White Paper on The EUROPEAN VISION For The 6G NETWORK ECOSYSTEM

25th November 2024

Mikko Uusitalo (Nokia), Carlos J. Bernardos (UC3M)

Agenda

- 16:00 Welcome – Opening, Mikko Uusitalo (Nokia), Carlos Bernardos (UC3M) and Artur Hecker (Huawei)
- 16:10 6G Global activities, Alex Kaloxylos (6G IA)
- 16:20 What is 6G?, Toon Norp (TNO), Håkon Lønsethagen (Telenor), Artur Hecker (Huawei)
- 16:40 Technological Enablers, Patrik Rugeland (Ericsson) and Chrysa Papagianni (Uni Amsterdam)
- 17:05 6G Architecture, Ömer Bulakci (Nokia) and Mårten Ericson (Ericsson)
- 17:30 Major differences with respect to 5G, Carles Antón-Haro (CTTC) and Bahare Masood Khorsandi (Nokia)
- 17:40 Next Steps, Valerio Frascolla (Intel) and Aurora Ramos (Capgemini)
- 17:50 Closing statements, Mikko Uusitalo (Nokia) and Carlos Bernardos (UC3M)

VISION For The 6G NETWORK ECOSYSTEM

- Unified 6G vision worldwide towards a single global consensus
- Focus on sustainability
  - making 6G systems sustainable and
  - using 6G to enhance sustainability across other sectors of industry and society
- 6G development driven by key priorities like security, AI, energy efficiency, and ubiquitous coverage
- 6G-enabled Services Vision highlighting the importance of interconnected and interoperable smart networks and services
- Relevant topics related to the upcoming 6G system include
  - advancements in hardware (HW) and radio technology,
  - flexible network topologies,
  - deterministic networking,
  - network softwarisation,
  - digital twinning,
  - widespread adoption of AI and ISAC.

VISION For The 6G NETWORK ECOSYSTEM

- Vision on the forthcoming 6G architecture
  - Interoperability,
  - resource awareness,
  - service-awareness,
  - multi-tenant federation,
  - deeper integration of user equipment (UE),
  - AI/Machine Learning (ML) support,
  - dependable communications,
  - ISAC,
  - seamless integration between terrestrial and non-terrestrial networks (TN and NTN),
  - enhanced security and privacy,
  - network simplification,
  - and sustainability.

VISION For The 6G NETWORK ECOSYSTEM

- 6G emphasizes sustainability, trustworthiness, and inclusion
- 6G needs a combination of frequency ranges to meet the coverage and enhanced capacity requirements and to serve new emerging IMT-2030/6G use cases.
  - At least 500 MHz of new wide-area spectrum is needed per network, in addition to the re-use of existing spectrum.
  - Wide enough bandwidths needed to meet the foreseen 6G capacity and coverage needs
  - New frequency bands studied within WRC-27 Agenda Item 1.7:
    - 4.4-4.8 GHz,
    - 7.125-8.4 GHz and
    - 14.8-15.35 GHz.

Chapter 1: 6G Global activities

The Voice of European Industry and Research for Next Generation Networks and Services

Alexandros Kaloxylos (6G IA), Kostas Trichias (6G-IA), Anastasius Gavras (Eurescom)

Work Items to meet the IMT-2030 targets

INTEGRATED SENSING AND COMMUNICATION

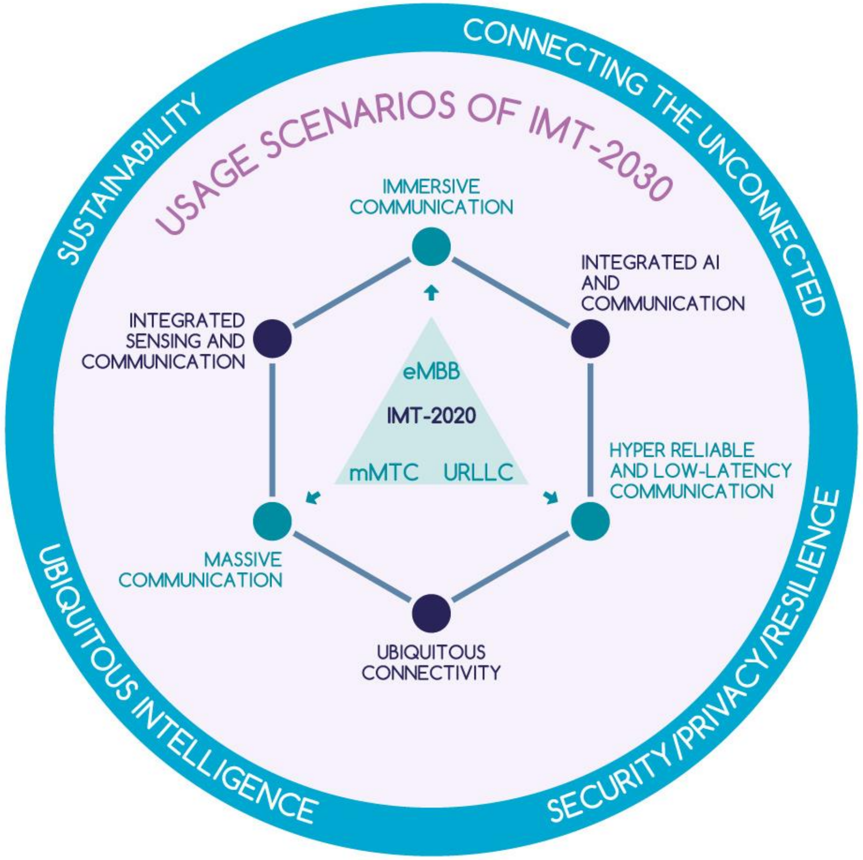
- Distributed sensing services
- Compact & Complete Data Representation
- Sensing control functions
- Continuity of sensing service
- mmWave spectrum blocking
- ISAC functionalities distribution across network elements
- Waveform and signalling optimization
- Deployment limitations (cost, power, size)
- Object/Target Management Function

INTEGRATED AI AND COMMUNICATION

- Data-driven Architecture
- AI model trustworthiness
- Intelligence at the edge
- AI framework & conflict management
- AI for RAN energy efficiency
- Self-evolving autonomous systems

UBIQUITOUS CONNECTIVITY

- Global, Open Service APIs
- Trust models
- Integration with NTN
- Integration of AI-solutions
- Federation
- User-centric approach
- Management plane centralization



IMMERSIVE COMMUNICATION
HYPER RELIABLE AND LOW-LATENCY COMMUNICATION
MASSIVE COMMUNICATION

- Flexible Service-Centric Design
- Minimized MIMO Processing Complexity,
- Efficient Orchestration (of Orchestrators)
- Energy-Efficient RAN
- Excellent Interoperability of RAN Components
- Integration of Localized Networks
- Optimization of Control Plane Signalling
- Alignment of Network Intelligence with network infrastructure
- Seamless Connectivity
- Quantum-Resilient Security
- Sustainable RAN Virtualization
- Reconfigurable Multi-Connectivity
- Optimization of RU Energy Consumption
- Programmable Transport

3GPP SA1: key drivers to enable 6G

- Security
- Support of AI
- Immersive Communication
- Sustainability / Energy Efficiency
- Ubiquitous & resilient coverage
- Integrated Sensing & Communications

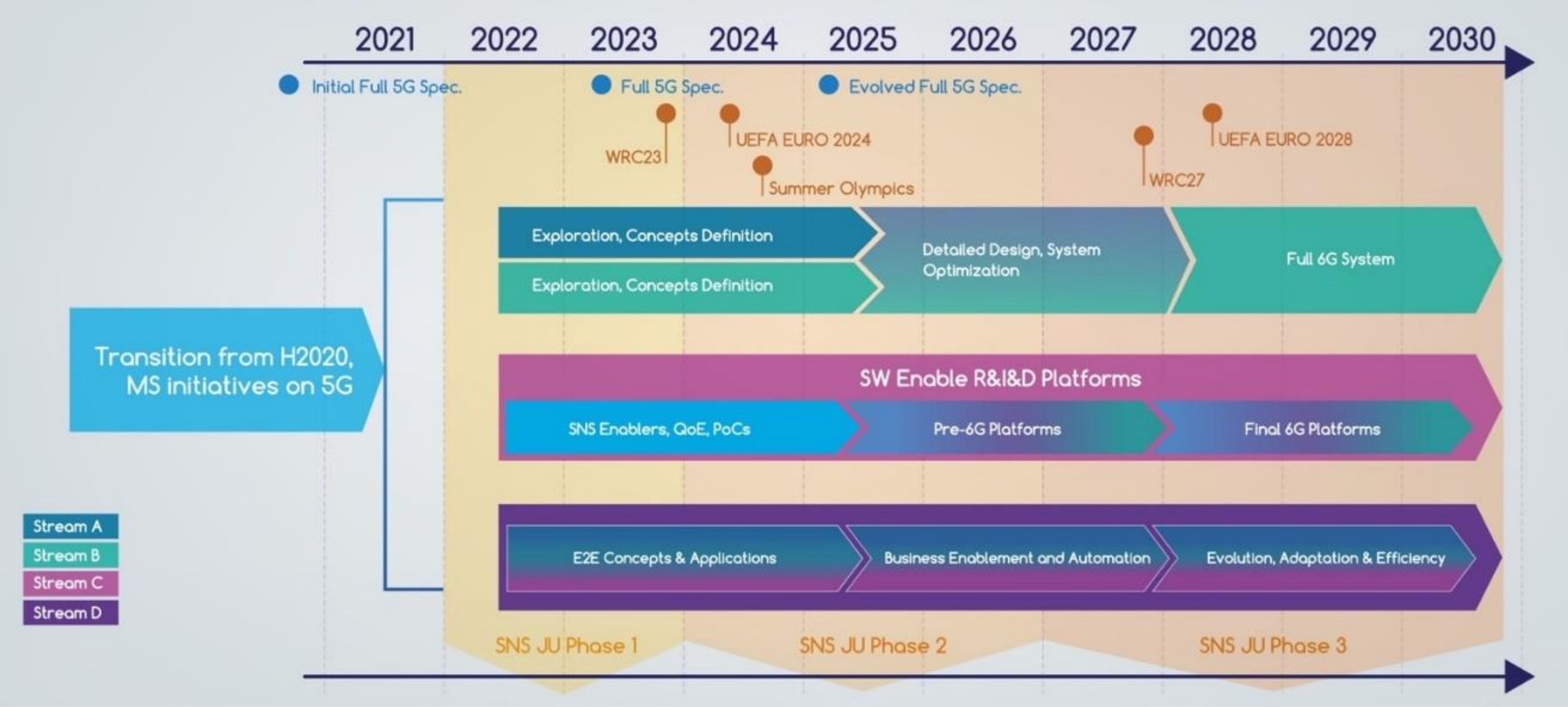
Europe: focus on societal and sustainability aspects

6G-IA will provide input to IMT-2030 radio interfaces for minimum technical requirements and target values

6G Use cases in focus around the world

6G Use Cases	Networld Europe SRIA 2022	5G Americas / Next G Alliance	Huawei (China)	B5G Consortium (Japan)	TSDSI (India)	MediaTek (Taiwan)	Survey Paper	ITU IMT-2030
Holographic Communications	✓	✓	✓	✓	✓	✓	✓	✓
Cyber-Physical Systems, DT, Manufacturing	✓	✓	✓	✓	✓	✓	✓	✓
Multi-Sensory extended Reality (XR), Gaming/Entertainment	✓	✓	✓	✓	✓	✓	✓	✓
Tactile/Haptic Communications	✓	✓	✓	✓	✓	✓		✓
Medical/Health Vertical, Telesurgery	✓	✓	✓	✓	✓	✓	✓	
Cooperative Operation among a Group of Service Robots / drones	✓	✓	✓	✓	✓		✓	✓
Imaging and Sensing	✓	✓	✓	✓	✓			✓
Transportation Vertical (automotive, logistics, aerial, marine, etc.)	✓	✓	✓	✓	✓		✓	
Space-Terrestrial integrated network	✓	✓		✓	✓		✓	✓
Intelligent Operation Network	✓		✓		✓		✓	✓
Critical Infra, Government/National Security	✓	✓		✓				
First Responder/Emergency Services		✓		✓	✓			
Smart Buildings			✓	✓	✓			
Agriculture / Smart Farming				✓	✓			

European perspective on 6G: The SNS JU



SNS JU (EC + 6GIA): Meeting public side policies and European private side priorities

Chapter 2: What is 6G?

The Voice of European Industry and Research for Next Generation Networks and Services

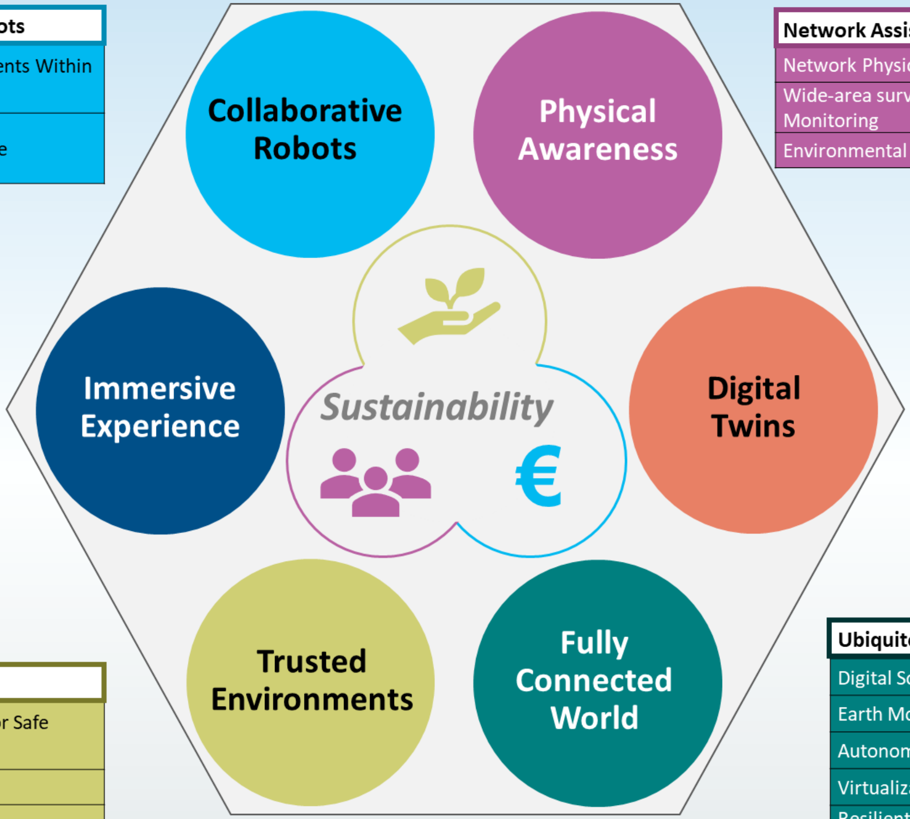
Toon Norp (TNO), Håkon Lønsethagen (Telenor), Artur Hecker (Huawei)

6G Use Case Families

Cooperating Mobile Robots
- Autonomous Embodied Agents Within Flexible Manufacturing
- Mesh Embodied Intelligence

Network Assisted 3D Mobility
- Network Physical Data Exposure
- Wide-area surveillance/Smart Crowd Monitoring
- Environmental radio sensing

Seamless Immersive Reality
- Immersive Enterprise & Industry
- Immersive Education
- Immersive Gaming
- Live and Interactive Immersive Content Creation



Realtime Digital Twins
- Cloud Continuum
- Smart Maintenance
- Digital Twins (Building Model)
- Public Protection & Disaster Relief Digital Twin

Human-Centric Networks
- Industrial Sensors Network for Safe Production & Manufacturing
- Wireless In-Vehicle Network
- Virtual Control Room

Ubiquitous and Resilient Network
- Digital Sobriety and Enhanced Awareness
- Earth Monitor, Sustainable Food Production
- Autonomous Supply Chain
- Virtualization of Device Functionalities
- Resilient Communication for Safety critical Applications

- Defining use cases, requirements and KPIs is an important step in the definition of new technology
- These use cases are based on the European consolidated R&I view on 6G use cases presented during the 3GPP SA1 workshop on 6G use cases (Rotterdam, May 2024).

COLLABORATIVE ROBOTS

The network's main users are machines.

Emphasis lies on task-specific local connectivity. Depending on the task or needs, the network topology may undergo frequent changes. The level of machine autonomy determines the communication requirements.

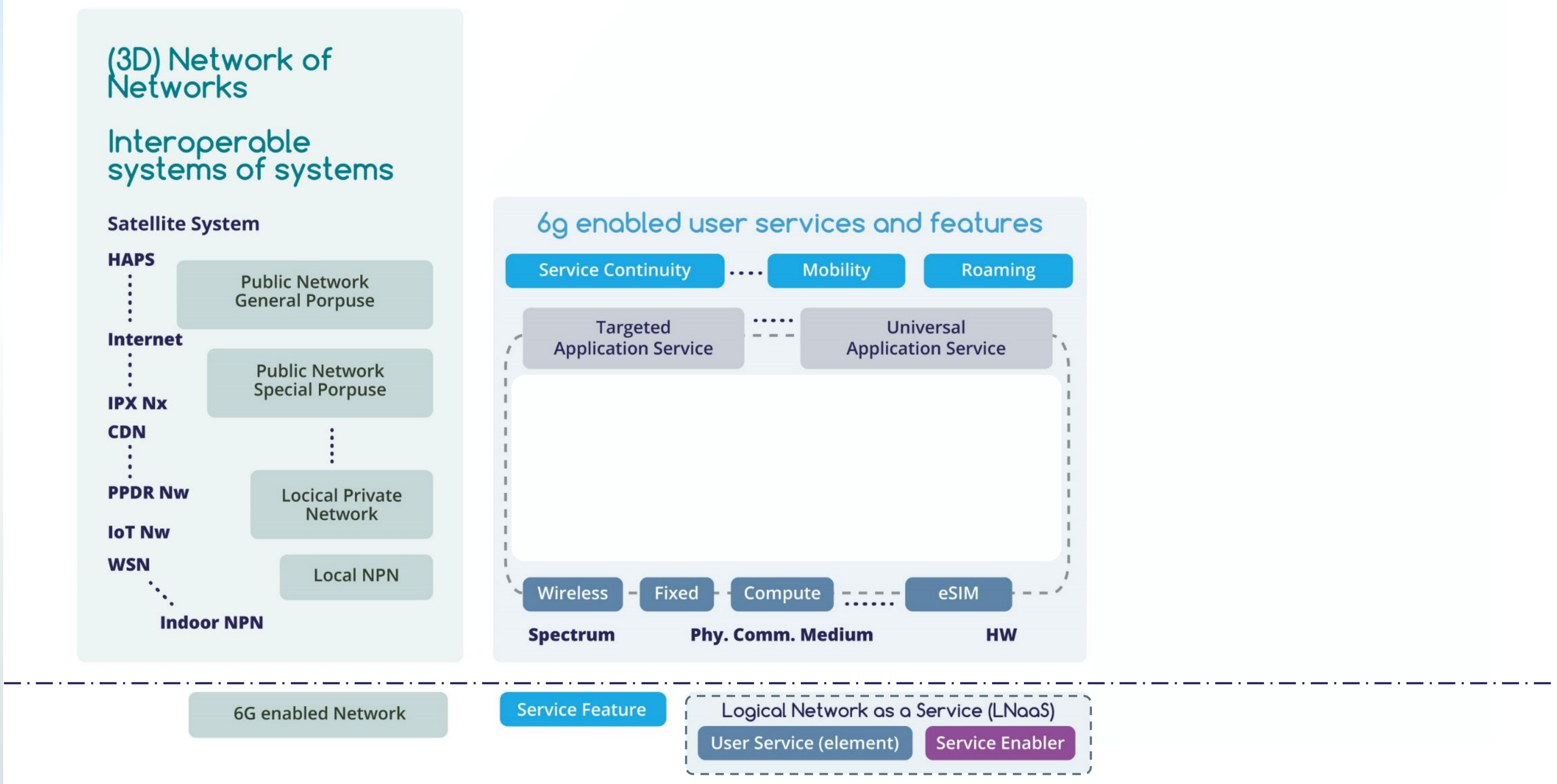
Towards 6G Smart Networks and Services

- Affirming Transition: Sustaining 5G Innovations into the Next Era
- 6G enabled Services Vision
- 6G enabled Interoperable Smart Networks and Services
- Towards a new ecosystem level approach to Business Model Innovation

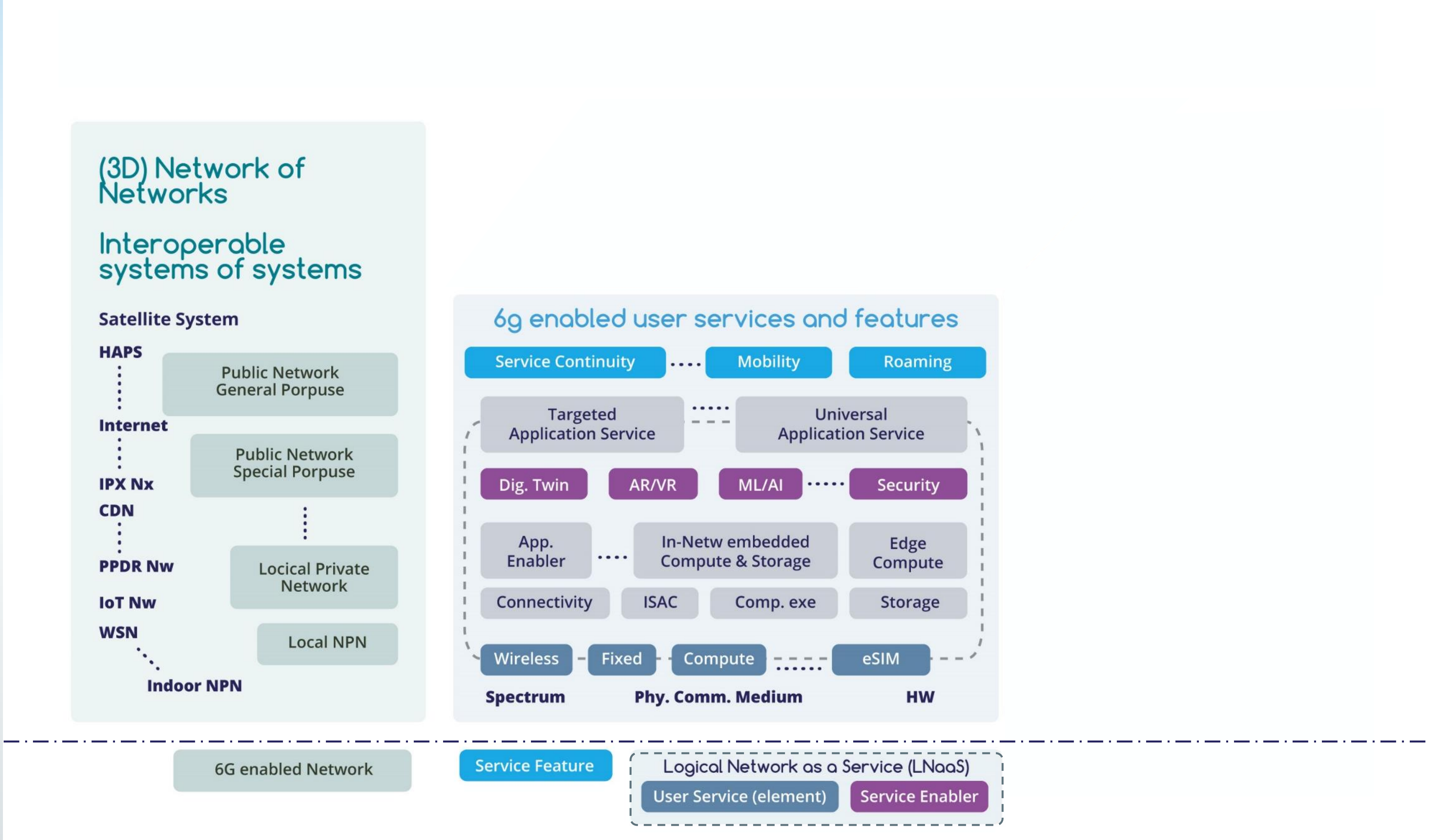
A vision for 6G enabled services and interoperable smart networks

- Evolving from 5G and 5G Advanced
- Adding new capabilities
- Evolved Service KPIs

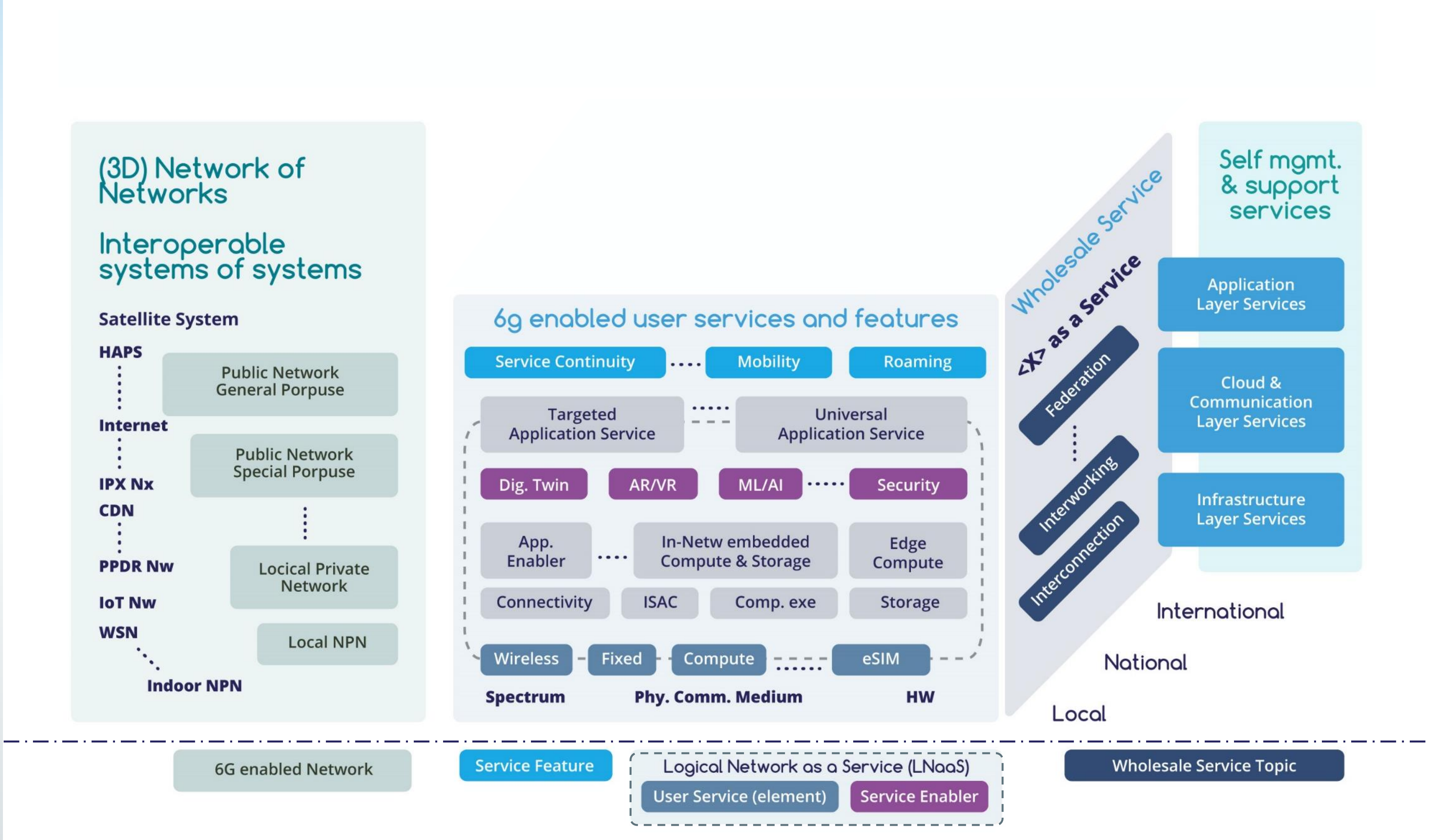
A vision for 6G enabled services and interoperable smart networks



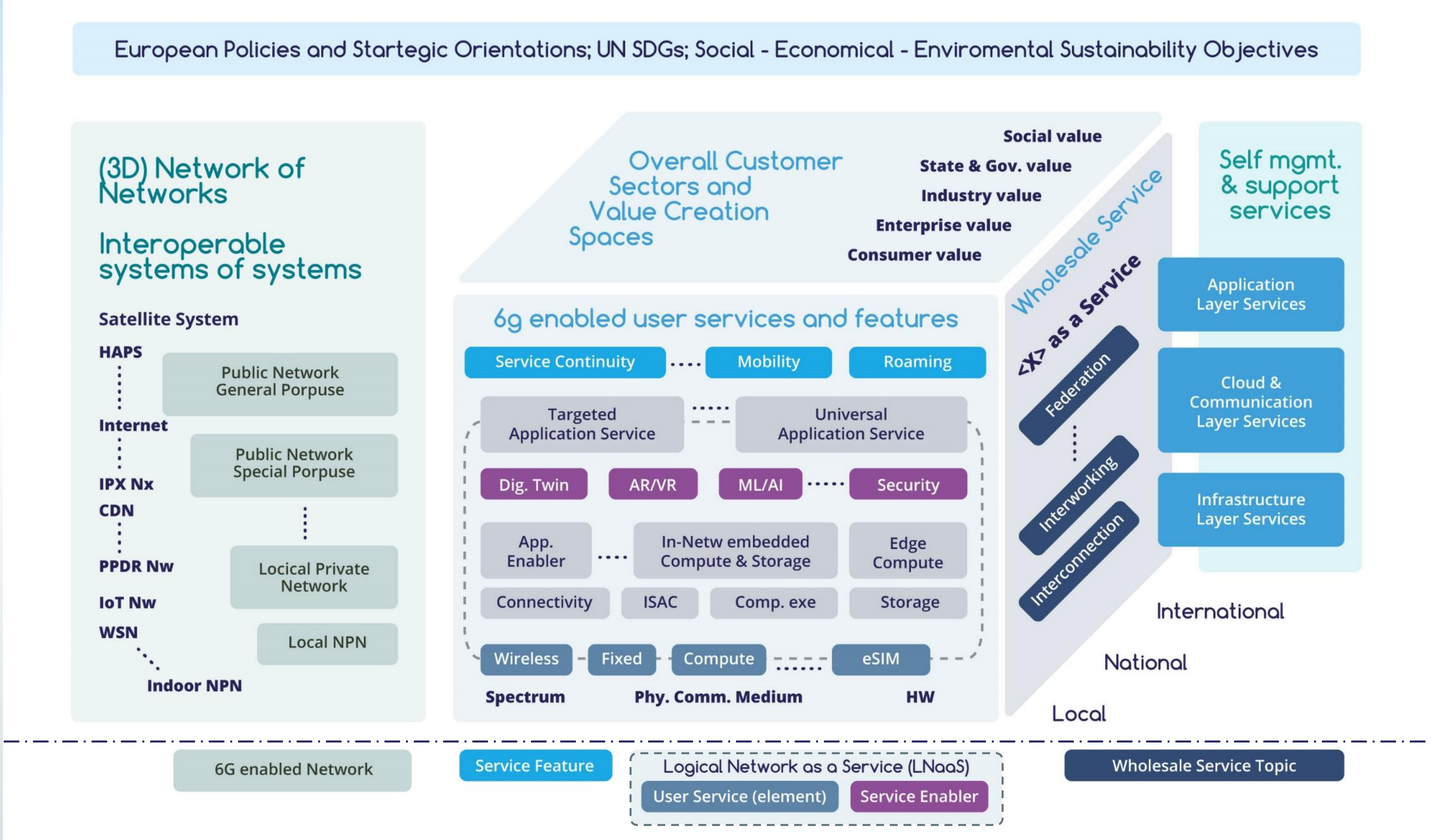
A vision for 6G enabled services and interoperable smart networks



A vision for 6G enabled services and interoperable smart networks



A vision for 6G enabled services and interoperable smart networks



6G enabled Interoperable Smart Networks And Services

Harmonization across interoperable smart networks and services

Towards a new ecosystem level approach

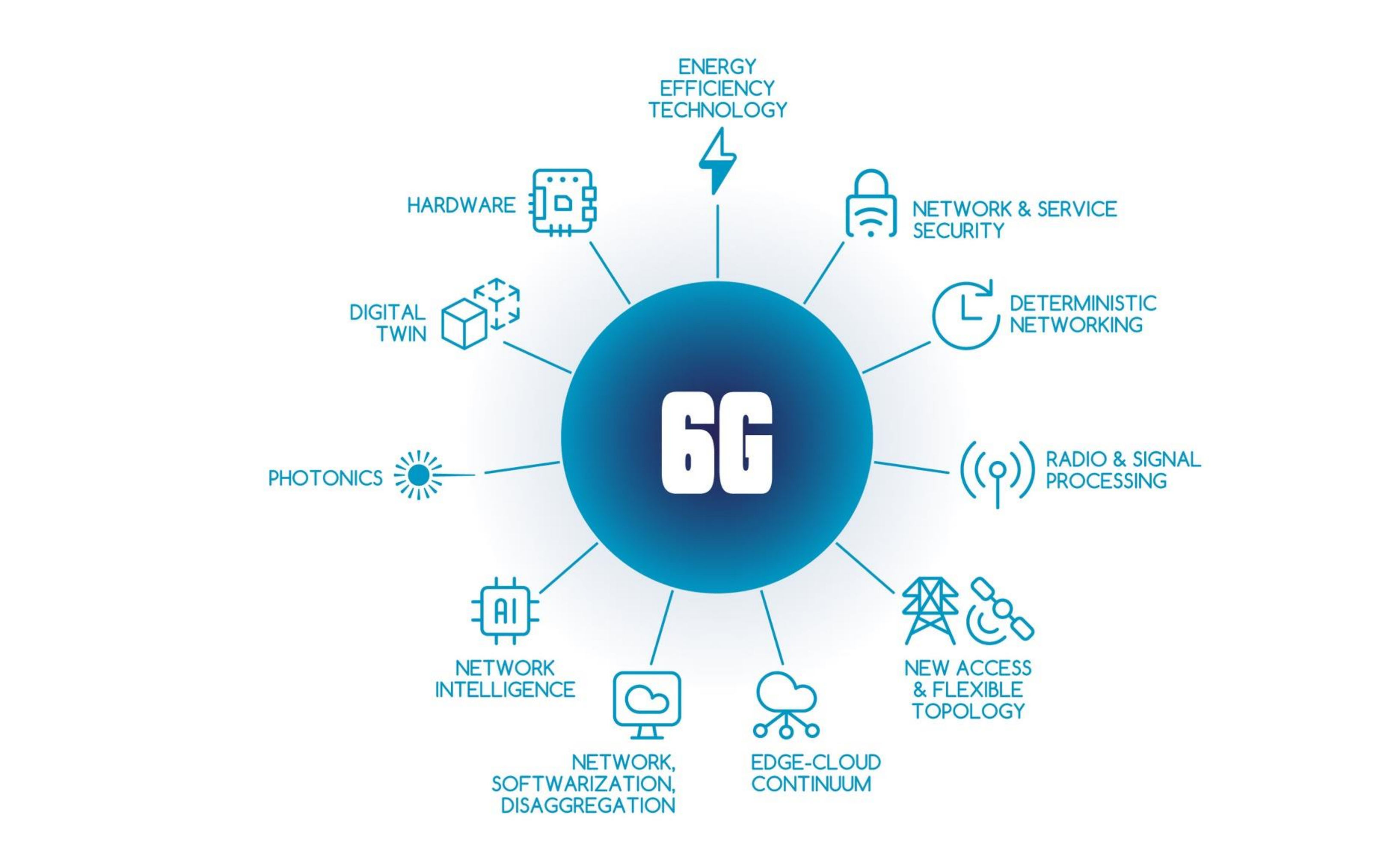
- Multi-stakeholder platform ecosystem
- Business model innovation while addressing sustainability
- Iterative process considering inherent ecosystem dynamics
- Address the richness of 6G services and topologies

Chapter 3: Technology enablers

The Voice of European Industry and Research for Next Generation Networks and Services

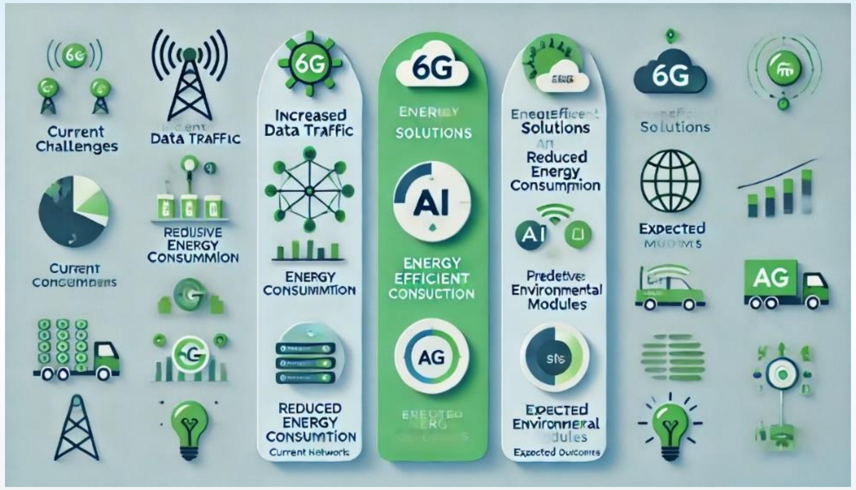
Patrik Rugeland (Ericsson), Chrysa Chrysa Papagianni (University of Amsterdam)

6G technology enablers



Energy efficiency technology

Network energy efficiency



- Important to break the energy curve
- Enable efficient sleep modes
- Possibility to use AI/ML for predictive network management

Energy harvesting

- Enable low energy operations with energy harvesting, e.g., wireless power transfer

Network and Service Security

Zero-trust architecture

- Dynamic trust assessment with continuous trust evaluation

Trust-assessment Framework

- Associate intents with required level of trust
- Run-time estimation of actual trust levels

Post-quantum cryptography

- Countering threat from quantum computers

Deterministic networking

Time sensitive networking

- Adapt the IEEE 802 TSN from wired to wireless to WiFi and 3GPP since Rel-16
- 3GPP TSN bridge adapter can integrate with other domains, but so far lacks standardized interfaces

Network redundancies

- Determinism and dependability through redundancy, e.g., IEEE 802.1CB known as Frame Replication and Elimiantion for Reliability (FRER)

Radio and Signal Processing

Deployment technology

Ultra-massive MIMO
- Extend to huge number of MIMO layer to increase throughput

Reconfigurable intelligent surfaces
- Extend coverage to blindspots

High-frequency technology

Coding and modulation schemes for sub-THz
- Delayed Bit-Interleaved Coded Modulation

Random access for massive communication
- NOMA

Waveforms and multiple access
- DFT-s-OFDM

Integrated sensing and communication

Expand network to beyond communication services
Improve communication performance

Multi-RAT spectrum sharing

Leverage on 5G deployment with dynamic spectrum reuse
Low overhead since 5G has lean carriers

New Access and Flexible Topology

Multi-connectivity

Single aggregation technique (instead of both CA and DC)

Non-terrestrial networks (NTN)

Extend coverage to remote areas

Incorporate satellites with transparent or regenerative architecture

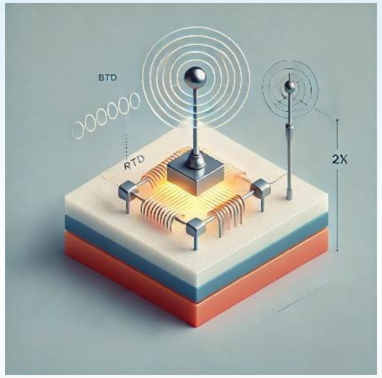
Special purpose networks

Local optimized sub-networks

Possibility to act autonomously

Hardware

High-frequency transceivers

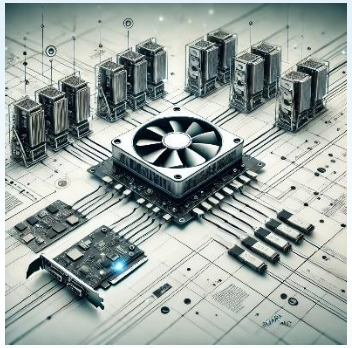


- Resonant tunneling diode (RTD) show promising performance for sub-THz

6G devices and their classes

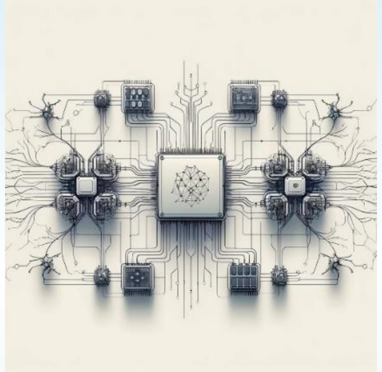
- Reliable high datarate with bounded latency
- HRLL
- Energy neutral
- Enhanced MTC

Hardware accelerators



- SmartNIC can be used to handle data processing at line rate used for e.g.:
- Encryption
- Compression
- Deep packet inspection

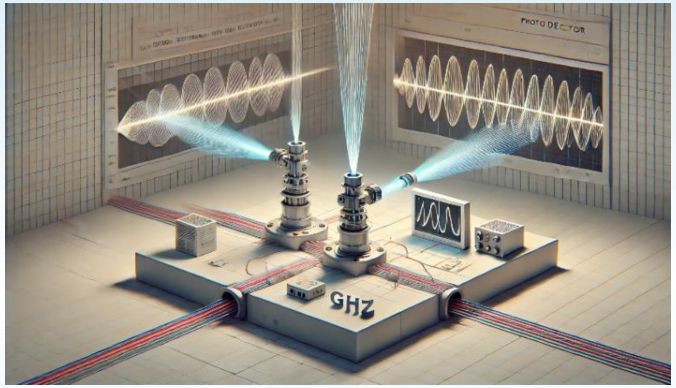
Neuromorphic computing



- Real-time energy efficient processing for e.g.,
- Deep neural networks
- Optimizations
- Dynamic routing

Photonics

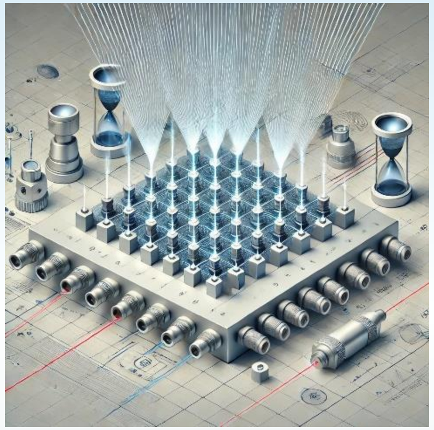
Photonics based RF generation



Heterodyne detection (mixing two lasers)

- High RF frequency (<2.5 THz)
- Broad tuning range (5 GHz - 2.5 THz)
- Typically, large freq. drift (> 10 MHz/h)

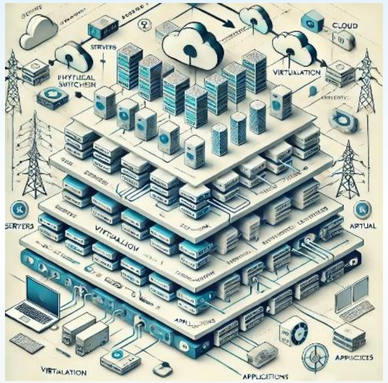
Photonic phase arrays



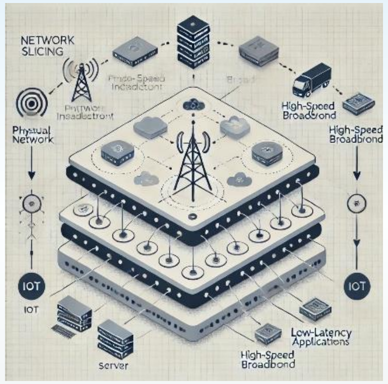
- Distribute the signal optically directly to the array elements
- Possibility to reach higher frequencies

Network softwarization disaggregation

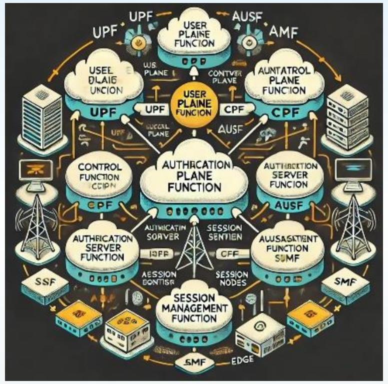
Network virtualization



Network slicing



Network disaggregation



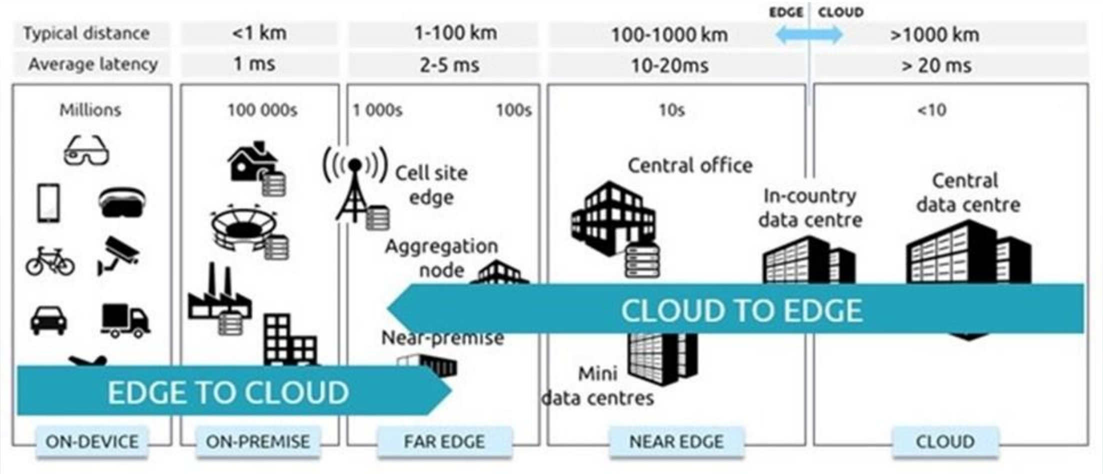
- Core disaggregation
- RAN disaggregation

Deep network programmability

Edge-cloud Continuum

Farhoudi M, Shokrnezhad M, Taleb T, Li R, Song J. Discovery of 6G Services and Resources in Edge-Cloud-Continuum. IEEE Network. 2024 Aug 5.

- Management and orchestration
- Serverless mobile networking
- Hardware Abstraction layer
- Function/workload offloading
- Federation



https://digital-strategy.ec.europa.eu/en/policies/iot-investing

Network Intelligence

- AI-driven air interface
- Edge-intelligence
- Zero-touch management
- AI native 6G architecture
- AI-enable intent-based networking
- Data management

Digital Twins

- Network digital twin
  - Network automation with (near) real-time representation of the network state
  - Possibility to predict future state of the network

6G SNS IA

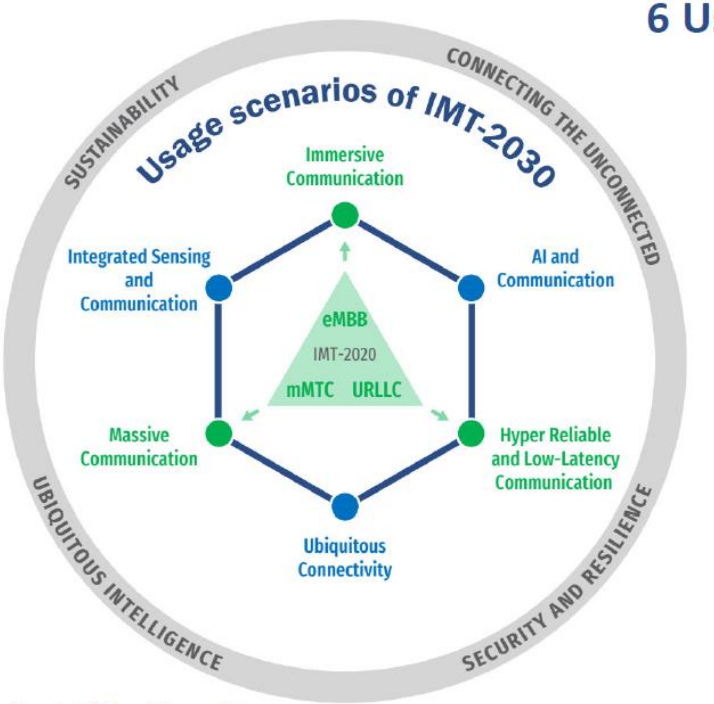
Chapter 4: 6G Architecture

The Voice of European Industry and Research for Next Generation Networks and Services

Xi Li (NEC), Ömer Bulakci (Nokia), Marco Gramaglia (UC3M), and Mårten Ericson (Ericsson)

6G Usage Scenarios

Usage scenarios



So called "Wheel diagram"

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

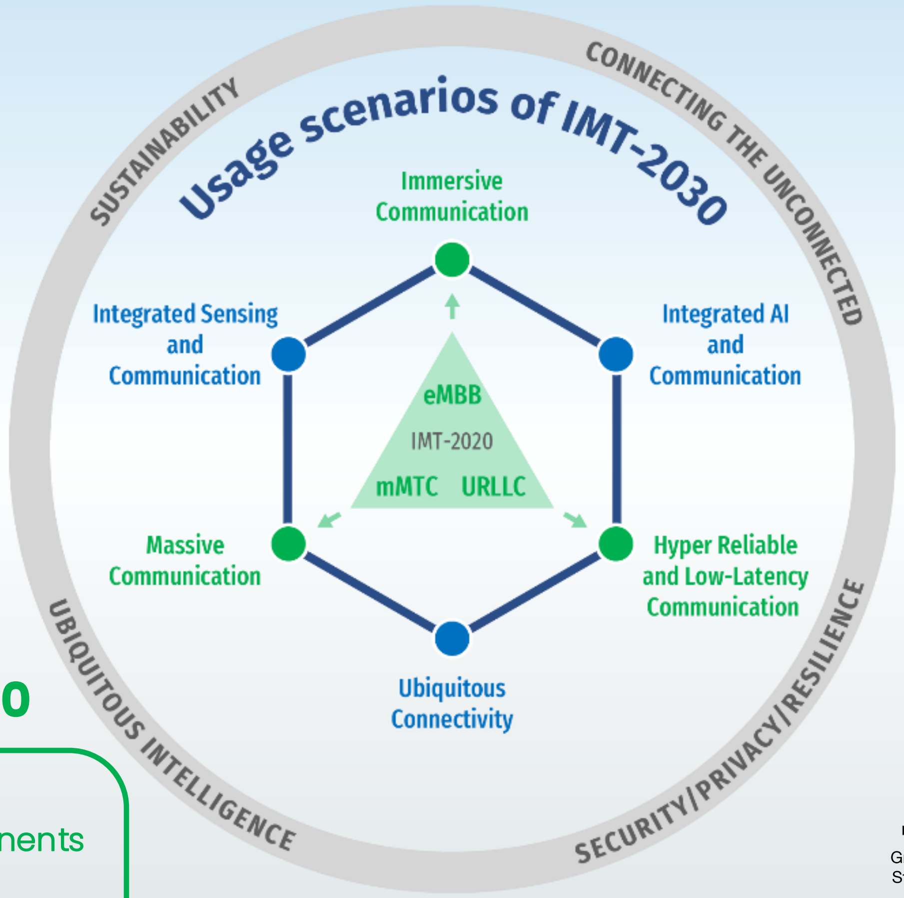
Sustainability, Connecting the unconnected,
Ubiquitous intelligence, Security/resilience

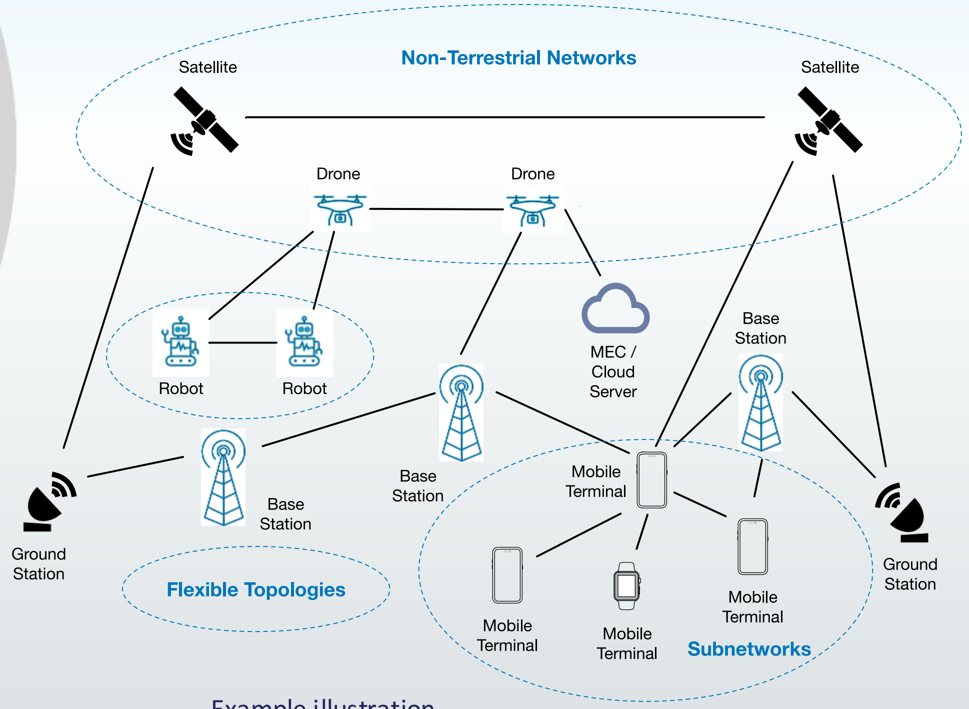
Q1: What are key Architecture Challenges for 6G?

Q2: What is the vision of 6G-IA for 6G Architecture Innovations?

IMT 2030 Framework and overall objectives of the future development for 2030 and beyond

Architecture Challenges of Transforming 5G towards 6G



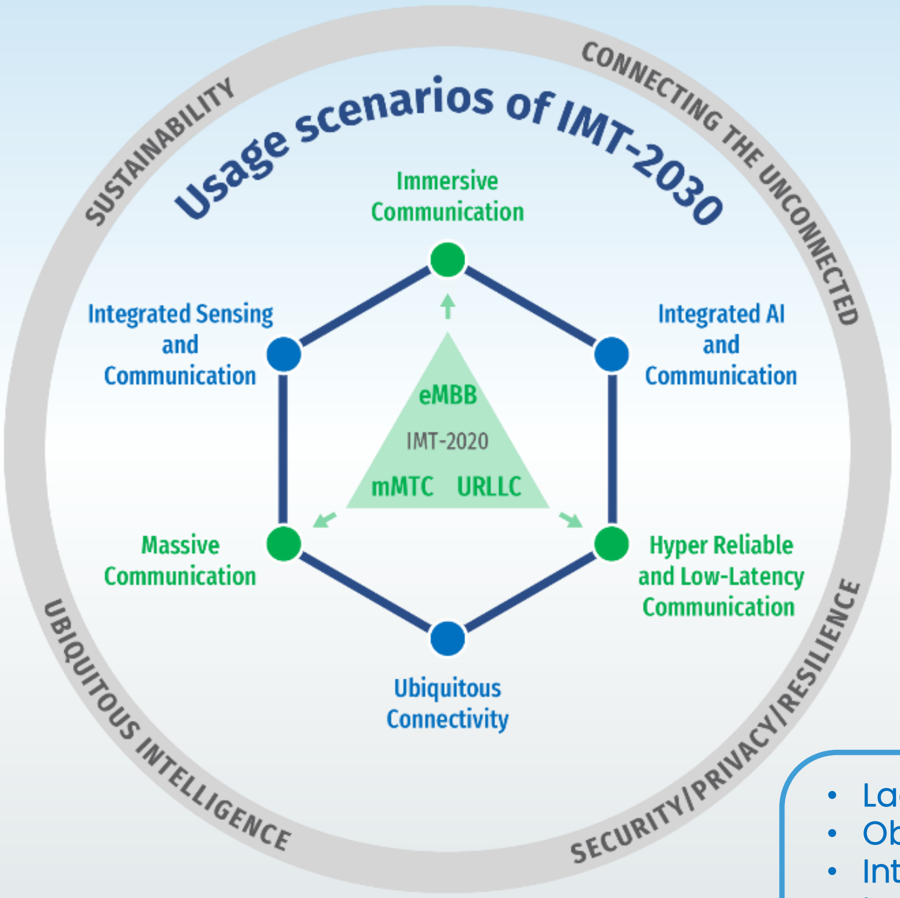


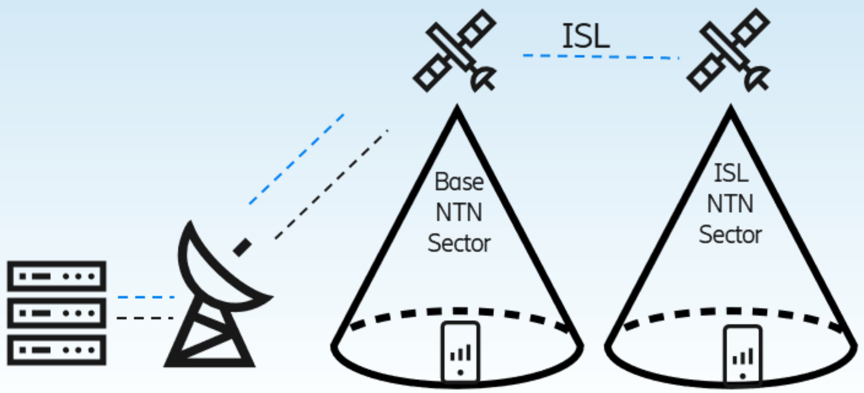
Example illustration

EXTENSION OF IMT-2020

- Unsustainable RAN Virtualisation
- Poor Interoperability of RAN components
- Reconfigurable Multi Connectivity
- Integration of localised Networks
- Non-Flexible Service-Centric Design
- Extreme MIMO Processing Complexity
- Growing RU Energy Consumption

Architecture Challenges of Transforming 5G towards 6G



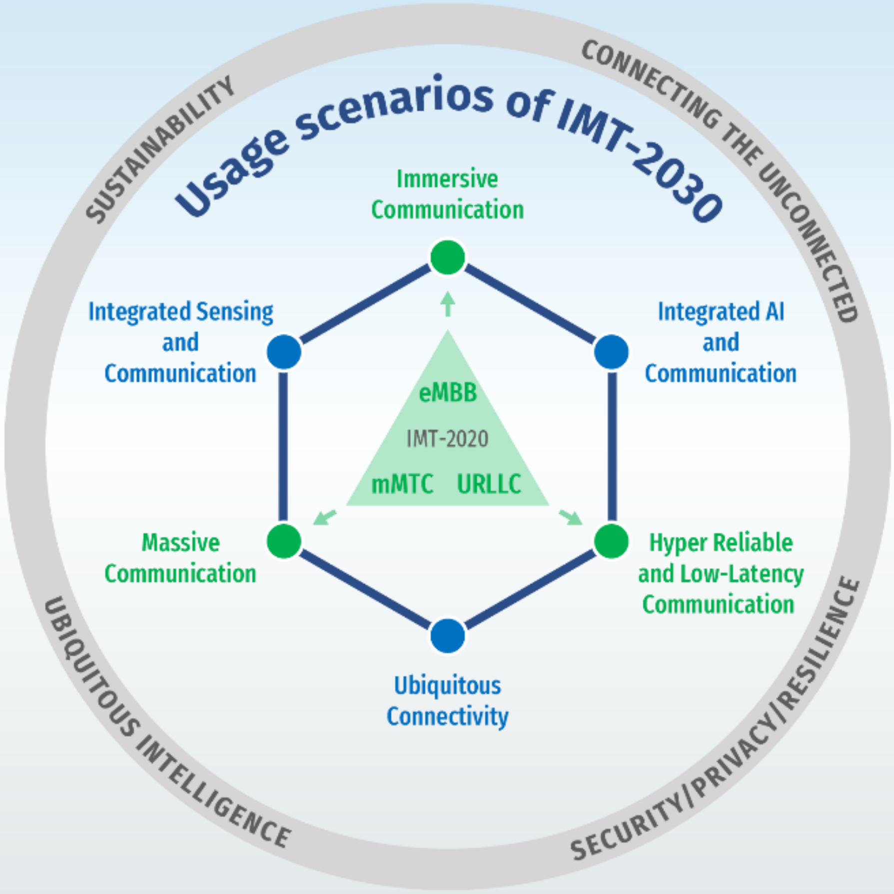


Example illustration

UBIQUITOUS CONNECTIVITY

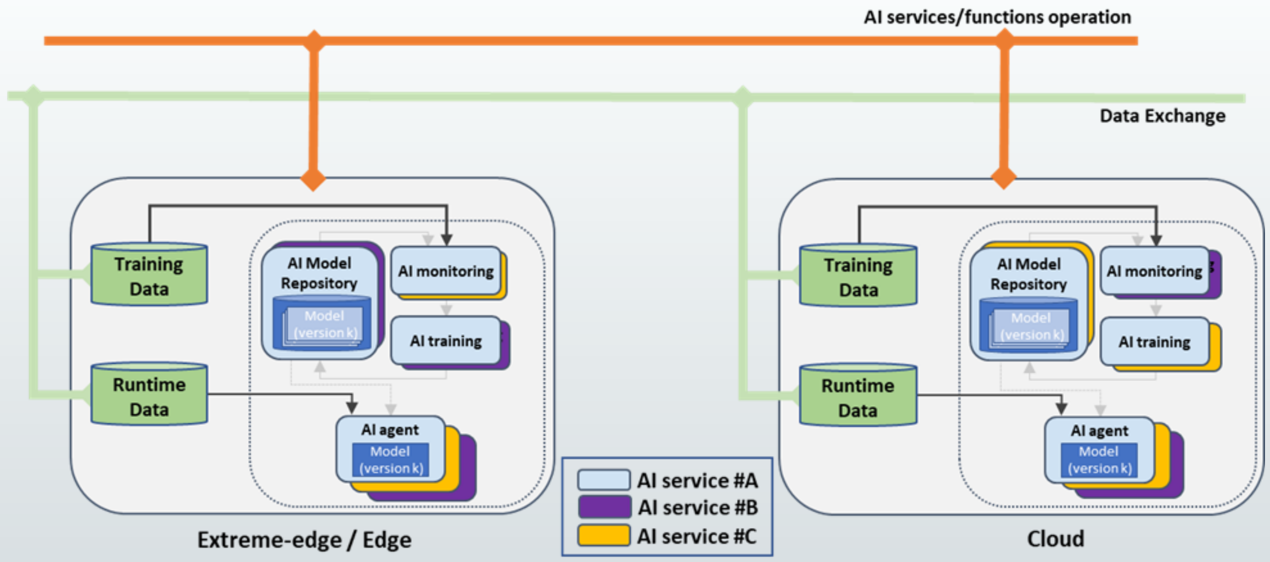
- Lack of Global, Open, and Easy-to-Use Service APIs
- Obsolete Trust Model Hinders Performance
- Integration among TN and NTN Networks
- Lack of Integration among different AI-Based Deployments
- Challenges in Federation
- Support for Semantic Communications
- Management Plane Centralization

Architecture Challenges of Transforming 5G towards 6G



AI & COMMUNICATION

- Enable an AI-Assisted Data Driven Architecture in 6G
- AI Models Involved in Decision Automation
- Learning at the Edge: The Scarce Resources Challenge
- Lack of a Unified E2E AIOps Framework and AI Conflict Management
- Efficient Application of AI/ML Algorithms for Automation of Energy-Efficient RAN Operations
- Need for Self-Evolving, Autonomous, and Extendable Systems with Predicting Capabilities

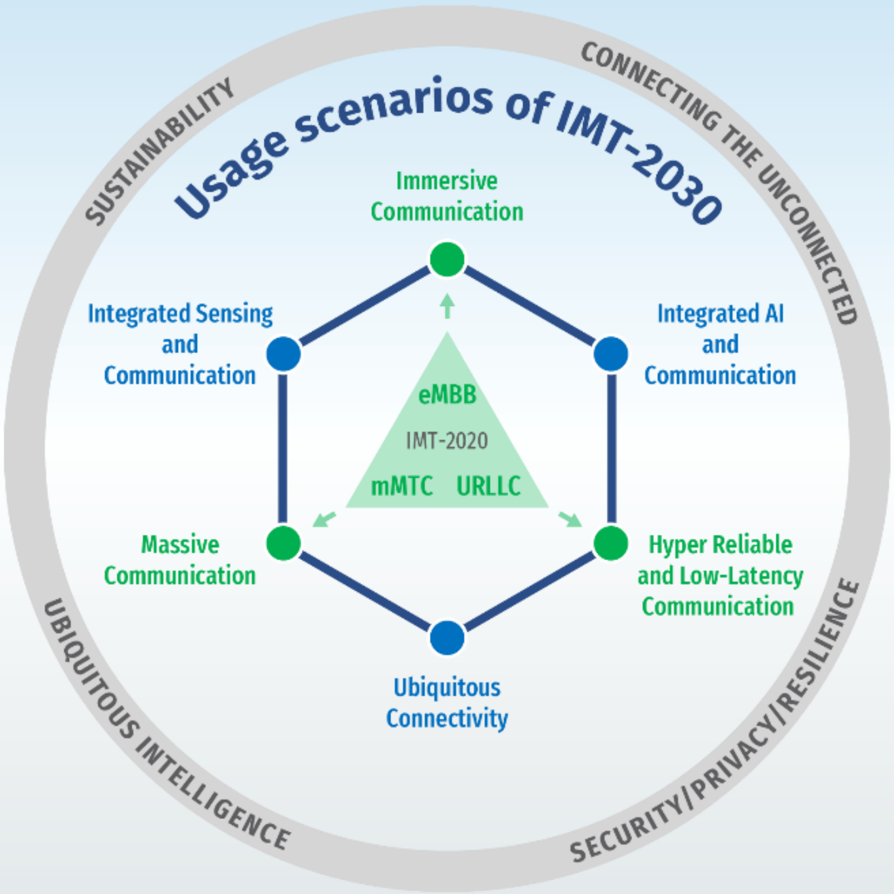


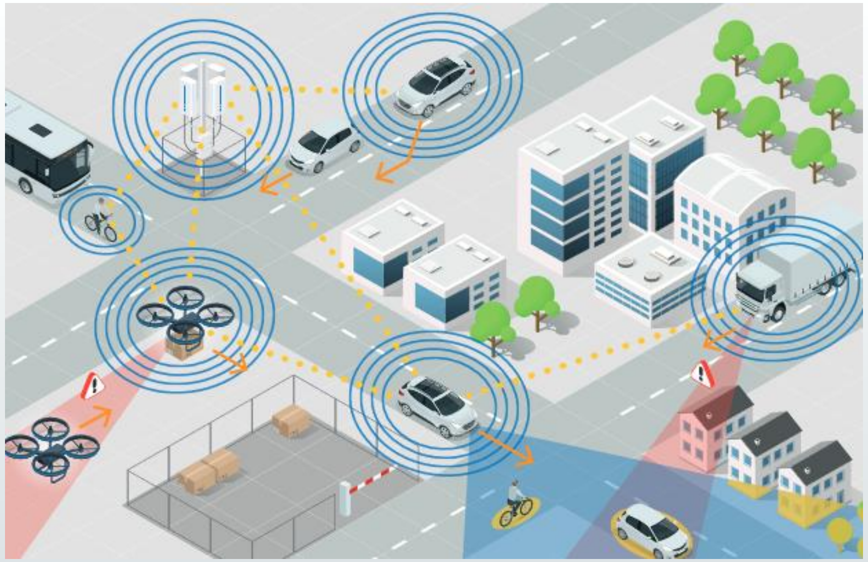
Example illustration

Architecture Challenges of Transforming 5G towards 6G

INTEGRATED SENSING & COMMUNICATIONS

- Beyond Communication Network Services
- High Data Volume
- Lack of Compact and Complete Data Representation
- Lack of Sensing Control Functions
- Lack of Standard Ways to Select and Configure Sensing Resource
- Lack of Continuity of Service for Sensing Over a Large Area
- Lack of Synchronization Among Distributed Network Elements





Example illustration

From: https://www.vde.com/resource/blob/2108086/e9ead7b7c95eacb5cb7f2eb88103eaa9/joint-communication--sensing-position-paper-pdf-file-data.pdf

6G E2E Architecture Foundation: Vision on Architecture Innovations

Sustainable Massive Communications

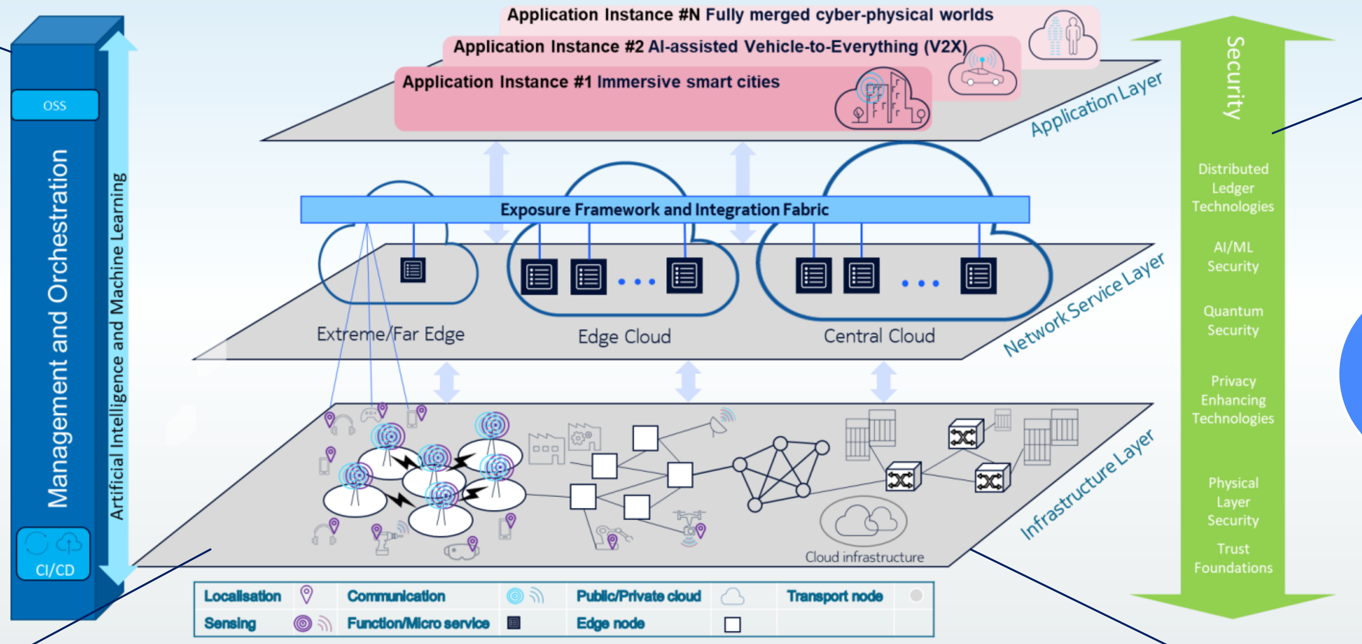
Low-density LEO for massive IoT
Decentralized implementation of UPF-CU-DU
GPU-based acceleration for DU/RU Offloading

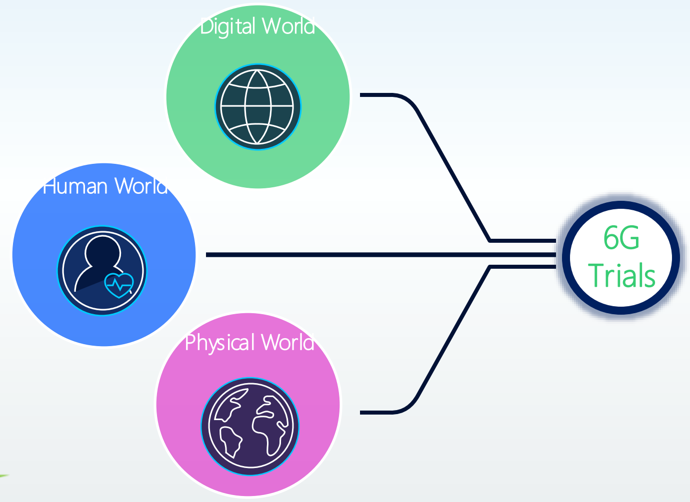
AI-powered Immersive Communication

Support for Immersive XR, e.g., holographic teaching
Joint computing & networking resource allocation
AI & Analytics Engine Orchestration

Secure, Reliable and Trustworthy AI & Communication

E2E Multi-domain Slicing as Mitigation Enabler
PQC
FL-based anomaly detection
AI-driven Security Analytics





Ubiquitous Connectivity

TN-NTN Integration
Unified RAN & Radio Interface
Multi-link Connectivity
RIS

Dependable & Resilient Communications

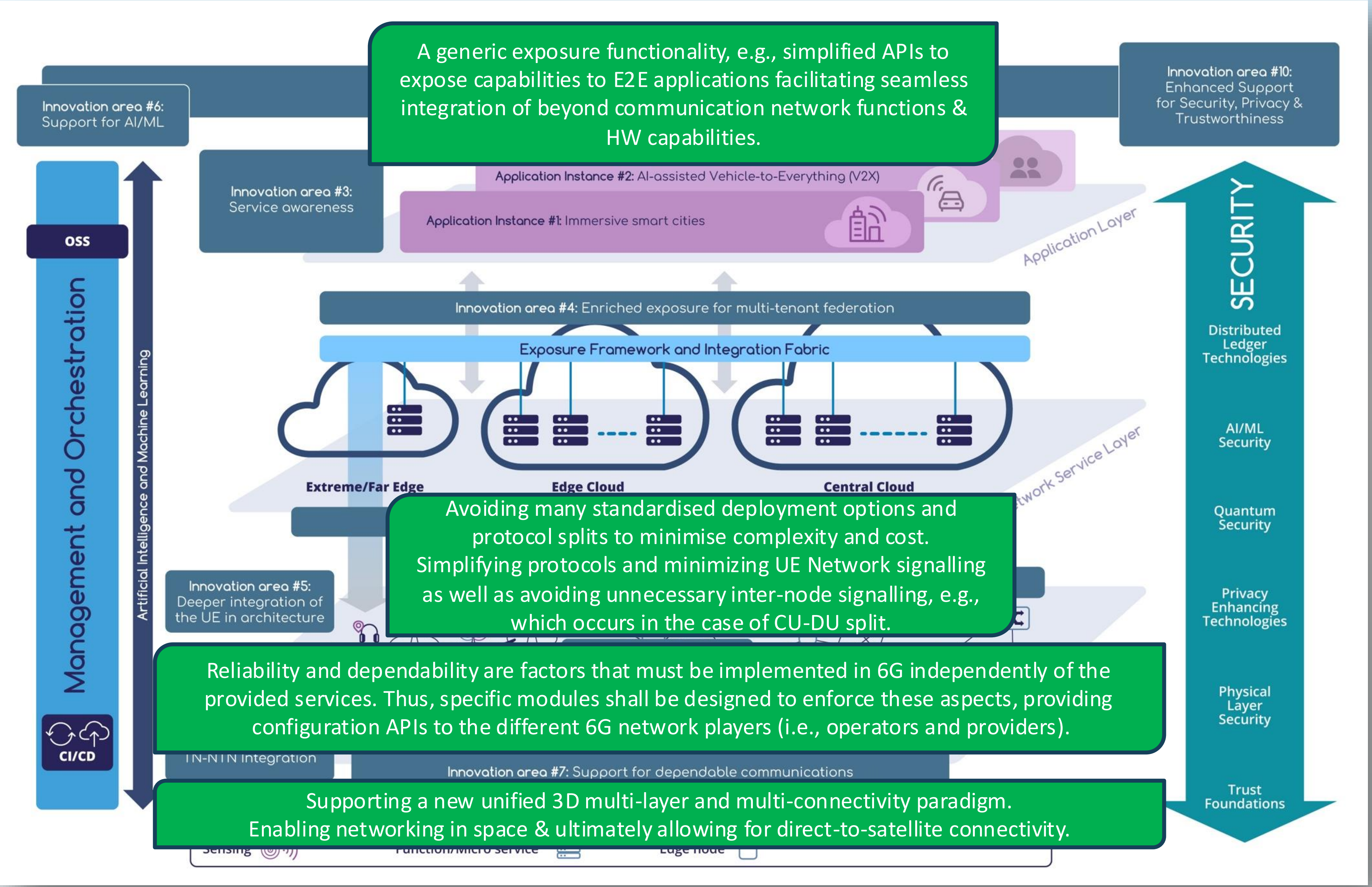
Time-critical Automation
Efficient & real-time network monitoring
Multi-domain & multi-technology Deterministic Communications
Predictable Packet Delay
In-X Subnetworks

Integrated Sensing and Communications-Enabled 6G Networks

Enabling new use cases, e.g., beam tracking, VRUs sensing
Joint Sensing & RIS Operation

Reference: 6G book "Towards Sustainable and Trustworthy 6G"

6G E2E Architecture Vision: Innovation Areas



Chapter 5: Major differences with respect to 5G

The Voice of European Industry and Research for Next Generation Networks and Services

Carles Anton (CTTC), Bahare M. Khorsandi (Nokia)

Major differences with respect to 5G

Capabilities	IMT-2030 (6G)	IMT-2020 (5G)
Peak data rate	50-100-200 Gb/s	20 Gb/s
User exp. data rate	300-500 Mb/s	100 Mb/s
Spectrum efficiency	1.5-3 x IMT-2020	
Area traffic capacity	30-50 Mb/s/m^2	10 Mb/s/m^2
Connection Density	10^6 –10^8 dev/km^2	10^6 dev./km^2
Mobility	500 – 1 000 km/h	500 km/h
Latency	0.1 – 1 ms.	1 ms.
Reliability	10^{-5}- 10^{-7}	10^{-5}

- IMT-2030 KPIs significantly more demanding than those for IMT-2020
- 6G to support selected United Nations' SDGs: sustainability, inclusion, trustworthiness,…
- Requires integration of new technology components: key innovations in radio access and core networks

Key Innovations in 6G networks

Radio Access Network (RAN)

- AI-native air interface design
- Integration of MEC and Edge AI (EAI)
- Use of Frequency Range 3
- Terahertz communications
- Extremely Large Antenna Arrays (ELAA) and Near-Field Communications (NFC)
- Integrated communication and sensing (ICAS)

Core Network (CN)

- Integration of AI/ML in the 6G core network
- Robust and future-proof network architecture
- Slicing with enhanced granularity beyond eMBB, URLLC and mMTC
- Support of a range of innovative technologies (e.g., integrated communication and sensing)

Chapter 6: Next Steps

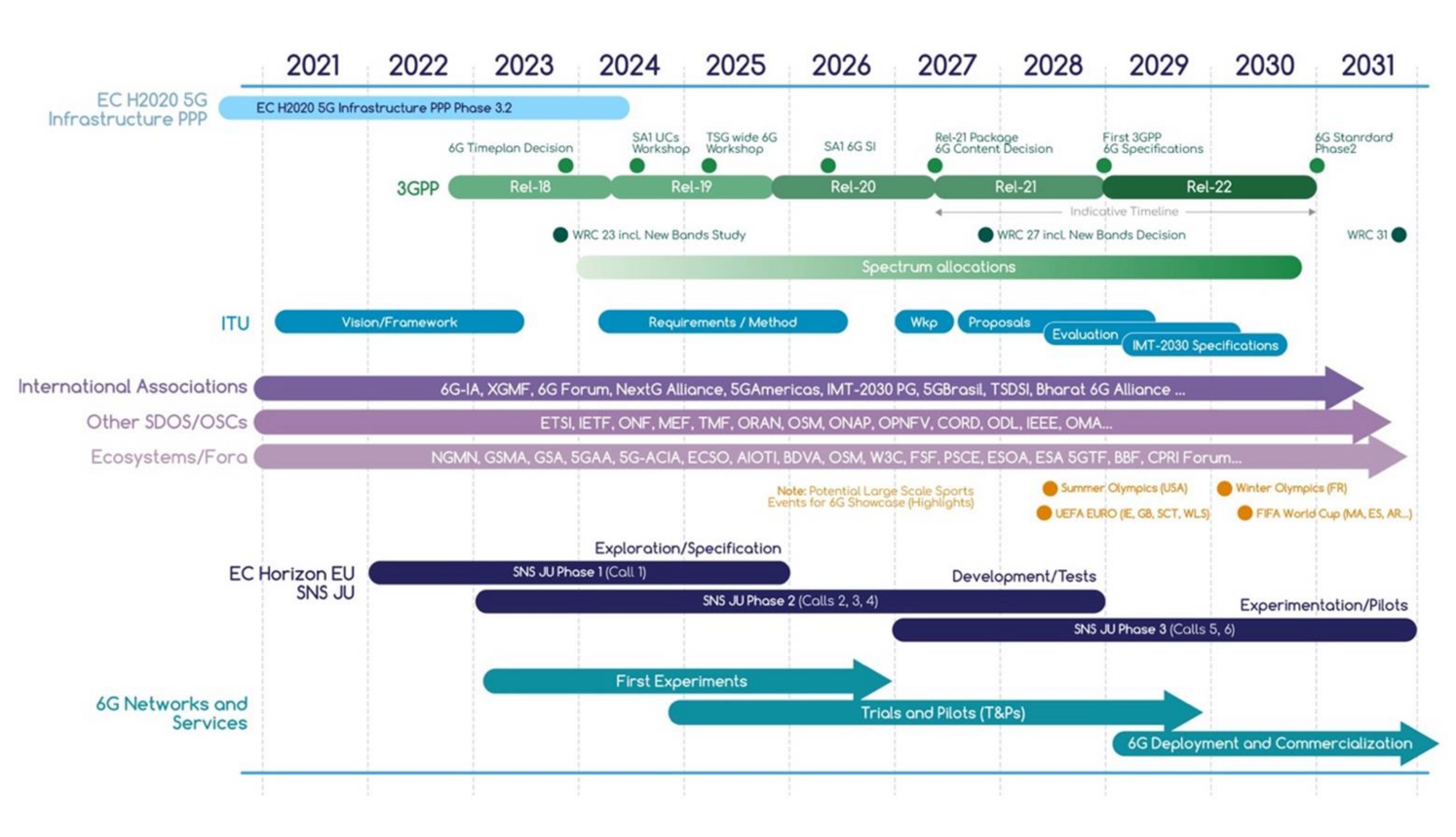
The Voice of European Industry and Research for Next Generation Networks and Services

Aurora Ramos (Capgemini), Valerio Frascolla (INTEL)

Next Steps – Standardization

- **6G standardization** has just started, will last several years and come in phases (similar to the evolution of 5G).
- **6G is a complex system of systems** and its standardization will involve the coordination and collaboration of several SDOs: 3GPP, ETSI, ITU, IETF, IEEE, …
  - Other more recent fora are to be considered as well, e.g., O-RAN.
- **3GPP and ETSI** will be the main SDOs **for 6G**.
- The first TRs (description docs) are expected within 3GPP Rel-20, the **first TSs (normative docs) within 3GPP Rel-21, not before 2028**.
- To help this complex standardization effort, **consensus and pre-standardization venues are important**: European associations (6G-IA, AIOTI, BDVA), GSMA, NGMN, …
  - **6G-IA** is in the driving role with its pre-standardization WG.

Next Steps – Standardization Roadmap



Next Steps – Regulation

- 6G will have to be deployed **worldwide**, therefore **regulation plays a key role in 6G roll-out**.
- **Cross-border services** involving personal data management will have to be regulated by a diverse set of national rules and entities.
- **To establish a fairer and citizen-focused market,** the EU has issued a set of acts, which will evolve and have to be taken into consideration when designing and developing 6G technologies:
  - AI Act
  - Data Act
  - Cybersecurity Act
  - RED.
- Other aspects are to be considered as well, e.g. the **Digital Product Passport** and its implication on all services and devices sold in the EU.
- **The work of other regulatory entities outside of the EU** is also a key factor to take into consideration.

Next Steps – Business Roadmap

- **Service-oriented paradigms** ➡ 6G networks turn into application platforms (NaaS, Intent-based requirements)
- Distributed cloud providers hosting both applications and networks + federation of network operators (aligned with 3C Networks concept) ➡ evolved new **multi-provider business models**
- NT – NTN integration ➡ business models for **MNOs and SNOs interaction**.
- **Open architecture and interfaces** ➡ for greater flexibility for operational efficiency in network roll-out
- 6G as catalyst for **sustainability in other vertical sectors** (6G for sustainability)
- Native AI ➡ **Data as key factor of production**.

Main business challenges ahead

- Europe has a strong position regarding infrastructure, but:
  - Increasing **competence by hyperscalers** or online service provides ➡ better market balance by "same rules for same services" ensuring fair commercial outcomes
  - Need to **reinforce on AI capabilities and cloud technologies**
  - Joint dedicated effort with **chipset technologies**
  - Push new STEM degrees **combining computer science, telecom, cyber and AI/ML**

Global Sustainability related challenges

- Measurement and assessment (applicable to the 3 dimensions: environmental, social and economic)
- Integration into the 6G services by default
- Handle trade-offs with technological and economic efficiency

6G SNS IA

European 6G Vision

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