Is 5G the Final Frontier? Considerations towards the 6G

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Introduction: Assessing the Current State

Current Societal and Technological Trends

- *Modern societies are becoming more and more data-centric, data-dependent and automated.*
- *Radical automation of industrial manufacturing processes will drive productivity.*
- *Autonomous systems are hitting our roads, oceans and air space.*
- *Millions of sensors will be embedded into cities, homes and production environments, structuring the IoT.*
- *New systems operated by artificial intelligence (AI) residing in local "cloud" and "fog" environments will enable a plethora of new applications.*

Current Societal and Technological Trends

Facing to and dealing with a multiplicity of challenges:

- Energy efficiency and environmental responsibility
- Efficient industries and agricultural
- Efficient public services and socializing
- Smart cities, interconnected communities
- Security and privacy for individuals

4G and 5G have started to address these trends…

…but we are just at the start of the path

Evolution of the 5G Technology: Challenges

Peak data rate

5G will offer significantly faster data speeds, where peak data rates can hit 20Gbps downlink and 10Gbps uplink per mobile base station.

Low latency

Latency, the time it takes data to travel from one point to another, should be at 4 milliseconds in ideal circumstances, and at 1 millisecond for use cases that demand the utmost speed.

Efficiency & Reliability

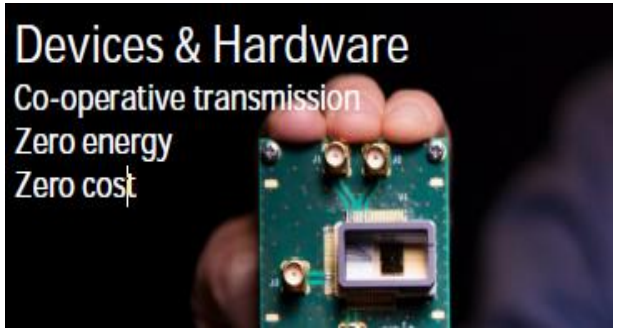
Radio interfaces should be energy efficient when in use, and drop into low-energy mode when not in use. Ideally, a radio should be able to switch into a low-energy state within 10 milliseconds when no longer in use.

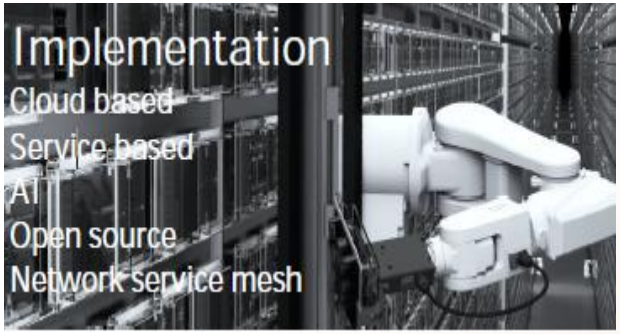
Mobility

With 5G, base stations should support movement from 0 to 310 mph. This means the base station should work across a range of antenna movements.

However... *The number of active connections is estimated at 125 billion at the end of 2030, which exceeds the capabilities of 5G communication...*

Evolution of the 5G Technology – Current Views





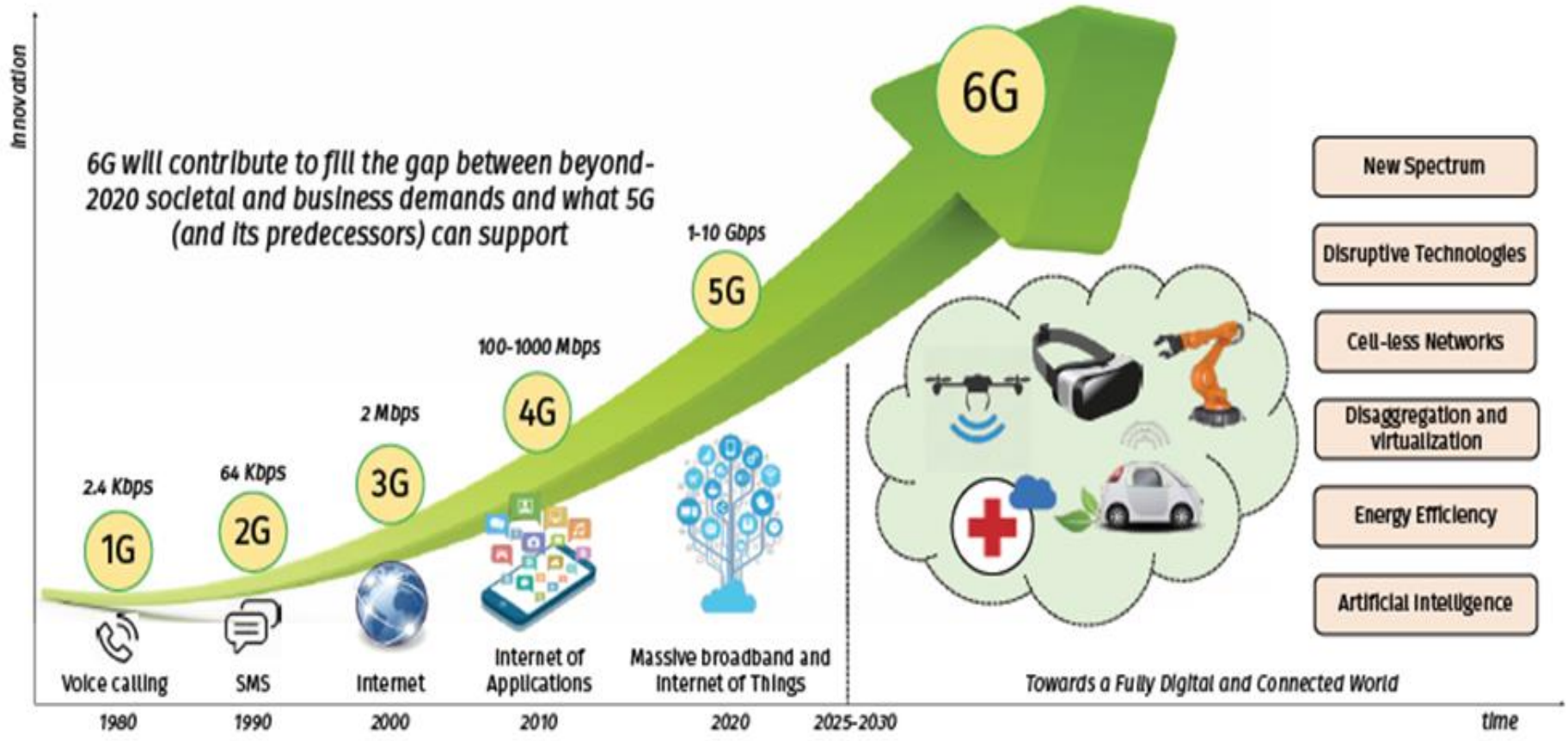
Integrated connectivity and mobility

Zero touch

Trusted Networking (low error transmission)

5G currently faces numerous challenges
due to the fast evolution of the underlying infrastructures/networks/facilities intending to successfully "meet" new requirements for providing facilities/services to the various categories of the involved users...

Evolutionary process towards 6G



Each generation has been designed to meet the specific needs of end-users and network operators

[Source: Giordani, M., Mezzavilla, et al. (2020): Towards 6G Networks: Use Cases and Technologies. IEEE Communications Magazine, 58(3), 55-61]

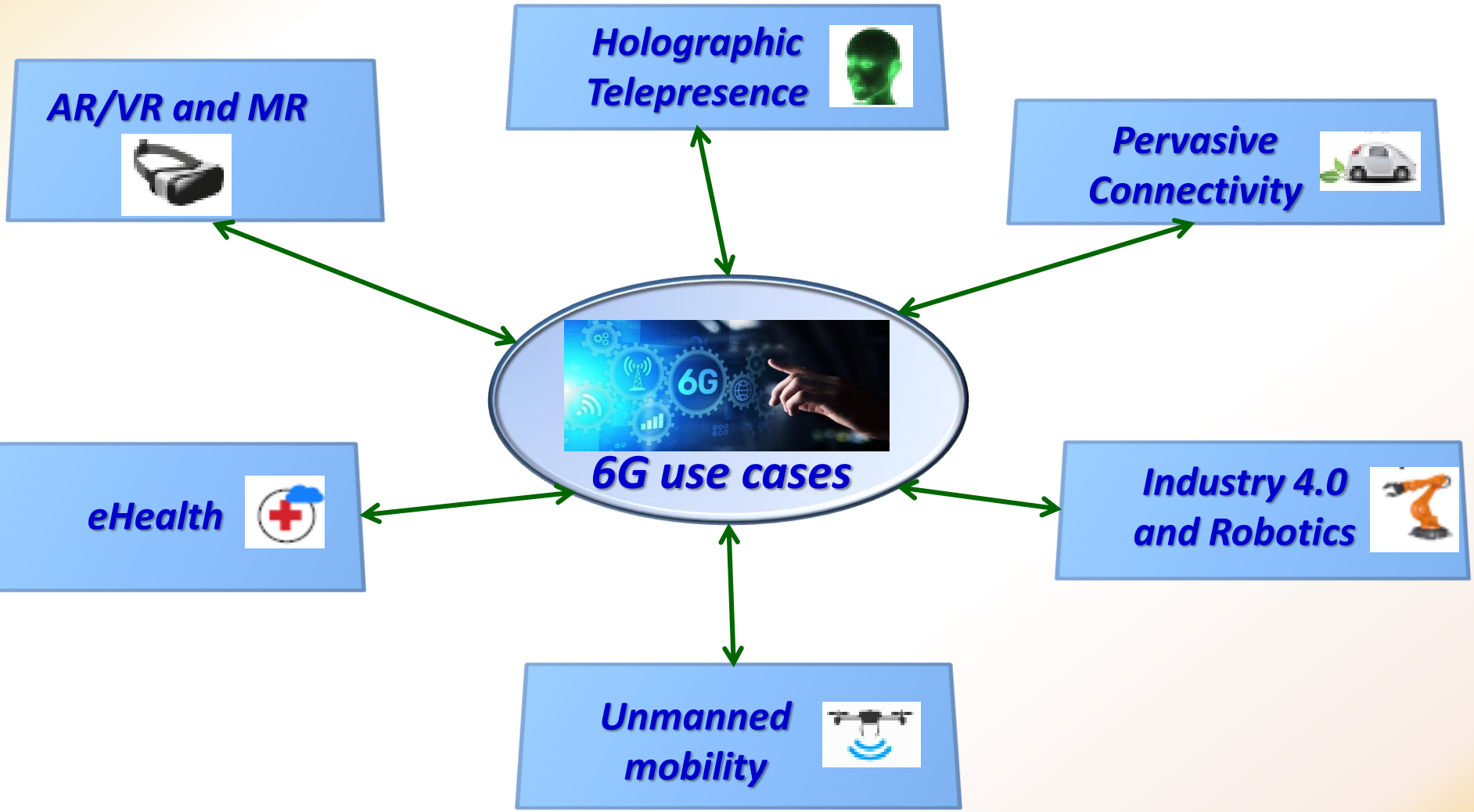
Towards 6G: Use Cases

6G Use Cases

- *5G presents trade-offs on latency, energy, costs, hardware complexity, throughput, and end-to-end reliability.*
  For example, the requirements of mobile broadband and ultra-reliable low-latency communications are "addressed" by different configurations of 5G networks.

- *6G, on the contrary, will be developed to "jointly meet" stringent network demands (e.g., ultra-high reliability, capacity, efficiency, and low latency) in a holistic fashion,*
  in view of the foreseen economic, social, technological, and environmental context of the 2030 era.

Some Essential 6G Use Cases



Augmented Reality (AR), Virtual Reality (VR) & Mixed Reality (MR)

Current state:

- Video-over-wireless has demonstrated a high potential, especially in 4G.
- The increasing use of streaming and multimedia services currently justifies the adoption of new spectrum (*i.e., mmWaves*) to guarantee higher capacity in 5G.
- However, this multi-Gbps opportunity is attracting new applications which are more data heavy than bi-dimensional multimedia content.

Future challenges:

- **5G triggers the early adoption of AR/VR , towards MR.**
- **The explosion of AR/VR applications will exhaust the 5G spectrum and will require a system capacity above 1 Tbps** *(as opposed to the 20 Gbps target defined for 5G).*
- Furthermore, to meet the latency requirements that enable real-time user interaction in the immersive environment, **AR/VR cannot be compressed and the per-user data rate needs to "touch" the Gbps**, *in contrast to the more relaxed 100 Mbps 5G target.*

Holographic Telepresence (Teleportation)

Current state:

- Holographic Telepresence (Teleportation) is a modern and innovative trends that will further enhance interactive communication, *for a great variety of purposes (business, entertainment, education, etc.).*

Future challenges:

- **Holographic Telepresence will appear as a complement of AR/VR/MR applications.**
- **Specific requirements for a 3D holographic display will be a core issue for 6G** *(for example, a raw hologram, without any compression, with colors, full parallax and 30 fps, would require 4.32 Tbps).*
- The **latency requirement will implicate for thousands of synchronized view angles**, *as opposed to the few required for VR/AR.*
- **In order to fully realize an immersive remote experience, all the 5 human senses are destined to be digitized and transferred across future networks, *thus increasing the overall target data rate.***

eHealth

Current state:

- eHealth is an indispensable domain of modern economy and society, *offering multiple benefits for the society and the business actors.*
- *Network upgrade and modernization offer new opportunities for further growth in a multi-converged environment*
- *Current major limitations are due to the lack of real-time tactile feedback*.

Future challenges:

- **6G will revolutionize the health-care sector, eliminating time and space barriers through remote surgery and guaranteeing health-care workflow optimizations.**
- **eHealth services challenge the ability to meet specific QoS requirements,** *implicating for:* ***continuous connection availability*** *(99.99999% reliability),* *ultra-low latency* *(sub-ms) and* ***mobility support***.
- The **increased spectrum availability will offer guarantee to fulfill necessary KPIs**, *together with 5-10x gains in spectral efficiency.*

Pervasive Connectivity

Current state:

- **Mobile traffic is expected to grow 3-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)* **and more than 125 billion devices worldwide by 2030.**

Future challenges:

- **6G will connect personal devices, sensors** *(to implement the smart city paradigm)*, **vehicles and others from the IoT world,** *stressing already congested networks.*
- **6G networks will require a higher overall energy efficiency (10-100x with respect to 5G),** *to enable scalable, low-cost deployments, with low environmental impact and better coverage.*
- **6G networks will provide seamless and pervasive connectivity in a variety of different contexts, matching strict QoS requirements in outdoor and indoor scenarios.**

Industry 4.0 and Robotics

Current state:

- **5G has started the digital transformation of manufacturing** through cyber-physical systems and IoT services.
- **Industry 4.0 has just been revolutionized, while robotics are penetrating major industrial sections.**

Future challenges:

- **6G will further support the Industry 4.0 revolution** *and will enable Internet-based diagnostics, maintenance, operation and direct machine communications in a cost-effective, flexible and efficient way.*
- **Automation comes with its own set of requirements in terms of reliable and isochronous communication**, *which 6G is positioned to address through various disruptive technologies.*
- **Promotion of real-time operations** *with: (i) guaranteed μs delay jitter, and; (ii) Gbps peak data rates for AR/VR industrial applications (e.g., for training, inspection)*

Unmanned Mobility

Current state:

- **The evolution towards fully autonomous transportation systems offers various benefits** *(i.e., safer traveling, improved traffic management, support for infotainment, etc.).*
- **Flying vehicles (drones) represent a huge potential for various scenarios** (*e.g., construction, first responders)*

Future challenges:

- **Connecting autonomous vehicles demands unprecedented levels of reliability and low latency** (i.e., above 99.99999% and below 1 ms, respectively) **even in ultra-high mobility scenarios** (up to 1000 km/h).
- **The increasing number of sensors per vehicle will demand increasing data rates** *(with Terabytes generated per driving hour),* **beyond current network capacity.**
- **Drones will need improved capacity for expanding Internet connectivity.**
- **6G will pave the way for connected vehicles *through advances in hardware, software, and the new connectivity solutions.***

Towards 6G: Further Concerns around Use Cases and Technological Background

Reduced Latency, Precision Positioning and Enhanced Connectivity

Moving towards the 6G realization…

Zero Perceived Latency

Internet of Skill

3D scanning & transmission: 100 Tera-pixel/m² [Technical Gazette]

Everything Connected at 2030

[CISCO]

Super-Precision Positioning

Transition from 5G to 6G - KPIs

Enhanced latency, capacity and reliability

Representation of multiple KPIs of 6G use cases, together with the improvements with respect to 5G networks

Comparison of 6G-Enabling Technologies and Related Use Cases

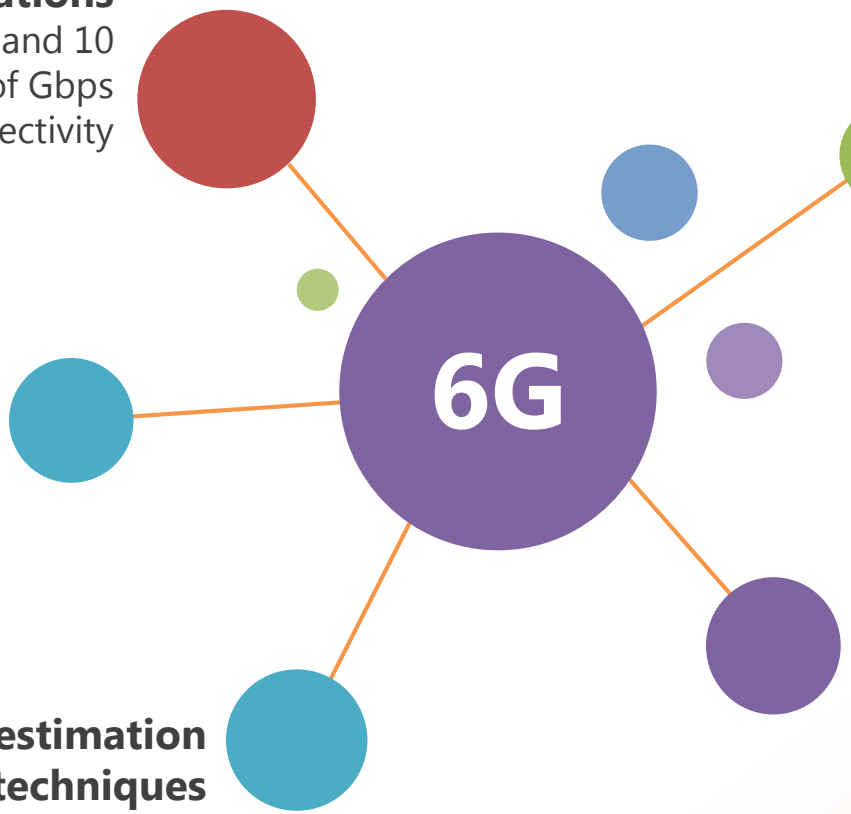
Enabling Technology	Potential	Challenges	Use cases
New Spectrum			
Terahertz	High bandwidth, small antenna size, focused beams	Circuit design, high propagation loss	Pervasive connectivity, industry 4.0, holographic telepresence
VLC	Low-cost hardware, low interference, unlicensed spectrum	Limited coverage, 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 end-points 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	

Disruptive Communication Technologies for 6G Support

Terahertz communications
Operate between 100 GHz and 10 THz, for hundreds of Gbps connectivity

Sensing and network-based localization
6G networks will improve control operations, and rely on context information to shape patterns and reduce interference and predicted handovers

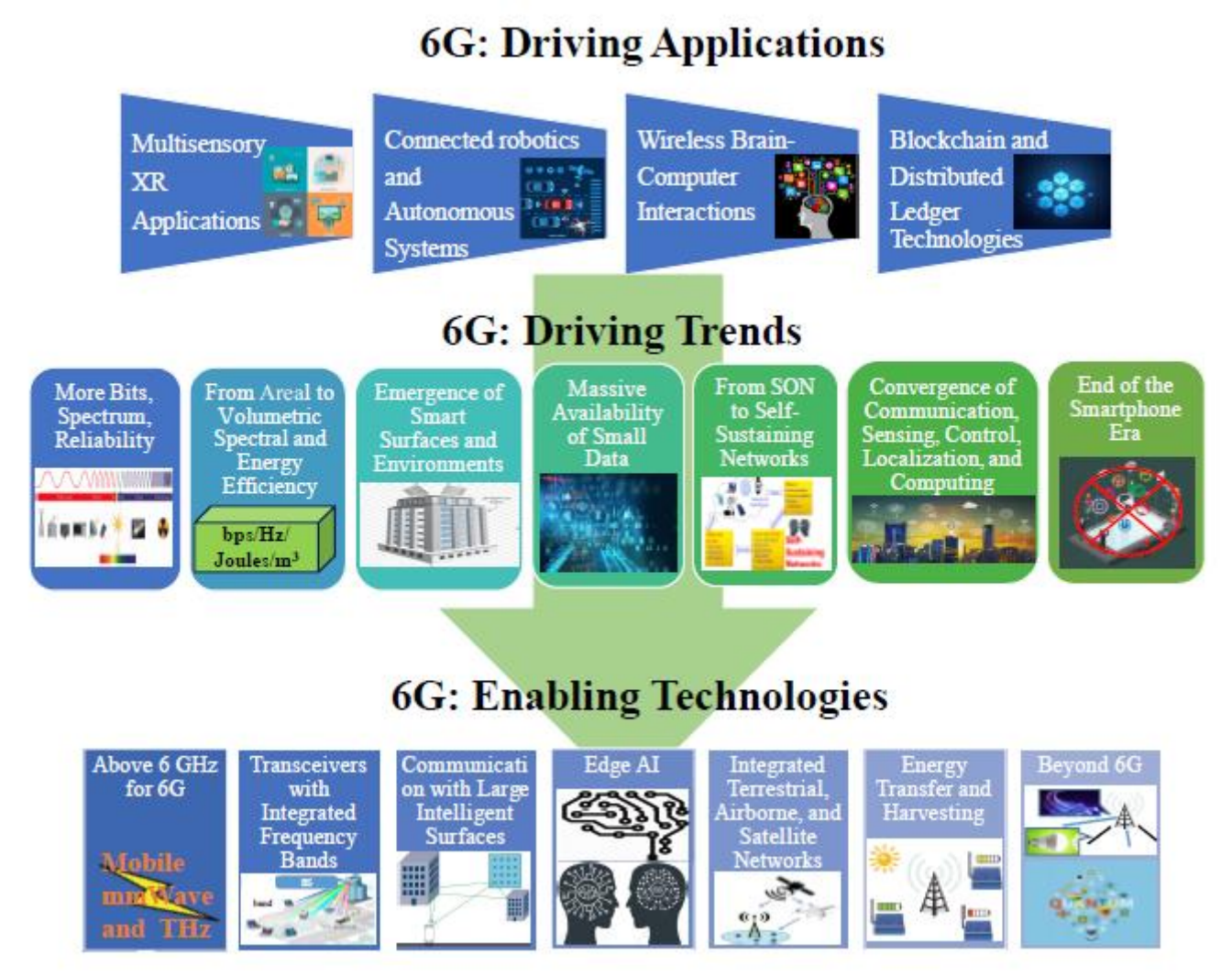
Novel channel estimation techniques
Improved beam management for directional communications



Visible light communication (VLC)
These devices can switch between different light intensities to modulate a signal to be transmitted to a device. Mostly used for indoors

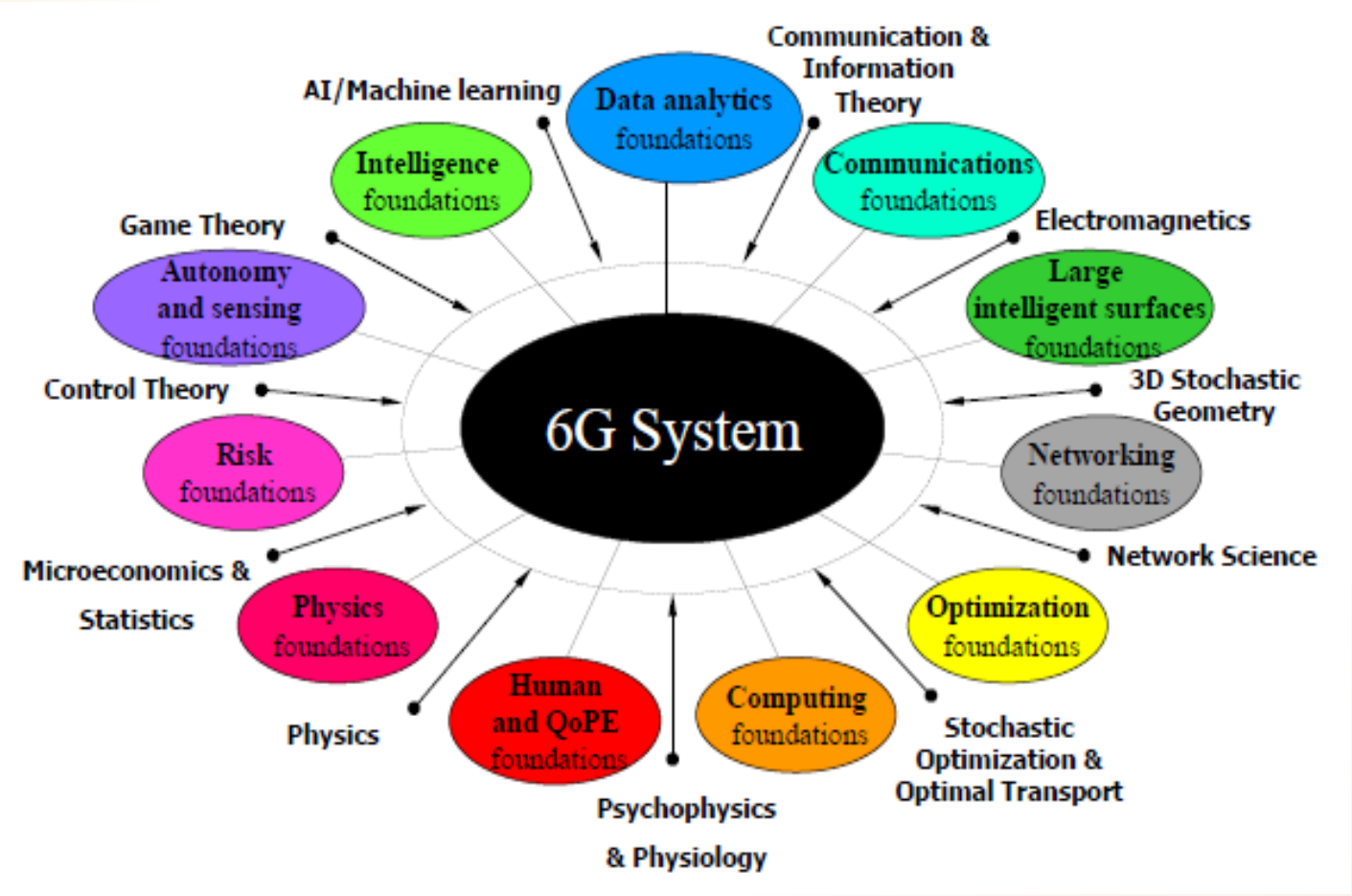
Full-duplex communication stack
The transceivers will be capable of receiving a signal while also transmitting, thanks to carefully designed self-interference-suppression circuits

6G: Driving Applications, Driving Trends & Enabling Technologies

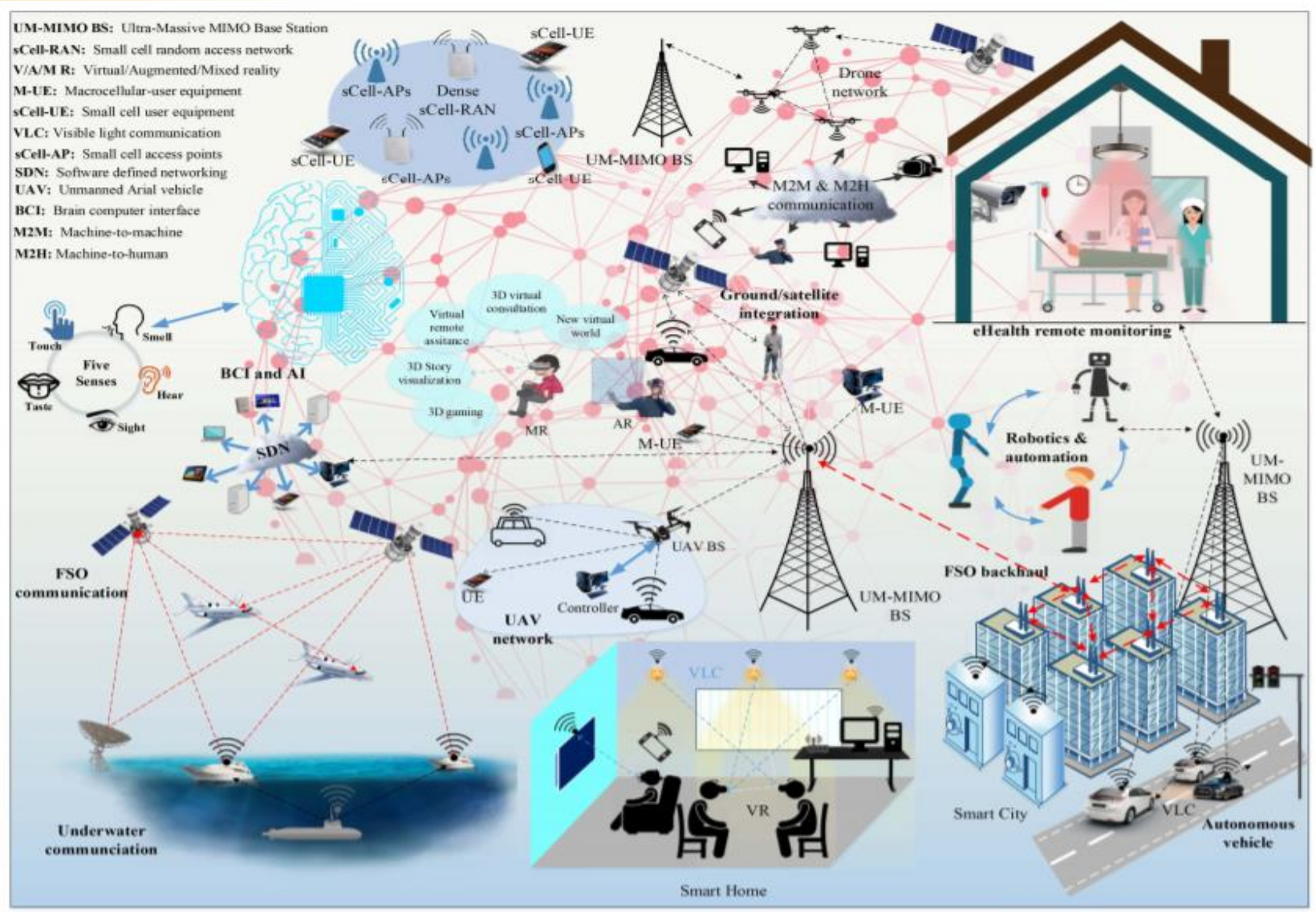


[Source: Saad, W., Benis, M., and Chen, M. (2020): A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems. *IEEE Network, 34(3), 134-142]*

6G: Involved Foundations and Associated Analytical Tools

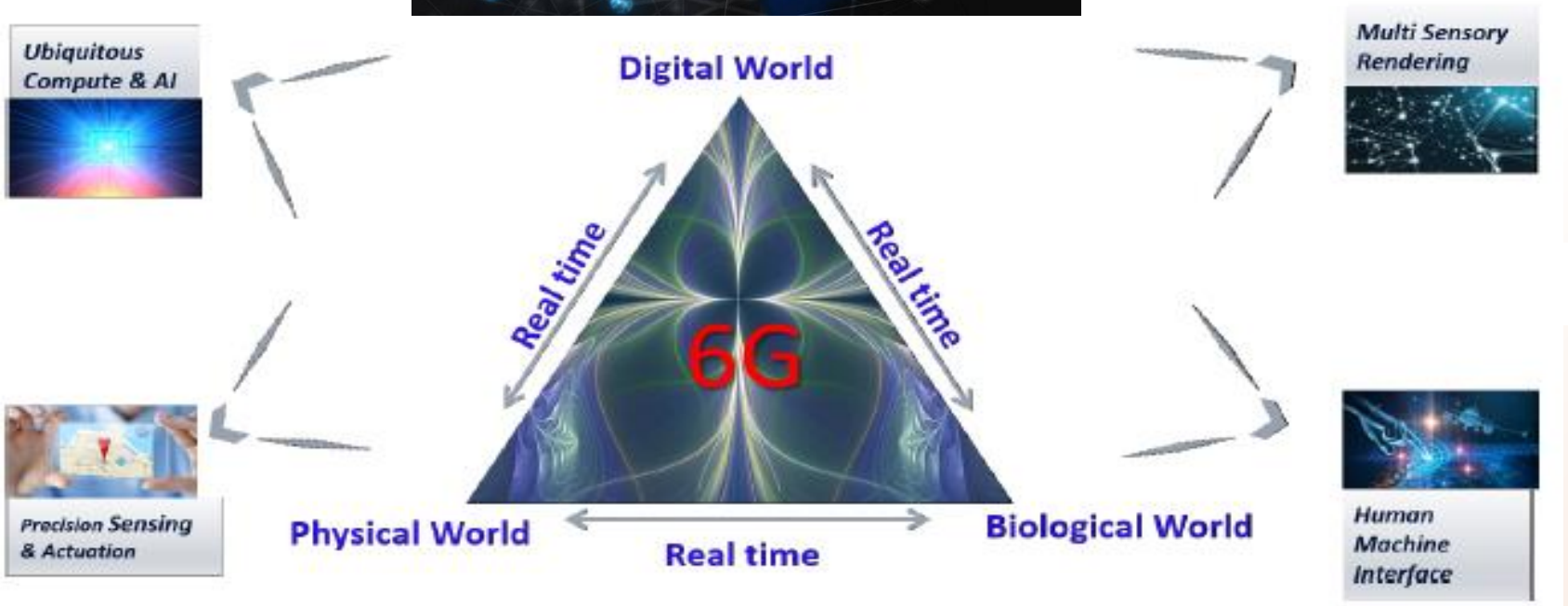


6G: A Bright New World!



[Source: Chowdhury, M.Z., Shahjalal, M., et al. (2020): 6G Wireless Communication Systems: Applications, Requirements, Technologies, Challenges and Research Directions. IEEE Open Journal of the Communications Society, 1, 957-975]

6G for the Interconnection of Physical, Biological and Digital Worlds



[Source: Viswanathan, H., and Mogensen, P.E. (2020): Communications in the 6G Era. IEEE Access, 8, 57063-57074]

Concluding Remarks…

- The rapid development of data-centric and automated processes, require a data rate in order of terabits per second, that exceeds even the capabilities of the emerging 5G systems

- **New 6G technology is essential *in order to promote digital trends and technological innovations for the society of 2030.***

- 6G wireless technology introduces 4 concepts of high-tech development:
  - *Enhanced latency (close to 0.1ms)*
  - *Huge capacity (Very fast – up to THz download speed)*
  - *High reliability (super long range/indoor coverage)*
  - *Superficial mobility (3D positioning)*

- ***Science fiction turns into reality beyond the 5G applications!***

For further communication…

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