What to expect from 6G?

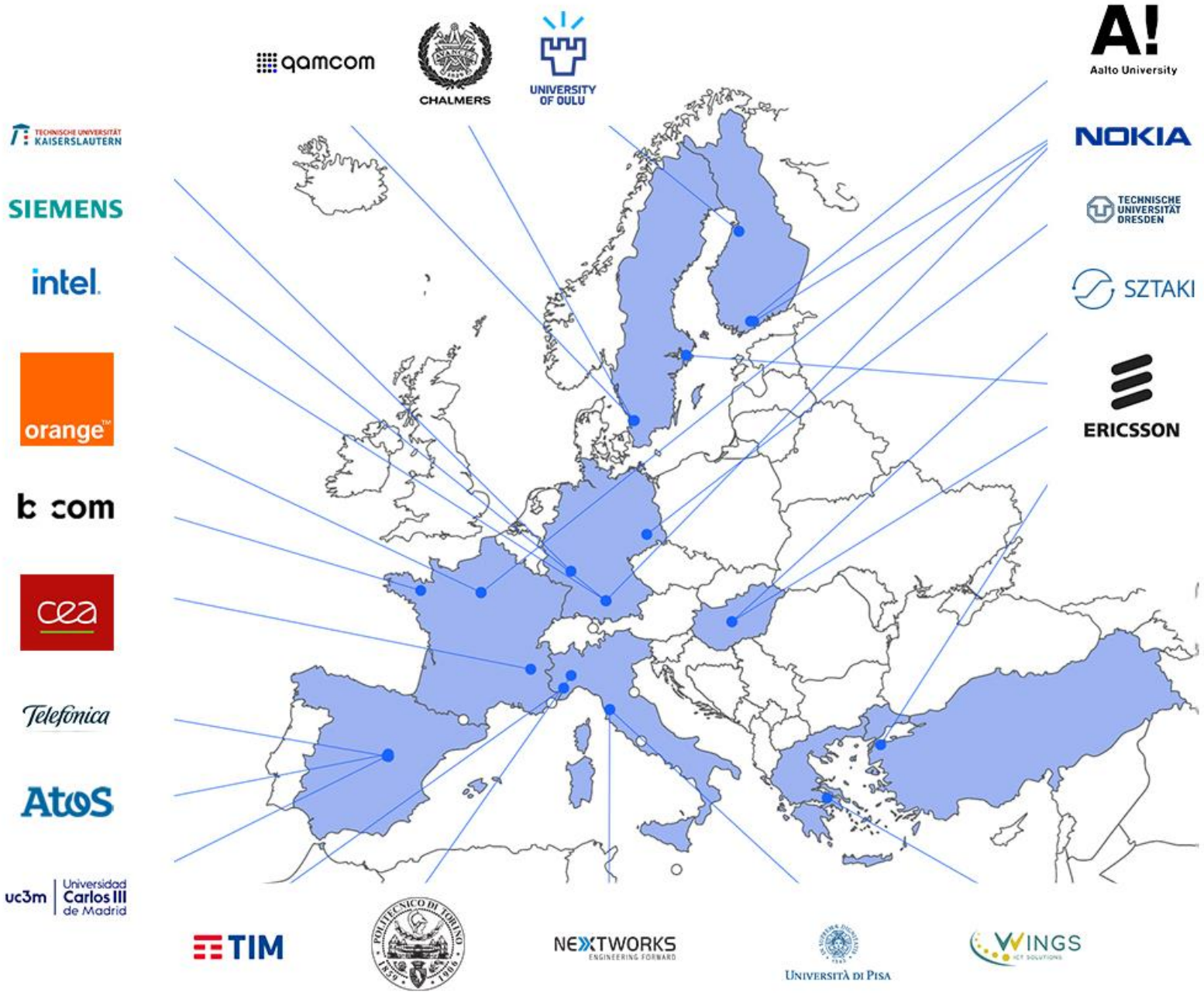
Aalto Internet Forum

hexa-x.eu

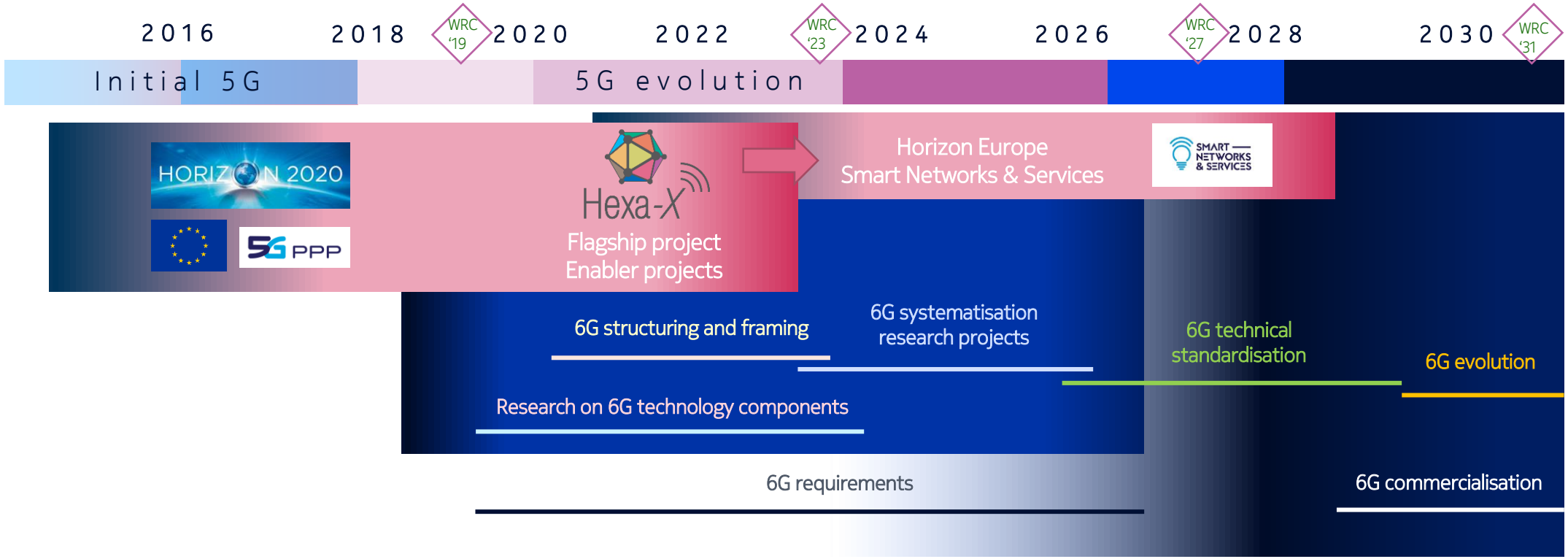
Mikko.Uusitalo@nokia-bell-labs.com

	1G (1980s)	2G (1990s)	3G (2000s)	4G (2010s)	5G (2020s)	6G (2030s)
Mobile Access	Analog Δ=30kHz 	GSM <2 GHz Δ=200kHz 	UMTS <2GHz Δ=5MHz 	LTE <6GHz Δ=nx20MHz 	5G <100GHz Δ=nx200MHz 	6G <THz Δ=10GHz 
Compute Platform						
Network Platform	Analog	Circuit (TDM)	Circuit/Packet (ATM)	Packet (IP)	Cloud	AI/ML
Copper Access	POTS 	ISDN Δ=20kHz 	ADSL Δ=1MHz 	VDSL Δ=30MHz 	G.(mg)fast Δ=200MHz 	FTTH / FWA Δ=10GHz 
Defining Application	Voice	Voice	WAP, Video	Web	IIoT	Digital – Physical Worlds
Unexpected App	Fax	SMS, ringtones	Web	Facebook YouTube	?	?
Defining EU Projects	NA	COST207	RACE 1043 (others, incl. FRAMES)	FP6: WINNER (WWI)	FP7: METIS (5GPPP)	**HEXA-X** **(SN&S)**

Hexa-X Consortium



Timeline


2016
2018
WRC '19
2020
2022
WRC '23
2024
2026
WRC '27
2028
2030
WRC '31
Initial 5G
5G evolution
HORIZON 2020
5G PPP
Hexa-X
Flagship project
Enabler projects
Horizon Europe
Smart Networks & Services
SMART NETWORKS & SERVICES
6G structuring and framing
6G systematisation research projects
6G technical standardisation
6G evolution
Research on 6G technology components
6G requirements
6G commercialisation

6G Ecosystem

North America

- NEXT G ALLIANCE
- NSF RINGS

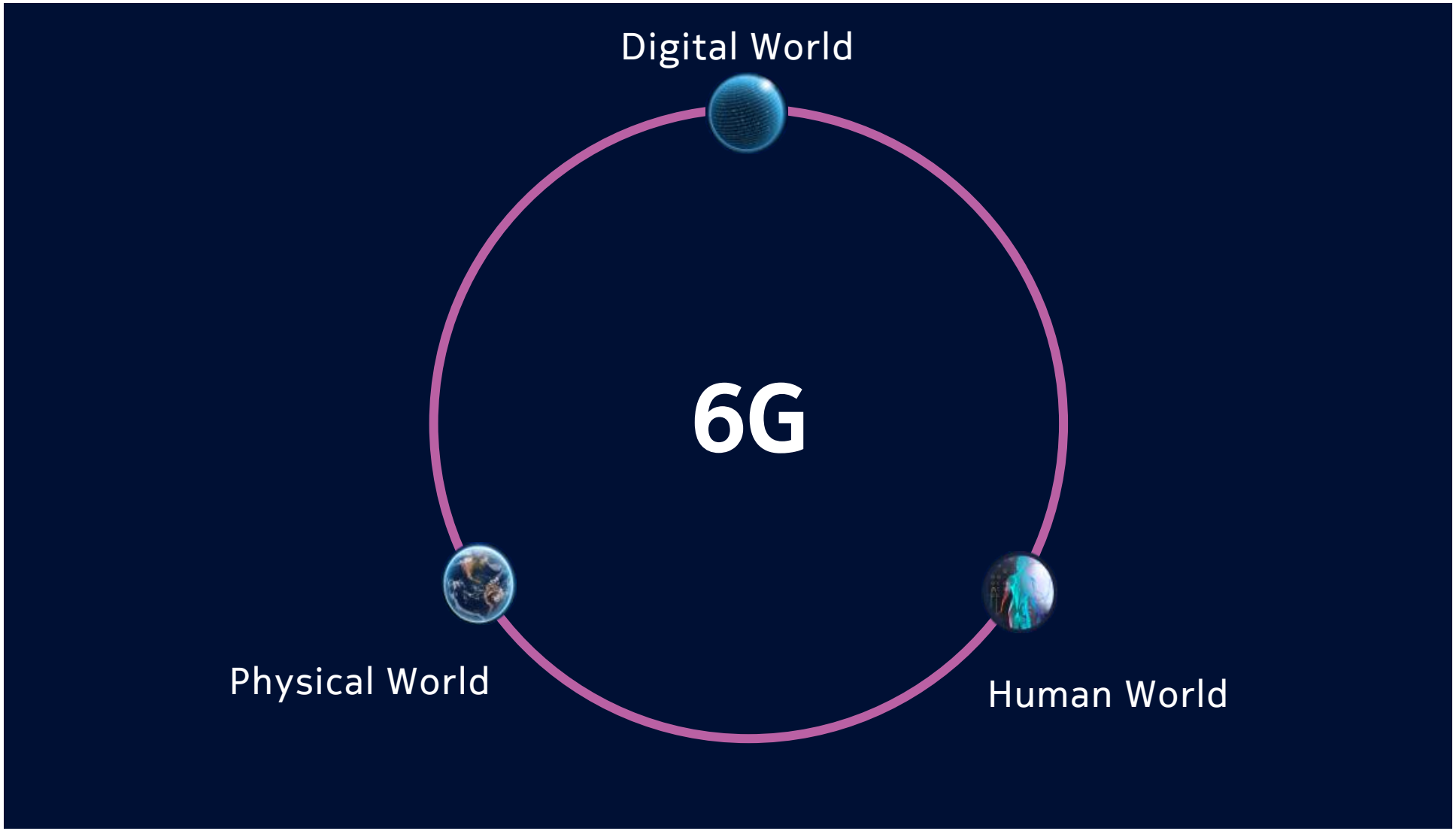
Europe

- EU: Hexa-X, SMART NETWORKS & SERVICES
- FI: 6Genesis
- DE: BMBF, 6G Hubs

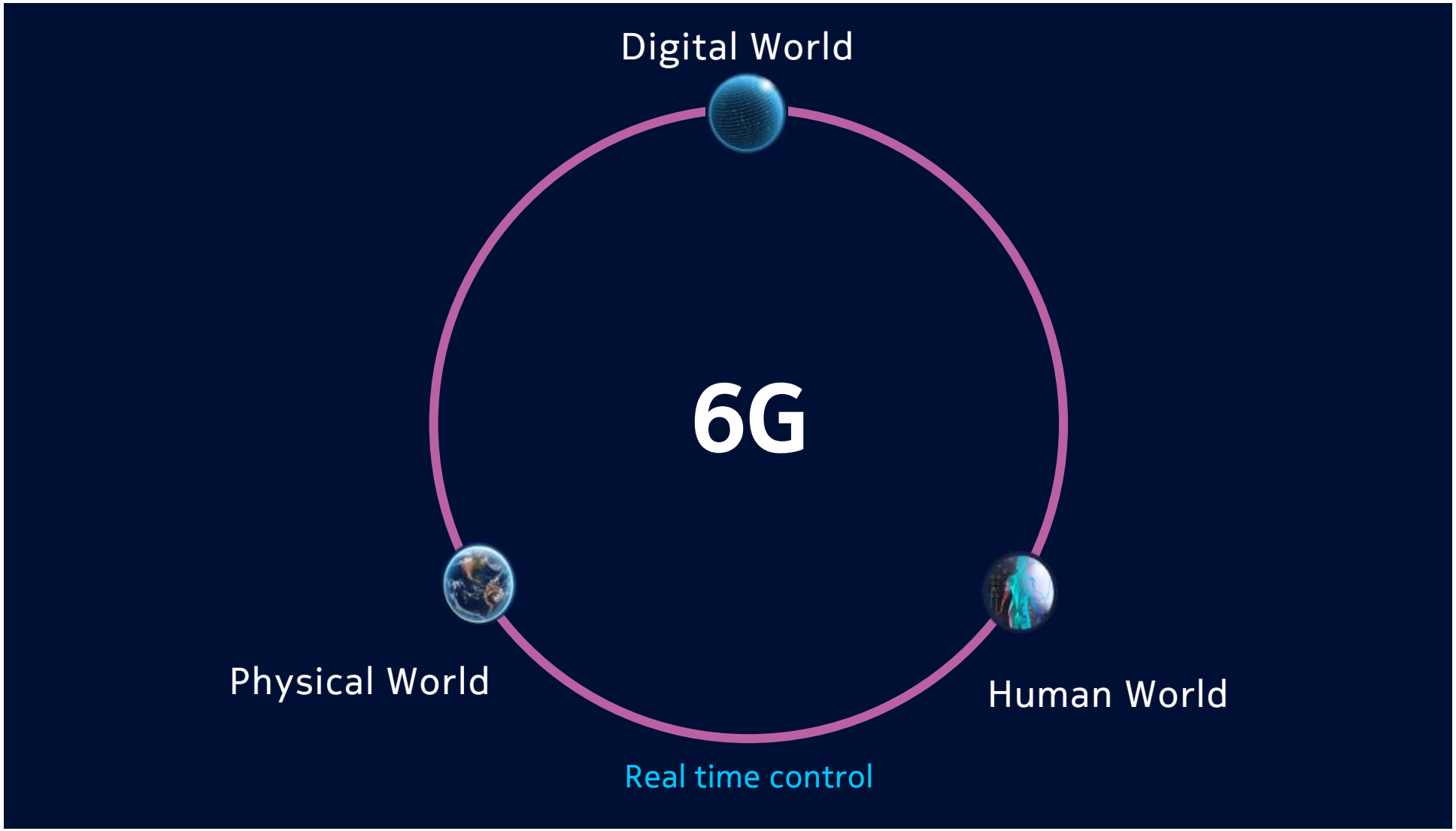
Asia

- CN: MIIT, 中华人民共和国科学技术部 Ministry of Science and Technology of the People's Republic of China, 未来移动通信论坛 FUTURE MOBILE COMMUNICATION FORUM
- KR: Ministry of Science and ICT, 5G Forum
- JP: MIC Ministry of Internal Affairs and Communications, IOWN GLOBAL FORUM
- IN: tsdsi

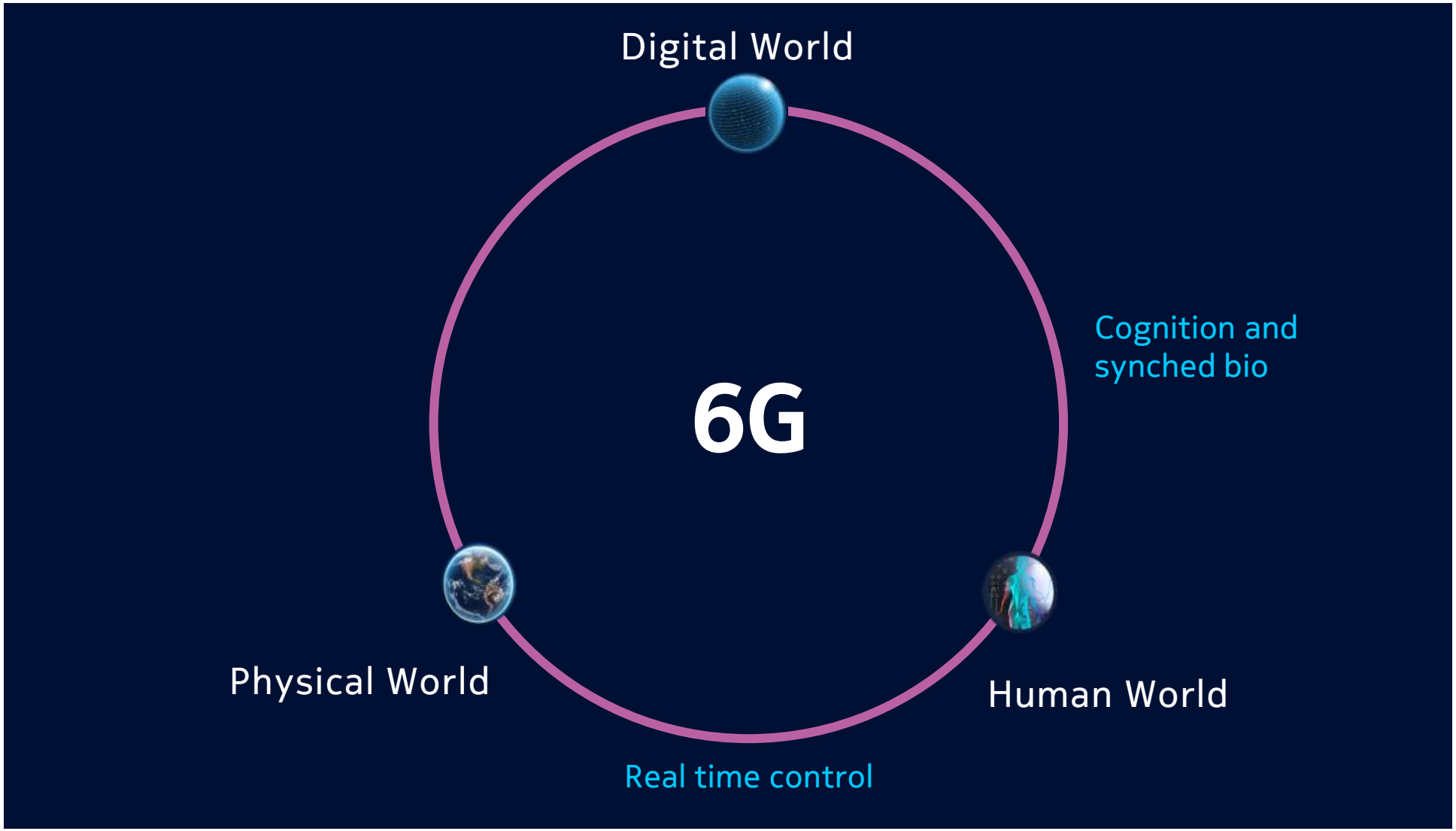
Hexa-X Vision



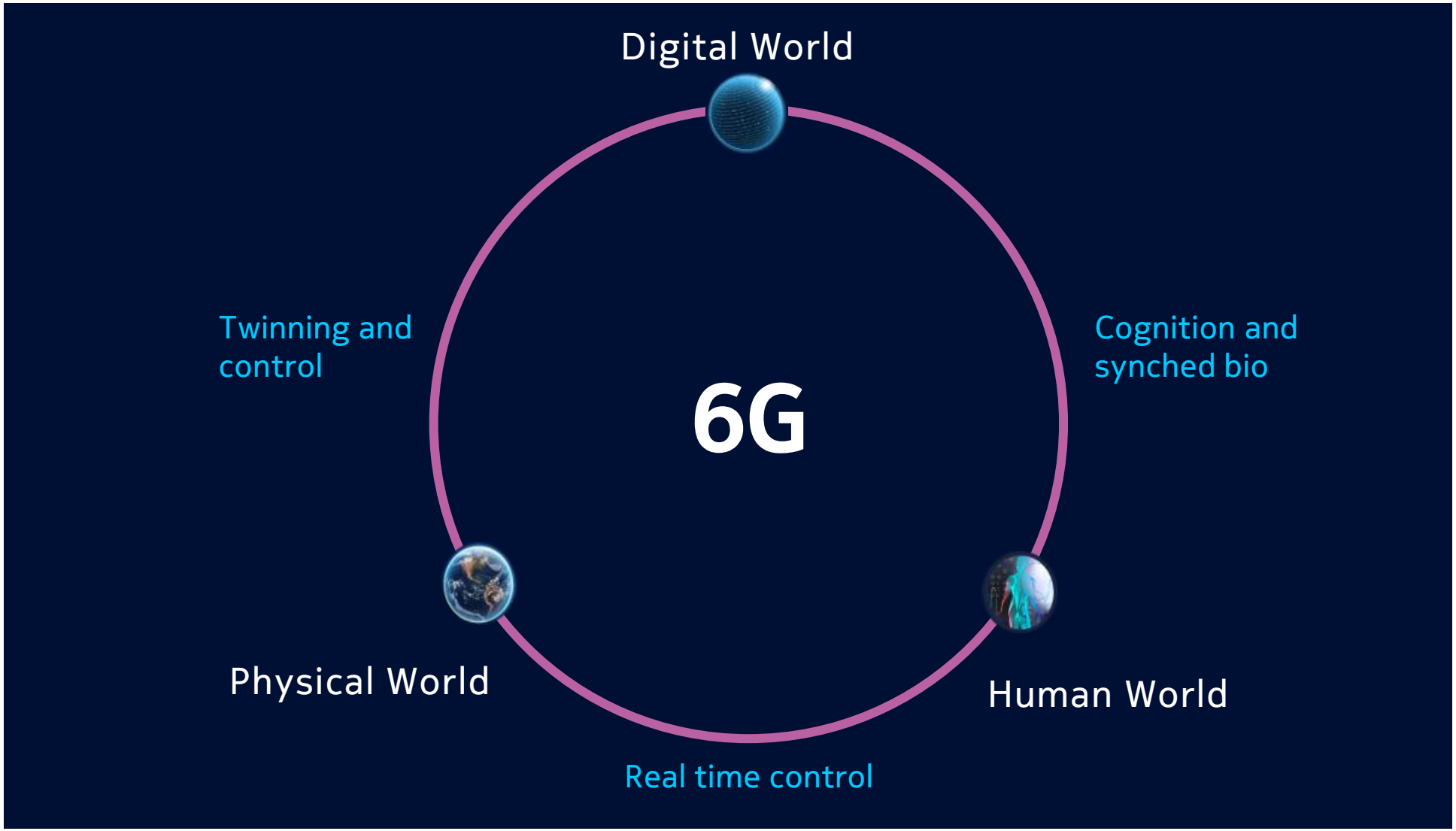
Hexa-X Vision



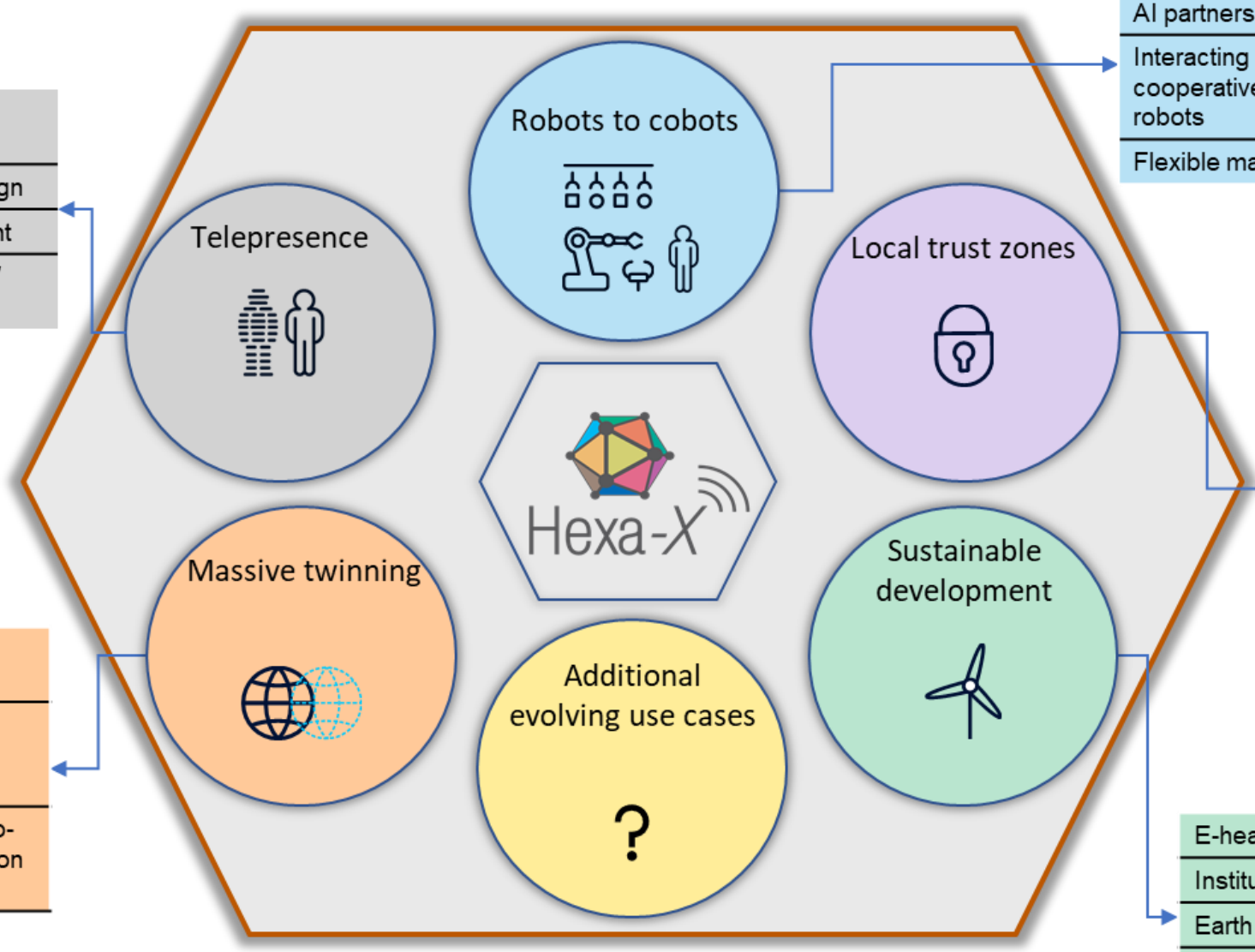
Hexa-X Vision



Hexa-X Vision



Hexa-X use cases



- Consumer robots
- AI partners
- Interacting and cooperative mobile robots
- Flexible manufacturing

- Fully merged cyber-physical worlds
- Mixed reality co-design
- Immersive sport event
- Merged reality game/ work

- Enabling precision healthcare and personalized medical treatment
- Sensor infrastructure web
- 6G IoT micro-networks for smart cities
- Infrastructure-less network extensions and embedded networks
- Local coverage for temporary usage
- Small coverage, low power micro-network in networks for production & manufacturing
- Automatic security

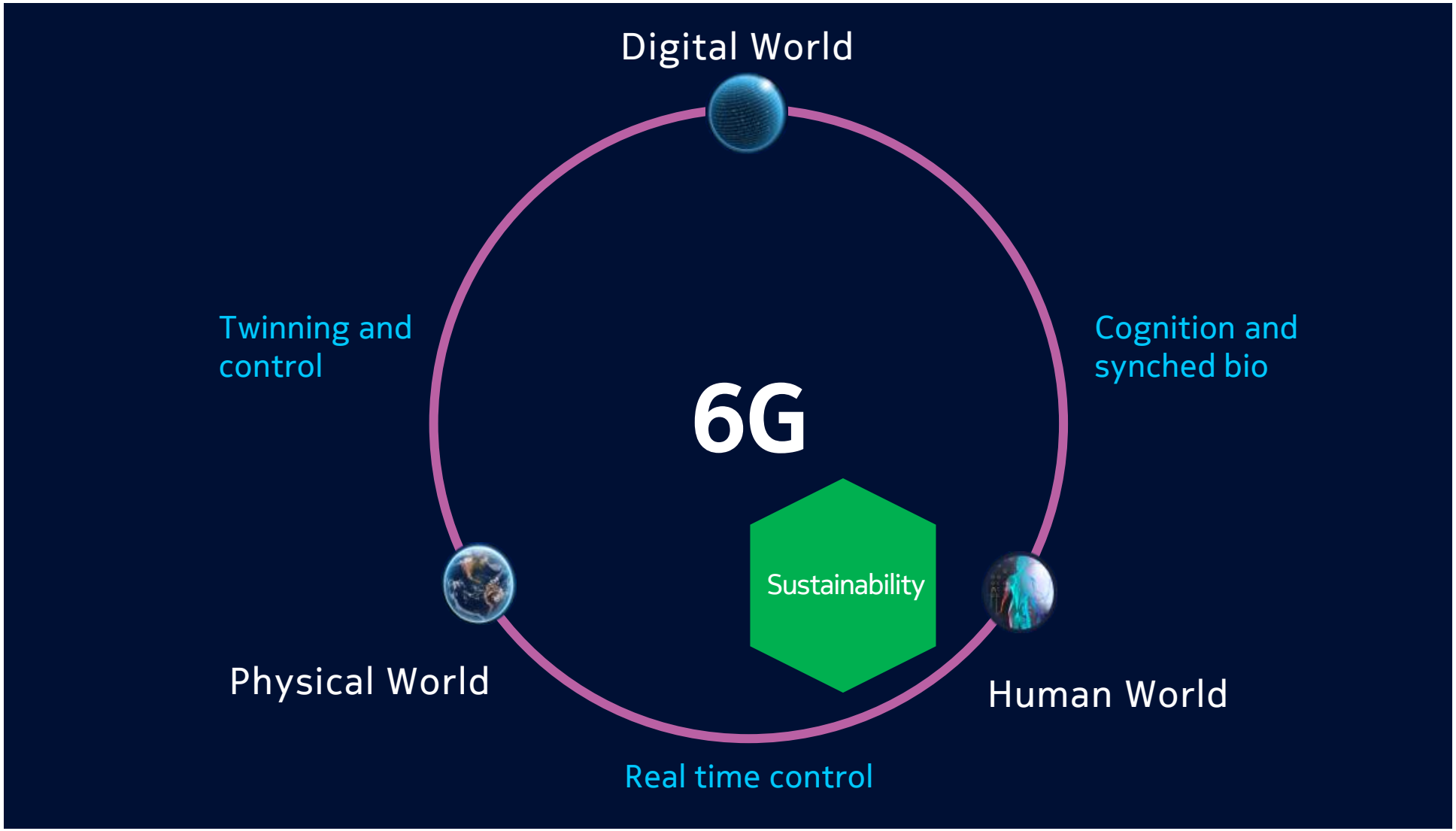
- Digital Twin for manufacturing
- Management of city flows to optimize the Liveability
- Digital Twins for zero-hunger and production sustainability

- E-health for all
- Institutional coverage
- Earth monitor
- Autonomous supply chains

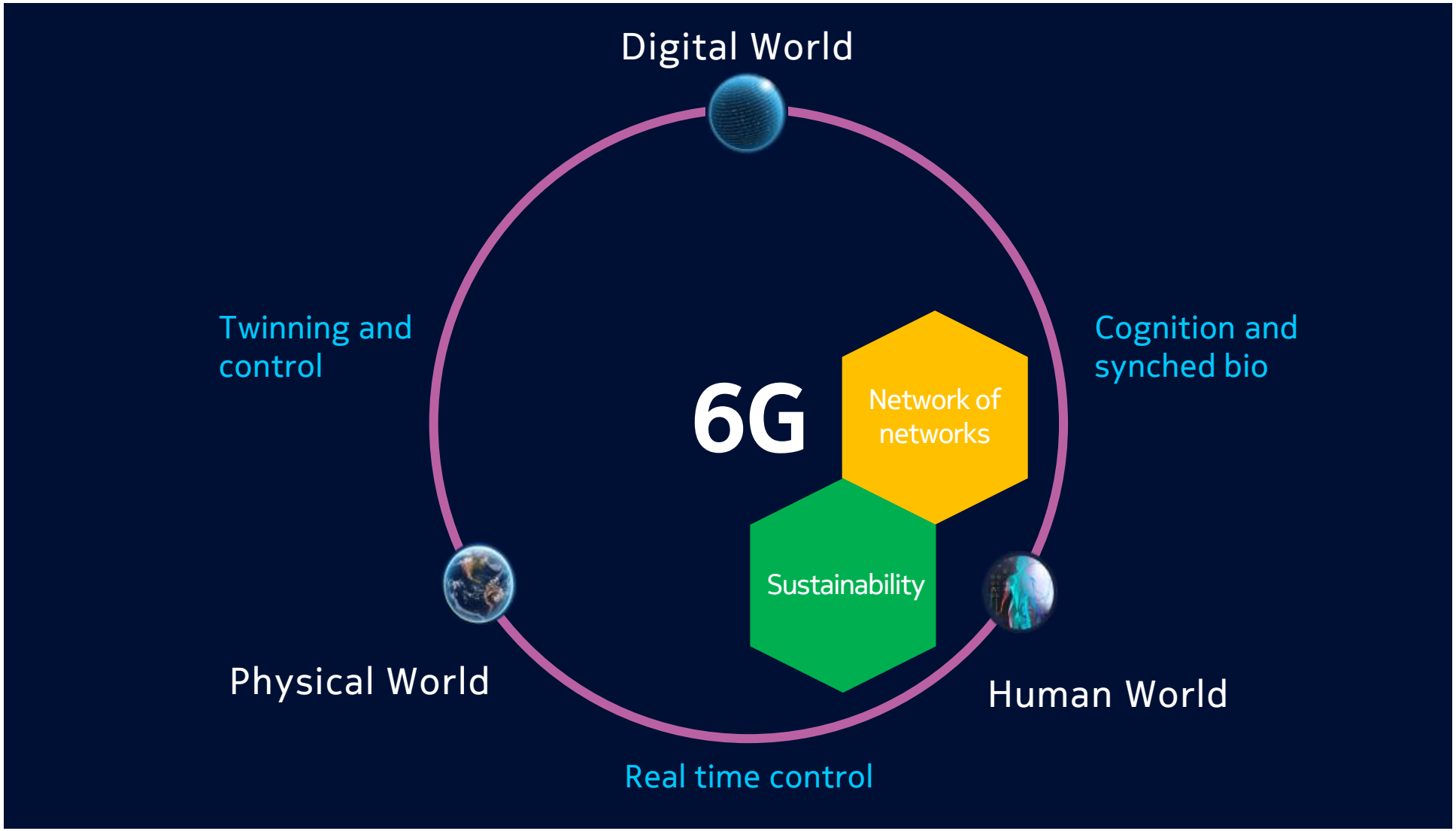
Creating the ‘augmented human’ in the 6G Era

NOKIA Bell Labs

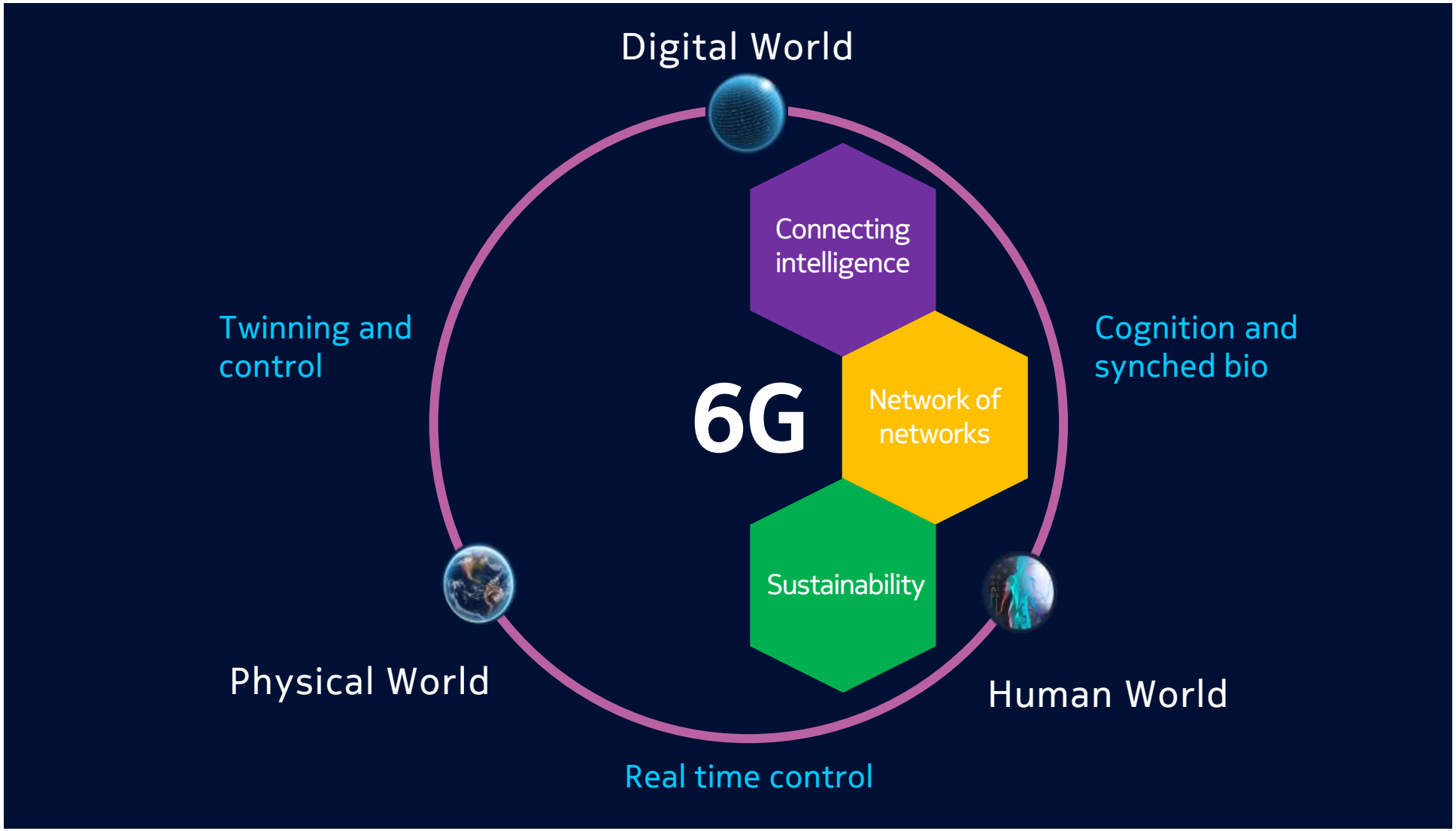
Hexa-X Vision



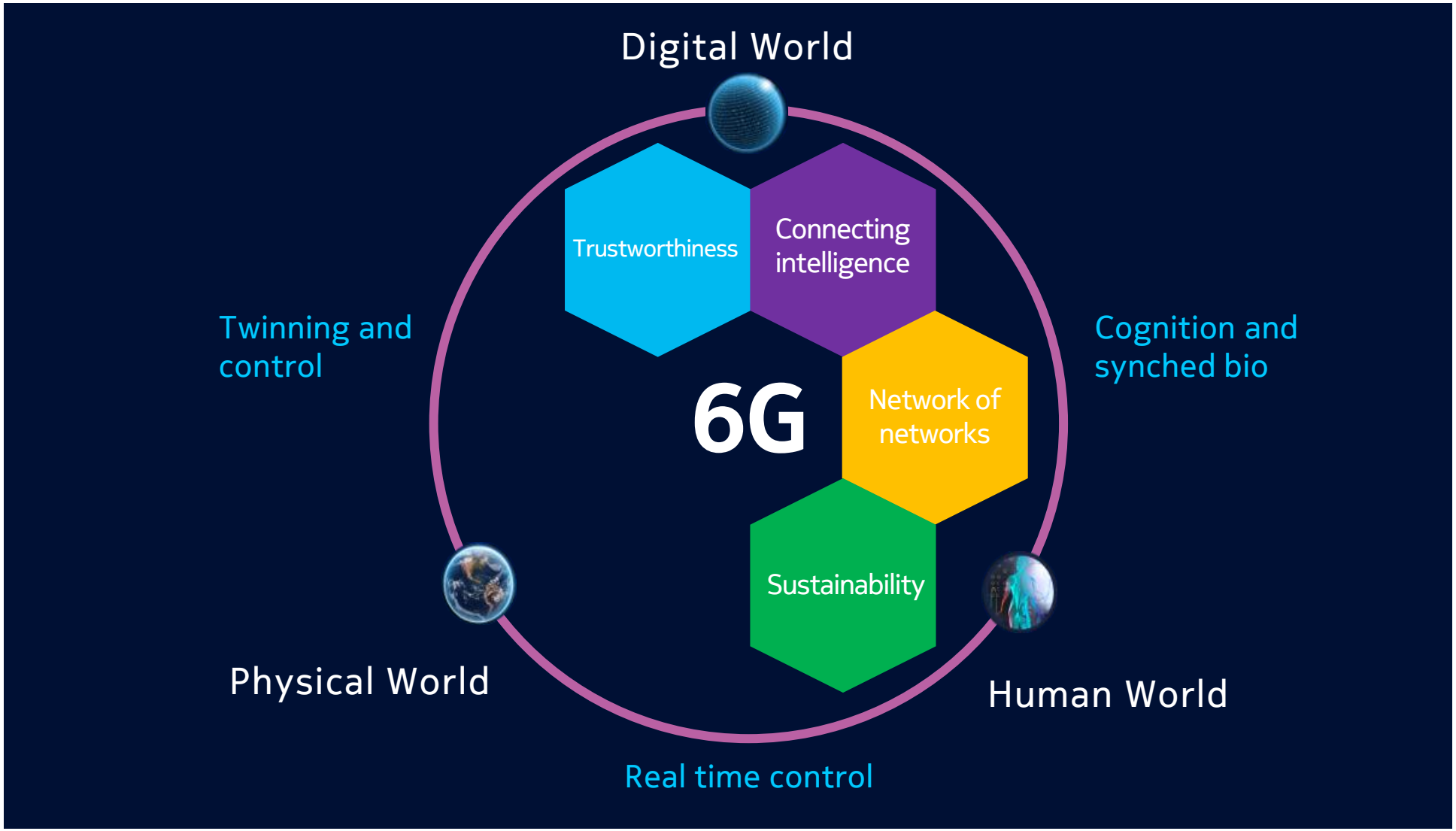
Hexa-X Vision



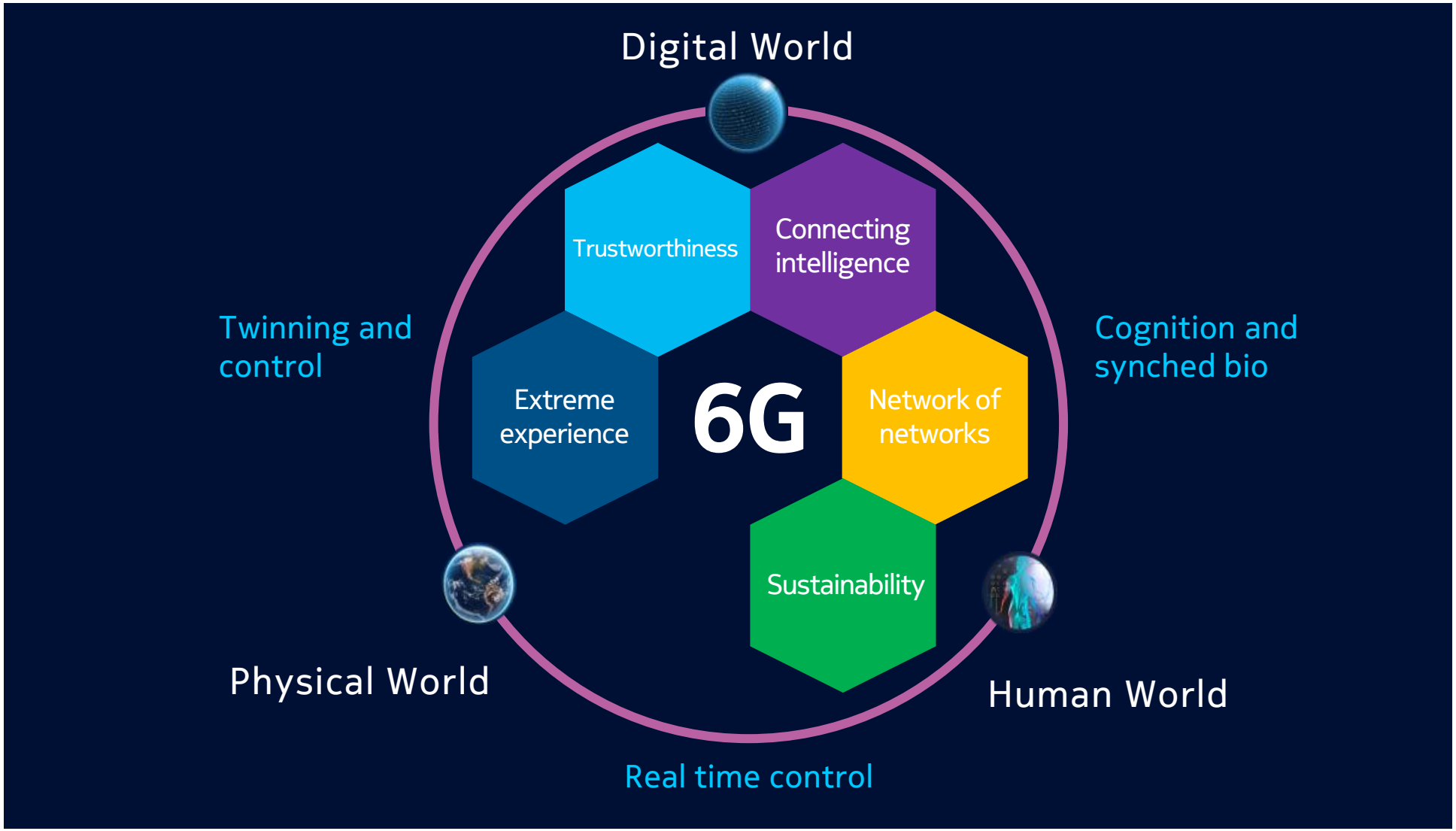
Hexa-X Vision



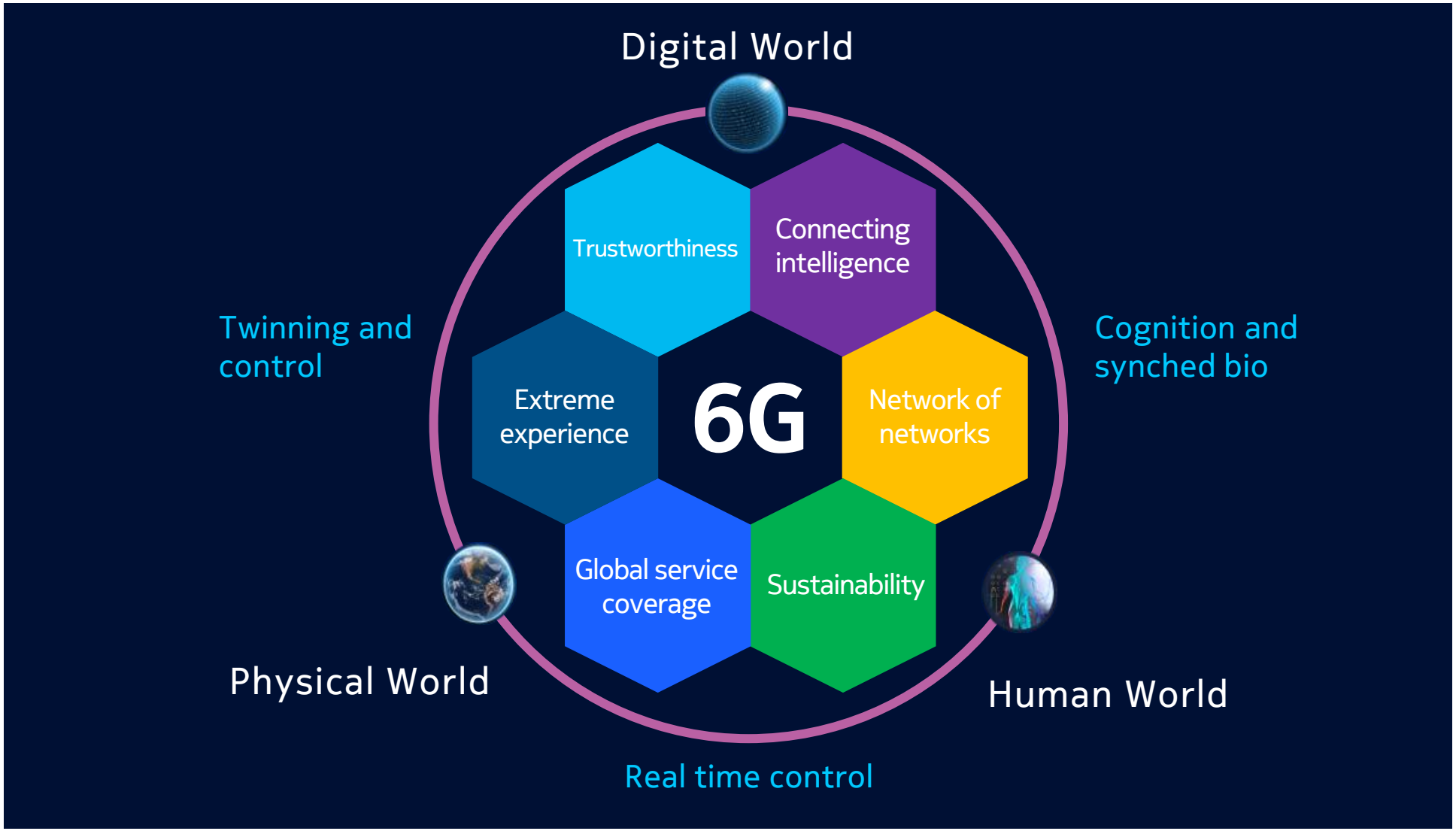
Hexa-X Vision



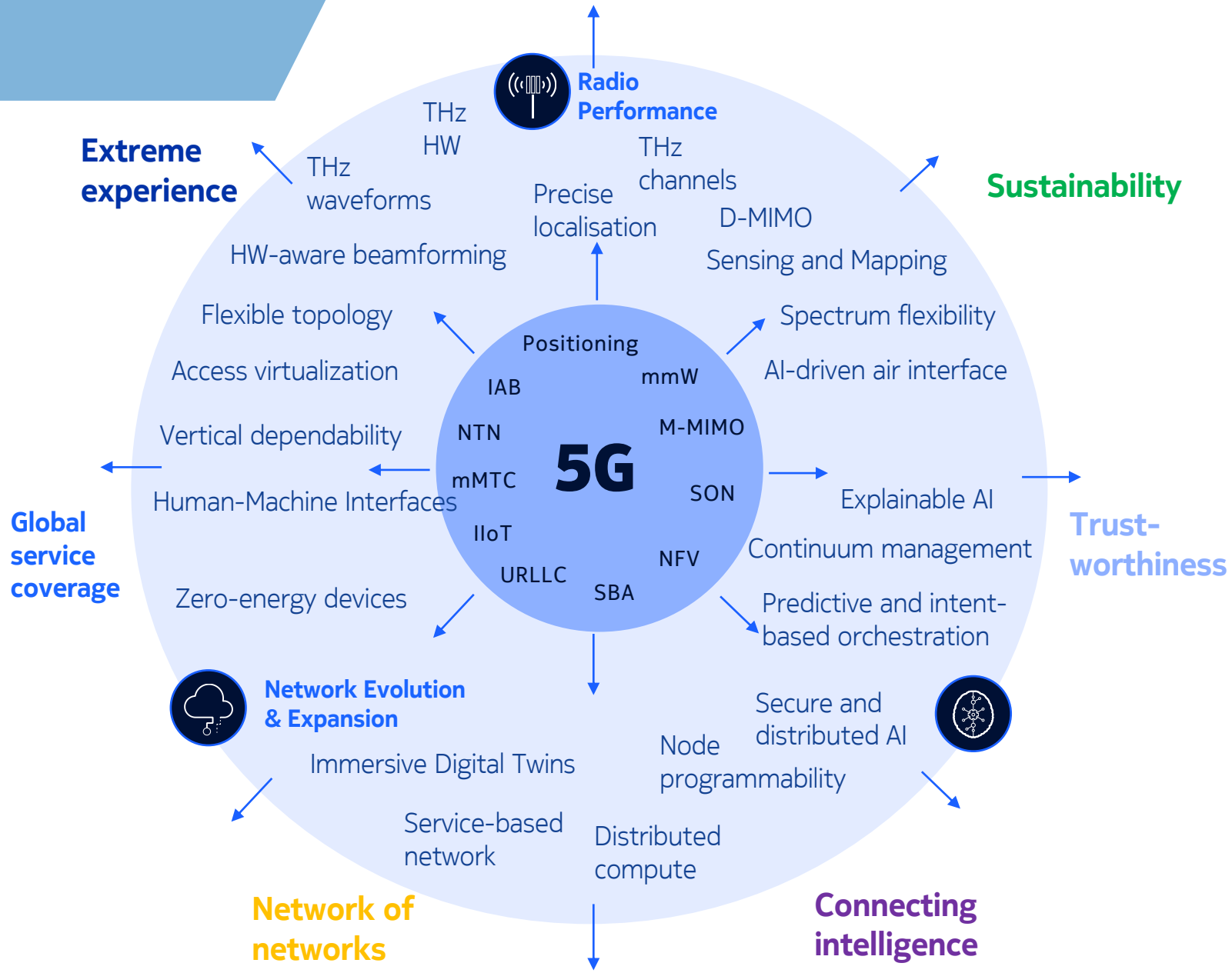
Hexa-X Vision



Hexa-X Vision

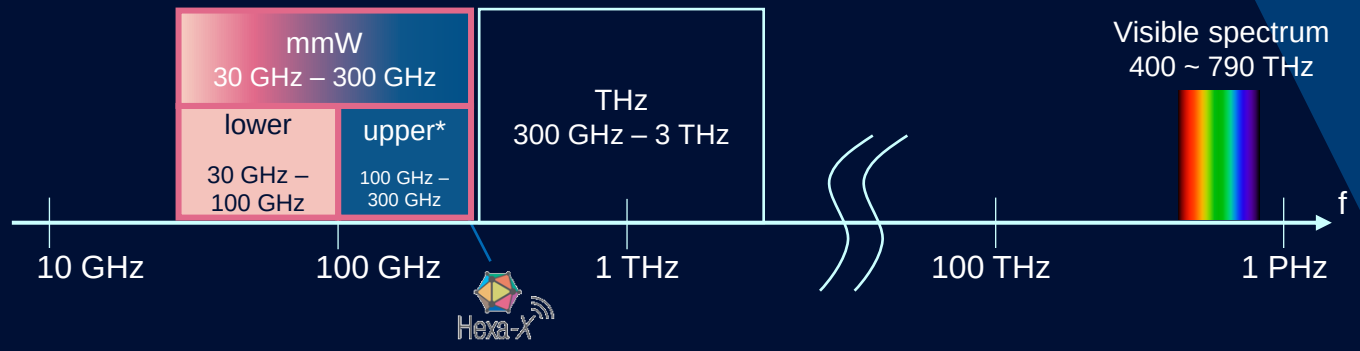


Ambitions


Radio Performance
THz HW
THz channels
Precise localisation
D-MIMO
Sensing and Mapping
Extreme experience
THz waveforms
HW-aware beamforming
Sustainability
Flexible topology
Spectrum flexibility
Access virtualization
AI-driven air interface
Positioning
IAB
mmW
NTN
M-MIMO
5G
Vertical dependability
mMTC
SON
Human-Machine Interfaces
Explainable AI
Trust-worthiness
Global service coverage
IIoT
Continuum management
NFV
URLLC
SBA
Zero-energy devices
Predictive and intent-based orchestration
Network Evolution & Expansion
Secure and distributed AI
Node programmability
Immersive Digital Twins
Service-based network
Distributed compute
Network of networks
Connecting intelligence

Addressing extreme performance

- For Radio research Hexa-X focuses resources on upper mmW (100-300 GHz)
- Lower bands will be essential for coverage but may reuse 5G NR PHY
- Rest of project are mostly frequency-agnostic – solutions should be valid for all ranges (0-300 GHz)

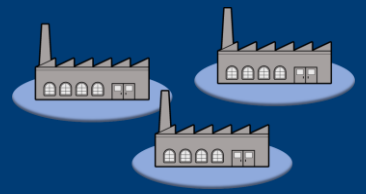


*upper mmW is sometimes known as: “THz” or “sub-THz”. In Hexa-X the preferred term is upper mmW

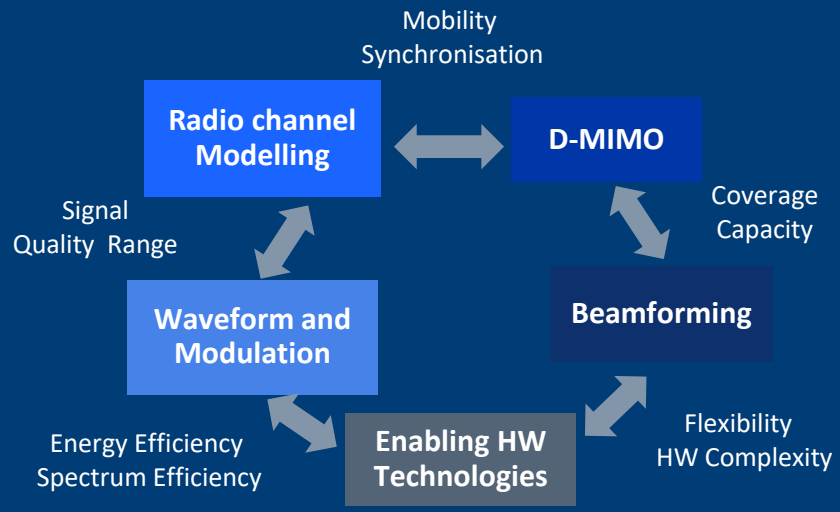
Co-existence with legacy technology

Smooth migration to 6G capabilities

Local spectrum licenses



Enabling new use cases



Source D2.1: Hexa-X_D2.1.pdf)

Classification of mmW technology by communications & sensing functions

6G mmW technology
(in upper & lower frequencies)

Short-range wireless links
Small cells & access points, <100m

- Wireless access (D2I)
  - **D2I** at short ranges with low mobility
- Local networks (D2D)
  - **D2D** to disseminate information locally

Long-range wireless links
Front-, mid-, back-haul

- Fixed wireless links
  - When laying **fibre** to extend the reach of wireless networks **is not convenient**
- Mobile wireless links
  - When at least one communication node is moving, **fibre is not possible**

Sensing w/ radio waves
Not “sensor networks”

- Localization
  - Devices obtain accurate location information about **own location**
- Mapping, Tracking
  - Capture the shape of the **environment** or objects/people
- Spectroscopy
  - **Interaction** of EM radiation **with matter**

Initial Technical Requirements for 6G Radio beyond 5G NR

Parameter	First wave 6G radio requirement	Long-term vision for 6G radio
Data rate (R)	100 Gbps	1 Tbps
Operational/carrier frequency (f_c)	100 – 200 GHz range	Up to 300 GHz range
Radio link range (d)	100 – 200 meters	10 – 100 meters
Duplex method	Time Division Duplexing (TDD)	TDD
Initial device class targets	Device to infrastructure, mobile backhaul/fronthaul	Infrastructure backhaul/front haul, local fixed links, and interfaces (data centres, robots, sensors, etc.)

Reimagining purpose of radio connection

Joint communication and sensing

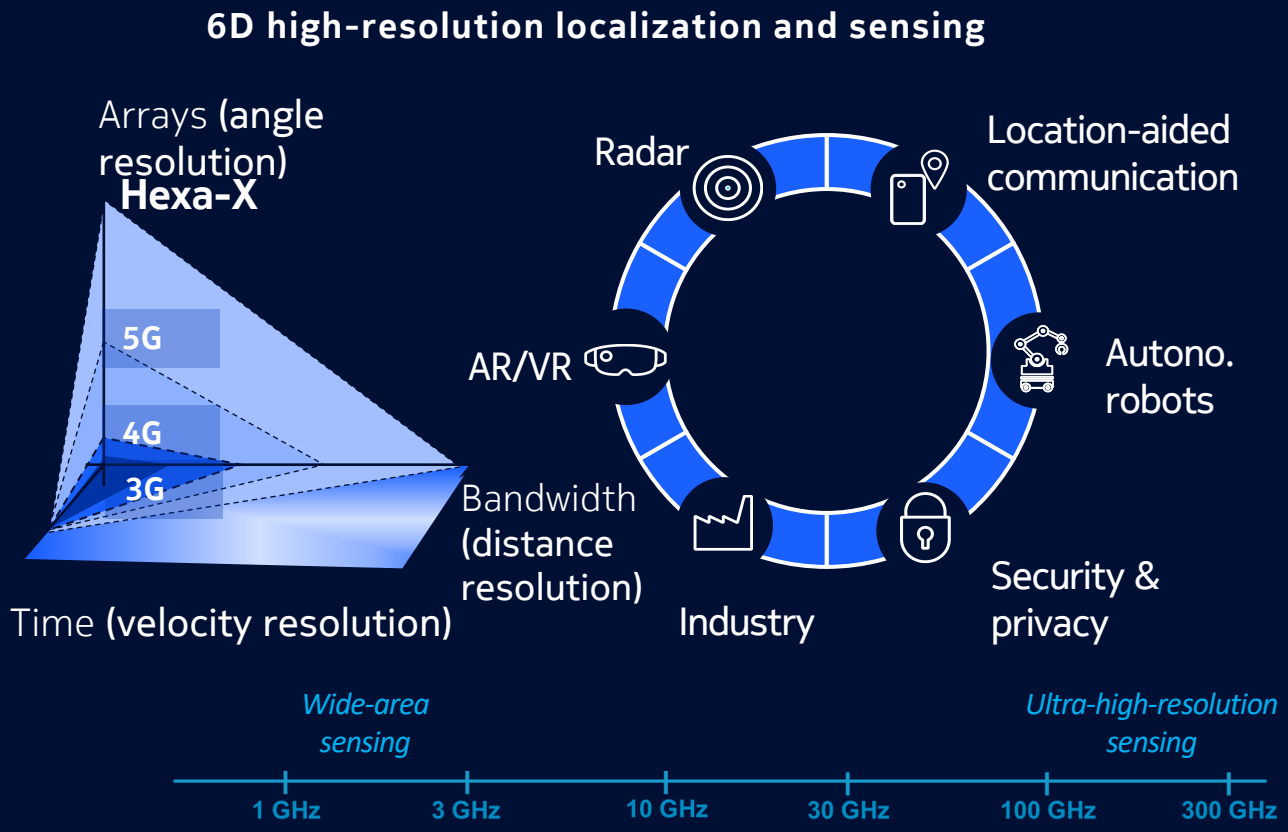
Sensing functionality as an integrated part of the communication network

- Low-cost introduction of sensing functionality
- Benefit from huge number of network nodes ⇨ Enhanced sensing capabilities

To enable new and enhanced services

To enhance the network performance

First results will be available end of December

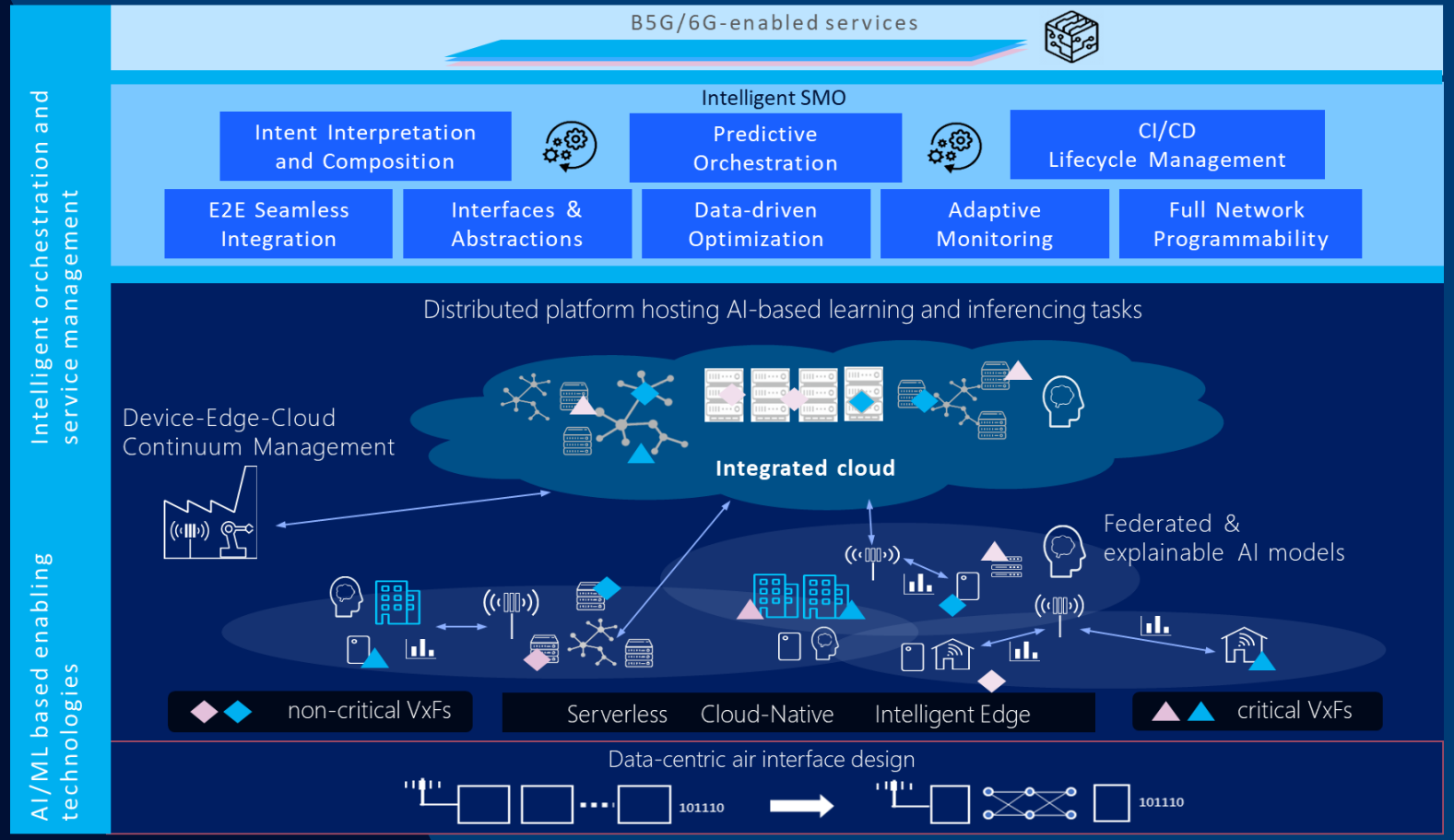


Data-driven operation

- **Overall trend:**
  - More and more AI
- **Why this trend? AI can help to:**

  a) Automate management

  b) Optimize certain resource or KPIs
- **Consequence of this trend:**
  - AI models everywhere. Models need to be trained. Training requires data.
  - Data needs to be available and secure



Intelligent network management and orchestration

Goal State-Features

Feature 1. Continuous Orchestration from end-devices to the core

Feature 2. Orchestration for heterogeneous service definitions

Feature 3. Multi-stakeholder orchestration

Feature 4. Support for private Networks

Feature 5. AI driven Orchestration

Feature 6. Advanced Monitoring

Feature 7. Means for automation and network programmability

Feature 8. Security Architecture

Feature 9. Implementation

State of the art

1 **SDOs and Open-Source Communities**

- Description of different service orchestration SDOs concentrating on network automation and management system architecture

2 **Industry Fora**

- Breadth of input relevant to evolution of service orchestration.

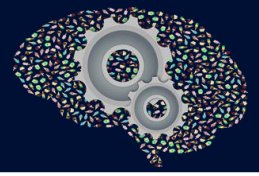
3 **Research Projects**

Direction for future research

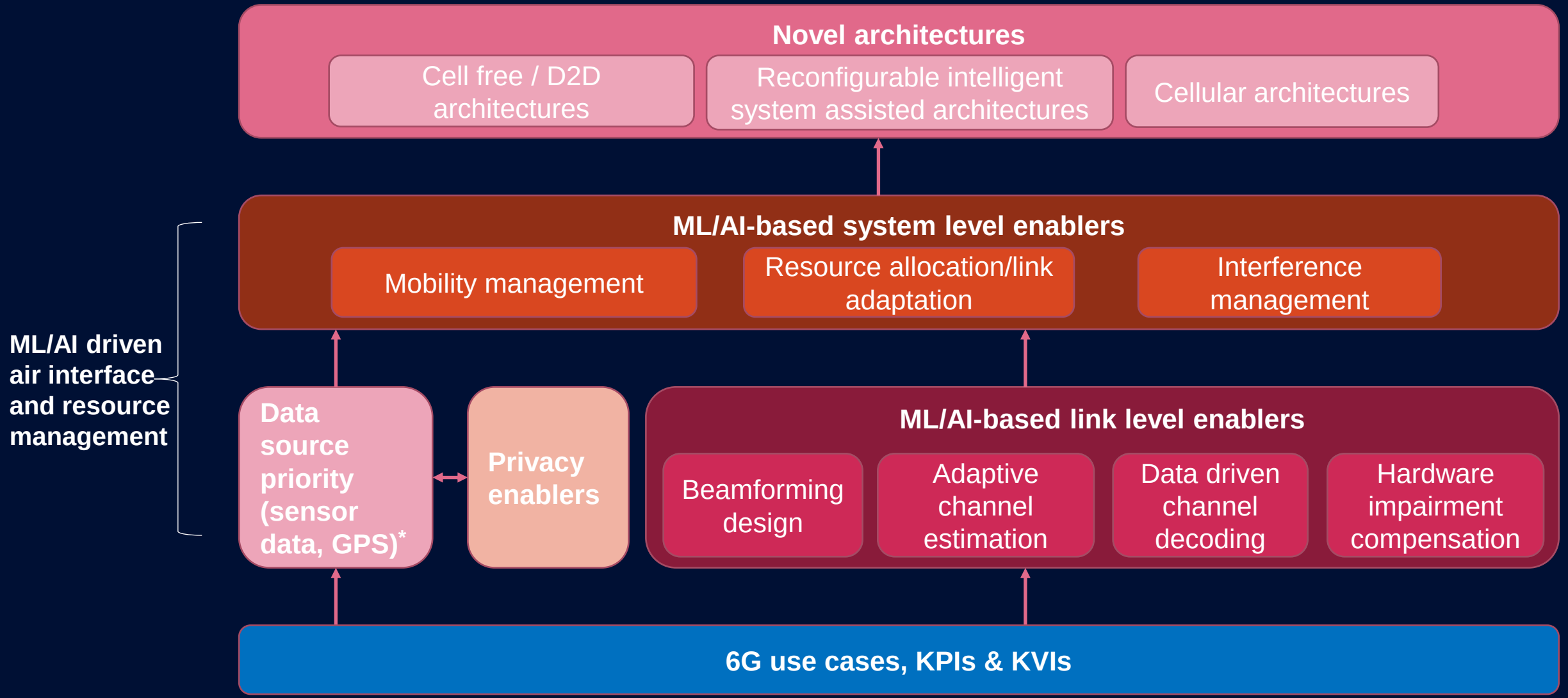
O&M ARCHITECTURE

D-E-C CONTINUUM ORCHESTRATION

AI / ML

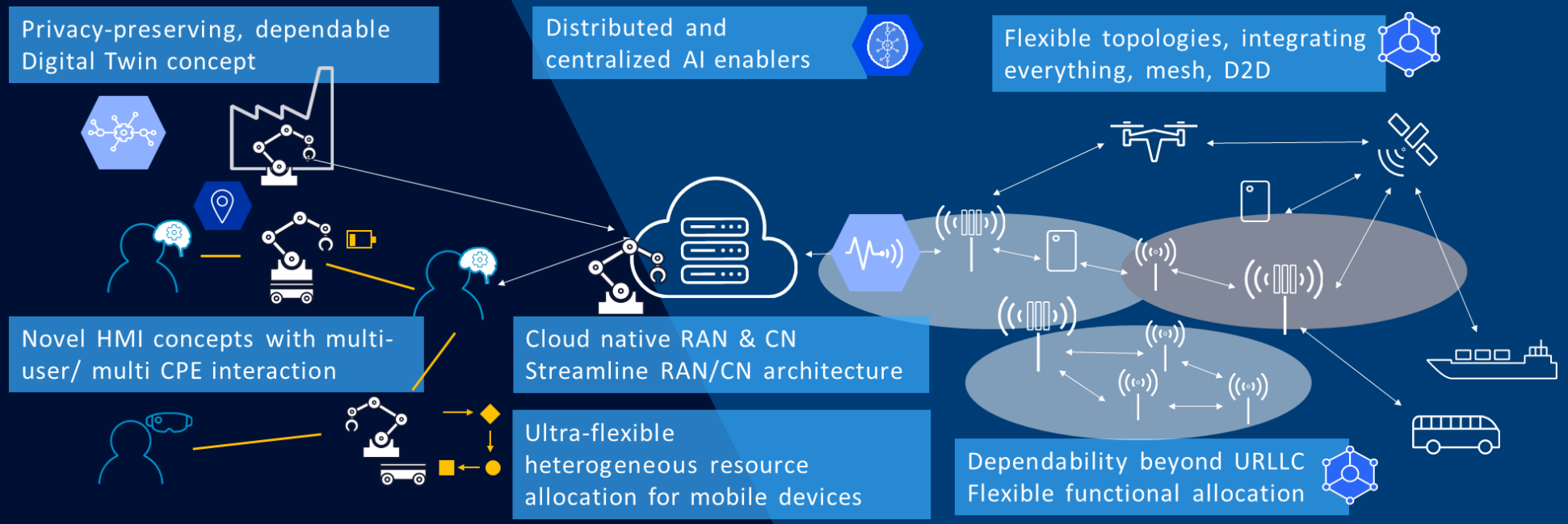


Overview of proposed enablers for AI driven air interface design



*Data source priority based on availability and privacy requirements

Network evolution and expansion towards 6G



Flexible and dynamic networks

Integration of new types of access nodes and devices

Versatile programmable transport, devices and network for cost effective densification and faster TTM

Dynamically deployable AI/ML agents

Addressing needs from enterprises and verticals

Network architecture optimized for cloud

Based on a common cloud platform and IT tools

Fully service-based

Having enhanced functional separation

Enabling optimization and simplification

Needed capabilities

Extended KPIs

- Bit rates
- Connection density
- Traffic capacity
- Location accuracy

Needed capabilities

E2E KPIs

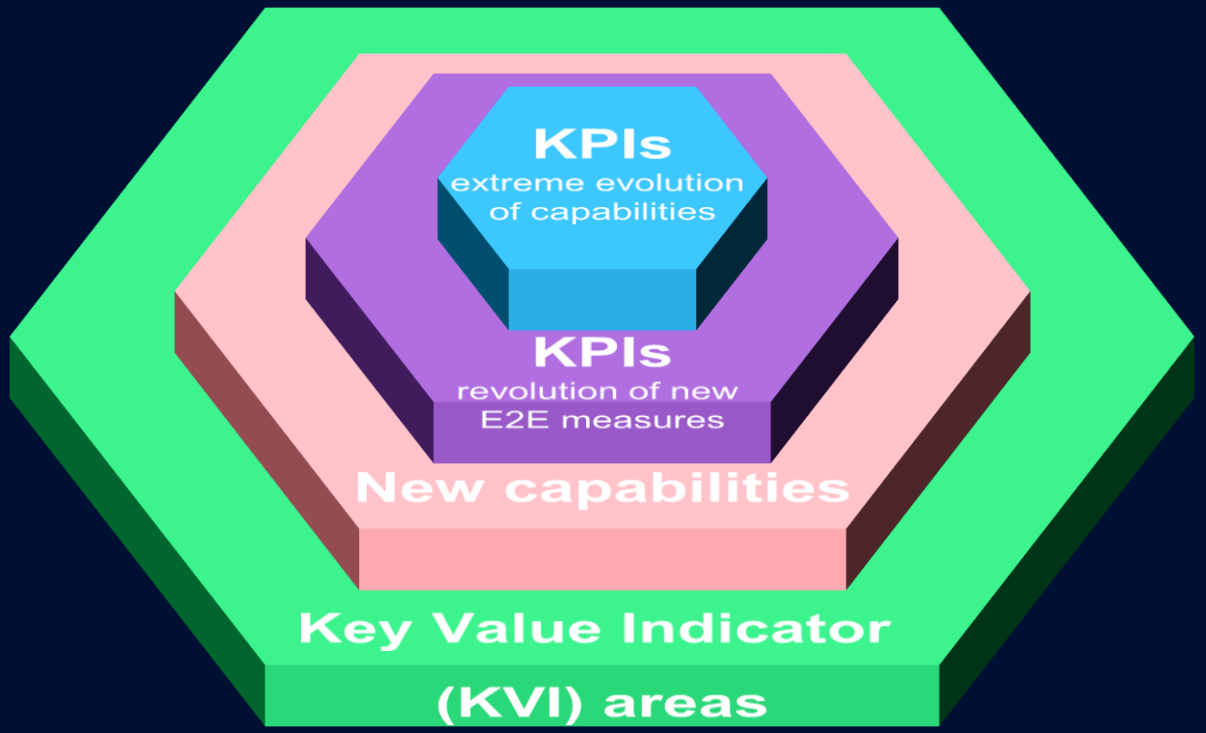
- NW energy efficiency
- Dependability
- Coverage
- Service availabiltiy

Needed capabilities

New capabilities

- Integrated sensing
- Local compute
- Ubiquitous AI
- Embedded devices

Needed capabilities



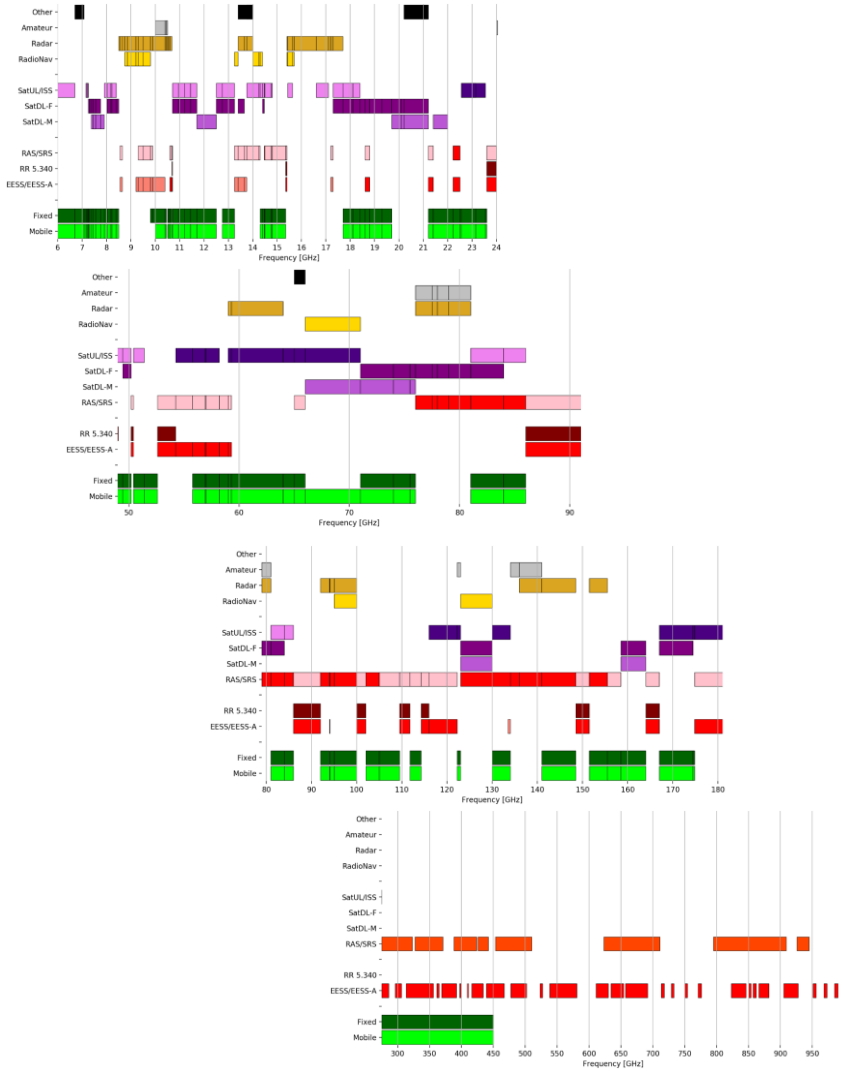
KVIs:

- Sustainable 6G
- 6G for sustainability
- Trustworthiness
- Digital inclusion

Spectrum evolution aspects

Improve spectrum utilization & extend current spectrum boundaries

- THz spectrum will be utilized with combinations of bands: low, mid, and mmw ranges to optimize wireless link characteristics and cooperatively provide the full set of service requirements
- Spectrum under 6 GHz pivotal for wide radio coverages
- Possible usage of spectrum in 6-24 GHz range; currently not available for mobile communications to be exploited by proper design of sharing methods with current users
- Improved intelligent spectrum access systems, in particular in newly available spectrum resources in higher bands, to dynamically assign frequency resources to authorised subsystems on both time and geographical basis while preventing interference issues
- Studies on intelligent spectrum usage and interference management schemes will include scenarios for, e.g.,
  - nomadic, mobile, or temporary spectrum usage
  - spectrum access for local low power networking
  - exploitation of predictable properties of radio transmissions for AI-based interference avoidance
- New regulation and licensing strategies aspects in support of both dynamic spectrum sharing and access to new spectrum will be comprehensively addressed



An overview of spectrum allocations in several ranges between 6 GHz and 1,000 GHz

6G New Spectrum Technologies
Band options for a new generation

6G peak capacity layers and high precision sensing

Localized high capacity & FWA

6G capacity expansion layer

Basic capacity layers, NTN & URLLC

Basic coverage & IoT

6G coverage expansion layer

6G **Sub-THz** W-band (92-114.25 GHz), D-band (130-174.8 GHz), >100GHz

5G, 6G **mmWave** 24-52 GHz (licensed) 57-71 GHz (unlicensed)

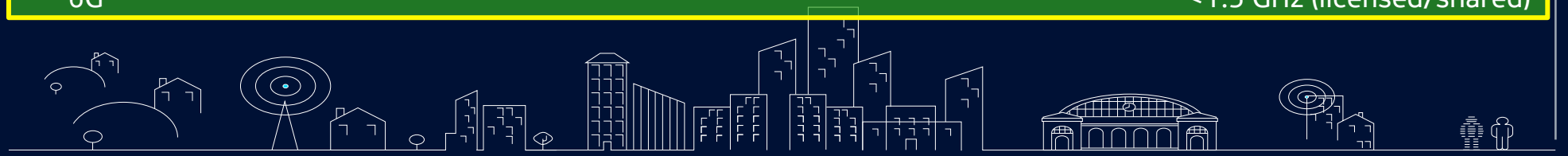
5G+, 6G 7-20 GHz (shared) ~10GHz

5G, 6G **Mid band** 2.5-7.1 GHz (licensed/shared/unlicensed)

4G, 5G, refarming to 6G 1.5, 1.8, 2.1, 2.3, 2.6 GHz (licensed/shared)

4G, 5G, refarming to 6G **Low band** 600, 700, 800, 900 MHz (licensed) <1GHz

6G <1.5 GHz (licensed/shared)



>3000m	1000m	300m	100m	30m	<10m
Rural	Urban	Dense urban	Hot spot	Local area	Short range

NOKIA Bell Labs

Sustainability

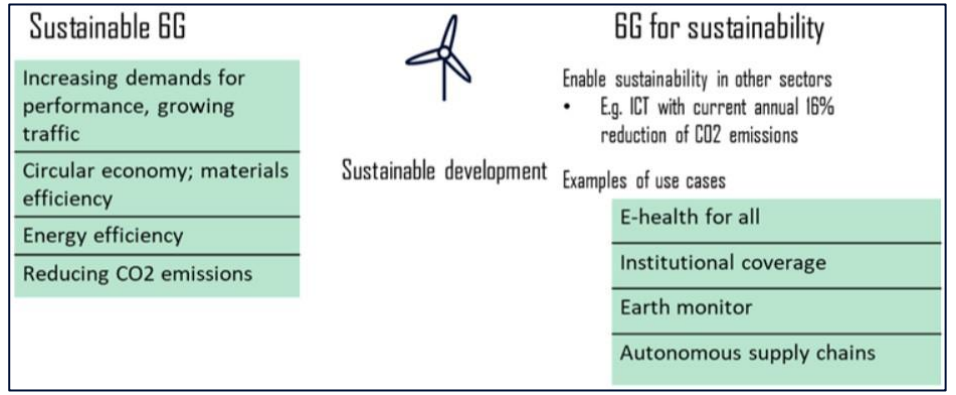
Ambition

ICT is linked to all 17 UN SDGs and interacts with all of them. For instance:
•#9 (Industry, innovation and infrastructure): 6G will contribute to bridging the digital divide to provide equal access to information and foster entrepreneurship, for billions.
•#11 (Sustainable cities and communities): ICT enables innovative approaches to city management (smart water and waste management, intelligent transportation).
•#13 (Climate action): 6G will help monitor climate change and strengthen resilience, and will enable other sectors to reduce their own emissions. At the same time, 6G will have its own carbon footprint which should be minimized

UN Action plan:
17 goals
165 targets
231 indicators

How

- Embedded energy monitoring systems everywhere.
- Adaptive telecommunication protocols, to avoid the need for 'always-on' infrastructure; push toward Zero watt @ zero load for all products.
- Systematic assessment of environmental impact of materials and design choices, including virtualization and softwarization (e.g. balance between latency and energy).
- Equipment and consumer products eco-design: modularity, upgradeability, reparability.
- Limiting obsolescence: circularity, refurbishment, effective management of end-of-life.
- New energy efficient material (e.g. GaN for sub 3 GHz products).
- Continue the development of energy efficiency features and compact and efficient renewable energy supply solutions.
- Big potential using AI for green networks (overdimensioning...)
- EMF-aware networks.



Summary

“6G” will be much broader than the radio-access technology

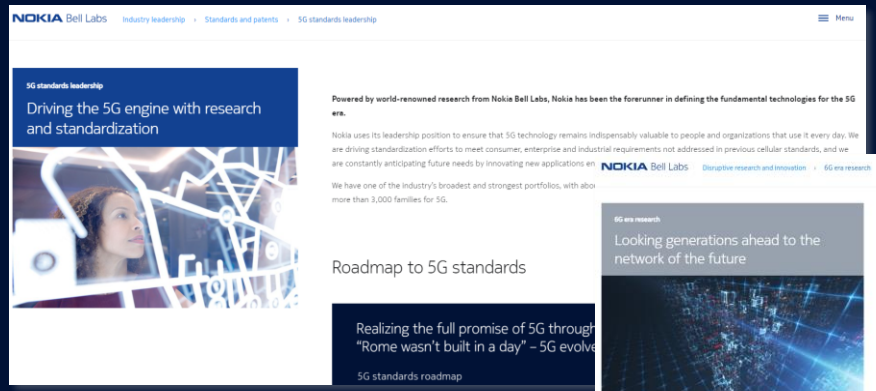
- A flexible platform providing connectivity, data, compute, intelligence, and sensing

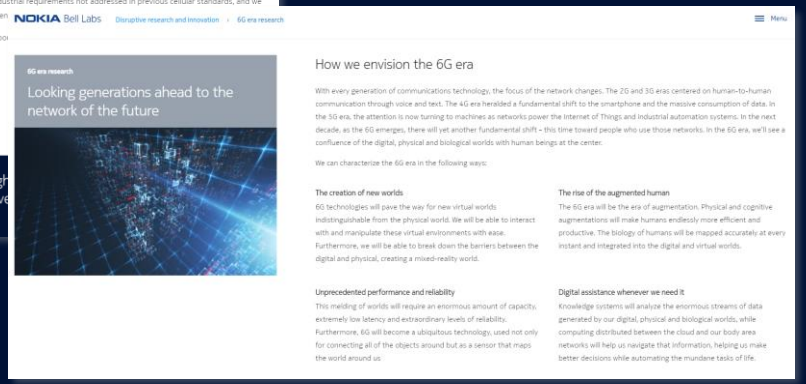
Forming and defining 6G is still in the research phase

- Hexa-X will lay the foundation for the networks of 2030 **exploring key technological enablers** and will actively drive and encourage **inclusive research cooperation** across industry and academia for global harmonization

6G related resources

- Webpage: Nokia Bell Labs 6G era research page
- White Paper: Communications in the 6G Era
- Webpage: Hexa-X official website





Thank you!

HEXA-X.EU

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101015956.