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Technology Trends towards 6G

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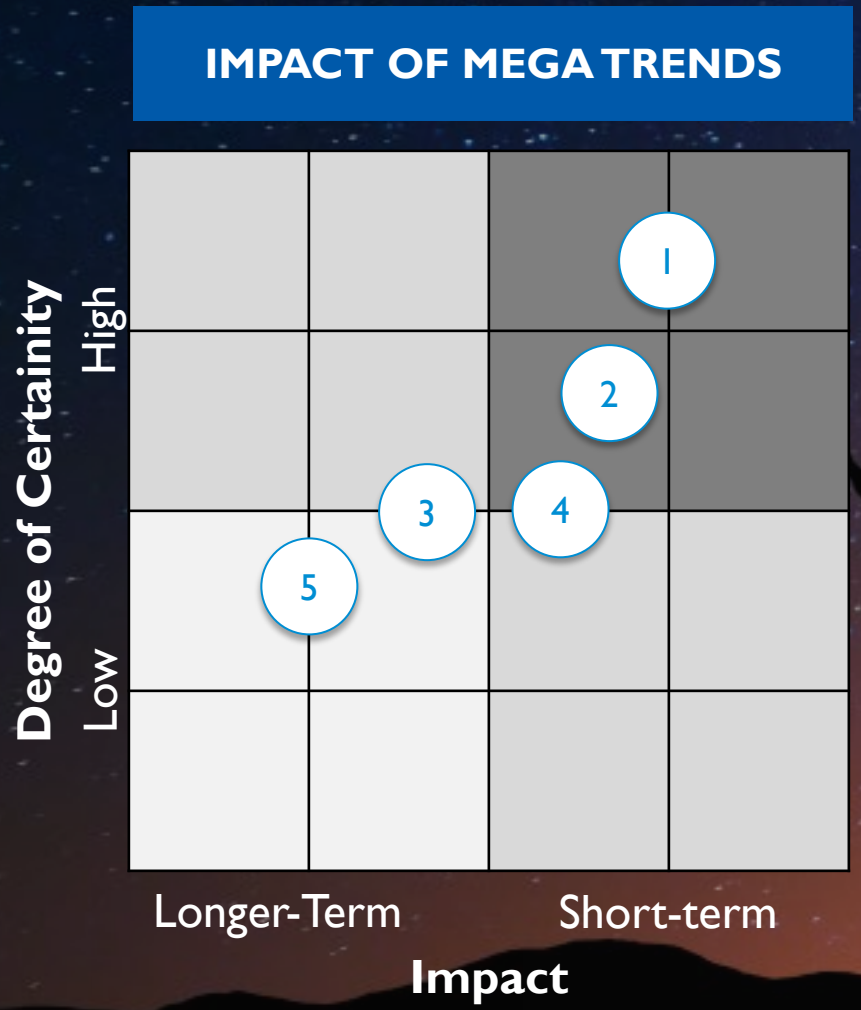
interdigital™

Mega Trends to 6G

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

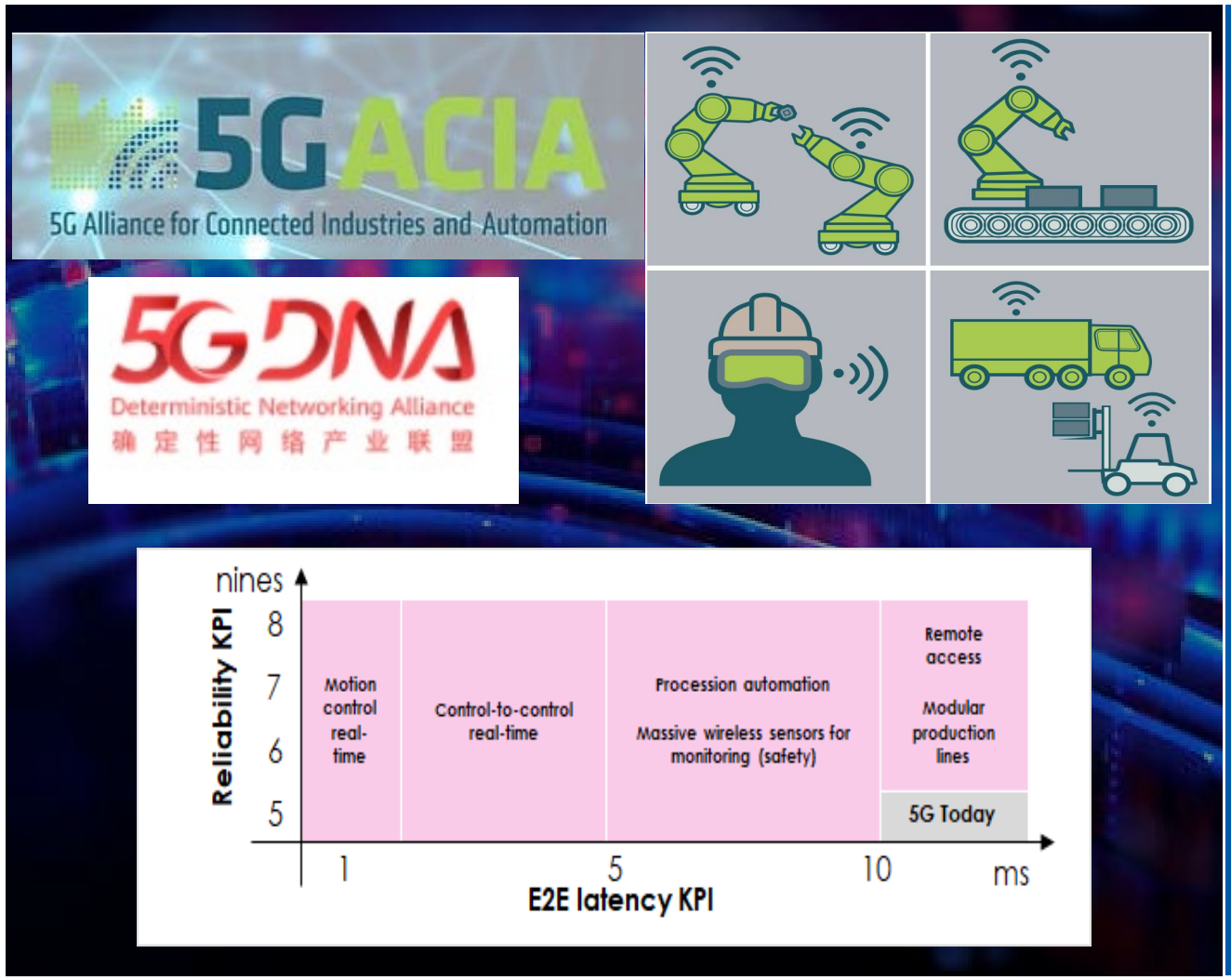
Key Insight:

- *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

Momentum for support of more Verticals



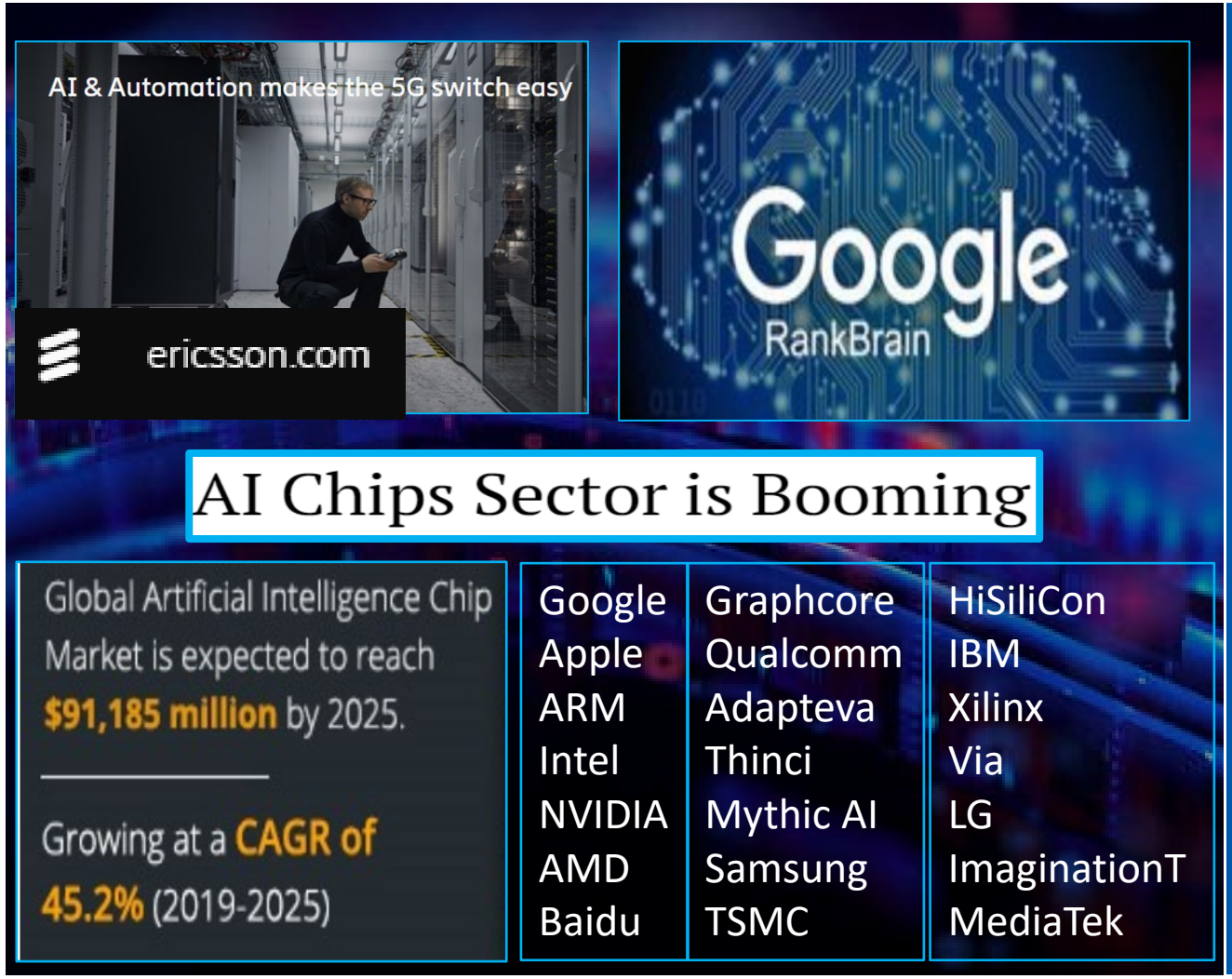
Key Insight:

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

Rise of data-driven networks with AI/ML



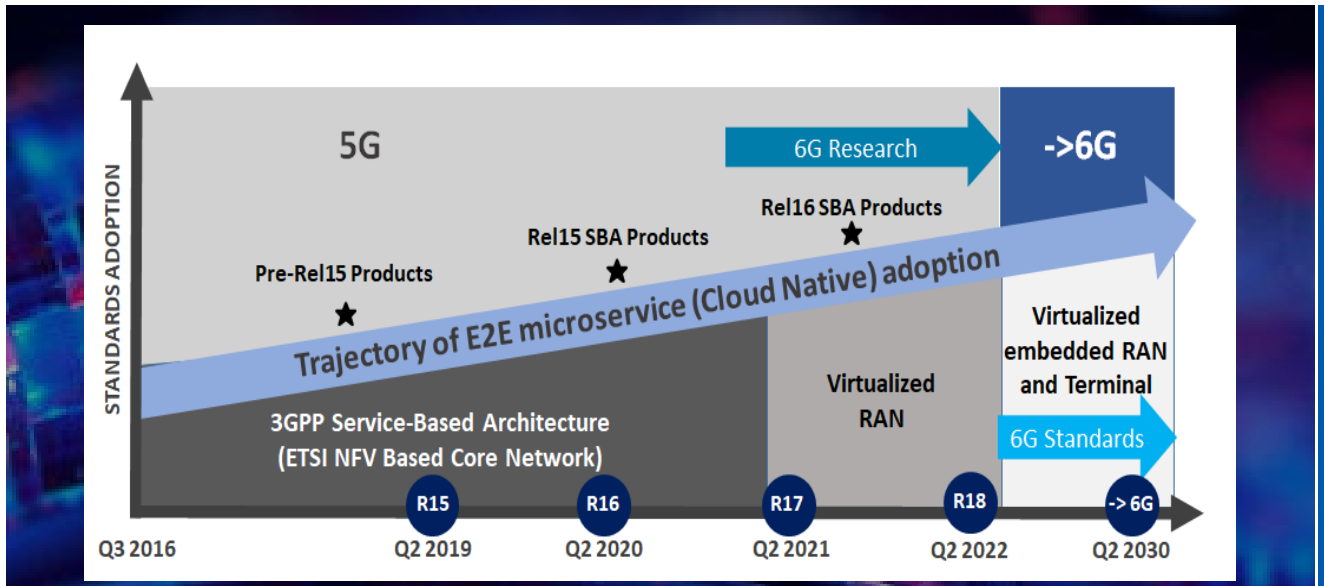
Key Insight:

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)

Widespread virtualization and disaggregation



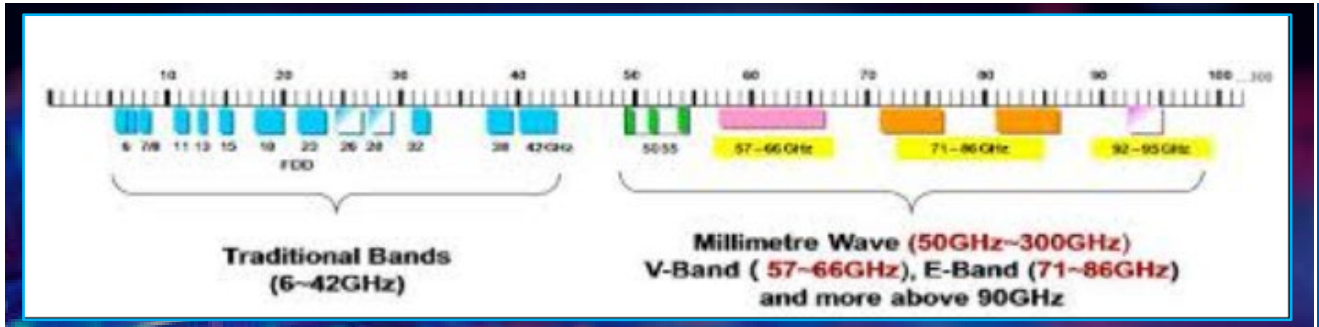
Key Insight:

- *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.

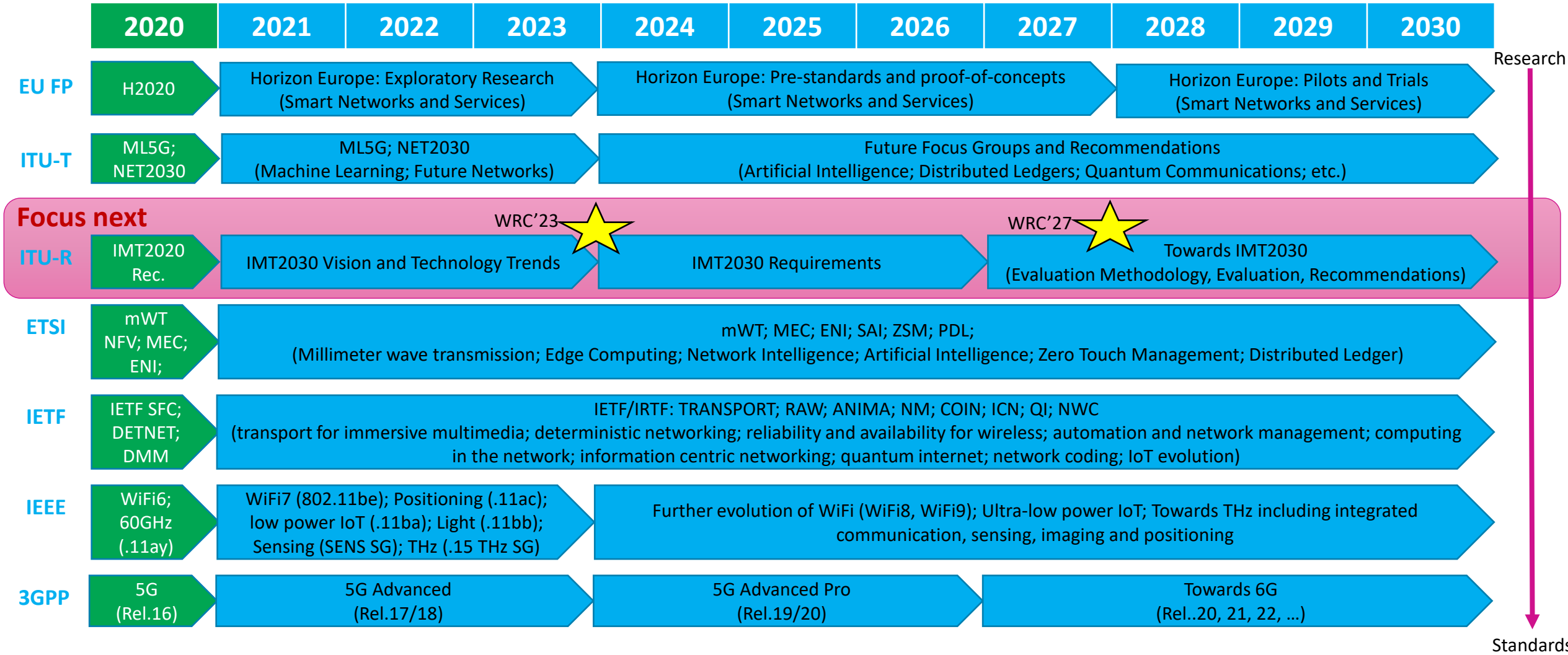
FCC Opens Spectrum Above 95 GHz, Encourages Experimentation

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

- Key Forums
- Target Capabilities
- Technology Trends

Key Stakeholders Forums



From IMT-2020 To IMT2030

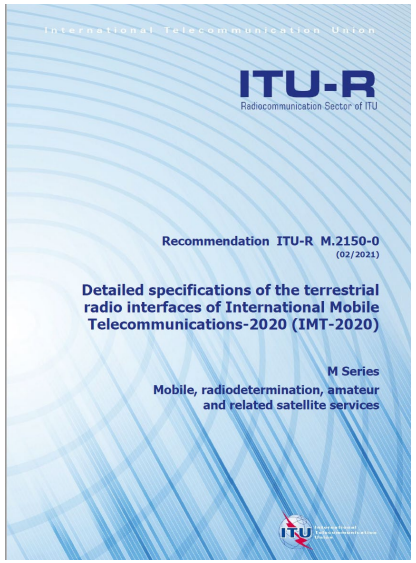
IMT-2020

IMT-2030

Recommends (as of Feb'21)

that the terrestrial radio interfaces for IMT-2020 should be

- 3GPP 5G-SRIT
- 3GPP 5G-RIT
- TDSI 5Gi



Working on

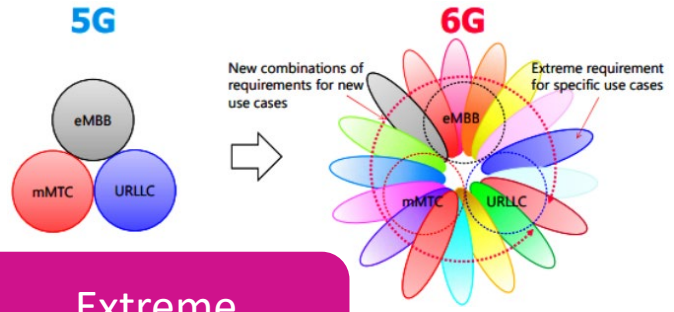
Technology Trends Towards 2030 (target release Jun'22)

Source: Document 5D/TEMP/213

Workplan towards preliminary draft new Report ITU-R M.[IMT.FUTURE TECHNOLOGY TRENDS TOWARDS 2030 AND BEYOND]

Title	Workplan for a preliminary draft new Report ITU-R M.[IMT.FUTURE TECHNOLOGY TRENDS TOWARDS 2030 AND BEYOND]
Identifier	IMT.FUTURE TECHNOLOGY TRENDS
WP 5D Lead Group	WG Technology Aspects
SWG Chair	Mr. Marc Grant (marc.grant@att.com)
Editor	Mr. Marc Grant (marc.grant@att.com)
Focus for scope and work	This Report provides a broad view of future technical aspects of terrestrial IMT systems considering the time frame 2020-[2023] and beyond. It includes information on technical and operational characteristics of terrestrial IMT systems, including the evolution of IMT through advances in technology and spectrally-efficient techniques, and their deployment. Elements of this Report could be seen as useful for WRC-23 studies.

IMT-2020 to IMT-2030 Capabilities

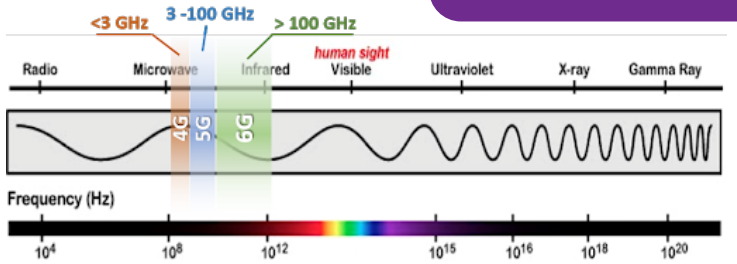


Extreme Requirements

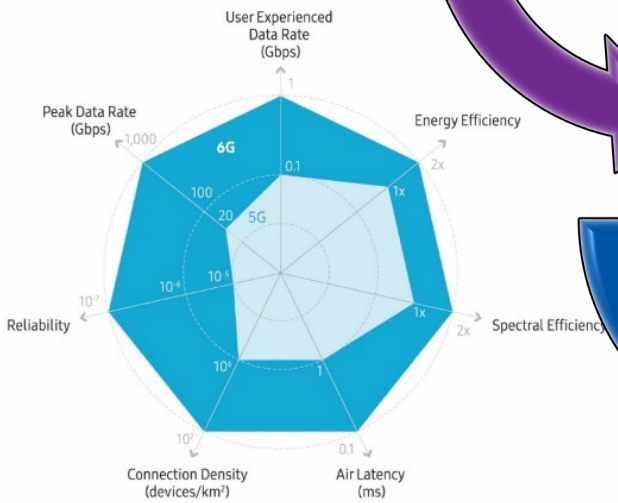
Services

Spectrum

Performance



Extreme Frequency (Sub-THz ≥100 GHz)



Extreme Performance

Services Underpinning 5G Evolution to 6G

- Multi-Sensory Extreme Reality (XR)
- Smart Industries
- Private, Personal and Local networks
- Non-terrestrial satellite services
- Unmanned Aerial Vehicles (UAV)
- Massive IoT (tens of millions of UEs)
- Future Railways
- Advanced V2X services

- **Various combinations of performance requirements** such as user experienced data rates, latency, reliability, positioning (I/O-H/V), coverage, connections density, range and speed.
- Further requirements for **significant improvements in resource efficiency** in all system components (e.g. UEs, IoT devices, radio interface, access network, core network).

Spectrum and Performance Capabilities

	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	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	Today										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 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		

Conclusions

- **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**
- **Emerging use cases** for B5G/6G seem quite familiar but hide a truth that 5G may only open the door to these use cases
- **Extreme requirements** will continue to push the evolution of wireless well beyond 5G and 6G
- Looking out to the future on the promising technology trends, it appears that **there will be inflection points that may lead to a 6G by 2030 a.k.a. IMT-2030 / NET-2030**

Acknowledgment to Current B5G Collaborations

www.advancedwireless.eu

EMPOWER

H2020: Empowering Transatlantic Platforms for advanced Wireless Research

www.5growth.eu

5GROWTH

H2020: 5G-enabled GROWTH in Vertical Industries

www.5g-dive.eu

5GDIVE

H2020: Edge Intelligence for Vertical Experimentation

www.5gclarity.com

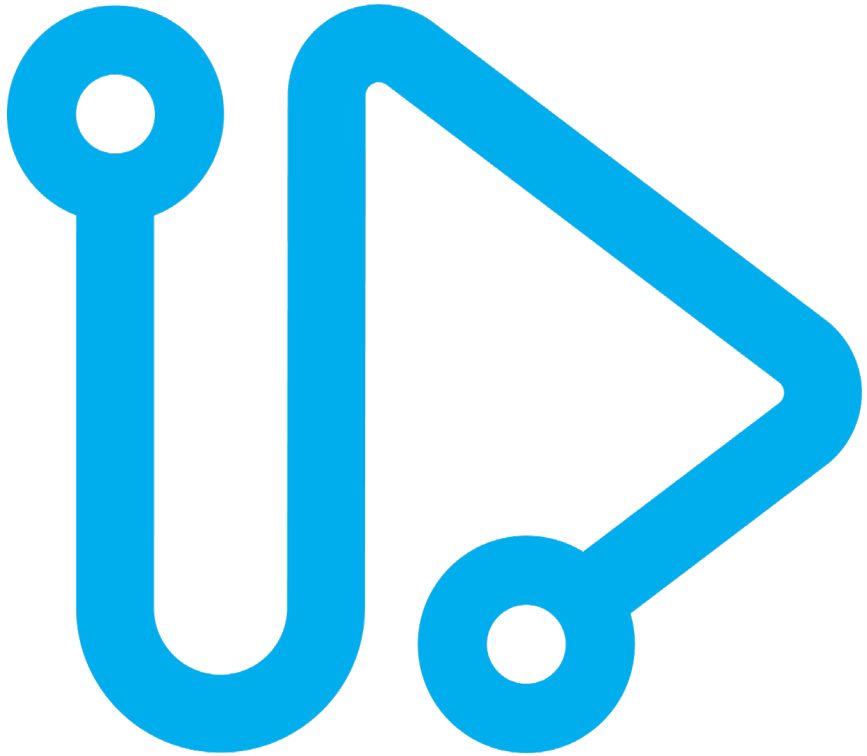
5GCLARITY

H2020: B5G Multi-Tenant Private Networks Integrating Cellular, Wi-Fi, and LiFi, Powered by AI and Intent Policy

https://aimm.celticnext.eu/

AIMM

CELTIC: Artificial Intelligence-enabled Massive MIMO



Thank You

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