RSPG subgroup’s 6G hearing
Sept 27th 2024

Update from European 6G Flagship Hexa-X-II

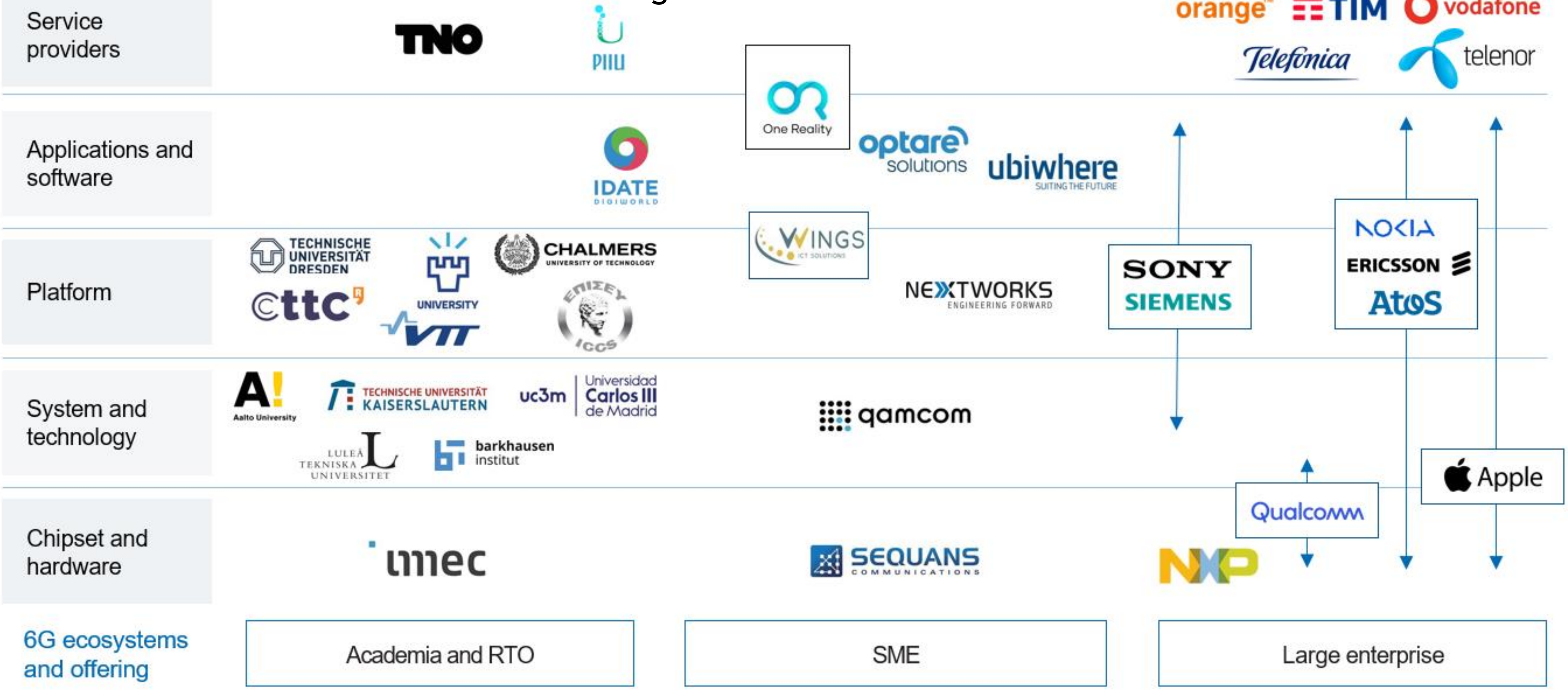
Mikko.Uusitalo
@nokia-bell-labs.com





Hexa-X-II European 6G Flagship
Consortium covering the entire value stack

- Nokia is overall leader
- Ericsson is technical manager



Overall objectives of Hexa-X-II

A holistic flagship towards the 6G platform and system

to inspire digital transformation for the world to act together in meeting needs in society and ecosystems with novel 6G services

Hexa-X

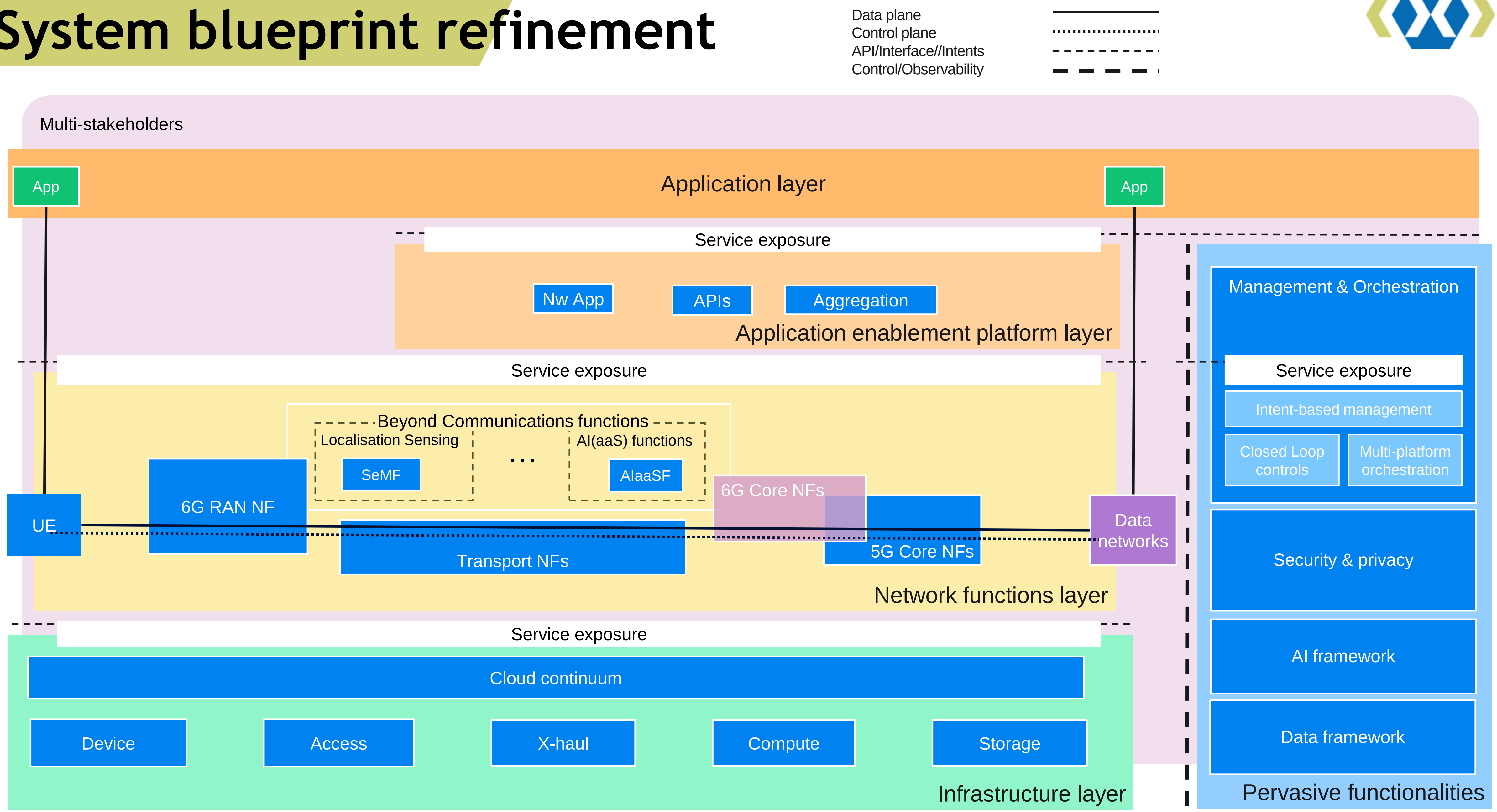
Hexa-X & Horizon-2020 candidate enablers →

HEXA-X-II

- 6G use cases, services, and requirements → Value for society
- 6G system blueprint and platform → Global dissemination impact
- 6G technology readiness → Strategic autonomy

↑ SNS stream B projects

System blueprint refinement



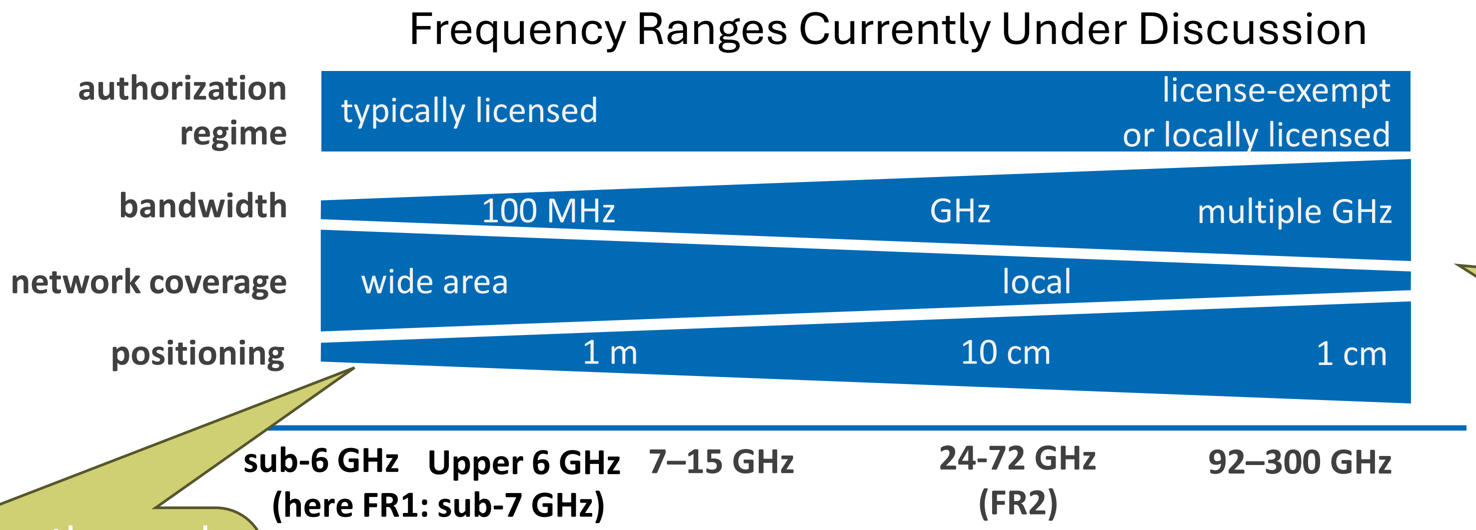
#2 - Use cases for future spectrum needs

6G goals for spectrum use

Hexa-X-II, D1.1

Provide additional capacity	• Enhance current mobile communication by providing more capacity while re-using existing base station grid, reducing the cost of identifying, acquiring, and deploying additional base station sites by operators.
Support high data rate services	• New services, such as extended reality (XR) and holographic presence, require larger bandwidths, which are typically easier to find in mid and high frequency ranges.
Support mobility	• Most applications of mobile communications need mobility. Mobility requirement may be combined with requirement for high data rates. Consequently, spectrum needs to support high data rates and continuous coverage required for mobility.
Support wide area coverage	• Making 6G inclusive implies that 6G is available everywhere. For wide area coverage, lower frequency ranges are more suitable. In addition, non-terrestrial networks might be a supplement to wide area coverage provided by terrestrial networks in sparsely populated and underpopulated areas.
Provide indoor coverage	• Increasing volumes of indoor mobile data can be supported by 1) outdoor to indoor coverage from outdoor base stations in low and mid frequency ranges and/or 2) Indoor to indoor coverage with indoor radio solutions in higher frequency ranges, noting the propagation limitations of higher frequencies.
Service continuity	• Seamless continuation of connectivity travelling across e.g., outdoor-indoor, urban-rural, private-public situations.
Enable positioning and sensing	• In general, higher frequency ranges imply more accurate positioning and sensing.

Overview of considered frequency bands and spectrum authorization regimes



The closer to currently used frequency bands, the greater the possibility of reusing existing base stations grids.

The higher the frequency, more bandwidth and better positioning accuracy.

General statement on use cases and spectrum:
Spectrum allocations are derived from use cases, and spectrum capabilities and current authorization regimes

- **Wide area use cases →** continue with exclusively licensed spectrum
- **Use cases: indoor, local**, high bandwidth, position accuracy
  → reduced need to license nationwide spectrum in the sub-THz range

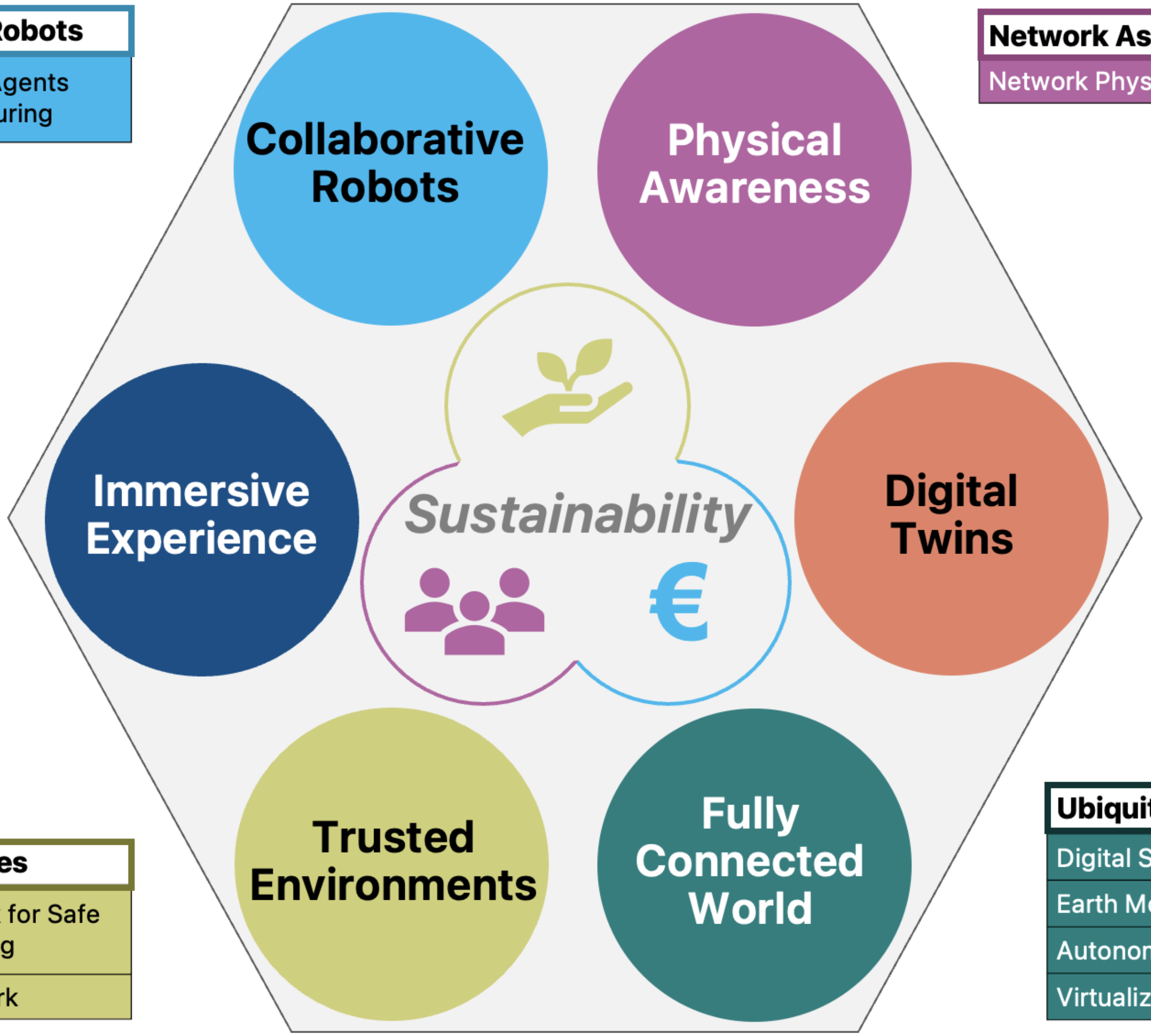
Spectrum affects the 6G radio and network design, which again depends on the foreseen use cases.

Hexa-X-II Use Case Families

Cooperating Mobile Robots
- Autonomous Embodied Agents Within Flexible Manufacturing

Network Assisted Mobility
- Network Physical Data Exposure

Seamless Immersive Reality
- Immersive Education
- Immersive Gaming
- Live and Interactive Immersive Content Creation



Realtime Digital Twins
- Cloud Continuum
- Smart Maintenance
- Digital Twins (Building Model)

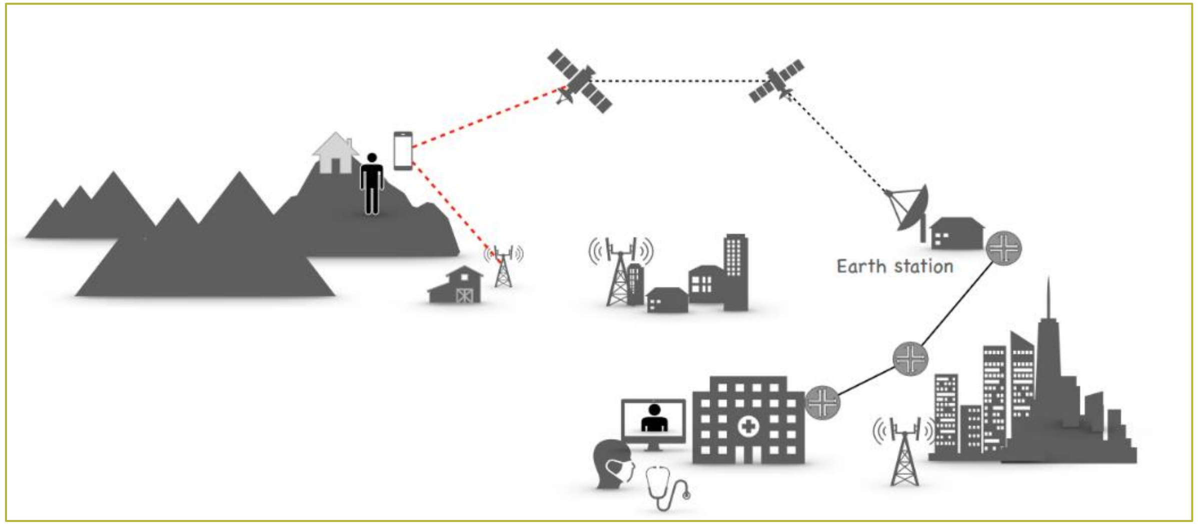
Human-Centric Services
- Industrial Sensors Network for Safe Production & Manufacturing
- Wireless In-Vehicle Network

Ubiquitous Network
- Digital Sobriety and Enhanced Awareness
- Earth Monitor, Sustainable Food Production
- Autonomous Supply Chain
- Virtualization of Device Functionalities

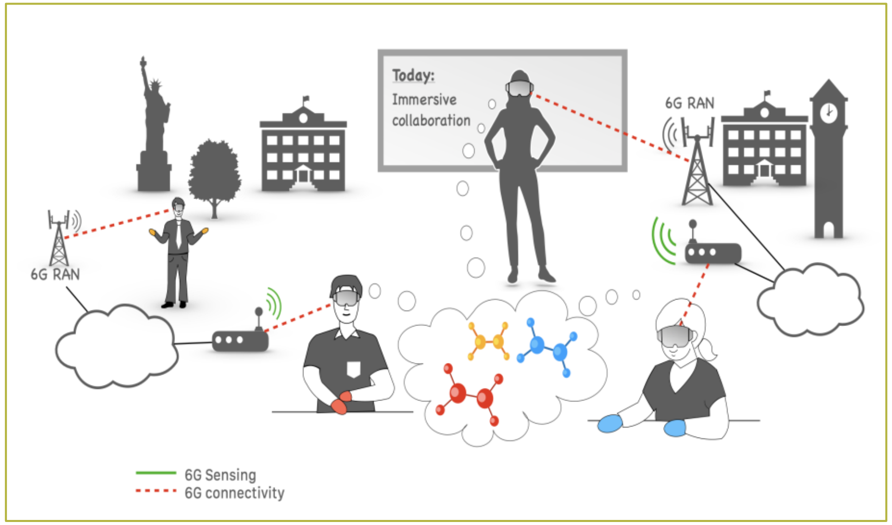
Hexa-X-II Use Cases with Highlighted Representative Use Cases

Spectrum implications of use cases - Example 1

More outdoor usage:
Ubiquitous Network use case



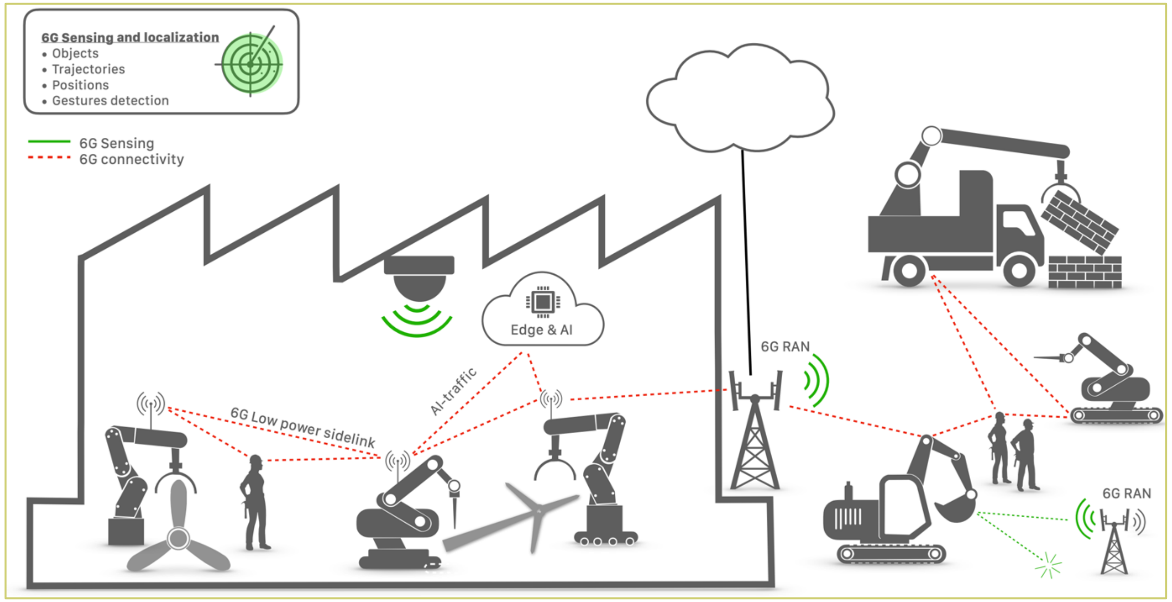
More indoor usage:
Seamless Immersive Reality use case



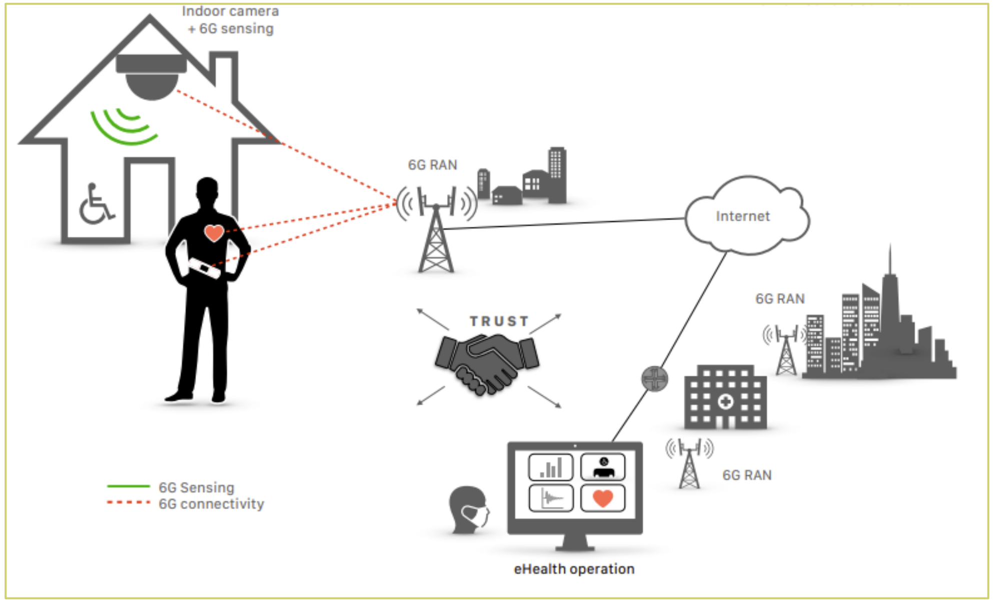
Some Hexa-X-II use cases are more outdoor than indoor

Spectrum implications of use cases - Example 2

Cooperating Mobile Robots use case



Human-Centric Networks use case



Some Hexa-X-II use cases require service continuity, i.e., private and public network and spectrum interoperability

Hexa-X-II, D1.2

Spectrum implications of use cases

- Deployments of use cases within specific frequency ranges depend on ***technical and non-technical aspects*** such as license availability.
- To achieve reliable nationwide-area coverage, which is specifically important for representative *network-assisted mobility* and *ubiquitous network* use cases, **low-band spectrum is essential, preferably below 1 GHz.** This can be supplemented by non-terrestrial network (NTN) systems in sparsely and underpopulated areas.
- Since achievable data rate and capacity in low frequency band deployments is limited, **higher frequency bands in FR1 (sub-7 GHz) will be needed, including the upper 6 GHz band, as well as new bands in the 7-15 GHz range**, which would supplement low band deployments to achieve the needed capacity for both existing and new use cases, for instance in urban and sub-urban environments. The lower the frequency within 7-15 GHz, the better (e.g., **7/8 GHz**).
- For use cases in confined areas like *cooperating mobile robots* and *human-centric services*, **small-cell deployments** could be used.
- Additionally, **FR2 (24-72 GHz), or local sub-THz deployments,** which is still being researched, can be used to meet even higher data rate and capacity requirements, however with limited coverage.

Hexa-X-II D1.2.

6G spectrum ecosystem stakeholders, roles and motivations

Telecom operators (mobile network operators)	• 6G is expected to be deployed in the same frequency bands as earlier generations. Nationwide area coverage can be achieved using sub-GHz (below 1 GHz) spectrum while spectrum in the 1-6 GHz range as well as new bands (e.g., Upper 6 GHz and 7/8 GHz (or parts thereof)) can be used for coverage and capacity and can re-use existing base station grids.
Stakeholders deploying private networks and specific purpose networks	• Public-network-integrated non-public-networks (PNI-NPN) might share RAN and spectrum with the public network. • Stand alone non-public networks (S-NPN) are often deployed in dedicated spectrum (3.8-4.2 GHz).
Network vendors, software vendors and/or system integrators	• Expected to meet different network deployments (e.g., "global" or local) and the variety of operator models that can emerge.
End user equipment manufacturers	• Devices are likely to include a multitude of wireless technologies. • Regional and global harmonization will benefit the 6G ecosystem as scale will be bigger, bringing costs down.
Incumbent users	• There is a variety of primary incumbent services, in the potential new frequency bands envisaged for 6G and will need to be considered accordingly.
Regulators	• Enablers of 6G market emergence by making spectrum available for 6G and assigning spectrum access rights.
Building owners	• Drivers for indoor coverage demands and potential investors for indoor network solutions, which in turn are linked to deployed frequency ranges and spectrum access mechanisms.
Neutral hosts	• Build and operate (indoor) radio networks and rent capacity to network operators. Deployment choices affect spectrum use

Hexa-X-II, D1.1

#4 – Role of private networks in 6G

#4 – Role of private networks in 6G

On stakeholder roles in future 6G business ecosystem:

- ***Stakeholders deploying private networks and specific purpose networks*** include telecom operators and others. Public-network-integrated non-public-networks (PNI-NPN) might share radio access network (RAN) and spectrum with the public network. Stand-alone NPN (S-NPN) are often deployed in dedicated spectrum (e.g., 3.8-4.2 GHz) or via spectrum leasing. Further spectrum made available for 6G will also be of interest for such use. For spectrum above 100 GHz, the very short communication ranges potentially allow reuse of the same spectrum in the same area.
- ***Building owners demand indoor coverage*** in their home, office, factory, or other building even where coverage from outside public mobile networks is a challenge. Because they see indoor coverage as crucial, they are also prepared to invest in Wi-Fi networks, ***private networks***, or indoor cellular solutions. Which of the available solutions these building owners chose determines the deployed frequency range and spectrum access mechanisms.

#5 - Role of license exempt spectrum

Role of license exempt spectrum

- Overall, unlicensed use of spectrum presents a ***lower hurdle for operations*** by end users and small or private networks.
- The higher the frequency range, the more bandwidth is usually available and can reach up to multiple contiguous GHz at sub-THz frequencies. However, due to the physical constraints in RF propagation, sub-THz will target highly localized use cases. As a result, this minimises the need to license spectrum nationwide in the sub-THz range. ***A license-exempt regulatory framework may be more appropriate in the sub-THz range***.

Hexa-X-II D1.1.

#7 - Sustainability and Security

6G use case sustainability assessment framework in Hexa-X-II with general example considerations

Hexa-X-II D1.2.

	Positive impacts/handprints/benefits	Negative consequences/footprints/costs
Environmental sustainability	• Reduced use of natural resources • Reduced emissions	• Increased electronic waste • Increased energy consumption
Social sustainability	• Access to digital services • Enhanced opportunities • Enhanced safety and well-being	• Potential digital divide • Potential risks for trustworthiness
Economic sustainability	• Reduced costs • Improved efficiency/productivity • New business opportunities • Improved economic resilience	• Equipment cost affecting profitability • Massive initial investments

6G sustainability and environmental issues implications on spectrum management

Environmental sustainability:

- It is not so that any frequency bands, by nature, are more climate friendly than others, but it points to issues like ***tower/network grid sharing***, ***suitability of certain frequency bands for indoor/outdoor coverage and capacity*** **and** ***contiguous bandwidths*** instead of aggregating multiple narrower bandwidths from separate frequency bands as **factors to reduce energy consumption** (and carbon footprint) through equipment operating more energy efficiently.
- ***The closer to currently used bands***, the greater the possibility of reusing the existing base station grids and the ***lower the number of required new sites***, costs and power consumption for delivery of services.

Hexa-X-II D1.1.

6G sustainability and environmental issues implications on spectrum management

Economic sustainability related risks regarding spectrum:

- The ***potential lack of globally harmonized spectrum*** for 6G can lead to ***lost business opportunities and increased cost*** in different use cases limiting the deployments.
- ***Potential local/national/regional differences*** in the way the spectrum is made available and priced could result in ***ecosystem fragmentation and thus increased costs***, less affordable solutions and lack of scaling.
- The potential ***restrictions about the way spectrum is managed in different regions/countries*** may risk the provision of the required capacity in the different use cases in 6G devices ***not achieving economies of scale*** in production.

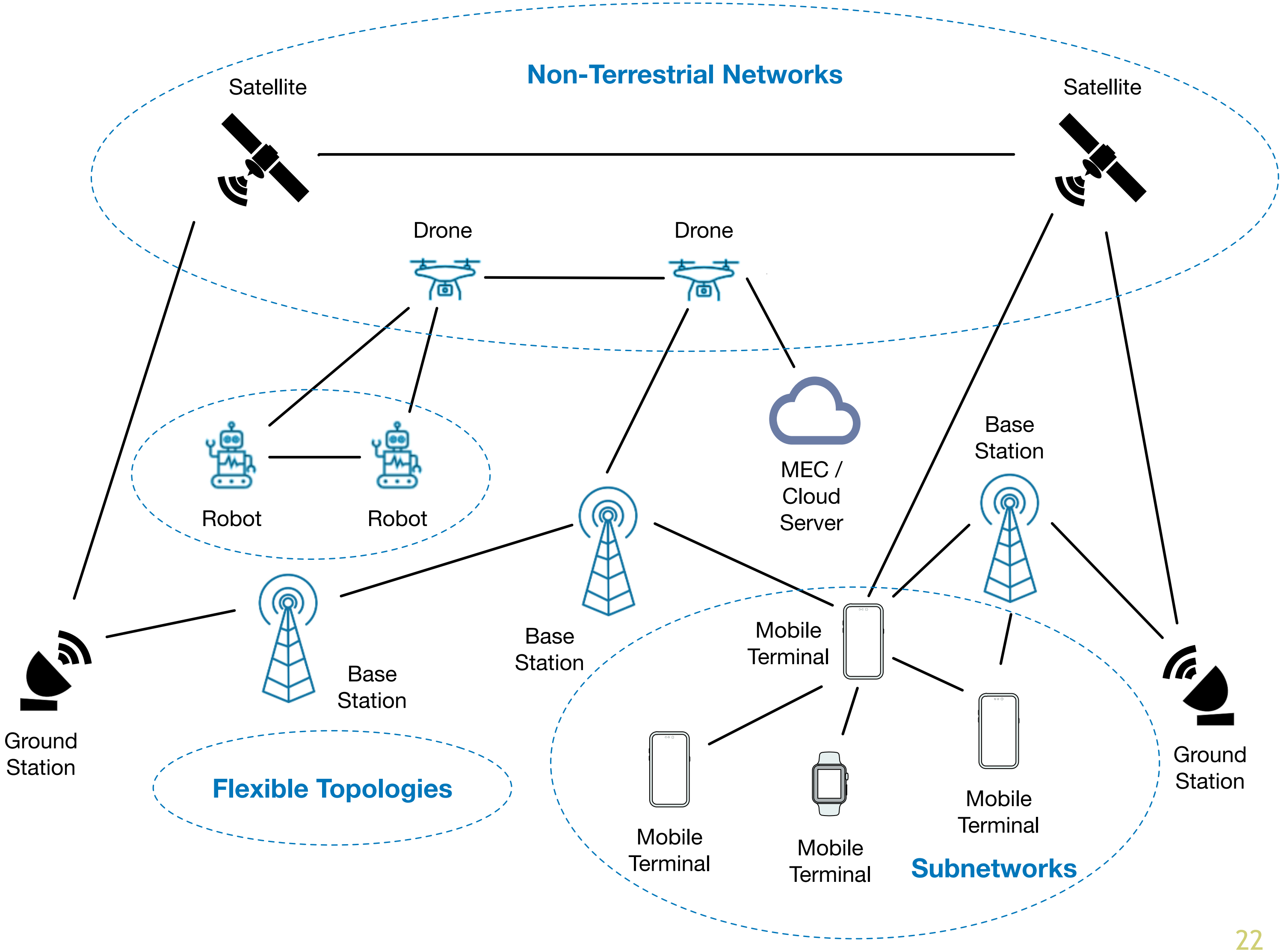
➢ The mitigation strategy for this is to ensure timely availability of new harmonized regional or global spectrum for 6G use across low/medium/high frequency bands to facilitate the economies of scale for development of 6G ecosystem for 2030 target deployment.

Hexa-X-II, D1.3.

#7 - Hexa-X-II NTN view

Introduction
Hexa-X-II Network of Networks paradigm

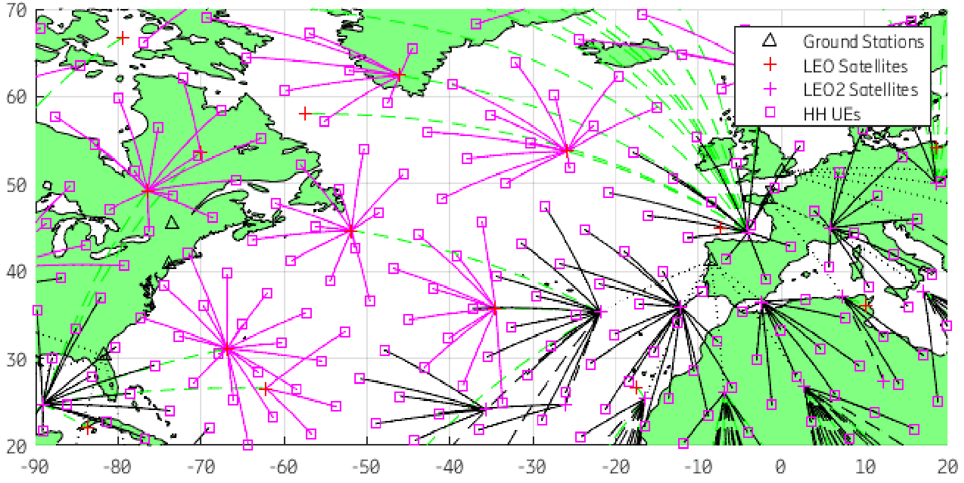
- Interconnected networks, each with its own unique characteristics and capabilities, that function as a unified, larger network
- Network of networks enables:
  - a seamless and ubiquitous communication system
  - integration of multiple subnetworks, including terrestrial, aerial and non-terrestrial nodes
- Work focuses on:
  - Subnetworks and NTN architecture
  - Management procedures and resource allocation frameworks
  - Prediction of future coverage developments

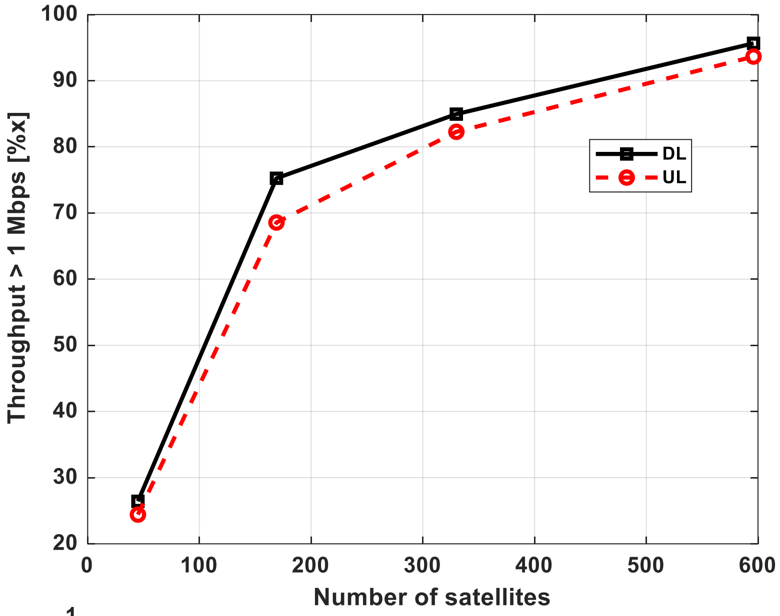


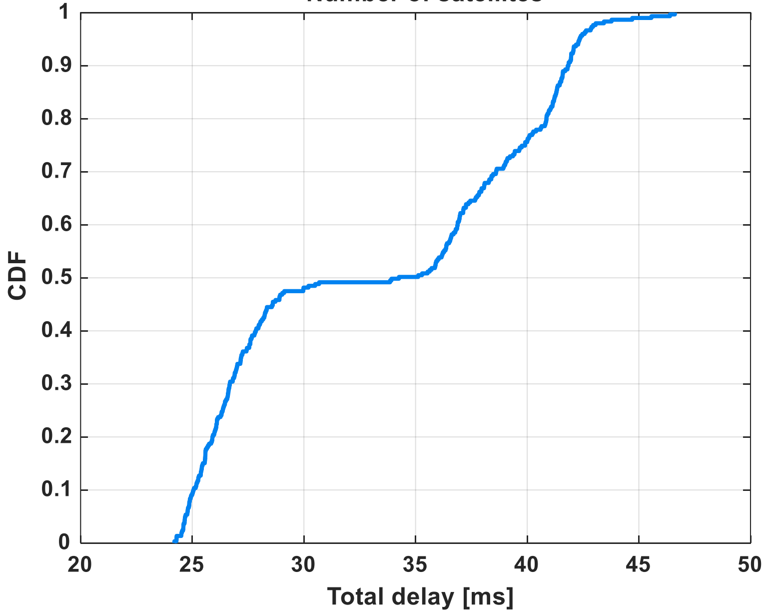
Introduction
NTN ocean coverage

- **Global service coverage evaluated in Hexa-X**
  - LEO deployment evaluated for Atlantic ocean coverage
    - Handheld (HH) device connected directly to the LEO Satellites
    - Inter-satellite-link (ISL) hops to provide coverage with adjacent path
    - Regenerative architecture assumed here
    - Very low traffic load per beam
    - Possible to achieve 1 Mbps for 99% of the users

Scenario 1; LEO Satellites and the handheld devices





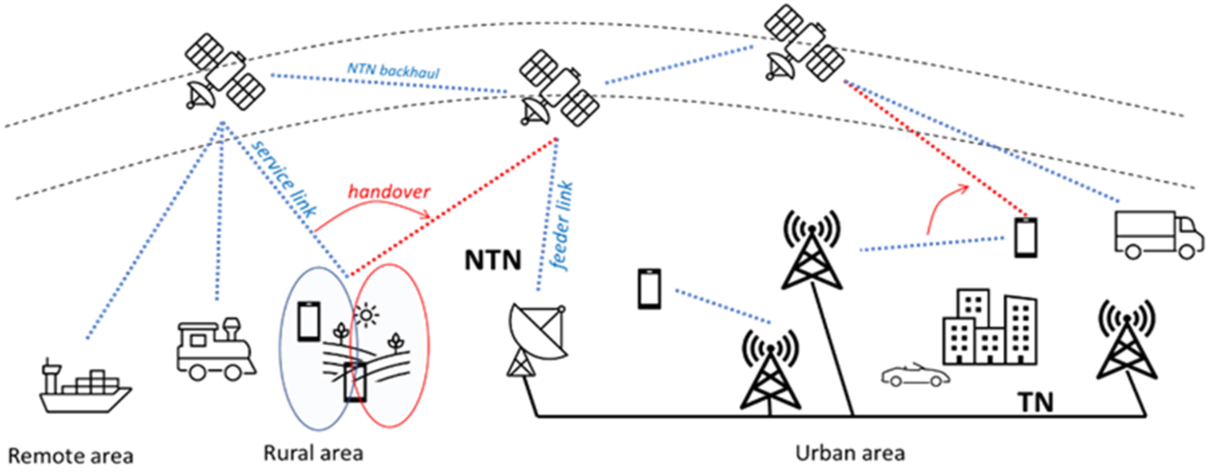


23

NTN mobility

NTN Mobility problems

- Interruption time due to frequent HO
- Large number of UEs may need to perform HO concurrently
- Handover signalling overhead

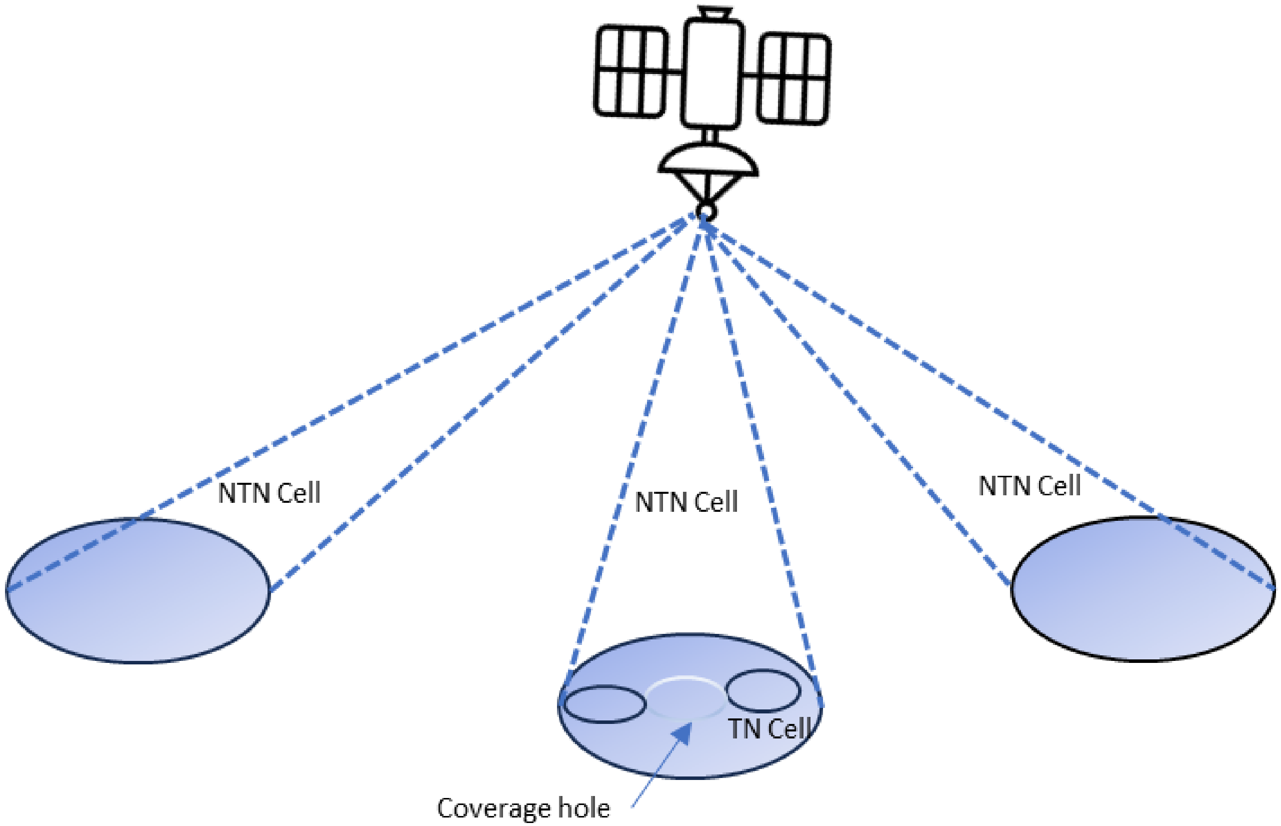


Possible solutions

- QoS-aware omission of HO common information
  - for sporadic data, delay tolerant traffic
  - + HO common info from SIB broadcasting during source/target cell overlapping time to ensure validity
- Random time-based handover
  - avoids overloading RACH
  - if not using RACH-less HO
- PCI change only (i.e., cell change without HO)
  - DAPS is complex for implementation at UE
  - PCI unchanged constraints soft switch

NTN mobility
NTN-TN global coverage and coverage holes

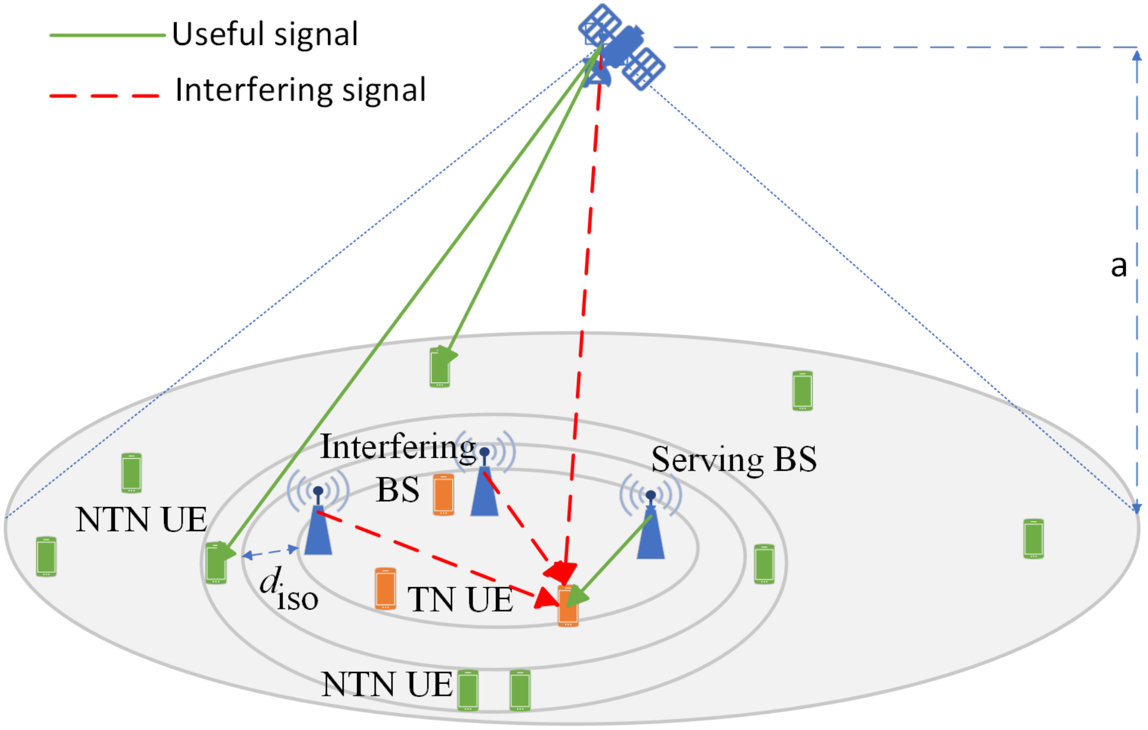
- As part of global coverage, user may stick to TN coverage as much as possible and NTN may be used to cover the TN coverage holes.
- Fast switch dual connectivity between NTN and TN can handle coverage holes and improve the (possible) interruption time
  - UE anchor/master could be TN or NTN cell
  - The TN and NTN links may have rather different latencies which may impact the connection negatively



NTN-TN Spectrum Sharing

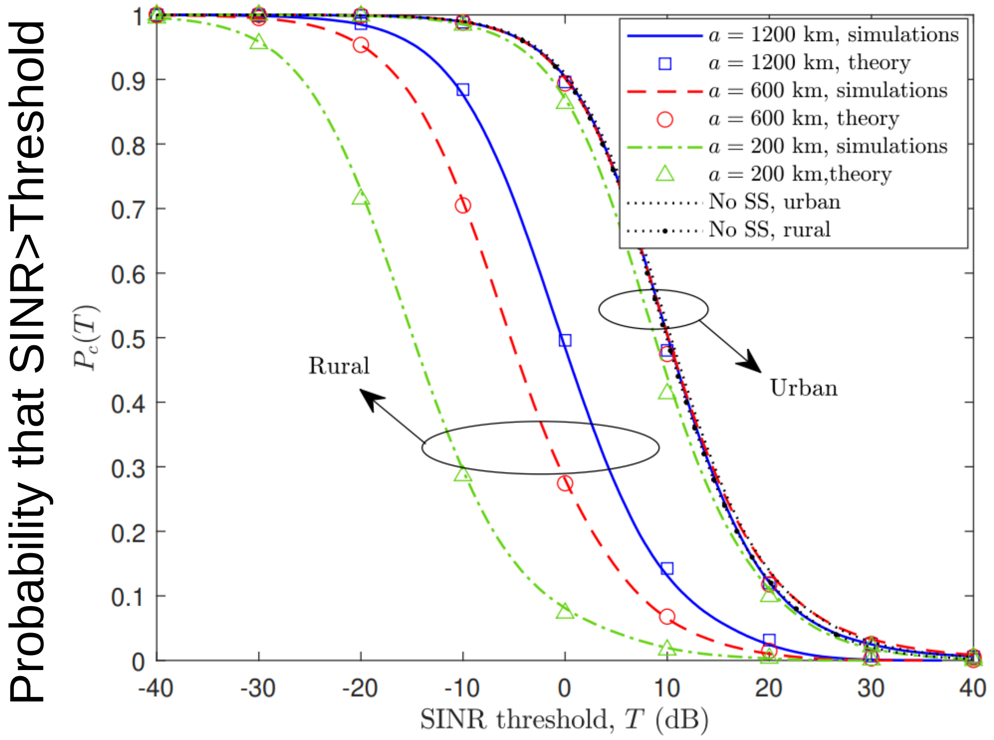
- NTN is already a reality
  - Direct to Device
  - Starlink, Kuiper, ASTMobile, OneWeb, Lynk, …

- Sharing and Coexistence studies started
  - Protection criteria, separation distance, maximum power



Performance study of TN-NTN integrated networks in S-band
NTN and TN share same spectrum (2 GHz band)

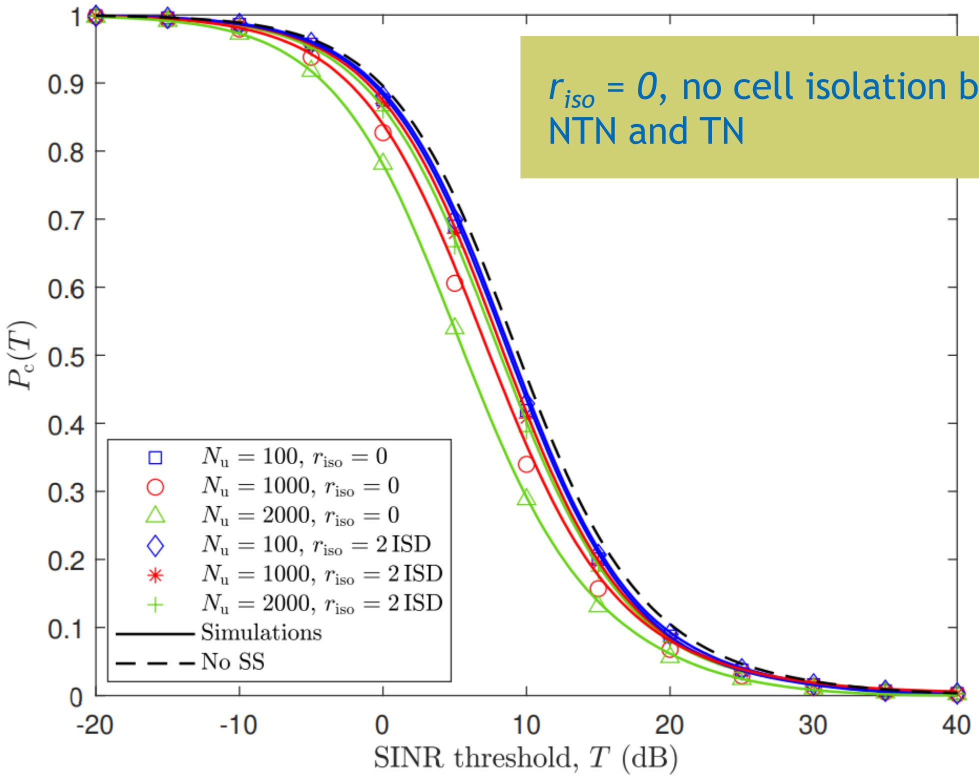
Downlink,
NTN DL interferes with TN DL



(a) 100% load.

The altitude of satellite an impact on TN rural area SINR

Uplink,
NTN UL interferes with TN DL



$r_{iso} = 0$, no cell isolation between NTN and TN

(a) 100% load.

[2401.08453] Co-existence of Terrestrial and Non-Terrestrial Networks in S-band (arxiv.org)

Conclusions and takeaways on NTN

- NTN can provide coverage with descent in remote areas such as Atlantic ocean
- NTN mobility can be further improved with various solutions to minimize overhead, signaling and interruption time
- NTN complementing TN coverage via a fast switch connectivity may improve coverage holes but is not without challenges

- Spectrum sharing in 2 GHz band (interference from NTN to TN)
  - Interference from NTN may not always be harmful to TN.
  - Interference from NTN can be harmful particularly for
    - Rural areas (larger ISDs) and
    - TN cell edge users
  - Separation distance and power limits must be defined

- Hexa-X-II standardisation efforts towards 3GPP RAN and ITU

- More details can be found in deliverables D3.3 and D4.3, https://hexa-x-ii.eu/

Hexa-X-II results from https://hexa-x-ii.eu/results/

- D1.2 – 6G use cases and requirements
- D1.3 – Environmental and social view on 6G
- D2.3 – Interim overall 6G system design
- D3.3 – Initial analysis of architectural enablers and framework
- D4.3 – Early results of 6G Radio Key Enablers
- D5.3 – Initial design and validation of technologies and architecture of 6G devices and infrastructure
- D6.3 – Initial Design of 6G Smart Network Management Framework
- Also presentations and videos from our workshops

Remember also: https://hexa-x.eu/insightful-new-book-on-6g-now-available/

HEXA-X-II

HEXA-X-II.EU //

Co-funded by the European Union

6GSNS

Hexa-X-II project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101095759.