5G and 6G mobile communications

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Content

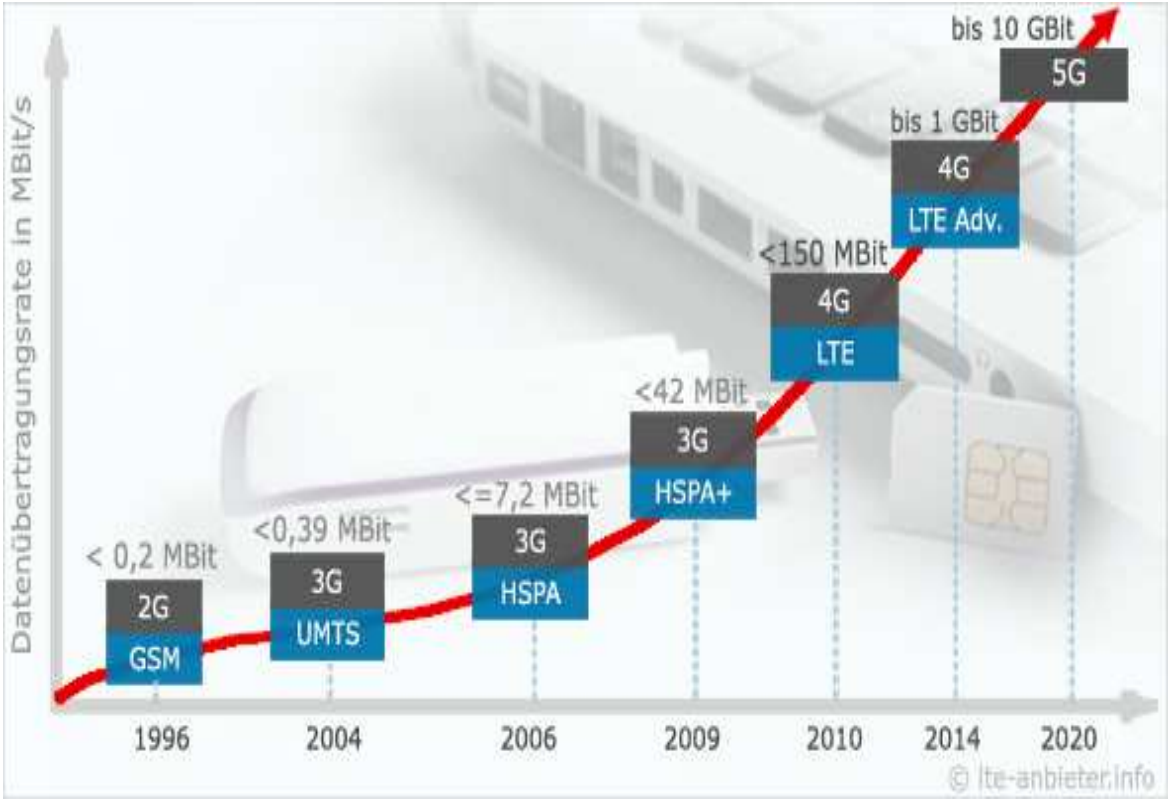
- Development of mobile communications from 1G to 5G
- 5G requirements
- Vertical application domains
- 5G concept and frequency spectrum
- Interworking with other communication systems like NTN
- Drivers towards 6G
- 6G requirements and concept
- 6G outlook

Evolution of Mobile Generation Technology: 1G to 5G

Technology	1G	2G	3G	4G	5G
Systems	A-net AMPS B-net ETACS B/B2-net NMT C-net NTT JTACS NTACS	GSM DAMPS IS-95 CDMA PDC	UMTS EDGE CDMA2000	LTE WiMax WiFi	5G
Start/Deployment	1958 – 1980	1990 – 2004	2004 – 2010	2010 – now	Start around 2020
Data Bandwidth	2 kbps	64 kbps	2 Mbps	1 Gbps	Higher than 1 Gbps
Technology	Analog	Digital	Digital	Digital	WWWW (Wireless World Wide Web)
Core network	PSTN	PSTN	Packet network	Internet	Internet
Multiplexing	FDMA	TDMA/CDMA	CDMA	OFDM	OFDM
Switching	Circuit	Circuit, packet	Packet	All packet	All packet
Primary service	Analog phone calls	• Digital phone calls and • Messaging	• Phone calls • Messaging • Data	All-IP service (including voice messages)	• High speed • High capacity • Provide large broadcasting of data in Gbps
Key differentiator	Mobility	• Secure • Mass adoption	Better Internet experience	• Faster broadband • Internet • Lower latency	• Better coverage • No dropped calls • Much lower latency • Better performance
Weakness	• Poor spectral efficiency • Major security issue	• Limited data rates • Difficult to support demand for Internet and e-Mail	• Real performance fails to match expectations • Failure of WAP for Internet access	• Extensive Battery use • Required complicated and expensive hardware	?

Source: Based on Lopa J. Vora: Evolution of Mobile Generation Technology: 1G to 5G and Review of upcoming wireless Technology 5G. International Journal of Modern Trends in Engineering and Research (IJMTER), Volume 02, Issue 10, October – 2015, https://pdfs.semanticscholar.org/4dfd/40cc3a386573ee861c5329ab4c6711210819.pdf.

Timeline and Data Rate 2G, 3G, 4G and 5G



Fundamental digital needs for new human & business value creation

seemingly infinite capacity

1 **Need:** 100x capacity growth in <10 years

imperceptible latency

2 **Need:** Millisecond latency for networks & new 'human' services

terascale things

3 **Need:** Optimize TCO for a trillion things

global-local alliance

4 **Need:** Massive distribution of cloud infra with global federation

human cognitive operation

5 **Need:** Human assistance & task automation @ machine scale

personalized protection

6 **Need:** Enable dynamic, contextual security & trust @ terascale

Source: Nokia

Key Challenges Beyond 2020

Massive growth in
Connected Devices

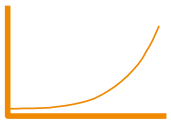
Massive amount of communicating machines

"50 billion devices"

Massive growth in
Traffic Volume

Further expansion of mobile broadband
Additional users and increased usage

Additional traffic due to communicating machines



">1000x"

Wide range of
Requirements & Characteristics

Multi-Gbps in specific scenarios

Hundreds of Mbps generally available

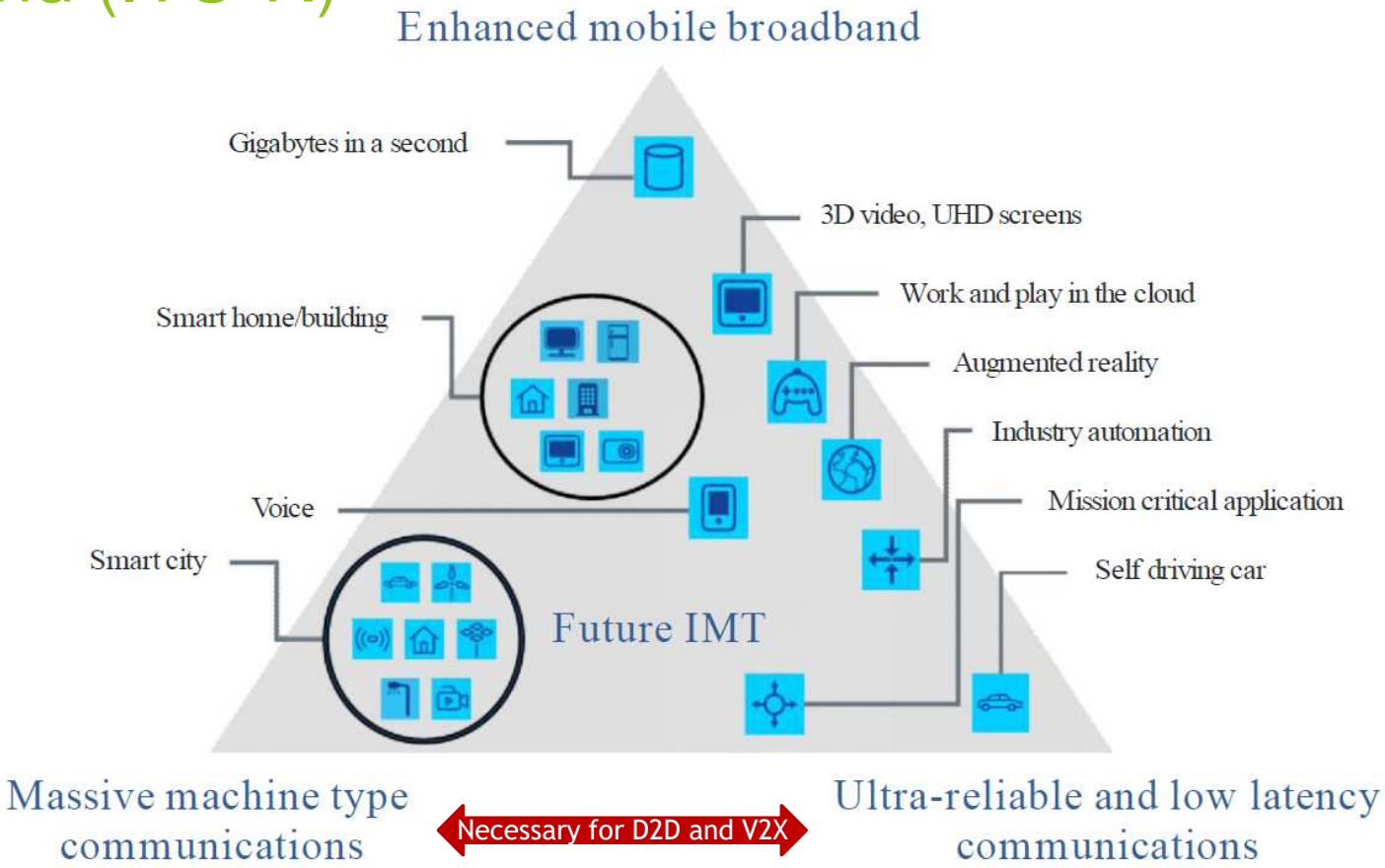
Ultra-low latency

New requirements and characteristics due to communicating machines

Affordable and sustainable

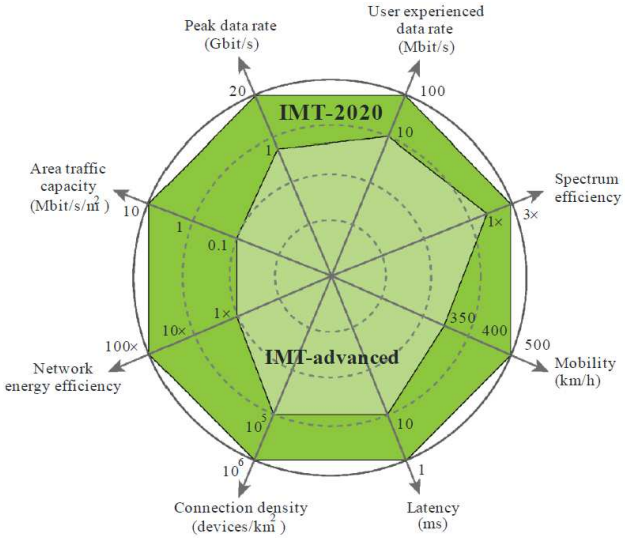
Source: Ericsson

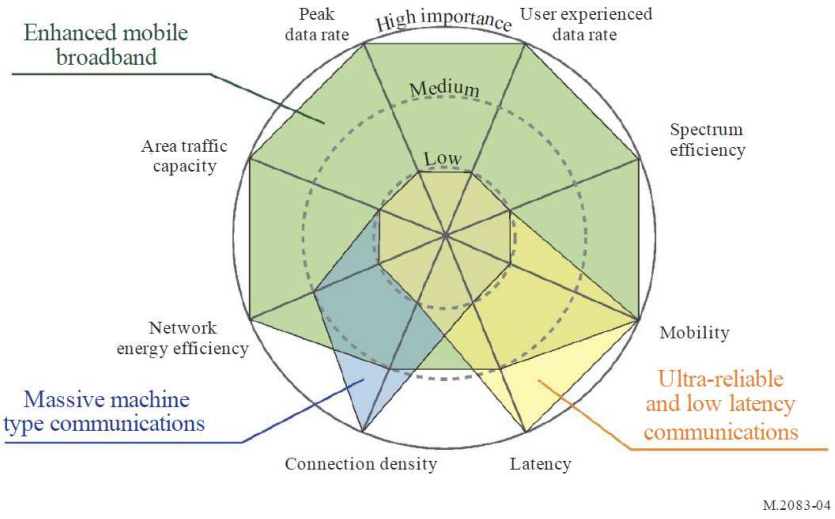
Usage scenarios for IMT-2020 and beyond (ITU-R)



Source: ITU-R: IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond. Recommendation ITU-R M.2083-0 (09/2015), https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf.

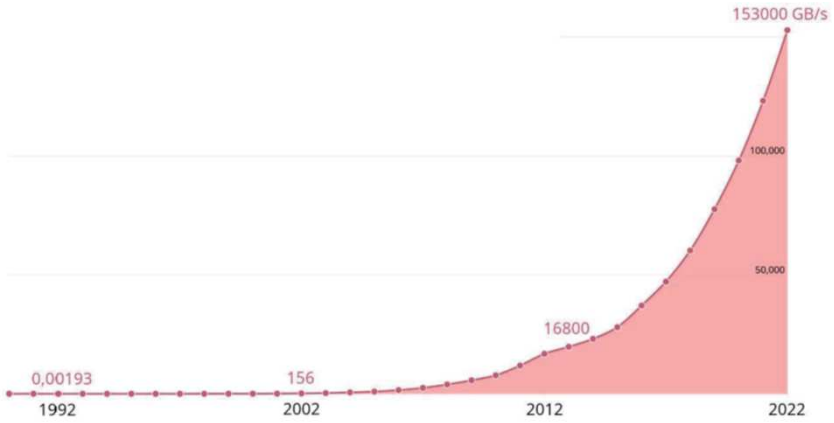
Enhancement of key capabilities from IMT-Advanced to IMT-2020 (ITU-R)



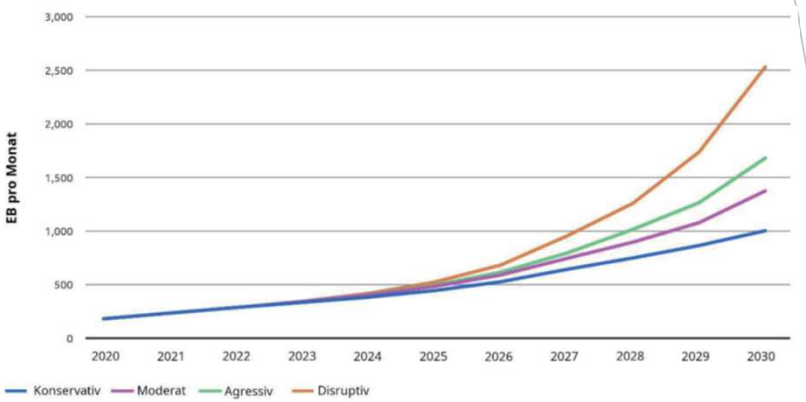


Source: ITU-R: IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond. Recommendation ITU-R M.2083-0 (09/2015), https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf.

Growth of data volume



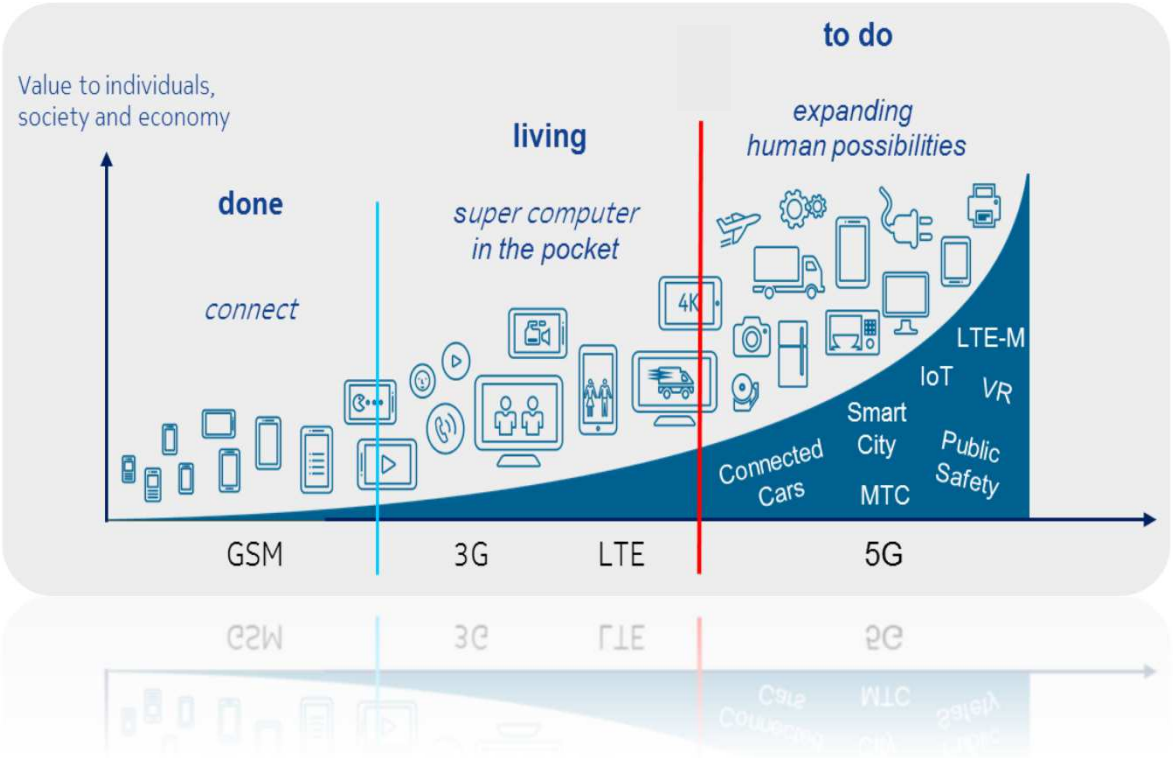
Growth of global data volume 1992 to 2022



Expected data volume growth in ICT networks by 2030

Source: VDE – ITG: Kommunikations- und Informationstechnik als Weg für eine nachhaltige Zukunft

Telco industry – the world is opening up

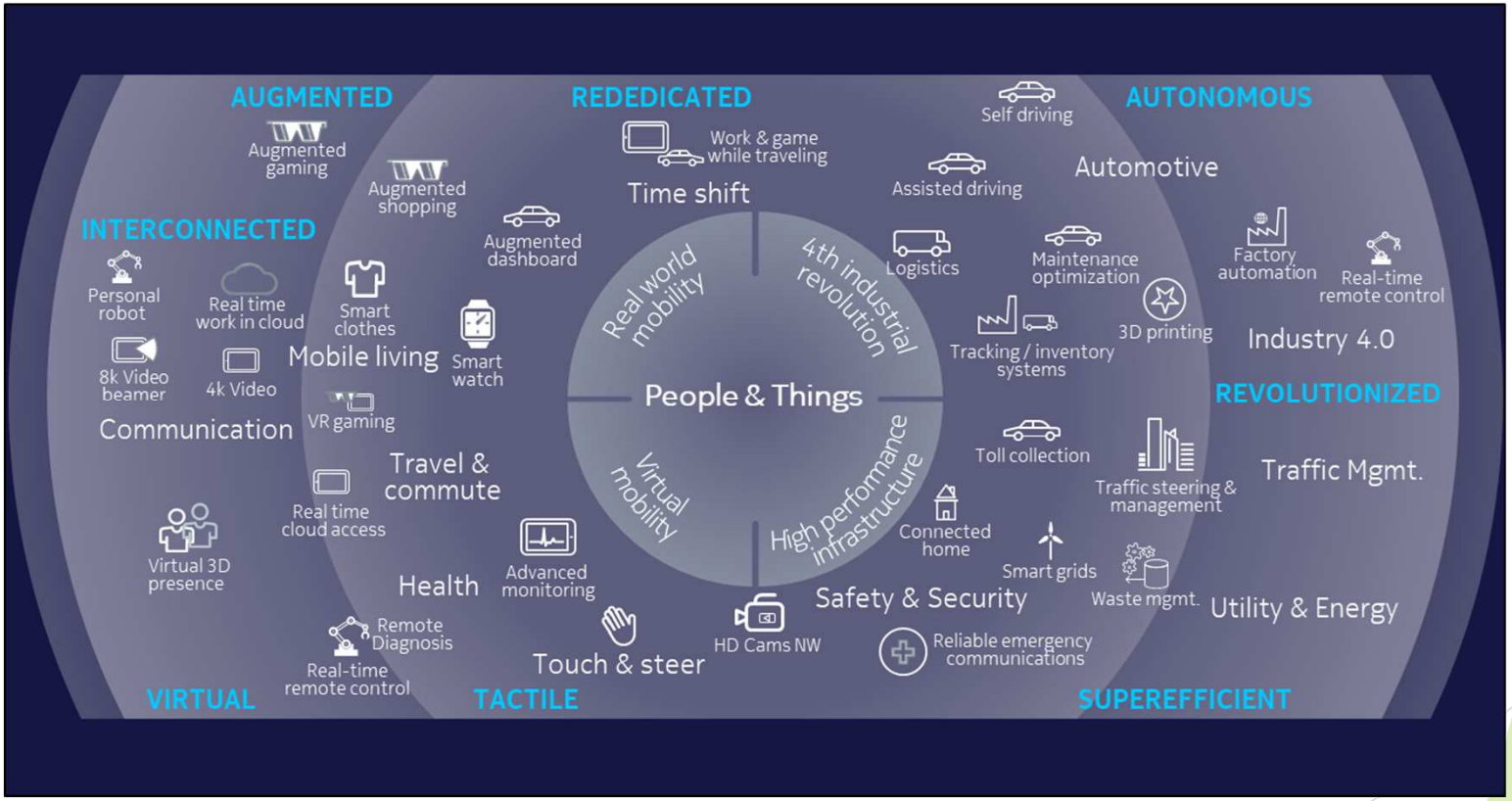


Source: Nokia

Communication at a turning point

Beyond Connectivity

Explosion of possibilities:
New performance levels of people and things



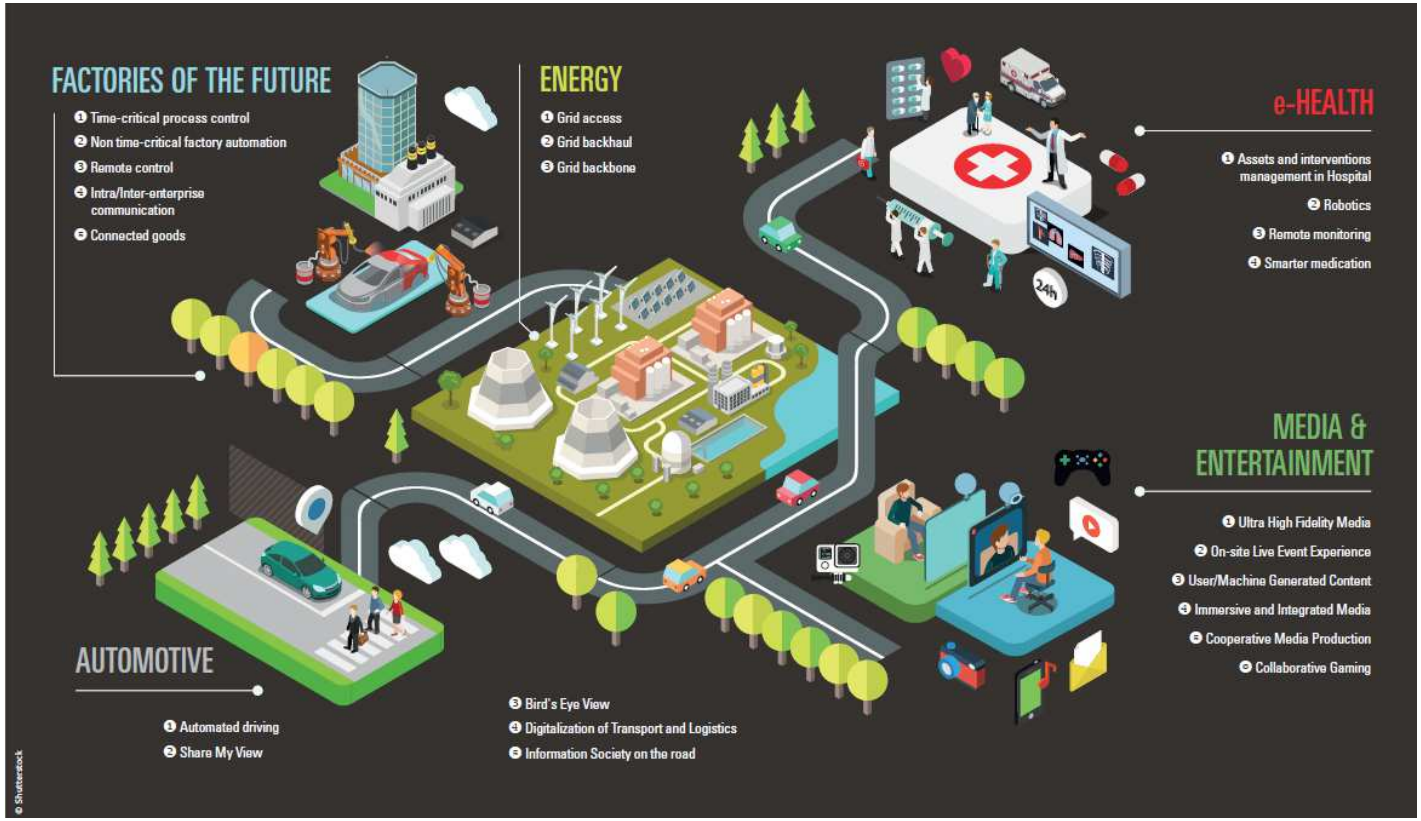
Source: Nokia

5G use case families and related examples, NGMN view

Broadband access everywhere 50+ MBPS EVERYWHERE 	**Broadband access in dense areas** PERVASIVE VIDEO 	**Higher user mobility** HIGH SPEED TRAIN 	**Massive Internet of Things** SENSOR NETWORKS 
Extreme real-time communications TACTILE INTERNET 	**Lifeline communications** NATURAL DISASTER 	**Ultra-reliable communications** E-HEALTH SERVICES 	**Broadcast-like services** BROADCAST SERVICES 

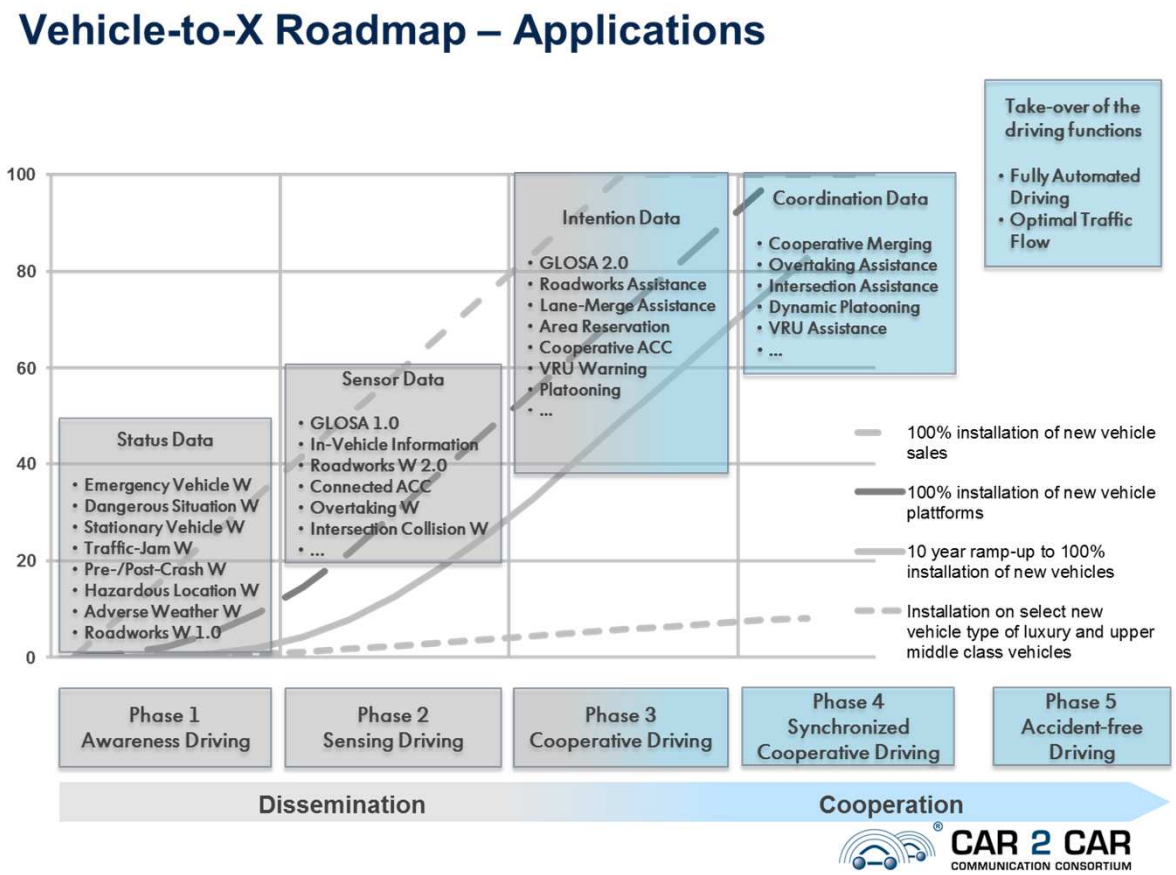
Source: NGMN: NGMN 5G White Paper. February 2015, https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf.

5G – A driver for industrial and societal changes (5G PPP – 5G Public Private Partnership)



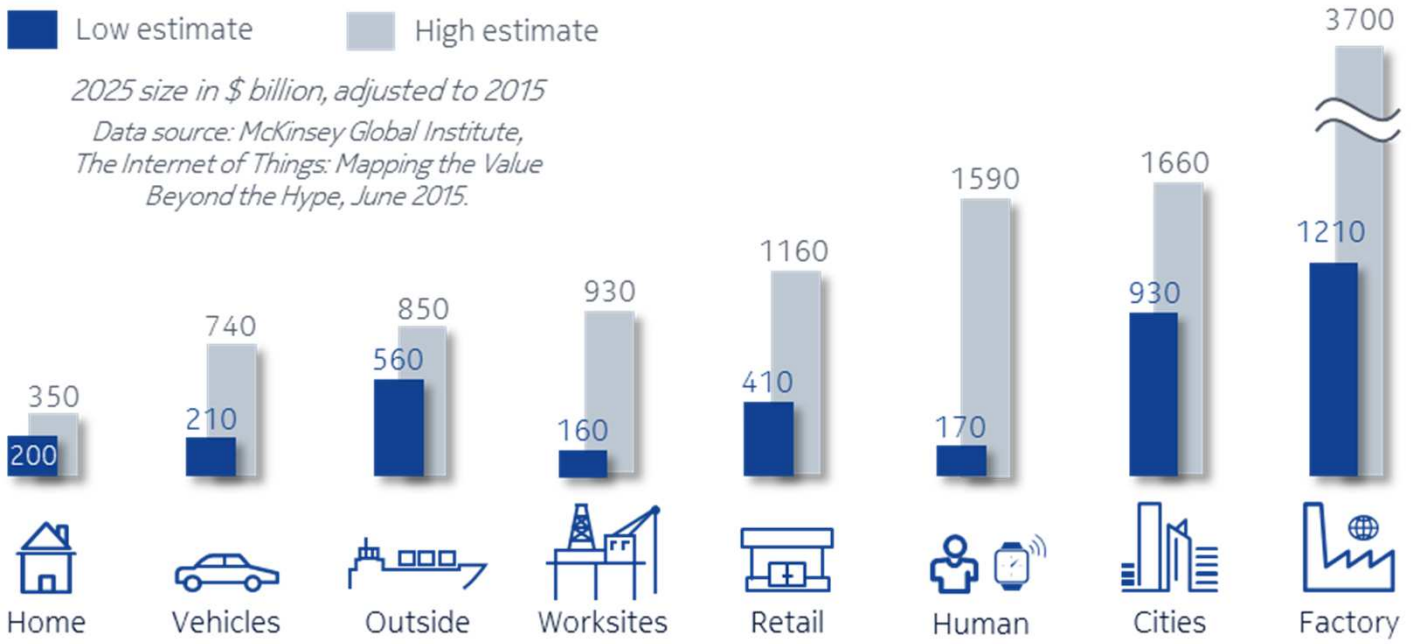
Source: 5G Infrastructure Association: 5G Empowering vertical industries. White Paper, 2016, https://5g-ppp.eu/wp-content/uploads/2016/02/BROCHURE_5PPP_BAT2_PL.pdf.

The Car-2-Car Communication Consortium applications roadmap



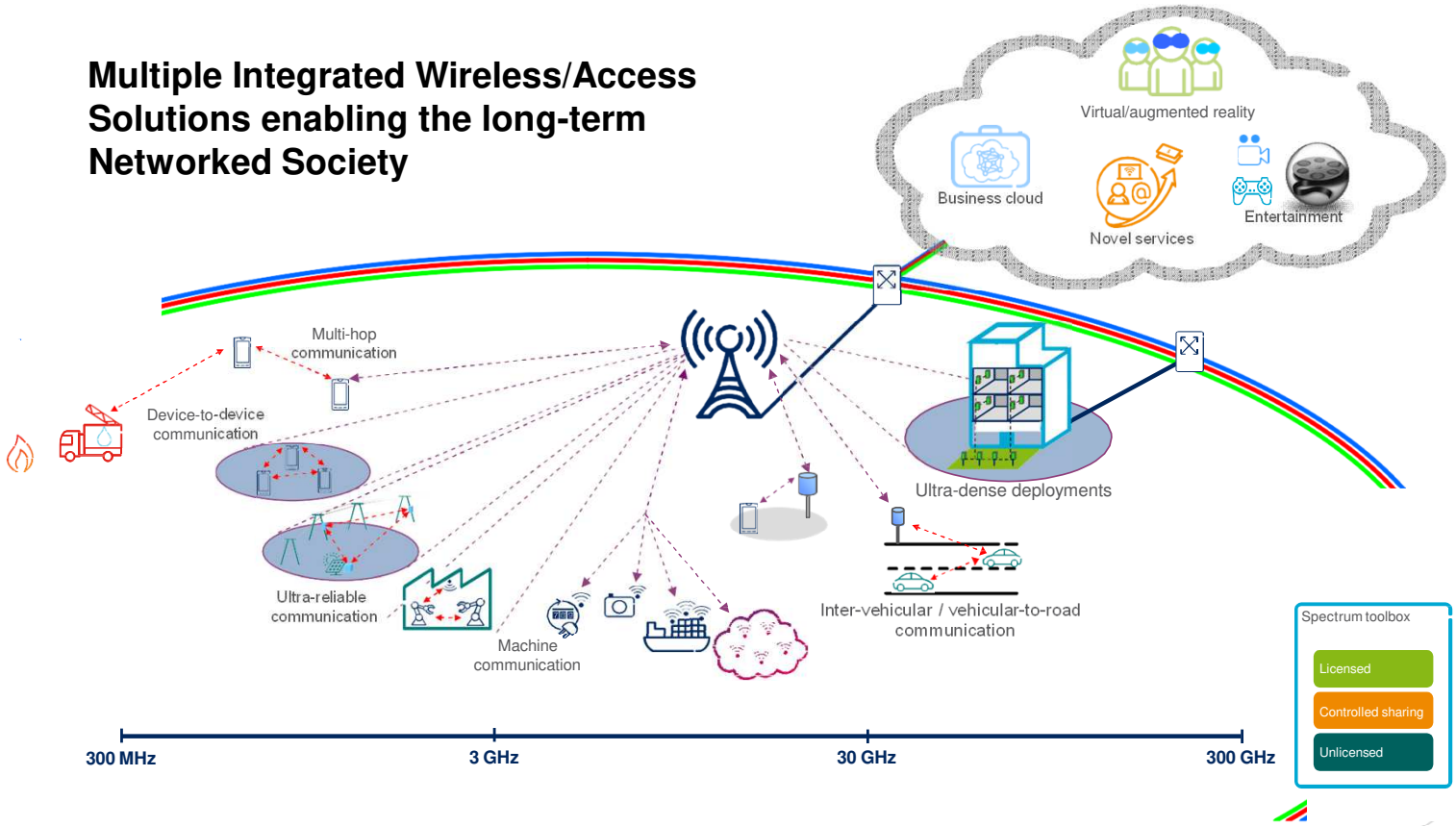
Source: 5G PPP, 5G Automotive Vision. October 20, 2015, https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf.

Estimated value creation potential by 2025 of the Internet of Things



Source: McKinsey Global Institute: The Internet of Things: Mapping the Value Beyond the Hype. June 2015.

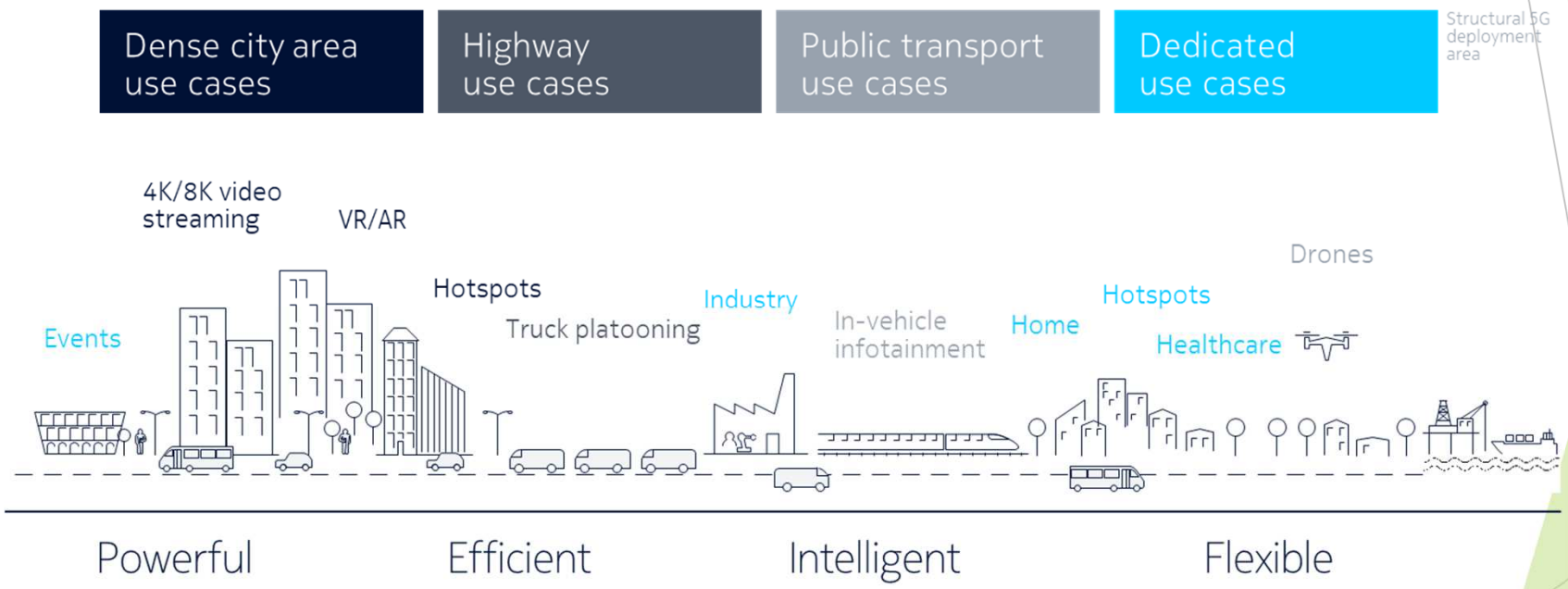
5G Concept



Source: Ericsson

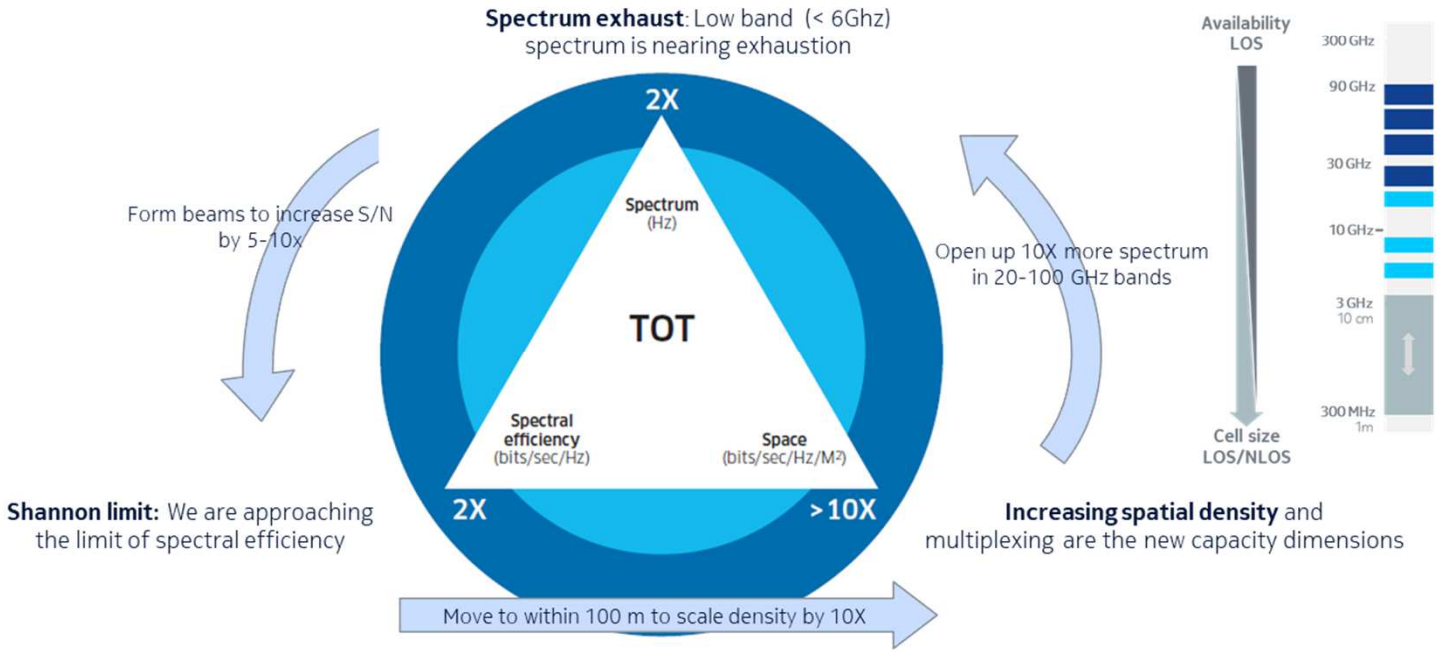
High value 5G business models

- 5G early market use cases



Source: Nokia.

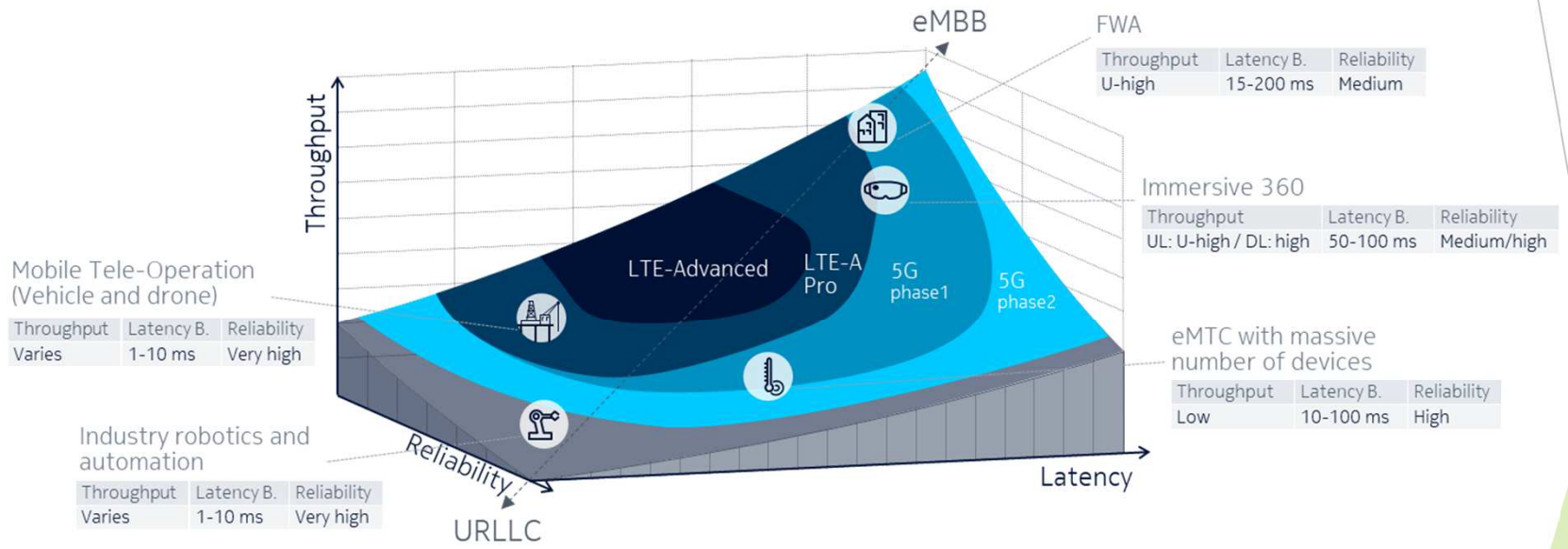
Seemingly infinite capacity – Networks are reaching physical limits



Radical shift in network architecture needed to deliver required access capacity

Source: Nokia

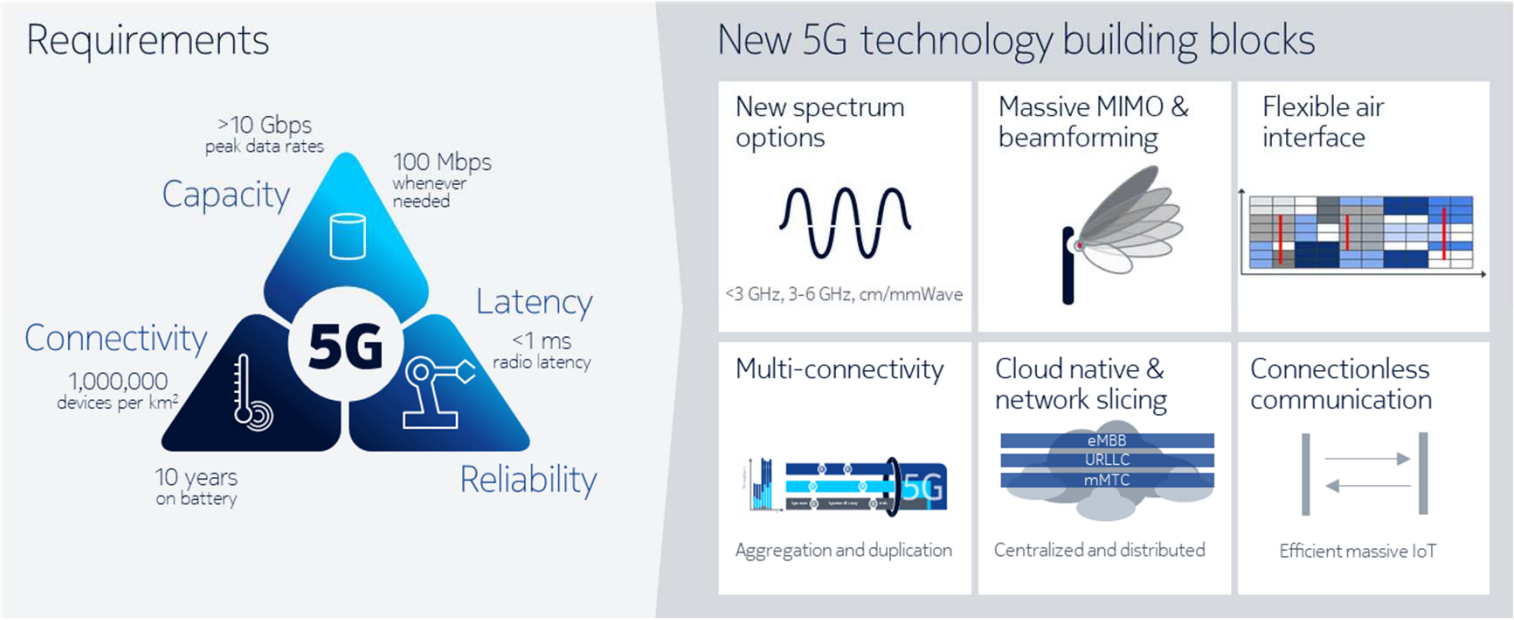
IoT connectivity technologies
Reliability, latency, and throughput requirements



5G NR: the only radio technology to simultaneously provide high reliability & low latency

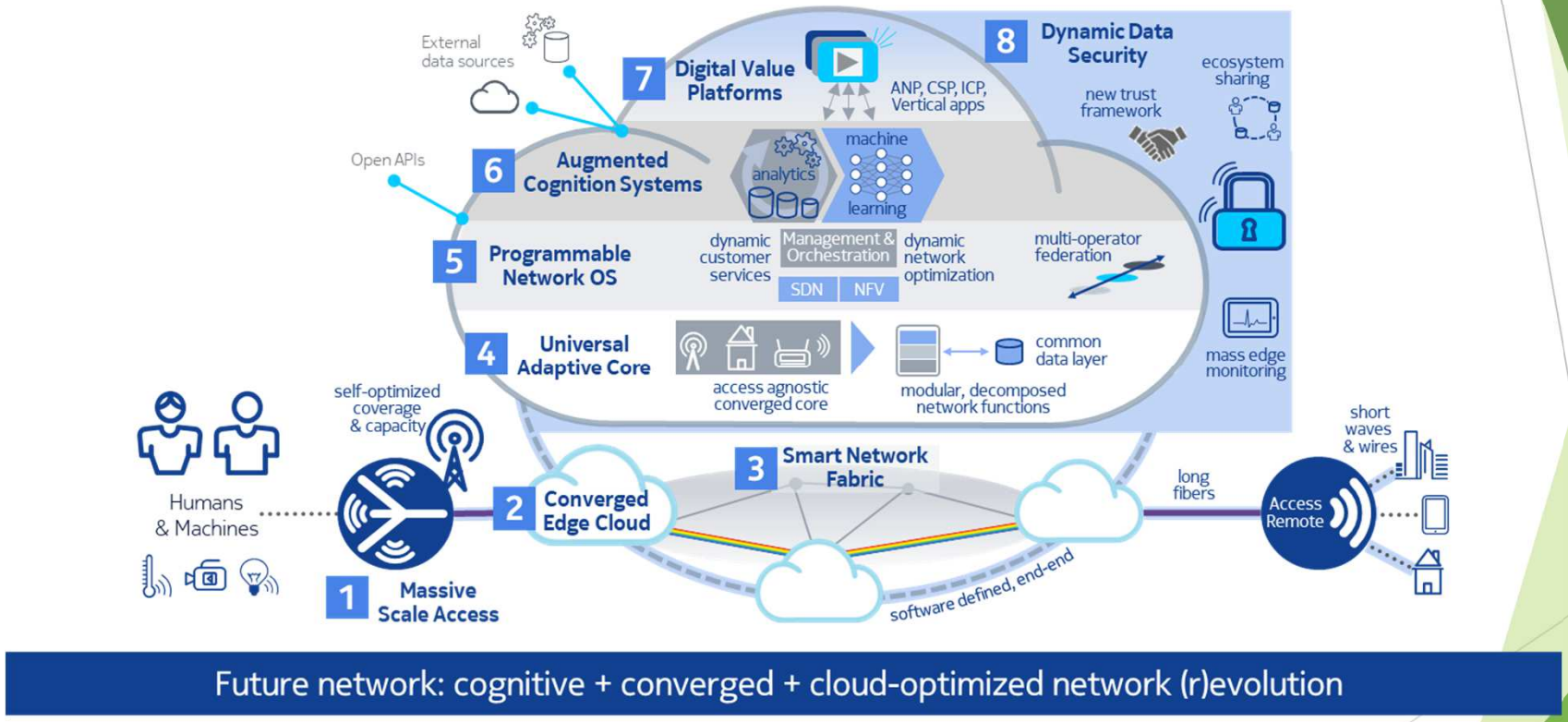
Source: Nokia

5G is a giant leap powered by a set of new technologies



Source: Nokia

High level architecture:
The Future Network Architecture



Source: Nokia

Frequency ranges

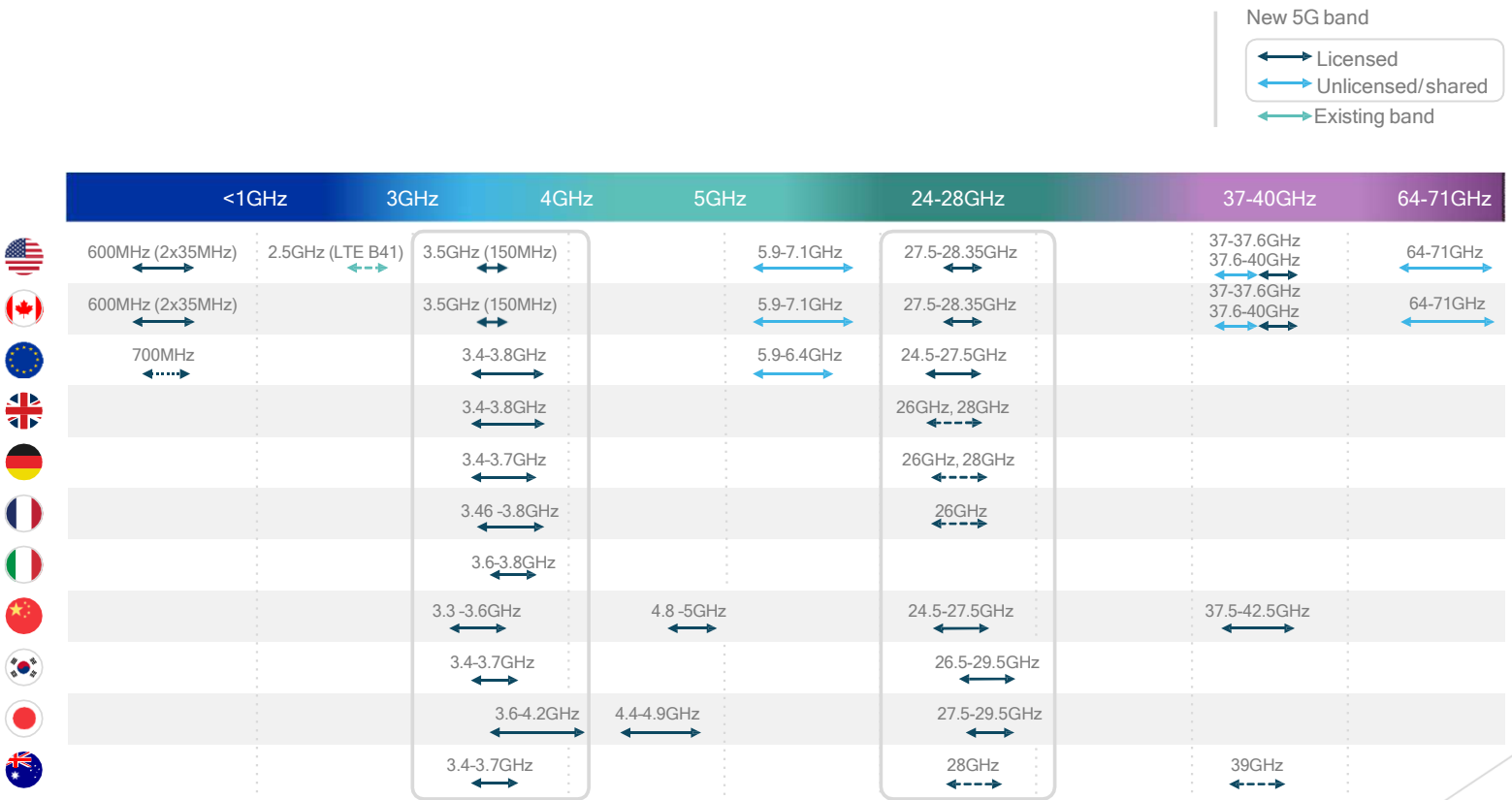
- 5G is defining two basic frequency ranges for technology specification
- These are not identified frequency bands by regulators like WRC (ITU World Radiocommunications Conference) and national/regional regulators

Frequency range designation	Corresponding frequency range
FR1	410 MHz – 7125 MHz
FR2	24250 MHz – 52600 MHz
FR3 under discussion towards WRC 2027	4400 – 4800 MHz 7125 – 8400 MHz 14.8 – 15.35 GHz

Source: 3GPP TS 38.101-1 and 38.104

Global snapshot of 5G spectrum

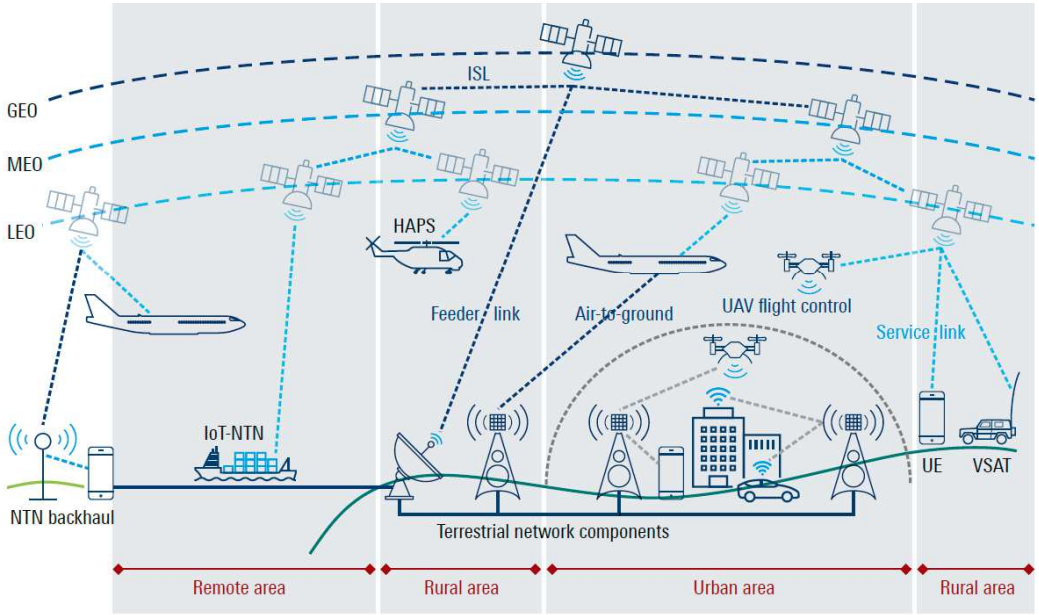
Around the world, these bands have been allocated or targeted



Source: Nokia

NTN (Non-Terrestrial Networks) in 5G
General connectivity overview

Figure 2: General connectivity overview of non-terrestrial networks



Source: Rohde & Schwarz: 5G NTN Takes Flight: Technical Overview of 5G Non-Terrestrial Networks. July 2022.

Megatrends are changing the world, and the ways we connect with it

Network, compute & storage

Broadband everywhere, distributed cloud, near infinite storage

Internet of Things

Connectivity for a trillion things

Augmented intelligence

Human assistance and task automation at machine scale

Human & machine interaction

Virtual and augmented reality, reshaping how we interact with

Social & trust economics

Sharing economy and digital currencies making trust and security essential

Digitalization & ecosystems

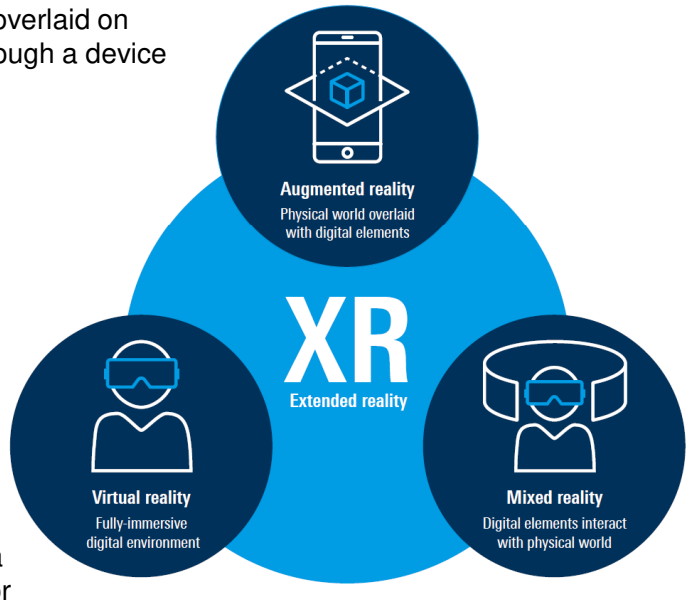
Digitalization of services, operations, network and supply chain

Source: Nokia

Extended reality spans VR, AR and MR

- An immersive, persistent, pervasive, interconnected virtual 3D world
- shaped by extended reality applications
- where many people can gather to work, shop, play, and socialize

Augmented Reality
AR is one such variant,
where digital information is overlaid on
images of reality viewed through a device



Virtual Reality
Users are totally immersed in a
simulated digital environment or
a digital replica of reality

Mixed Reality
MR includes all variants
where virtual and real
environments are mixed

Source: Pair, J. and A. Rößler: The Metaverse and Extended Reality – Introductory overview, 5G to 6G aspects, use case testing. Rohde & Schwarz White paper, Version 01.00, September 2024.
Webinar The Metaverse and Extended Reality. February 2024.
https://www.nokia.com/metaverse/industrial-metaverse/the-metaverse-at-work-research/
https://www.nokia.com/sites/default/files/2023-02/potential-of-the-industrial-metaverse-market.png

Different types of the Metaverse

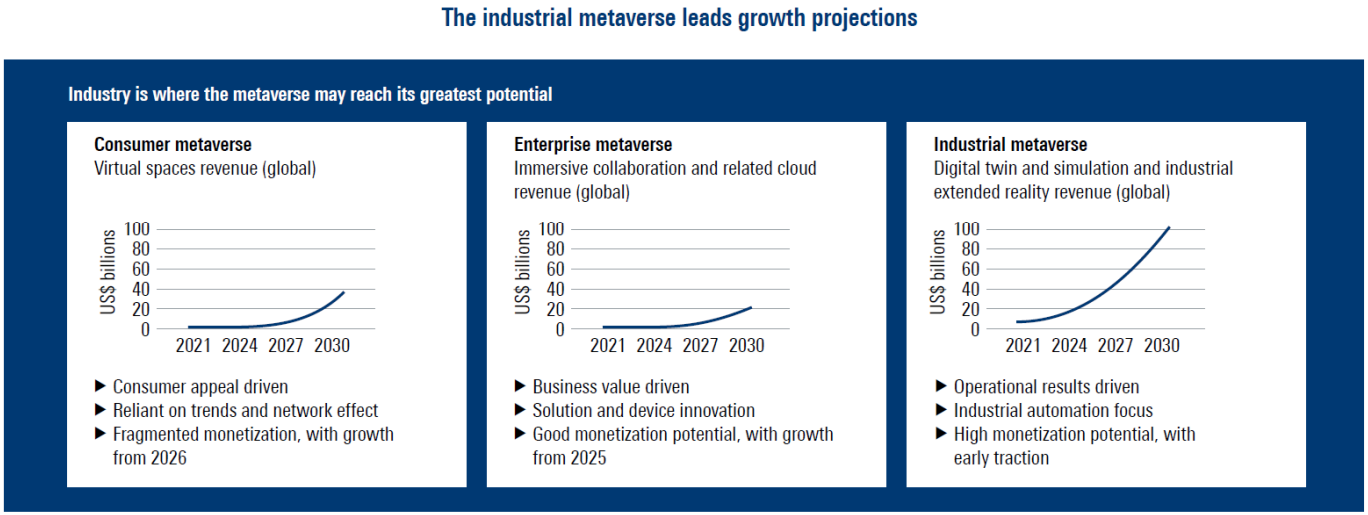
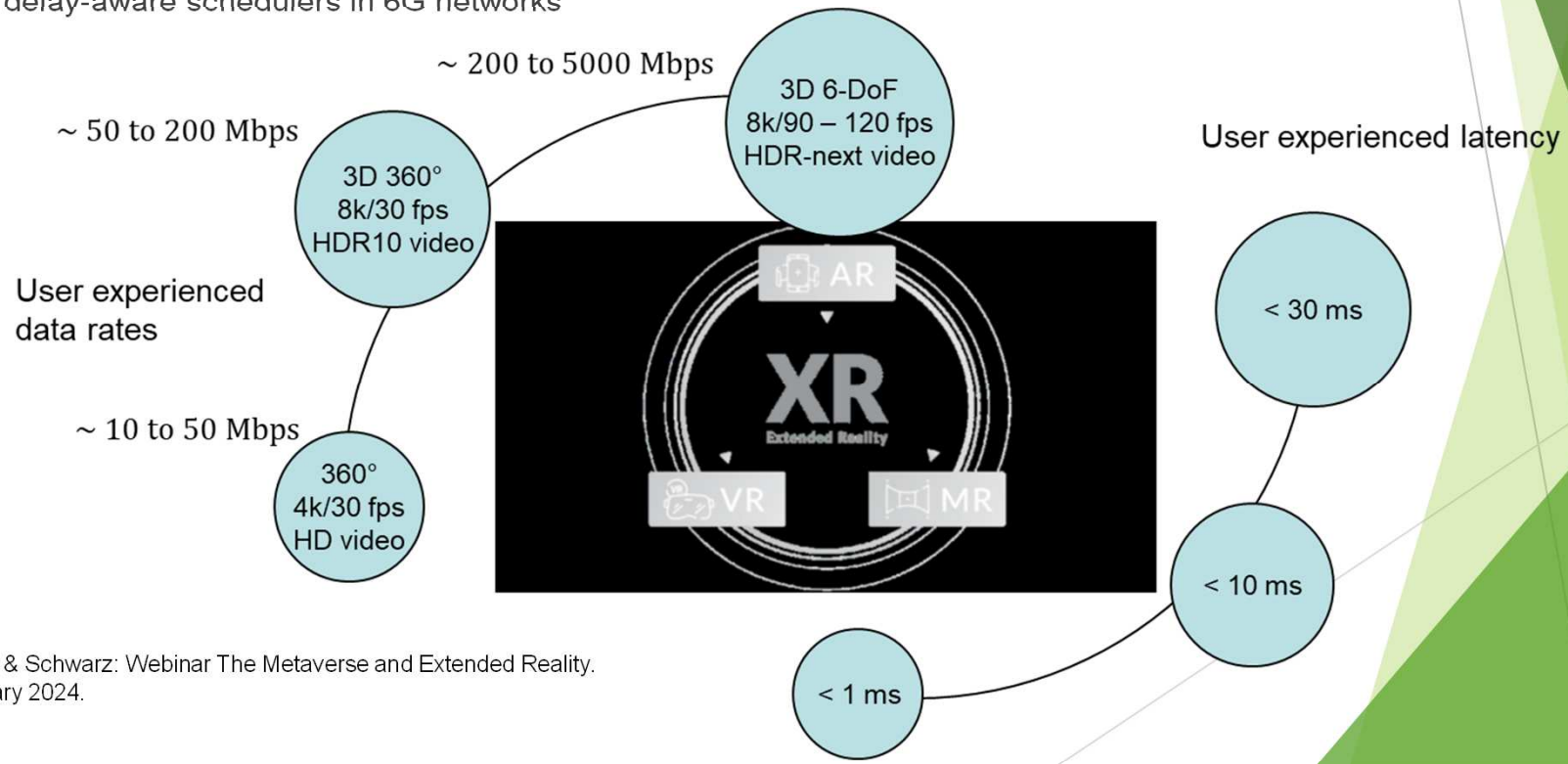


Image Source: Nokia, "Powering the Industrial Metaverse" [4] and ABI Research, "Evaluation of the Enterprise Metaverse Opportunity, Third Quarter 2022" [5]

Source: Pair, J. and A. Rößler: The Metaverse and Extended Reality – Introductory overview, 5G to 6G aspects, use case testing. Rohde & Schwarz White paper, Version 01.00, September 2024.
Webinar The Metaverse and Extended Reality. February 2024.
https://www.nokia.com/metaverse/industrial-metaverse/the-metaverse-at-work-research/
https://www.nokia.com/sites/default/files/2023-02/potential-of-the-industrial-metaverse-market.png

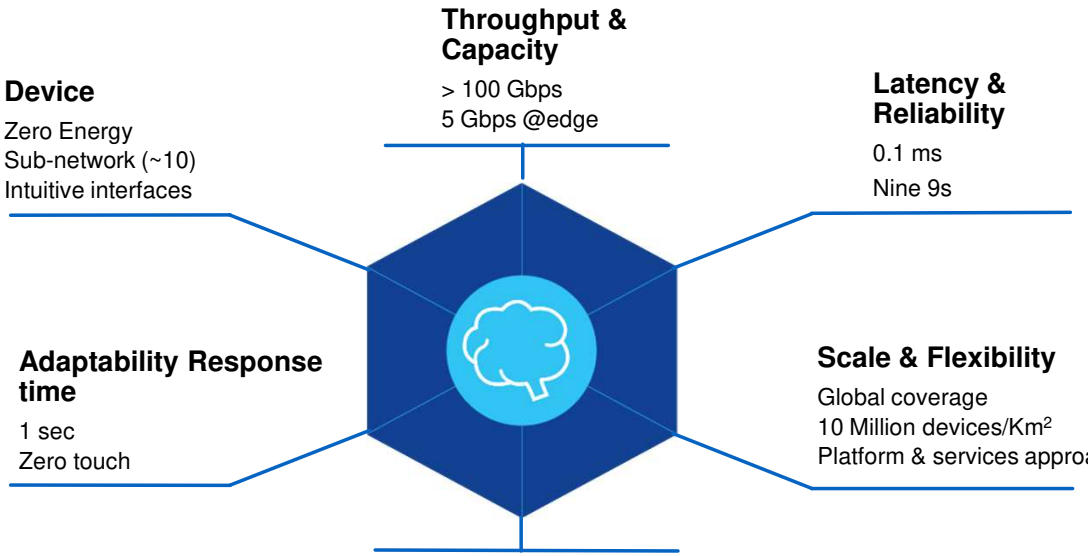
Role of 5G and 6G to unlock the full potential of the Metaverse

- High data rates, low latency
- Device form factor for consumer applications: small, lightweight, even fashionable; low power consumption
- Optimized edge processing and split rendering architectures to effectively handle Motion-to- Render-to-Photon latency (M2R2P)
- Future: delay-aware schedulers in 6G networks



Source: Rohde & Schwarz: Webinar The Metaverse and Extended Reality. February 2024.

The new 6G requirements

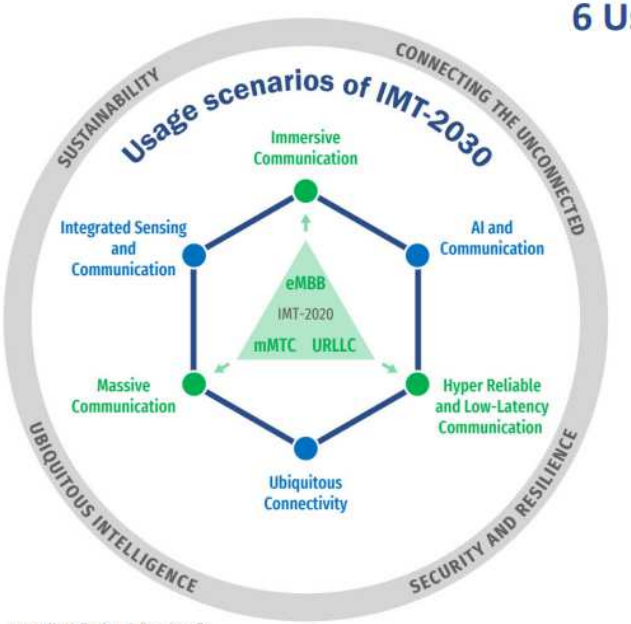


Note: Extreme attributes of performance may apply to specialized sub-networks only and all the requirements may not be achieved simultaneously.

Source: Nokia.

Usage Scenarios IMT 2030 Framework

Usage scenarios



So called "Wheel diagram"
Source: Document 5/131 and edited in SG 5

6 Usage scenarios

Extension from IMT-2020 (5G)

- eMBB ➡ Immersive Communication
- mMTC ➡ Massive Communication
- URLLC ➡ HRLLC (Hyper Reliable & Low-Latency Communication)

New

- Ubiquitous Connectivity
- AI and Communication
- Integrated Sensing and Communication

4 Overarching aspects:

act as design principles commonly applicable to all usage scenarios

Sustainability, Connecting the unconnected,
Ubiquitous intelligence, Security/resilience

Source. ITU-R: The ITU-R Framework for IMT-2030, July 2023 WP 5D Management Team, https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/Documents/IMT-2030 Framework. WP 5D Management Team.pdf.

R. Liu, et.al.: Beginning of the journey toward 6G: Vision and Framework. IEEE Communications Magazine, October 2023, pp. 8.

New and enhanced capabilities of IMT-2030

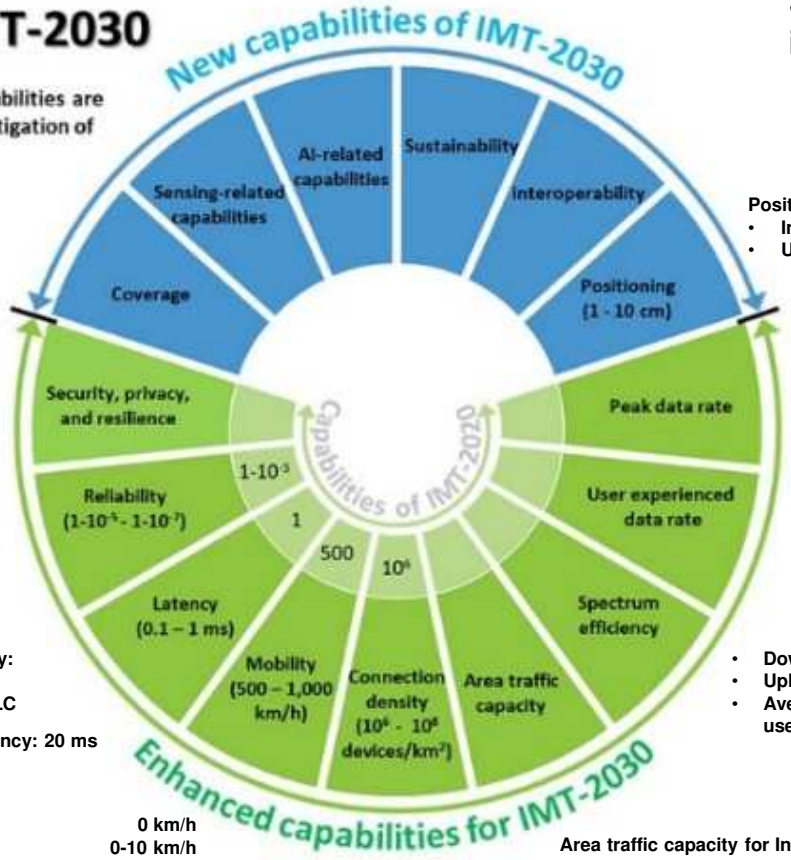
IMT-2030 as important enabler for the following characteristics:

- Inclusivity
- Ubiquitous connectivity
- Sustainability
- Innovation
- Enhanced security, privacy and resilience
- Standardization and interoperability
- Interworking

Status in ITU-R WP5D in February 2026

Capabilities of IMT-2030

NOTE: The range of values given for capabilities are estimated targets for research and investigation of IMT-2030.



Sensing-related requirements
- Detection probability 95 %
- False alarm probability 5 %
- Horizontal localization accuracy
  - Indoor Factory – ISAC 2 m
  - Urban Macro – ISAC 5 m
- Vertical localization accuracy
  Urban Macro – ISAC 8 m
- Velocity accuracy
  - Indoor Factory – ISAC 2 m/s
  - Urban Macro – ISAC 4 m/s

Positioning accuracy
- Indoor Factory – ISAC 0.75 m
- Urban Macro – ISAC 6 m

- Theoretical downlink peak data rate: 36 Gbit/s
- Theoretical uplink peak data rate: 18 Gbit/s

Reliability: 1-10^{-5}

- 5th percentile user data rate downlink (Dense Urban-IC): 300 Mbit/s
- 5th percentile user data rate uplink (Dense Urban-IC): 50 Mbit/s

User plane latency:
- 4 ms for IC
- 1 ms for HRLLC

Control plane latency: 20 ms

- Downlink peak spectral efficiency is 60 bit/s/Hz.
- Uplink peak spectral efficiency is 30 bit/s/Hz.
- Average spectral efficiency and 5th percentile user spectral efficiency significantly lower

Mobility
- Stationary: 0 km/h
- Pedestrian 0-10 km/h
- Vehicular: 10-120 km/h
- High speed vehicular: 120-500 km/h

Connection density:
10^6 devices per km^2

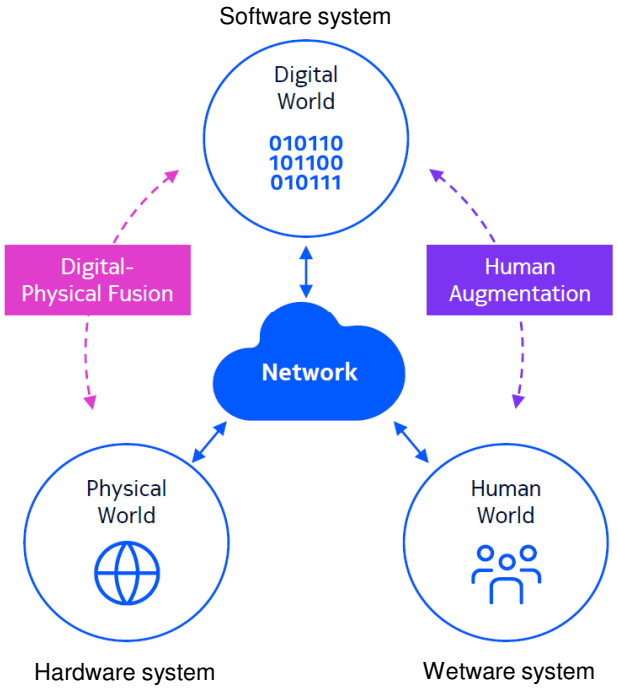
Area traffic capacity for Indoor Hotspot-IC in downlink: 40 Mbit/s/m^2

Source. ITU-R: The ITU-R Framework for IMT-2030, July 2023 WP 5D Management Team, https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/Documents/IMT-2030 Framework. WP 5D Management Team.pdf.

R. Liu, et.al.: Beginning of the journey toward 6G: Vision and Framework. IEEE Communications Magazine, October 2023, pp. 8.

6G approach

6G is framed by digital-physical fusion & human augmentation



Digital-Physical Fusion

Dynamic, network-connected representations of real-world things in the digital world

Allows the physical world to be replicated, simulated and automated within the digital world - opening doors to a wealth of new possibilities for human benefit.

Human Augmentation

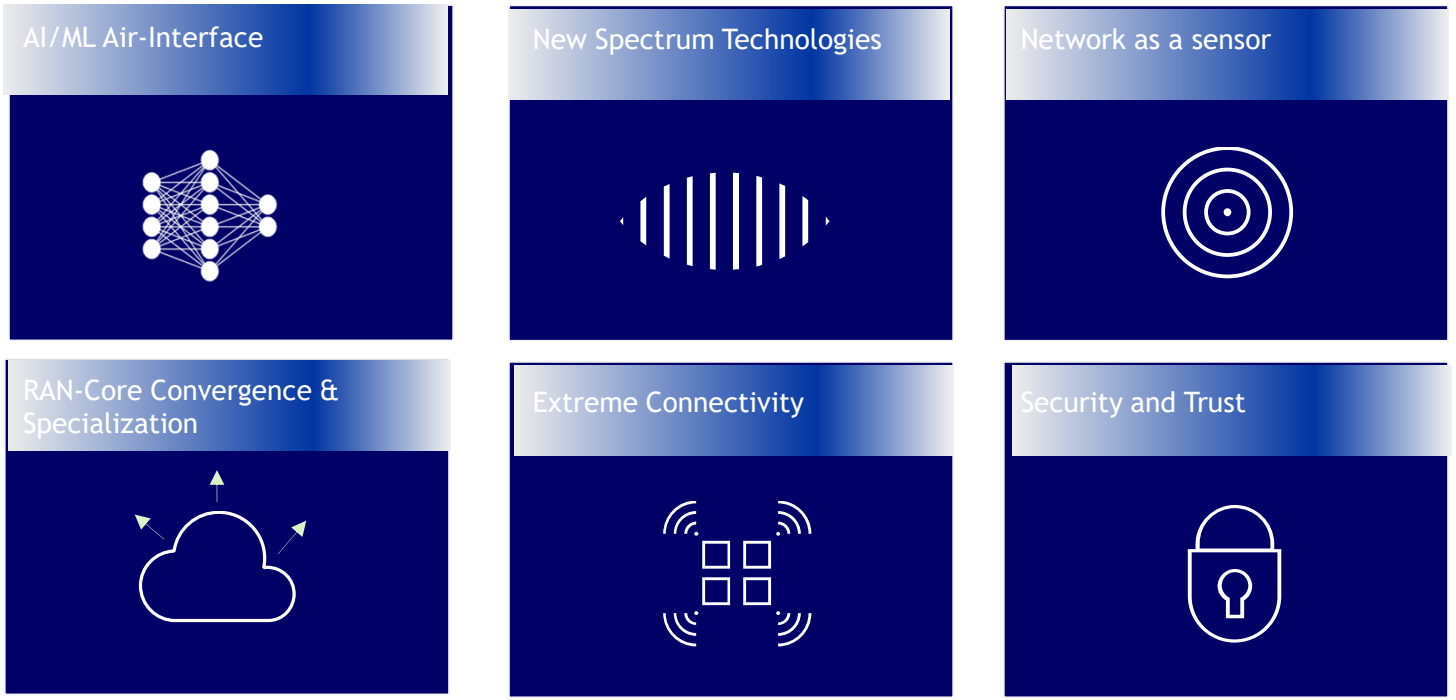
Extensions that enable people to interact with and within the digital world

Evolves the digital world from being a source of two-dimensional experiences and information, to a focal point of immersive and productive interaction

NOKIA

Source: Nokia

Six key technologies for 6G

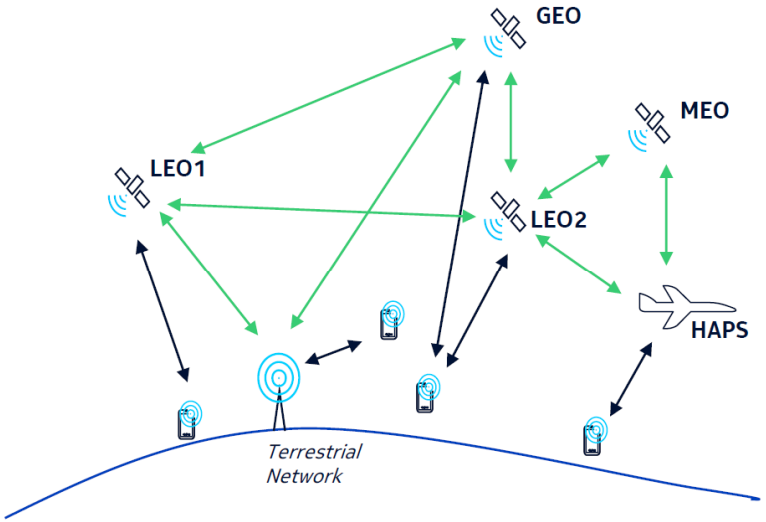


Source: Nokia.

Combination of different networks including NTN use cases

- Global coverage for search and rescue
- Maritime coverage
- Consumer handheld connectivity in remote areas
- NTN for connectivity in high mobility
- NTN as backup for disaster relief
- Global IoT coverage for full range of IoT devices
- Solving the digital divide

Network of Networks



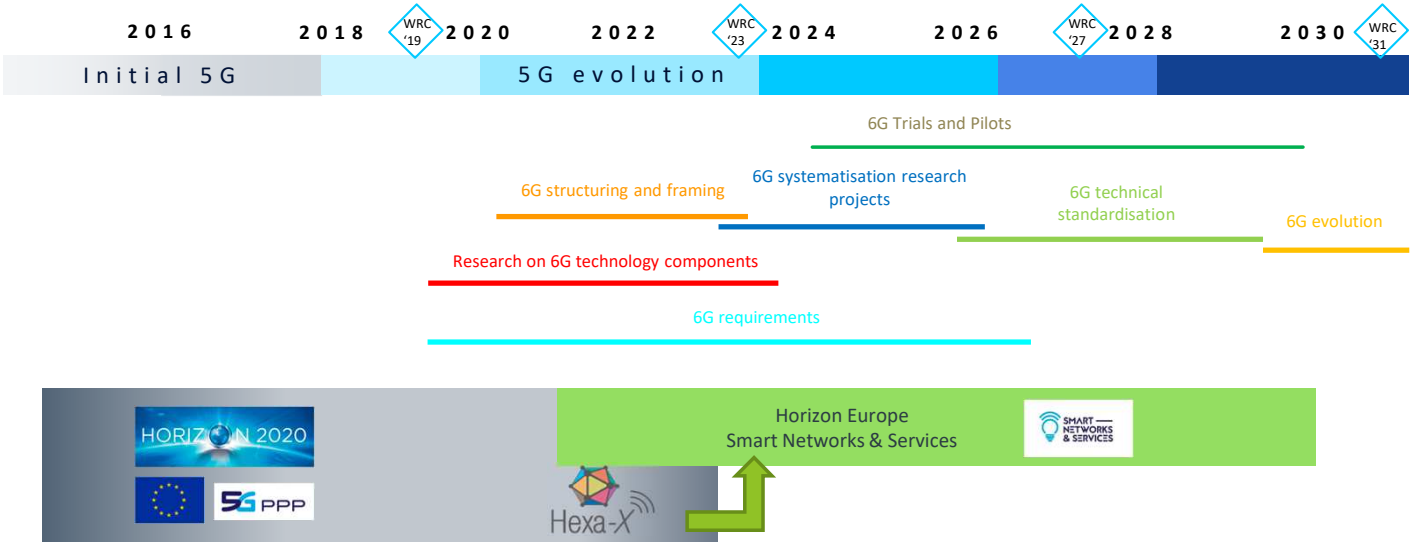
- Efficiency from complementary usage advantage
- Fit each service (with different requirements) to suitable networks
- “Route” optimization of users (load balancing)
- Resilience
- Decrease of CO2 by turning of TN network and serving users from space at times of low load

Source: Nokia

NOKIA

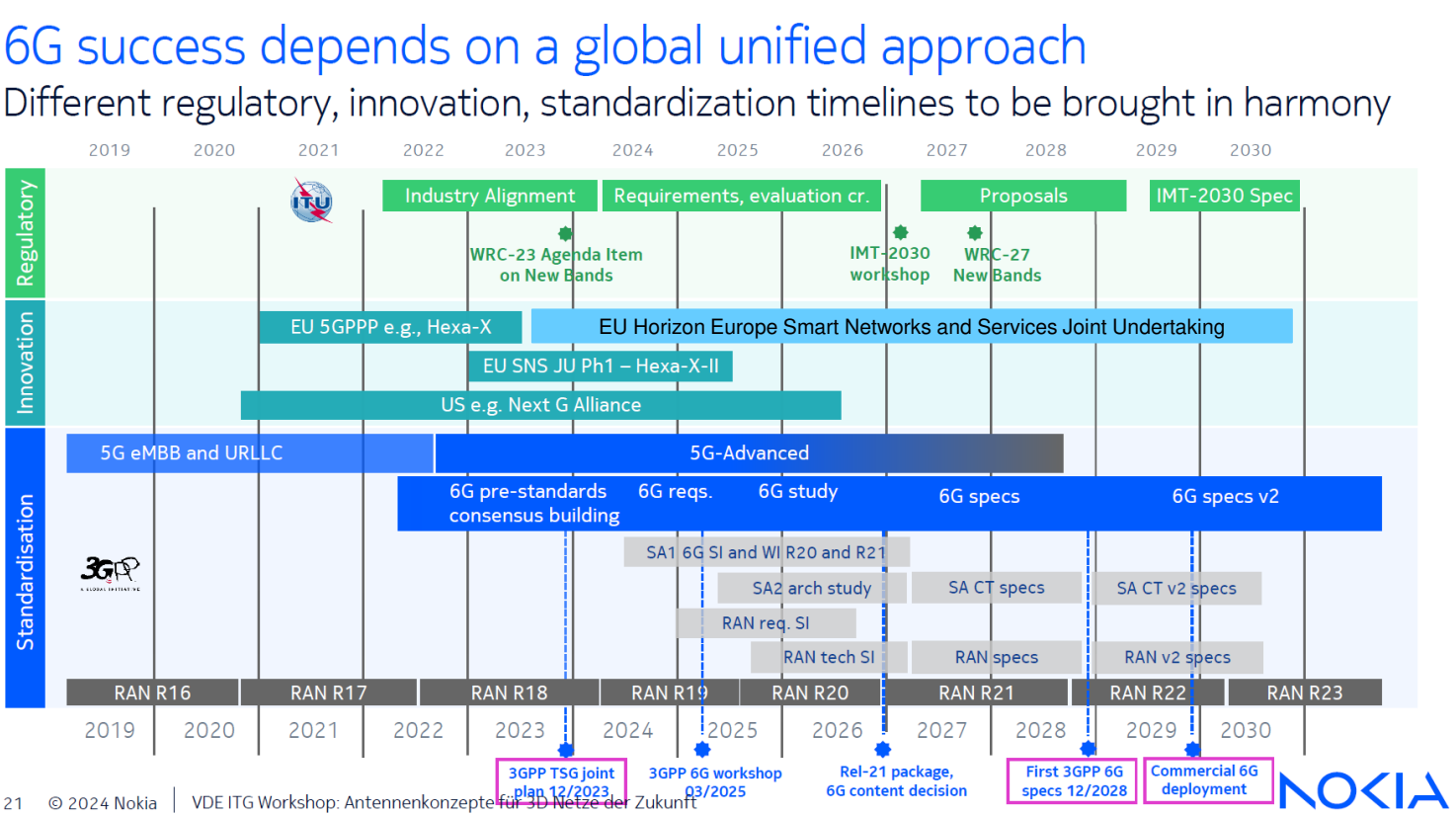
Lay the foundation for the networks of 2030

Instruments of collaborative research and funding



Source: Nokia.

International Roadmap towards 6G



Source: Nokia