Hexa-X: WP1 – Deliverable D1.4

Hexa-X architecture for B5G/6G networks – final release

30.06.2023

hexa-x.eu

Mission and scope

- WP1 defines an overall vision, use cases, architecture of the x-enabler fabric which is capable to connect intelligence, sustainability, trustworthiness, inclusion, and extreme experience.
- D1.4 is the last deliverable of WP1, providing the latest updates and achievements on use cases, KPIs and KVIs, and spectrum, as well as achievements with respect to sustainability.
- The final version of the E2E architecture as well as, the security architecture and updated guidelines for security are also presented.

Call: H2020-ICT-2020-2

Project reference: 101015956

Project Name:

A flagship for B5G/6G vision and intelligent fabric of technology enablers connecting human, physical, and digital worlds

Hexa-X

Deliverable D1.4
Hexa-X architecture for B5G/6G networks – final release

Common vision

Analysis of current trends in society and technology

Societal trends towards 2030:

- 6G: The connectivity platform for a better and more sustainable world.
- Sustainable 6G
- Built-in trustworthiness in an open society:
  - Covers security, privacy, availability, resilience, compliance with ethical frameworks
- Digital inclusion that serves all populations.

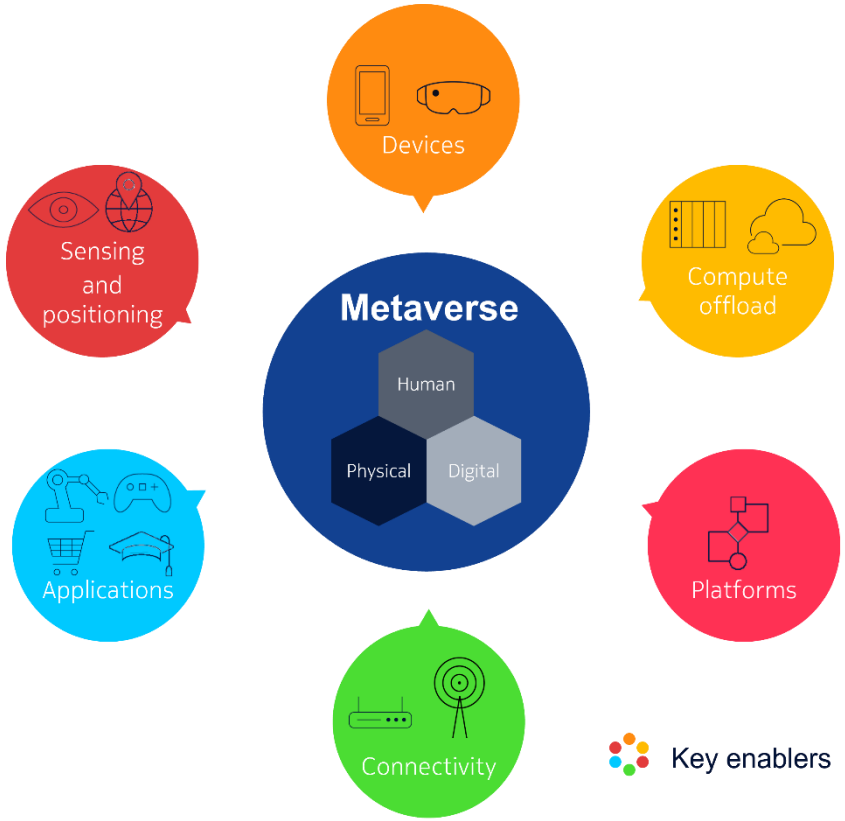
Analysis of current trends in society and technology

Societal trends towards 2030:

- Pervasive AI for automation
- Metaverse

Economic trends towards 2030:

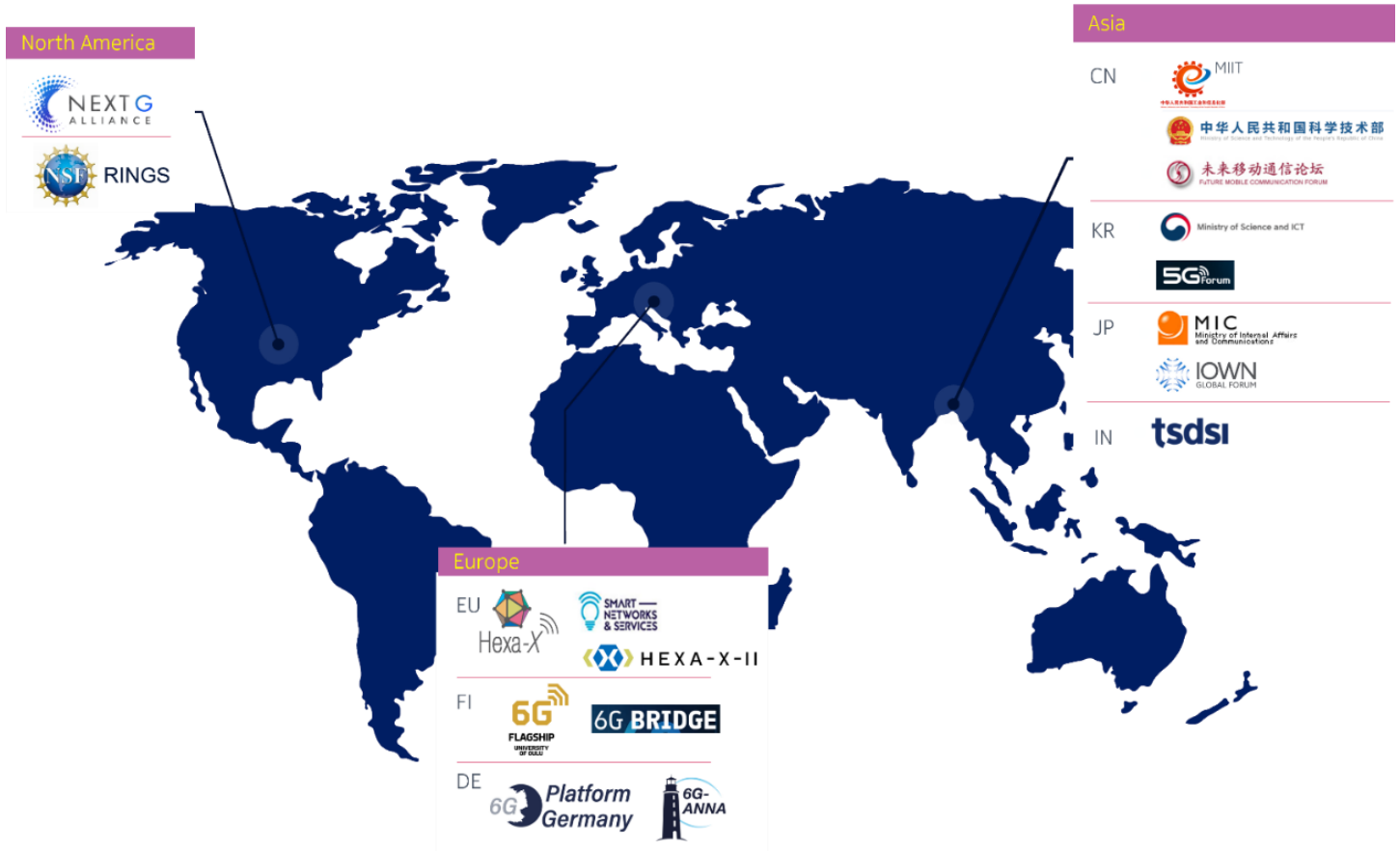
- Digitalization as a foundation for economic recovery and sustainable growth
- New business models, use-cases, and market segments
- Disruptive transformation of global education, skill, and labor markets



Analysis of current trends in society and technology

Technological trends towards 2030:

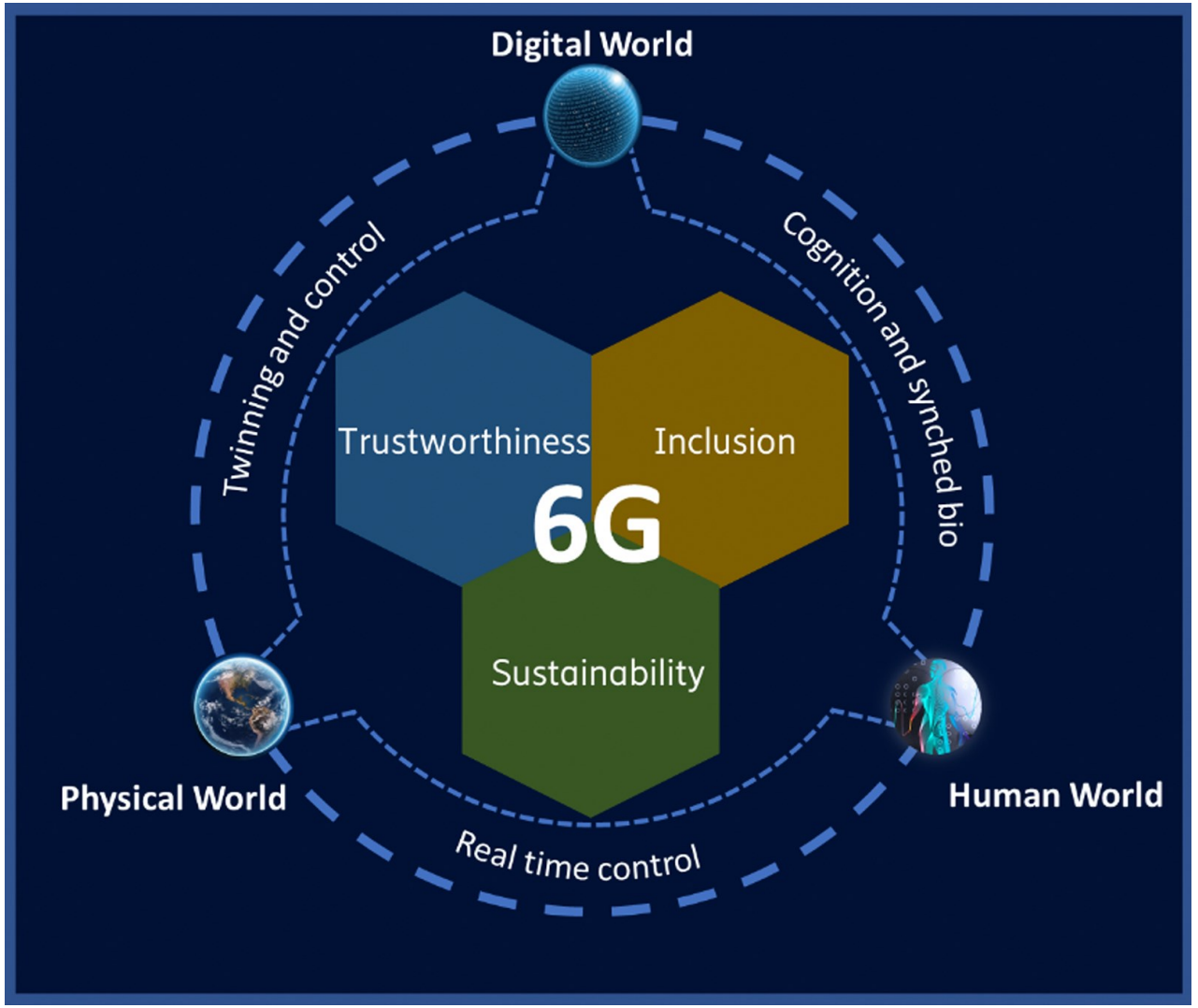
- Convergence of communications, localization, and sensing
- Use of AI/ML in network
- Flexible network architecture
- New devices and interface
  - Human-machine, machine-machine, and AI-AI communication
- Network of networks
- Integration of non-terrestrial networks



Most significant global activities on future connectivity

Hexa-X vision on 6G

- Connecting the physical, digital and human world
- Key values:
  - Sustainability
  - Inclusion
  - Trustworthiness
- Research challenges:
  - Connecting intelligence
  - Network of networks
  - Sustainability
  - Global service coverage
  - Extreme experience
  - Trustworthiness



Services and Use cases

Key value and performance indicators (KVIs/KPIs)

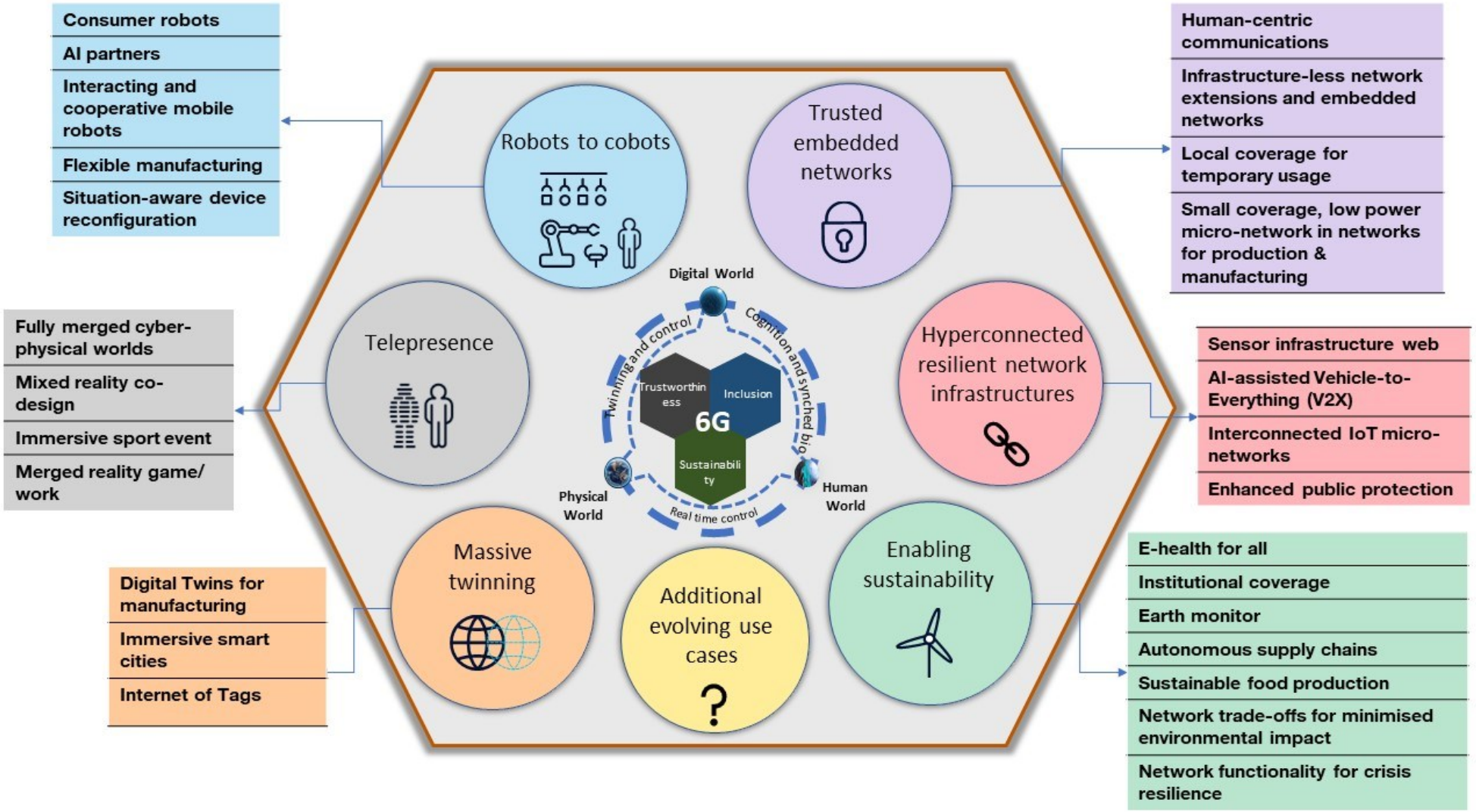
Hexa-X final set of use cases

- The final set of Hexa-X use cases consolidated the 6 families of use cases.

- The consolidation led to the refinement of the *Fully merged cyber-physical worlds* use case, which can cover a wide range of usages. It has been subdivided into two use cases, corresponding to the two extremes:
  - *Holographic communications*, the most demanding version of this use case, requiring high-end devices
  - *Generic Mixed Reality experience*, targeting a mass usage and low-ends devices, less demanding on the infrastructure

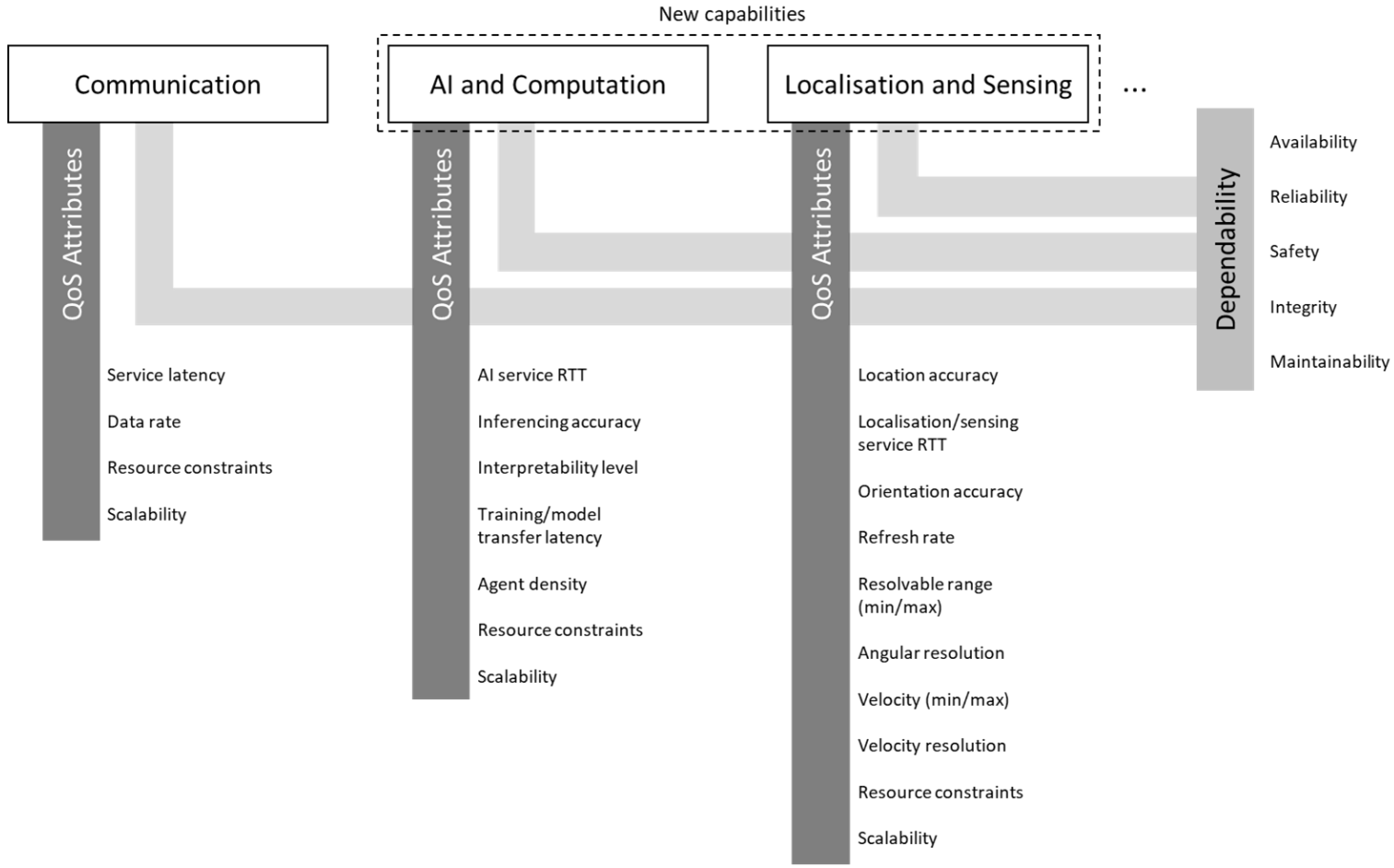
- A comparison with State-of-the-Art (White-papers, projects, academic papers) has been conducted and showed a good coverage of Hexa-X use cases

Hexa-X final set of use cases



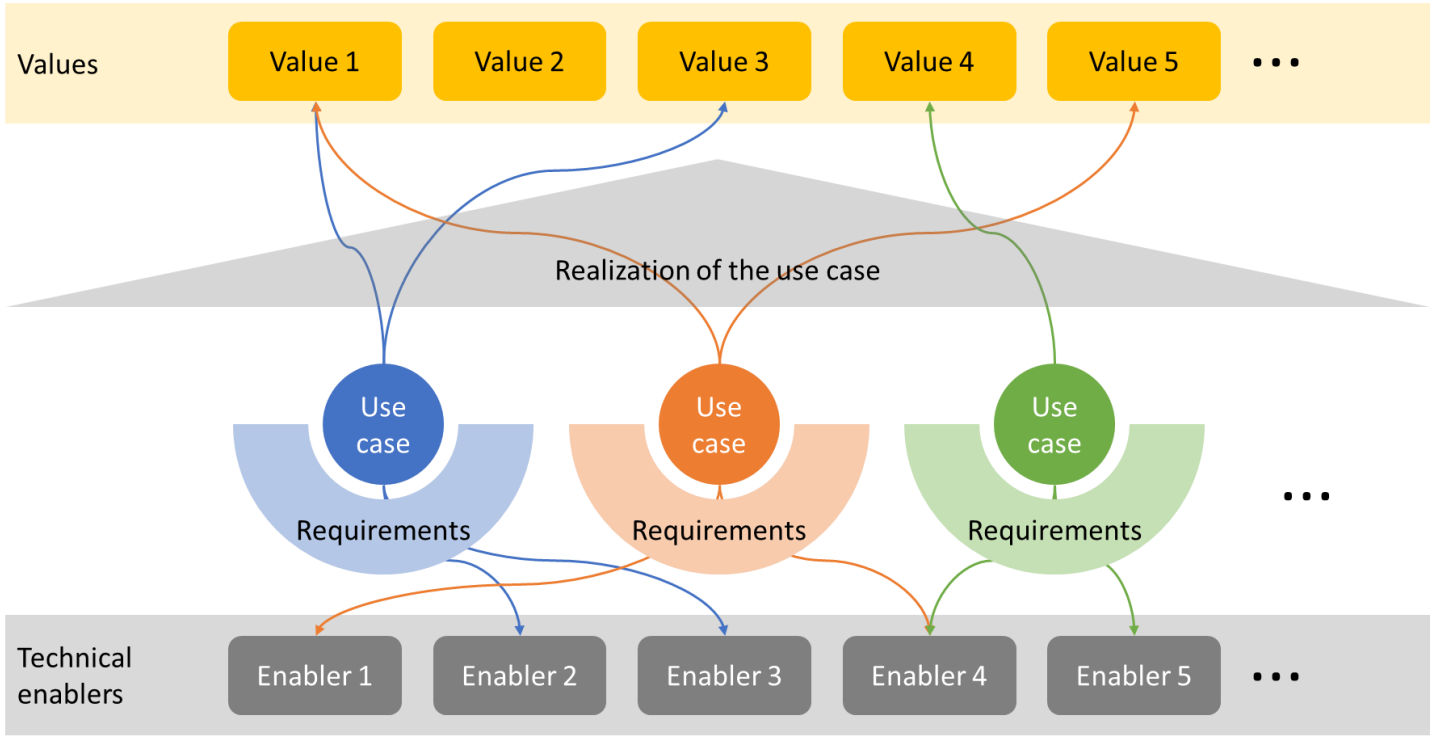
Hexa-X Key Performance Indicators (KPIs)

- Brief update compared to D1.3
- Final definitions of Hexa-X KPIs, including new capabilities
- Mapping against ICT-52 projects, research papers, and whitepapers



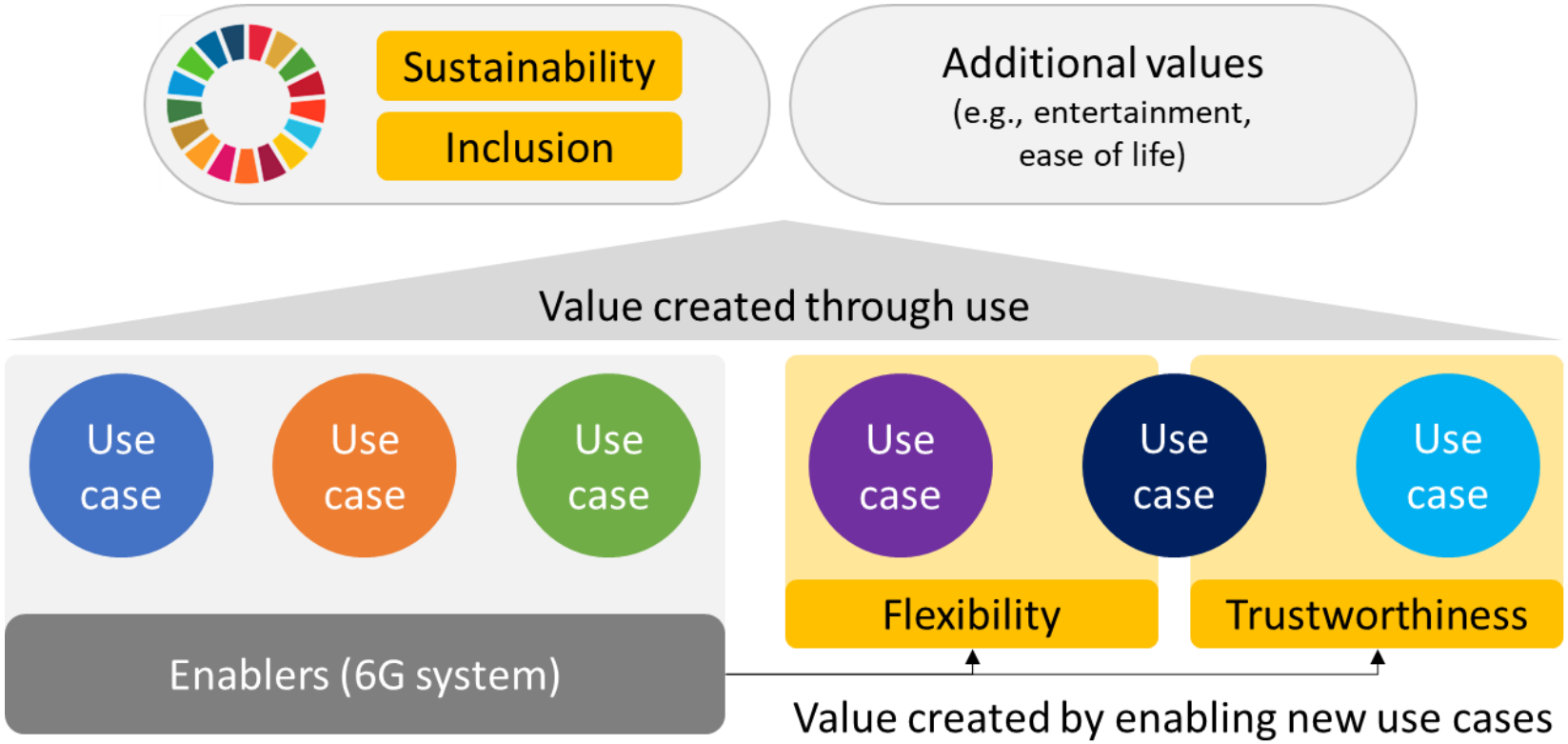
Hexa-X Key Value Indicators (KVIs)

- Updated methodology and comparison against SotA
- Values achieved with the realization of use cases
- Realization based on requirements with technical enablers



Hexa-X Key Value Indicators (KVIs)

- Values “flexibility” and “trustworthiness” act as enablers for additional use cases
- These additional use cases create value through their realization
- Discussion of enablers, measurements, challenges

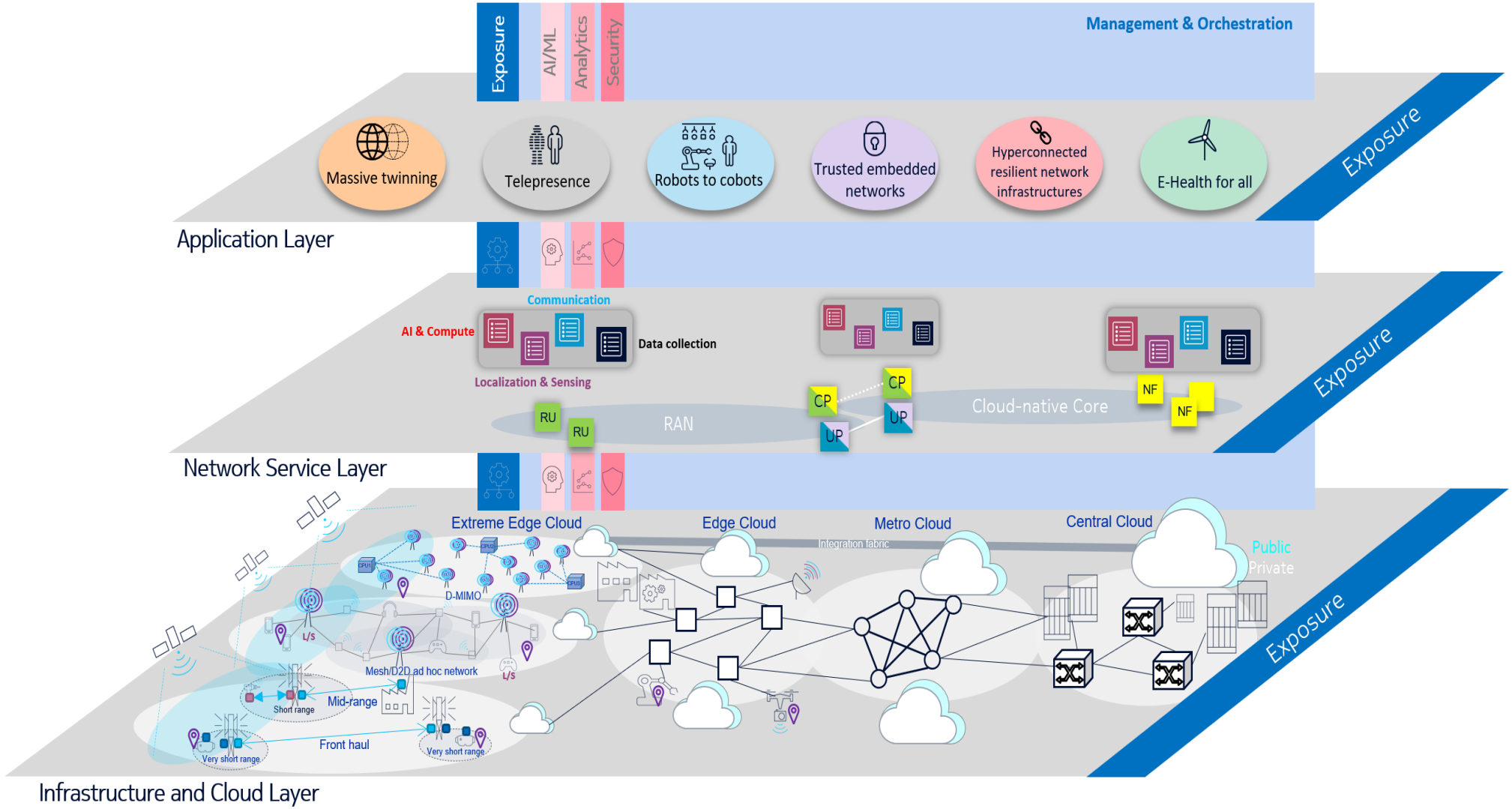


End-to-End Architecture

End-to-end architecture

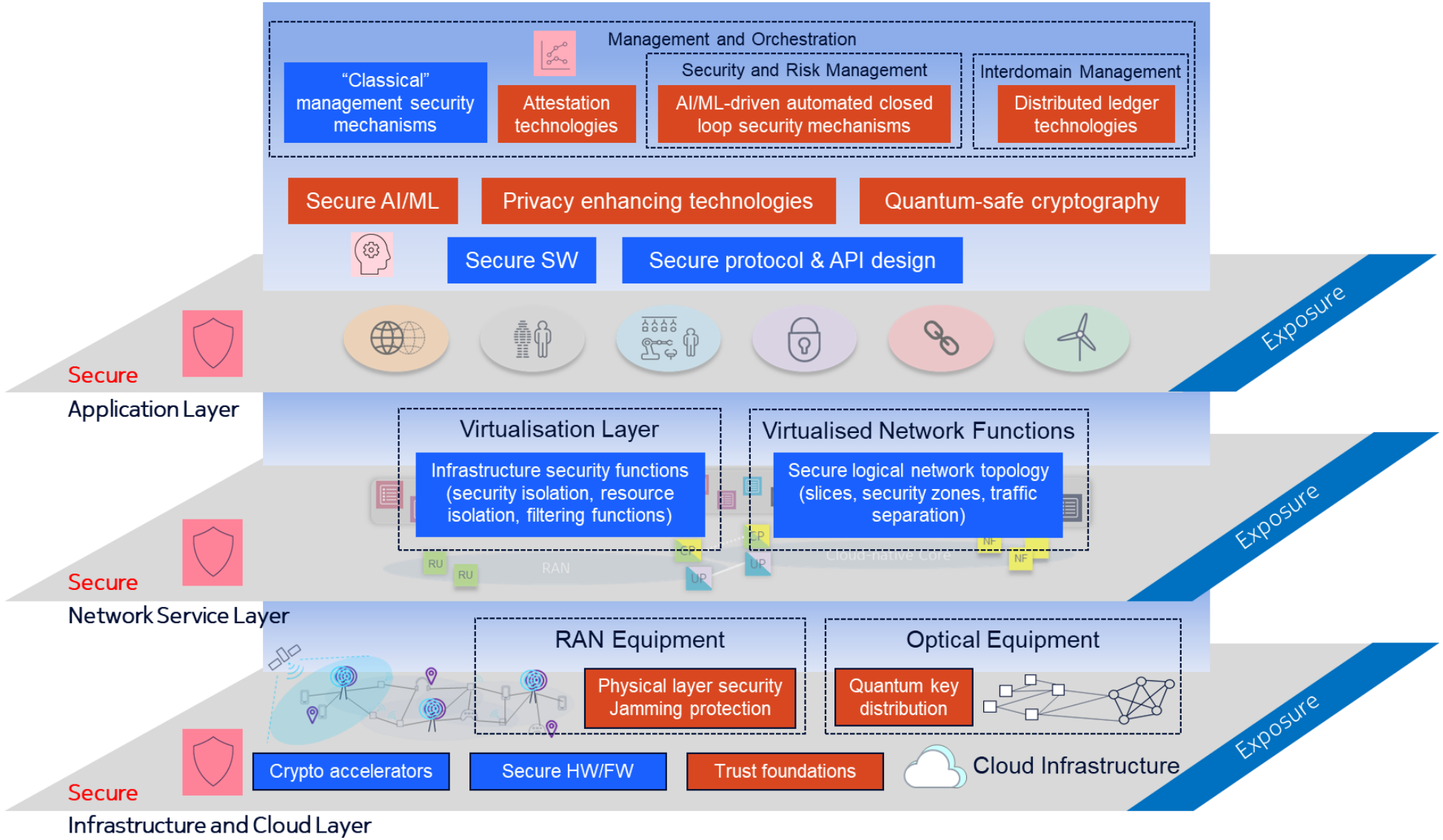
- Final Hexa-X system-level end-to-end 6G architecture.
- It reflects the latest key technical enablers provided by Hexa-X technical WPs.
- The design proposal is an update version of the first draft (D1.3) and aligned with the architectural principle conducted by Hexa-X WP5.
- The relation between architectural technical enablers and Hexa-X contributions are also presented.

Hexa-X final end-to-end architecture



Security, Privacy, and Trust

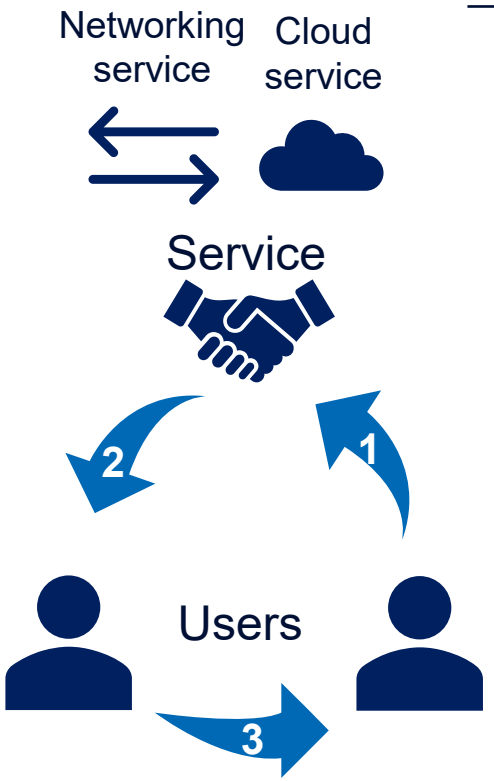
Hexa-X Security Architecture



Trustworthiness based on Security and Privacy

- Security and privacy are essential for trustworthiness
  - Aspects like resilience and ethical framework compliance are also relevant for trustworthiness
- Security and privacy KPIs may be used as “proxies” for the trustworthiness KVI
  - Most security KPIs apply to concrete network deployments
  - Typical examples: number of intrusions per time interval or downtime due to cyber-attacks
- 6G-technology- or 6G-standard-related security KPIs may comprise:
  - The strength of specified crypto algorithms, in particular quantum safety
  - The rigor and insistence of security policies (e.g. re-authentication patterns)
  - The coverage of the security specification in terms of interfaces and services
  - The coverage of security assurance specifications
  - The impact of known attacks against the standardized procedures and protocols
    - An unmitigated attack example for 4G: IMSI-catching
- Privacy builds on security, adding technical measures such as privacy preserving technologies
  - The pervasiveness of these mechanisms can be considered privacy KPIs.
- Non-technical aspects may still be dominant for users’ trust wrt privacy protection
  - Perceived reputation of the service provider, existence of a strong legal framework, etc.

Trustworthiness – Multi-Agent



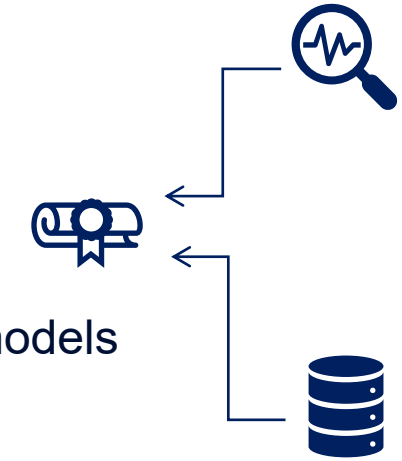
Trust relations in multi-agent system:

1. User trusting a service (network / cloud)
2. Service provider trusting a user
3. A user trusting another

Generally, data will be shared by one agent to another and exploited by the latter.

Risk of data injection:
Compromising the data authenticity without violating privacy or integrity

Direct trust:
Based on own historical observations



Hybrid trust:
Fusing both models

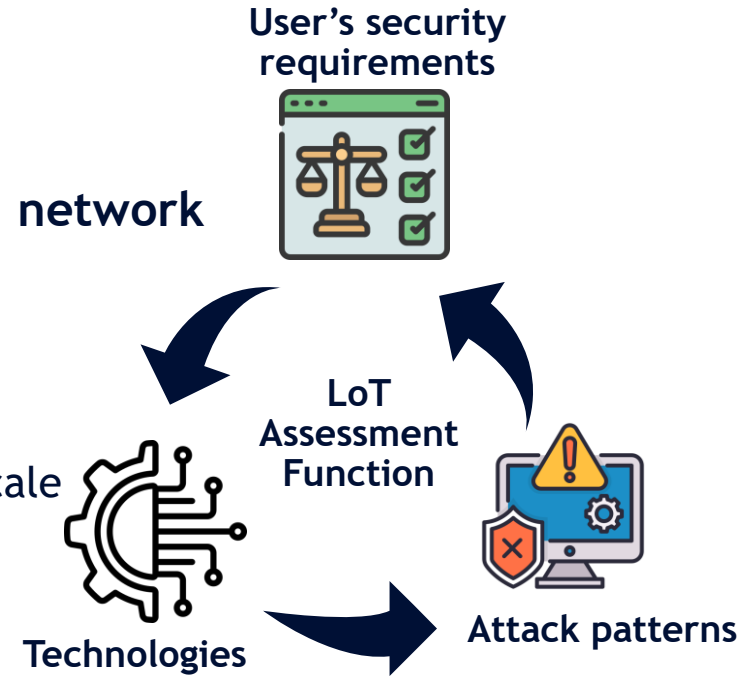
Indirect trust (reputation):
Based on other agents' assessment

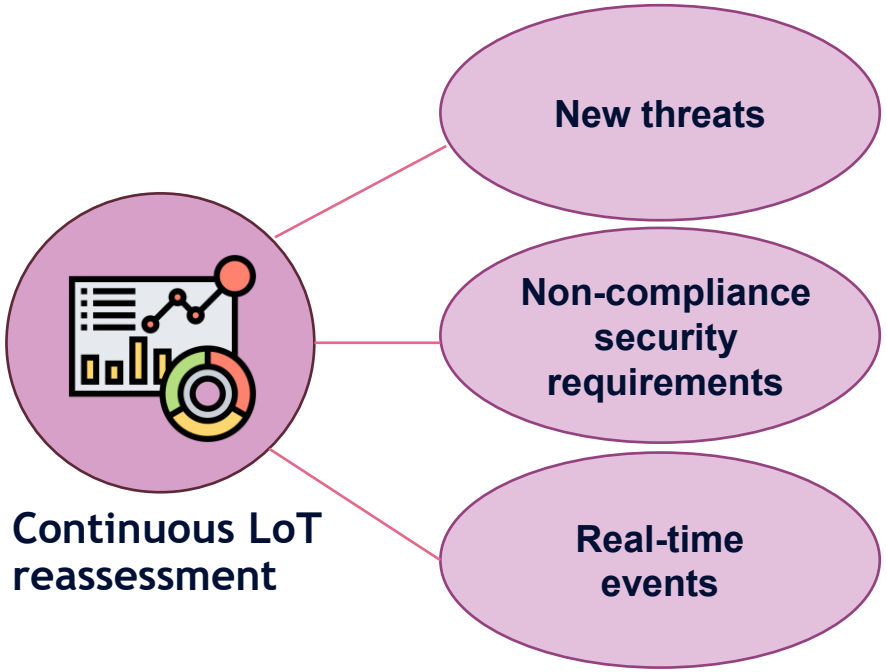
A third-party entity/platform required to record, maintain, update, and distribute the reputation score
- the 6G MNO/MVNO as the most appropriate party

Trustworthiness – LoTAF

Assess the security and privacy of a network service in 6G environments

- AI-driven pre-processing
- Balance in terms of cost, risk and impact
- Categorize services in a trustworthiness scale

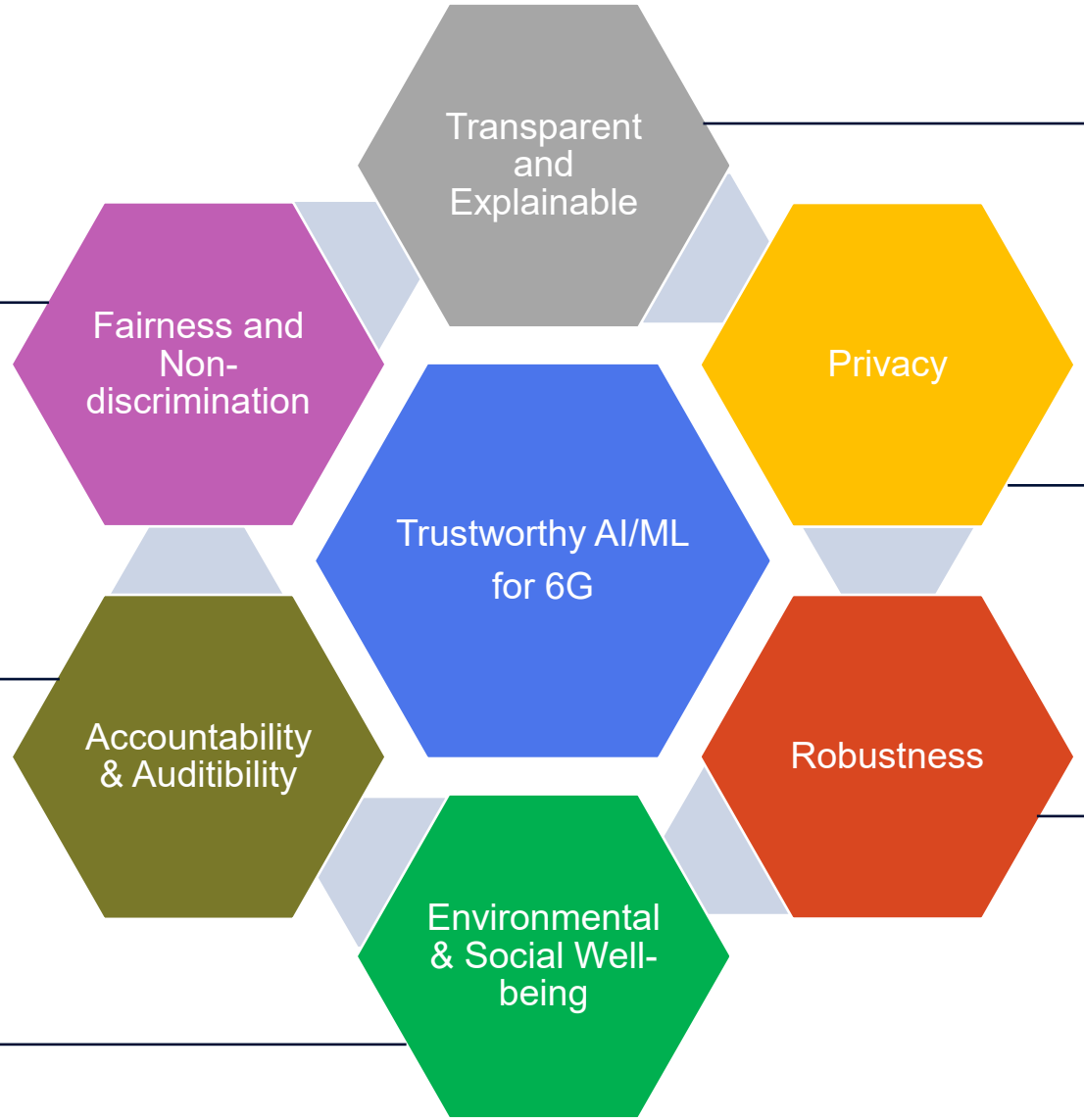




Neutral and bidirectional

- Trustors may select services based on customised and on-demand security requirements
- Trustees may get some notion of how well a service complies with security requirements

Trustworthy AI/ML for 6G



Fair AI

- AI systems should not lead to any kind of discrimination in relation to race, religion, gender, sexual, ethnic, origin or any other personal condition.

Transparent and Explainable AI

- The traceability of AI systems should be ensured.
- Certain level of understanding about the decisions taken by an AI system.

Privacy-preserving AI

- AI systems should avoid leaking any private information.

Responsible AI

- AI system should be assessed by a third party and, when necessary, assign responsibility for an AI failure.

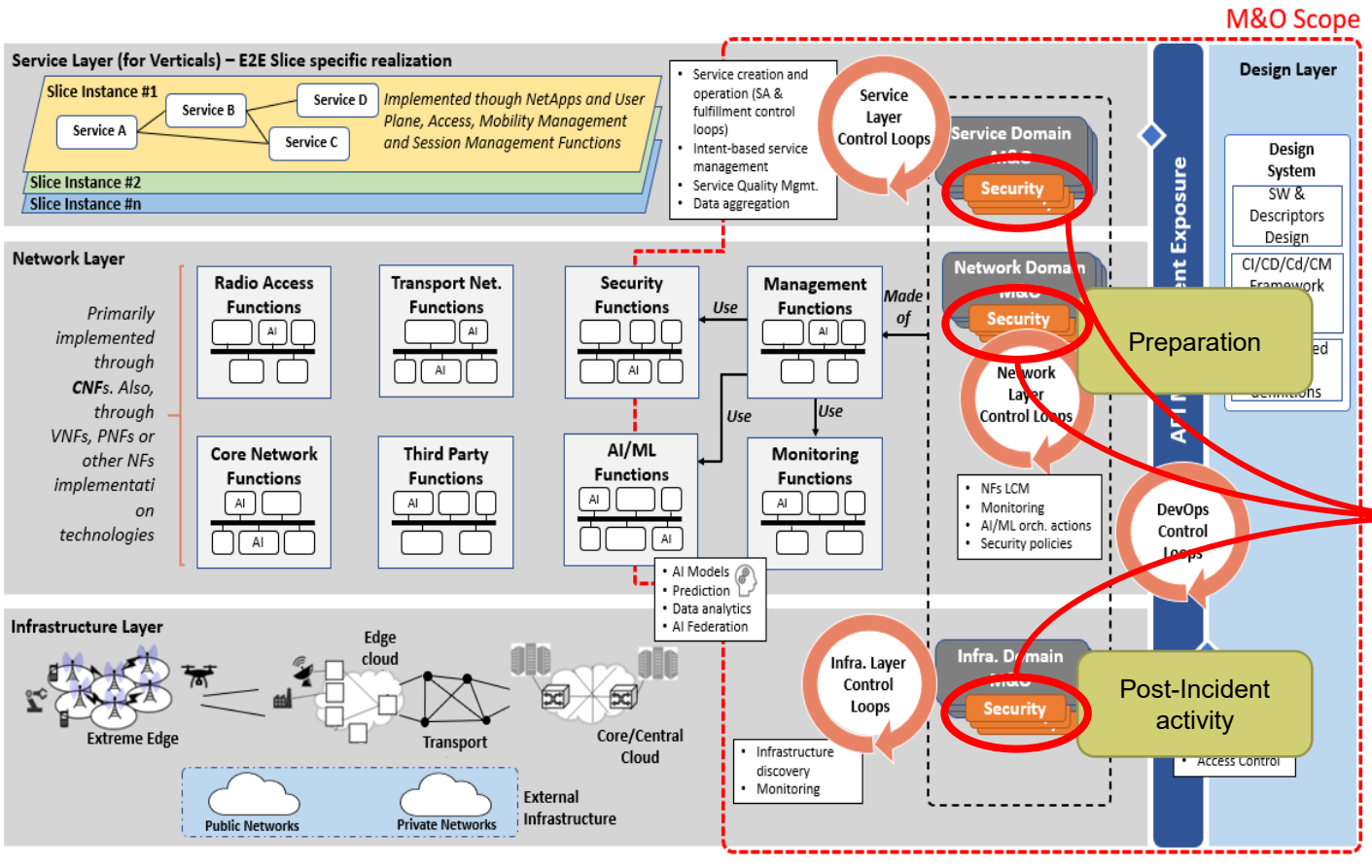
Robust AI

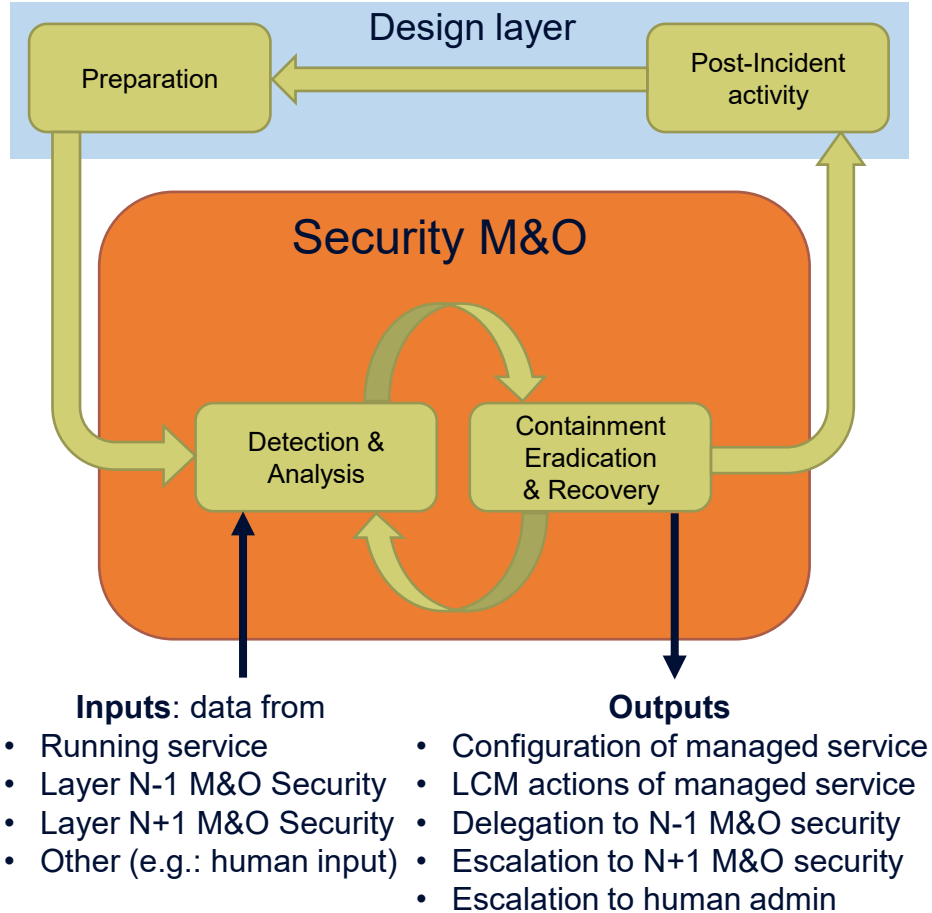
- AI system should be robust to adversarial perturbations of inputs.
- AI should make secure decisions.

Environmental & Social Well-being

- AI system should be sustainable and environmentally friendly.

M&O Considerations





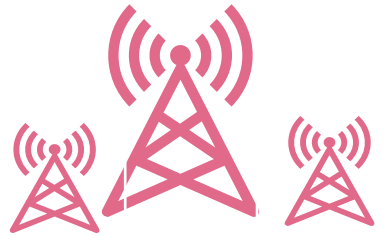
Inputs: data from
- Running service
- Layer N-1 M&O Security
- Layer N+1 M&O Security
- Other (e.g.: human input)

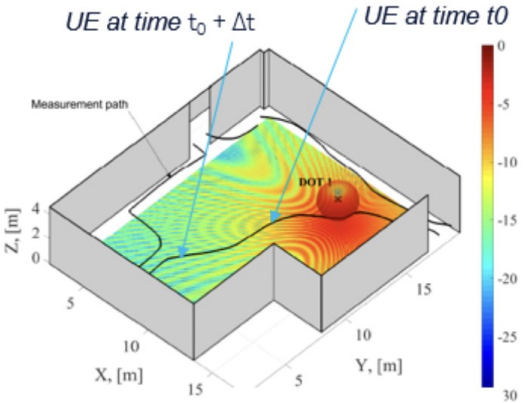
Outputs
- Configuration of managed service
- LCM actions of managed service
- Delegation to N-1 M&O security
- Escalation to N+1 M&O security
- Escalation to human admin

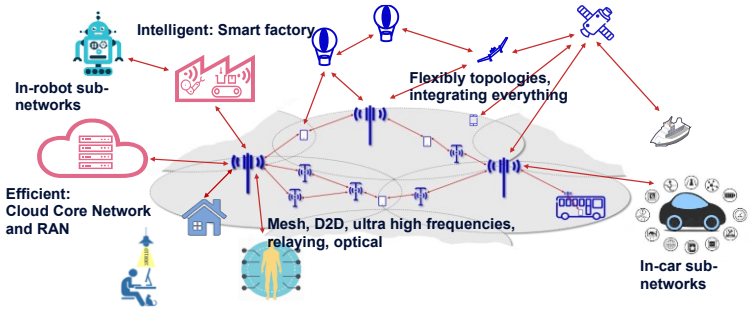
- M&O architecture is ready to handle security requirements
- Cybersecurity guidelines can be applied through this architecture to enhance security
- The architecture allows the automation of security processes to improve efficiency

Other Security Considerations

- D-MIMO requires enhancements to security procedures
  - Allowing UEs to establish and maintain multiple security associations to multiple access points in the network
  - More complex, and diverse fronthaul networks will be required, probably more physically exposed
- 6G localization and sensing implies specific security and privacy scenarios
  - Threats on the physical layer require dedicated and suitable protection measures
- The considerations on architecture evolution imply an integral edge cloud continuum
  - Requirements on attestation and trusted execution
  - Specific evaluation of functional isolation







Summary and Way Forward

- Security in networking is an activity required to work both horizontally and vertically
  - Across different network segments and domains to address E2E properties
  - Addressing the different planes and layers and their interactions
- The Hexa-X security work has analyzed the *6G security delta*, with special emphasis on
  - The architectural mapping of security components
  - The impact of security and privacy network service trustworthiness KVI
  - The assessment of trustworthiness through measure and evidence
  - The importance of data trustworthiness in evidence-based network management
  - The requirements and technologies for a trustworthy application of AI
  - Other specific 6G security aspects identified during the project
    - Related to D-MIMO, location services, functional isolation, etc.
- These considerations set the ground for further development of 6G security procedures
  - Early experimentation is required, as technologies consolidate

Spectrum evolution aspects

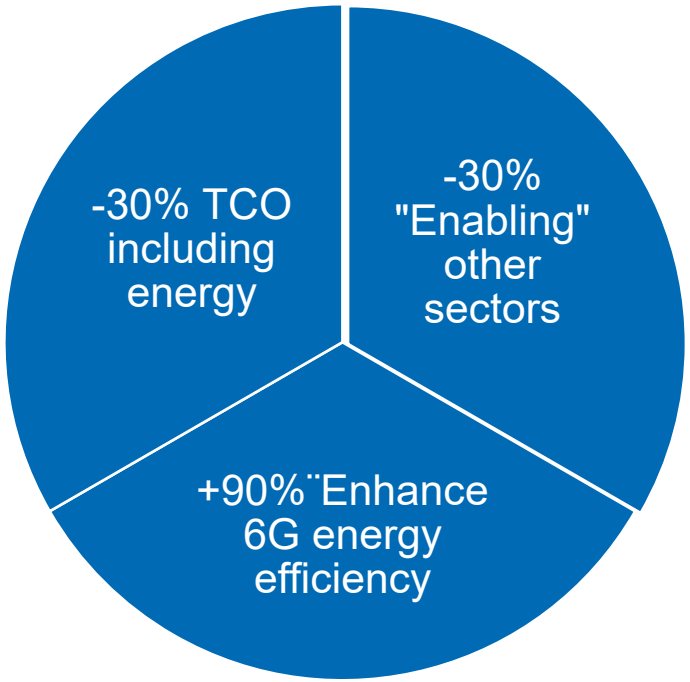
Main topics - Summary

- Extend spectrum utilisation to new frequency bands
  - Traditional frequency ranges (low, mid, and mm-wave) already in use + new potential bands in 7-15 GHz range
  - New frequency bands in the sub-THz range
- Enhancements to further optimise spectrum utilization
  - Distributed MIMO and advanced carrier aggregation for 3GPP technologies
  - 6G “Networks in Network” (NiN) concepts for interference-controlled operation in shared spectrum scenarios
- Use of AI/ML for e.g.,
  - Throughput and spectral efficiency improvement
  - AI-assisted spectrum sharing in non-wide area networks scenarios
  - Spectrum (and computing) resources dynamic orchestration in edge cloud server offloading
  - Digital-Twin-based human presence model for flexible and dynamic spectrum management at high frequencies (mm-wave, sub-THz, and above)
- Overview on initiatives to enable new spectrum for mobile, complemented by a set of additional high-level spectrum-related elements that were deeply considered at both Task and Project levels

Sustainability targets

Hexa-X project sustainability targets

- For environmental sustainability, the analysis reveals a tenfold (x10) enhancement in 6G Energy Efficiency (EE) corresponding to 90% improvement compared to 5G NR system.
- The assessment methodology of the Total Cost of Ownership (TCO) for financial sustainability shows that 6G networks will achieve almost 30% reduction of TCO compared to 5G.
- The enablement potential of ICT solutions in 6G-powered industries is estimated around 30% GHG emissions reductions compared to 5G.
- Conclusive outcomes regarding the sustainability assessment of ICT solutions, and considerations.
- A comprehensive analysis of the enablement potential evaluation methods.



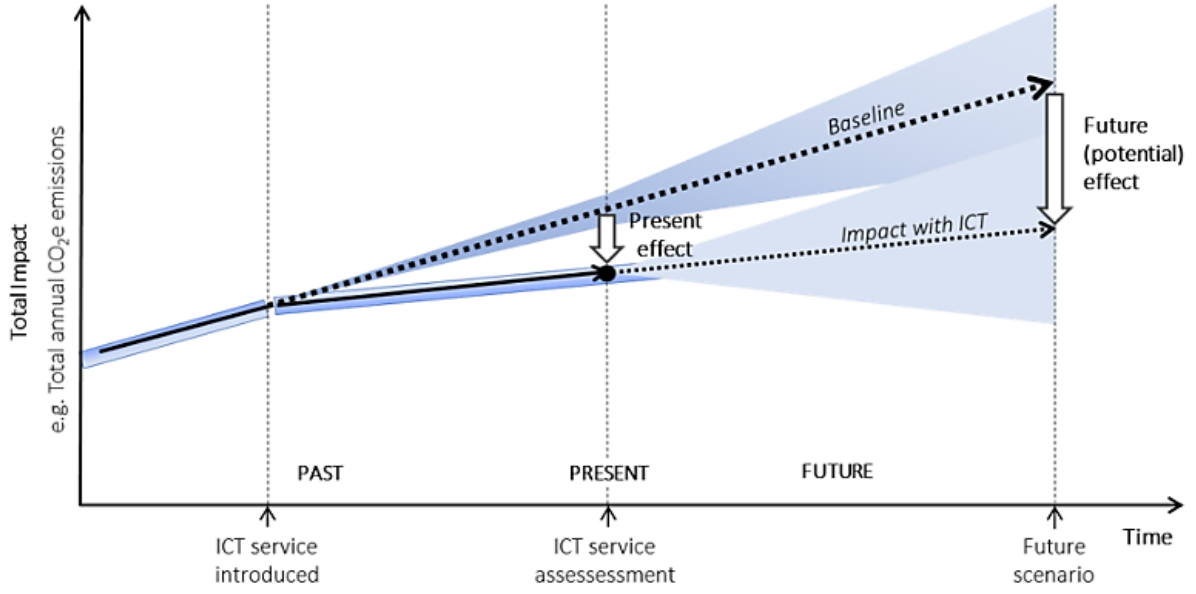
6G levers for improving energy efficiency

- 6G targets to enhance Energy efficiency (EE) by a factor 10 (i.e., 90% reduction in energy consumed per transported data unit (Wh/bit) in the RAN perimeter), following the trend observed for previous generations.
- Energy Efficiency Improvement Factors:
  - RF power amplifier improvements for FR1 bands (targeting 20% improvement) and efficient sleep mode implementation for FR2 and sub-THz bands
  - Electronic components efficiency aiming for 100-1000 EE improvement at the elementary computing unit
  - Utilizing Artificial Intelligence, multi-goals optimization, and adaptive air interface for energy savings (-20% target) while maintaining QoS
  - Sleep modes and network orchestration design considerations for enhanced efficiency without compromising QoS
  - Path loss reduction techniques such as precise beamforming and network densification to reduce energy waste and interference
  - Infrastructure sharing solution for improved coverage, capacity, and OPEX savings (estimated 30% EE improvement and energy consumption saving)

Levers	Targeted EE Improvement	Improvement Factor by 2035 (30% traffic load)
Spectral efficiency	+20% band FR1 +100% band on FR2	1.2 2*
Infra. Network Sharing	30%	1.3
PA technology	20% (in FR1)	1.2
Signal / Baseband Processing (Semiconductors, circuit architecture)	50%	1.5
QOthers techno independent from 6G (e.g., cooling)	10%	1.1
6G Sleep Modes (micro DTX, mMIMO muting, cell switch off)	30%	1.3
AI, multi-goals optimization and Agile air interface	20%	1.2
Adaptive architecture (RAN acceleration, Centralization, densification)	Up to 40%	1.4
Reduced pathloss (D-MIMO, RIS…)	Local deployment	1 (no estimation)
Total potential		between 7 and 11 improvement factor

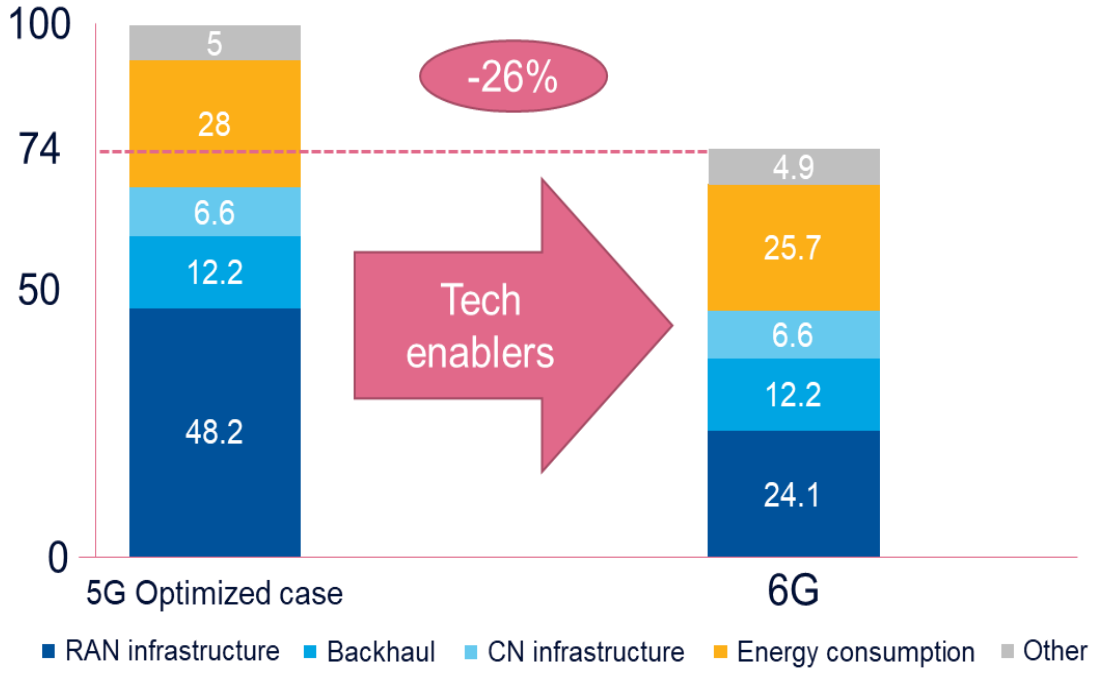
Enablement potential of ICT solutions

- Assessing enablement effects is based on a comparison between a scenario with a 6G-powered ICT solution, and a reference situation with a reference activity not powered with 6G.
- ICT solutions have the potential to help other sectors reduce GHG emissions by almost 30%.
- ICT Assessment methods for enablement include first, second and higher order effects.
- Applicability of ITU-T L1480 assessment method is provided to two 6G use cases: Fully automated factory and Remote maintenance.



Total 6G network TCO reduction

- Technological enablers have the potential to reduce the 6G network TCO.
- The potential weight of each cost item when applying the two technical enabler families, results in 26.4% reduction of the total 6G network TCO compared to 5G NR SA.
- This study only considers two out of the four enabler families that impact the cost items; thus, it is reasonable to expect that the 30% TCO reduction target is provable by future research.



Thank you!

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