# Summary of M. Giordani et al.,"Toward 6G Networks Use Cases and Technologies," IEEE Commun. Mag., Mar. 2020, pp. 55-61.

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# Introduction (1/3)

- Sixth generation (6G) connections will move beyond personalized communication toward the full realization of the Internet of Things (IoT) paradigm, connecting not just people, but also computing resources, vehicles, devices, wearables, sensors, and even robotic agents
- The rapid development of data-centric and automated processes, which require a data rate on the order of terabits per second, a latency of hundreds of microseconds, and $10^7$ connections per $km^2$, may exceed even the capabilities of the emerging 5G systems

# Introduction (2/3)

- 6G could very much benefit from even higher spectrum technologies, for example, through terahertz and optical communications
- The need for 3D coverage calls for new cell-less architectural paradigms
- Integrating intelligence in the network
- 6G will be developed to jointly meet stringent network demands (e.g., ultra-high reliability, capacity, efficiency, and low latency)

# Introduction (3/3)

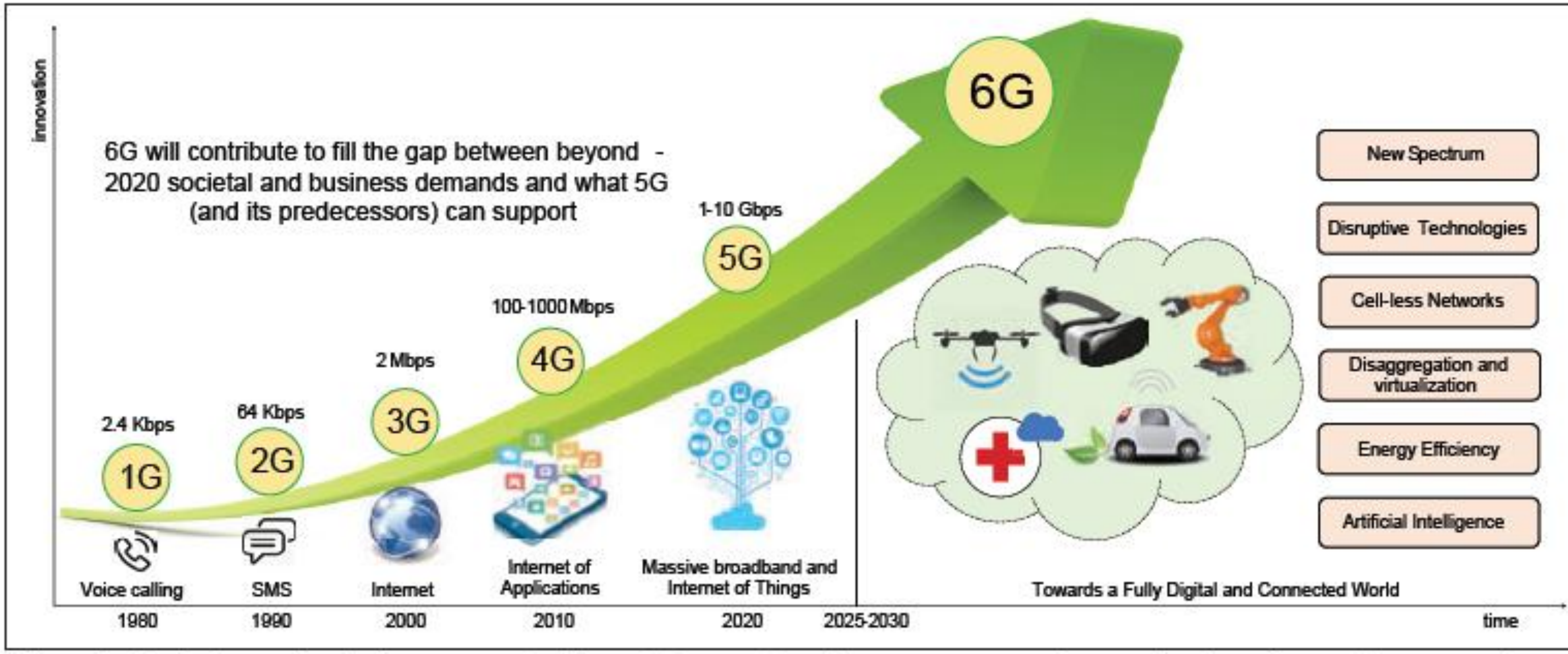


Figure 1. Evolution of cellular networks, from 1G to 6G, with a representative application for each generation.

# 6G Use Cases (1/4)

- Augmented Reality (AR) and Virtual Reality (VR)
  - 5G will trigger the early adoption of AR/VR
  - The proliferation of AR/VR applications will deplete the 5G spectrum, and requires a system capacity above 1 Tb/s, as opposed to the 20 Gb/s target defined for 5G
  - To meet the latency requirements that enable real-time user interaction in the immersive environment, AR/VR cannot be compressed (coding and decoding is a time-consuming process)

# 6G Use Cases (2/4)

- Holographic Telepresence (Teleportation)
  - A raw hologram, without any compression, with colors, full parallax, and 30 fps, would require 4.32 Tb/s. The latency requirement will hit sub-milli-second, and thousands of synchronized view angles will be necessary
- eHealth
  - 6G will revolutionize the healthcare sector, eliminating time and space barriers through remote surgery and guaranteeing health care workflow optimizations

# 6G Use Cases (3/4)

- Pervasive Connectivity
  - Mobile traffic is expected to grow three-fold from 2016 to 2021, pushing the number of mobile devices to the extreme, with $10^7$ devices per $km^2$ in dense areas (up from $10^6$ in 5G)
- Industry 4.0 and Robotics
  - 6G will fully realize the Industry 4.0 revolution started with 5G, that is, the digital transformation of manufacturing through cyber physical systems and IoT services
- Unmanned Mobility
  - The increasing number of sensors per vehicle will demand increasing data rates (with terabytes generated per driving hour)

# 6G Use Cases (4/4)

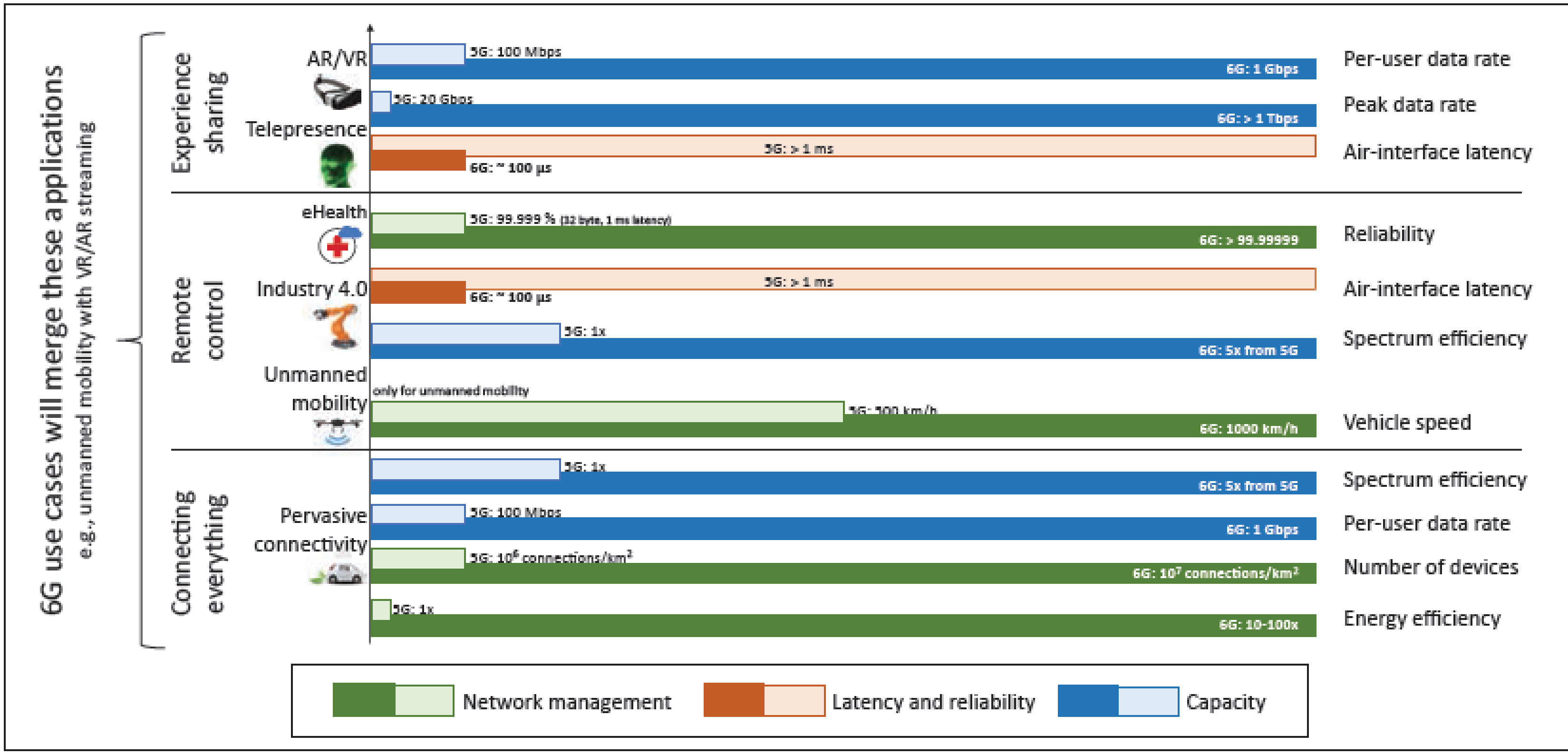


**Figure 2.** Representation of multiple KPIs of 6G use cases, together with the improvements with respect to 5G networks, using data from [1–9].

# 6G Enabling Technologies (1/2)

| Enabling Technology | Potential | Challenges | Use cases |
|---|---|---|---|
| **New spectrum** | | | |
| Terahertz | High bandwidth, small antenna size, focused beams | Circuit design, high propagation loss | Pervasive connectivity, industry 4.0, holographic telepresence |
| VLC | Low-cost hardware, low interference, unlicensed spectrum | Limited coverage, need for RF uplink | Pervasive connectivity, eHealth |
| **Novel PHY techniques** | | | |
| Full duplex | Continuous TX/RX and relaying | Management of interference, scheduling | Pervasive connectivity, industry 4.0 |
| Out-of-band channel estimation | Flexible multi-spectrum communications | Need for reliable frequency mapping | Pervasive connectivity, holographic telepresence |
| Sensing and localization | Novel services and context-based control | Efficient multiplexing of communication and localization | eHealth, unmanned mobility, industry 4.0 |
| **Innovative network architectures** | | | |
| Multi-connectivity and cell-less architecture | Seamless mobility and integration of different kinds of links | Scheduling, need for new network design | Pervasive connectivity, unmanned mobility, holographic telepresence, eHealth |
| 3D network architecture | Ubiquitous 3D coverage, seamless service | Modeling, topology optimization and energy efficiency | Pervasive connectivity, eHealth, unmanned mobility |
| Disaggregation and virtualization | Lower costs for operators for massively-dense deployments | High performance for PHY and MAC processing | Pervasive connectivity, holographic telepresence, industry 4.0, unmanned mobility |
| Advanced access-backhaul integration | Flexible deployment options, outdoor-to-indoor relaying | Scalability, scheduling and interference | Pervasive connectivity, eHealth |
| Energy-harvesting and low-power operations | Energy-efficient network operations, resiliency | Need to integrate energy source characteristics in protocols | Pervasive connectivity, eHealth |
| **Intelligence in the network** | | | |
| Learning for value of information assessment | Intelligent and autonomous selection of the information to transmit | Complexity, unsupervised learning | Pervasive connectivity, eHealth, holographic telepresence, industry 4.0, unmanned mobility |
| Knowledge sharing | Speed up learning in new scenarios | Need to design novel sharing mechanisms | Pervasive connectivity, unmanned mobility |
| User-centric network architecture | Distributed intelligence to the endpoints of the network | Real-time and energy-efficient processing | Pervasive connectivity, eHealth, industry 4.0 |
| Not considered in 5G | | With new features/capabilities in 6G | |

Table 1. Comparison of 6G enabling technologies and relevant use cases.

# 6G Enabling Technologies (2/2)

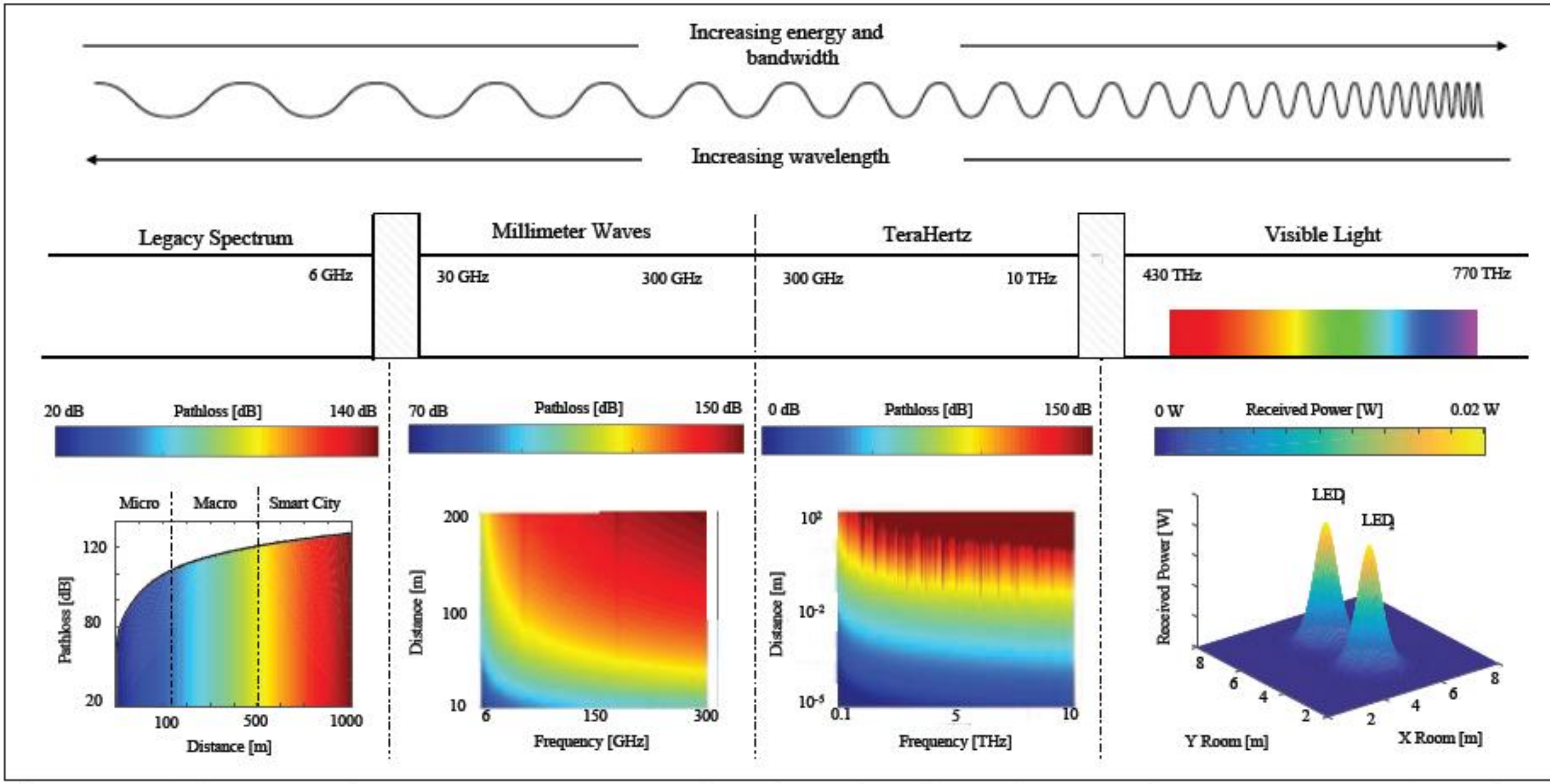


**Figure 3.** Path loss for sub-6 GHz, mmWave, and terahertz bands, and received power for VLC. The sub-6 GHz and mmWave path loss follows the 3GPP models considering both line-of-sight (LoS) and non-LoS (NLoS) conditions, while LoS-only is considered for terahertz [10] and VLC [11].

# Disruptive Communication Technologies (1/2)

- Massive multiple-input multiple-output (MIMO) and mmWave communications are both key enablers of 5G networks
- 6G networks are expected to rely on conventional spectrum (i.e., sub-6 GHz and mmWaves) but also on frequency bands that have not yet been considered for cellular standards, namely the terahertz band and visible light communications (VLC)
- Terahertz Communications
- VLC
- Full-Duplex Communication Stack

# Disruptive Communication Technologies (2/2)

- Novel Channel Estimation Techniques (e.g., Out-of-Band Estimation and Compressed Sensing)
- Sensing and Network-Based Localization

# Innovative Network Architectures (1/2)

- Tight integration of multiple frequencies and communication technologies and cell-less architecture
- 3D Network Architecture
- Disaggregation and Virtualization of the Networking Equipment
- Advanced Access-Backhaul Integration
- Energy-Harvesting Strategies for Low Power Consumption Network Operation

# Innovative Network Architectures (2/2)

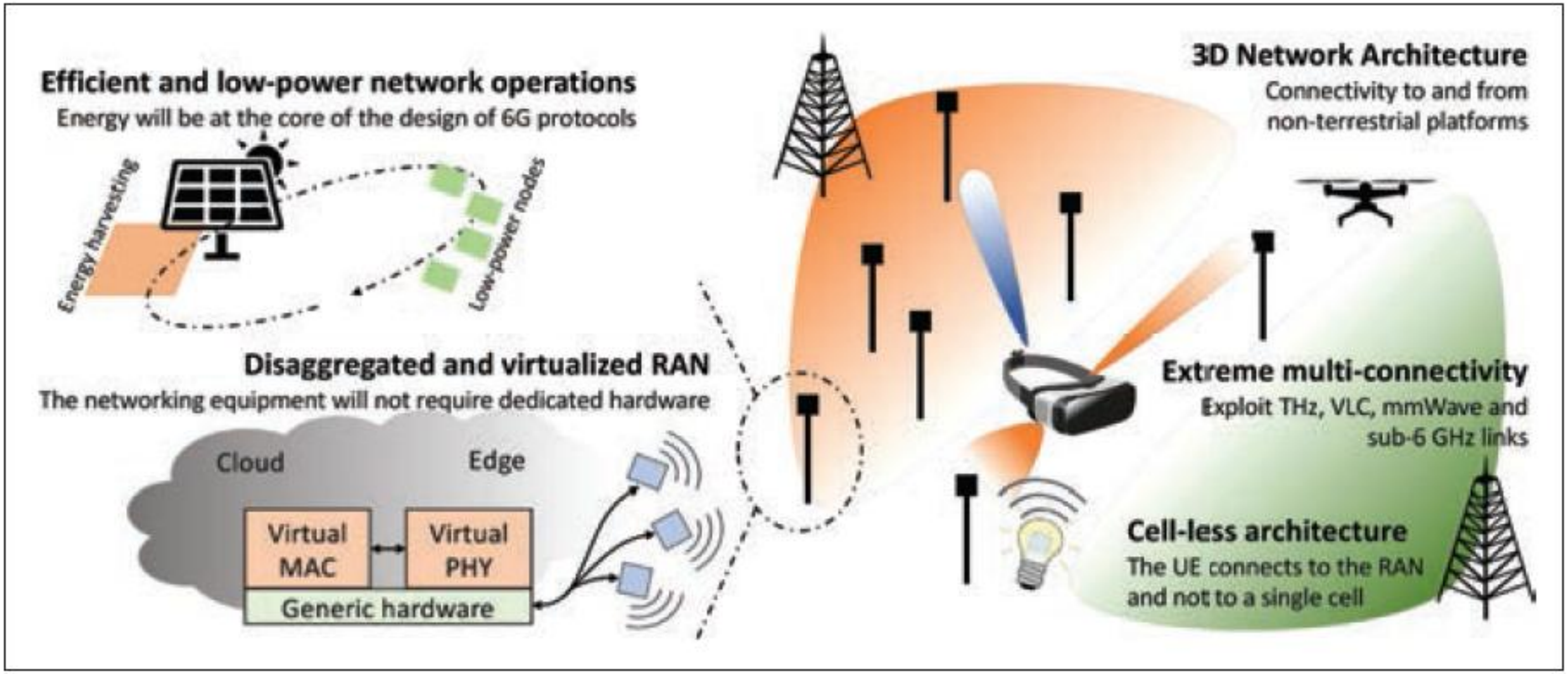


Figure 4. Architectural innovations introduced in 6G networks.

# Integrating Intelligence in the Network (1/1)

- Learning Techniques for Data Selection and Feature Extraction
- Inter-User Inter-Operatpor Knowledge Sharing
- User-Centric Network Architecture