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On the Path to 6G: Target Capabilities and Technology Trends

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Mega Trends to 6G

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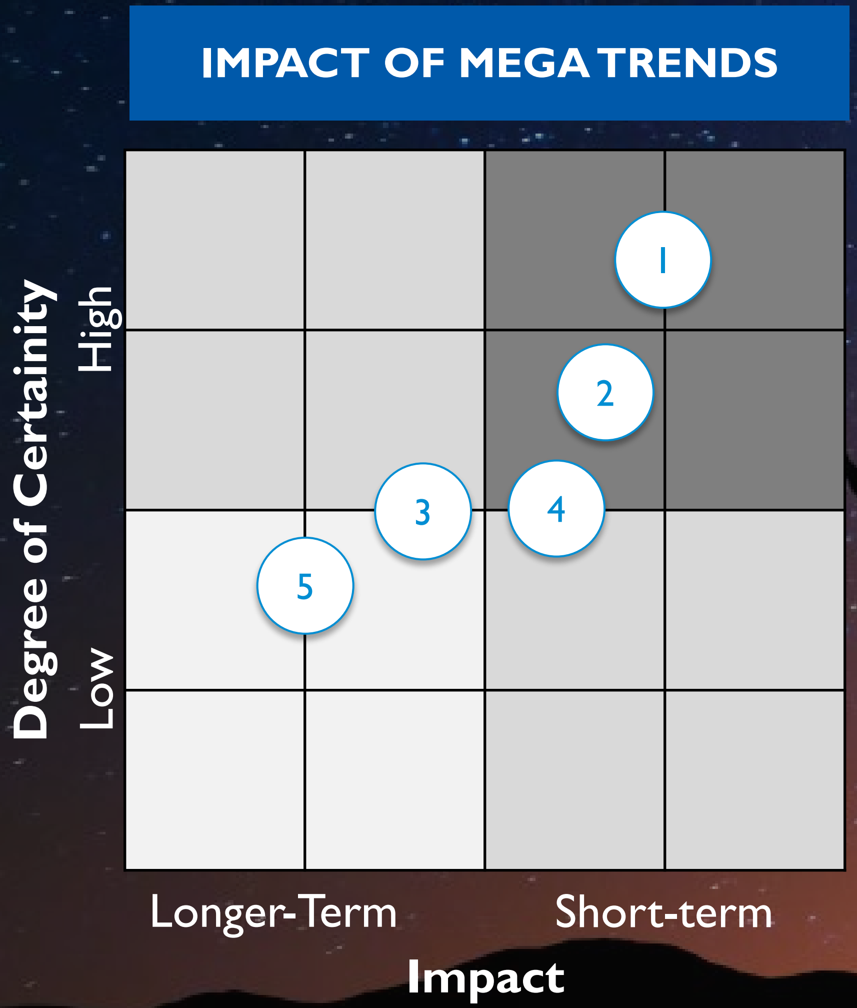
Mega Trends Underpinning the Path to 6G



- (1) Stakeholders race for 6G research leadership — MARKET TREND
- (2) Momentum for support of more Verticals — MARKET TREND
- (3) Rise of data-driven networks with AI/ML — TECH TREND
- (4) Widespread virtualization and disaggregation — TECH TREND
- (5) Drive for new spectrum and new regulation — TECH TREND

Stakeholders race for 6G research leadership

Key Insight:

- *The race for 6G research leadership is ON*
- *Multi-billion (USD) Multi-year government-funded research programmes are launching*
- *Key stakeholders are announcing their 6G roadmaps and opening 6G Labs*

Impact:

Puts onus on the industry R&D to drive 6G research agendas and lead harmonization efforts on 2030 system vision, technology trends and requirements in international forums such as ITU-R, GSMA, and NGMN

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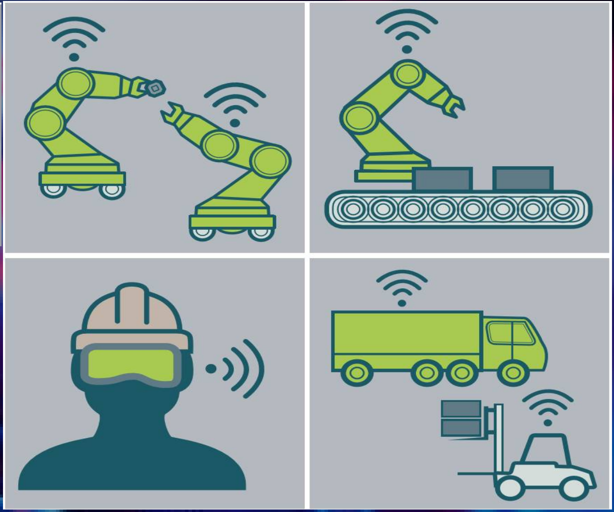
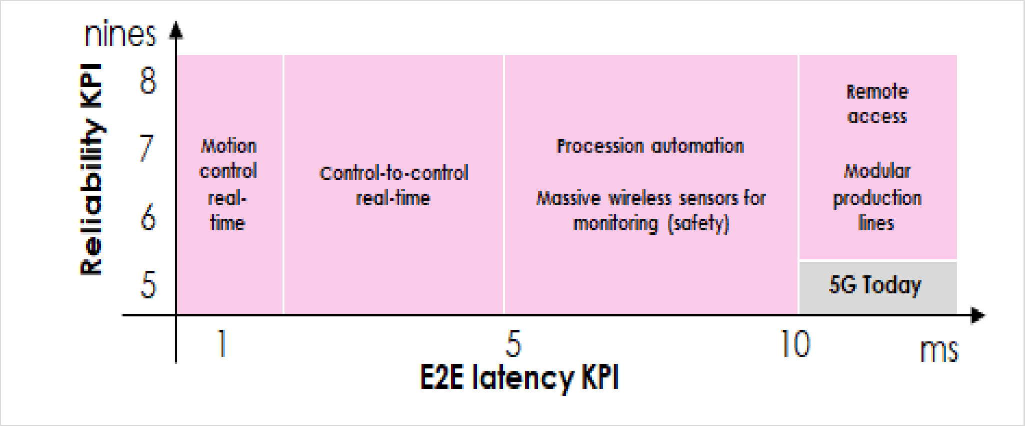
Momentum for support of more Verticals

5G ACIA
5G Alliance for Connected Industries and Automation

5G DNA
Deterministic Networking Alliance
确定性网络产业联盟





Key Insight:
Industrial applications (aka verticals) remain the biggest potential growth areas for wireless communications and a major driver in the evolution of wireless requirements

Impact:
Industry 4.0 describes a wide category of industrial internet use cases and it has become apparent that only a subset are addressable by current 5G KPIs. B5G/6G still has much work to do in the vertical markets that it has promised to support

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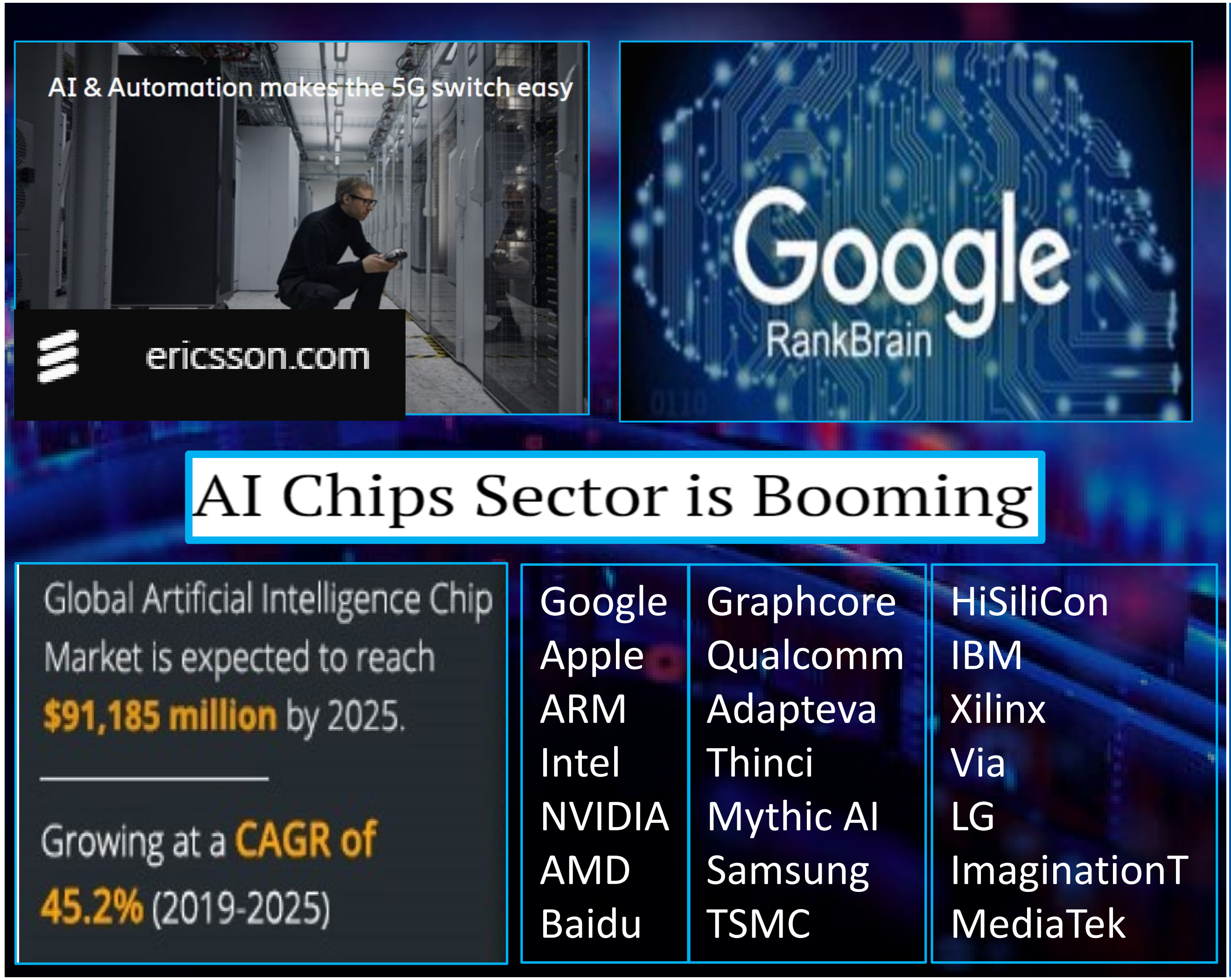
Rise of data-driven networks with AI/ML



Key Insight:
AI/ML has already deeply penetrated Web, network and chip technologies, and this trend will continue as AI/ML matures and more data becomes available

Impact:
Potential to disrupt the design of future wireless networks and devices, across all domains (core, access, edge, device)

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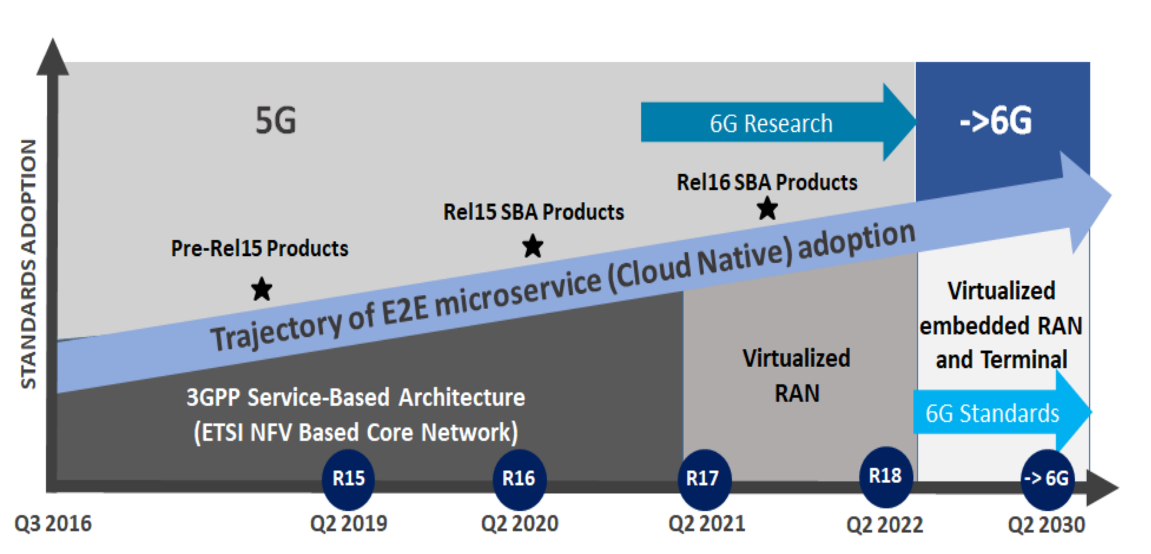
Widespread virtualization and disaggregation



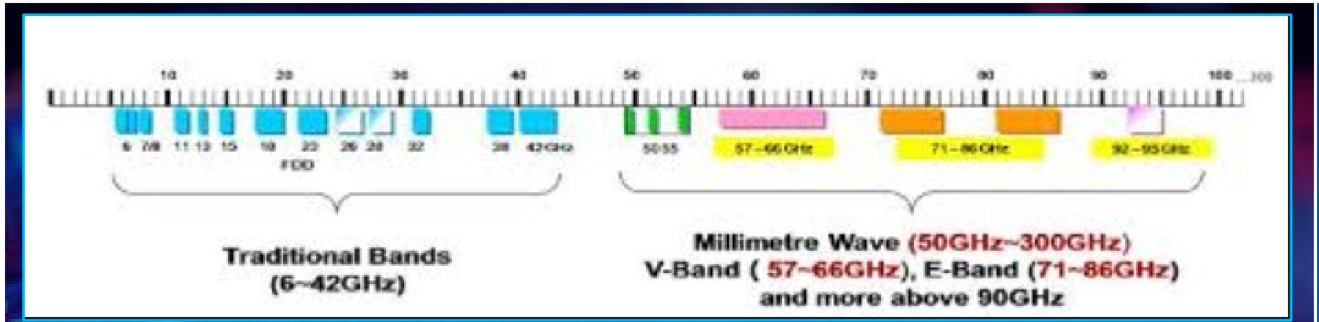
Key Insight:

- *5G is built on virtualization and it is critical in the vision of the Core Network and Edge with the momentum now gathering in RAN too (e.g. O-RAN, SD-RAN, OpenRAN)*

Impact:

This trend is disruptive in both technology and business factors (e.g. IPR, Regulatory) and even if technology challenges are overcome it may take until 6G before the full breadth & depth of possibilities are realized

Drive for new spectrum and new regulation



5G private licences spectrum in Europe

More contiguous spectrum
80-100 MHz per MNO
IN MID-BANDS AND
1 GHz per MNO
IN mmW

The 6GHz band is the widest band included in Resolution 245, and it has the potential of being an important band for citywide 5G services from 2025 onwards.

FCC Opens Spectrum Above 95 GHz, Encourages Experimentation

Key Insight:
Moving into higher frequency bands & new regulatory models is a key trend for achieving 100s of Gbps peak data rates over wireless and for driving more values from spectrum

Impact:
Fundamental problems begin to appear with digital design at above 100GHz, which promises a reengineering of several design elements including waveforms, codecs, massive MIMO, medium-access protocols

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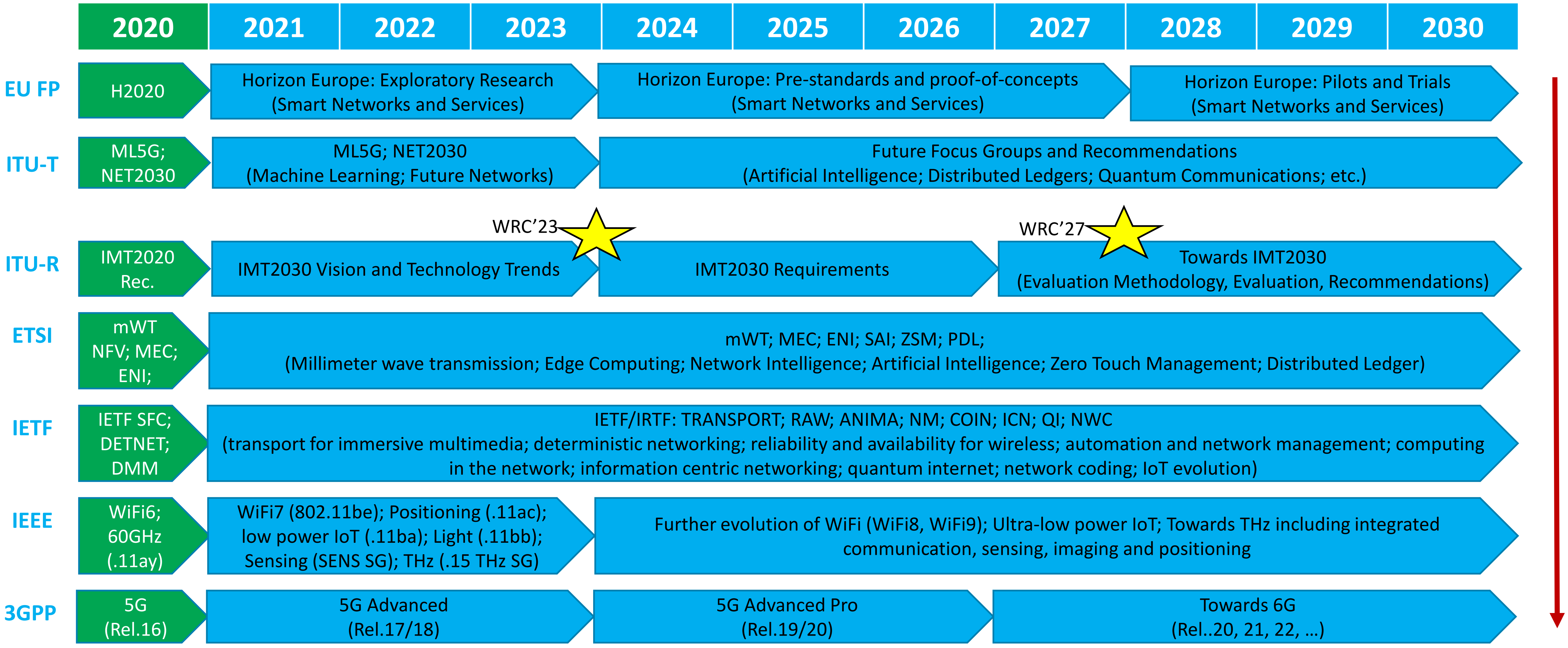
6G
Target Capabilities
Technology Trends

Key Forums Timelines



Future Wireless Capabilities

Wireless Capabilities	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030

	IMT-2020*	IMT-2030**
Spectrum	Up to 100 GHz	Carrier frequencies up to 300 GHz
Bandwidth	At least 100 MHz; Up to 1 GHz	Single channel bandwidth above 10 GHz
Peak data rate (DL/UL)	20 Gbps (DL) 10 Gbps (UL)	Peak data rate exceeding 200 Gbps (downlink) and 100 Gbps (uplink)
User data rate (DL/UL)	100 Mbps (DL) 50 Mbps (UL)	Average user data rate exceeding 1 Gbps (downlink) and 0.5 Gbps (uplink) for multi-sensory XR and volumetric media streaming
U-plane Latency	4 ms for eMBB 1ms for URLLC	U-plane latency below 0.5 ms for connected industries, autonomous vehicles and tactile use cases
C-Plane Latency	Below 20 ms (10 ms desired)	Control plane latency below 5 ms for connected industries, autonomous vehicles and tactile use cases
Reliability	Up to 5 nines	Reliability up to 8 nines for connected industries and autonomous vehicles
Connection Density	1 device per sqm	Connection density up to 10 devices per sqm (10m devices per km2) for ultra-massive sensor networks
Energy Efficiency	Qualitative	Terminal and network energy efficiencies up by 1000x today's values 5G system
Positioning Accuracy	NA	Positioning accuracy below 5 cm (indoor) and 10 cm (outdoor) helped by joint sensing and communications
Mobility	Up to 500 kmh	Mobility exceeding 1000 kmh for flying objects (e.g. airplanes) supported by the integration with non-terrestrial networks

*ITU-R Doc 5/40-E "Minimum requirements related to technical performance for IMT-2020 radio interface(s)", Feb 2017

**H2020 EMPOWER www.advancedwireless.eu

Future Wireless Technologies

Wireless Technologies	2020 (Today)	2021–2023	2024–2027	2028–2030 (Future)
Spectrum	Backhaul/Access: (1) sub-6 GHz; and (2) up to 100 GHz	Enhancements for up to 100 GHz; New spectrum (6-7 GHz; 100-170 GHz)	New design for spectrum above 100 GHz; AI-aided spectrum management; joint sensing and comms	New design for spectrum up to 300 GHz; Integrated sensing and comms
Massive MIMO	Centralized arch.; Up to 256 AAs; Digital/Digital-Analogue beamforming	Enhancements to beamforming for higher frequencies and multi-users	Larger antenna arrays (e.g. 512 or more) and super-directivity at higher frequencies; Distributed and coordinated multi-point schemes.	Holographic beamforming; PAAs of 1024 or more; Reconfigurable intelligent surfaces; AI-aided ultra massive MIMO
Waveforms	OFDM-based with flexible numerology	OFDM-based with new numerology tailored to new frequencies	New waveforms to cope with (1) massive MTC (e.g. UFMC); (2) higher frequencies (e.g. Impulse-based); (3) positioning accuracy; and (4) low power and higher energy efficiency	
Coding and Modulations	LDPC/Polar codes; Uniform constellations (up to 256QAM)	Enhancements to LDPC/Polar + QAM; Early non-uniform constellations	AI-aided channel codes (e.g. LDPC/Polar/Read-Muller) for 100s of Gbps throughputs; AI-aided constellation shaping and non-uniform constellations with orders exceeding 256QAM	
Multiple Access	Orthogonal T/F/C-DMA; TDD/FDD duplexing	Limited enhancements; Dynamic duplexing	Resurgence of non-orthogonal multiple access aided with AI; Resurgence of in-band full duplexing aided with AI	
Multi-connectivity	Dual connectivity (e.g. 3GPP); Dual-access (3GPP-WiFi)	Integrated access (licensed and unlicensed; 3GPP and WiFi); IAB enhancements	Multi-access-based multi-connectivity (terrestrial and non-terrestrial); (Wireless and optical wireless); AI-aided multi-access management	
Low power	Power saving (3GPP); and wake-up radio (IEEE 802.11)	Up to few 10's of % increase in IoE device-life, handset standby time	Zero-Energy TRX operating with 10's of nW; Energy harvesting including backscattering	AI/ML assisted self-sustaining devices reaching power density of 0.1W/mm2; Wireless power transfer
Positioning	Solutions <1m; Ongoing specs (.11az, 3GPP)	Improved accuracy <20 cm based on cooperative techniques, high frequencies and angular separation	Improved accuracy <10 cm based on integration with sensing and RF fingerprinting; Integration with non-terrestrial networks; and use of AI	

Future Network Capabilities

Network Capabilities	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030

	NET-2020	NET-2030*
Automation	Human operated	Self-operating requiring human operators to only validate the decisions
Flexibility	Service-based and slicing limited to core/transport	Fine-grain flexibility based on micro-services and improved end-to-end slicing (core; transport; access; device)
Service deployment time	Few hours	Reduced by a factor of 10 compared to similar tasks in 2020, based on slice creation and instantiation on the fly
Latency	Few tens of ms	Enabling application to application response time in the few milliseconds range
Determinism and Resilience	Limited to wired	Extended to support deterministic and resilient networking for industrial wireless
High network bandwidth	100s Gbps and a few biillion devices	Supporting Terabits per second throughputs and trillions of devices
Data-driven and distribution	Centralized big-data based analytics in core and cloud	Supporting small-data based distributed analytics and distributed AI
Energy consumption	Moderate	A significant energy reduction of network operation compared to 2020
EMF-awareness	Moderate	Support deployment in areas with challenging EMF limits (due to spectrum bands and network densification)
Coverage	Segregated terrestrial and satellite	Ubiquitous based on integration of terrestrial and non-terrestrial networks (satellites and HAPs)
Security and trust	Moderate	Enhanced security based on cyber-physical integration; AI; and quantum keys

*Reference: Horizon Europe, Smart Networks and Services, 2021-2027

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Future Network Technologies

Network Technologies 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030

Today **Future**

Edge native computing	Edge-cloud solutions; Ongoing specifications (ETSI MEC/3GPP)	Edge+5G integration; Distributed edge enhancements (e.g. microservices)	Inter-edge interworking and federation; Support for mobile and power-constrained edge hosts	AI-powered solutions and Apps; Seamless integration across domains and tech
Virtualization	SDN and NFV enablers; Mature specifications (e.g. ETSI NFV)	Lightweight virtualization (e.g. unikernels); Improved runtime perf.	Service continuity, elasticity and portability of virtual networking functions (VNF) in the core and RAN	Extensions for VNF support on board constrained mobile devices
Slicing	Key feature in 5GS; Ongoing specifications (3GPP)	Improved control of distributed resources, and inter-slice interworking	Support for "on the fly" slice creation, instantiation and scaling	
Deterministic and reliable networking	Deployed in wired networks; Specified in IETF and IEEE 802.1	Support for wireless (e.g. private networks)	Extended support for reliability and availability over wireless (e.g. IETF RAW); Enhanced determinism and time sensitivity to support time-critical (tactile) internet Apps	
Automation and Network AI/ML	Big-data based management solutions (OSS/BSS); Ongoing specifications (3GPP, ETSI)	AI-powered network control including for non-real time RAN management	Zero touch management; Small-data based distributed analytics and distributed AI for control and user planes	Full automation and distribution end-to-end including on-the-device
Non-terrestrial networks	Separate systems (GEO/LEO); Ongoing specification for future integration (e.g. 3GPP)	Convergence with terrestrial (e.g. virtualization, edge, slicing, latency)	Seamless integration with terrestrial (unified connectivity, extreme coverage)	Extensions for support of massive miniaturized (nano) satellites and HAPs
Distributed ledgers	Cloud-based solutions; Early specifications (e.g. ETSI PDL, SAI)	Blockchain for network data management and security	Blockchain for support of distributed networks, distributed AI, and distributed Edge	
Quantum Internet	Preliminary research started in IETF	Single hop experiments	Multi-hop deployments but with low # of Qubits	Initial roll out of larger scale networks with higher # of Qubits

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Conclusions - Takeaways

- **Today**, we are in quite early stages of the rollout of 5G and we do still have a long way to go with the evolution of this technology
- That said, now is historically the **right time to be asking what is next** and it is fair to say that the path ahead of us appears to be rich
- The **emerging use cases** for B5G/6G may seem quite familiar but hide a truth that 5G may only open the door to these roadmaps
- **Extreme requirements** will continue to push evolution of wireless well beyond 5G and in time will enable a new service experience
- Looking out to the future on the promising tech. trend lines it does appear that **there will be inflection points that may lead to a 6G**

Acknowledgement

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