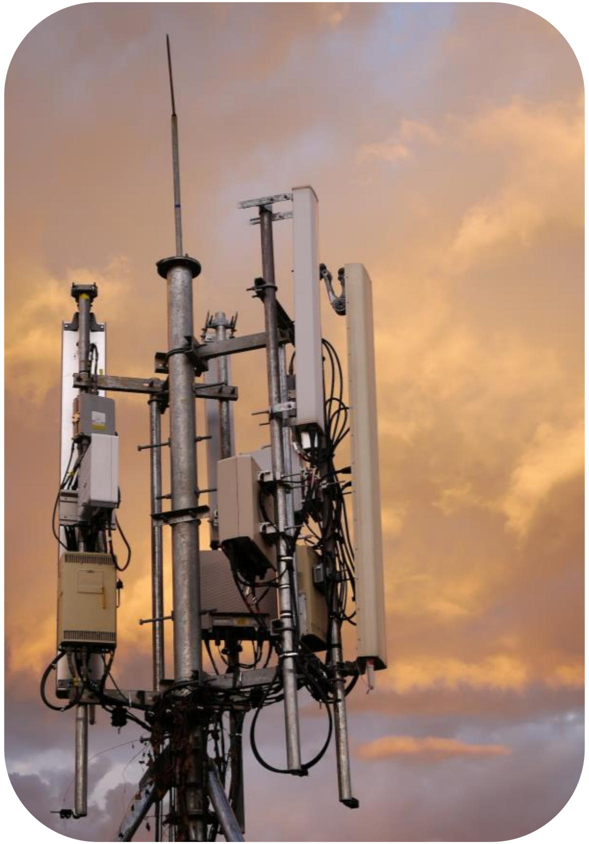


- Standalone (SA) Options (2, 5): Full 5GC with native 5G capabilities like CUPS, network slicing, and MEC.
- Non-Standalone (NSA) Options (3, 3a, 3x, 4, 4a, 7, 7a, 7x): Use LTE EPC or 5GC with dual connectivity to accelerate 5G deployment while leveraging existing infrastructure.

Example of Transition Options



Source: Samsung Technical Report, 5G Core Vision, 2019.



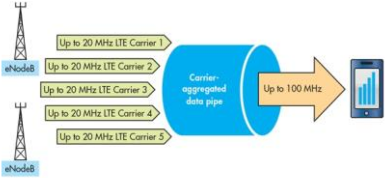
4G vs 5G RAN Technologies

- The 4G Radio Access Network (RAN) employs eNodeBs (evolved Node Bs) as advanced base stations to connect user equipment (UE) to the EPC.

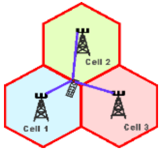
Some key Feature such as:

Orthogonal Frequency Division Multiple Access (OFDMA)

Carrier Aggregation (CA)



Coordinated Multipiont (CoMP)

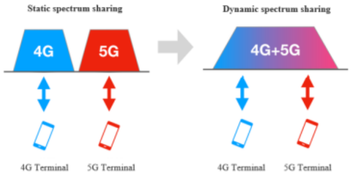


- The 5G Radio Access Network (RAN) uses gNodeBs (next-generation Node Bs) to enhance network capacity, efficiency, and flexibility.

Some key Feature such as:

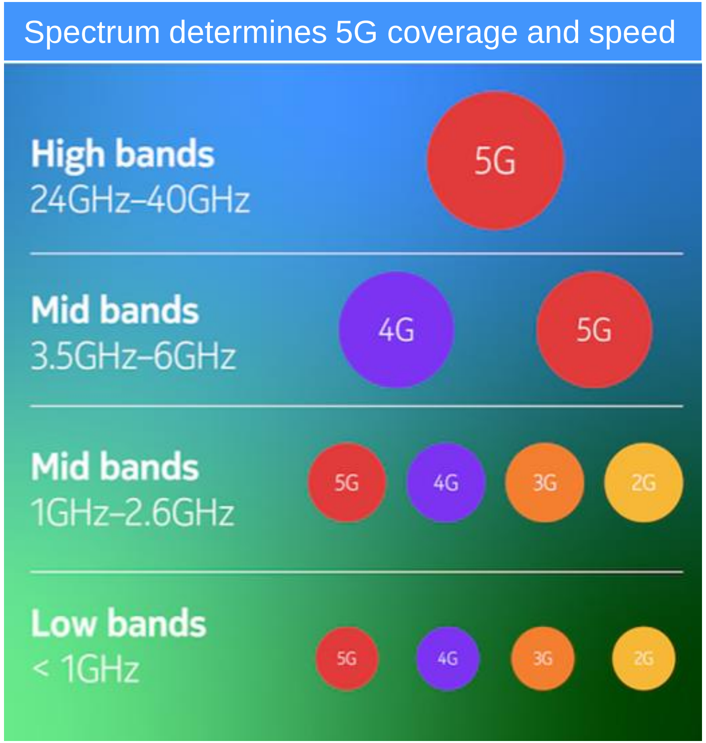
Massive MIMO

Dynamic Spectrum Sharing (DSS)



Network Slicing

Spectrum Distribution



4G Spectrum: Primarily uses sub-3 GHz frequencies, balancing coverage and capacity with low bands (e.g., 700 MHz) for wide-area coverage and mid-bands (e.g., 1.8 GHz) for higher capacity in urban areas.

5G Spectrum: Utilizes a broader range, including:

Super Data Layer (> 6 GHz)

- **Key Features:** High bandwidth for ultra-fast speeds.
- **Advantages:** Supports extreme mobile broadband for high-traffic areas.
- **Limitation:** Limited coverage and poor building penetration.

Coverage and Capacity Layer (2-6 GHz)

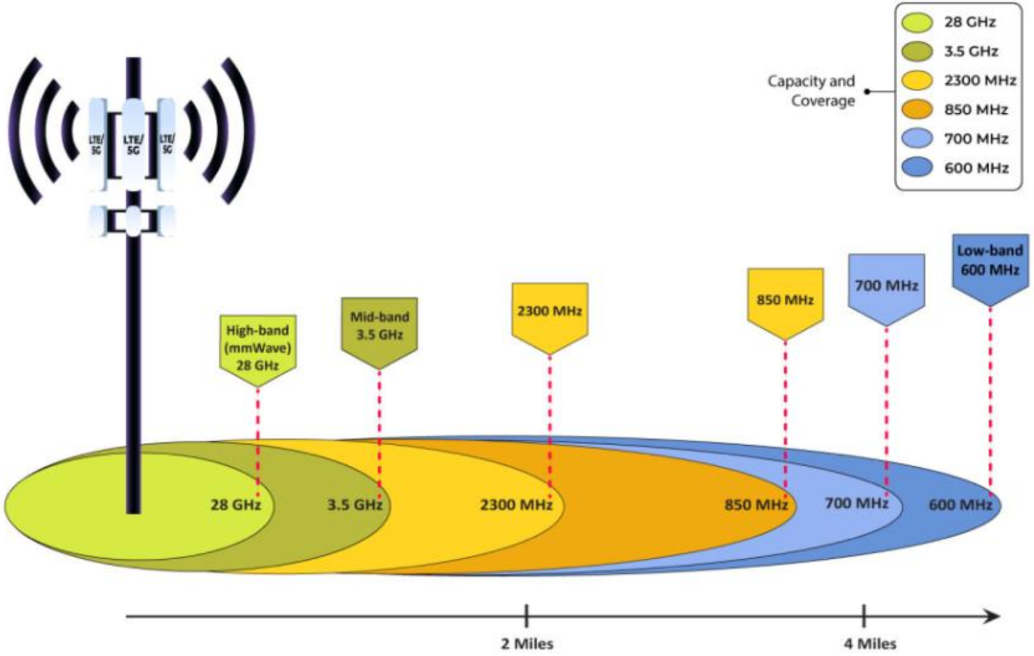
- **Key Features:** Balanced coverage and capacity.
- **Advantages:** Reuses existing 4G cell sites, reducing deployment costs.
- **Limitation:** Coverage is smaller than low-band but offers more capacity.

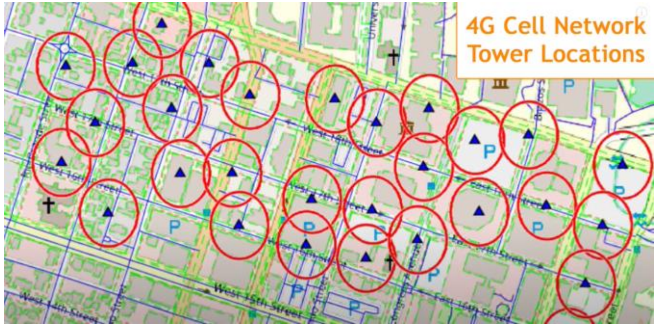
Coverage Layer (< 2 GHz)

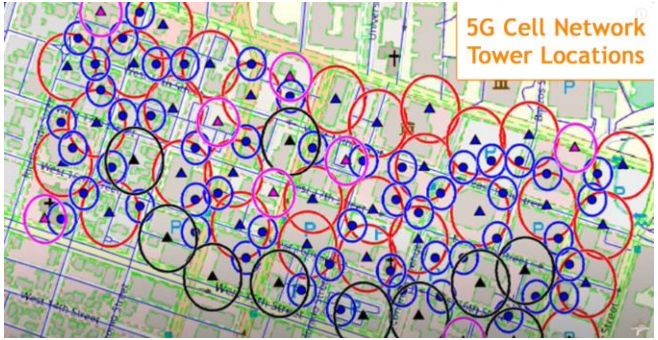
- **Key Features:** Wide coverage, good building penetration.
- **Advantages:** Fewer base stations needed, ideal for rural areas due to cost-effectiveness.
- **Limitation:** Limited available bandwidth.

Source: Huawei 5G Spectrum Public Policy Position, 2017.

Frequency vs Coverage Propagation







Source: *https://nybsys.com/5g-bands/*

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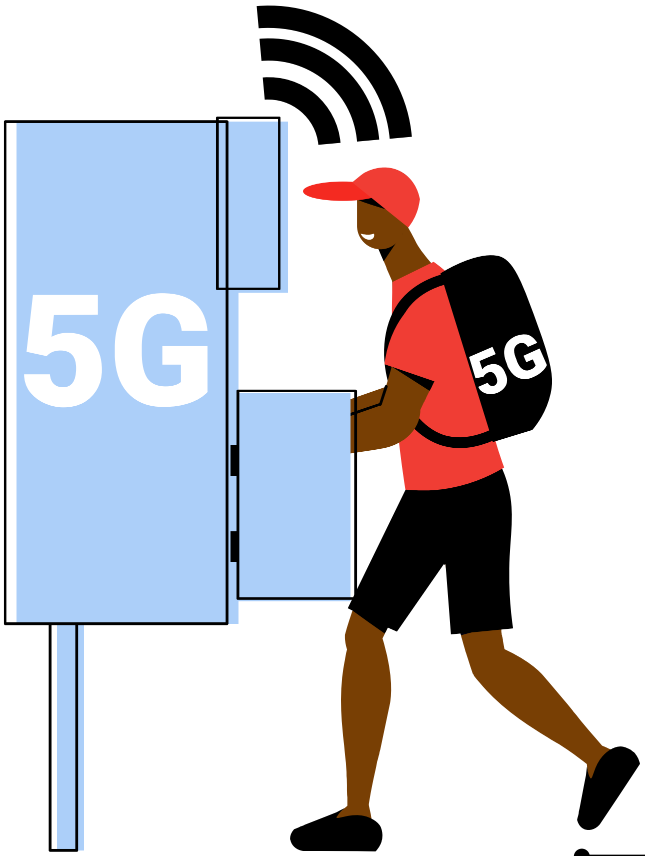
Challenges in the Transition

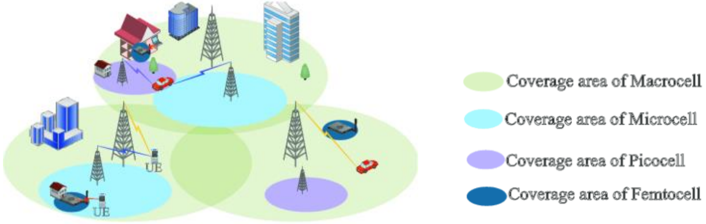


Technical | Industry

Technical

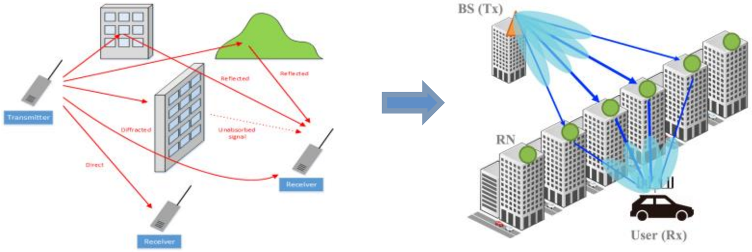
01 Infrastructure Upgrades

- Need for a denser network of small cells.
- Investment and regulatory approval requirements.



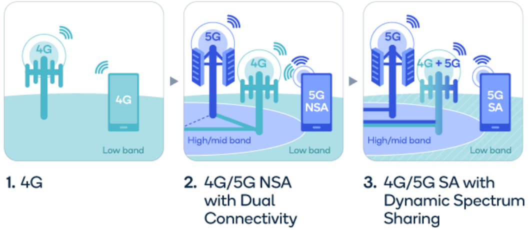
02 Signal Propagation at Higher Frequencies

- Short range and blockage issues.
- Solutions like beamforming and relay stations.



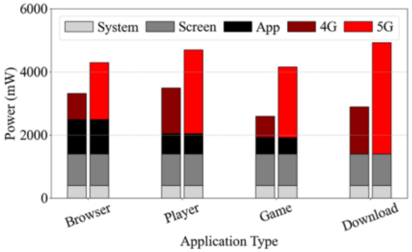
03 Compatibility with legacy systems

- Dynamic spectrum sharing and dual connectivity.
- Complexity in network management.



04 Power efficiency and energy consumption

- Higher Energy Consumption: 55% more than 4G.
- Effective Power Management is crucial for optimizing energy consumption.



Energy Consumption Breakdown in 4G and 5G for Daily App Usage

Energy Comparison Reference: D. Xu, A. Zhou, X. Zhang, G. Wang, X. Liu, C. An, Y. Shi, L. Liu, and H. Ma, “Understanding operational 5G: A first measurement study on its coverage, performance and energy consumption,” in *Proc. ACM SIGCOMM*, Virtual Event, NY, USA, 2020.

Industry

01 Standardization and Regulations

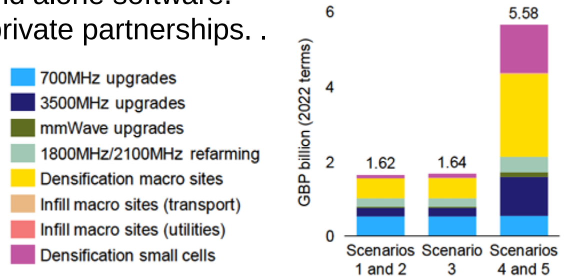
- Collaboration among governments, industry stakeholders, and standardization bodies.

03 Workforce and Ecosystem Readiness

- Need for skilled professionals.
- Industry-academia partnerships and training programs.

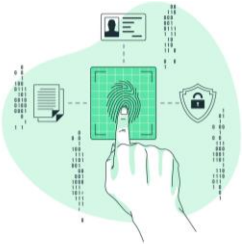
02 Investment and Cost Considerations

- Significant investment in infrastructure, hardware, and stand alone software.
- Public-private partnerships. .



04 Cybersecurity and Data Privacy

- Expanded attack surface with cloud-native architectures.
- Importance of zero-trust architectures and AI-driven security.



Investment and Cost Reference: Analysys Mason, "5G wireless infrastructure deployment scenarios over the next decade," National Infrastructure Commission (NIC).

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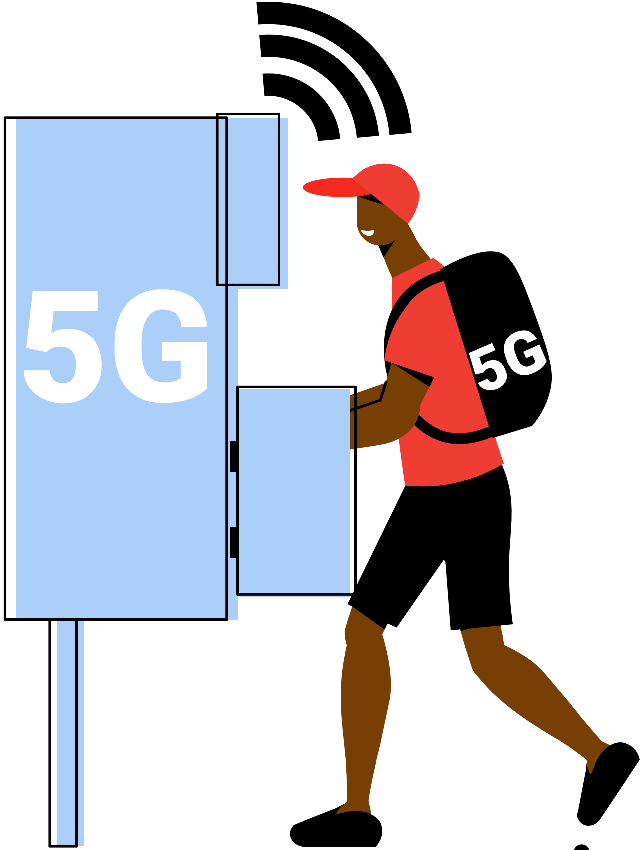
Future Prospects and Trends



Exploring Real-World Applications of 5G Across Industries:

SpaceX - Starlink

A satellite internet project to deliver broadband services with speeds comparable to 5G.

Facebook (Meta) – AR & VR

Utilizing 5G to deliver high-quality VR/AR experiences with low latency and high bandwidth, enabling real-time interactions in the metaverse.

Verizon - 5G Smart City

Smart City projects in the U.S. (Chicago, Miami, Sacramento, and Las Vegas) improve traffic management, public safety, and energy efficiency.

AT&T - 5G Healthcare Solutions

Providing telemedicine, remote monitoring, and real-time data sharing for better care and timely interventions.

BMW - Autonomous Driving

Testing 5G vehicle to everything (V2X) technology in Germany, China, and the U.S. to enhance autonomous driving with real-time data exchange.

Samsung - Smart Manufacturing

Implementing 5G in manufacturing to enable real-time monitoring, predictive maintenance, and automation of production lines.

Innovations driving developments:

Artificial Intelligence (AI)-Driven Network Optimization:

Huawei "0 Bit 0 Watt" Solution

Enables network equipment to enter a deep sleep mode, consuming nearly zero power when idle, and swiftly reactivating as data demand increases.

Nokia: AI-Driven Network Automation

Nokia collaborates with operators like Telenor to utilize AI and orchestration, simplifying 5G deployments and tailoring services to diverse customer needs.

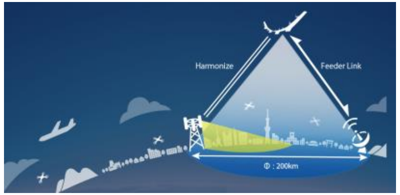
Ericsson: NetCloud Assistant (ANA)

A generative AI-based virtual expert designed to simplify enterprise 5G network administration, providing real-time insights, automated tasks, and improved reliability.

Non-Terrestrial Networks (NTNs):

SoftBank's HAPS (Japan)

Extends 5G connectivity using solar-powered UAVs in the stratosphere, supporting remote areas, urban traffic offloading, disaster recovery, and global connectivity.

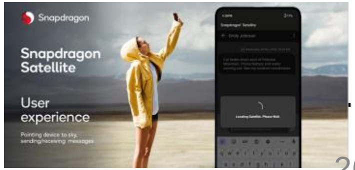


Airbus - Zephyr HAPS (Europe)

a solar-powered UAV developed in Europe to provide persistent 4G/5G connectivity from the stratosphere. It supports rural broadband, disaster recovery, and military communication. Partnering with NTT DOCOMO Japan.

Qualcomm's Snapdragon Satellite for Emergency Communication

Enables two-way text messaging via 5G Non-Terrestrial Networks (NTN) using Iridium's global LEO satellite constellation.

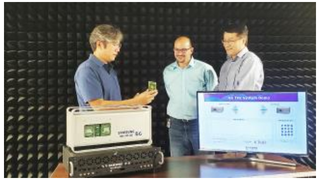


Future Technologies and Use Cases for 6G:

Terahertz (THz) Communication:

Samsung – THz Communication:

Samsung is researching Terahertz (THz) communication to enable ultra-fast wireless data transfer, high-precision localization, and improved indoor connectivity for 6G networks.



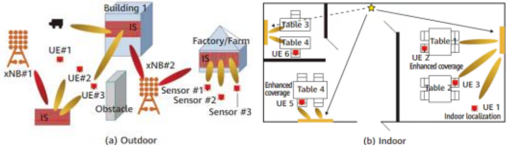
Nokia Bell Labs – THz Communication:

Nokia Bell Labs is exploring THz frequencies for 6G communication, focusing on high-capacity, low-latency transmissions to support future wireless applications.

Reconfigurable Intelligent Surfaces (RIS):

Huawei – RIS

Huawei is researching RIS technology to dynamically control electromagnetic waves, enhancing signal strength, coverage, and spectral efficiency in challenging environments.



Massachusetts Institute of Technology (MIT) - RIS

MIT is developing RIS for 6G to optimize wireless communication by manipulating wave propagation to reduce interference and extend coverage.

Joint Communication and Sensing (JCS):

Ericsson – JCS

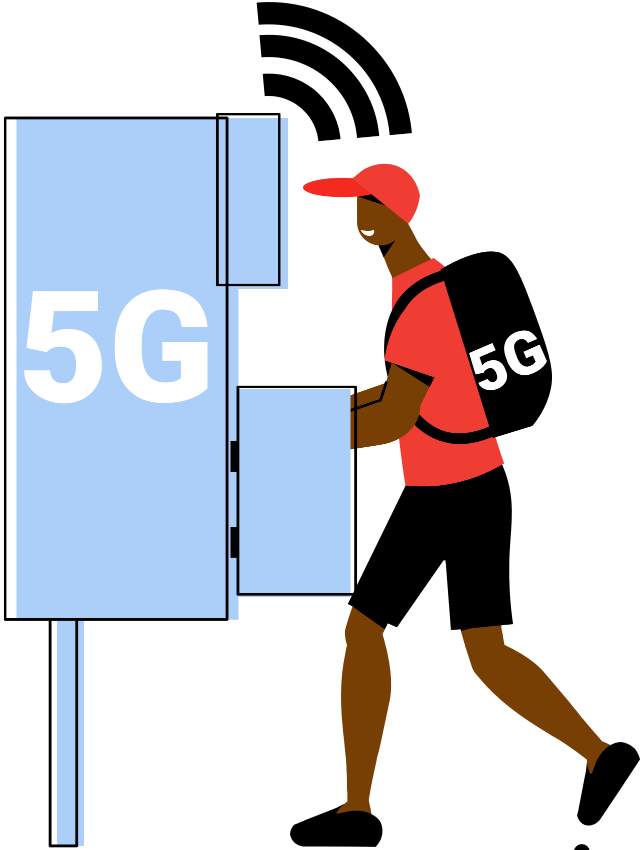
Ericsson is investigating JCS to integrate communication with sensing capabilities, supporting applications like autonomous vehicles, smart cities, and environmental monitoring.

Qualcomm – JCS

Qualcomm is exploring JCS technology for 6G networks, aiming to improve spectral efficiency and simplify hardware for target positioning and smart environments.

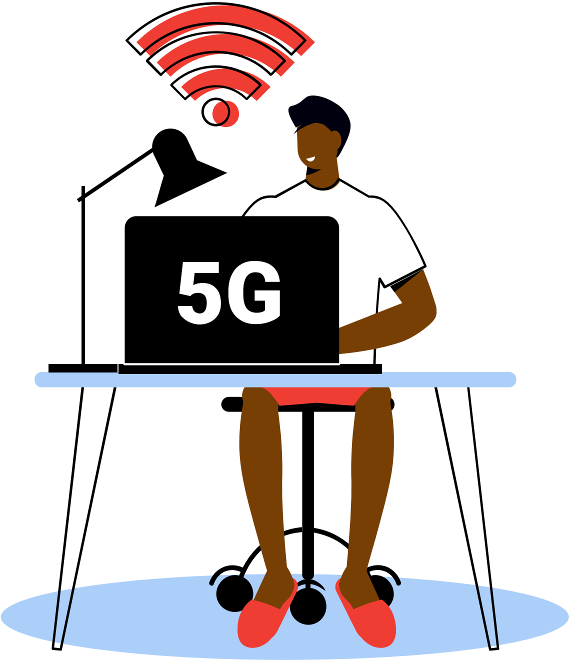
05

Conclusion



Key Takeaways

1. **5G delivers ultra-fast speeds** (up to **10 Gbps**), **sub-1 ms latency**, and **massive connectivity** (1,000,000 devices/km²), enabling 8K video, cloud gaming, autonomous vehicles, remote surgeries, and large-scale IoT.
2. **The 5G Core (5GC) introduces a flexible, service-based architecture**, allowing better resource utilization, network slicing, and dynamic service adaptation.
3. **Advanced technologies like Massive MIMO, beamforming, and CUPS (Control and User Plane Separation)** enhance network efficiency, capacity, and scalability.
4. **5G operates across low, mid, and high bands**, optimizing **coverage, capacity, and speed** based on deployment needs.
5. **Deploying 5G requires extensive small cell infrastructure**, facing challenges like high energy consumption, interference management, and legacy system compatibility.
6. **Significant investments in infrastructure, spectrum licensing, and hardware are needed**, driving costs for network operators.
7. **5G's cloud-native approach introduces new cybersecurity risks**, requiring strong encryption, network security policies, and real-time threat monitoring.



Thanks

Does anyone have any questions?

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