Escola Politécnica da Universidade de São Paulo
Computer Engineering

Towards 5G/6G Networks: State of the Art, Evolution and Applications

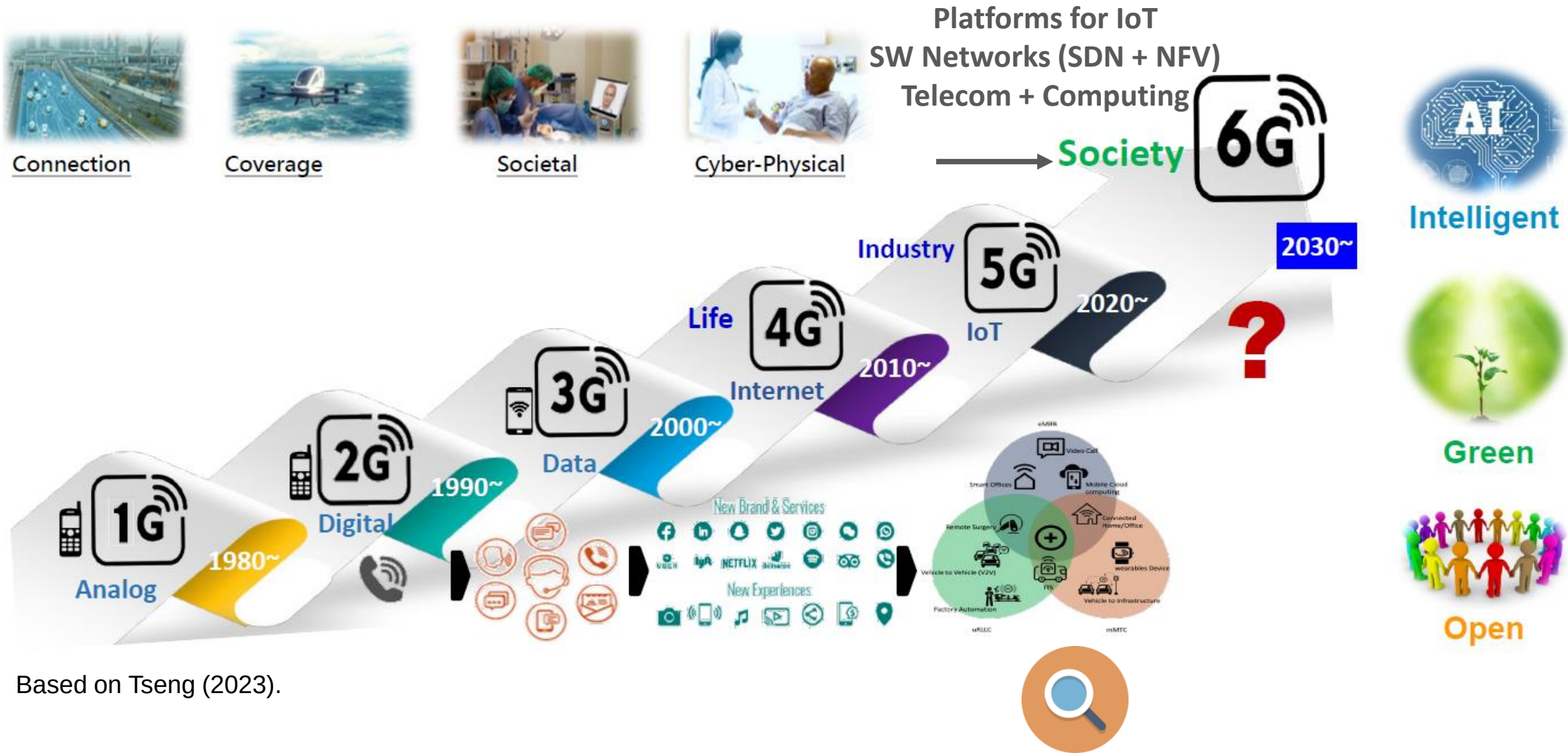
São Paulo, October 11, 2023

Agenda

- Introduction

- State of the art
- Trends in mobile networks
- What is 6G all about?
- Questions and Answers

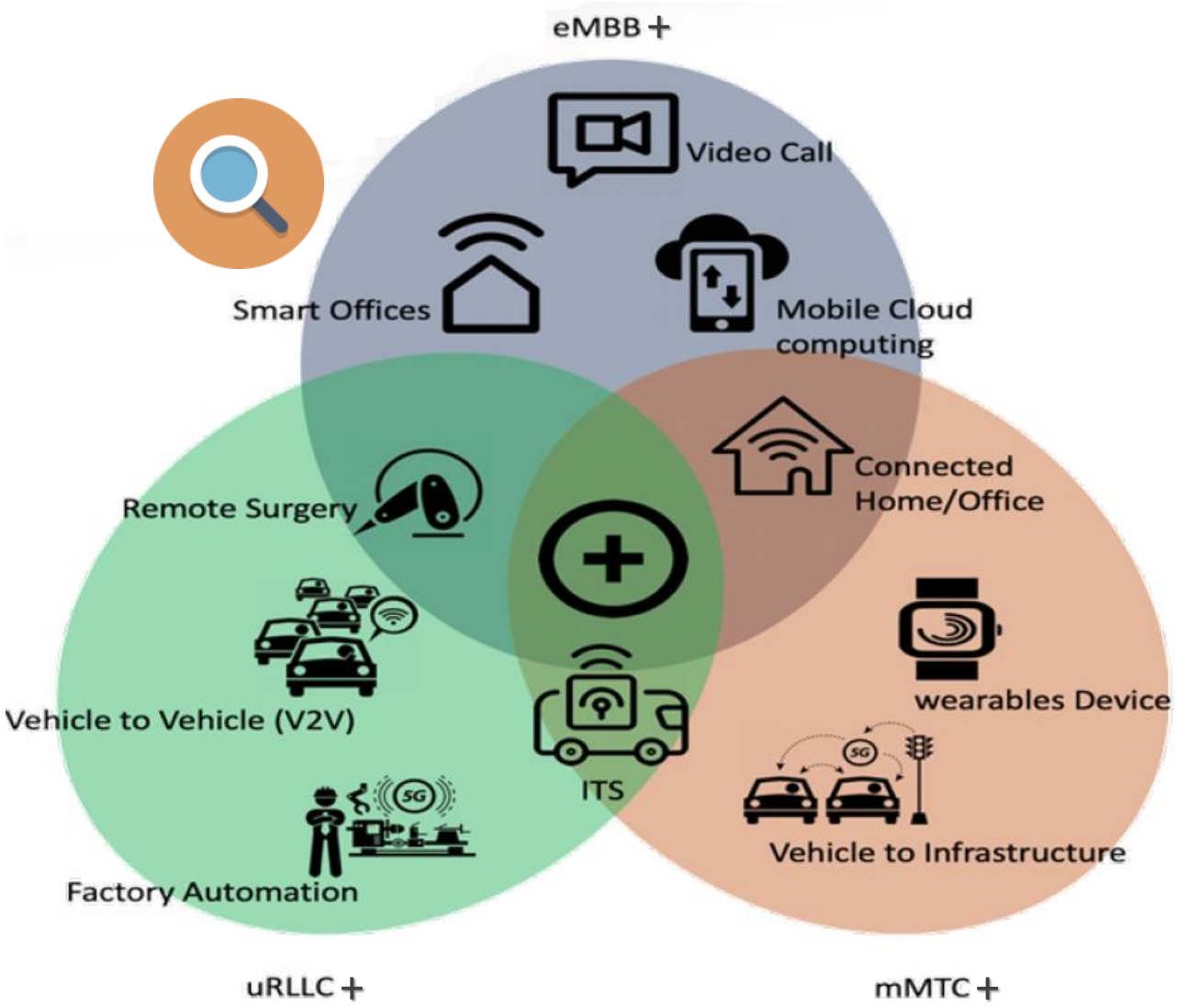
(R)evolution of mobile networks



Based on Tseng (2023).

Next: 4) Advanced use cases

Advanced use cases



Based on Tseng (2023).

Next: 5) Change how we live

Change how we live

Home-based patient care

Remote surgery and scanning

AI-enabled patient digital twin

Ambient assisted living

V2V and V2P safety improvement and awareness

Autonomous, coordinated and remote driving

Real-time 360° situational awareness

Leveraging EGE innovation for education

Metaverse experiences

Immersive knowledge and learning

Hologram receivers

Next Gen mission critical communications

AR headsets and glasses

Networked robots and UAVs

Connected ambulances

Based on Nawrocki and Next G Alliance (2022).

Next: 6) Change how we work

Change how we work

Factories of the future

AI-managed automatic guided vehicles

Massive sensors to manage environment and resources

Movement between farming and road infrastructure

High precision irrigation and fertilizer treatments

Massive sensing and remote actuation

Communications across mobile and NTN

Extreme connectivity

Tele-operation for hazardous environments

Use of digital twin replicas

High precision accuracy and tracking

Urbanization density and access to resources

Zero energy IoT devices

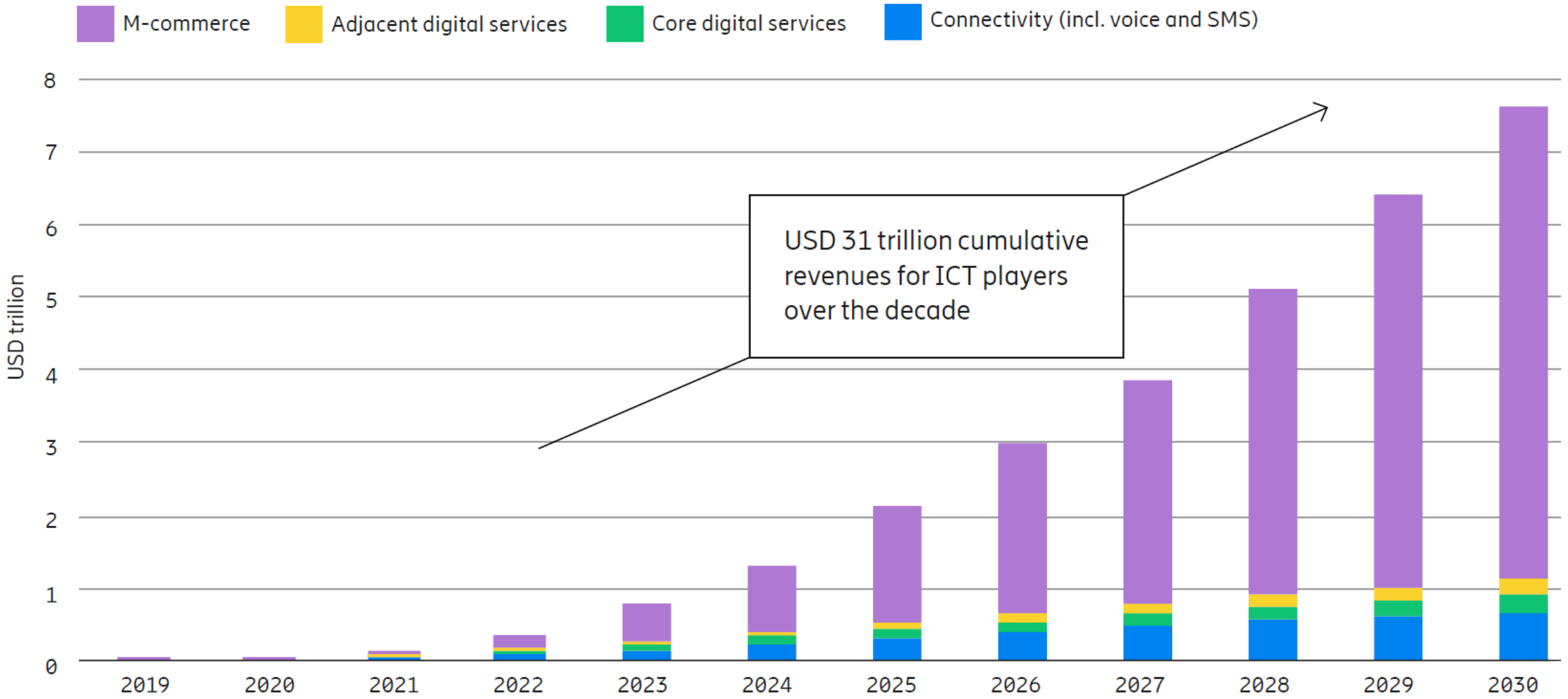
AI-driven data decision-making

Government-provided playing fields for 6G innovation

Based on Nawrocki and Next G Alliance (2022).

Next: 7) Global total 5G-enabled consumer revenues addressable market for ICT industry

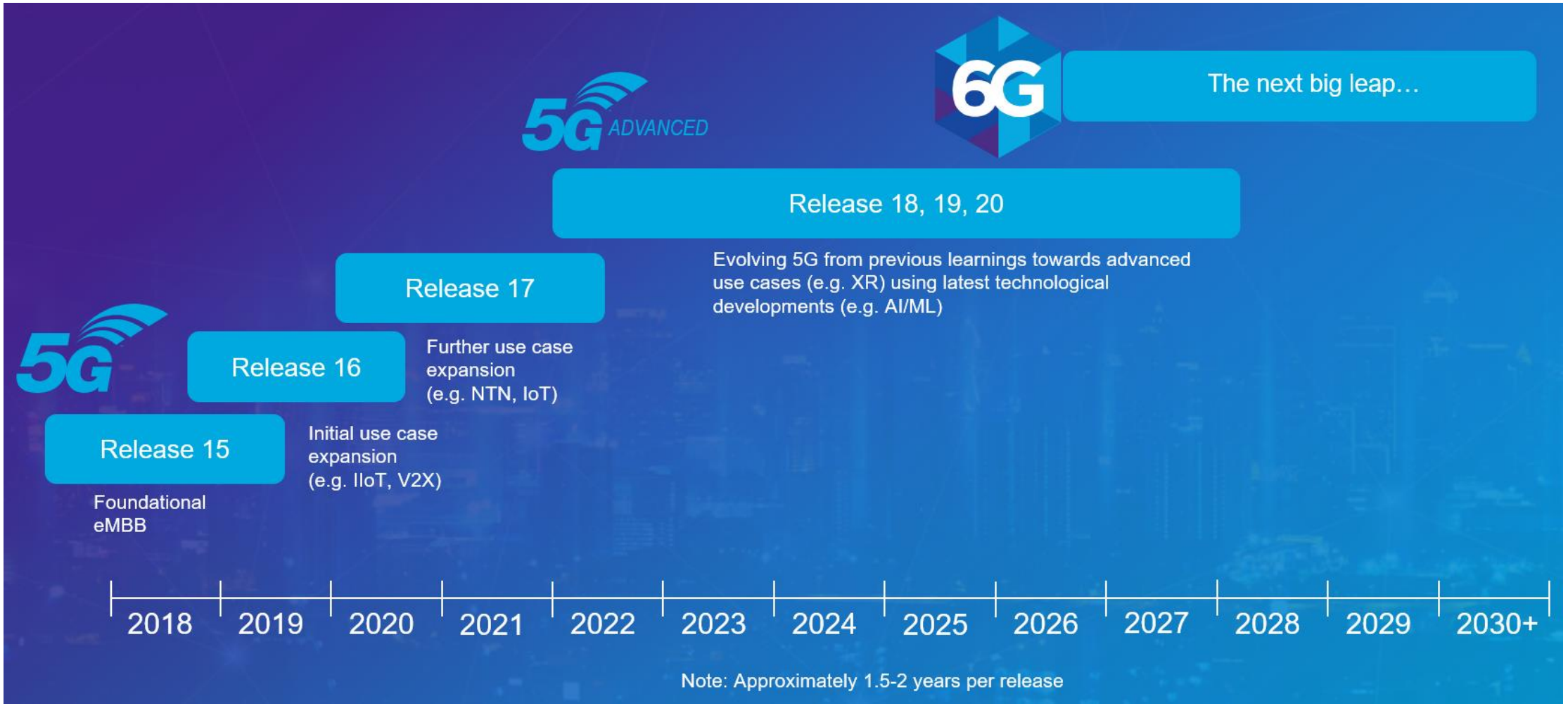
Global total 5G-enabled consumer revenues addressable market for ICT industry



Based on Ericsson (2020).

Next: 8) Releases stipulated by 3GPP

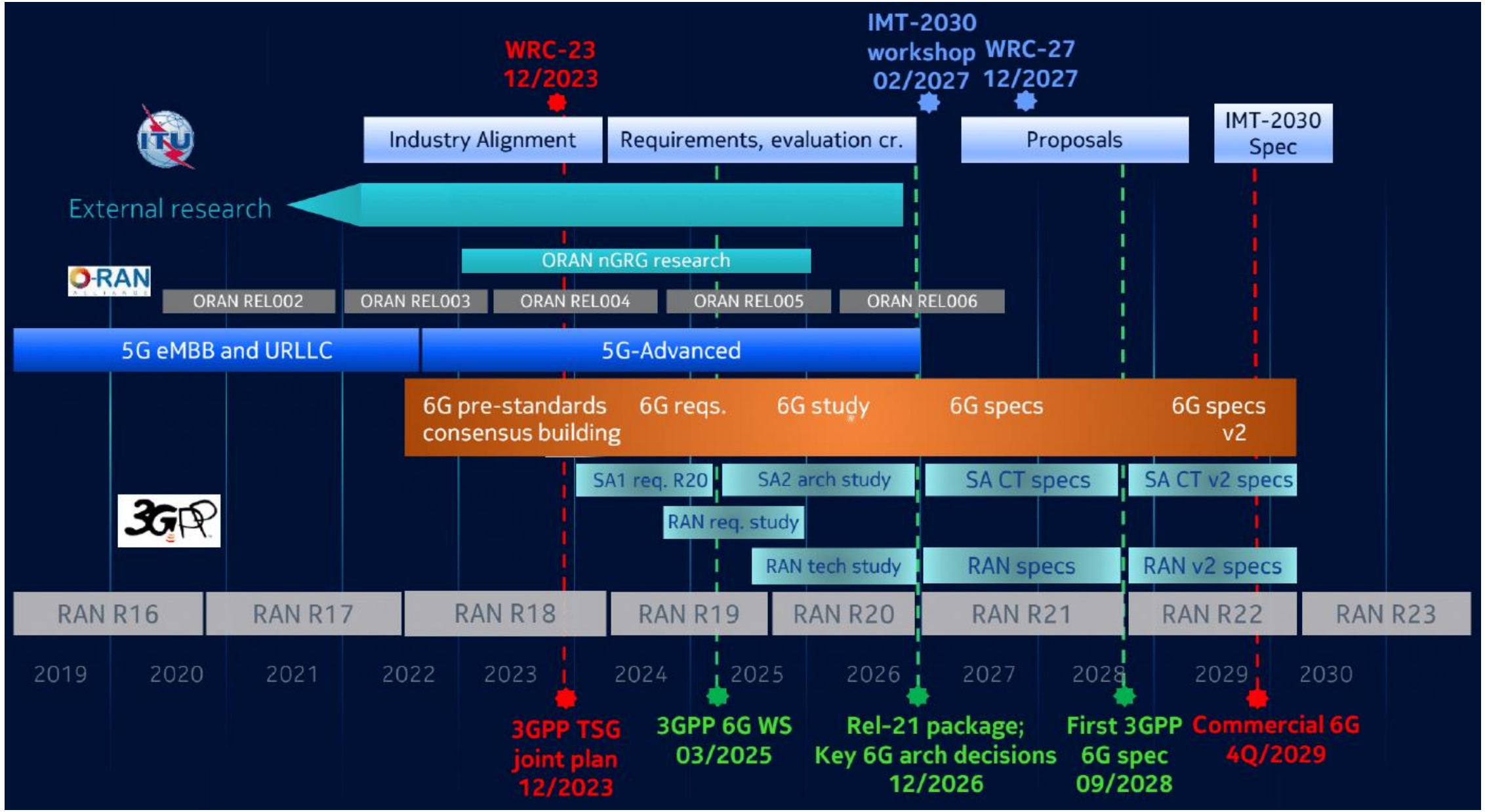
Releases stipulated by 3GPP



Based on Wong (2022).

Next: 9) Standardization of 5G and 6G: 3GPP and ITU

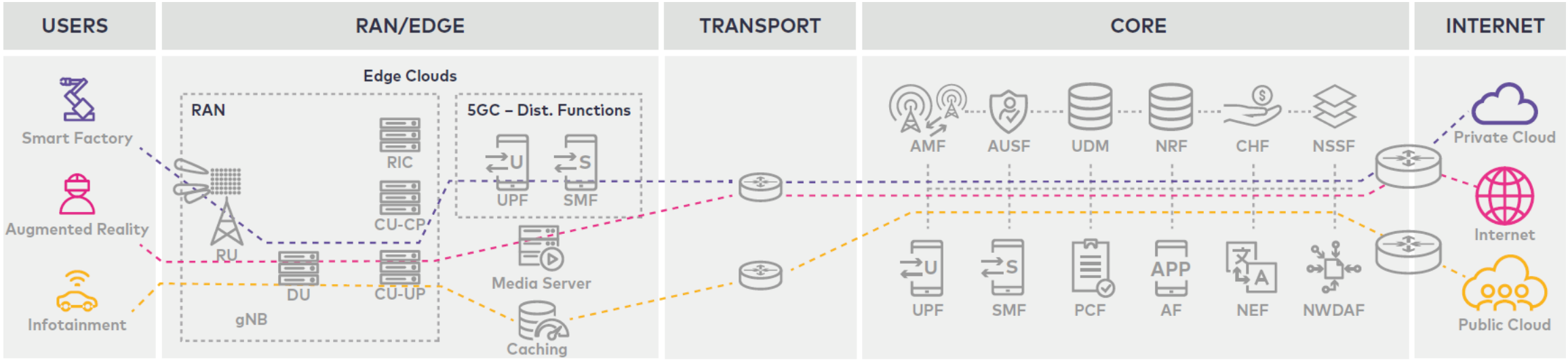
Standardization of 5G and 6G: 3GPP and ITU



Based on Baker and Nokia (2023).

Next: 10) The mobile network segments

The mobile network segments



Based on Amdocs (2020).

Next: 11) State of the art

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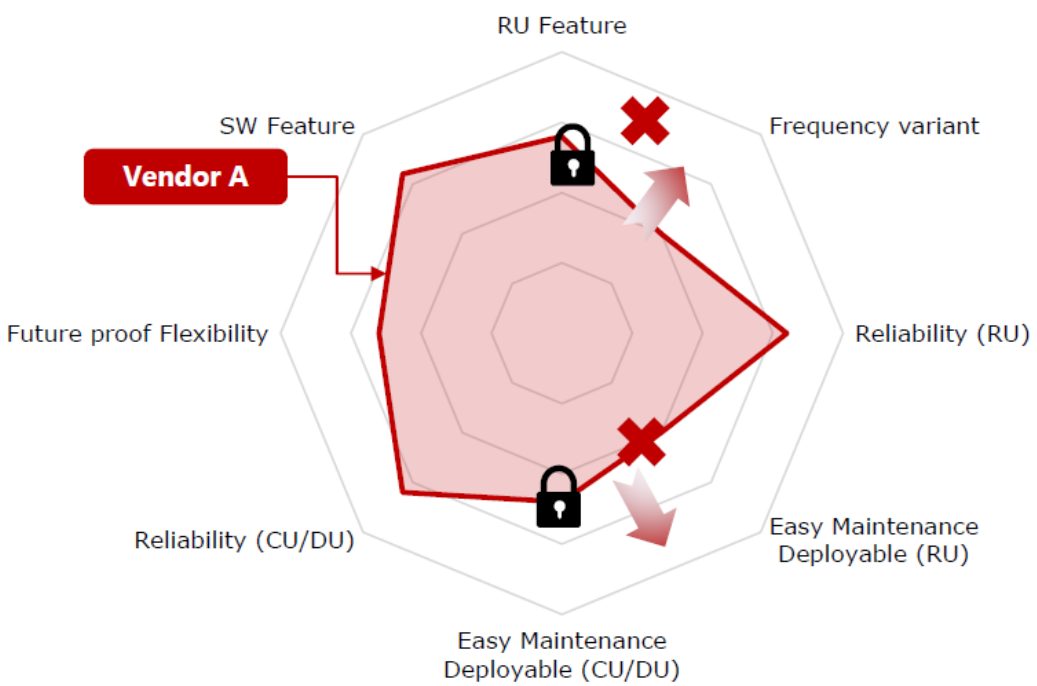
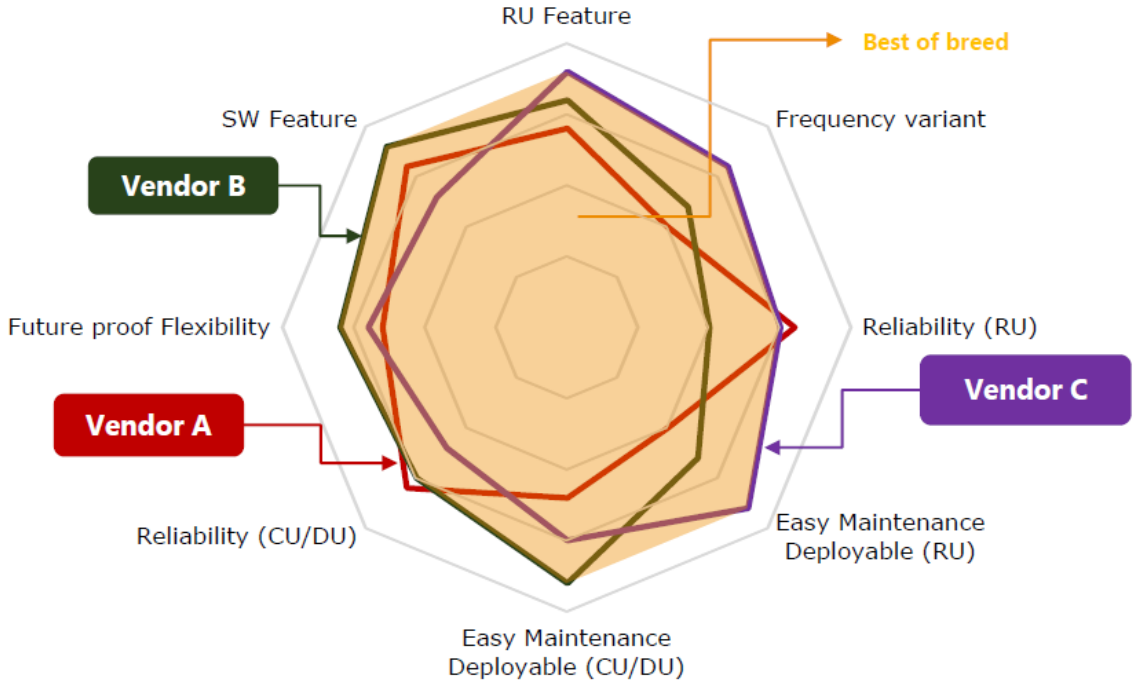
RAN vs Open RAN

Closed HW-Based RAN



Relying on vendor's roadmap and capability

Open RAN



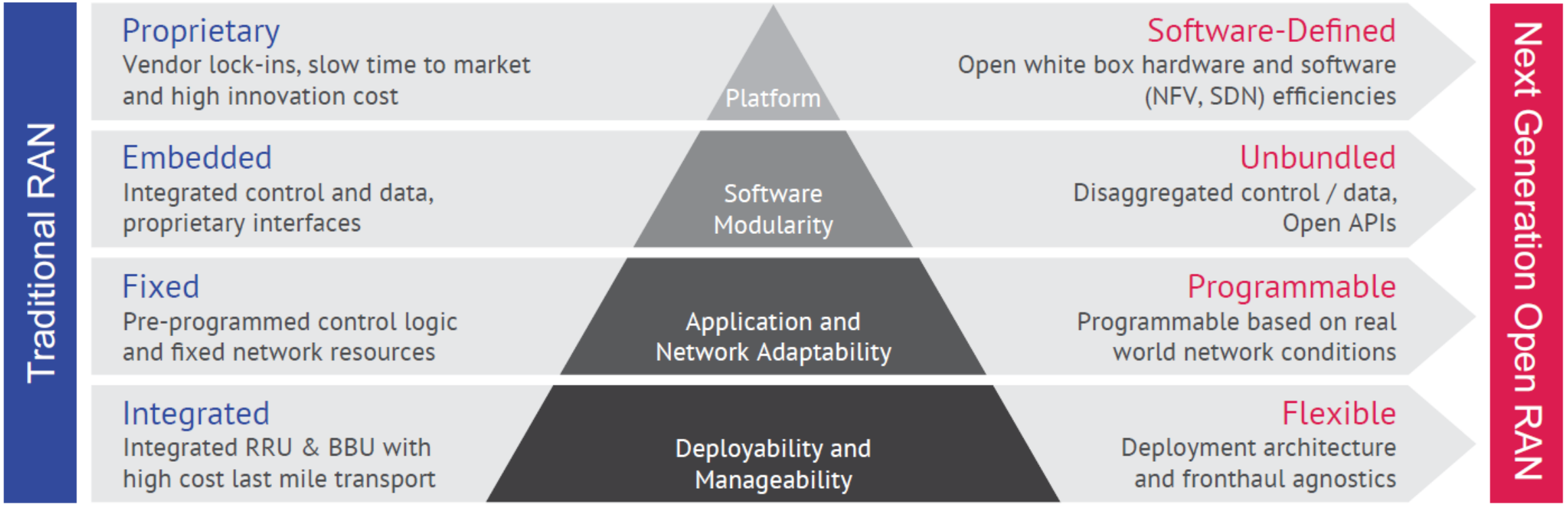
Select innovative, best-of-breed products
Reduce vendor lock-in

Open vRAN allows to select innovative, best-of-breed products more flexibly without the need to fully rely on vendors who provide RAN by only HW-based own RAN product

Based on Murakami (2022).

Next: 13) From RAN to Open RAN

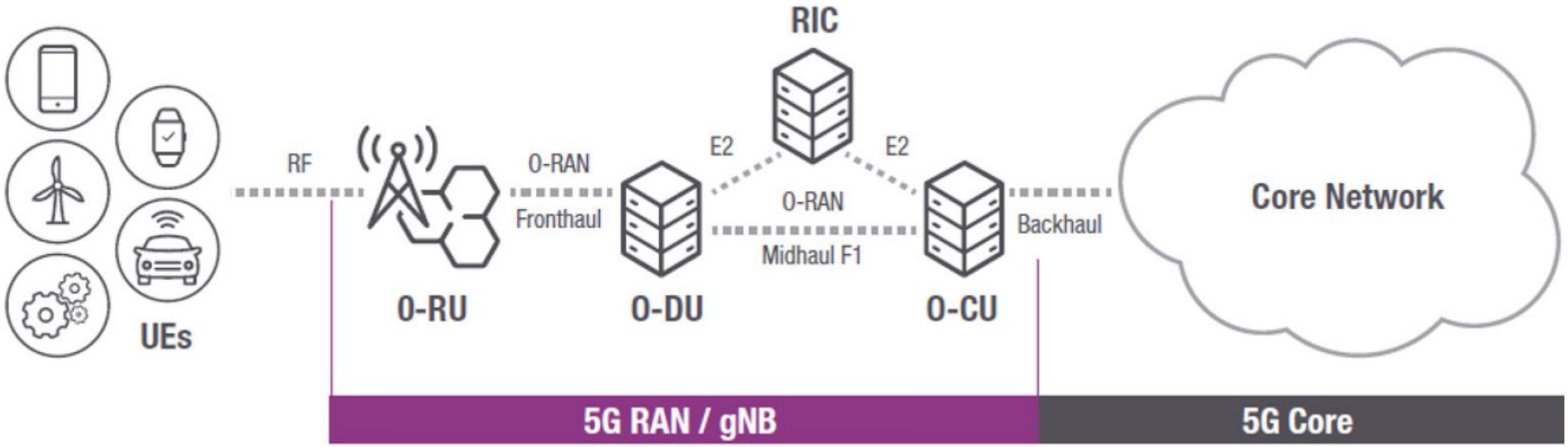
From RAN to Open RAN



Fonte: Radisys (2022).

Next: 14) Open RAN macro vision

Open RAN macro vision

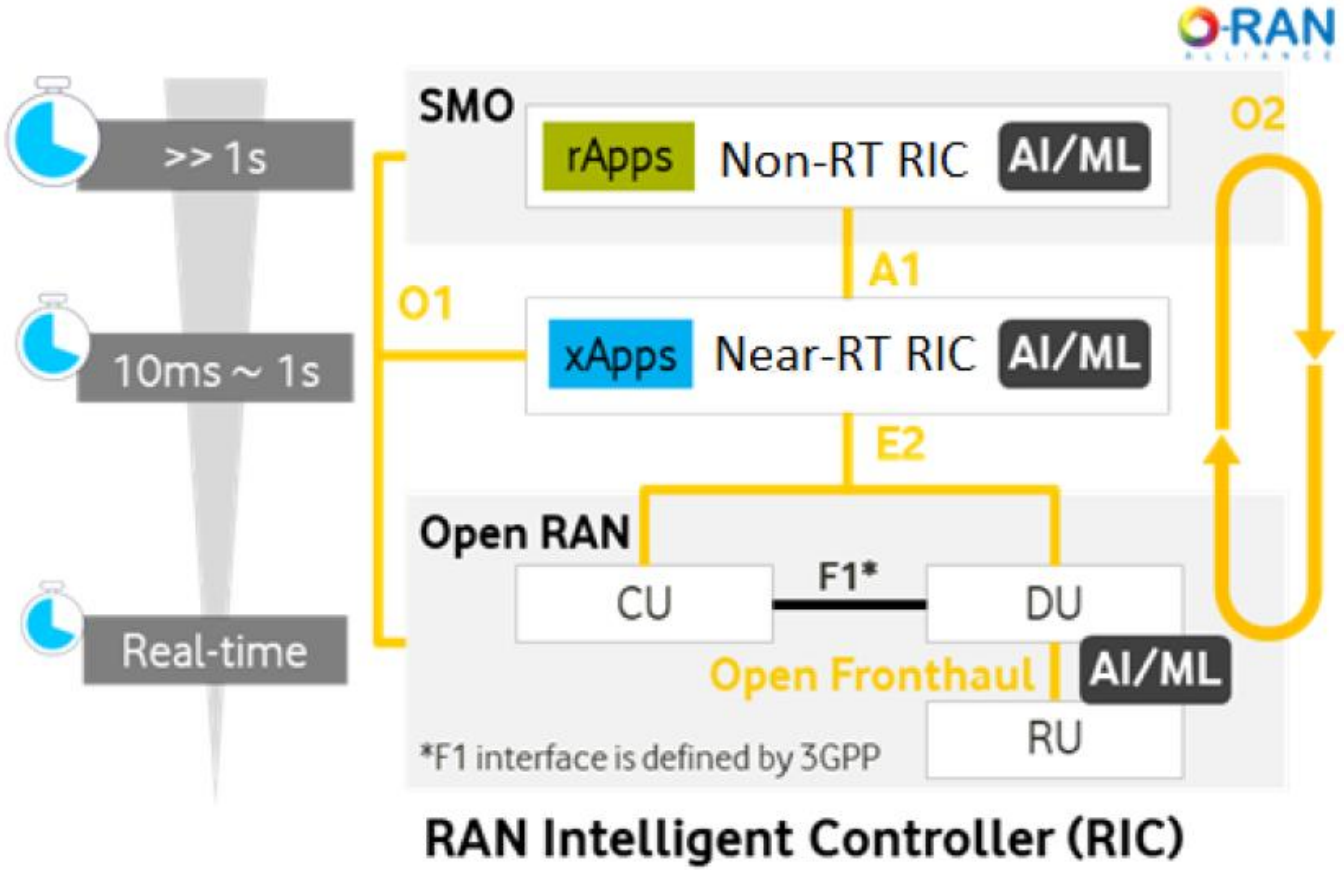


Based on Keysight (2023a).

Next: 15) RIC

RAN Intelligent Controller

RAN Intelligent Controller (RIC) will allow open RAN networks to enable real wide multi-vendor ecosystem of applications that will implement basic and novel RAN optimization automation use cases

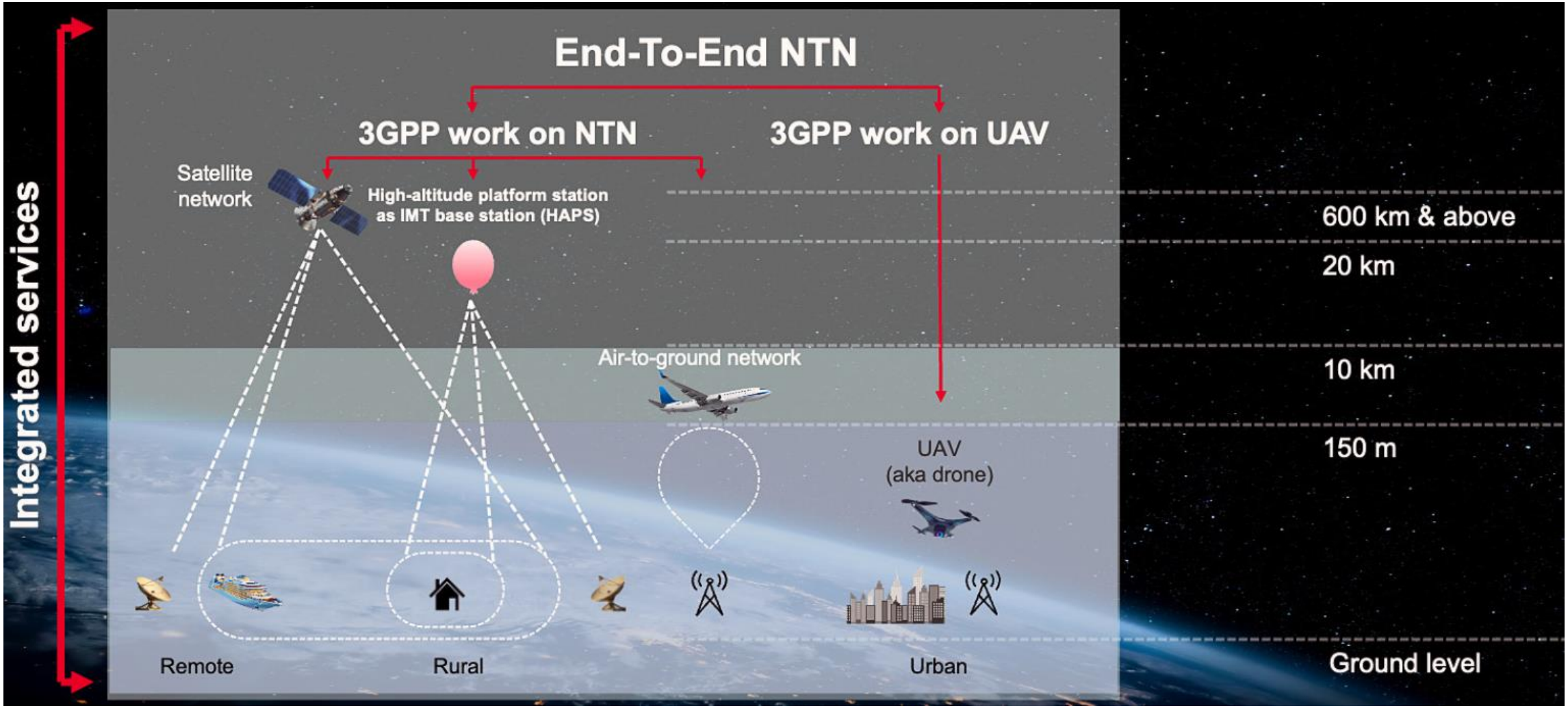


RAN Intelligent Controller (RIC)

Based on Miguel (2023).

Next: 16) A conceptual overview of NTN

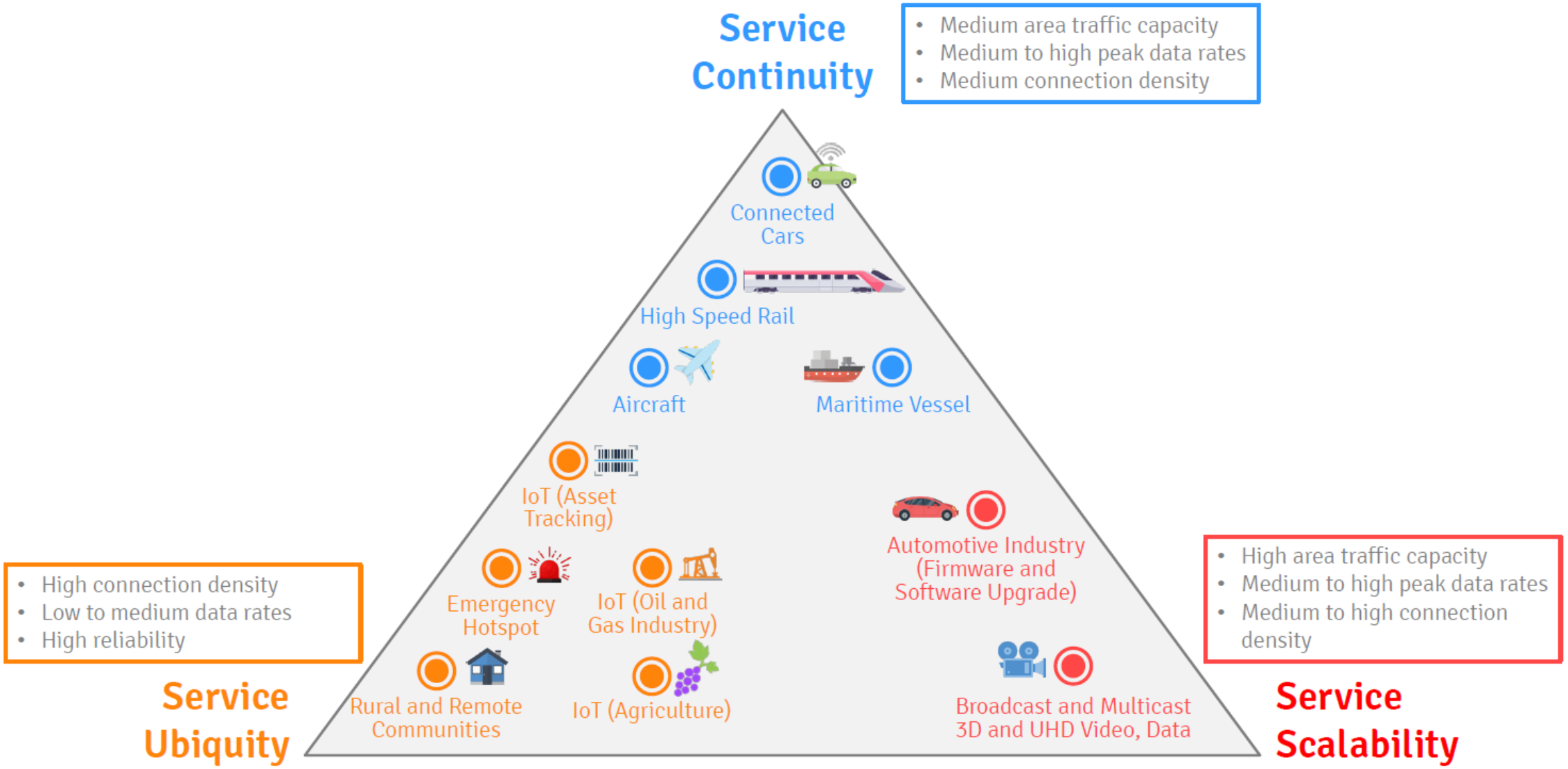
A conceptual overview of Non-Terrestrial Networks



Based on Keysight (2023a).

Next: 17) Usage scenarios for NTN

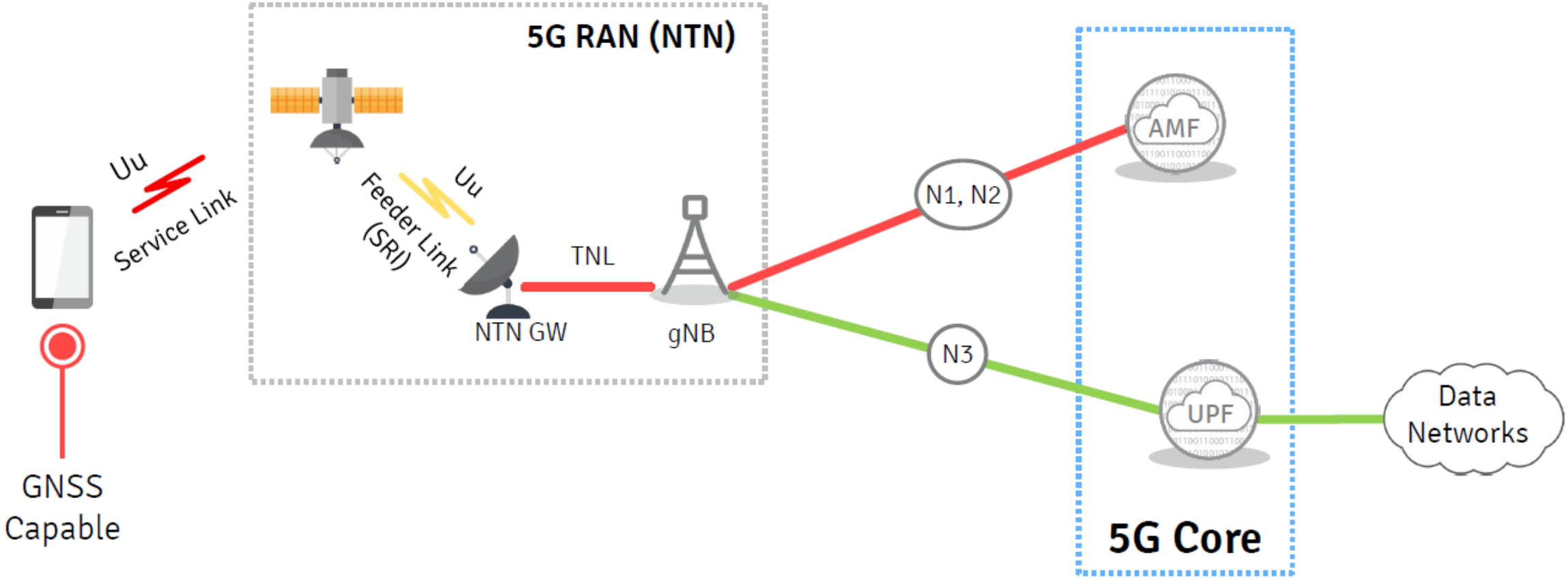
Usage scenarios for NTN



Based on Shepherd and Roberts (2022).

Next: 18) Example of NTN architecture

Example of NTN architecture



SRI: Satellite Radio Interface
NTN GW: Non-Terrestrial Network Gateway
TNL: Transport Network Layer
GNSS: Global Navigation Satellite System

Based on Shepherd and Roberts (2022).

Next: 19) Key network characteristics: 5G verticals

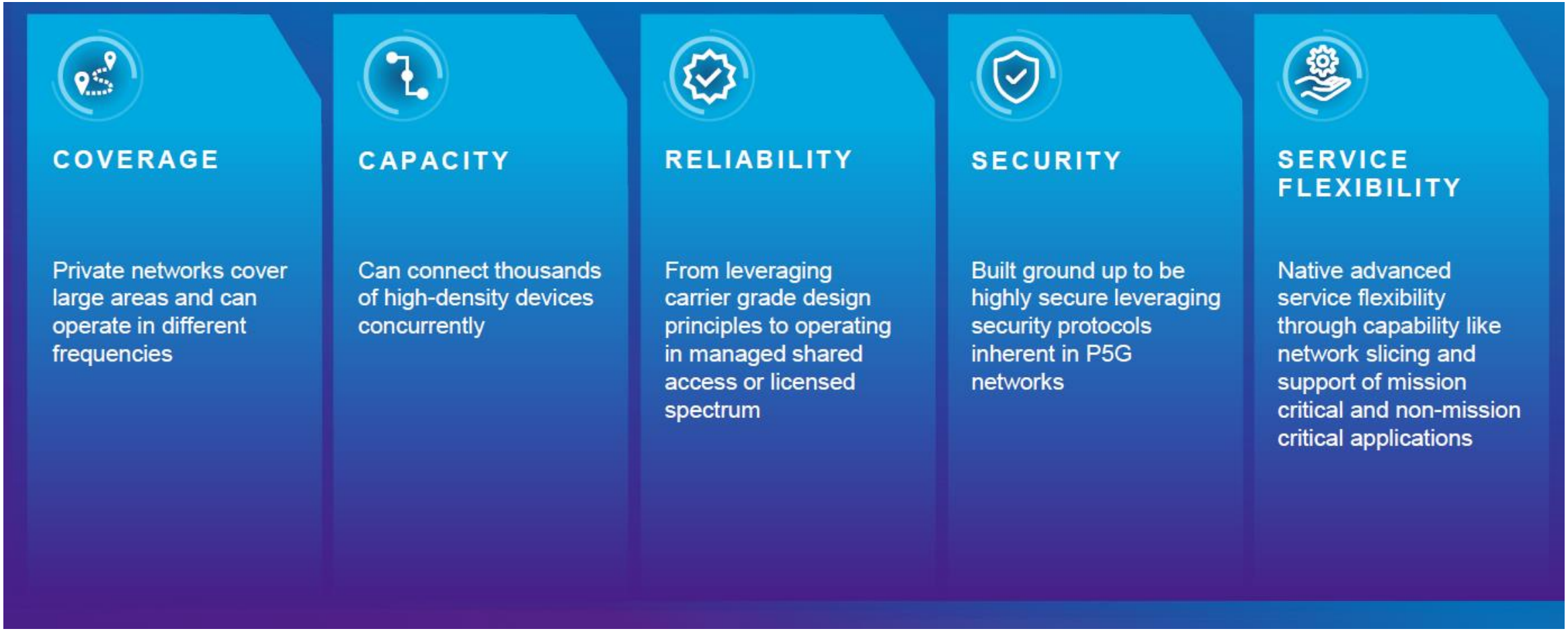
Key network characteristics: 5G verticals

	5GMBB	Automotive	Industry	Public Safety	Healthcare	Energy & Utilities	Public Transport	Retail	Media	Gaming	Financial
Low Latency		●		●	●		●		●	●	●
Virtualization/ cloud	●	●	●	●	●	●	●	●	●	●	●
Scale	●	●		●	●	●	●	●	●	●	●
Densification	●	●				●	●				
Reliability	●	●	●	●	●	●	●				●
Private			●		●						●
Automation	●	●	●								
Mobility	●	●		●			●	●		●	
Bandwidth	●				●			●		●	●
End to End for Mobile Edge	●	●	●	●		●			●	●	
End-to-End	●				●				●		
Indoor	●							●		●	
Security			●	●	●	●					●

Based on Urvik, S, Neuens, and Viavi (2022).

Next: 20) Why NPN?

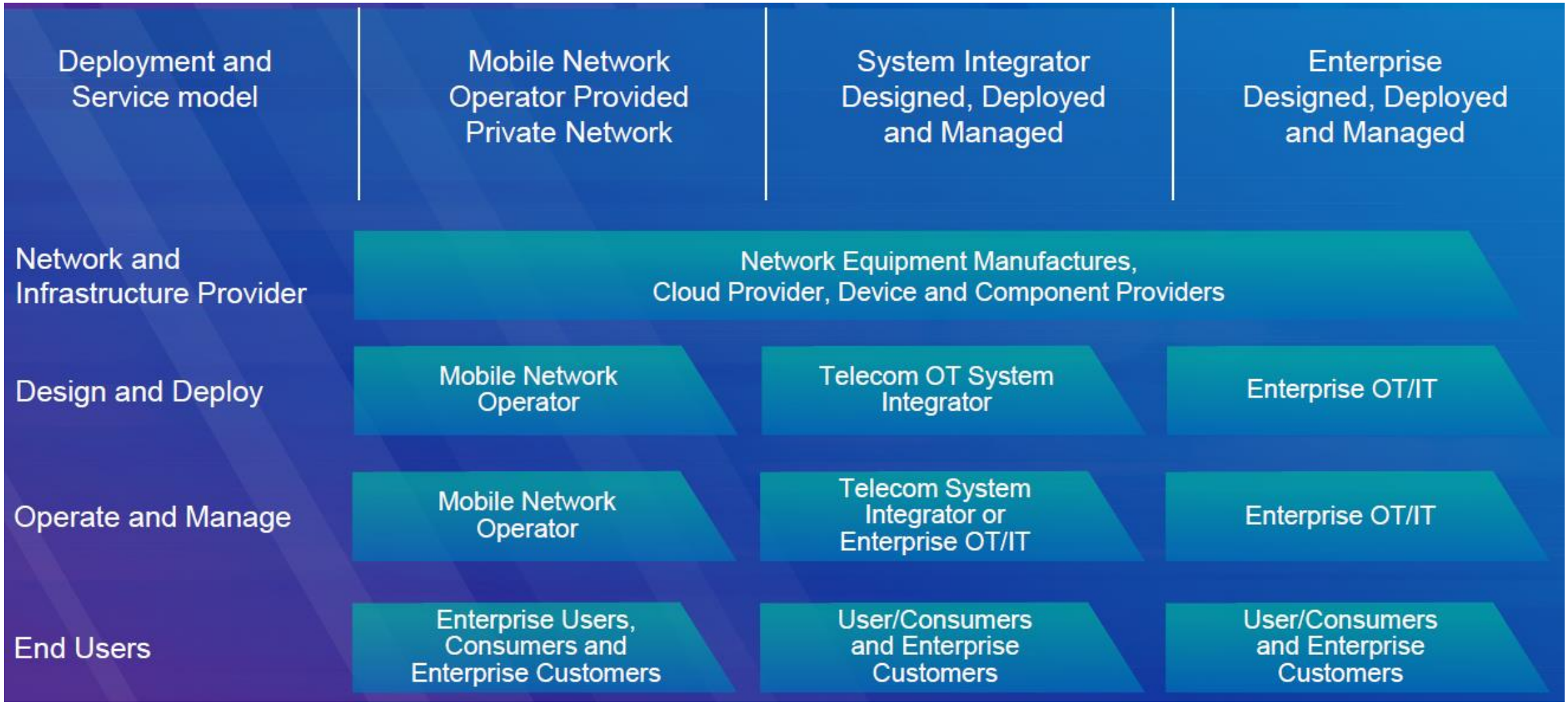
Why Non-Public Networks?



Based on Urvik, S, Neuens, and Viavi (2022).

Next: 21) Members of the NPN ecosystem

Members of the NPN ecosystem



Based on Urvik, S, Neuens, and Viavi (2022).

Next: 22) Trends in mobile networks

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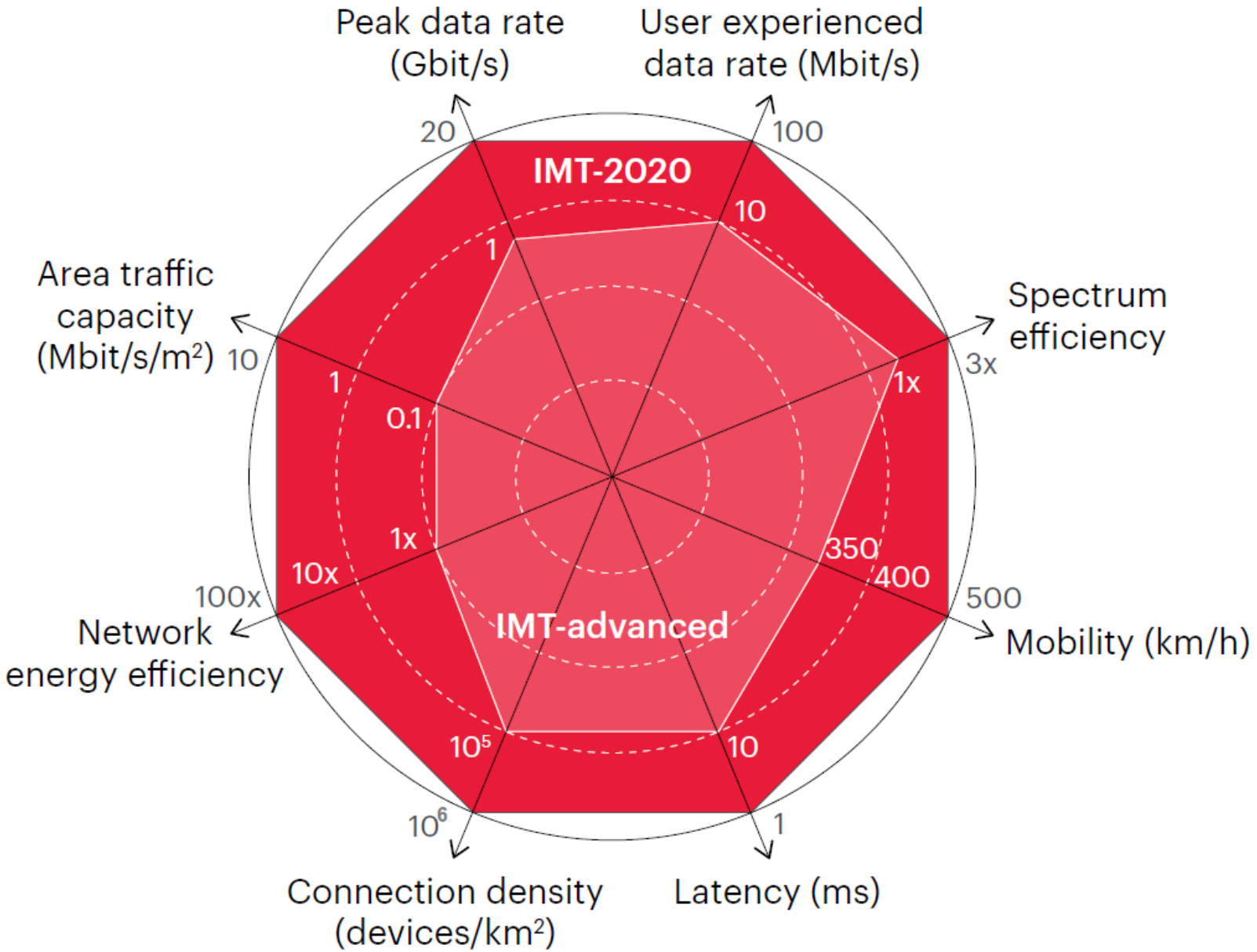
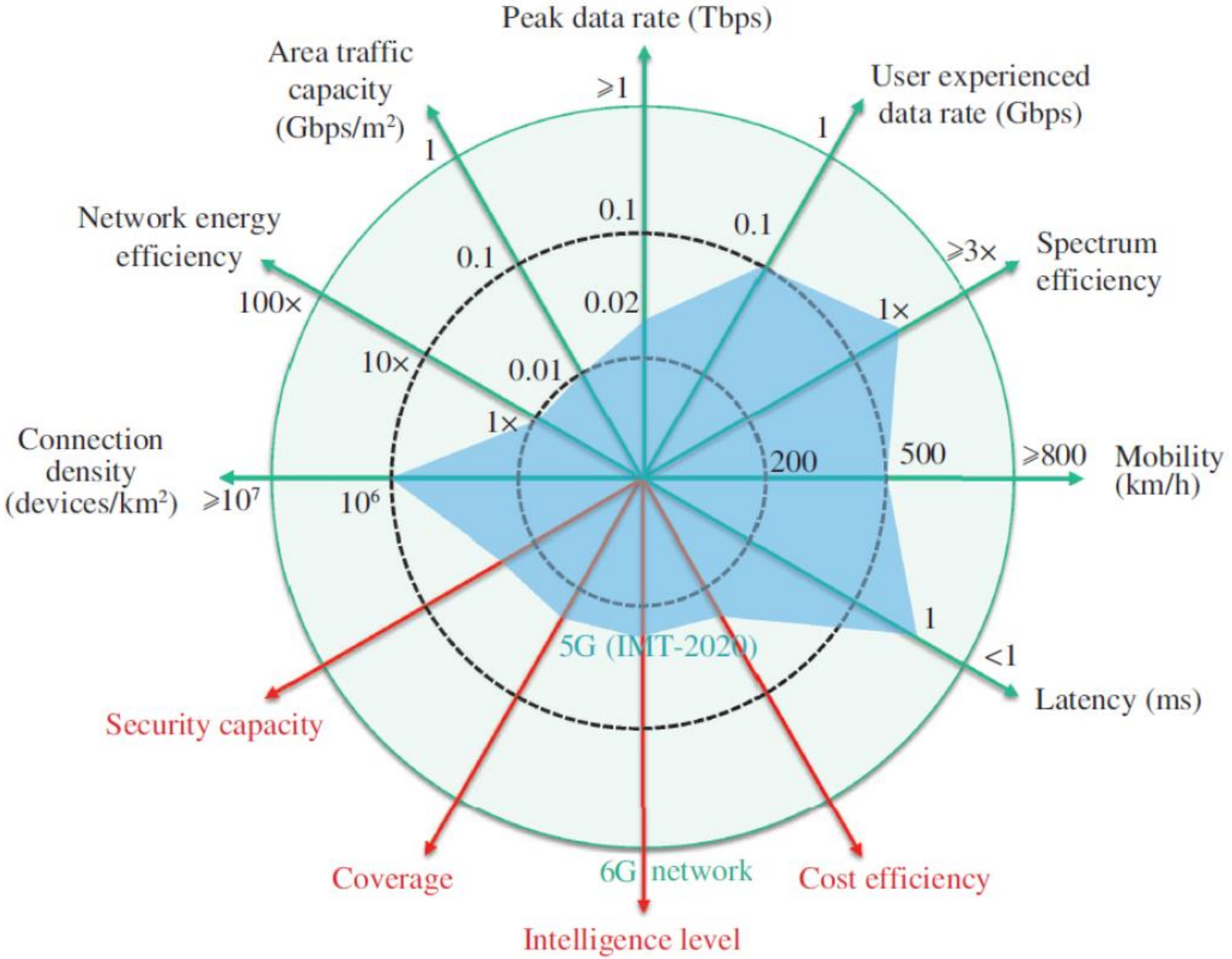
From 4G to IMT-2020: performance metrics for 5G



Based on Keysight (2023b).

Next: 24) Scientific and technological challenges — 5G vs 6G

Scientific and technological challenges — 5G vs 6G

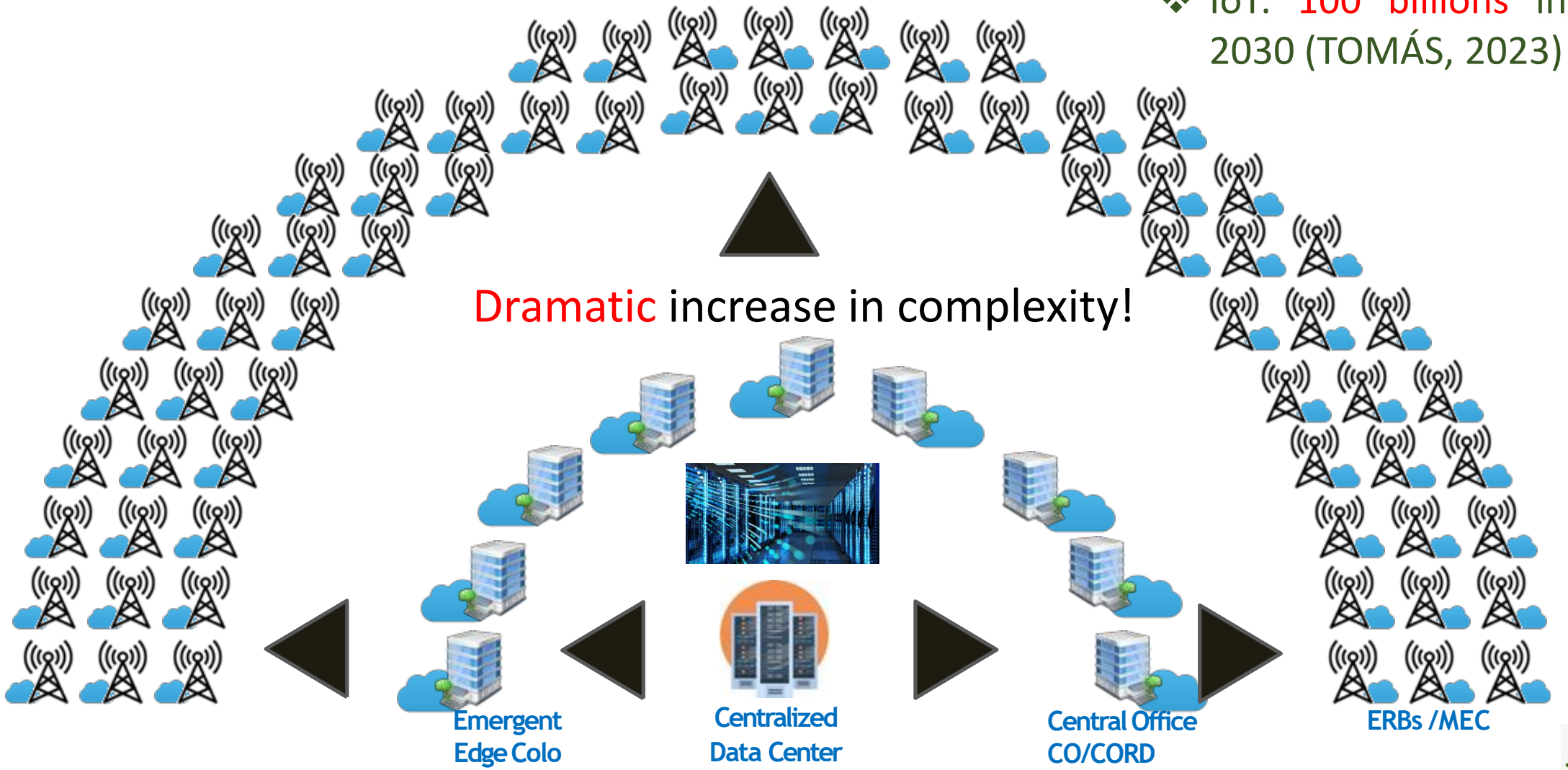


Based on You et al. (2021) apud Silva, Batista Jr, Sousa, Mostaço, Monteiro, Bressan, Cugnasca, and Silveira (2022).

Next: 25) Innovation and environmental sustainability challenges

Innovation and environmental sustainability challenges

- IoT: 100 billions in 2030 (TOMÁS, 2023)



Based on Roseboro, Capuano, and Barbieri (2019).

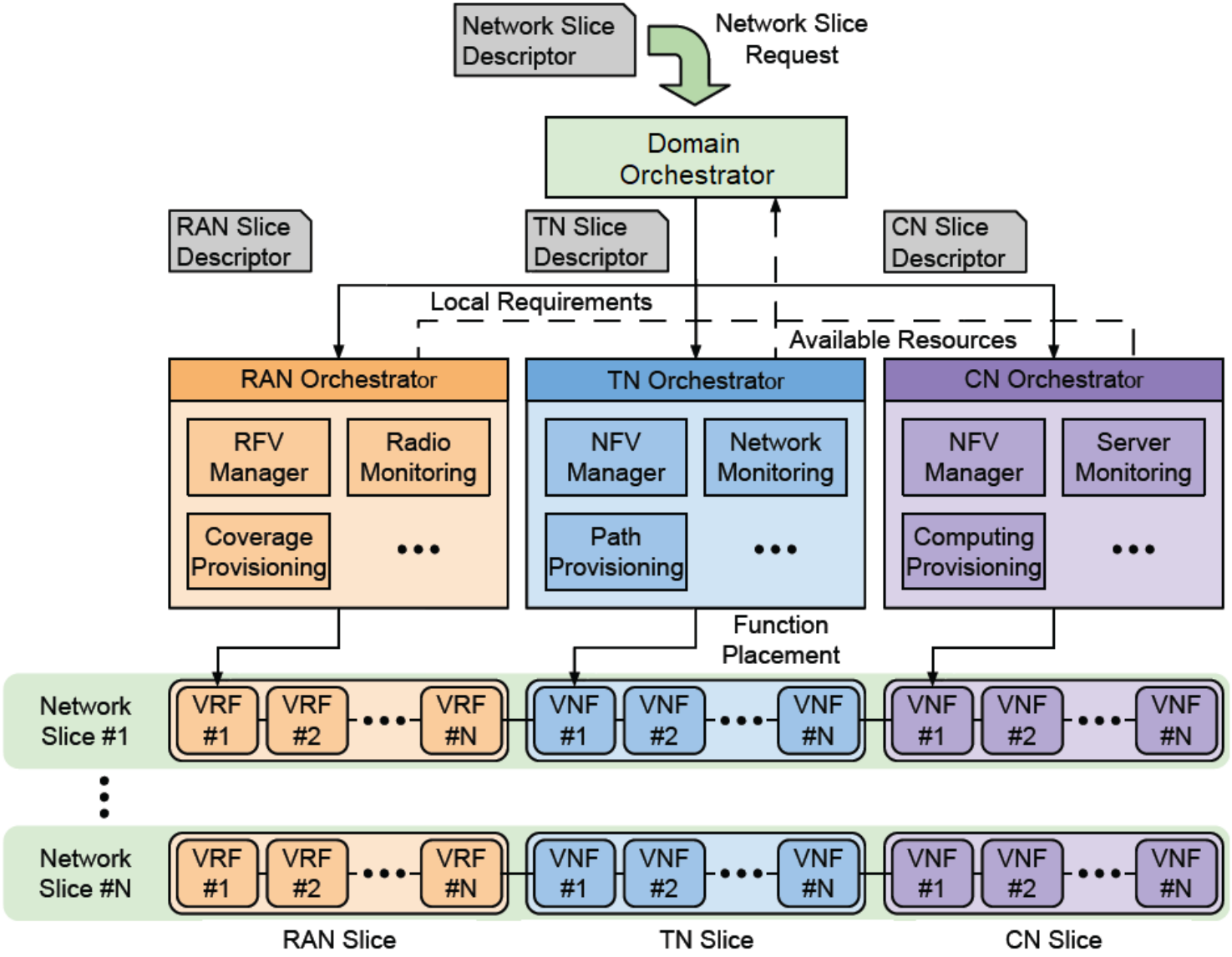
Network Service Orchestration (NSO)

Feature of Slice	4G/5G NSA Static	5G SA Static	5G SA Dynamic
Automated with orchestration	No	No	Yes
High scalability and variety of attributes	No	Medium	Yes
Required infrastructure	*Core* 4G	*Core* 5G	*Core* 5G + Orchestration

Based on Bourdot (2022).

Next: 27) Network slicing throughout different Orchestrators

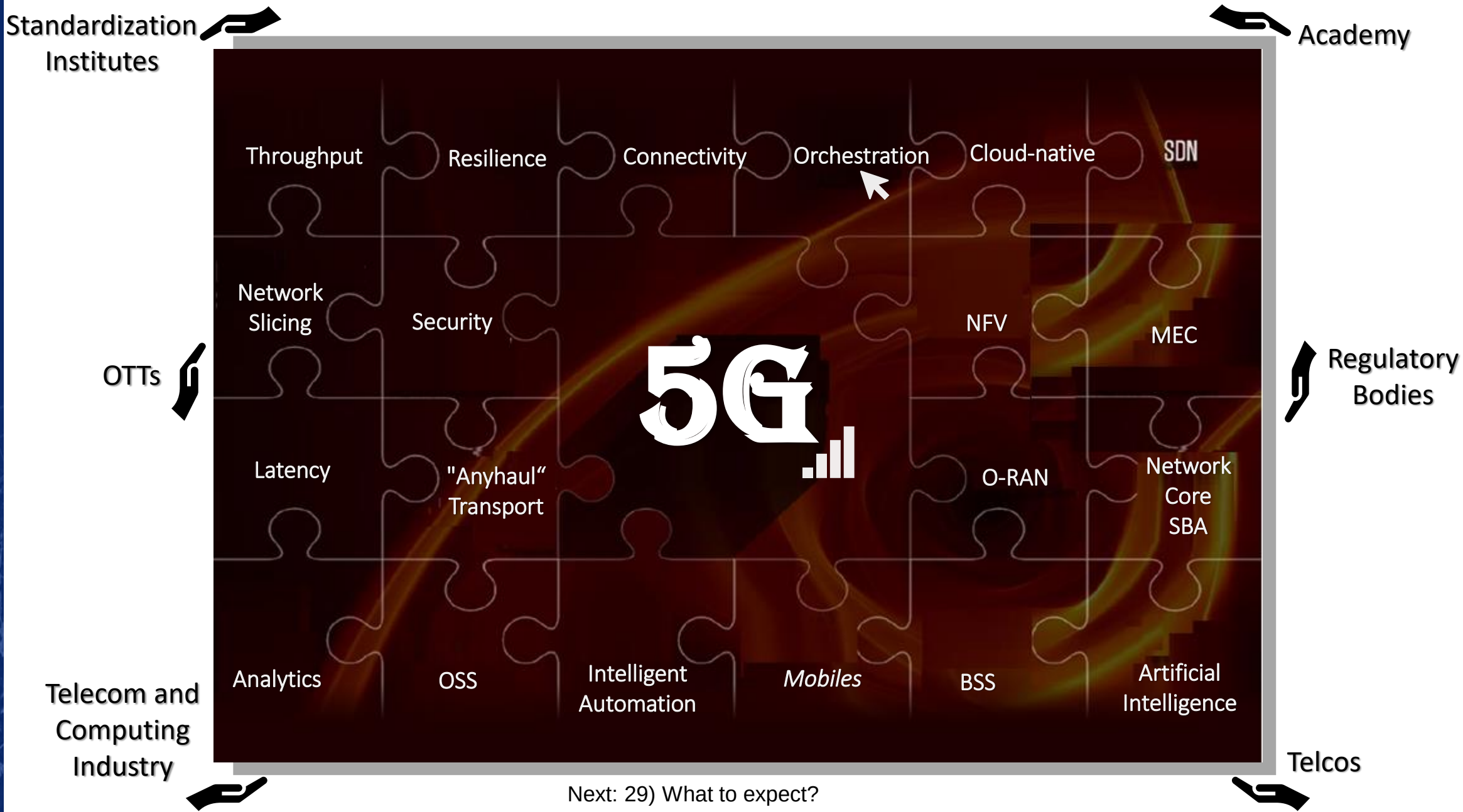
Network slicing throughout different Orchestrators



Based on Santos et al. (2020).

Next: 28) 5G networks facing their potential: R&D

5G networks facing their potential: R&D



Next: 29) What to expect?

What to expect?

❑ Networks

- standardized (YEH; HUYSSTEEN, 2023; YOU et al., 2021)
- disaggregated and “open” (OLIVEIRA; BATISTA JR; NOVAIS; TAKASHIMA; STANGE; MARTUCCI JR; CUGNASCA; BRESSAN, 2023; QUALCOMM, 2019)
- segregated (AFOLABI et al., 2018; BOURDOT, 2022; SOUSA; PEREZ; ROSA; SANTOS; ROTHENBERG, 2019)
- distributed cloud (BATISTA JR; MOSTAÇO; SILVA; BRESSAN; MARTUCCI JR; CUGNASCA, 2019; ROSEBORO; CAPUANO; BARBIERI, 2019)
- predictive (BATISTA JR; SILVA; MARTUCCI JR; SILVEIRA; CUGNASCA; 2021; YEH; HUYSSTEEN, 2023)
- to immersive experiences (YOU et al., 2021)
- “green” (KESHISHYAN, 2023)

Next: 30) What is 6G all about?

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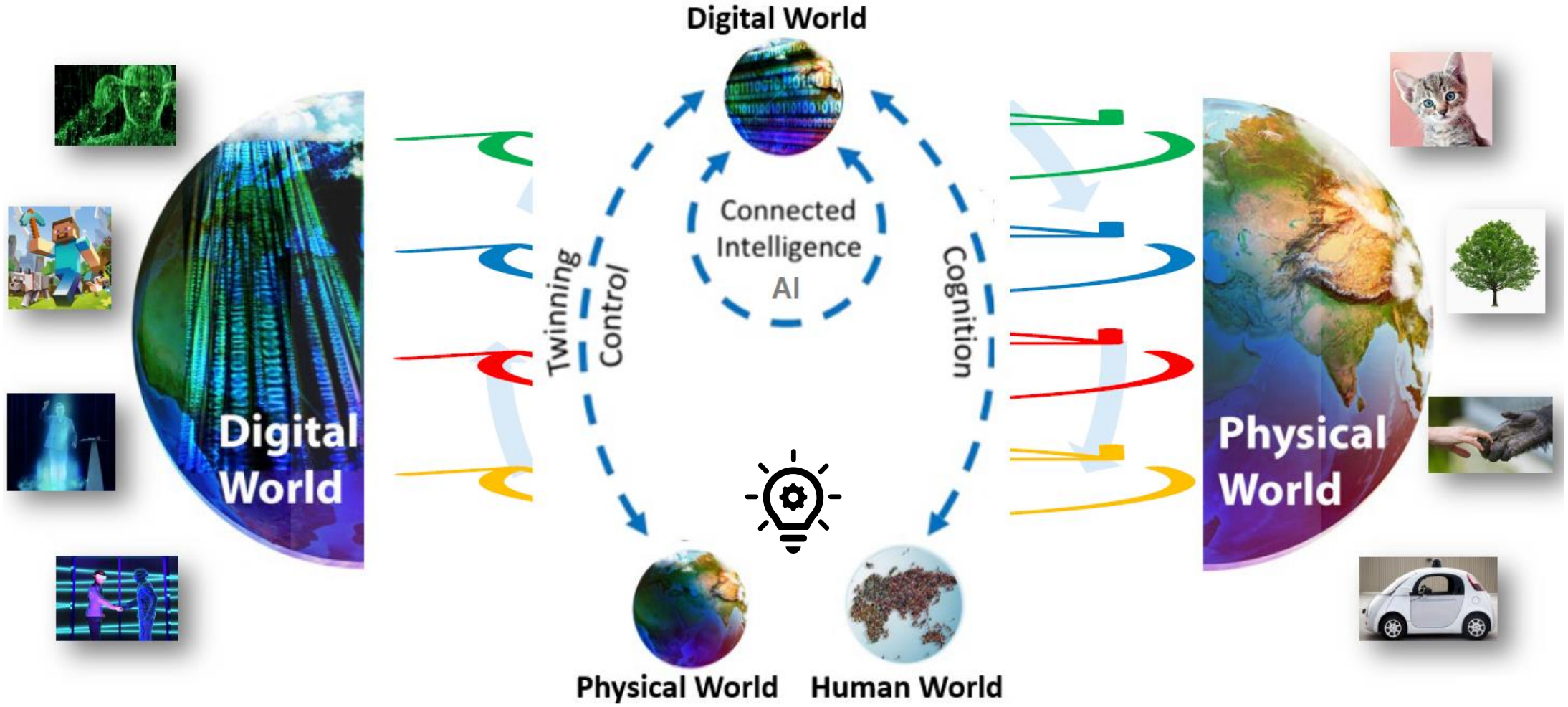
Common vision emerging from early 6G research



Based on Scrase and European Telecommunications Standards Institute (2023).

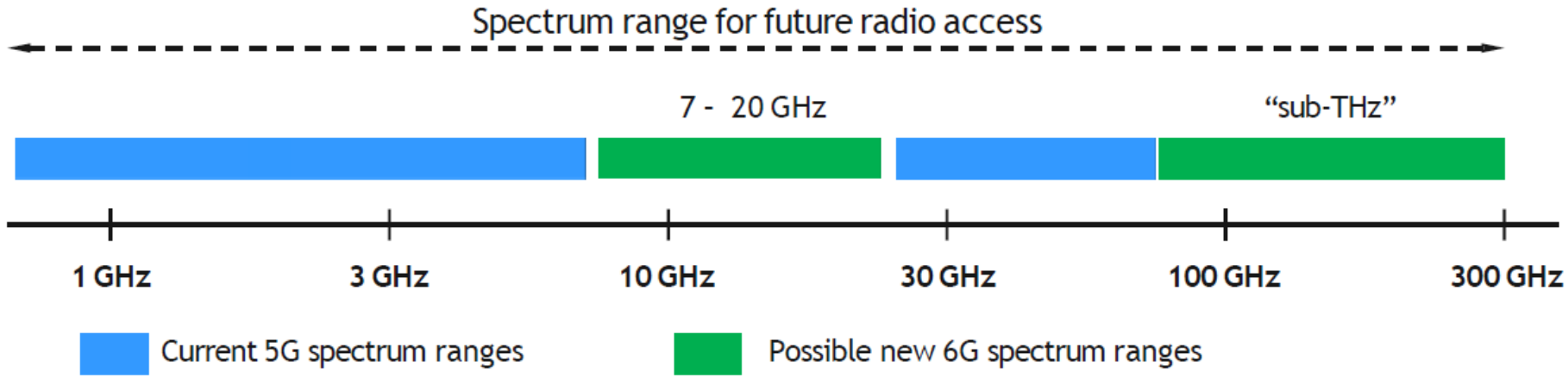
Next: 32) Digital and physical realities

Digital and physical realities

Based on Frodigh and Ericsson (2023).

Next: 33) 5G and 6G spectrum ranges

5G and 6G spectrum ranges



"Existing" spectrum

- sub-6 GHz important for coverage
- Dynamic spectrum sharing with 5G essential

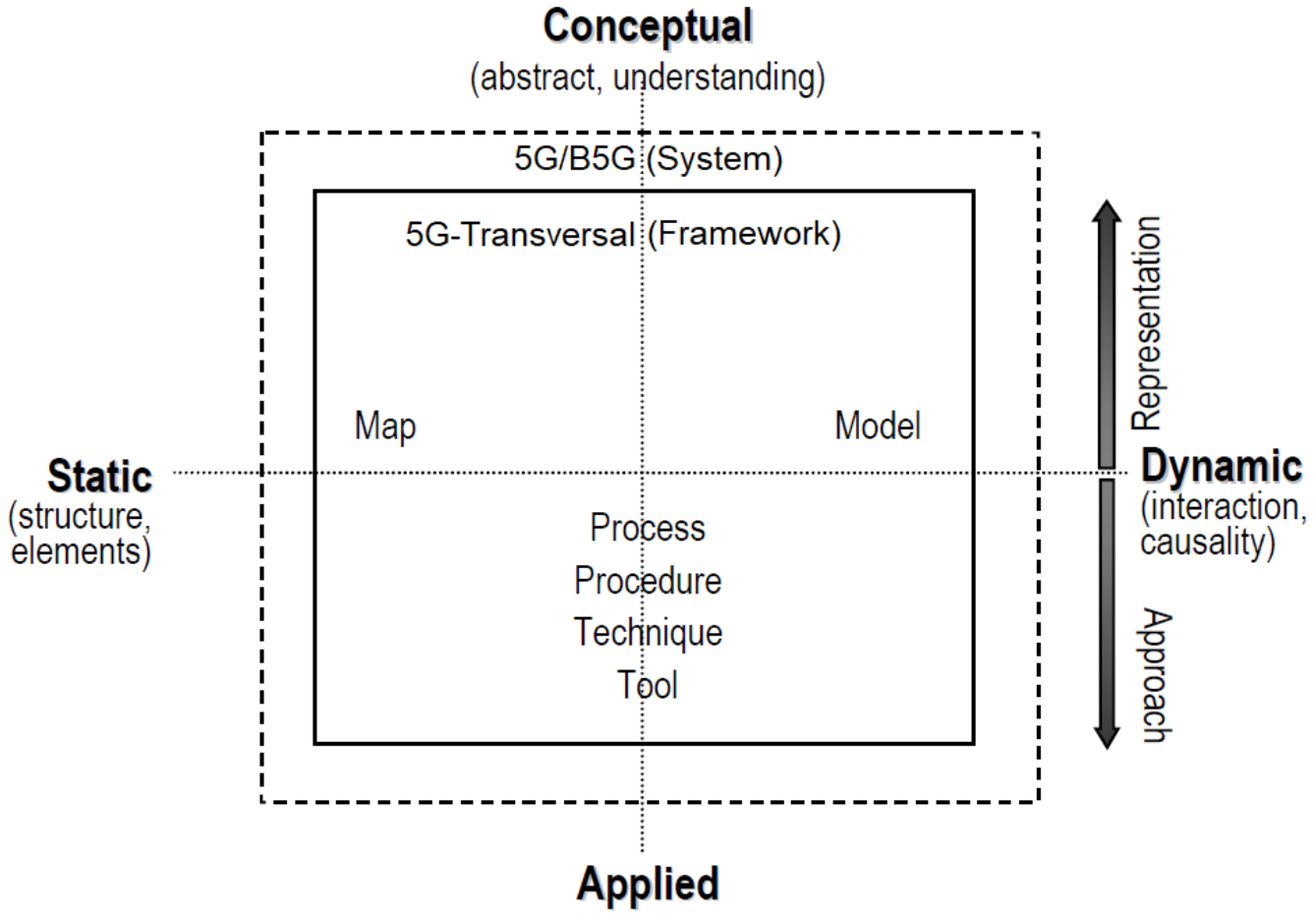
"New" spectrum

- 7 - 20 GHz - highly relevant range
- "sub-THz" - for specific scenarios

Based on Almeida and Ericsson (2023).

Next: 34) Moving forwards

Moving forwards



Fonte: adaptada de Shehabuddeen et al. (1999).

For further information, please download this doctoral thesis at

https://doi.org/10.11606/T.3.2023.tde-12092023-081721

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Thank you very much!

Research Creates New Values

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