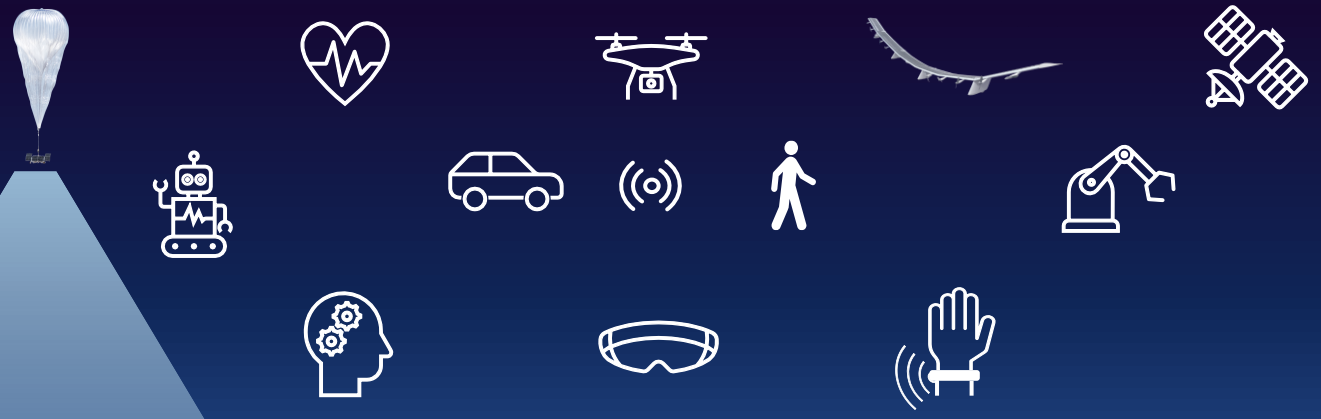


6G Mobile Wireless Communications

Vision, Roadmap, Technologies & Use Cases

6G Requirements

ZAHID GHADIALY

JANUARY 2021

@6Gtraining

@3g4gUK

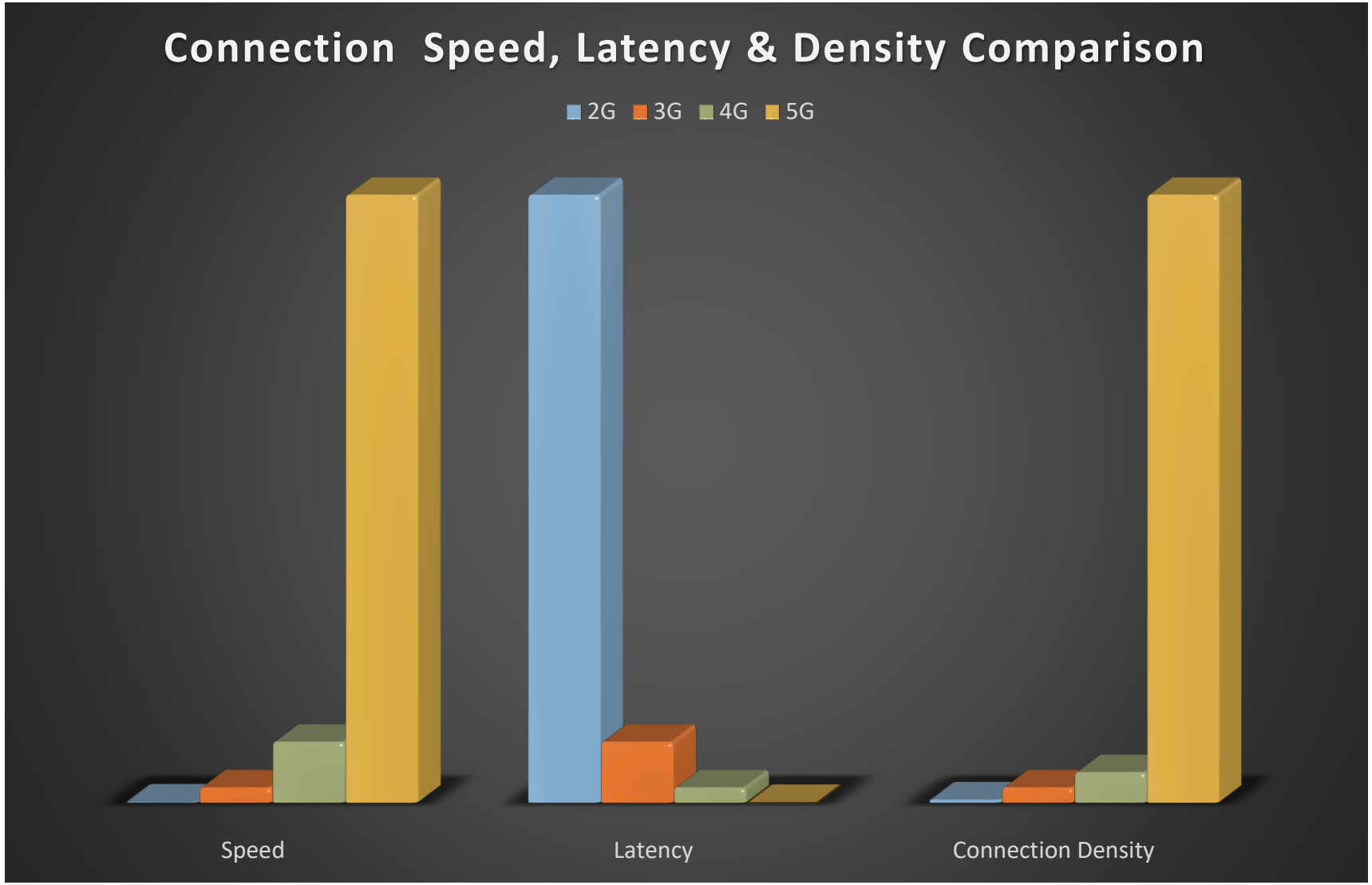
#Free6Gtraining

Comparison* of different Technology Generations

	2G	3G (HSPA+)	4G	5G
Year	1990	2000	2010	2020
Max DL Speed (theoretical)	473.6 Kbps	42 Mbps	3 Gbps	20 Gbps
Avg DL Speed (practical)	50 Kbps	8 Mbps	100 Mbps	300 Mbps
Max UL Speed (theoretical)	473.6 Kbps	11.5 Mbps	1.5 Gbps	10 Gbps
Avg UL Speed (practical)	50 Kbps	2 Mbps	50 Mbps	100 Mbps
E2E Latency (practical)	600 ms	120 ms	30 ms	10 ms
Reliability	99%	99.9%	99.99%	99.999%
Connection Density	N/a	N/a	10^5 devices/km^2	10^6 devices/km^2
Mobility	150 km/h	300 km/h	350 km/h	500 km/h

* Approximate values to show comparisons.

Comparison of 2G, 3G, 4G & 5G technologies



Example only.
Not according to scale

5G (IMT-2020) Requirements

ITU-R IMT-2020 requirements

>10 Gbps
Peak data rates

100 Mbps
Whenever needed

100 x
More devices than 4G

10000 x
More traffic than 4G

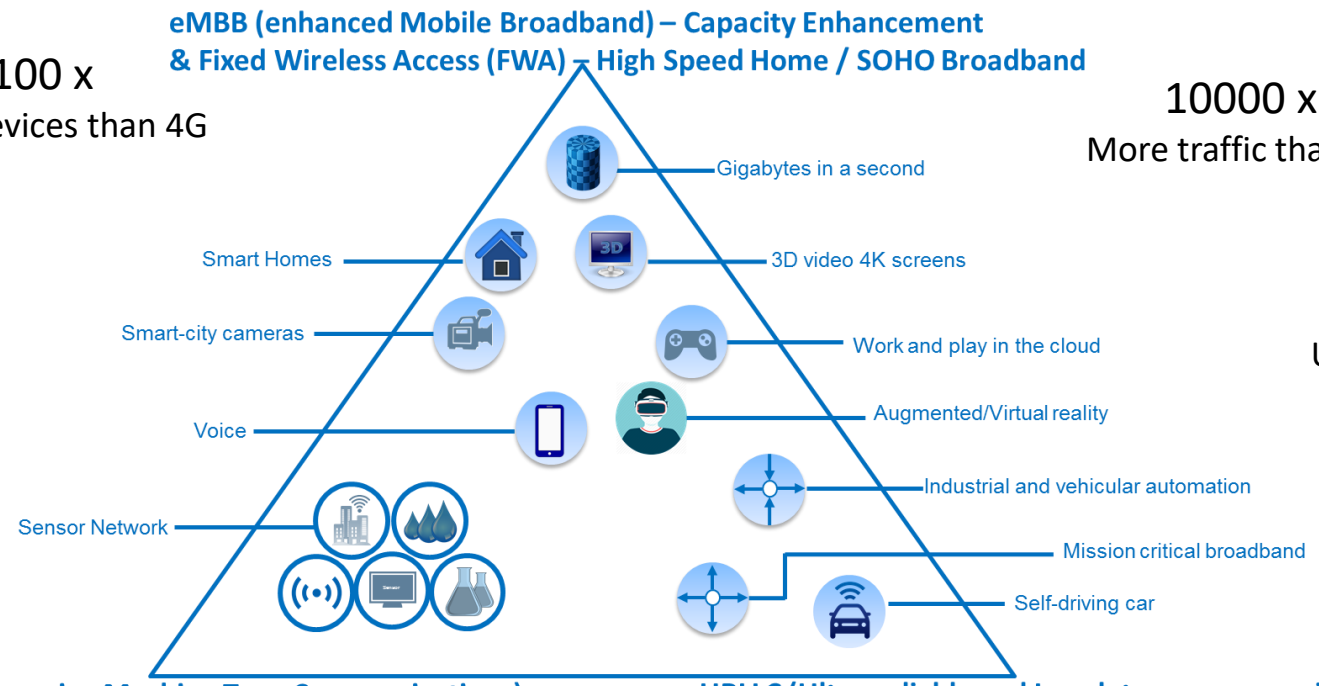
M2M
Ultra low cost

UR
Ultra-Reliable
(99.999%)

10 years
battery life

1,000,000
devices per km^2

< 1 ms
Low latency on
radio interface



5G Americas Next G Requirements

4.2.10 Summary: Use Cases to Tech Requirements

Technology Requirement	Use Case(s)	Notes
4.2.1 Very High Bandwidth	4.1.1 Holographic Communications 4.1.2 Tactile/Haptic Communications Appendix - Digital Twins	BW 0.5 – 1.0 Tbps
4.2.2. Very Wide Coverage	4.1.3 Ubiquitous Services Appendix - Massive Scale IoT Networks Appendix - Agriculture & Livestock	Gbps coverage everywhere with new coverage areas, e.g., sky (10000 m), sea (200 NM), space etc.
4.2.3 Enhanced Reliability	Appendix - Augmented Reality/ Virtual Reality/Mixed Reality Appendix - Digital Twins 4.1.2 Tactile/Haptic Communications 4.1.4 Medical/Health Appendix – Telesurgery 4.1.5 Government/National Security 4.1.7 First Responder/Emergency Services 4.1.9 Transportation Vertical	"seven 9's" availability (99.99999%)
4.2.4 High Density of Endpoints	Appendix - Massive Scale IoT Networks Appendix - Smart Agriculture & Livestock	10 million devices/km^2
4.2.5. Synchronization of Multiple Flows to Multiple Devices	Appendix - Augmented Reality/ Virtual Reality/Mixed Reality 4.1.1 Holographic Communications Appendix - Digital Twins 4.1.2 Tactile/Haptic Communications Appendix - Telesurgery	synchronized parallel media streams, originating in different points of network
4.2.6 Time Sensitive Operations	Appendix - Digital Twins 4.1.2 Tactile/Haptic Communications Appendix - Telesurgery 4.1.9 Transportation Vertical	air interface latency < 10 ns, E2E latency < 100 µs Jitter order of µs
4.2.7. Precise Location Tracking	Appendix - Augmented Reality/ Virtual Reality/Mixed Reality 4.1.2 Tactile/Haptic Communications 4.1.9 Transportation Vertical	Six degrees of motion: (x,y,z) plus pitch, yaw, and rotation
4.2.8. Extremely Low Power and Resource Constrained Devices	Appendix - Use Case: Massive Scale IoT Networks Appendix - Smart Agriculture & Livestock	Extremely low power including devices never to be charged (e.g., absorbing energy from its environment)
4.2.9 General Industry Requirements	4.1.8 Cyber-Physical Systems/ Manufacturing	

5G Americas Whitepaper: Mobile Communications Beyond 2020 - The Evolution of 5G Towards the Next G

NTT Docomo 6G Requirements

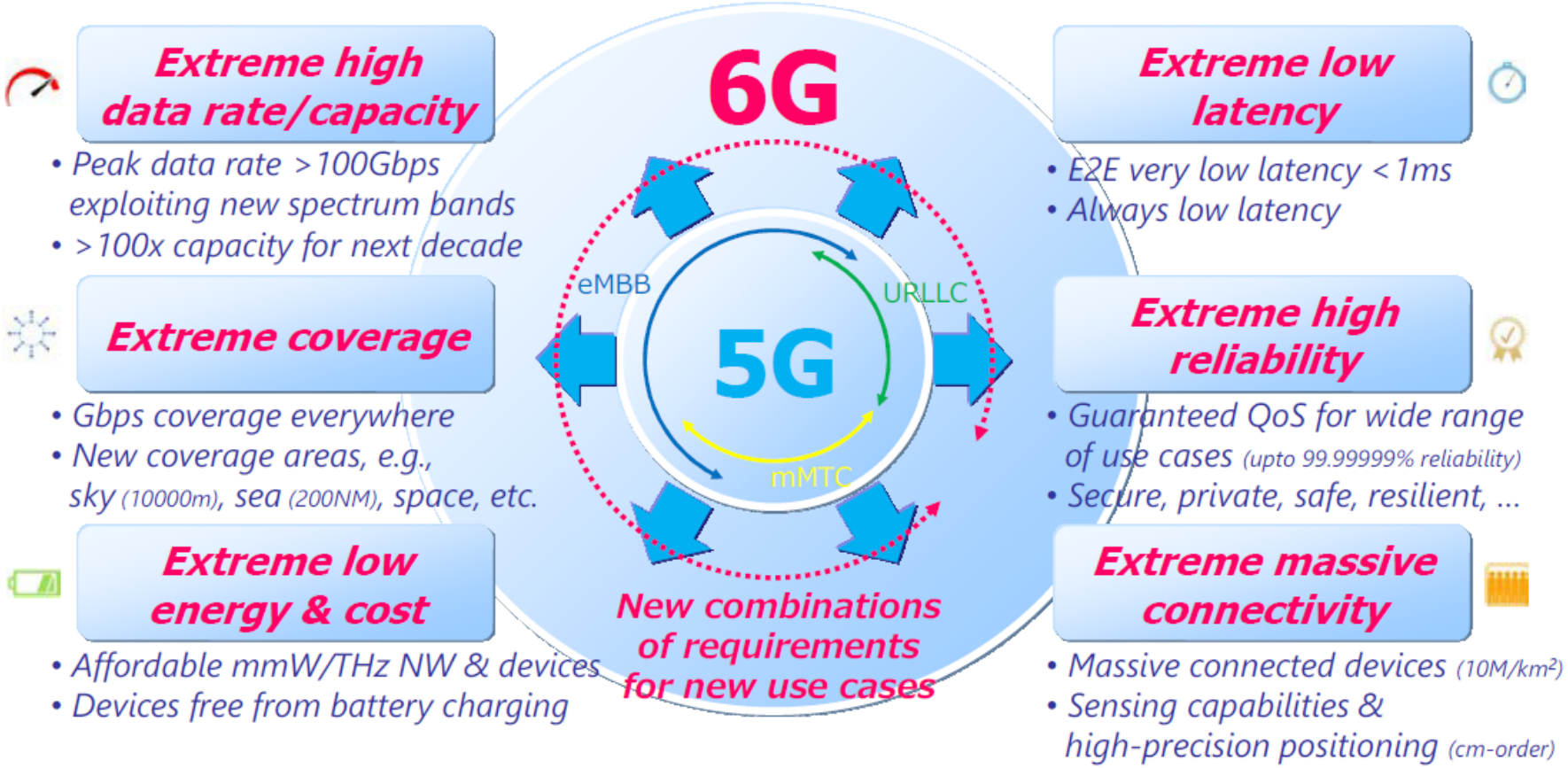


Figure 3-1. Requirements for 6G wireless technology

Source: NTT Docomo 6G Whitepaper, Jan 2020

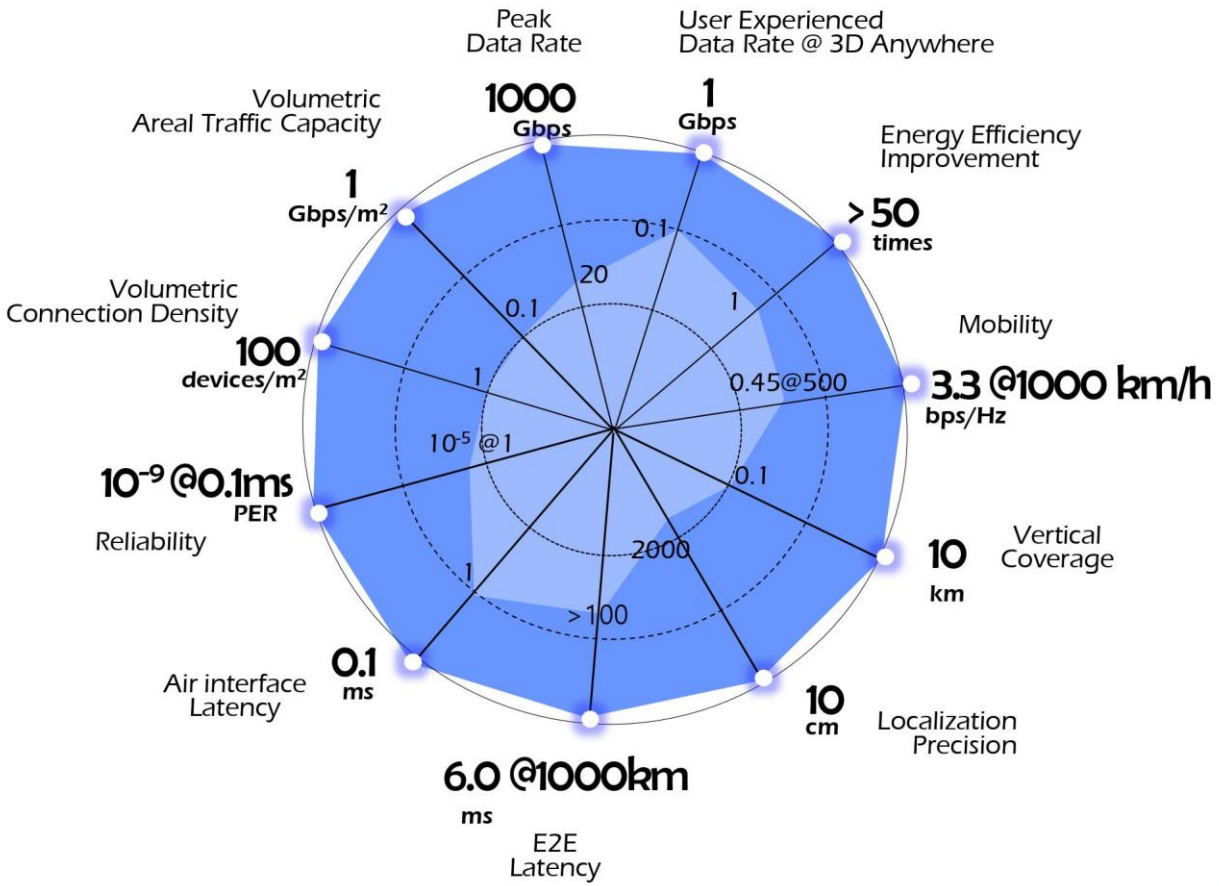
6G Research Visions, 5G & 6G KPIs Comparison

KPI	5G	6G
Peak data rate	20 Gb/s	1 Tb/s
Experienced data rate	0.1 Gb/s	1 Gb/s
Peak spectral efficiency	30 b/s/Hz	60 b/s/Hz
Experienced spectral efficiency	0.3 b/s/Hz	3 b/s/Hz
Maximum bandwidth	1 GHz	100 GHz
Area traffic capacity	10 Mb/s/m^2	1 Gb/s/m^2
Connection density	10^6 devices/km^2	10^7 devices/km^2
Energy efficiency	not specified	1 Tb/J
Latency	1 ms	100 µs
Reliability	$1\text{-}10^{-5}$	$1\text{-}10^{-9}$
Jitter	not specified	1 µs
Mobility	500 km/h	1000 km/h

Table 1: A comparison of 5G and 6G KPIs [4–6,9].

6G Research Visions: White Paper 10 on Broadband Connectivity in 6G

ETRI: 6G KPIs



Source: ETRI, South Korea (link)

6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies
Zhengquan Zhang; YUE XIAO; Zheng Ma; Ming Xiao; Zhiguo Ding; Xianfu Lei; George K Karagiannidis; Pingzhi Fan
https://ieeexplore.ieee.org/document/8766143/

		4G	5G	6G
Usage Scenarios		• MBB	• eMBB • URLLC • mMTC	• FeMBB • ERLLC • umMTC • LDHMC • ELPC
Applications		• High-Definition Videos • Voice • Mobile TV • Mobile Internet • Mobile Pay	• VR/AR/360° Videos • UHD Videos • V2X • IoT • Smart City/Factory/Home • Telemedicine • Wearable Devices	• Holographic Verticals and Society • Tactile/Haptic Internet • Full-Sensory Digital Sensing and Reality • Fully Automated Driving • Industrial Internet • Space Travel • Deep-Sea Sightseeing • Internet of Bio-Nano-Things
Network Characteristics		Flat and All-IP	• Cloudization • Softwarization • Virtualization • Slicing	• Intelligentization • Cloudization • Softwarization • Virtualization • Slicing
Service Objects		People	Connection (People and Things)	Interaction (People and World)
KPI	Peak Data Rate	100 Mb/s	20 Gb/s	≥1 Tb/s
	Experienced Data Rate	10 Mb/s	0.1 Gb/s	1 Gb/s
	Spectrum Efficiency	1×	3× that of 4G	5–10× that of 5G
	Network Energy Efficiency	1×	10–100× that of 4G	10–100× that of 5G
	Area Traffic Capacity	0.1 Mb/s/m^2	10 Mb/s/m^2	1 Gb/s/m^2
	Connectivity Density	10^5 Devices/km^2	10^6 Devices/km^2	10^7 Devices/km^2
	Latency	10 ms	1 ms	10–100 μs
	Mobility	350 km/h	500 km/h	≥1,000 km/h
Technologies		• OFDM • MIMO • Turbo Code • Carrier Aggregation • Hetnet • ICIC • D2D Communications • Unlicensed Spectrum	• mm-wave Communications • Massive MIMO • LDPC and Polar Codes • Flexible Frame Structure • Ultradense Networks • NOMA • Cloud/Fog/Edge Computing • SDN/NFV/Network Slicing	• THz Communications • SM-MIMO • LIS and HBF • OAM Multiplexing • Laser and VLC • Blockchain-Based Spectrum Sharing • Quantum Communications and Computing • AI/Machine Learning

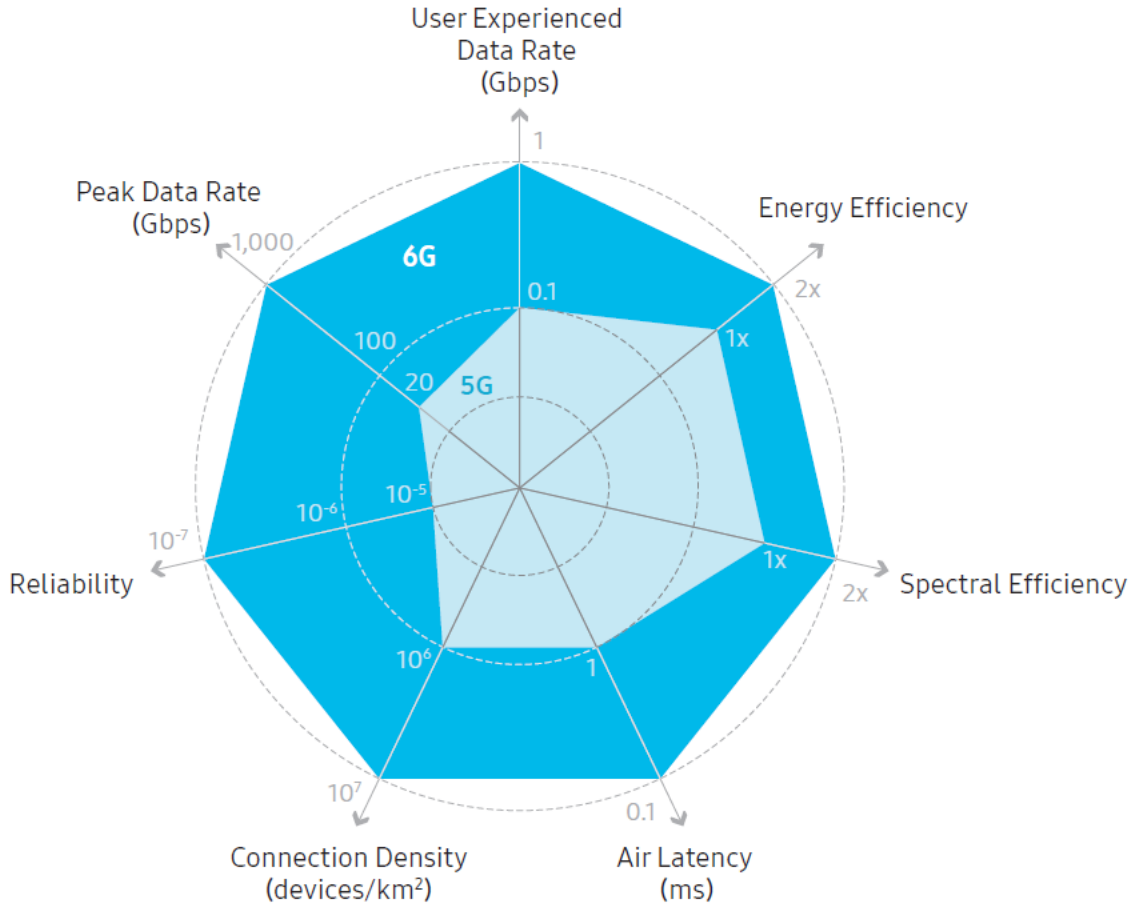
FIGURE 2 The network features of 4G, 5G, and the future 6G. AR: augmented reality; ELPC: extremely low-power communications; eMBB: enhanced mobile broadband; ERLLC: extremely reliable and low-latency communications; FeMBB: further-enhanced mobile broadband; LDHMC: long-distance and high-mobility communications; mMTC: massive machine-type communications; NFV: network function virtualization; SDN: software-defined networking; UHD: ultrahigh definition; umMTC: ultra-massive machine-type communications; URLLC: ultrareliable and low-latency communications; VR: virtual reality; V2X: vehicle to everything; KPI: key performance indicator; LDPC: low-density parity check codes.

Source

5G vs 6G Key Performance Requirements Comparison

Figure 7

Comparison of key performance requirements between 5G and 6G.



Samsung 6G Vision Whitepaper

Comparison* of different Technology Generations

	2G	3G (HSPA+)	4G	5G	6G**
Year	1990	2000	2010	2020	2030
Max DL Speed (theoretical)	473.6 Kbps	42 Mbps	3 Gbps	20 Gbps	1 Tbps
Avg DL Speed (practical)	50 Kbps	8 Mbps	100 Mbps	300 Mbps	1 Gbps
Max UL Speed (theoretical)	473.6 Kbps	11.5 Mbps	1.5 Gbps	10 Gbps	10 Gbps
Avg UL Speed (practical)	50 Kbps	2 Mbps	50 Mbps	100 Mbps	1 Gbps
E2E Latency (practical)	600 ms	120 ms	30 ms	10 ms	1 ms
Reliability	99%	99.9%	99.99%	99.999%	99.99999%
Connection Density	N/a	N/a	10^5 devices/km^2	10^6 devices/km^2	10^7 devices/km^2
Mobility	150 km/h	300 km/h	350 km/h	500 km/h	1000 km/h

* Approximate values to show comparisons. **Subject to change when standards process starts.

Background Material

- 3G4G: Bandwidth, Throughput, Latency & Jitter in mobile networks (link)
- 3G4G: Reliability - 5x9s vs 6x9s (link)

Further Reading

- 5G Americas: Mobile Communications Beyond 2020 – The Evolution of 5G Towards Next G, Dec 2020 (link)
- 6G Research Visions: White Paper 4 on Validation and Trials for Verticals towards 2030's, June 2020 (link)
- NTT Docomo white paper: 5G Evolution and 6G, January 2020 (link)
- 6G Research Visions: White Paper 10 on Broadband Connectivity in 6G, June 2020 (link)
- Z. Zhang et al., "6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies," in IEEE Vehicular Technology Magazine, 28-41, Sept. 2019 (link)
- The 3G4G Blog: NTT Docomo's Vision on 5G Evolution and 6G (link)

Thank You

To learn more, visit:

3G4G Website – https://www.3g4g.co.uk/

3G4G Blog – https://blog.3g4g.co.uk/

Telecoms Infrastructure Blog – https://www.telecomsinfrastructure.com/

Operator Watch Blog – https://www.operatorwatch.com/

Connectivity Technology Blog – https://www.connectivity.technology/

Free 5G Training – https://www.free5gtraining.com/

Free 6G Training – https://www.free6gtraining.com/

Follow us on Twitter: https://twitter.com/3g4gUK

Follow us on Facebook: https://www.facebook.com/3g4gUK/

Follow us on LinkedIn: https://www.linkedin.com/company/3g4g

Follow us on SlideShare: https://www.slideshare.net/3G4GLtd

Follow us on YouTube: https://www.youtube.com/3G4G5G