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instituto de telecomunicações

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Wireless Communications – RF – Part I

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Wireless Systems

Contents

- Background
  - Categories
  - Demands
  - The trend
  - The requirements
  - Bandwidth and coverage
- Beyond 2023 –Issues
- Channel capacity
- Throughput and how to increase it
- 5&6G

Wireless Systems

Two main categories

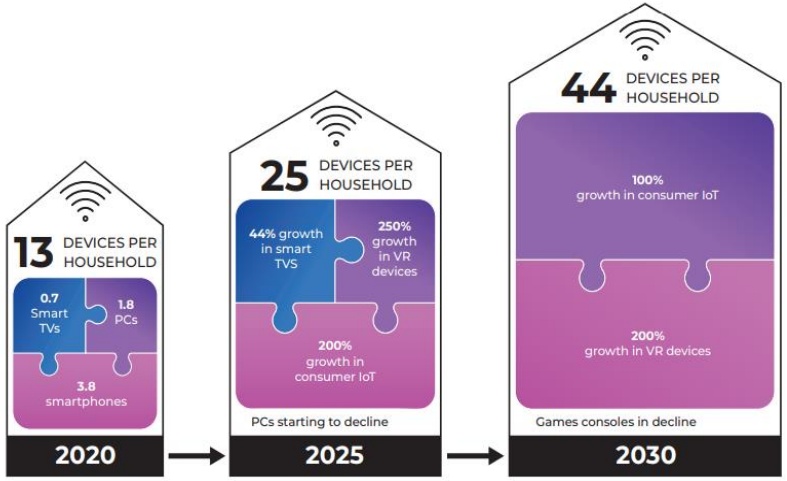
- Broadband
- Cellular

Several types of connections

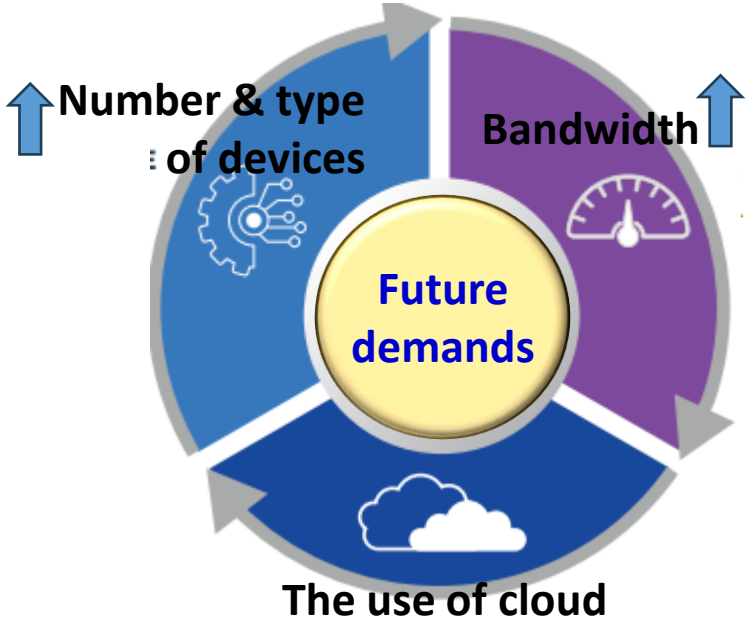
- Optical fiber
- 5G, 6G and beyond
- Fixed wireless access
- wWreless broadband
- cable
- DSL
- Satellite

Not all internet connections are created equal – i.e., asymmetrical connectivity.

Wireless Systems – Demands

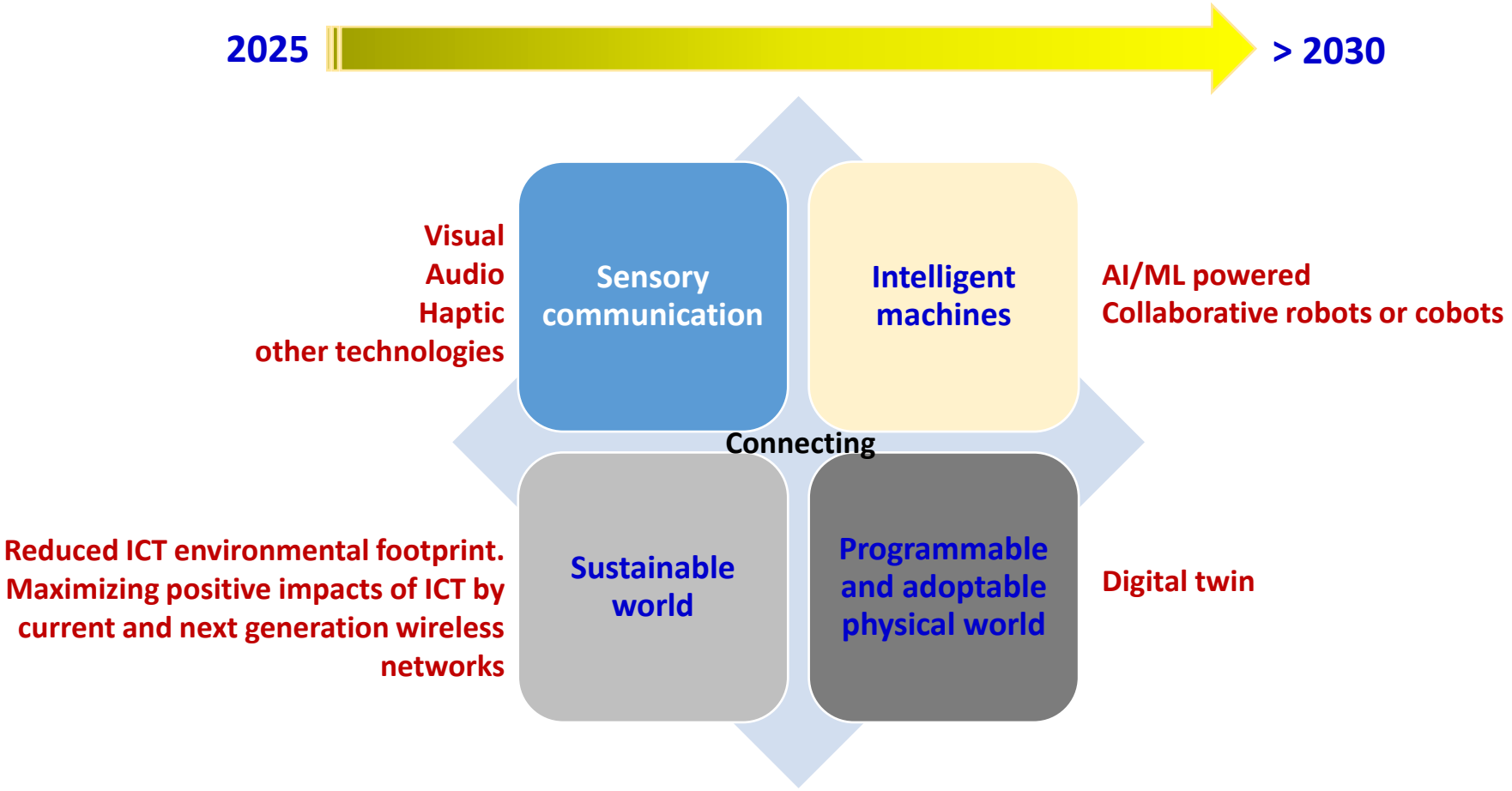


Source: OMDIA, https://worldbroadbandassociation.com/wp-content/uploads/2024/06/Next-generation-broadband-roadmap-2023-to-2030.pdf



- 2020 – 4k Video: 50 Mbps
- 2023 – VR: 100 Mbps
- 2025 – Cloud gaming: 30 Mbps
- 2027 – 8k Video: 300 Mbps
- 2030 - High-quality XR: 1 Gbps
- Beyond 2023
  - XR Free view: 2 Gbps
  - Live 3D TV: 5.5 Gbps

Wireless Technology - The Trend



Wireless Technology - The Requirements

Data rate requirements

Driven by the need to encode a multitude of high-resolution images and videos.

Low delay → The need for video coding → Demands on the data rates ↑

↓

In holographic communication

[e.g., in 6G, 100 Mbit/s and 1 Gbit/s, respectively, need to be supported for high-resolution holographic communication [1]]

↓

Wide-area urban environment (0.004 user/m²)

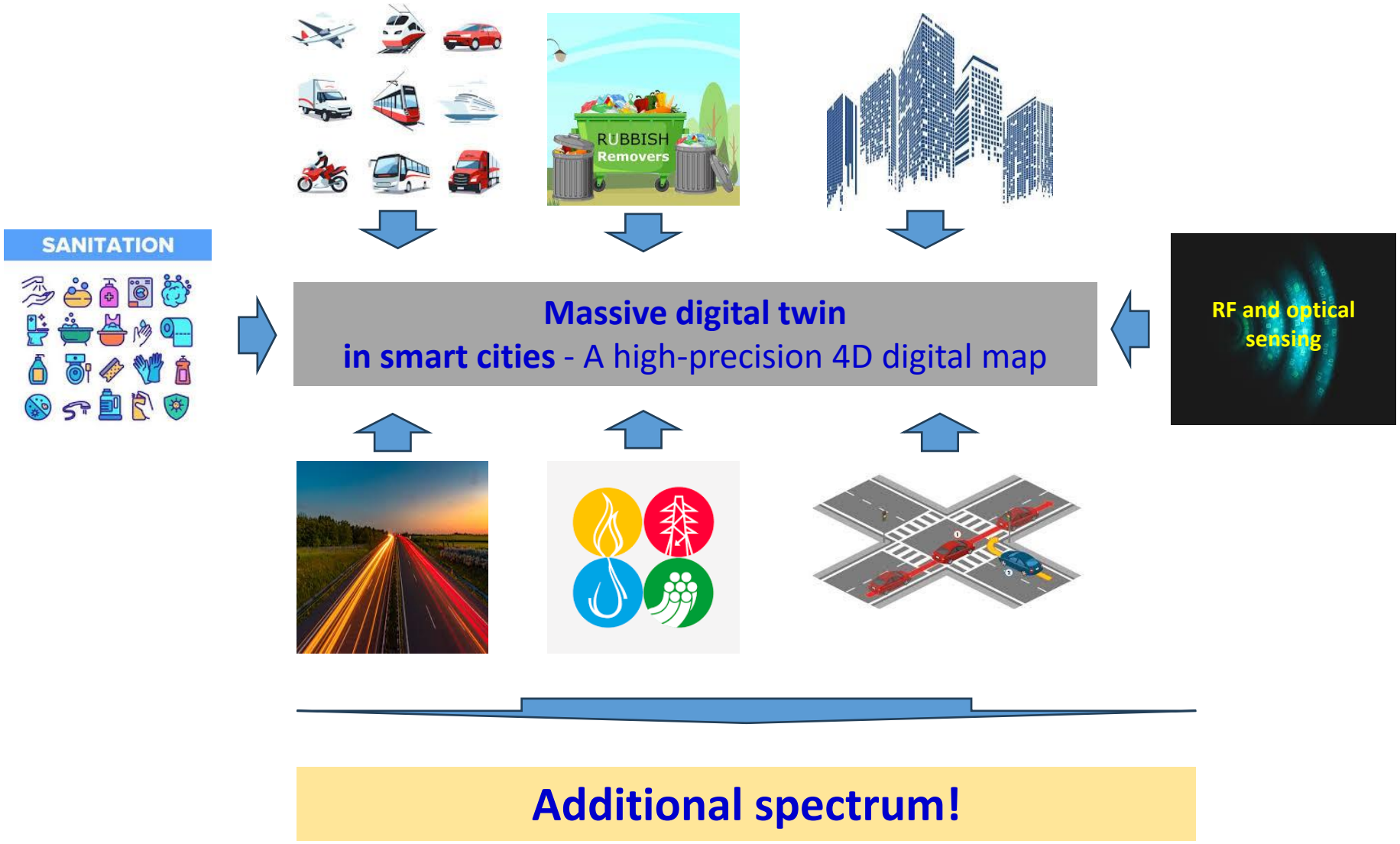
[1.6 Mbit/s/m² in the downlink with 60% traffic offloaded to Wi-Fi [1]

In a dense 3-sector network with inter-site distances of 200 m

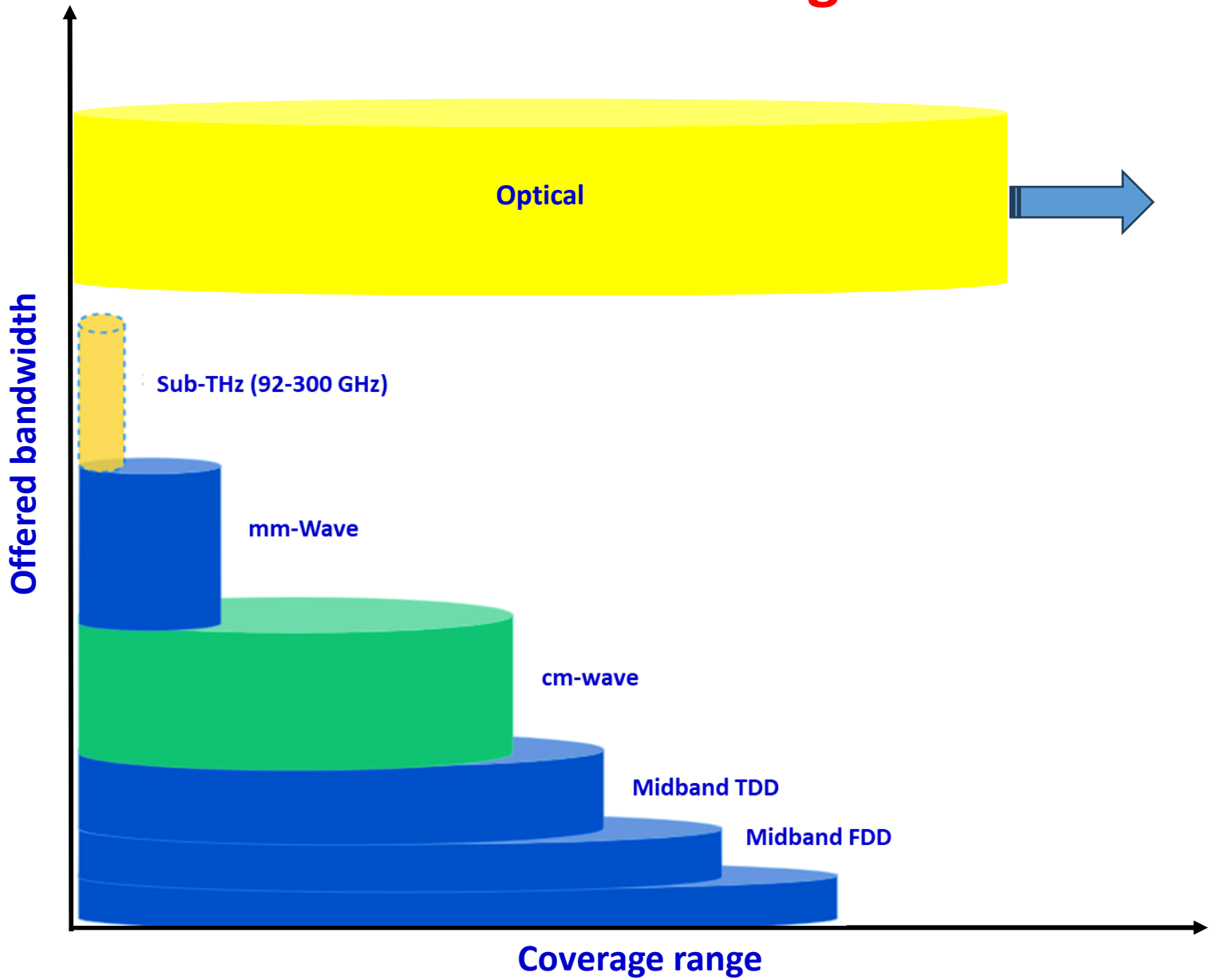
[need 55 Gbit/s/site. Assuming a downlink spectral efficiency of 7.8 bit/s/Hz per sector, → ~2.4 GHz of spectrum]

[1] https://www.ericsson.com/en/reports-and-papers/white-papers/6g-spectrum-enabling-the-future-mobile-life-beyond-2030

Wireless Technology - The Requirements



Wireless Technology - Bandwidth & Coverage



Paulo Sergio Rufino Henrique; Ramjee Prasad, "6G The Road to the Future Wireless Technologies 2030," in *6G The Road to the Future Wireless Technologies 2030* , River Publishers, 2021, pp.i-xxvi.

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Wireless Networks – Beyond 2030 – Issues (1/4)

Societal performance MUST have the same importance as system performance!

ICT – Mobil Networks - Energy efficiency and sustainability

The carbon footprint - Primarily determined by the:

- *overall energy usage from running the network*
- *carbon emission intensity of the energy sources.*

Intergovernmental Panel on Climate Change's - **Reporting on the global temperature rise by 1.2°C**

The ICT sector - Aim for a 45% reduction in greenhouse gas emissions by 2030.

Technology driving energy efficiency – ***Use of 5&6G***

But:

- **Massive MIMO in RF Consume too much power** (3 times more than 4G)
- **DSP** - Great in energy per bit compared with the noise

System architecture solutions, deployment and architecture strategies for networks

Site solutions based on renewable energy

The role of AL/ML

Applications and services

Wireless Networks – Beyond 2030 – Issues (2/4)

IoT applications

RFID tags
Smart sensors

Smart desks
Smart lighting

Biometric scanners for touchless entry

Smart cameras with AI - Detecting unusual activity after hours. Can learn normal patterns and identify unusual patterns.

IoT in the workplace introduces entry points in the network

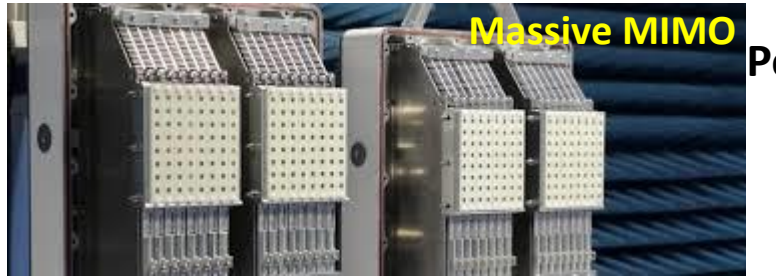
The need for a robust security infrastructure

The use of AI/ML

Enhances:
predictive analytics
real-time monitoring
proactive risk management

Wireless Technologies – Issues (3/4)

Concerns on impacts on human health and environment [1, 2]



Possible ranges - 20-150 m with smaller coverage areas/small cell

- A cell radius of 20 m → **about 800 base stations/km²**
  - This contrasts with 3/4G which use large or 'macro' cells, ranges of 2-15 km or more.

Compact cell antennas deployment

Constant exposure of people to mmW and THz radiations.

Reaching the EMI limit (World Health Organisation recommended regulations)!

Already reached!

[1] See '5G Deployment: State of Play in Europe, USA and Asia', European Parliament, June 2019; [2] R. M. Powell. See also similar opinions from experts such as T. Schoechle and P. Héroux, 'Fiber is safer, faster, more reliable, and far more cyber secure and energy efficient than wireless;

Wireless Networks – Beyond 2030 – Issues (4/4)

- Assessing network users, services, and environments
- Decision making, and dynamic adjustment of the network
- Network self-evolution mechanism

But. AI is not totally secure!

- At different levels depending on the requirements
- More computationally intensive
- Most popular for internet communicating, cloud

Life time needs to be long

- People must have access to the technology, which is simple and user friendly

Due to more complexity and deployment of many base stations in a small area.

- According to European Commission estimates, to reach the target, including urban areas, the cost is estimated at **€500 billion by 2025** [1].

[1] https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/646172/EPRS_BRI%282020%29646172_EN.pdf;

Wireless Technologies – Channel Capacity

$$\eta_{sp} = \frac{R/B}{k}$$ Bit/s/Hz/site (i.e. cluster size)

Shannon capacities of different types of channels over HetNets with **interference**

Seamless global network coverage:
(Space-air-ground-sea integrated network)
- Satellite communication
- UAV communication
- Terrestrial communication (UDN)
- Maritime communication
- Underwater acoustic communication

More bandwidth:
- mmWave, THz, optical wireless
- Unlicensed access/cognitive radio network (CRN)
- Full-duplex
- Multi-standard systems

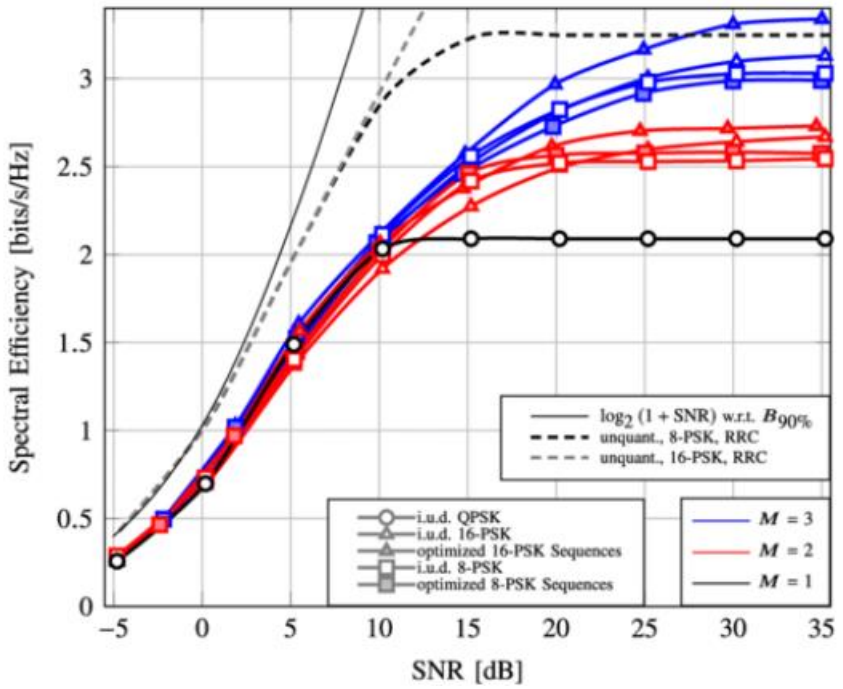
Less noise:
(filtering)

$$C_{sum} \approx \sum_{HetNets} \sum_{Channels} B_{n,i} \log_2[1 + P_{n,i}/(N_{n,i} + I_{n,i})]$$

More channels:
- Ultra-massive MIMO, spatial modulation
- Orbital angular momentum (OAM)
- New waveforms: F-OFDM/UFMC/FBMC
- HST/V2V/D2D, multiple access
- New devices: industry IoT, VR/AR/MR, wearable displays, mobile robots and drones

More power (efficiency):
- Small cells
- Green communications
- Advanced modulation and coding: network coding, polar code, LDPC, …

Less interference:
- Interference randomization
- Interference coordination
- Interference cancellation
- Interference alignment

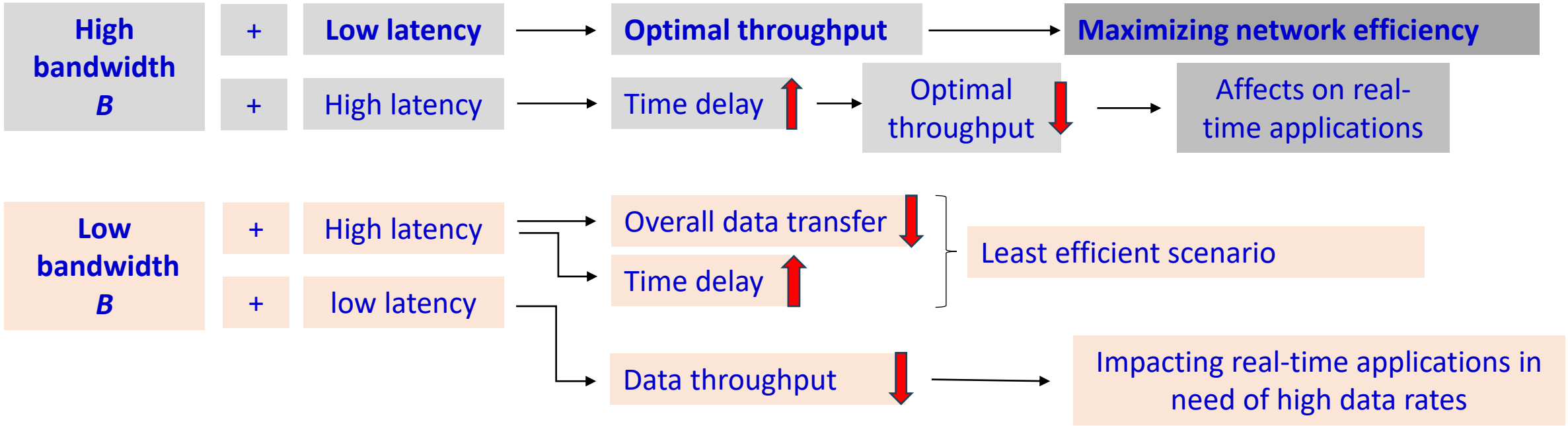


C. -X. Wang, J. Huang, H. Wang, X. Gao, X. You and Y. Hao, "6G Wireless Channel Measurements and Models: Trends and Challenges," in IEEE Vehicular Technology Magazine, vol. 15, no. 4, pp. 22-32, Dec. 2020, doi: 10.1109/MVT.2020.3018436.

Wireless Technologies – Throughput

Throughput R_{Th} = B [Hz] . D [cell/km^2] . η_{sp} [bit /s /Hz / cell]

Factors affecting R_{Th}



Wireless Technologies – Throughput

Throughput R_{Th} = B [Hz] . D [cell/km²] . η_{sp} [bit /s /Hz / cell]

Factors affecting R_{Th} - Densification of base stations (BSs)

According to Qualcomm, doubling the number of BSs doubles the capacity [1]

↓

R_{Th} gain ↓

↓

"Cooper's Law" must eventually hit a plateau

↓

Fundamental limits of densification

Cooper Law - The maximum number of voice conversations or equivalent data transactions that can be conducted in all of the useful radio spectrum doubles every thirty months.

Qs:

- What will cause saturation?
- What can be done to prolong Cooper's Law as long as possible by optimizing the wireless network design?

[1] Are We Approaching the Fundamental Limits of Wireless Network Densification?, J G Andrews, ete al, IEEE Communications Magazine, Octobre 2016

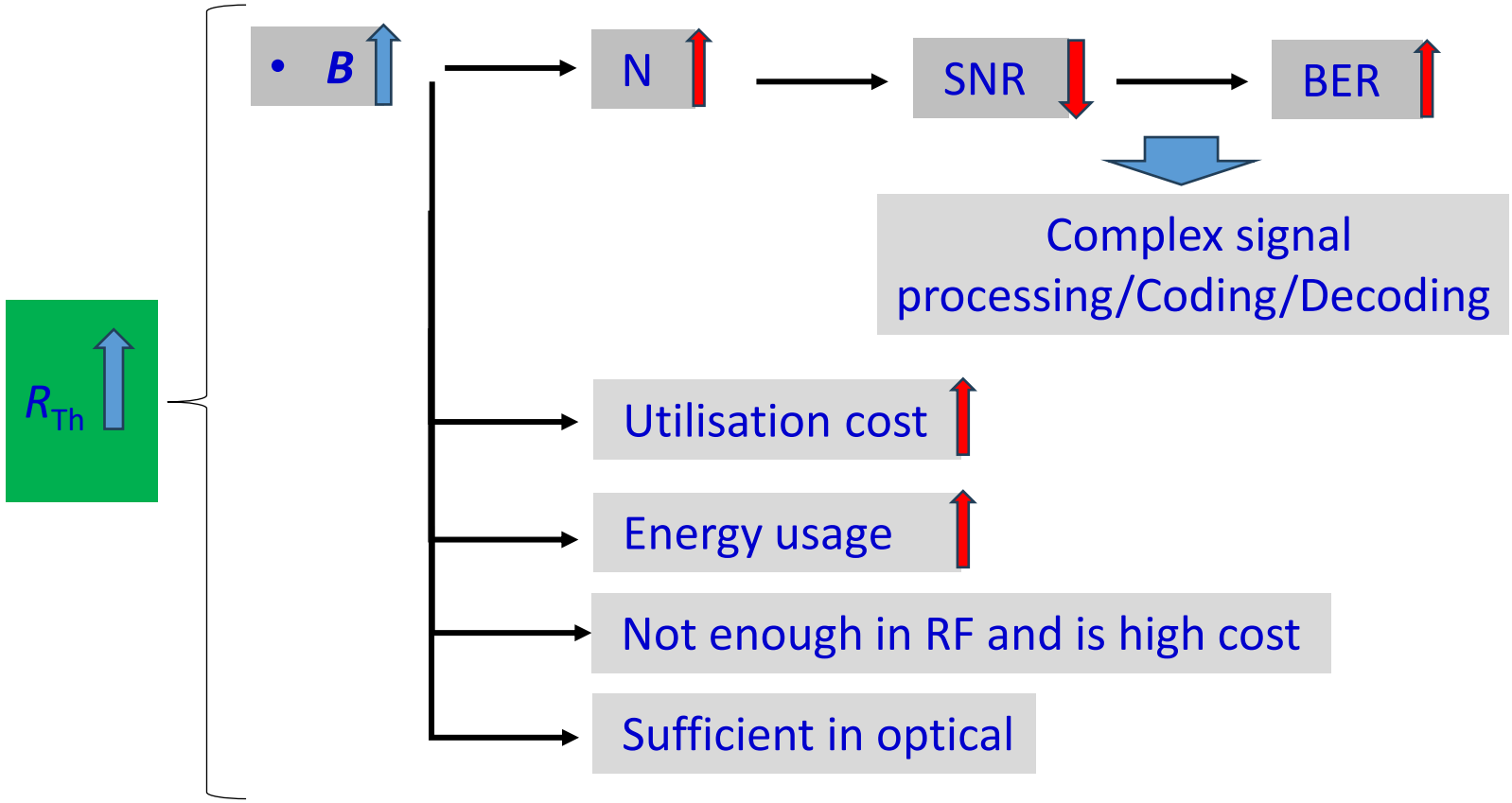
Wireless Technologies – Throughput

Throughput R_{Th} = B [Hz] . D [cell/km^2] . η_{sp} [bit /s /Hz / cell]

Options to increase R_{Th}

Leads to →

ICI: Inter channel interference
N: noise



Wireless Technologies – Throughput

Leads to →

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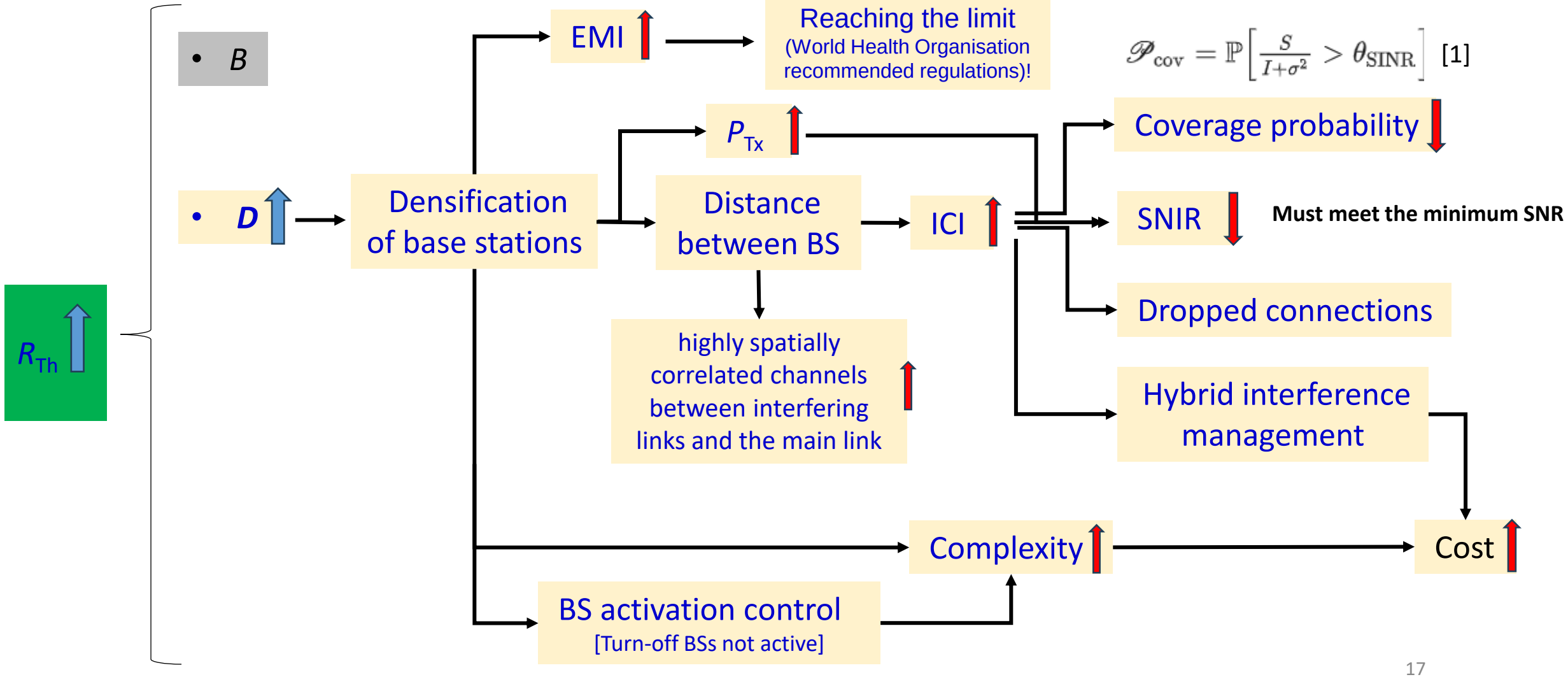


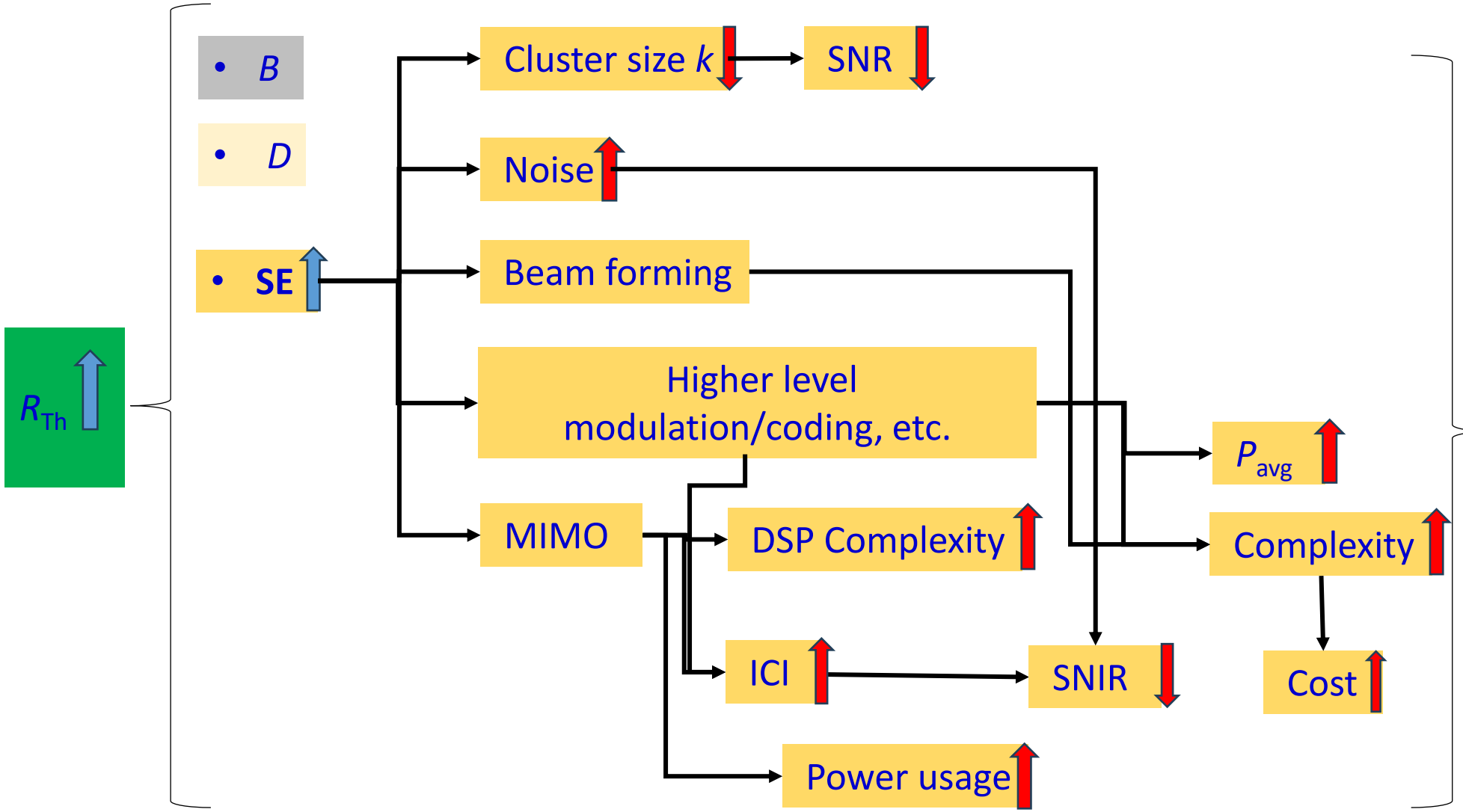
[1] Facing to wireless network densification in 6G: Challenges and opportunities, H Cho, et al, Science Direct, 9 (3), June 2023, https://doi.org/10.1016/j.icte.2022.10.001

Wireless Technologies – Throughput

Leads to

ICI: Inter channel interference
N: noise

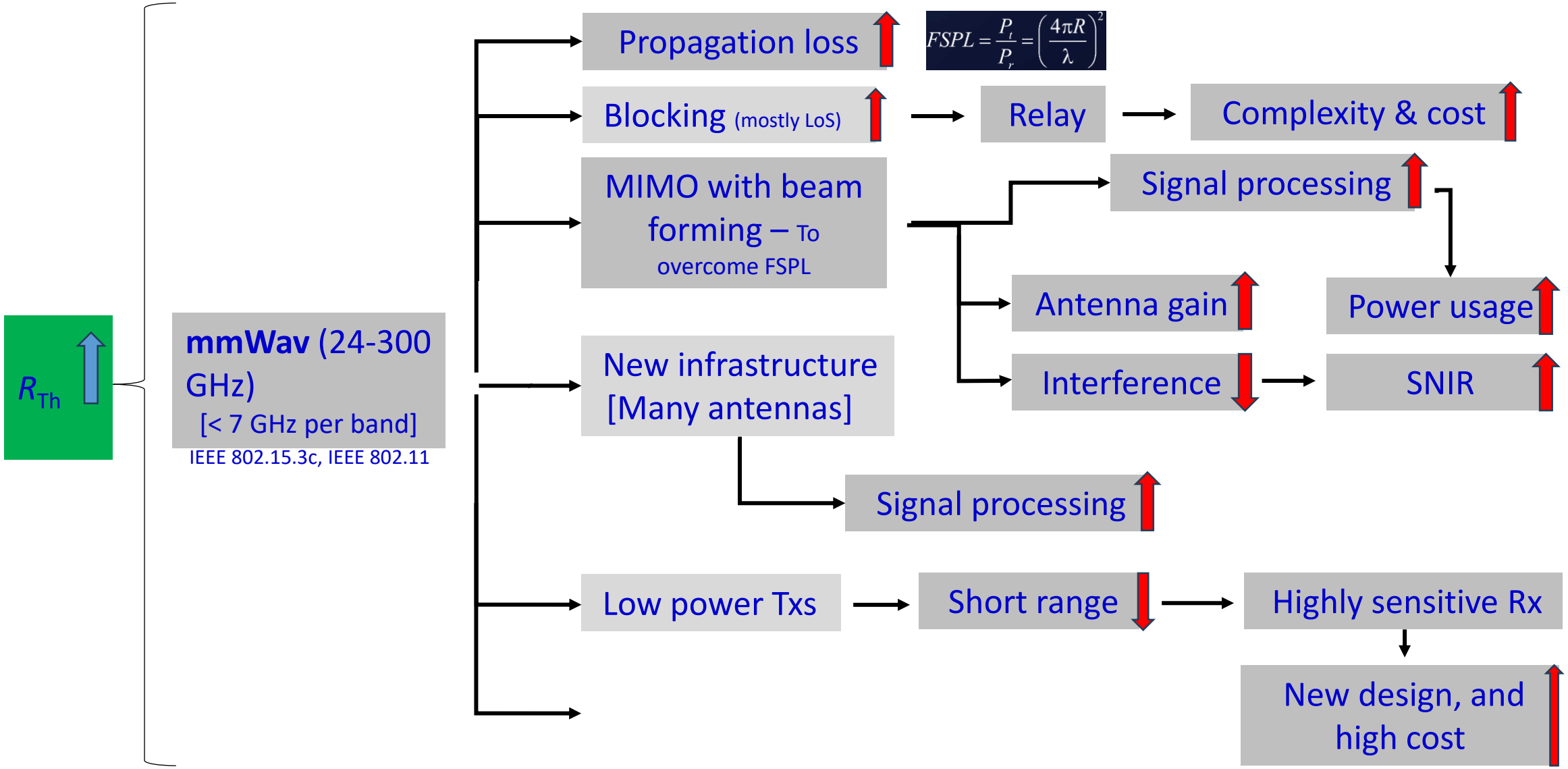
Throughput R_{Th} = B [Hz] . D [cell/km^2] . η_{sp} **[bit /s /Hz / cell]**



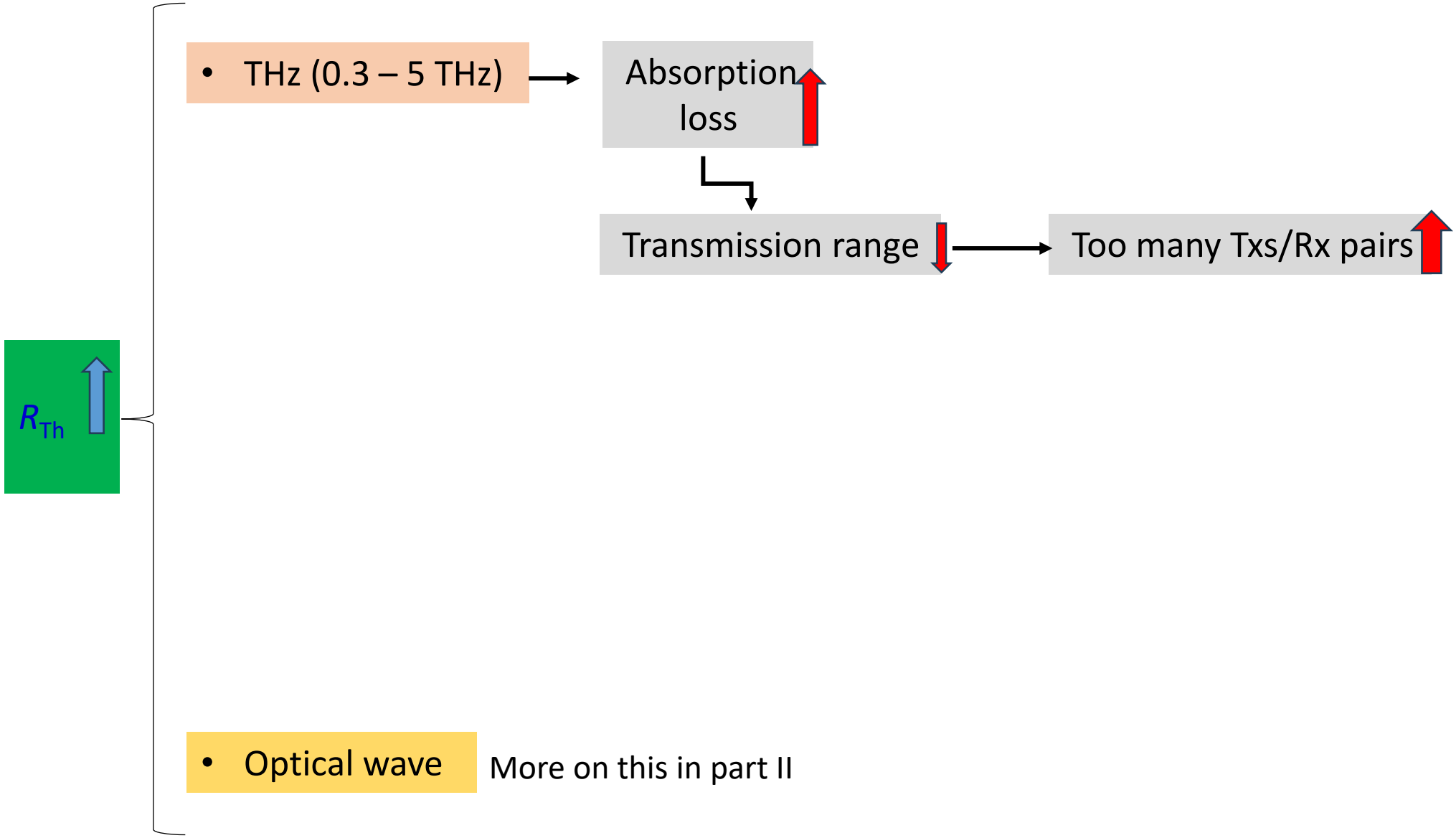
However, these solutions are reaching the state of saturation and limits of implementation, due to:

Costs
Complexity
Etc.

Throughput – Wireless Technology



Throughput – Wireless Technology



Wireless Networks – 5&6G

Combined with fiber and OWC networks, they offer energy efficiency and sustainability

Cloud network – By bringing data - once processed via physical hardware and data centers - to the edge of the network

Reduces delays in data processing and increases data security because there are fewer opportunities for a breach.

Decreased latency, or lag time, of data processing.

Faster (wide bandwidth) and more efficient decision making.

By creating an environment where data is more easily accessed and available via IoT.

- Less time to generate and evaluate data
- Less energy required to operate a business → improved energy efficiency.

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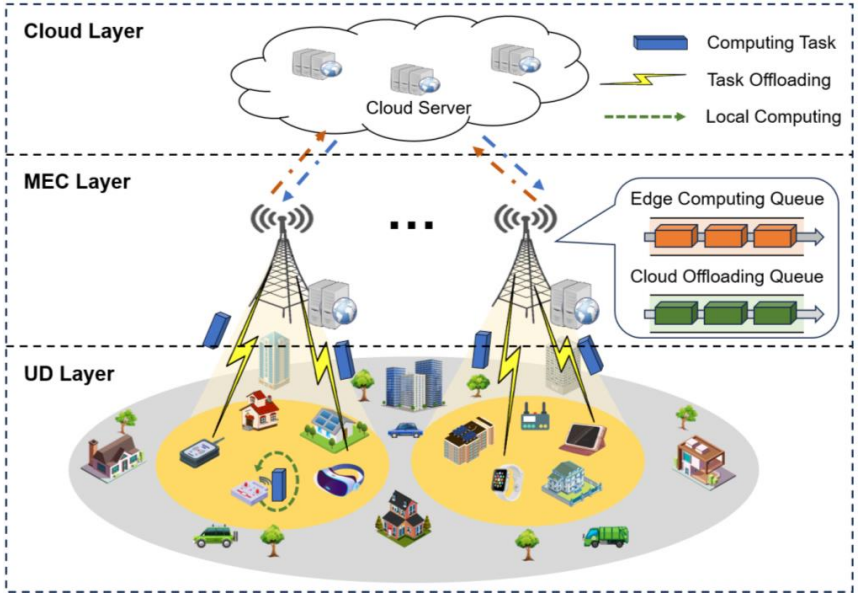
Wireless Networks – Edge cloud

Multi-access edge computing

- **help with energy efficiency – Since links are too short within certain environments and not at a data centre – far away**
- Provide on-site data processing for increased speed and privacy
- **Lower latency** → reduces traffic on centralized data centers → sustainable electronic waste → lower water and energy usage



G Sun, et al, IEEE Transactions on Mobile Computing, 2025-01-06https://arxiv.org/pdf/2501.02952

5&6 with MEC and OWC → Offer huge bandwidth → Allowing more devices (e.g., IoT) to be connected, monitored and data being analyzed.

- Reduced equipment outages
- Reduced waste
- Lower energy usage
- Others ……..

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Part II – Optical Wireless Communication.

Thank you!