European Vision for the 6G Network Ecosystem

The voice of the European industry for the development, deployment and evolution of 5G

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Societal, policy and business drivers for 6G

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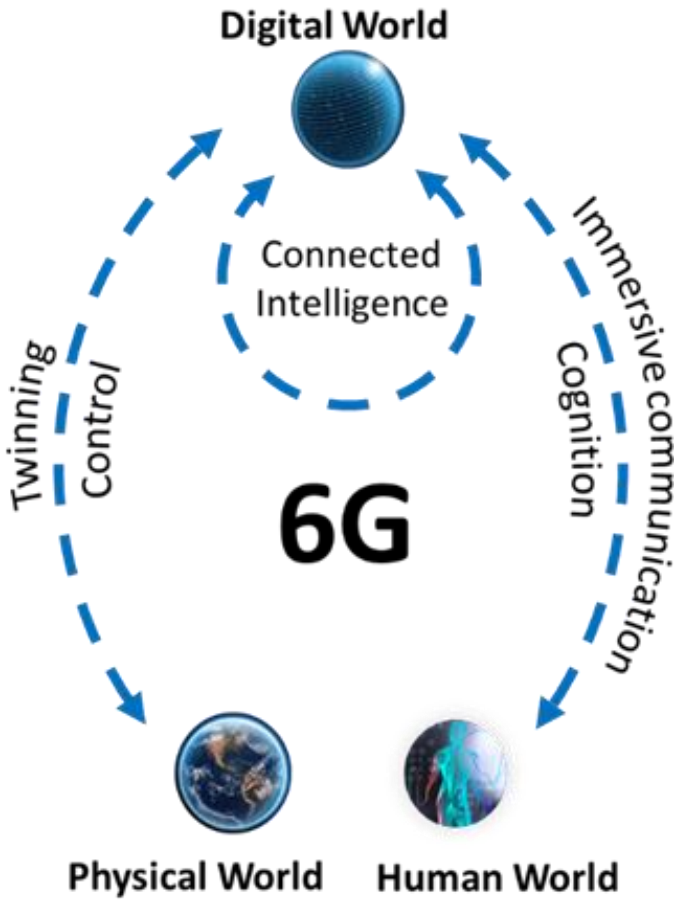
- **Society and global 6G activities**
  - Several ongoing initiatives worldwide
  - Need to address UN-defined Sustainable Development Goals (SDG)
  - Human-centric, benefit the whole society, needs to be trusted by the broadest possible public
- **Policy Context**
  - Technology sovereignty, staying at the verge of technology, e.g., fostering needed soft skills in the academia and advocate for new chip-factories and assembly lines based in the EU.
  - Comply with EU values
- **Business**
  - 6G has the potential to massively improve the economies of the EU Member States
  - Cope with new challenges, like COVID-19
  - 6G will introduce new business models

Main goals of 6G

Connected Intelligence	• **Convergence of digital, physical, and personal domains -> support for digital twinning, immersive communication, cognition and connected intelligence**
Programmability	• **Provide flexibility and programmability**
Determinism	• **Support deterministic end-to-end services**
Sensing	• **Integrated sensing and communication which will enable high accuracy localization and high resolution sensing services**
Sustainability	• **Reduce footprint on energy, resources, and emissions and improve sustainability in other parts of society and industry**
Trustworthy	• **Truly trustworthy infrastructure that will become the basis of societies of the future**
Affordable and scalable	• **Inclusive for all people across the world, it needs to be scalable and affordable**

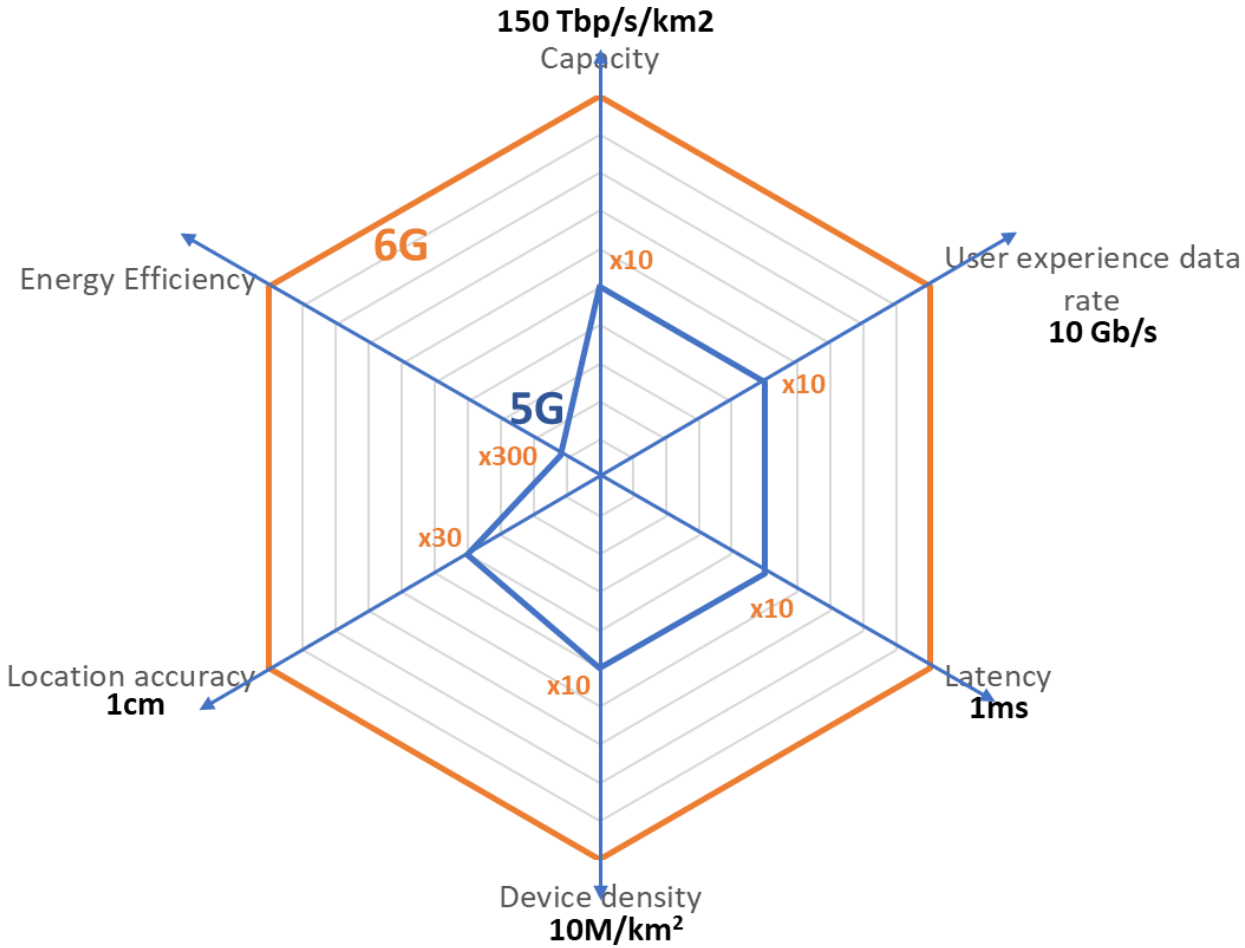
Connected intelligence

- Immersive communication, cognition and twinning, imply virtual representations in the digital world of entities in the physical and human world
- These virtual representations have dynamic relations with sensors, actuators, screens and cameras
- Connections between virtual representations in the digital world replace connections between mobile end-devices
- Fundamental impact on the mobile network

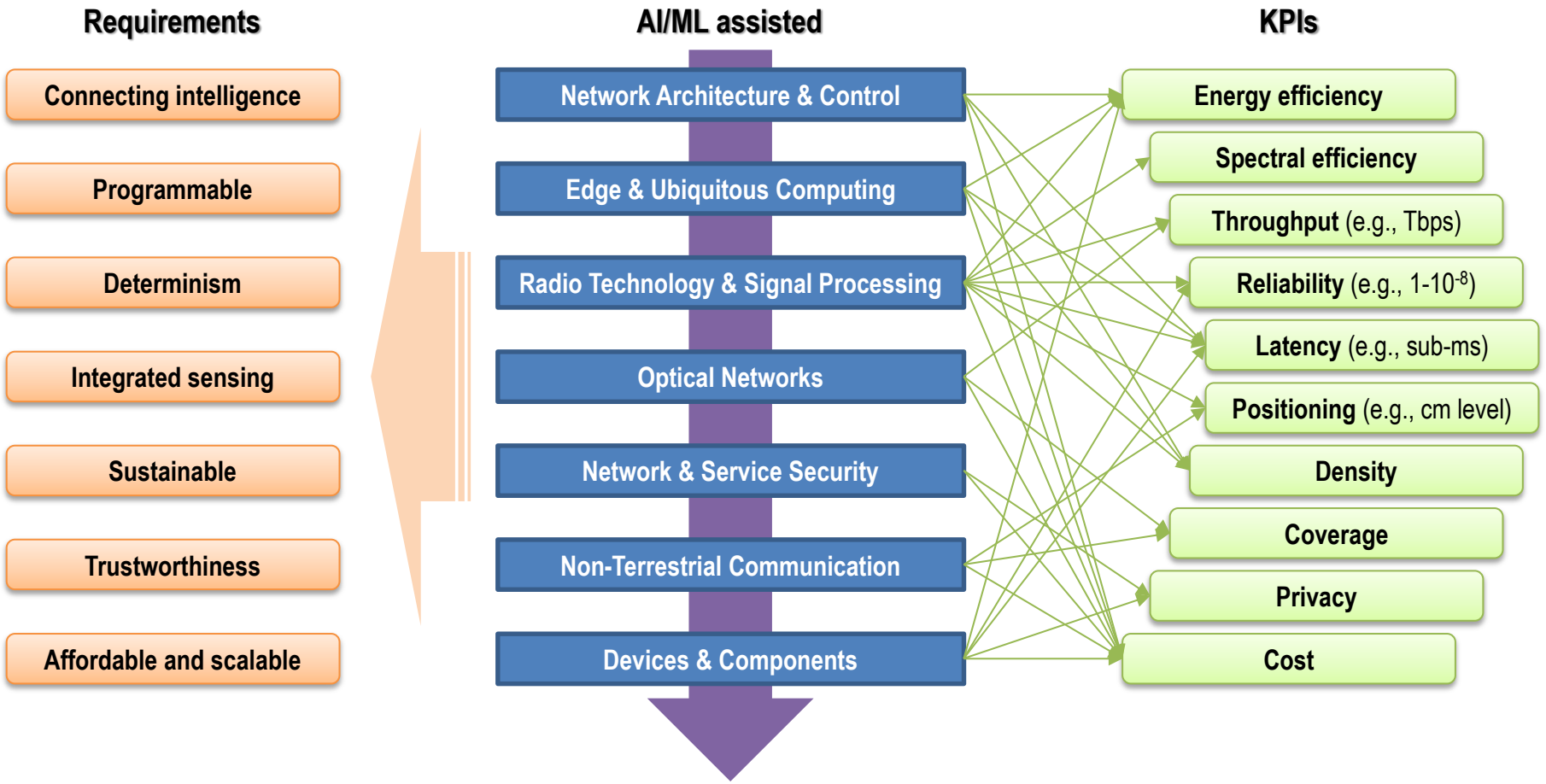


Stretching 5G KPIs

- More devices, more data, and higher data rates imply an increase of overall data traffic and required capacity
- Services like immersive communication and tactile internet require lower latency and higher data rates
- Better location accuracy will enable new applications
- Main improvement is needed in energy efficiency, to ensure overall power consumption does not grow beyond what it is now for 5G



4. Envisaged key technologies for 6G



Technology areas with strong impact on different 6G requirements and KPIs.

Radio technology and signal processing

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6G networks are expected to deal with more challenging applications **requiring Tbps** data throughput, **sub-ms latency** to the network layer, **extremely low packet error rate**, **increased device density**, **ultra-low energy consumption**, very high **security**, **cm-level** accuracy l**ocalization**, etc.

Key enabling technologies for 6G air interface design:

- **Spectrum** reutilization
- **mmWave** communication
- **Optical wireless** communication (OWC)
- **THz** communication including semiconductor technologies and new materials
- **Massive** and **ultra-massive MIMO**
- **Waveform**, **multiple access** and **full-duplex** designs
- Enhanced **coding** and **modulation**
- Integrated **positioning**, **sensing** and **communication**
- **Random access** for massive connections
- Wireless **edge caching**

Non-terrestrial networks communication

- **Architecture** design as a **single access network**.
- **Constellation** with **hierarchy** design.
- Smart NTN with **computing and storage in the sky**.
- **Resource optimization**, dynamic **spectrum management**, **coexistence** and sharing.
- **Radio access technologies** with flexibility and adaptability.
- **Software-defined payloads**, new **antenna** designs, new **components at THz**.
- AI for exploitation of NT dynamics.

Special purpose networks/subnetworks

- Increasing demand for 6G for verticals leads special purpose networks or **smaller range 'subnetworks'** that can operate in a **standalone** fashion, e.g. **in-body**, **in-robot**, **in-car** and swarm of **drones**.
- The air interface design for subnetworks requires **sub-ms latencies** and **extreme reliability** can be achieved by using large subcarrier spacings, ultra-short transmission intervals, blind packet repetitions and channel hopping.

System network architecture and control

- 6G technology research shall pave the way for **efficient, sustainable, smart and trustworthy distributed computation**.
- **AI/ML** will be needed for operation **cost-effectiveness** of envisioned complex **6G services,** and will enable the implementation of **predictive orchestration**.
- A very versatile, pervasive and **automatic resource control** is required.
- **Autonomic**, **distributed mechanisms** are required in all infrastructure and service components for the organization and maintenance of such resource control.

Edge and ubiquitous computing

- Edge computing is driven by factors like massive IoT, Industry 4.0, Smart Cities, etc.
- Main **goals** are to reduce **delays**, increase **responsiveness** and reduce the volume of **data flows** between user/IoT devices and centralized cloud computing resources.
- Important in 6G due to **transition toward distributed service-based architecture**.
- Computing and networking resources will **merge to a single computing continuum.**
- **Methods** are needed for the **collection of distributed data** for AI/ML and caching.

Optical networks

- **Smart optical transport** connectivity is going to be foundation of 6G: always **available**, intrinsically **secure**, **green** and with flexible **scaling**.
- All dimensions in space and frequency to be exploited to approach Shannon's limits, opening **new optical wavelength bands** and **space division multiplexing**.
- Development of **novel packet/optical switching** architectures.
- Tighter integration optical-wireless technologies: adoption of a **common transmission and switching** platform **with diverse switching granularities**.
- Technological advances require advances in network control, automation, etc.

Network and service security

- **Cybersecurity must evolve** as the system does.
- Highly **distributed computing and connectivity architecture** of envisioned 6G with softwarization and automatization of critical management functionalities create an **attack surface far more wide and complex** than 5G.
- **New approaches for security** in 6G: Virtualization, softwarization, deception and moving target defense, holistic approaches for the whole life cycle, cloudification.

Opportunities for devices and components

- **RF challenges**: Phase noise, MIMO/hybrid BF for large arrays, transceiver architectures, more power efficient converters, packaging, THz, on-chip antennas, ...
- **Optical domain challenges**: Monolithic integration, CMOS processing, photonic devices, new on-chip components.
- Bridge the **gap between high-efficiency and high-flexibility** programming devices.
- **Hardware for security** needs increased reliability, graceful degradation and automatic recovery, and robustness to quantum computing attacks.

Summary and future trends

- An essential tool will be **AI/ML** mechanisms for the optimization of the **physical** and **higher layers**.
- **Disaggregated**, micro-services based **RAN architecture**, combined with AI/ML as well as open and **standardized interfaces** allows for RAN functions and services to be flexibly selected, deployed and optimized for the specific use case.
- Exploitation of properties from quantum mechanics promises unprecedented performance in **quantum sensing**, **communication**, **security**, and **computing**.

Towards 6G architecture

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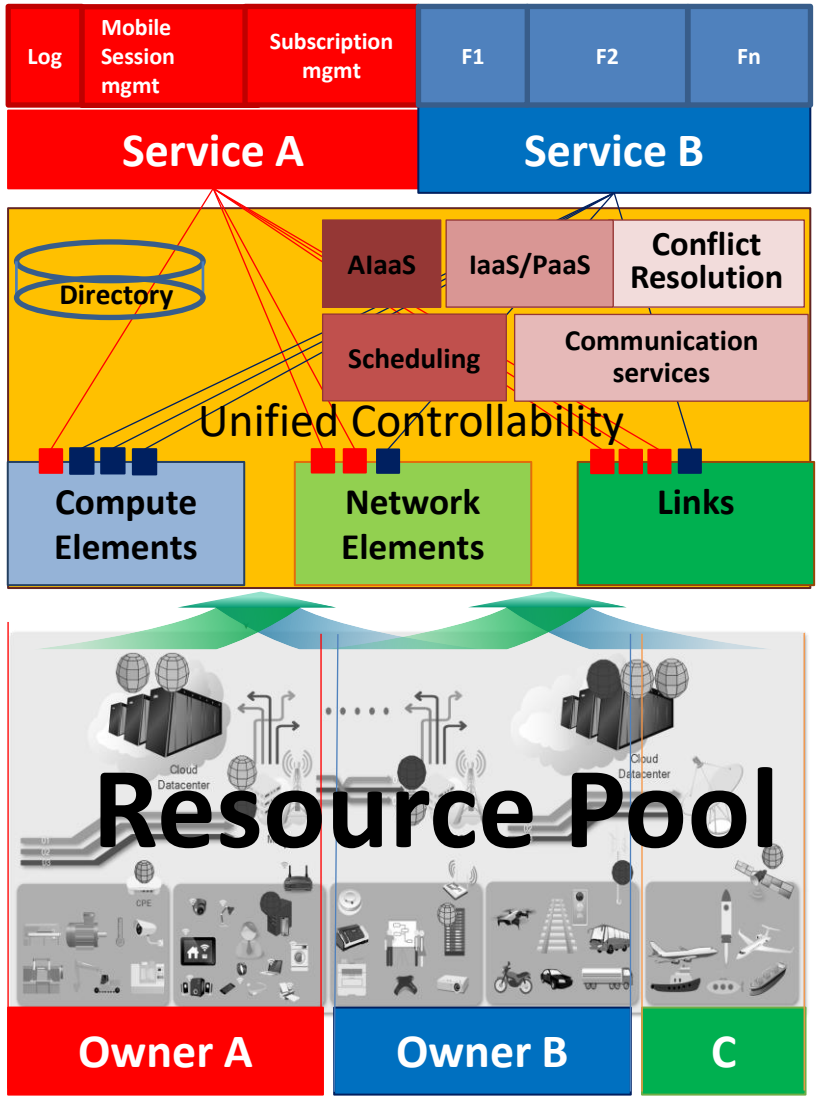
Dimensions of Evolution

6G as a Smart Service Execution Platform



Mobile System Architecture

Novel service requirements, **expected novel capabilities** and the **push of the programmable elastic system**

- Emergence of new types of functions within the user, control and management planes.
- **Mobile system architecture**, now **allocated as a service chain**, will preserve and uphold flexibility of the modern infrastructures
- **Mobile system** will look like a **computer program executed within the programmable infrastructure**.

Infrastructure

- **flexible on-demand provision.**
- **capable of resource control**
- **full-service platforms**, natively offering capabilities B E2E

Required Developments in :

- novel resource control plane scheme,
- integration of suitable distributed secure computations,
- autonomic and distributed conflict resolution
- distributed resource scheduling
- Distributed AI

6G Architecture vision summary

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5G has significantly increased both performance and flexibility of the provided service for users and service providers alike.

6G aims at direct integration of different resources from networking to computation and sensing.

5G NR has introduced new radio modes as **URLLC, mMTC** and **eMBB**.

5GC supports radio flexibility through slicing.

5G adopts **service-oriented architecture**.

5G principles on a per-domain basis reuse the terminal, RAN or CN domain boundaries of 4G.

E2E session in 5G

- employs different architectural patterns
- adheres to different realization principles
- assumes different types of realizations underneath.

Scope extended beyond the RAN and CN to terminals and data centers.

full end-to-end resource awareness.

Service-based architecture extends over the **whole network, across all planes and end-to-end**, **spanning the CN, RAN, and terminals**, providing for more deployment and operational flexibility.

6G supports **network-of-networks** and **system-of-systems** concepts for **easier subsystem integration and scalability.**

6G architecture must be able to integrate **mission-critical** networks with **reliability**, **availability**, and **resilience** beyond 5G's URLLC.

6G Architecture Analysis

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The main principles of a future mobile communication system should be the ability to handle a higher degree of flexibility and functionality.

1. Flexibility and functionality **should not add to the overall complexity**

   - **6G System** will require **softwarization**, **full cloud-native architecture** and **further developed SBA and software and hardware disaggregation.**

2. The **principle of "AI everywhere"** utilized to improve network performance and to deliver AI-as-a-Service in a federated network.

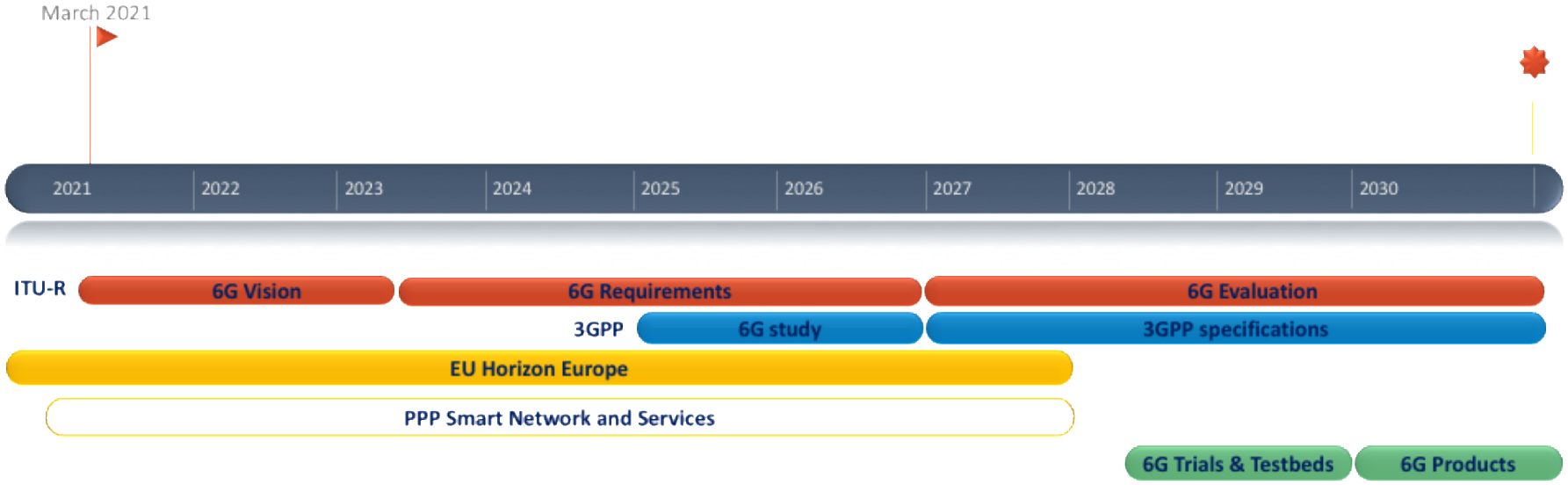
   - Capabilities that were previously only possible outside the network will be integrated into the **6G System**, as well as allow the **use of AI everywhere** in the network.
   - **6G System** must support a framework to efficiently collect the necessary information for the learning.

3. **Trustworthiness** is central

   - Related to **trustworthiness** is **digital inclusion** and global service coverage.
   - The **6G architecture** shall **enable coverage of remote places.**

Conclusions

- 6G will play a **key role for societies of the future**, with applications merging the digital, physical and personal domains (examples: holographic telepresence and AR/VR)
- **Global standards and renewed regulations** shall play a key role in the development and deployment of 6G Societal, policy and business drivers for 6G
- **AI/ML** mechanisms will become crucial elements
- **Reusing universal infrastructure** is required to provide more diversified services and achieve the increased sustainability awareness
- Envisaged **Timeline**:



Recommendations

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- 6G networks will grow in complexity exponentially -> challenges for security, identity validation, lawful interception, forensic analysis etc. New regulations and Ethic principles needed to address **certification** and **litigation** in the whole chain
- **Additional spectrum** needed for both terrestrial and NTN systems, including traditional MNOS and other actors (companies, research institutions, ..)
- 6G offers opportunities to new players in the ecosystem due to the need for combination and integration of more components. Regulation in Europe could help **new players** to emerge and to make sure that sovereignty and security requirements are met
- An opportunity for Digital Sobriety, with **moderation** when producing and consuming services, materials, or energy.
- **New professional skills** addressing communication protocols and software, cybersecurity, microelectronics, quality-testing-certification technologies, AI/ML with focus on gender balance

Overall recommendation: to compete with future's 6G enabled products in defence, automotive, white goods, industrial machinery, consumer goods, etc, Europe needs a world-class competence resource pool in wireless and wireline communications, microelectronics (at least in design), photonics, and software in industry as well as in academia, strengthen by a proactive Regulation adaptation to create strategic and business opportunities for EU companies.

Executive Summary (1/2)

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- 6G will…
  - Bring a near-instant and unrestricted complete wireless connectivity
  - Be a self-contained ecosystem of artificial intelligence (AI), enabling easy integration of everything – the *'AI everywhere'* principle
  - Include connected management and control functions, programmability, integrated sensing and communication, reduction of energy footprint, trustworthy infrastructure, scalability, and affordability
- 6G will be **one of the basic foundations of human societies of the future**, and will **reshape the way enterprises operate**
- **End-user engagement** will be key for the adoption of 6G technologies

The development of Europe-based 6G infrastructures and solutions is one of the keys to secure European sovereignty in critical technologies and systems

Executive Summary (2/2)

- Europe shall ensure **leadership in strategic areas** and **find alternate ways** of establishing a secure and trusted access to those technologies, where a European supply network cannot be established
- Public and private investment shall focus on **key 6G technologies**, and shall **foster entrepreneurship** with public and private participation
- **Global standards** shall be promoted, along with a common certification process
- Applicability of net neutrality rules and data protection regulations should be clarified
- **Ethics principles** that conform to European standards shall be applied for AI-related services
- The **emergence of new European players** shall be supported
- **Sovereignty and security** requirements shall be identified and enforced
- Europe shall build a **world-class 6G competence pool**

Europe shall become a sovereign, independent, and reliable source for 6G public and private network solutions and services

Thank you for your attention!

5G IA
INFRASTRUCTURE ASSOCIATION

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