Οικονομικό Πανεπιστήμιο Αθηνών
Τμήμα Πληροφορικής

Ευφυή Κινητά Δίκτυα: 6G

Εαρινό Εξάμηνο 2023-24

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Sources

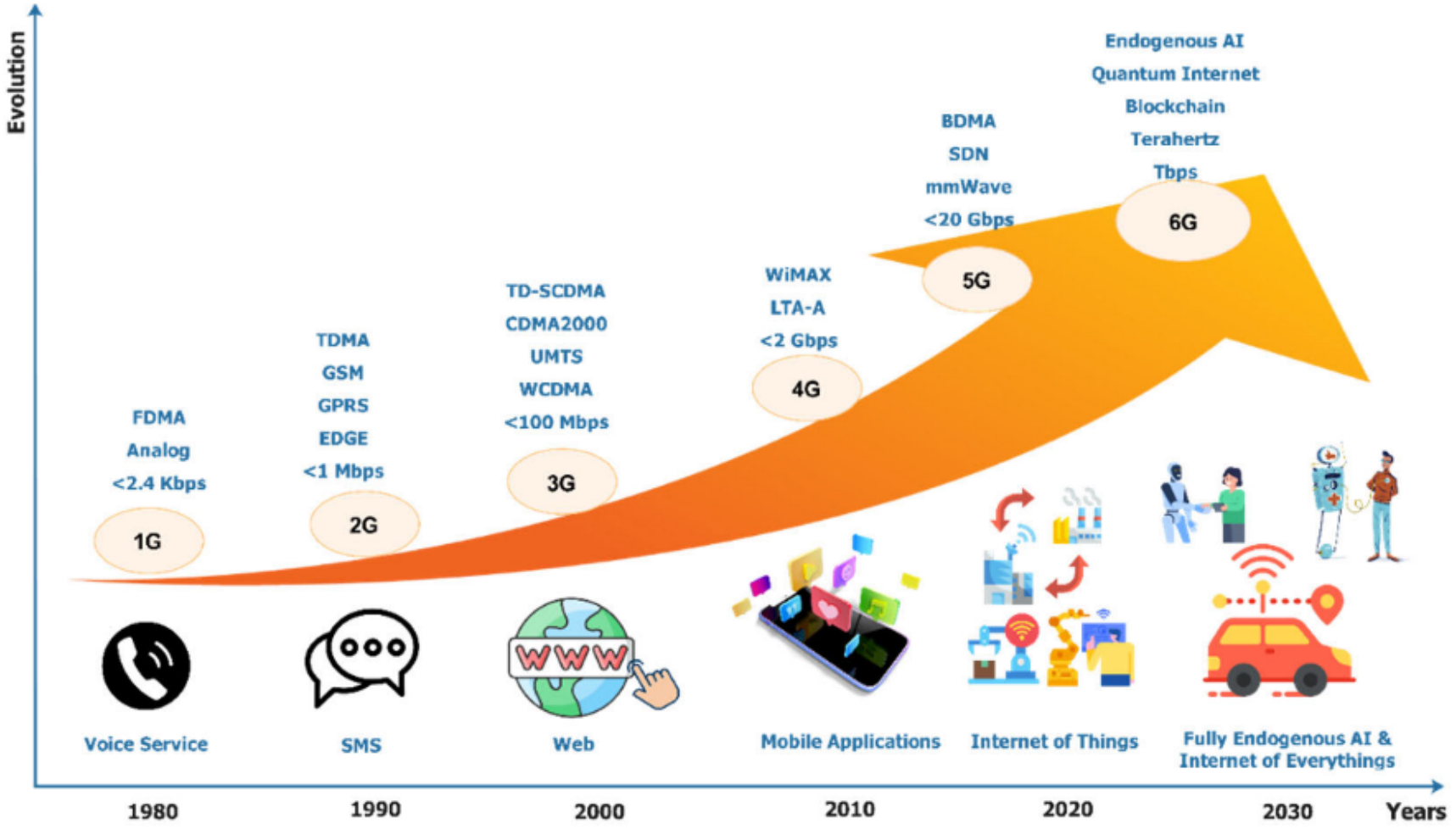
- **Innovative trends in the 6G era: A comprehensive survey of architecture, applications, technologies, and challenges.**
  - Quy, Vu Khanh, et al. "Innovative trends in the 6G era: A comprehensive survey of architecture, applications, technologies, and challenges." IEEE Access 11 (2023): 39824-39844.
- **6G: The Next Horizon From Connected People and Things to Connected Intelligence**
  - White paper, Huawei Technologies Co., Ltd.
  - https://www-file.huawei.com/-/media/corp2020/pdf/tech-insights/1/6g-white-paper-en.pdf?la=en
- **Envisioning a 6G future**
  - Ebook, Nokia & Bell labs
  - https://d1p0gxnqcu0lvz.cloudfront.net/documents/Nokia_Bell_Labs_Envisioning_a_6G_future_eBook_EN.pdf
- **Ad-hoc paper citations...**

6th Generation

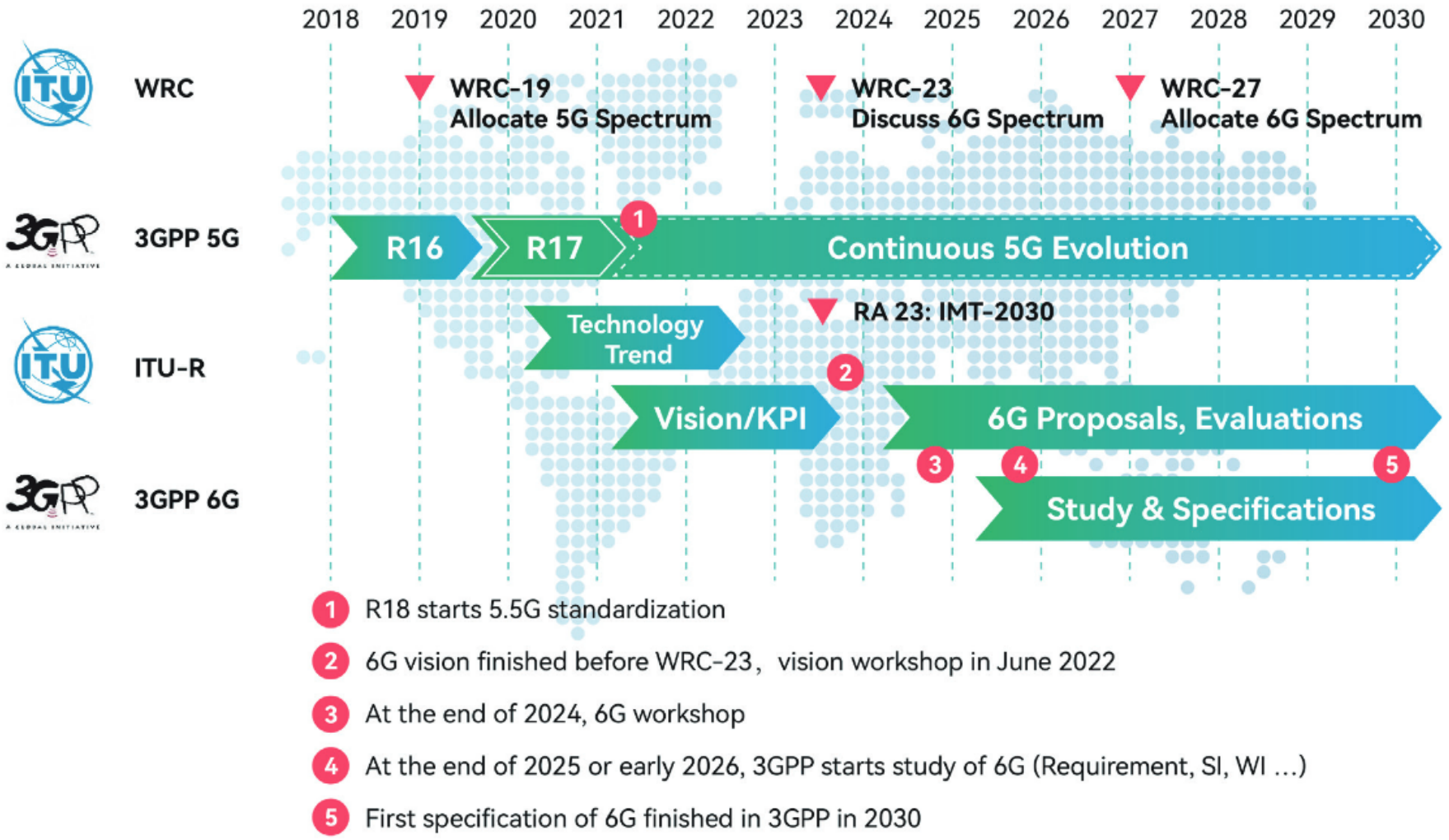
- Previous Gens aim mainly performance
  - More BW, less delay, more reliability
- 6G aims
  - Innovation
  - Artificial intelligence
  - Sensing
  - Virtualization & Digital Twins
  - Reduced carbon footprint
  - Sustainability
  - Trust
  - Unification of terrestrial, satellite, underwater networks

https://www.ericsson.com/en/reports-and-papers/white-papers/5g-wireless-access-an-overview

Evolution of mobile wireless gens



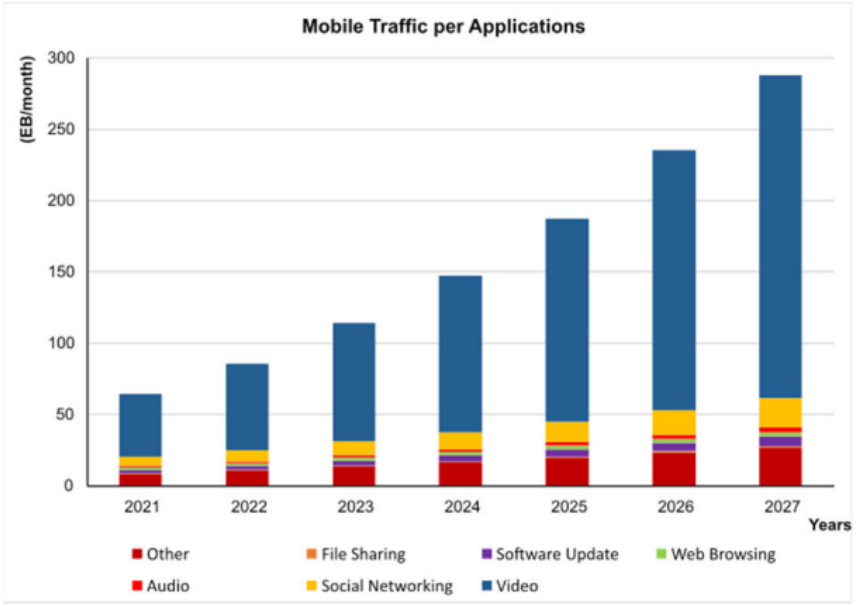
6G roadmap

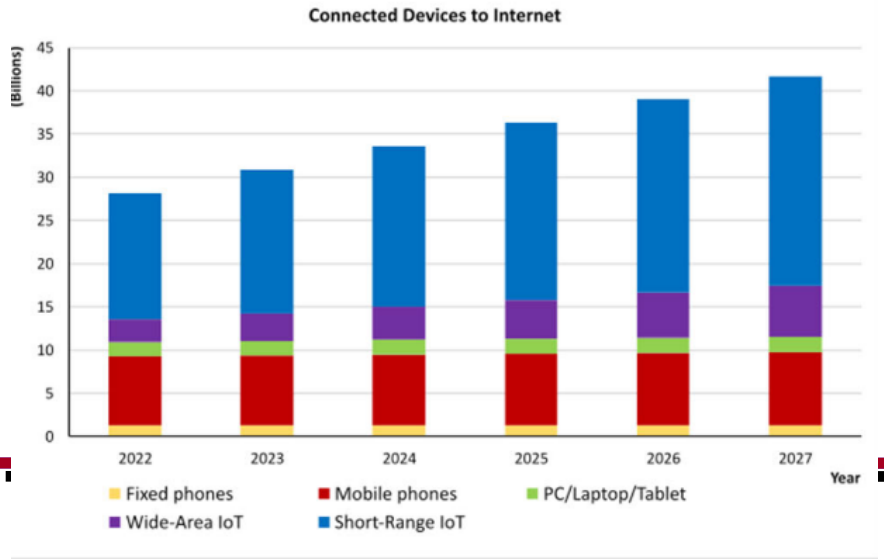

2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
WRC
WRC-19
Allocate 5G Spectrum
WRC-23
Discuss 6G Spectrum
WRC-27
Allocate 6G Spectrum
3GPP 5G
R16
R17
1
Continuous 5G Evolution
ITU-R
Technology
Trend
RA 23: IMT-2030
2
Vision/KPI
6G Proposals, Evaluations
3
4
5
3GPP 6G
Study & Specifications
1 R18 starts 5.5G standardization
2 6G vision finished before WRC-23, vision workshop in June 2022
3 At the end of 2024, 6G workshop
4 At the end of 2025 or early 2026, 3GPP starts study of 6G (Requirement, SI, WI …)
5 First specification of 6G finished in 3GPP in 2030

Drivers

- New Applications & New Business
- Proliferation of intelligence
- Sustainability / social responsibility

Driver 1: New Applications & New Business





Emerging applications:

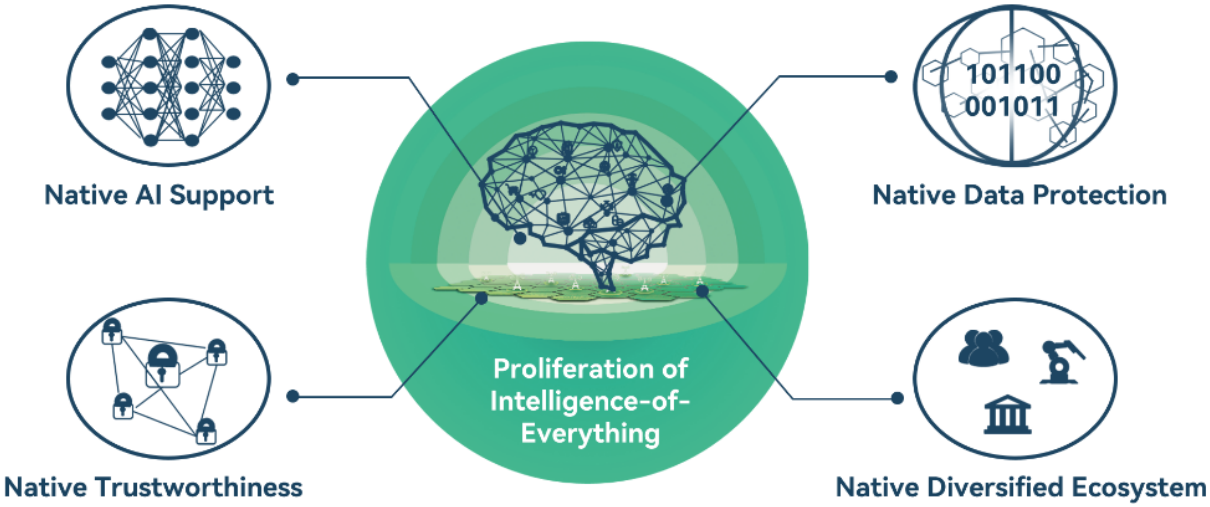
- Health care
- Intelligent transport systems
- Smart agriculture
- Smart cities
- Real-time entertainment

6G salient requirements:

- Tbps data rates
- Microsecond latencies
- Spatial multiplexing and THz frequency → 1000x capacity of 5G
- Energy efficiency
- Universal coverage
- Intelligent and reliable connections across the entire network

Driver 2: Proliferation of intelligence

- **Native AI support**: end-to-end (E2E) mobile communications systems will be designed with optimal support for AI and ML
- **Native data protection**: privacy, rights of data subjects, data control and processing, GDPR
- **Native trutworthiness**: multi-party & multi-lateral models
- **Native diversified Ecosystem**: collaboration and convergence of ICN and OT sectors



Driver 3: Sustainability

- Increased energy reqs
  - Growing (IoT) devices & AI computing
- 6G goal: 100-fold increase of bits/Joule
- New materials/ HW
  - performing many applications simultaneously, THz antennas, tunable materials/ intelligent surfaces
- New algorithms, protocols /SW
- New architectures
  - CRAN (fewer cells), dense topologies (less distance)
- New energy harvesting techniques
  - Renewable energy → solar, vibration,
  - RF harvesting

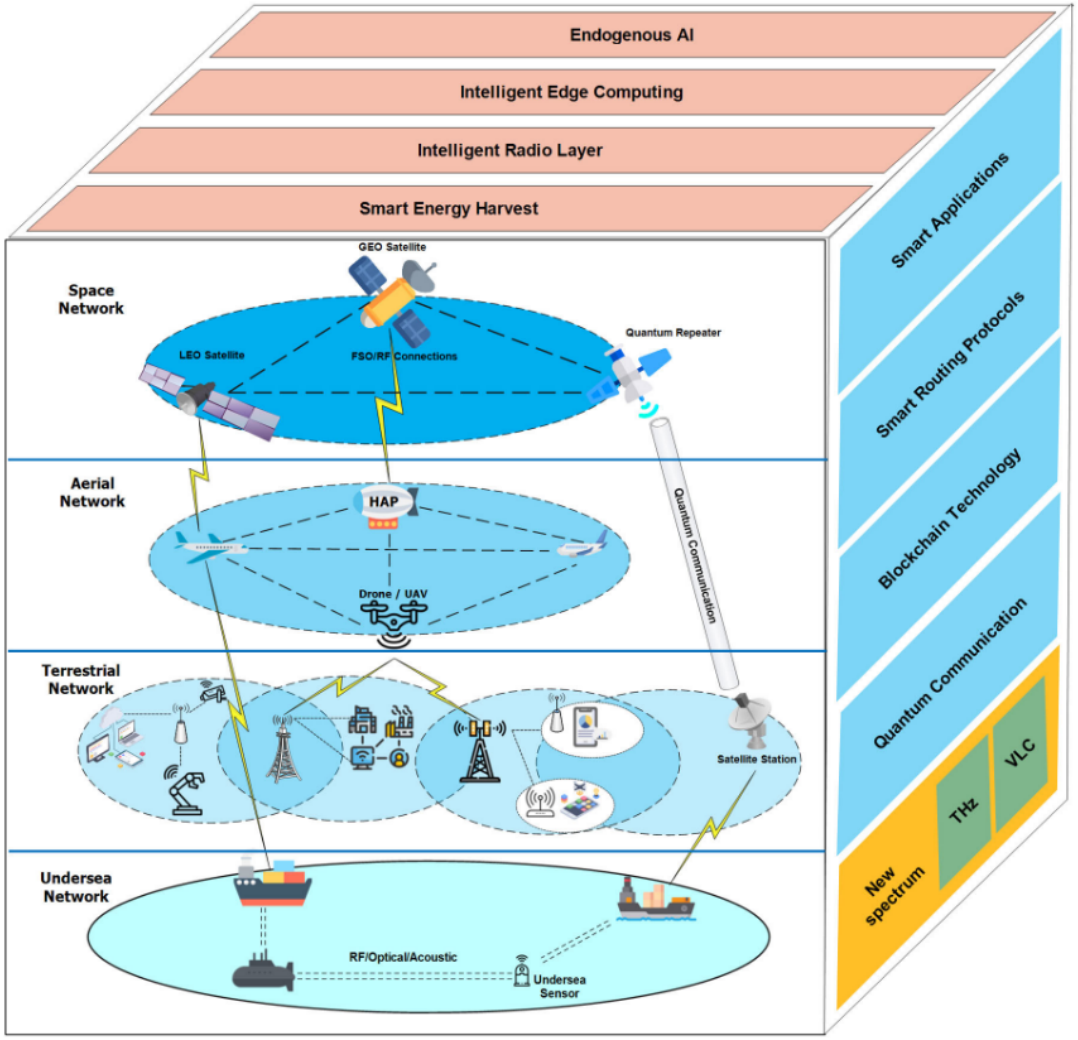
5G Vs. 6G

Features	5G NR	6G
Peak Data Rates	20 Gbps	1 Tbps
Latency	1ms	Less than 1ms
Area Traffic Capacity	10Mbps/m2	1Gbps/m2
Frequency Bands	Sub 6GHz, mmWave (24-52.6 GHz)	Sub 6GHz mmWave band THz, VLC
Connection Density	1M devices/Km2	10M devices/Km2
Device Services	Reliable connectivity of devices	Real-Time Physical Interaction Scenarios.
Network Type	SDN, NFV, Slicing	SDN, NFV, Intelligent cloud, AI-based Slicing Machine Learning, Deep Learning
Technique Computing	Fog/Edge Computing, Cloud computing	Quantum Computing, Fog/Edge Computing
Mobility	Up to 500 Kmph	Up to 700 Kmph
Technology	D2D communication, Ultra-dense Network, Relaying, Small Cell Access, NOMA	VLC and Quantum Communications, Endogenous AI, Blockchain, Smart Resource Allocation.
Applications	AR, VR, IoT, Smart Cities, Smart Home, Internet of Things	Augmented Reality, Telerobotic, Teledriving, AR/VR/XR, Tele-Education, Internet of Everything

Drivers → Vision

3 dimensions:

- **Universal architecture**
  - Global coverage
    - Ubiquitous access to heterogenous-nets
- **Novel solutions**
  - Intelligence
    - AI-driven self-awareness and self-adaptivity to address compexity and heterogeneity.
- **Novel technologies**
  - (0.1-10) THz spectrum
  - IRS



New spectrum

Low/mid-bands

Basic Coverage Layer

Mid-bands

Capacity/Coverage Layer

Ultra-high/high bands/high end of mid-bands

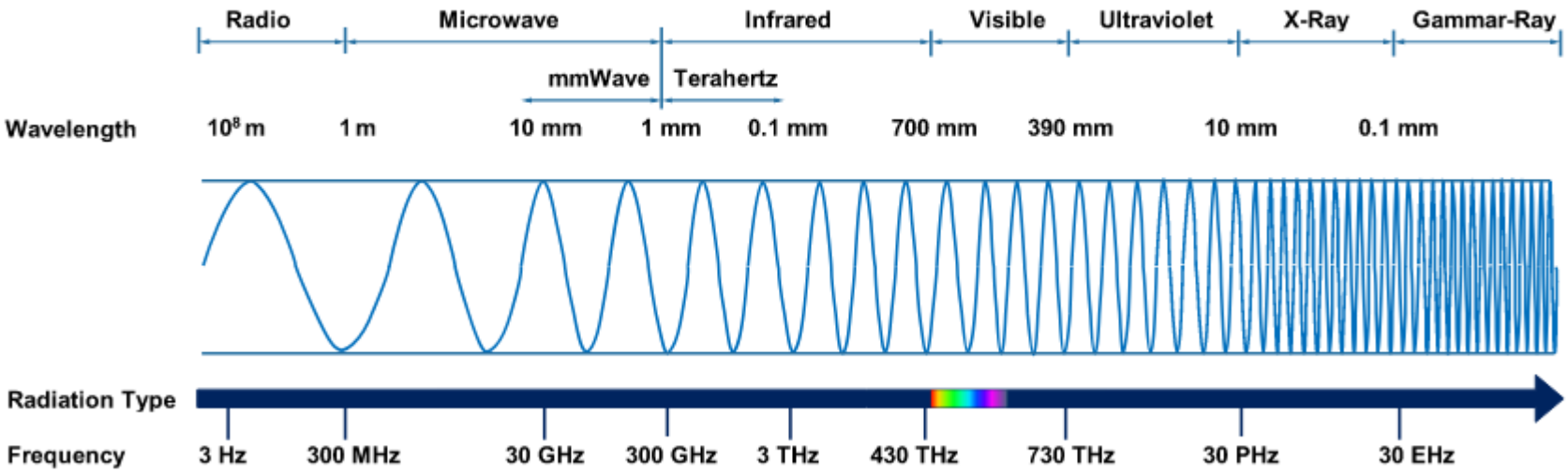
Ultra Experience Layer
(extremely high data rates, high-resolution positioning/sensing...)

Operating bandwidth of each generation follows the "five-times more" rule

2G: **200 KHz**
3G: **5 MHz**
4G: **20 MHz**
5G: **100 MHz**
6G: **500 MHz–1 GHz**

- **Low/mid-bands** remain the most cost-effective way for wide coverage
- **mmWave bands** become mature in 6G
- **THz bands** open new possibilities for sensing and communication

THz Spectrum



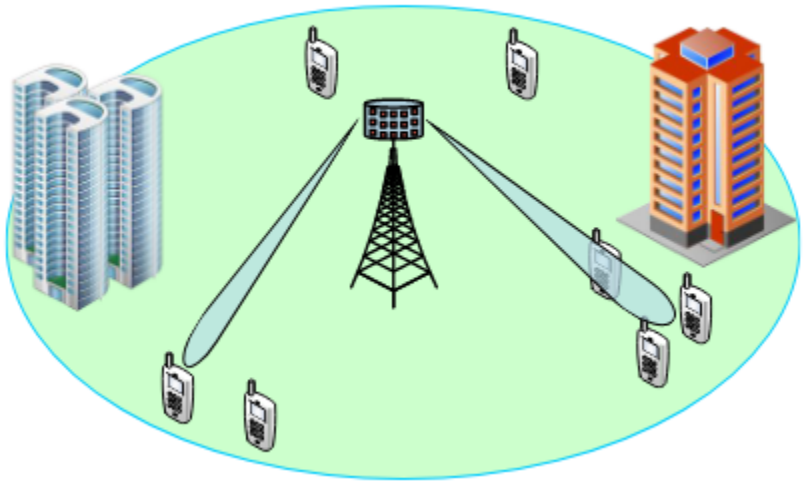
- Up to 100 Gbps with multi-GHz available bandwidth.
- More secure communications
  - the narrow beam and short pulse duration limit eavesdropping.
- Pass through numerous low-loss dielectric, nonmetallic, and low-absorption materials such as paper, plastic, ceramic, clothes, and packaging materials.
- Scatters less than near-infrared and optical approaches due to its longer wavelength.

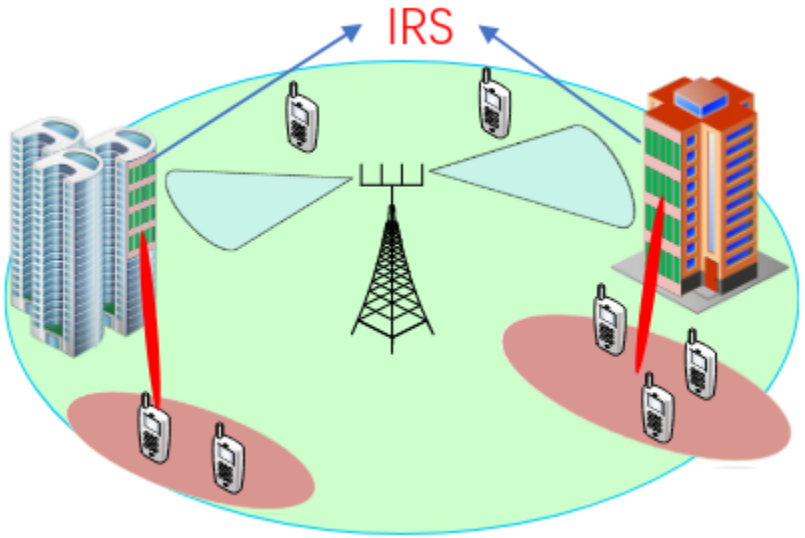
Optical wireless communication (OWC) – Visible Light Communication (VLC)

- most promising spectrum range of OWC/VLC is 430-790 THz
- LED can play a dual role
  - They are everywhere
  - fast switch to diff light levels → encoding
- Sort-range communication / line-of-sight (LOS)
  - Low deployment cost – LEDs are everywhere
  - VLC offers extremely high BW (Tbps)
  - Spectrum is unlicensed (yet?)
  - Enhanced security → absolute fading/shadowing
  - No electromagnetic radiation and/or interference → good for aircrafts

Intelligent reflecting surface (IRS)

- Game-changing 6G technology
  - Salient usecase: increase coverage of THz
- Tunable reflective elements
  - Control reflection amplitude and phase
- improve coverage, data throughput and energy efficiency
- Cheap: Planar arrays of metallic or dielectric patches with low power, complexity and cost

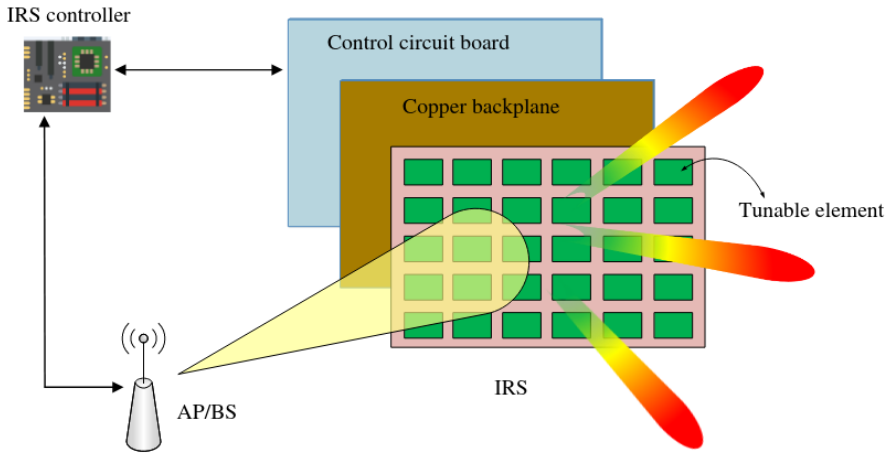




Wu, Qingqing, et al. "Intelligent reflecting surface-aided wireless communications: A tutorial." IEEE transactions on communications 69.5 (2021): 3313-3351.

IRS (cont.)

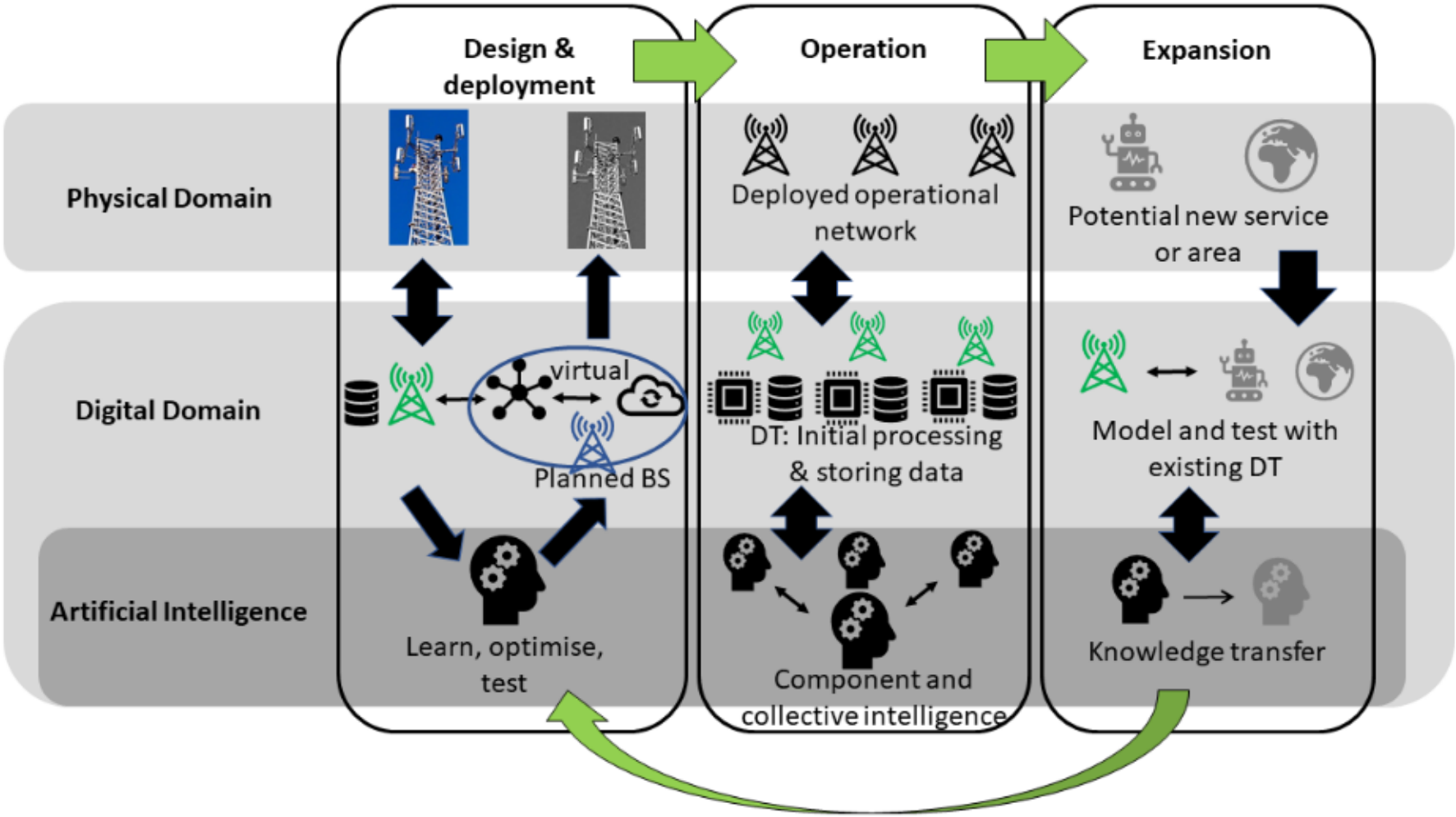
- Metasurface: tunable reflecting elements
  - Mechanical (rotate), functional (liquid crystals) & electrical (phase shift)
- IRS **controller** adjusts wireless propagation environment
  - Tuning requires channel estimation (sensing?)
  - reflection optimization is a hard problem (computationally)
- Channel time variance should be considered too.



Digital Twins (DTs)

- Digital representations of a physical entity or product
  - Including virtual functionality
- Indistinguishable digital counterpart for practical purposes
  - system simulation, integration, testing, monitoring, and maintenance
- 3 deployment levels:
  - Monitoring: mirror or virtual representation
  - Simulation: exploit virtual functionality (test/dev/predict)
  - Operation: bidiractional interaction of objs & Twins

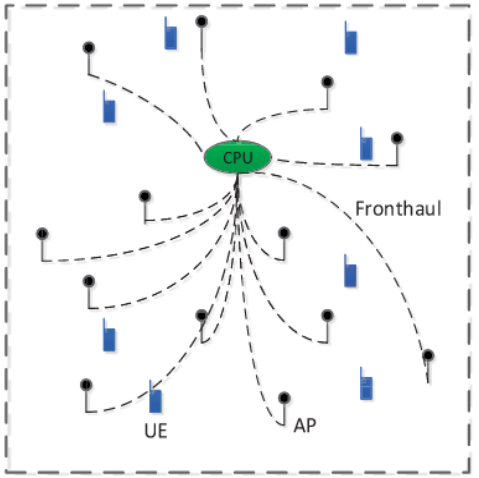
DT network life-cycle

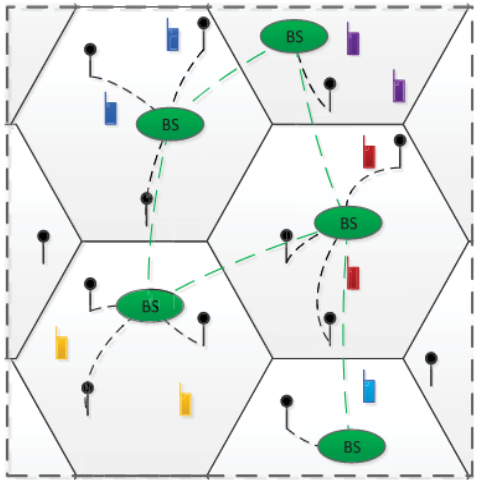


Ahmadi, Hamed, et al. "Networked twins and twins of networks: An overview on the relationship between digital twins and 6G." IEEE Communications Standards Magazine 5.4 (2021): 154-160.

Cell-free MIMO

- Goal: Avoid inter-cell interference & uniform service
- Densely distributed transmitters
- M trans server N users
  - Time-division-duplex (TDD) for up and down link
- Beamforming: spacial division
- Joint transmission: many to one
- Transmit preprocessing: one to many
- Complicated power control at the Aps
  - CPU can become a bottleneck
- Suitable for indoor and hot-spot coverage scenarios





Zhang, Jiayi, et al. "Cell-free massive MIMO: A new next-generation paradigm." IEEE Access 7 (2019): 99878-99888.

Joint Networking and **Sensing**

- Use cases:
  - localization for targets, Imaging, environment reconstruction, Monitoring, gesture & activity recognition
- New performance dimensions
  - Detection probability, sensing resolution and accuracy

https://www.ericsson.com/en/blog/2021/10/joint-sensing-and-communication-6g

Sensing Examples

- High-accuracy localization
  - Latency, Doppler, and angular spectrum information from scattered and reflected wireless signals can be processed to extract coordinates, orientation velocity
  - 3D space/ Device-free objs
  - High accuracy for unmanned Robots
- Simultaneous imaging, mapping and localization
  - Imaging obtains the view, localization obtains location, mapping combines both into a 3D map
  - Map can be used to refine network design, e.g., improve interference
  - Unmanned vehicles see what is behind the corner
- Augmented human senses
  - Wearable devices (or implants)
  - "seeing beyond eyes" concept / see hidden objects with mm-level resolution
  - spectrogram sensing / unique absorption characteristics of materials
    - food calorie detection and environmental PM2.5

Sensing Examples (cont.)

- Infrastructure is there: multiple connented APs/ BSs

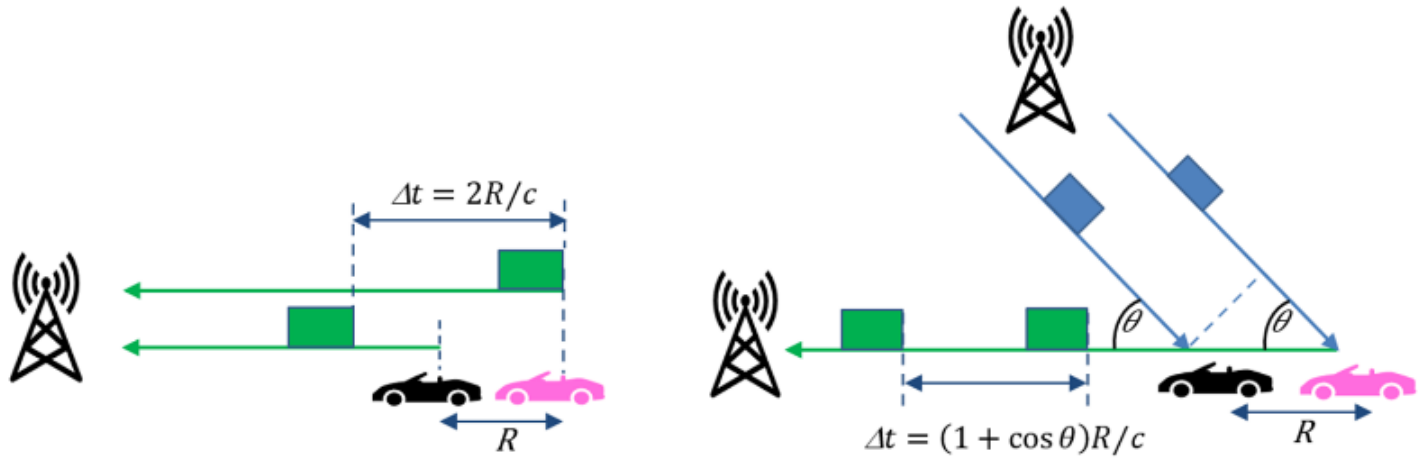
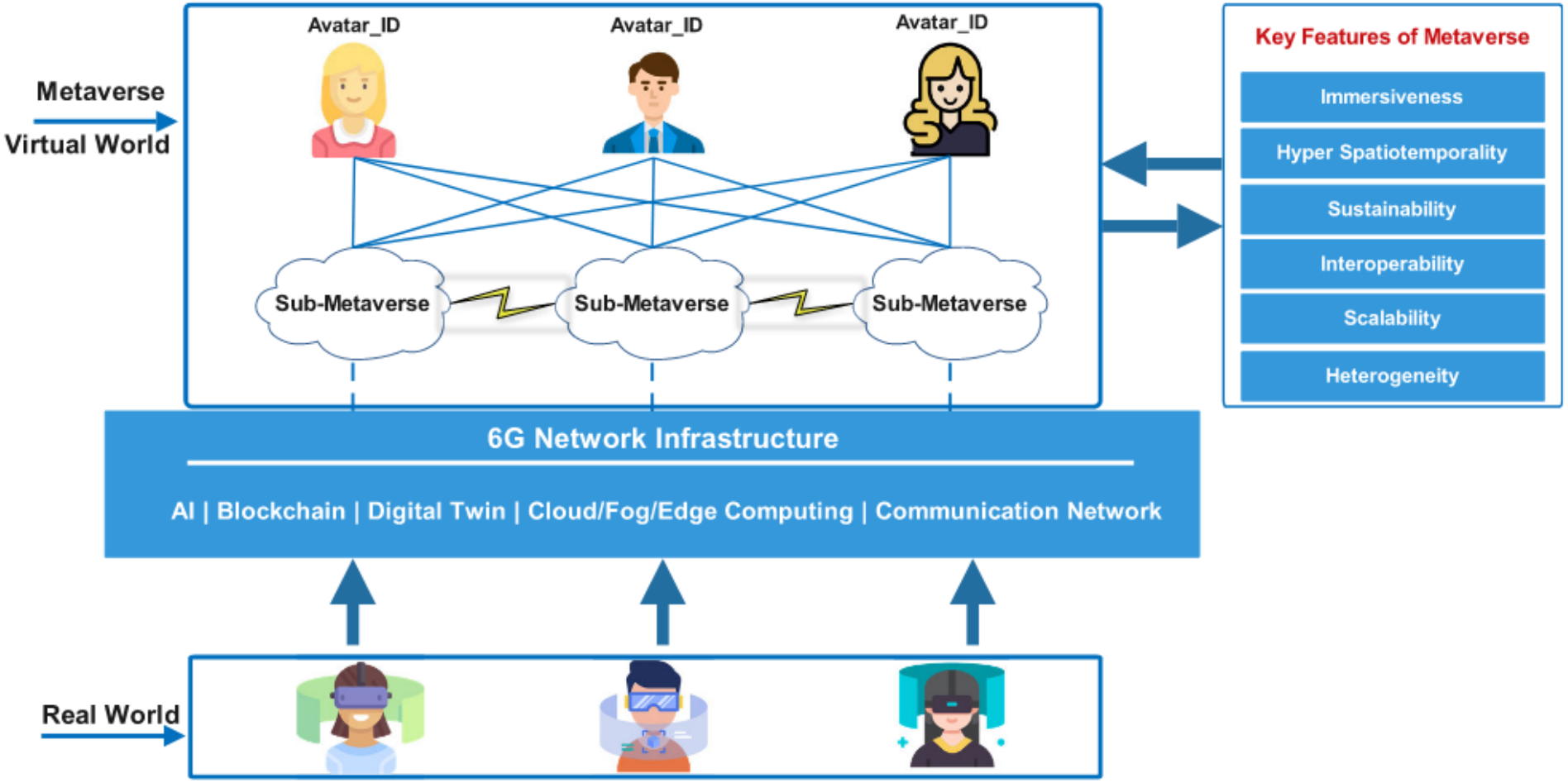


Figure 3: Monostatic (left) and bi-static (right) operation. The time Δt between received pulse echoes gives the distance R between the target positions. Here, 'c' is the speed of light.

Metaverse

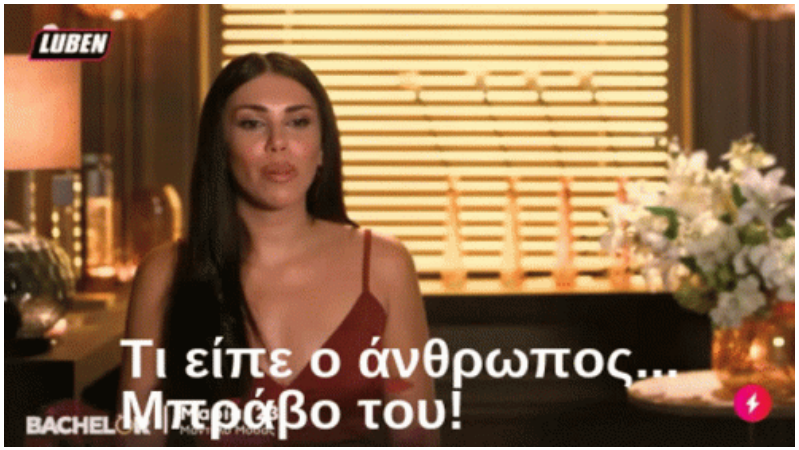
- Stems from AR, AI, and blockchain
- Extended reality (XR)
  - VR everywhere (not just office/home etc)
- two main tenets
  - Digital-physical fusion
    - digital and physical lives will become inextricably linked
  - Human augmentation
    - No cyborgs, rather insights into lives and control to physical via digital

Metaverse (cont.)



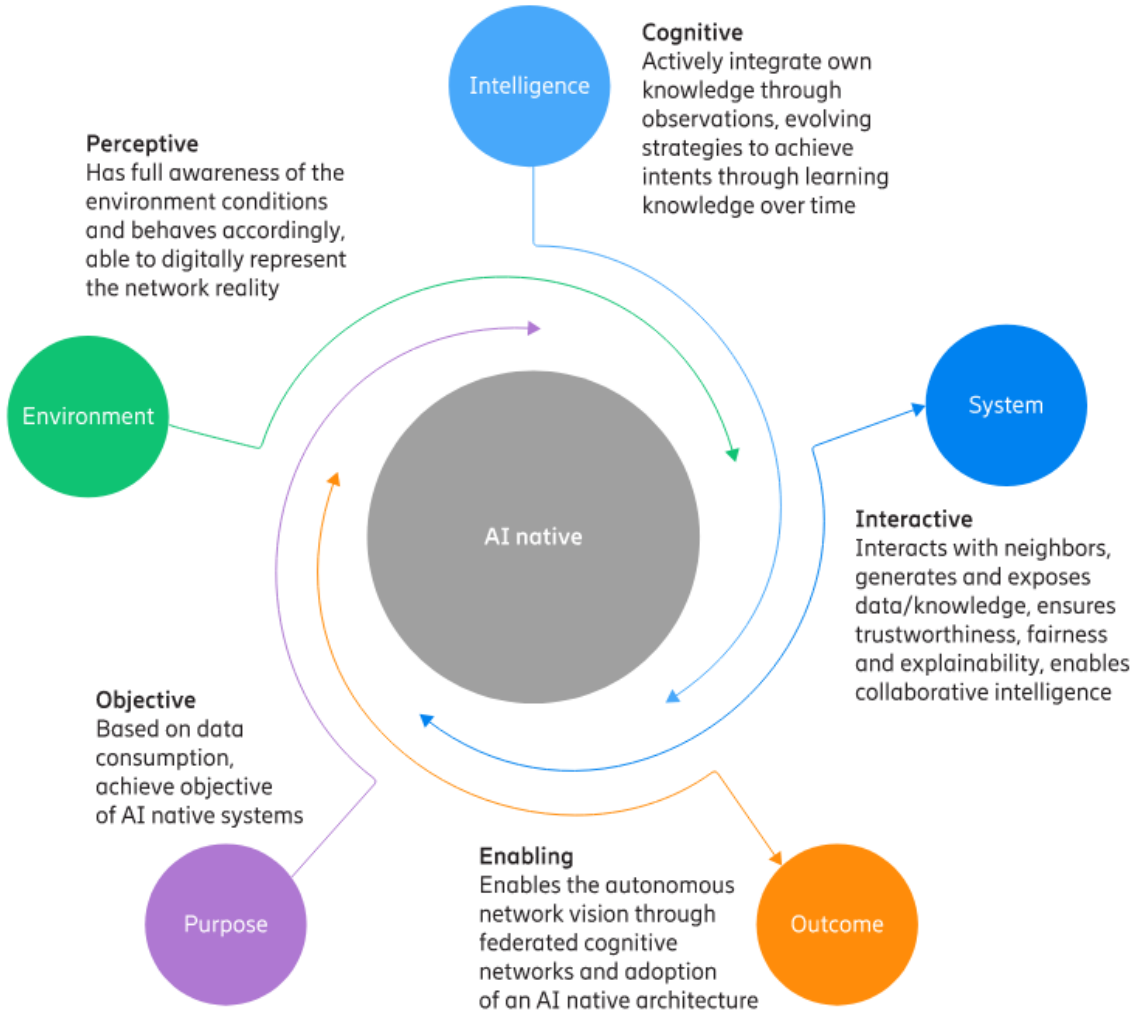
What is Native AI?

- Is having intrinsic trustworthy AI capabilities, where AI is a natural part of the functionality, in terms of **design, deployment, operation, and maintenance**.
- leverages a data-driven and knowledge-based ecosystem, where data/knowledge is consumed and produced to realize new AI-based functionality or augment and **replace static**, rule-based mechanisms with **learning adaptive** AI when needed.”



https://www.ericsson.com/en/reports-and-papers/white-papers/ai-native

Native AI in telecom



Cellural τέλος!

- Ερωτήσεις
- Σχόλια
- Προτάσεις
- Παράπονα;