# Some Key Challenges and Up-coming Trends for Future Wireless Systems

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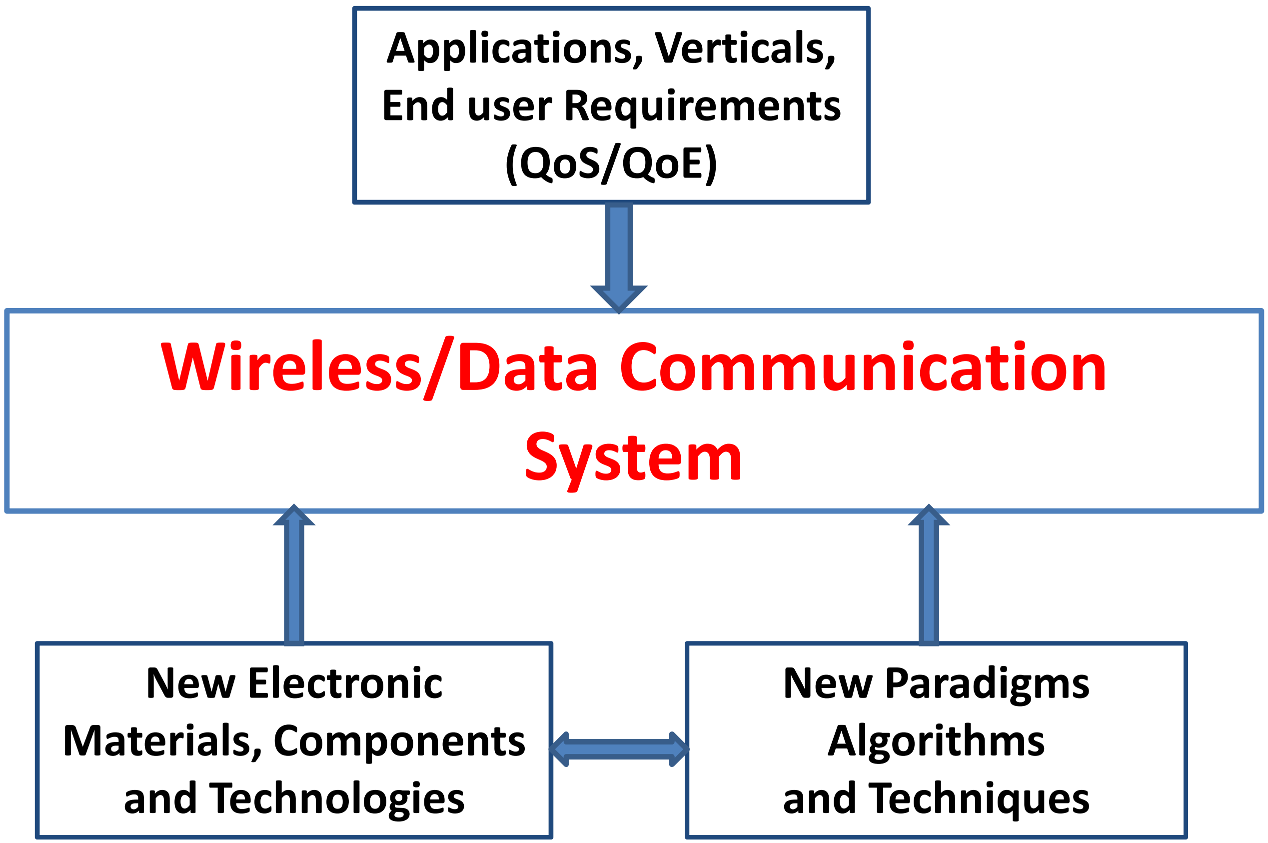
# Outline

- Drivers and Enablers for future systems
- Evolution of the main KPIs
- A vision and some challenges
- Examples of main research trends and enabling technologies

# Drivers and Enablers



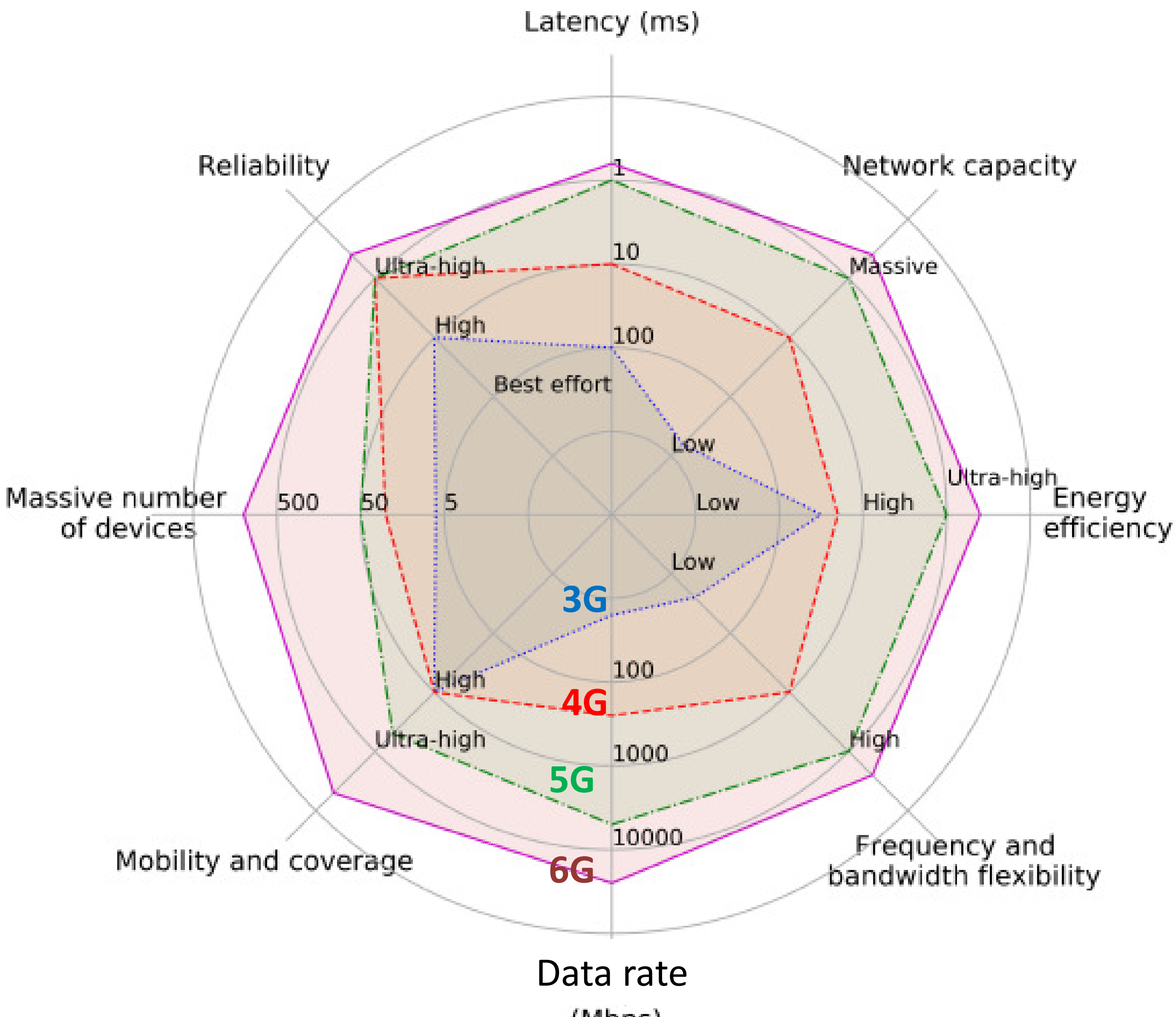
# Examples of Emerging Applications and Use Cases

- Ultra Reliable Low Latency Communications (URLLC)
- Enhanced Mobile Broadband (eMBB)
- Massive Machine Type Communications (mMTC)

Example use-cases

- Industry 4.0, Factories of the Future
- E-health and remote surgery
- Smart cities
- Co-operative mobile robots
- Internet of Things and of Everything (IoT/IoE)

# Evolution of Main KPIs



# A Vision for 6G

- Higher data rates (capacity and throughput improvement).
- Improved spectrum efficiency (bps/Hz/$m^2$).
- Enhanced end user Quality of Experience (QoE) with a wide variety of requirements including traditional Quality of Service (QoS) requirements, reliability, security and others.
- Reduced end to end latency.
- Seamless and improved coverage and mobility.
- Lower energy consumption / improved energy efficiency (Green radios).

# Main Challenges

## Efficient use of spectrum

- Innovation in spectrum efficiency & spectrum management
- Densification of spectrum sharing, particularly at lower frequencies.

## Widespread coverage

- Prevent the "digital divide"
- Contribute to improved health, social care and future transportation systems.

## Seamless connectivity

- Achieving a "network of networks", Internet of Everything (IoE)
- In addition to ensuring security and resilience

## Energy efficiency

- Net Zero targets and optimisation of energy consumption

## Economic viability and resilience

- Enabling new service possibilities and/or significant cost savings

# Main Governing Equation

**Shannon Equation**: Upper bound capacity for error free transmission through a communication channel.

$$C = B\log_2(1 + S/N)$$

- C = capacity (in bit/s)
- B = bandwidth of channel (Hz)
- S = signal power (in W)
- N = noise power (in W)

**Two main factors B and SNR**

Main factor to increase capacity (Linear effect and mainly at network level)

Logarithmic trend (mainly at component level)

# Examples of Main Research Trends

## (1) Bandwidth Enhancement

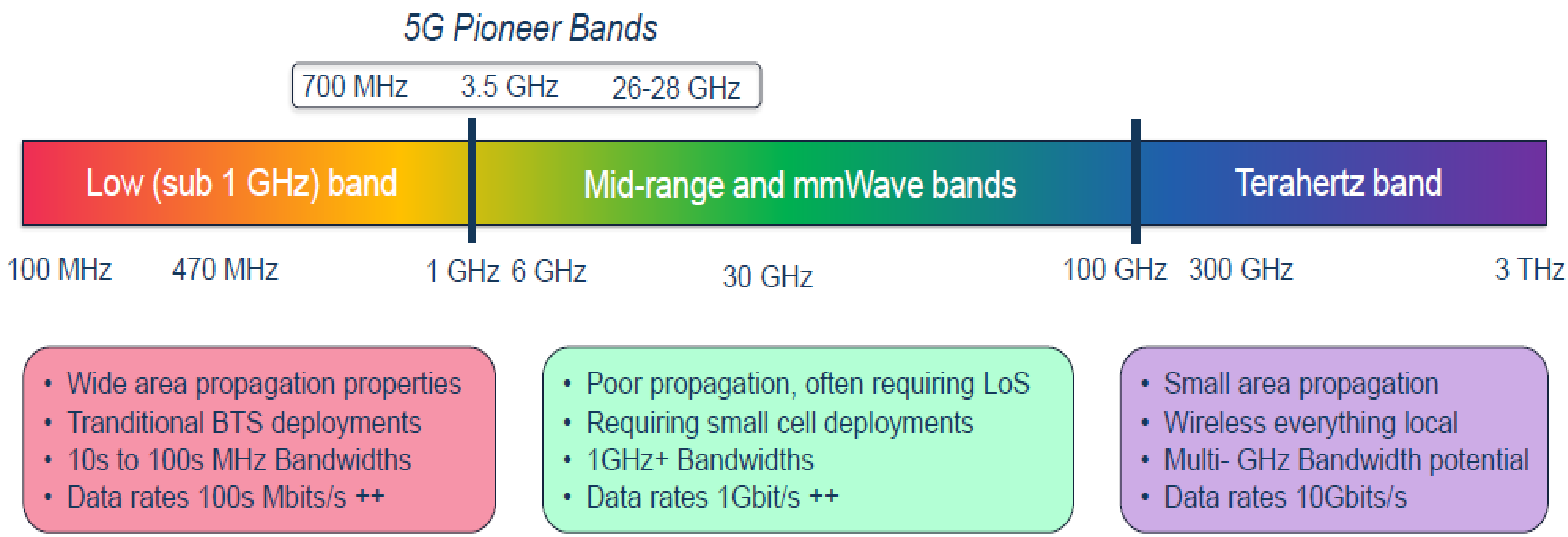
- Spectrum sharing and the use of higher frequency bands (use of THz, integration of visible light, fibre and satellite communication systems)
- New network architectures relying on dense small cells managed through Artificial Intelligence (AI) or machine learning techniques.

# Examples of Main Research Trends

## (2) SNR Enhancement

- New RF transceiver designs and new electronic components/subsystems targeting performance enhancement of the whole system.
- Massive MIMO
- New materials for RF engineering applications.

# A Look at the Spectrum: towards 6G



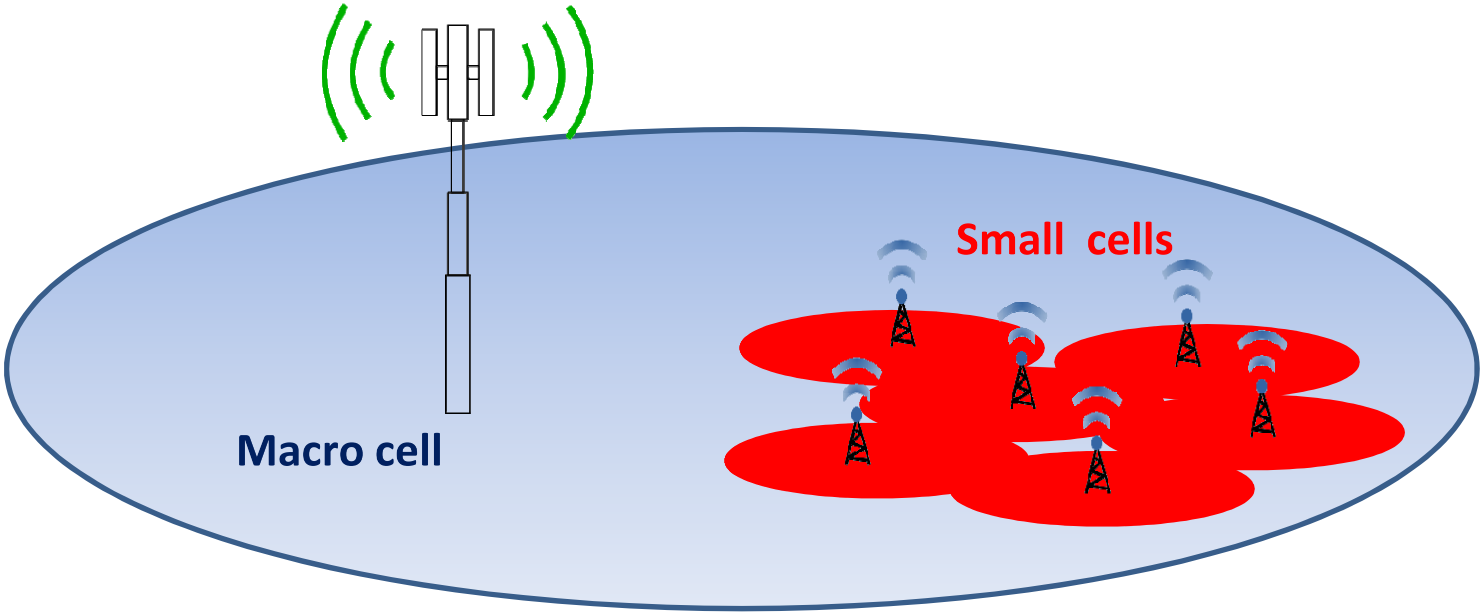

- Use of opportunistic, dynamically accessed spectrum to improve the overall utilisation leading to economic benefits.

- How to manage interference / thousands of users/devices operating in different bands simultaneously and achieve smart spectrum management?
- Cognitive radio/ Software Defined Radios (SDR) and spectrum sensing

# Some Enabling Technologies

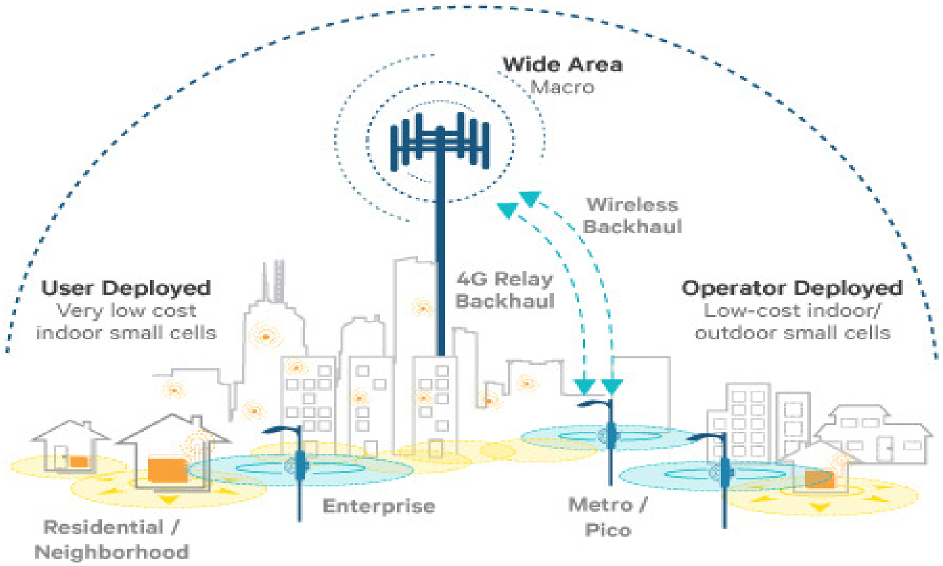
| Expectations and Features | Enabling Technologies and Trends |
|---|---|
| **Capacity and throughput improvement**, high data rate<br>(~1000x of throughput improvement over 4G, cell data rate ~10 Gbps, reduced signalling overheads) | Spectrum reuse and **multiband/multi technology operation** (from UHF to mm-wave/visible light communication bands),<br>**Heterogeneous / multi-tier networks , small cells**<br>**Multi RAT RRM/ C-RAN , SON**<br>Massive-MIMO, new air interface for spectral efficiency |
| **Reduced latency**<br>(2~5 milliseconds end-to-end latencies) | **Multi RAT RRM/ C-RAN , SON**, D2D communication, Full-duplex communication |
| **Network densification**: **Ultra Dense Networks**<br>(~1000x higher mobile data per unit area, 100~10000x higher number of connecting devices/users) | **Heterogeneous / multi-tier networks , small cells**<br>**Multi RAT RRM/ C-RAN, SON, Seamless operation** |
| **Advanced services and applications**<br>(e.g., smart city, service-oriented communication, IoT) | **Multi RAT RRM/ C-RAN, SON**<br>network virtualization, M2M communication |
| **Improved energy efficiency /green radios**<br>(~10x prolonged battery life) | Wireless charging, energy harvesting<br>**Multi RAT RRM/ C-RAN , SON** |
| **Autonomous applications and network management**,<br>Internet of Things | **SON/ cognitive networks**<br>M2M/ D2D communication |

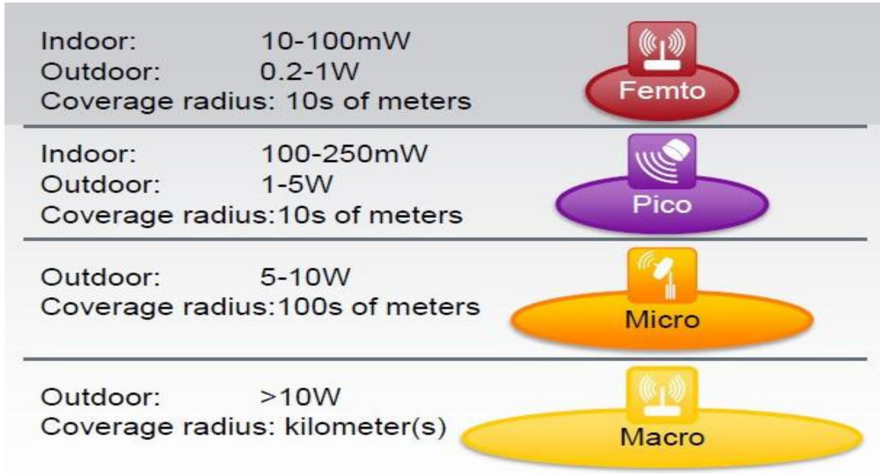
# Dense Small Cells




- An effective approach to high capacity provision under limited spectrum resources is to densely deploy small cellular base stations.
- Serving hard to reach users at the edge of coverage.
- Requires intelligent interference management and radio resource management techniques.

# Dense Small Cells




- **The deployment of small cells (pico and femto cells) is usually done in a decentralised plug and play fashion**.
- Reduces the need for busy hour capacity in the macro network layer.
- Improves indoor and outdoor coverage and reduces overall network power consumption (improves energy efficiency)
- Provides several folds capacity increase is the areas of high demand, and reduces the service provider overall network CAPEX and OPEX costs.

# Challenges for Dense Small Cells Deployment

## Network Complexity Management

- Traffic load balancing problems between macro cell and the small cell tiers or among small cells.
- Mobility management.
- Backhaul congestion management issues.
- **Self Organising Network (SON) Techniques**

## Spectrum and Radio Access Management

- Physical and medium access control layers issues such as
  - Co-tier and cross-tier interference mitigation
  - Intelligent Radio Resource Management (RRM) / **SON Techniques**
    - Cognitive Radio / Dynamic Spectrum Access (DSA)
    - Delivering reliable QoS as well as reducing signalling overhead in a dynamic radio network/environment

## Energy Efficiency

- Intelligently control the number of activated cells based on the dynamics of user traffic, as well as maintaining adequate QoS and capacity

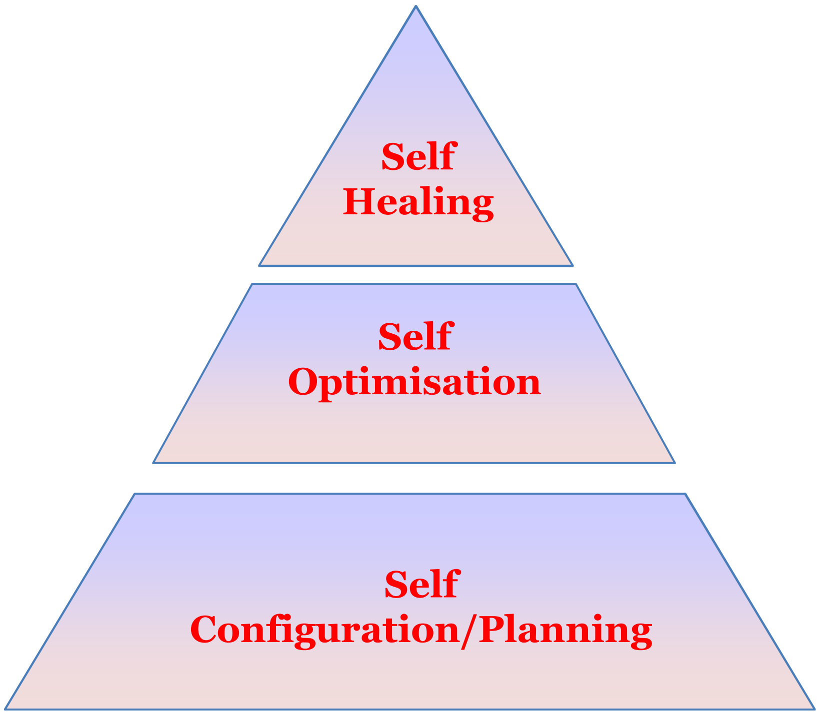
# Self Organising Networks (SON): The Need

- Very large number of small cells/devices to be deployed.
- Manual processes for configuration and optimisation are no longer practical/feasible
- Dynamic deployment requires quick and frequent adaptation
- Continuous adjustments of parameters during operation based on actual measurements and KPIs

## Advantages

- Keeping operational effort at an acceptable level/ ideally eliminate user intervention.
- Protecting network operation by reducing the probability of errors
- Speeding up the planning, configuration, management, optimisation and healing of mobile communications networks.

# Self Organising Networks (SON)




Alarm correlation
Root cause analysis
Sleeping-cell detection
Cell outage compensation

Coverage and capacity optimisation
Inter-cell interference coordination
Energy saving

Auto connectivity/configuration
Dynamic radio configuration
Automatic neighbour cell configuration

- Artificial intelligence and machine learning approaches
- Load balancing across multiple cells in a network, how to associate users to a cell/base station?

# SON Main Architectures

- **Distributed SON (D-SON)**
  - Small scale short term techniques
  - Reacts to problems such as handover failures (time scales of seconds)
  - Performed locally based on information exchanged between neighbours
- **Centralised SON (C-SON)**
  - Large scale and longer term techniques
  - Jointly adjust parameters of an entire cluster of cells to daily traffic variations
  - Requires some central coordination to improve overall network capacity based on long term average values
- **Hybrid SON (H-SON)**
  - A mix of D-SON and C-SON

# Some Open Research Questions

- Signalling overheads, Latency constraints and backhaul constraints
- Complexity and implementation issues
- Energy efficiency
- Multi RAT operation
- Context awareness solutions /prediction of user behaviour

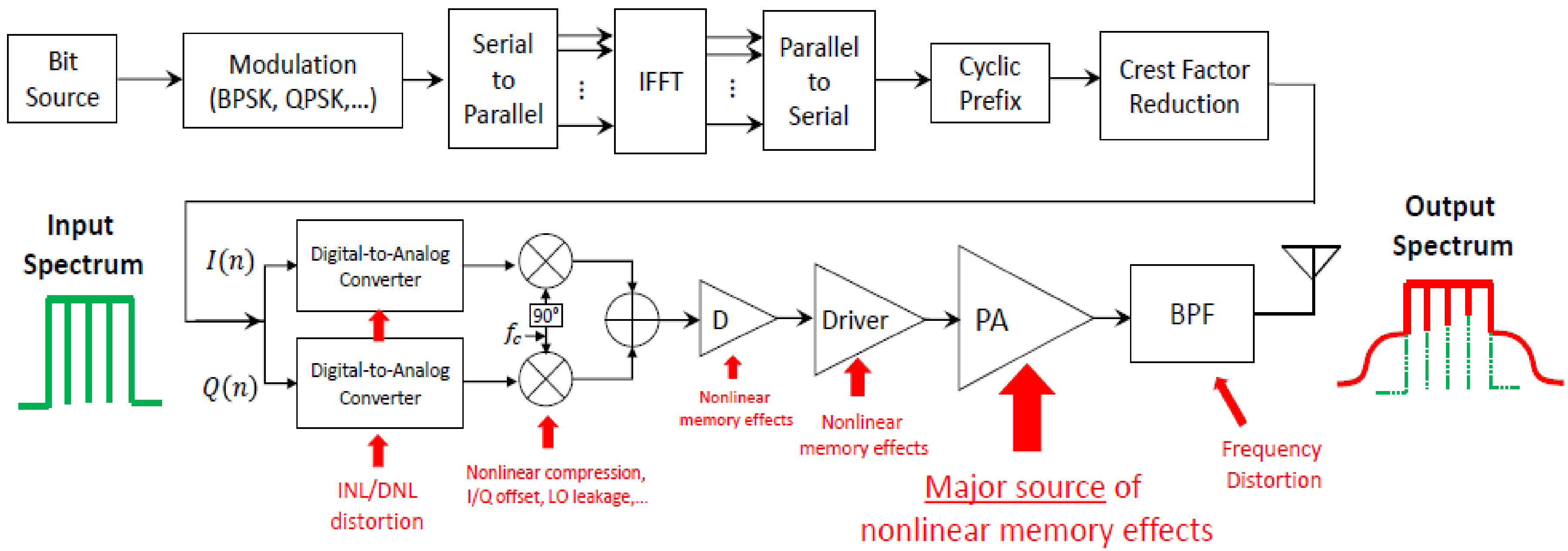
# Examples of SNR Enhancement Techniques

- Improving power amplifier linearity
- Multiband power amplification
- Advanced antenna/ filtenna designs and cognitive array techniques.
- Metamaterials and IRS

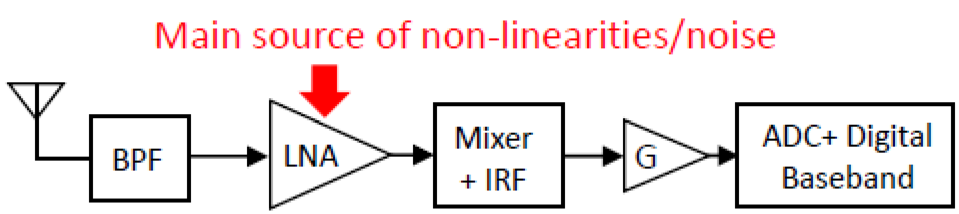
# Some Sources of Non-Linearities and Noise

## Transmitter

**OFDM System**

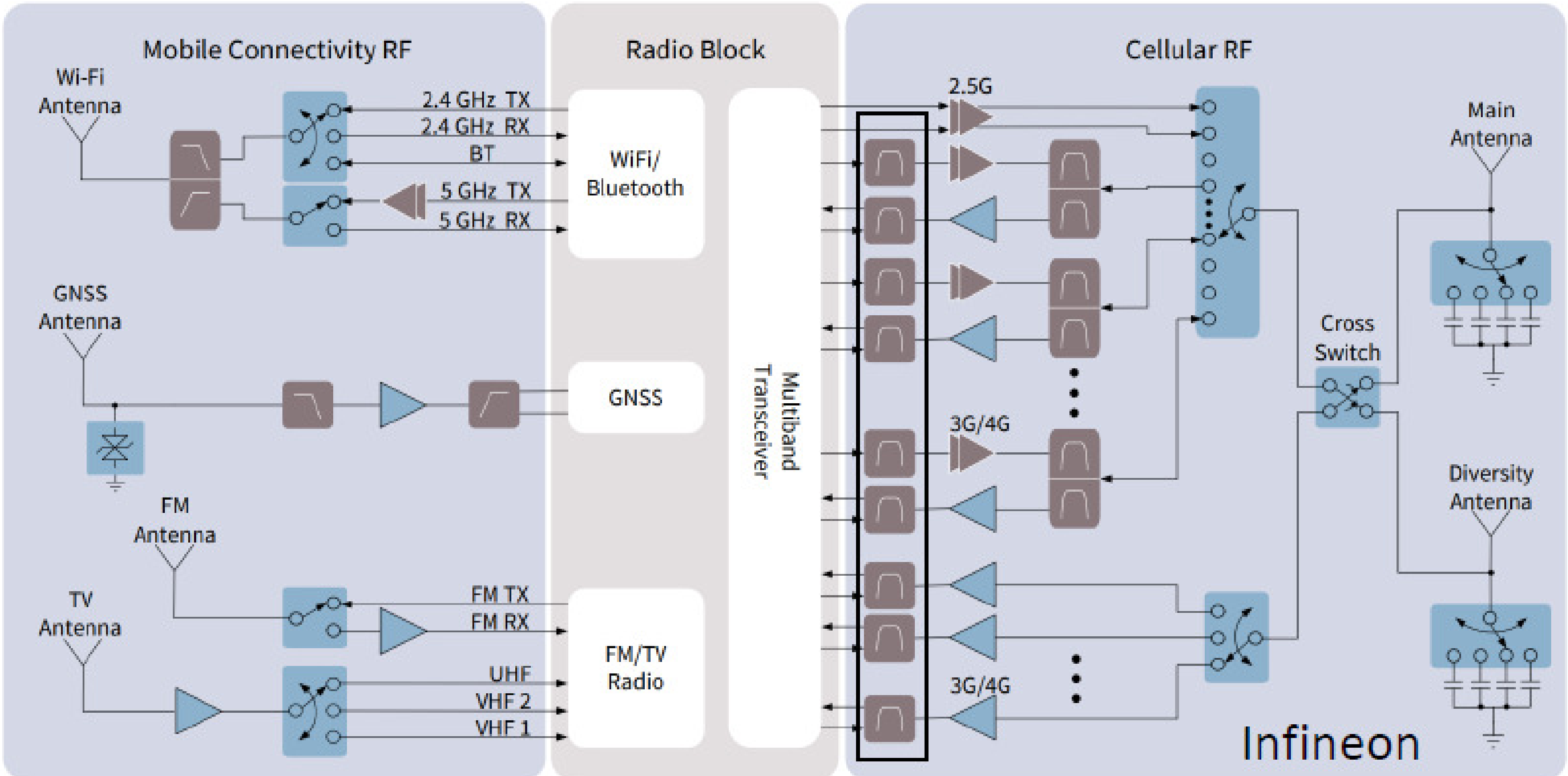



## Receiver



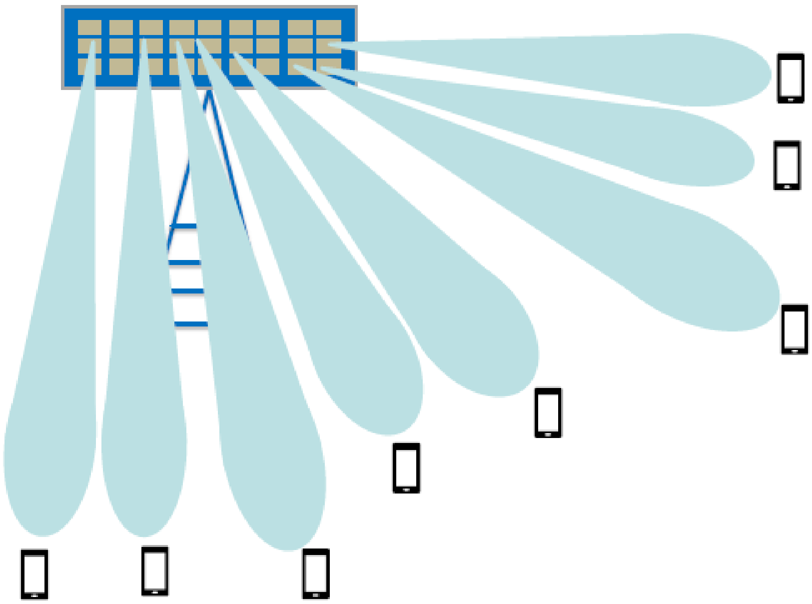

Amplifier linearisation techniques and Multiband operation

# Mobile Receiver Complexity




- As we move towards 6G, the filtering requirements will only get more challenging (more bands, higher frequencies)
- New electronic materials e.g. GaN and new structures

# Massive MIMO versus Cell free Massive MIMO

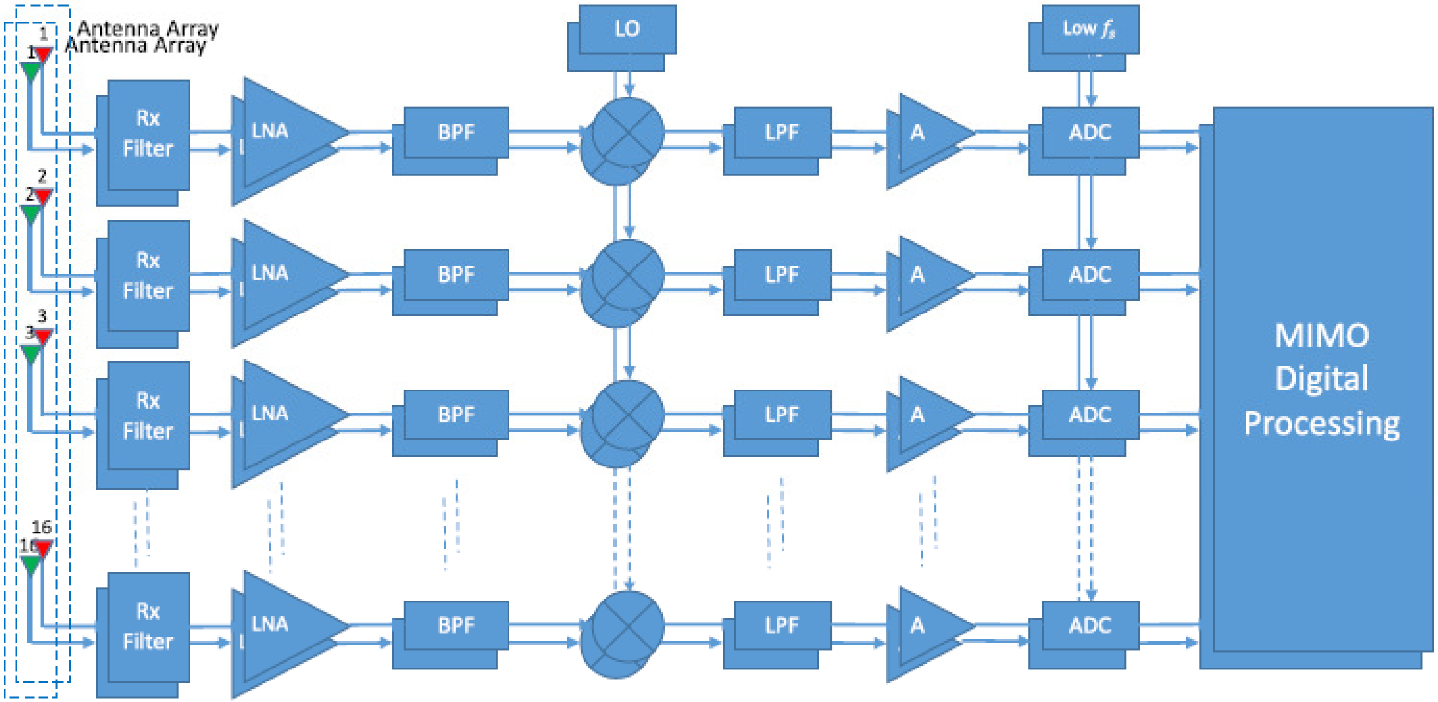


- Exploiting the spatial domain , separating users by location/angle: SDMA versus FDMA, TDMA, CDMA

- How to select/adapt beams dynamically in realtime to serve intended users?

- An alternative approach is to distribute the antennas from the base station array across the cell in a **distributed antenna system (DAS)**
–while still combining signals at the base station as in a collocated antenna array
- **Cognitive array processing**

# Conventional MIMO Transceiver

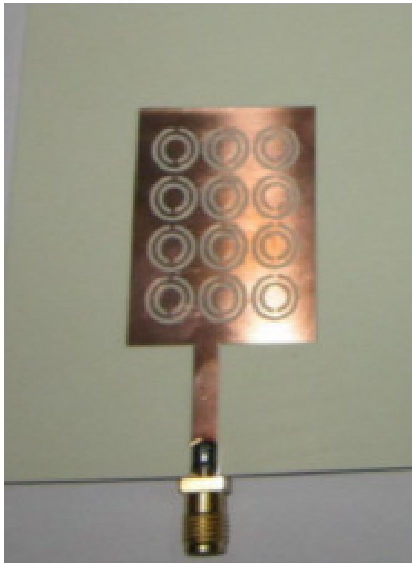



•How to design the individual components while reducing their number, complexity and improving energy efficiency?

• Filtennas, compact reconfigurable antennas and filters
Direct RF sampling, multiband amplification

# Metamaterials

- Composite materials in which the constituents are designed and spatially arranged through a rational design-led approach to change the manner in which electromagnetic, acoustic or vibrational energy interacts with the material.
- Achieve a property or performance which is not possible naturally.



# Metamaterials

- Driving the design of new components

**Example Applications:**

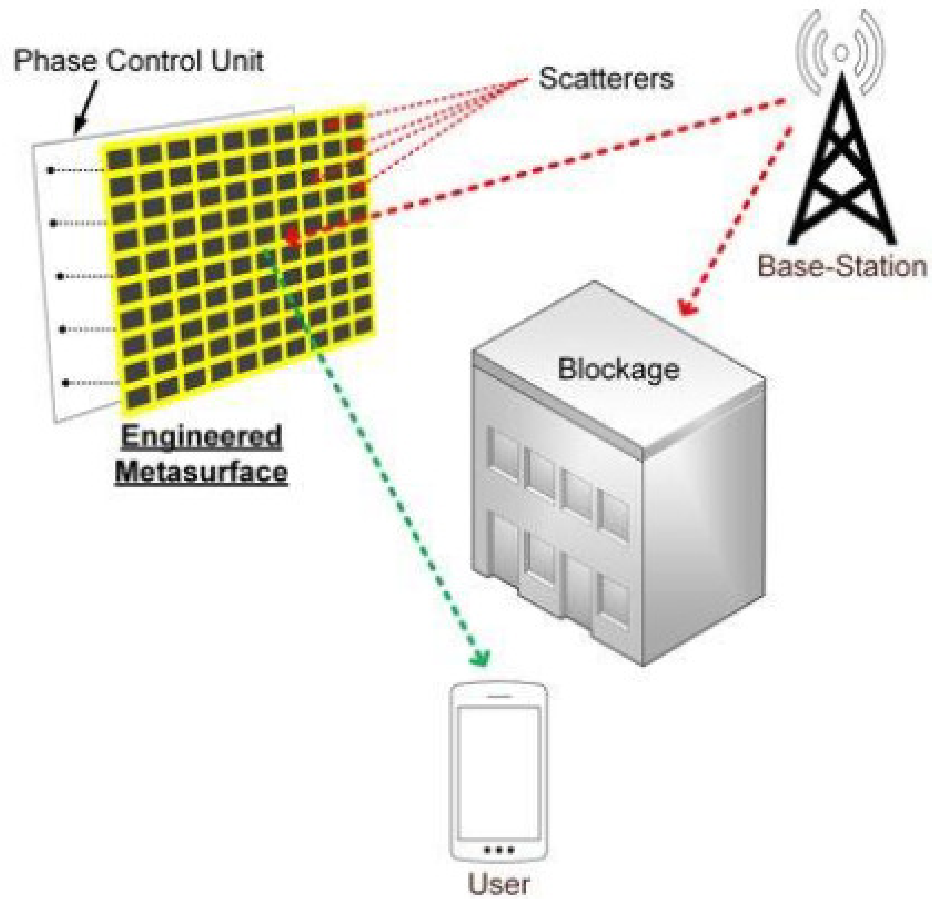
- Making antennas more compact
- Reducing the weight of systems
- Making systems conformal
- Improving efficiency
- Broad-band or Multi frequency response
- Bespoke directivity, and radiation patterns

# Reconfigurable Intelligent Reflective Surfaces (IRS)

- Control the reflective properties of a surface, hence controlling the channel (or the environment) using metamaterials.

# Reconfigurable Intelligent Reflective Surfaces (IRS)

- Create **intelligent propagation environments** using meta-surfaces.
- The environment acts as part of the wireless system itself, as opposed to an external (often hostile) player.
- Energy efficiency compared to relay nodes.
- Can be deployed in buildings as windows or glass panes without impacting the aesthetics of the infrastructure.



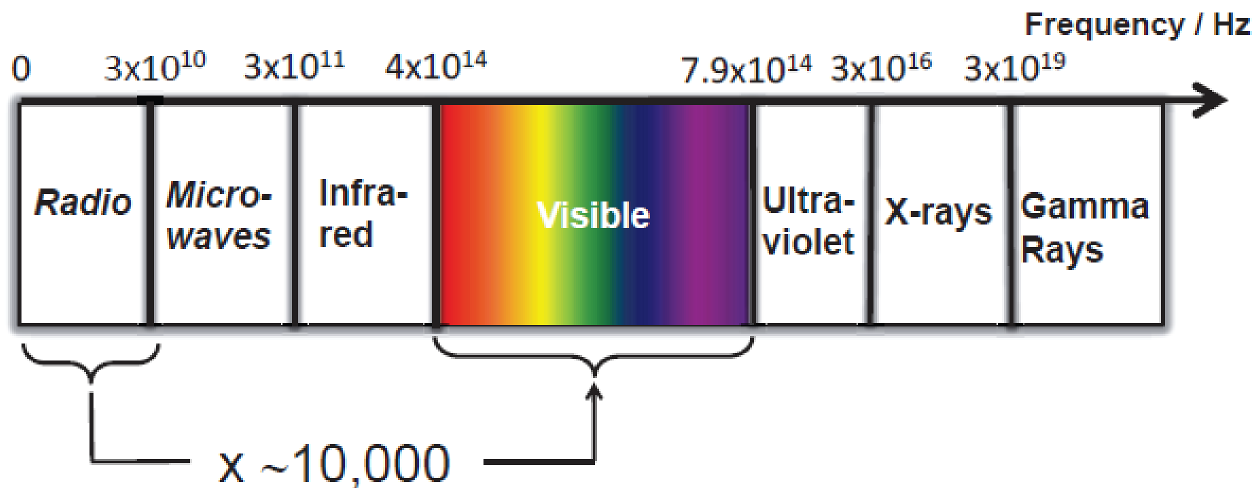
# Open Research Issues for Radiowave Propagation

- Measurements and models for the newly introduced higher frequency bands.
- Electromagnetic characterisation of materials at higher frequencies.
- Development of new propagation prediction tools taking into account:
  - Multiband operation
  - Newly introduced concepts such as IRS and multiple antennas at the two ends of the link
  - Models targeting new applications and services:

    e.g. industrial/ mMTC, vehicular (V2X), high speed trains, e-health applications and integrating the human body (BAN)

# Additional Technologies/Techniques

- New waveforms for multiple access: Non orthogonal and spectrum efficient signals (SEFDM/NOMA versus OFDM/OFDMA)
- Full duplex systems and distributed processing.
- Integration of fibre and satellite systems (rural and hard to reach area coverage)
- THz and VLC (Visible light) communication systems.



Thank you for your attention!

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