1G to 6G

Introduction & Flow

- *Applications*
  - *Use Cases and Requirements*
- *Suitable Technologies*
  - *Communication systems*
  - *Wireline, Wireless*
  - *Standardization*
- *Technology & Application relevance*
  - *1G to 6G*

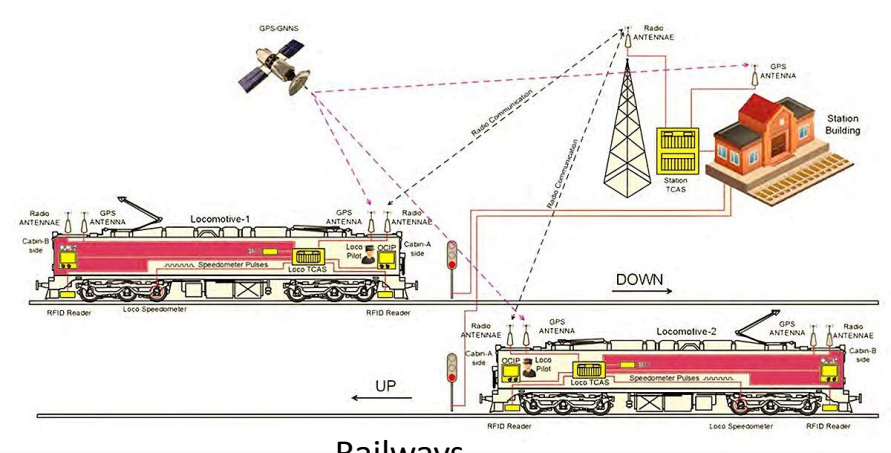
Use Cases & Selecting a suitable Technology

Use Cases

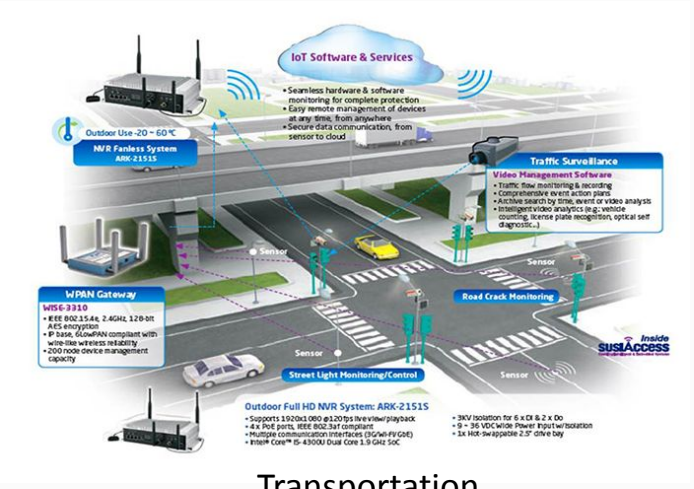
Agriculture

Mining

Healthcare



Railways



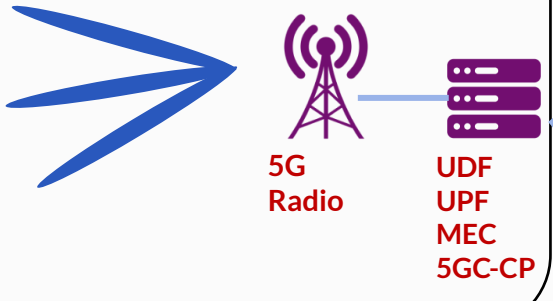
Transportation

And Many more ….

Typical Infrastructure 5G Use Case

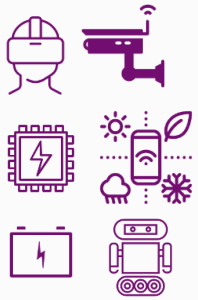
Low Latency

- Time and Space positioning
- Intelligent safety tool management
- Amphibious live operation robot
- Automatic Power Distribution
  - Remote Control/communication/test
- UAV inspection
- Accurate Load control



High Capacity & Coverage

- IP Surveillance
- Visual O&M of smart Power Plants
- Charging pie
- Low voltage power information collection
- SCADA
- IIoT (Sensors)



Data Network / Internet

Central Location

- Operation & Maintenance
- Remote Surveillance
- Remote Configuration / Automation

Use Cases – Mining - Detailed

Use Case - Mining

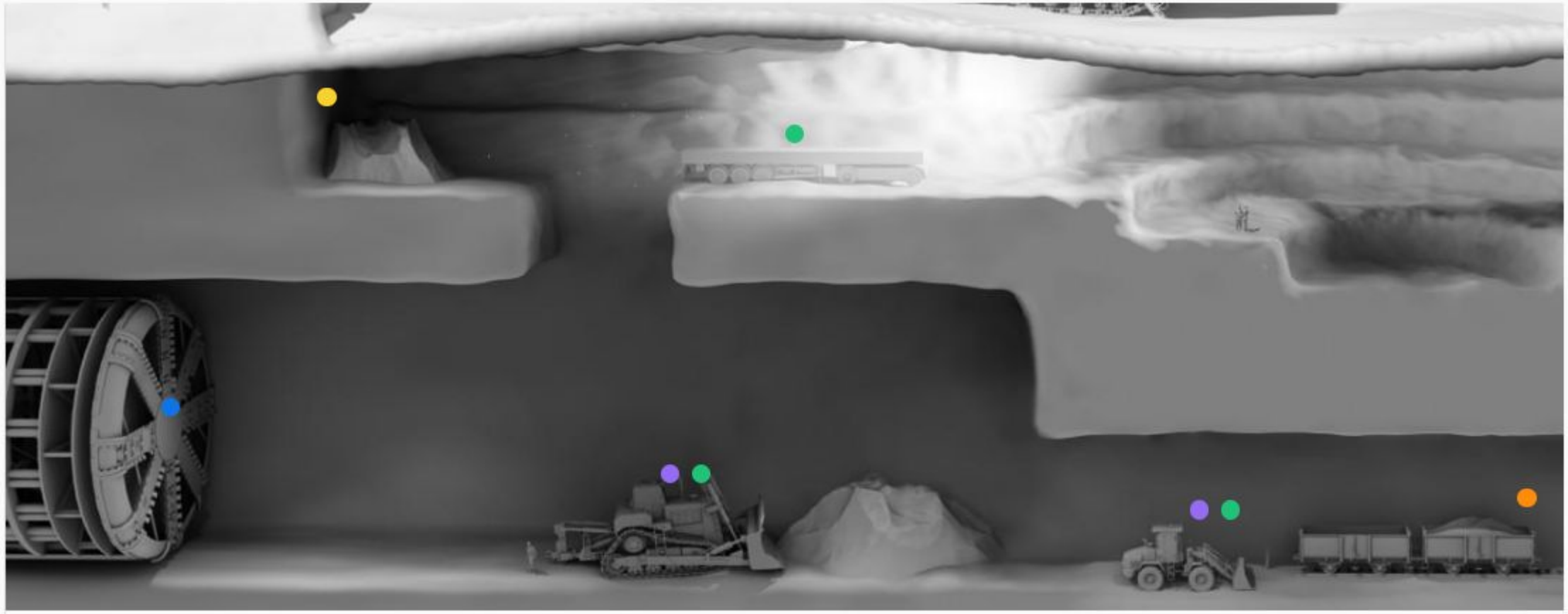
A key element of the global economy, global mining produces $1.5 trillion in materials, roughly 2% of the world's gross domestic product, per World Mining Data 2020. Digital mines are showing that automation can optimize operations to be more safe, productive and cost effective.

Operations – Surface

- Autonomous Vehicles
- Real-Time Condition Monitoring
- Remote Controlled Drill Rigs

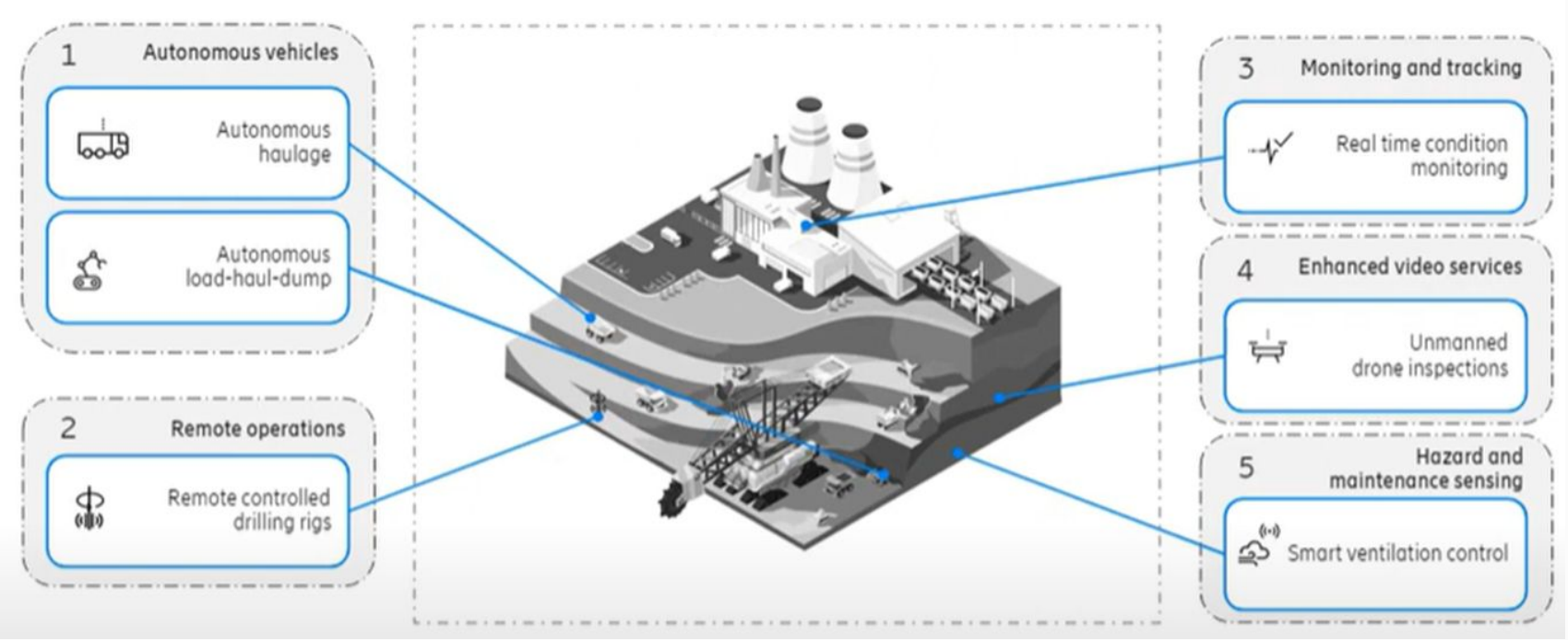
Operations - Underground

- Autonomous Vehicles
- Real-Time Condition Monitoring
- Remote Controlled Drill Rigs
- Unmanned Drone Inspections
- Smart Ventilation Control



Typical Work Items

- Autonomous Haulage & Drilling Systems
- Remote Operations & Control Rooms
- Worker Safety & Wearables
- Predictive Maintenance & IoT Sensors
- High-Resolution Video Monitoring & Drones
- Underground Connectivity
- AR/VR Training and Maintenance
- Environmental Monitoring

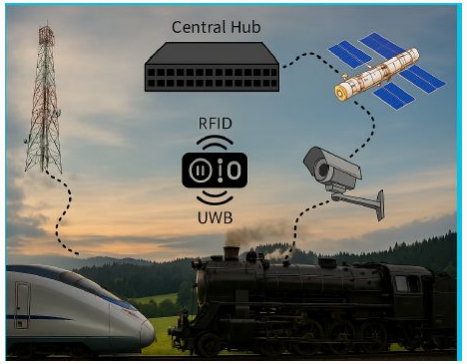


Use Cases – Others

Railways

Anti Collision System

- AI-based central & onboard systems
- Real-time navigation and speed control
- Auto-braking in emergencies



Rail Bogie Management

- Sensor data from bogies
- Detects derailment, detachment
- Monitors temp, humidity, noise, stress

Disaster Management System

- Quick communication via satellite/terrestrial networks
- Unified control for public-private response

Defense

Features

- Secure & Resilient Communications
- Real-Time Battlefield Awareness & ISR (Intelligence, Surveillance, and Reconnaissance)
- Network Slicing for Mission-Critical Tasks
- Cybersecurity & Electronic Warfare (EW) Protection
- Smart Military Bases & Logistics

Technical Challenges

- 5G NIB (Network in a box) – Integrated Core and BS
- Custom security includes custom waveforms
- Reliable and Deployable quickly

What you can do

- Mesh networking, Handovers, etc.
- Use cases: Reliable Communication etc.

What We Can offer

- Integration with Core/MEC/IMS
- Wireshark log collection of link performance logs like NGAP, F1AP which intern provides all protocol, KPIs.

Industrial 4.0

Features

- Smart Factories & Automation
- Digital Twins & Simulation
- Internet of Things (IoT) & Connectivity
- Cybersecurity & Data Protection

Performance

- Users: up to1K ~10K on multiple cells
- Coverage: around one square KM

Technical challenges

Integration with Legacy controllers like devices supporting PLC, etc

What you can do

- Integration with Sensors and controllers of industrial systems.

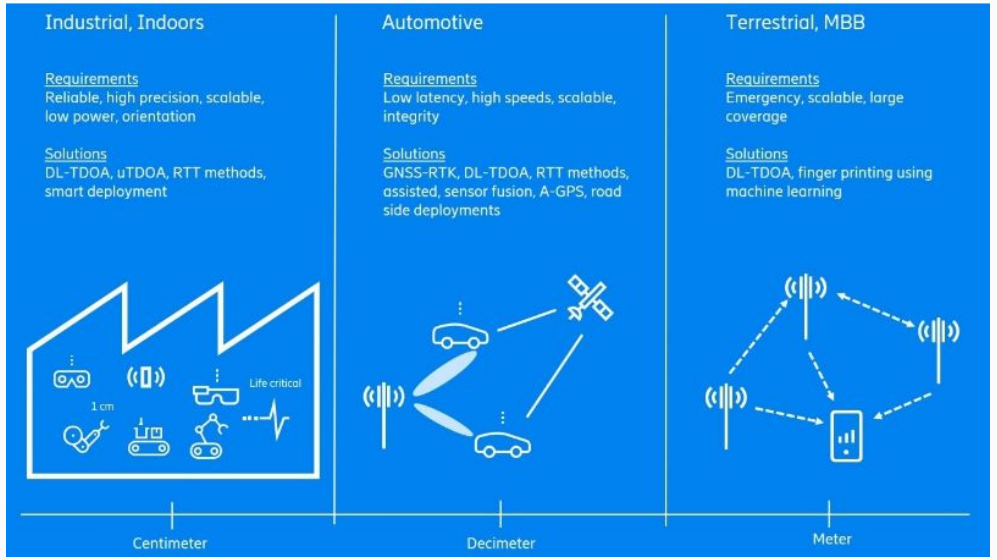
What We Can offer

- Wireshark log collection of link performance logs like NGAP, F1AP which intern provides all protocol, KPIs.

5G Drone Corridor

- 5G Connectivity & Network Infrastructure
  - High-speed, low-latency communication via **5G towers and satellites**
- Digital Air Traffic Management (ATM)
  - Holographic pathways or virtual lanes to guide drones and avoid collisions.
  - Geofencing to restrict drones from unauthorized areas.
- Autonomous Navigation & AI Integration
  - Edge computing for real-time processing onboard drones.
  - 5G positioning, GPS and sensor fusion for accurate positioning.
  - AI-powered collision avoidance systems.
- Applications
  - Logistics & Delivery, Surveillance & Security, Agriculture & Precision Farming, Disaster Relief & Emergency Response, Military & Defense

5G Positioning is the key !!



https://www.ericsson.com/en/blog/2020/12/5g-positioning--what-you-need-to-know

What you can do

- Indoor and Outdoor positioning, etc. with LMF, etc.

What We Can offer

- Wireshark log collection of link performance logs like NGAP, F1AP which intern provides all protocol, KPIs.

Systems & Sensors -Requirements

Use Case	Typical Speed Requirement	Notes
	Everyday Communication	
Voice Calls (VoIP / Telephony)	100 Kbps – 1 Mbps	Low latency & jitter are critical
Web Browsing / Email	1 – 5 Mbps	Basic tasks, very low requirements
	Entertainment & Streaming	
HD Video Streaming (1080p)	5 – 10 Mbps	Netflix recommends ~5 Mbps
4K Ultra HD Streaming	15 – 25 Mbps	Netflix/YouTube suggest 25 Mbps
Cloud Gaming	15 – 50 Mbps	High speeds + <20 ms latency
	Work & Education	
Video Conferencing (Zoom, Teams, Meet)	2 – 6 Mbps (HD), ~8 Mbps (Full HD)	Stability is more important than speed
Online Education (Virtual Classroom)	2 – 5 Mbps	Similar to conferencing
	Emerging Applications	
Augmented/Virtual Reality (AR/VR)	50 – 200 Mbps + <10 ms latency	Needs high throughput & ultra-reliability
Autonomous Vehicles (V2X)	~10 Mbps (control), >100 Mbps (sensors)	Ultra-low latency (<1 ms) required
	Industrial & Infrastructure	
IoT Devices (Smart Home, Sensors)	Few Kbps – few Mbps	Low power, small data packets
Industrial IoT / Smart Factories	10 Mbps – 1 Gbps	Reliability & deterministic latency key
Smart Cities (CCTV, traffic systems)	10 – 100 Mbps per cluster	Heavy video + real-time control
Cloud Backup / Large File Transfer	100 Mbps – multi-Gbps	Enterprises use 10–100 Gbps fiber
High-End Data Centers	10 – 400 Gbps per link	Fiber backbone with ultra-high throughput

Communications

Communication

Why Do We Need Communication?
- Voice, Video, and Data (browsing, control, collaboration)
- Enables personal, business, and IoT connectivity

What is Wireless?
- No Cables – communication via radio signals
- Flexible, mobile, and easy to deploy

Performance & Cost
- Speed: Wireline still offers higher peak speeds
- Cost: Similar today – driven by semiconductor tech & volume production
- Benchmarks: bit/Hz/price, calls/sec, cost per Gbps
- CapEx: One-time installation cost
- OpEx: Wireless often lower than wireline due to easier maintenance

Is Wireless Meeting Today's Needs?
- Yes – Keeps up with daily application demands
- In-home: 100 Mbps to 1 Gbps with ease
- Outdoor: ~100 Mbps typical

Why Wireless Can Be More Suitable
- Quick, simple setup – avoids complex cable installation
- Ideal for mobility and evolving layouts
- Rapid scalability for new users and locations

Fading memories

Recent

Wireless and wireline coexist: Wireless excels for indoor and city-limit connectivity, while intercity communication relies on wireline—typically via high-speed optical fiber cables.

Wireline

Wireline Medium	Technology Examples	Typical Speed Range	Notes
Twisted Pair (Copper)	DSL (ADSL, VDSL); Ethernet (Cat 5e–Cat 8)	DSL: 1 Mbps – 300 Mbps (distance-dependent) Ethernet: 100 Mbps – 10 Gbps (Cat 5e–6a) Up to 40–100 Gbps (Cat 8, short distance)	Used in last-mile broadband and LAN cabling
Coaxial Cable	DOCSIS (Cable Internet); Cable TV systems	DOCSIS 3.1: 1–10 Gbps down / 1–2 Gbps up DOCSIS 4.0: up to 10 Gbps symmetrical	Shared medium, actual speeds vary with network load
Optical Fiber	GPON, XGS-PON, NG-PON2; Backbone DWDM systems	GPON: 1–2.5 Gbps XGS-PON: 10 Gbps NG-PON2: 40 Gbps+ DWDM backbone: 100 Gbps – 1 Tbps per channel	Highest capacity, long-distance, future-proof
Power Line Communication (PLC)	HomePlug AV/AV2; G.hn (Gigabit Home Networking)	HomePlug AV2: 200 Mbps – 1.2 Gbps G.hn: 1–2 Gbps (ideal conditions)	Strongly affected by wiring quality and interference

Wireless

Wireless Medium	Technology Examples	Typical Speed Range	Notes
Radio Frequency (Wi-Fi)	Wi-Fi 4 (802.11n); Wi-Fi 5 (802.11ac); Wi-Fi 6/6E (802.11ax); Wi-Fi 7 (802.11be, upcoming)	Wi-Fi 4: ~300 Mbps Wi-Fi 5: ~3.5 Gbps Wi-Fi 6/6E: ~9.6 Gbps Wi-Fi 7: ~40 Gbps (theoretical)	Short range, high throughput, interference prone
Cellular (Mobile Networks)	3G (UMTS/HSPA+); 4G LTE; 5G NR (sub-6 GHz & mmWave); 6G (research)	3G: ~1–10 Mbps 4G LTE: ~100 Mbps – 1 Gbps 5G: 1–10 Gbps (lab: 20 Gbps) 6G: >100 Gbps (expected)	Wide area coverage, supports mobility
Microwave (Point-to-Point)	Licensed microwave backhaul; 5G mmWave	1–10 Gbps (short range)	Used for backhaul and fixed links
Infrared (IR)	TV remotes; IR data transfer (legacy)	Few Kbps – few Mbps	Line-of-sight, very short range
Optical Wireless (FSO, LiFi)	Free-Space Optics; LiFi	FSO: 1–10 Gbps (clear conditions) LiFi: 1–10 Gbps+	High-speed but requires line-of-sight
Satellite Links	GEO (Geostationary); MEO; LEO (e.g., Starlink)	GEO: ~100 Mbps MEO: 100 Mbps – 1 Gbps LEO: 50–250 Mbps, moving towards 1 Gbps+	Global coverage, latency depends on orbit

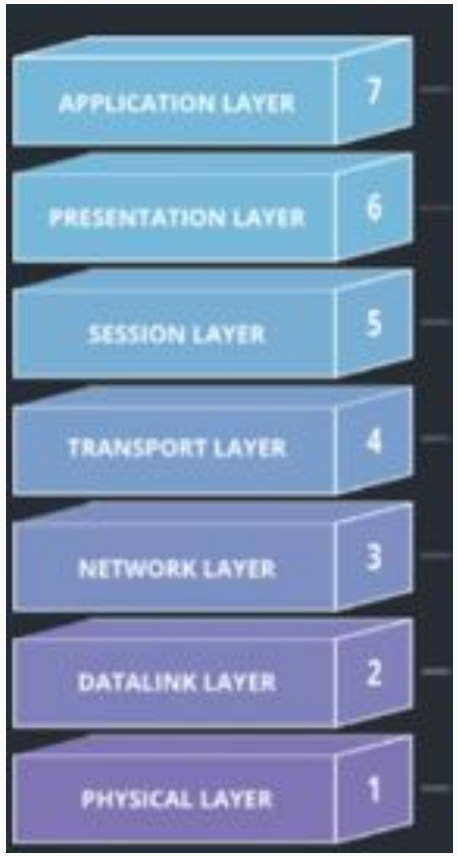
Standardization bodies (Popular)

Body	Full Name	Parent / Umbrella	Type / Status	Focus / Notable Work	Headquarters
ITU-T	International Telecommunication Union – Telecommunication	ITU (United Nations)	Sector of a UN specialized agency	Telecom standards, numbering, signaling, video/audio codecs	Geneva, Switzerland
3GPP	3rd Generation Partnership Project	Partnership of ETSI (Europe), ATIS (USA), ARIB & TTC (Japan), CCSA (China), TSDSI (India), TTA (Korea)	Collaborative project (not a legal entity)	Mobile communication standards (GSM, UMTS, LTE, 5G, 6G)	No HQ (hosted by ETSI, France)
IEEE	Institute of Electrical and Electronics Engineers	Independent	Professional association	Wi-Fi (802.11), Ethernet (802.3), floating-point arithmetic (IEEE 754)	New York, USA
IETF	Internet Engineering Task Force	Internet Society (ISOC) / IAB	Open community standards body	Internet protocols: TCP/IP, HTTP, DNS, IPv6, TLS	No formal HQ (global, supported by ISOC, Virginia USA)
ETSI	European Telecommunications Standards Institute	Independent (recognized by EU)	European SDO	GSM, role in 3GPP, digital video broadcasting (DVB)	Sophia Antipolis, France
ISO	International Organization for Standardization	Independent NGO (members = national standards orgs)	International NGO	Industrial & technical standards (ISO 9001, OSI model, ISO/IEC 27001)	Geneva, Switzerland
IEC	International Electrotechnical Commission	Independent	International NGO	Electrotechnical standards, works jointly with ISO	Geneva, Switzerland
ANSI	American National Standards Institute	Independent	U.S. private non-profit standards body	ANSI C, SQL, represents U.S. in ISO & IEC	Washington, D.C., USA

1G to 6G

Networking - OSI Layers

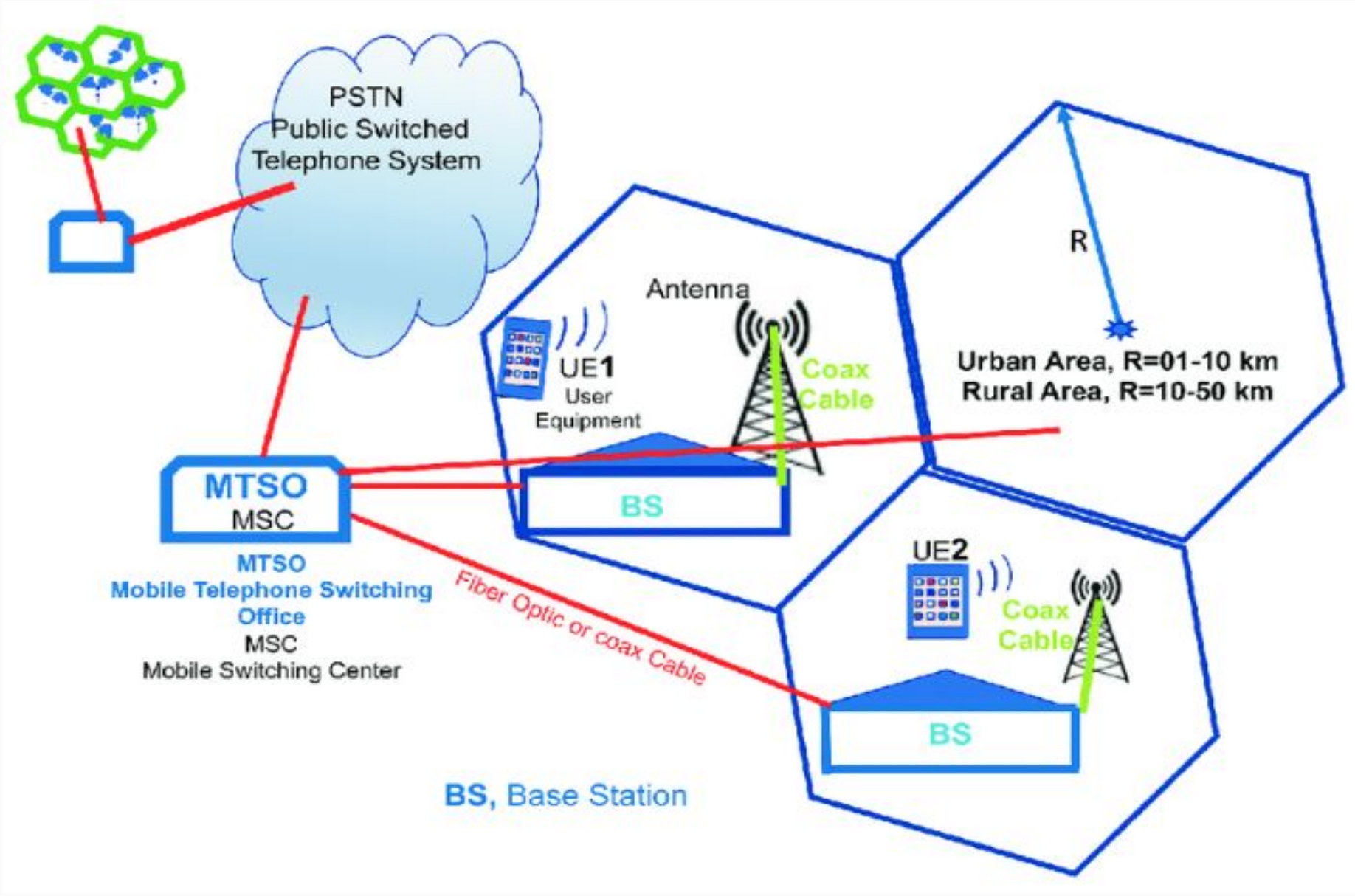
OSI Layer	3GPP / 5G Protocols & Functions	Description
Layer 1 – Physical Layer	**NR PHY (OFDMA), CORE (Ethernet)**	Handles modulation, coding, and physical transmission over radio waves.
Layer 2 – Data Link Layer	**MAC, RLC, PDCP (in RAN)**	Manages framing, error correction, retransmission, and logical link control.
Layer 3 – Network Layer	**RRC (Radio Resource Control), GTP-U (in Core), IP**	RRC controls connections; GTP-U tunnels user data; IP provides addressing.
Layer 4 – Transport Layer	**TCP, UDP, SCTP**	Provides reliable (TCP/SCTP) or connectionless (UDP) transport of signaling/data.
Layer 5–7 – Application Layers	**NAS (AMF/SMF signaling), IMS (SIP/VoNR), Service Applications**	Handles mobility management, session management, and multimedia/VoNR services.



1G to 6G

Generation	Era	Technology	Access / Core	Data Rate	Latency	Key Features
1G	1980s	**Analog Voice**	FDMA / PSTN	~10 kbps	~500 ms	Voice only (AMPS)
2G	1990s	**Digital Voice & SMS**	TDMA/CDMA / MSC	56–114 kbps	~300 ms	Voice, SMS, GPRS
3G	2000s	**Mobile Internet**	WCDMA / CS+PS	384 kbps–2 Mbps	~100 ms	Voice + Data, Video Call
4G	2010s	**Mobile Broadband**	OFDMA / EPC	100 Mbps–1 Gbps	~10 ms	All-IP, VoLTE, HD Streaming
5G	2020s	**Smart Connectivity**	OFDMA / 5GC	1–20 Gbps	~1 ms	eMBB, URLLC, mMTC, Network Slicing
6G	~2030	**AI-Driven Intelligent Network**	THz / AI Core	Up to 1 Tbps	<0.1 ms	AI-native, Quantum-secure, Holographic, Global 3D Coverage

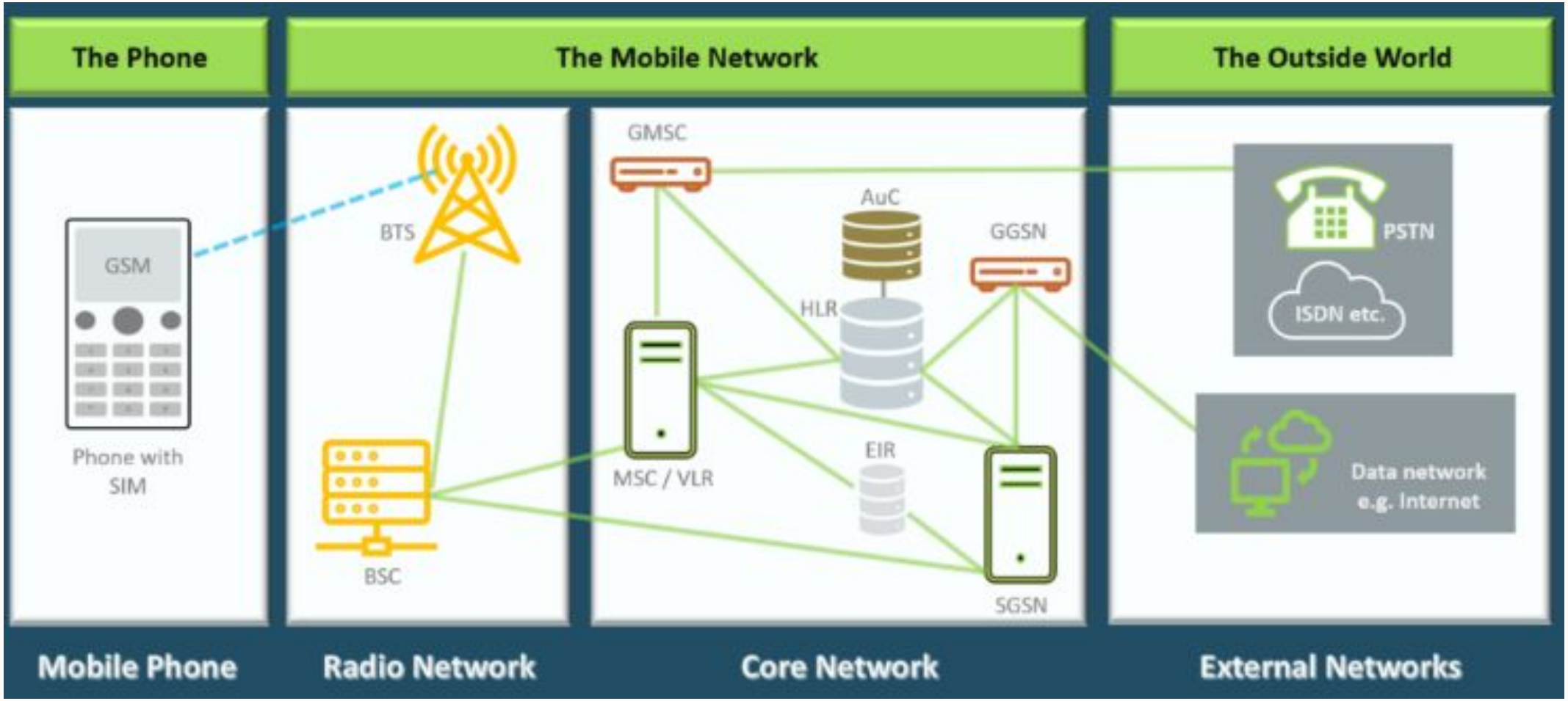
1G AMPS(Advanced Mobile Phone System)



1G AMPS

OSI Layer	AMPS	Description	Typical Throughput
Layer 1 – Physical Layer	**Analog FM (FDMA)**	Voice and control transmitted via analog FM; each call used one 30 kHz channel.	~10–12 kbps (effective bandwidth for signaling tones within 30 kHz channel)
Layer 2 – Data Link Layer	**Supervisory Audio Tone (SAT), Signaling Tone (ST)**	Simple analog tones (e.g., 5970/6000/6030 Hz) for supervision (call setup, handoff, disconnect).	Few hundred bits per second (tone-based control)
Layer 3 – Network Layer	**Control Channels (FOCC/RECC)**	Forward (FOCC) and Reverse (RECC) control channels for registration, paging, and call setup.	~10 kbps on control channels
Layers 4–7 – Transport to Application	**Analog Voice Path**	No digital data — direct analog audio voice transmission via FM modulation.	~3.1 kHz voice bandwidth (~64 kbps PCM equivalent when digitized)

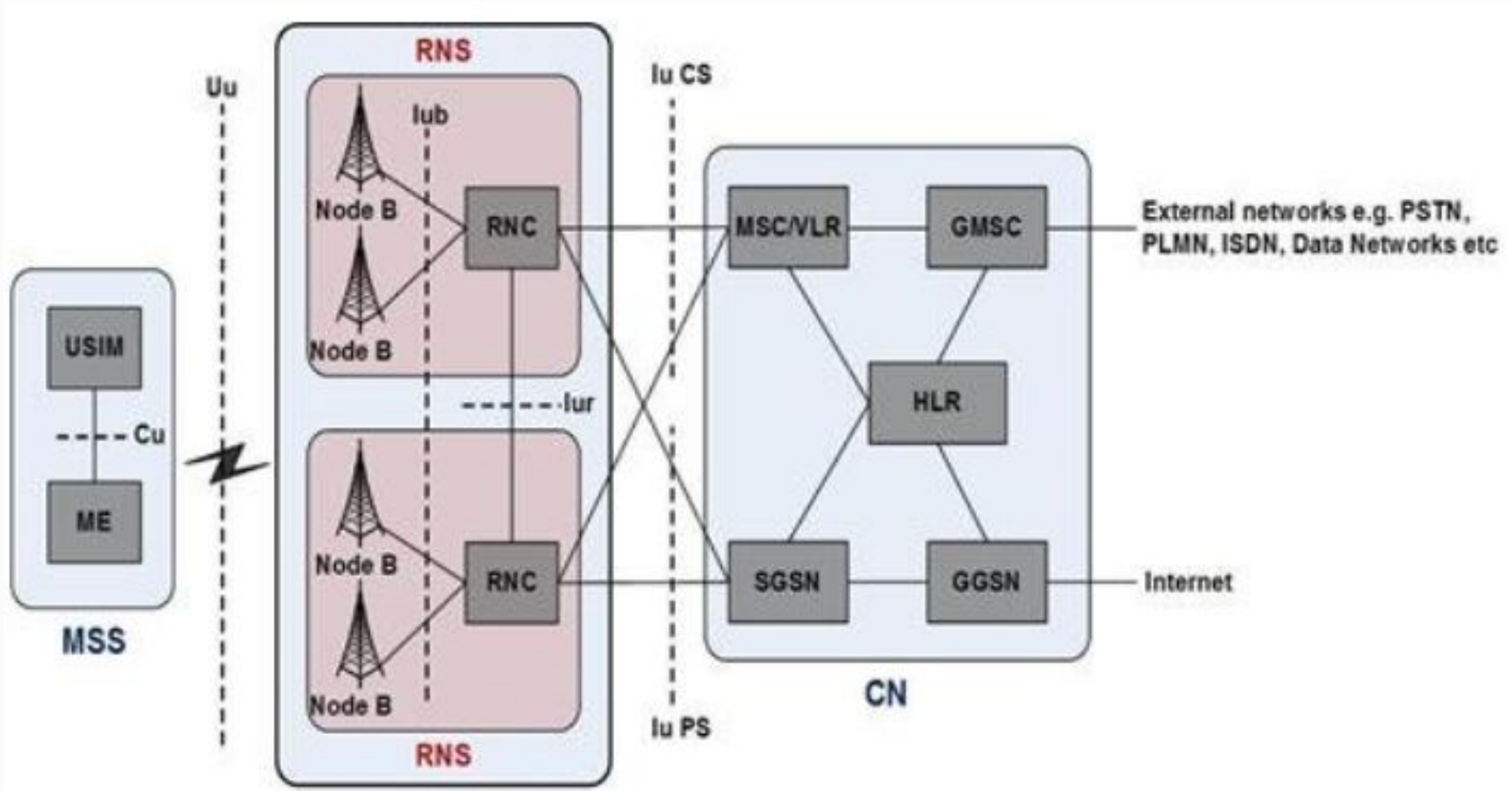
2G GSM/GPRS


The Phone
The Mobile Network
The Outside World
GSM
Phone with SIM
BTS
BSC
GMSC
AuC
GGSN
HLR
MSC / VLR
EIR
SGSN
PSTN
ISDN etc.
Data network e.g. Internet
Mobile Phone
Radio Network
Core Network
External Networks

2G GSM/GPRS

OSI Layer	GSM / GPRS	Description	Typical Throughput
Layer 1 – Physical	**GSM Radio Interface (TDMA, GMSK)**	Digital modulation over 200 kHz channels (8 time slots per carrier).	GSM: 270.8 kbps raw / per timeslot ~33.8 kbps
Layer 2 – Data Link	**LAPDm (GSM), RLC/MAC (GPRS)**	Provides error detection, retransmission, and logical link control.	GPRS: per timeslot ~21.4 kbps (theoretical)
Layer 3 – Network	**RR (Radio Resource), MM (Mobility Management), SM (Session Management)**	Handles connection setup, mobility, and session establishment.	Control signaling only (~1–3 kbps effective)
Layer 4 – Transport	**UDP/TCP over IP (for GPRS)**	Enables transport of data packets for internet access.	GPRS user data ~56–114 kbps (multi-slot, ideal)
Layer 5–7 – Application	**Voice, SMS, WAP, Internet Apps**	Voice, text messaging, and basic data services.	Application throughput depends on radio & coding scheme (CS-1 to CS-4).

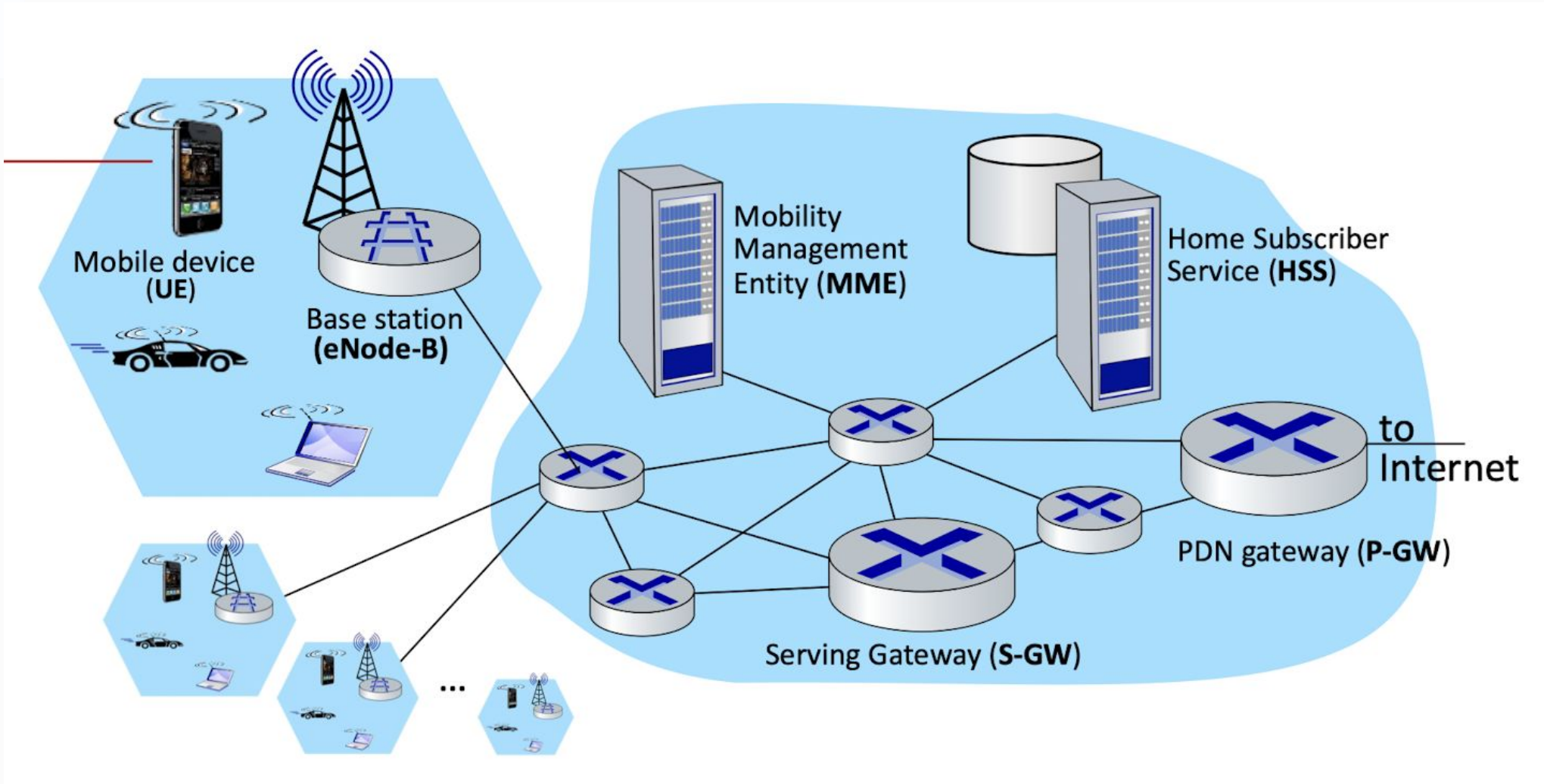
3G UMTS(Universal Mobile Telecommunications System)



3G UMTS(Universal Mobile Telecommunications System)

OSI Layer	UMTS	Description	Typical Throughput
Layer 1 – Physical	**WCDMA (Wideband CDMA)**	Spreads signal across 5 MHz carrier; supports soft handover and variable data rates.	Up to 384 kbps (Release 99); up to 2 Mbps (Release 5 HSPA)
Layer 2 – Data Link	**MAC, RLC, PDCP, BMC**	Handles multiplexing, retransmission (ARQ), segmentation, and ciphering.	384 kbps – 2 Mbps (depends on channel and coding)
Layer 3 – Network	**RRC (Radio Resource Control)**	Manages radio bearers, mobility, and power control.	Control signaling only
Layer 4 – Transport	**UDP / TCP / GTP-U**	Carries packet data over the core (user plane).	User data throughput same as air interface
Layers 5–7 – Application	**NAS (MM, SM), IP Apps, IMS**	Mobility/session management, IP services, VoIP, video, and web access.	Up to several Mbps with HSPA

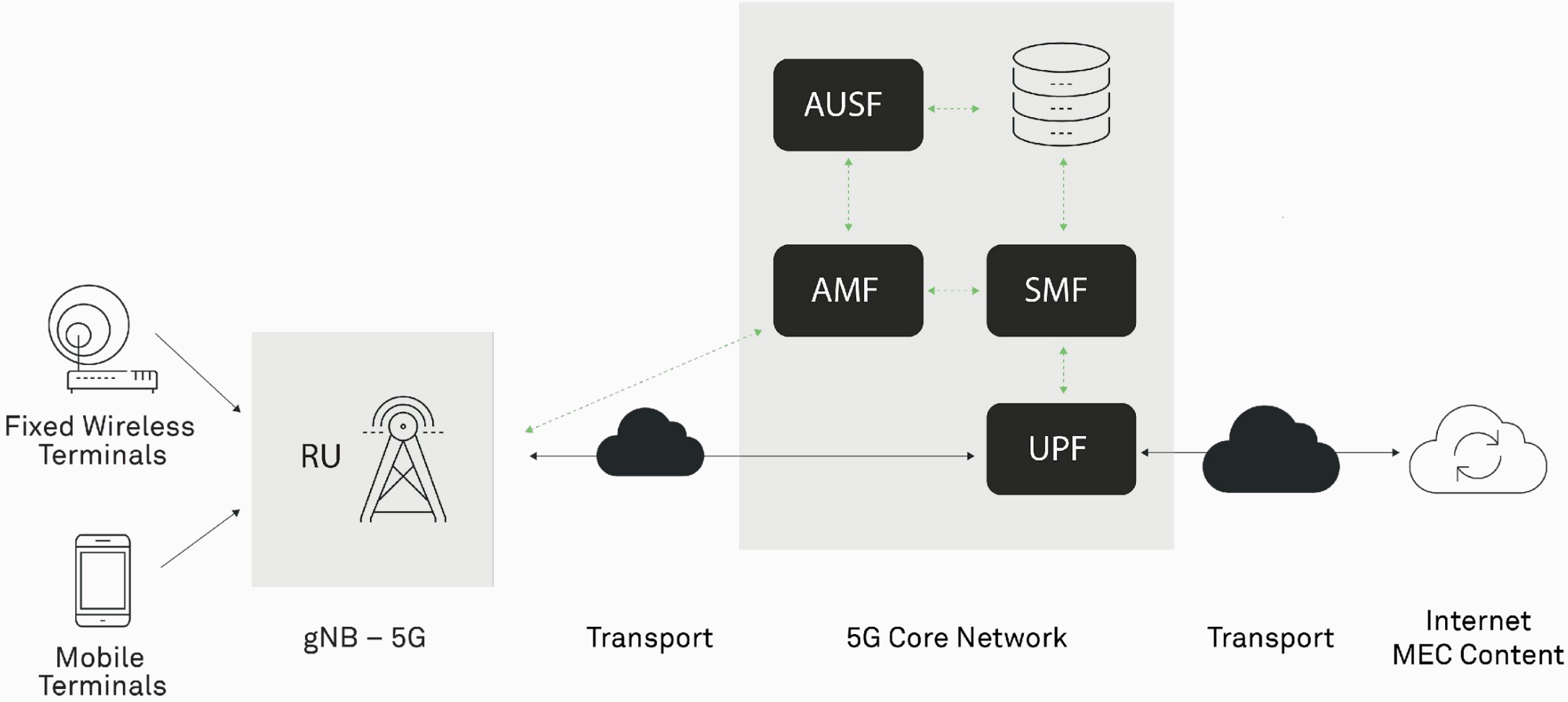
4G LTE(Long Term Evolution)



4G LTE(Long Term Evolution)

OSI Layer	LTE	Description	Typical Throughput
Layer 1 – Physical	**OFDM / SC-FDMA**	Radio interface using OFDMA (downlink) and SC-FDMA (uplink).	Up to 100 Mbps (DL) / 50 Mbps (UL) (Release 8)
Layer 2 – Data Link	**MAC, RLC, PDCP**	Handles scheduling, error correction, header compression, ciphering, and retransmission (ARQ).	~10–100 Mbps depending on modulation (QPSK/16QAM/64QAM)
Layer 3 – Network	**RRC (Radio Resource Control)**	Manages connections, mobility, and security between UE and eNodeB.	Signaling only
Layer 4 – Transport	**UDP / TCP / GTP-U**	User-plane data tunnels via GTP-U; signaling via S1-AP over SCTP.	User data throughput same as radio
Layers 5–7 – Application	**NAS (EMM/ESM), IMS, IP Apps**	Core services like registration, session management, VoLTE, and internet apps.	Up to 1 Gbps (with LTE-Advanced / Carrier Aggregation)

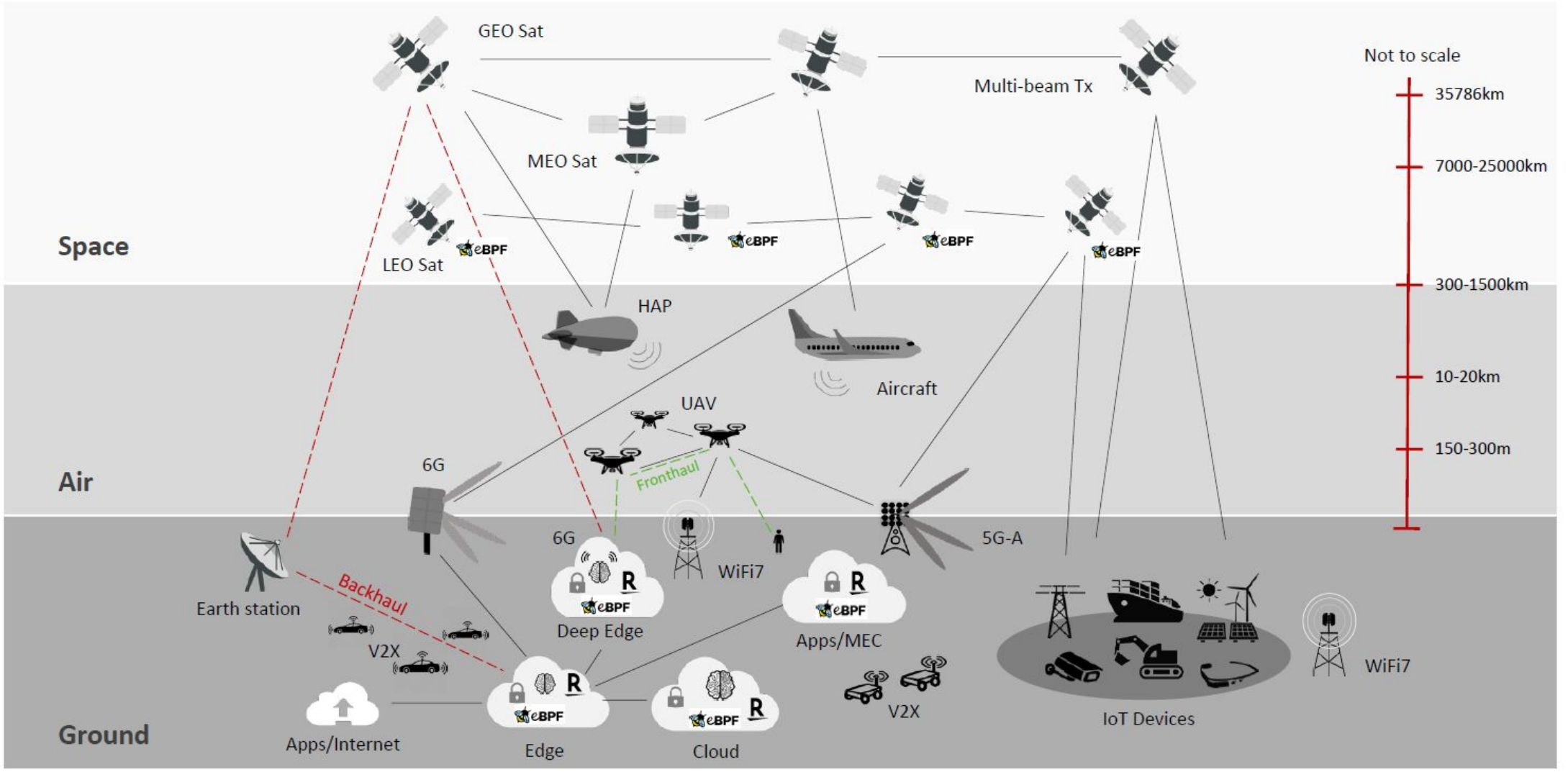
5G NR(New Radio)



5G NR(New radio)

OSI Layer	5G NR	Description	Typical Throughput
Layer 1 – Physical (PHY)	**OFDM (Flexible Numerology)**	Supports scalable subcarrier spacing (15–240 kHz), massive MIMO, beamforming.	Up to 20 Gbps DL / 10 Gbps UL (theoretical with mmWave)
Layer 2 – Data Link	**MAC, RLC, PDCP, SDAP**	MAC handles scheduling; RLC ensures retransmission; PDCP manages ciphering & compression; SDAP maps QoS flows to data bearers.	Multi-Gbps user throughput (depends on bandwidth, MIMO, and band)
Layer 3 – Network	**RRC (Radio Resource Control)**	Manages connection setup, mobility, and configuration between UE and gNB.	Control signaling only
Layer 4 – Transport	**UDP / TCP / SCTP / GTP-U**	User plane data tunnels over GTP-U; signaling over SCTP (NGAP).	Supports full user-plane throughput
Layers 5–7 – Application	**NAS, IMS, User Apps**	Registration, session management, VoNR/IMS, and IP-based services.	User experience: multi-Gbps data / <10 ms latency

6G


GEO Sat
Multi-beam Tx
MEO Sat
LEO Sat
eBPF
HAP
Aircraft
UAV
Fronthaul
6G
Space
Air
Ground
Not to scale
35786km
7000-25000km
300-1500km
10-20km
150-300m
Earth station
Backhaul
V2X
Apps/Internet
Deep Edge
Edge
Cloud
WiFi7
5G-A
Apps/MEC
IoT Devices

6G

Layer	6G Evolution / Equivalent	Description	Target Performance
Physical (L1)	**THz Radio, Sub-THz, Visible Light, Reconfigurable Intelligent Surfaces (RIS)**	Uses spectrum from **100 GHz to 1 THz** for extreme data rates and precision sensing.	Up to **1 Tbps** peak rate, **<100 µs** latency
Data Link (L2)	**AI-driven MAC & RLC, Dynamic Spectrum Sharing**	Intelligent scheduling, adaptive coding, and network self-optimization via machine learning.	>99.99999% reliability (URLLC++)
Network (L3)	**RRC+, AI-Enhanced Routing, Integrated Sensing and Communication (ISAC)**	Unifies communication and environment sensing; supports holographic and tactile connectivity.	Mobility up to **1000 km/h**
Transport (L4)	**Quantum-secure Transport (Post-Quantum TCP/UDP)**	Uses ultra-low overhead protocols with native encryption and deterministic latency.	Secure, ultra-fast end-to-end delivery
Application (L5–L7)	**Cognitive Services Layer (AI-native Core, Edge AI, Digital Twin Services)**	AI becomes part of the network fabric; supports metaverse, telepresence, robotics, autonomous systems.	Context-aware, self-learning services