Practical Overview of Enabling Technologies for Heterogeneous 5G-IoT Ecosystem and its Applications

Presented by: Assoc. Prof. Jiri Hosek, Ph.D.

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- Wireless System Laboratory of Brno (**WISLAB**)
  - Team of highly **motivated researchers** and engineers
  - Working with the latest equipment including own **full-scale LTE-A cellular system**

- Mostly **industry-oriented R&D** with strong focus on **rapid prototyping** and real-world experimentation

- Next-generation **5G-IoT technologies and applications**
  - LPWAN communication technologies (LoRaWAN, Sigfox, NB-IoT)
  - Massive IoT (Smart Grids)
  - Consumer / Industrial IoT applications (Smart Home Gateway, AI, Industry 4.0, Wearables, Augmented reality)
  - Sub 6GHz + mmWave technologies
  - Advanced Spectrum Utilization (Licensed Shared Access)

- „The **Internet of Things** refers to the use of **sensors, actuators, and data communications technology built into physical objects**"

- IoT enables those objects to be tracked, coordinated, or controlled across a data network or the public Internet

- **"Smart" should not mean just to be connected to Internet!**

- There are three steps in Internet of Things applications:
    - **Capturing data from the objects** (e.g., simple location data or more complex information data sets)
    - **Aggregating** that information across a data network
    - **Acting** on that information – taking immediate action or collecting data over time to design proces

- IoT as **"killer" application** for 5G
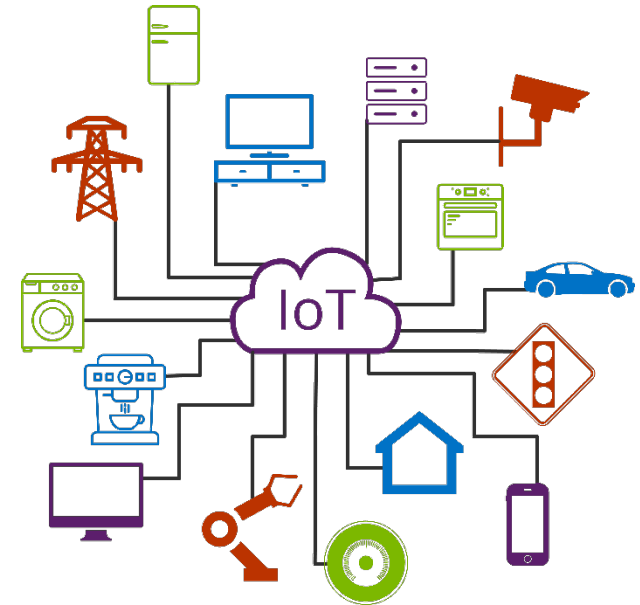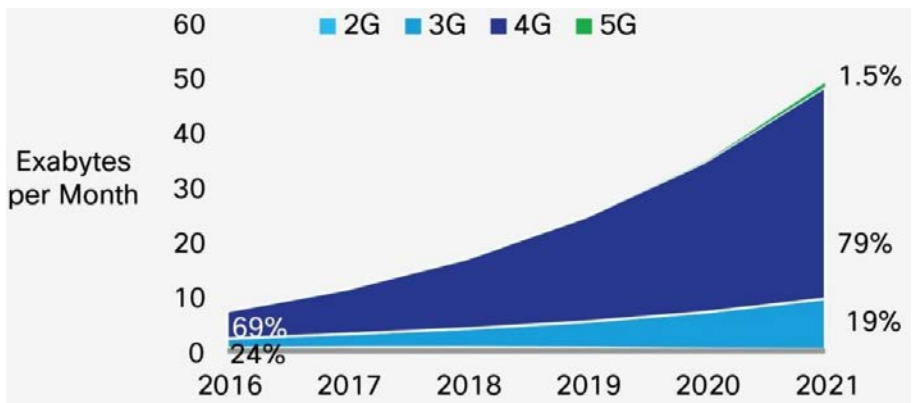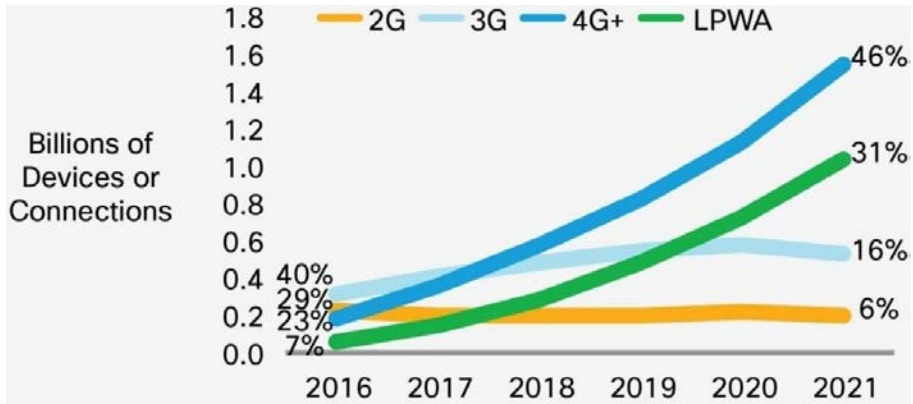
- **212B** installed things

- **30B** autonomously connected things

- Approximatelly **3 milion peta bytes** of embedded systems data

- **$8.9 trilion** of business value

It would take an individual more than

5,000,000 YEARS

to watch the **amount of video** that will cross global IP networks **each month in 2020**.

- Human-to-Human **(H2H)** vs. Machine-to-Machine **(M2M)**

Transforming our world

through intelligent connected platforms

Last 30 years
Interconnecting people

Next 30 years
Interconnecting their worlds

Utilizing unparalleled systems leadership in connectivity and compute

- Convergence of **spectrum types/bands**
- Diverse services, and deployments

A unifying connectivity fabric

Always-available, secure cloud access

5G

Enhanced mobile broadband
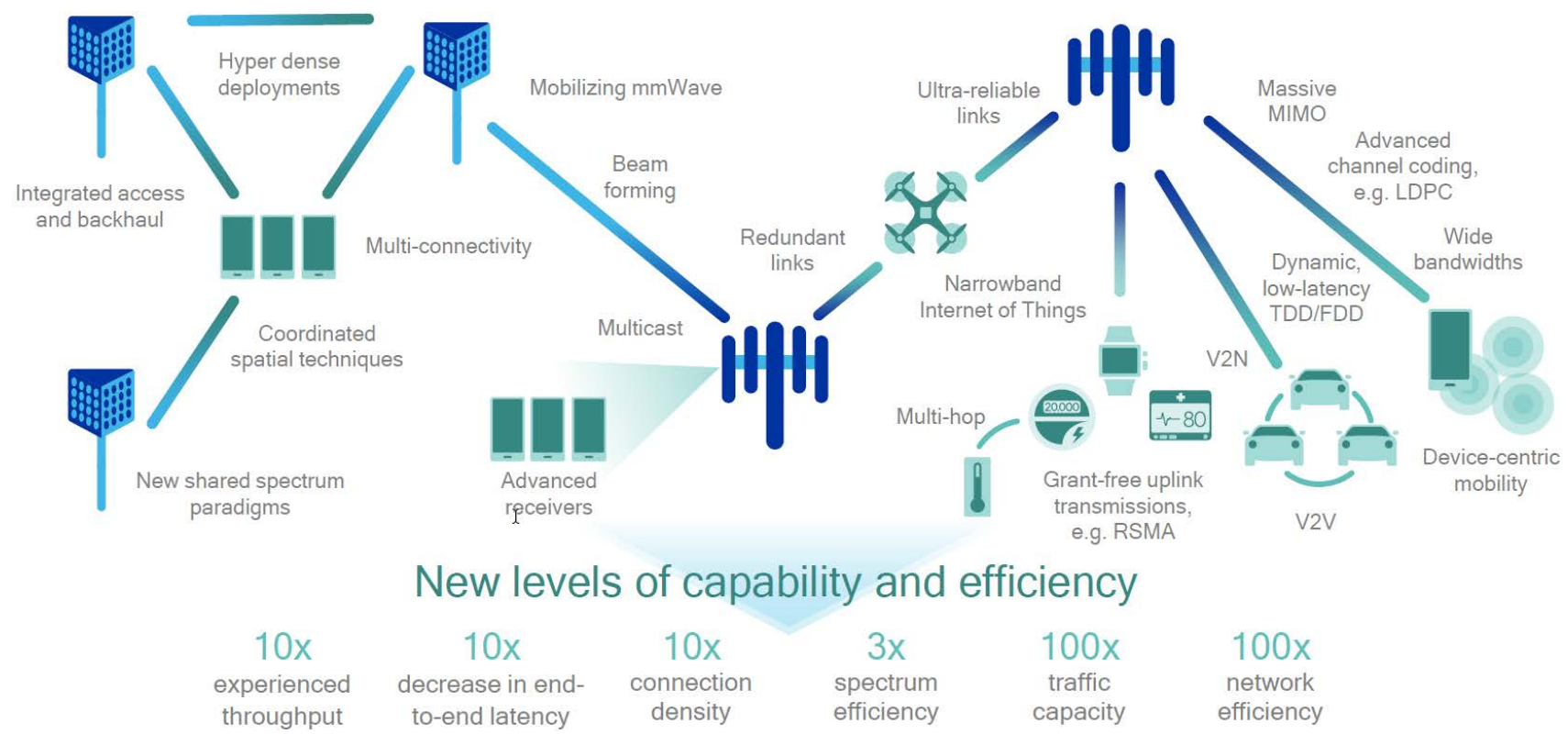
Mission-critical services

Massive Internet of Things

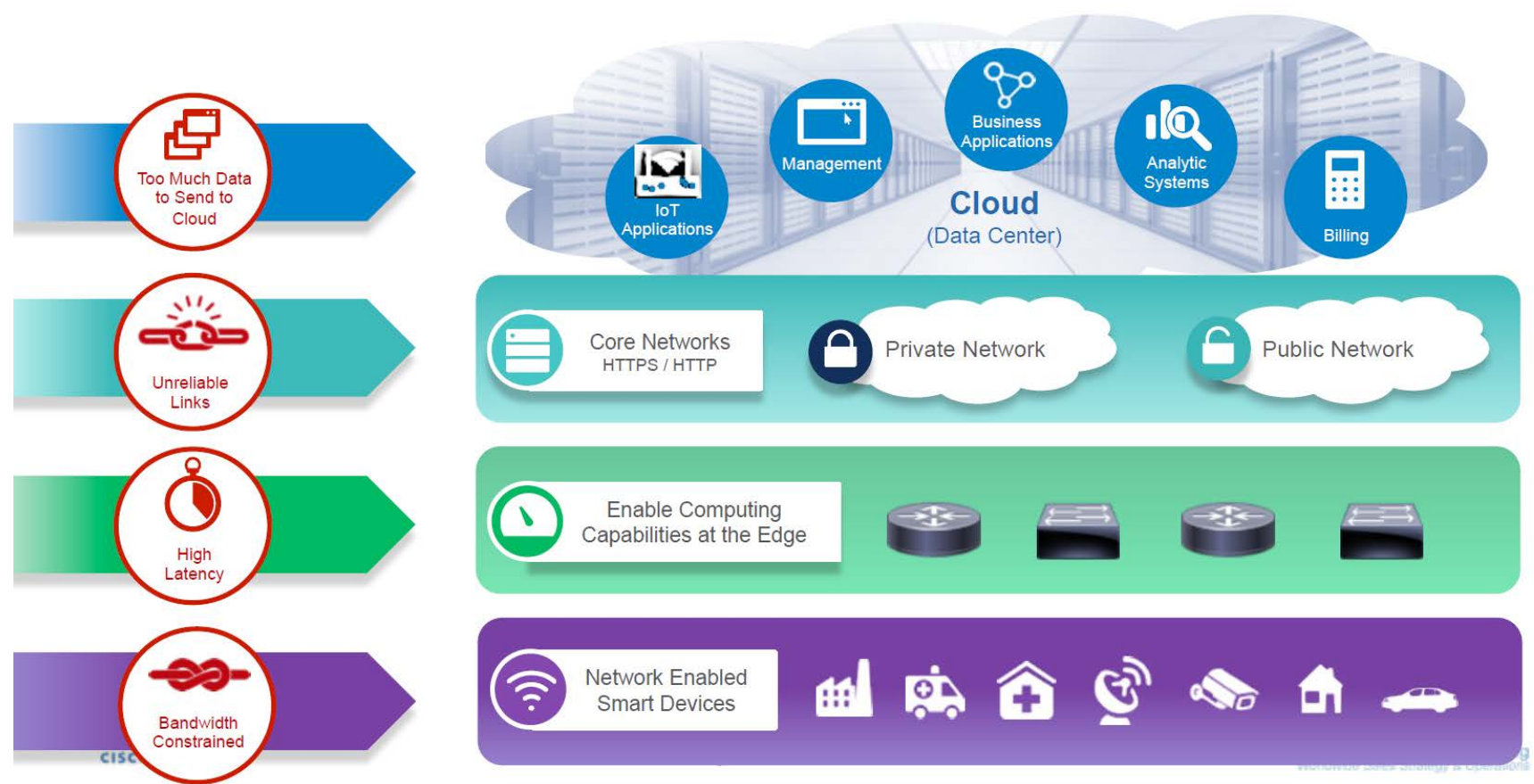- Pioneering **new technologies** to meet **5G** requirements

Hyper dense deployments

Integrated access and backhaul

Mobilizing mmWave

Beam forming

Multi-connectivity

Coordinated spatial techniques

Multicast

Redundant links

Ultra-reliable links

Massive MIMO

Advanced channel coding, e.g. LDPC

Wide bandwidths

Dynamic, low-latency TDD/FDD

Narrowband Internet of Things

New shared spectrum paradigms

Advanced receivers

Multi-hop

Grant-free uplink transmissions, e.g. RSMA

V2N

V2V

Device-centric mobility

New levels of capability and efficiency

10x	10x	10x	3x	100x	100x
experienced throughput	decrease in end-to-end latency	connection density	spectrum efficiency	traffic capacity	network efficiency

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- Required fog application response and latency **of < 50 ms**

- **Traditional approach**
  - Take data to the processing
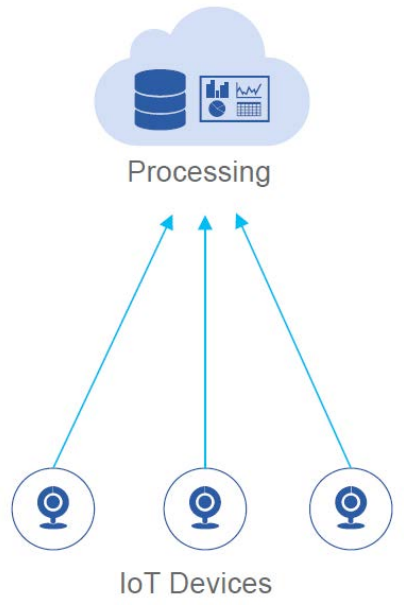
- **Future approach for 5G-IoT**
  - Take processing to the data
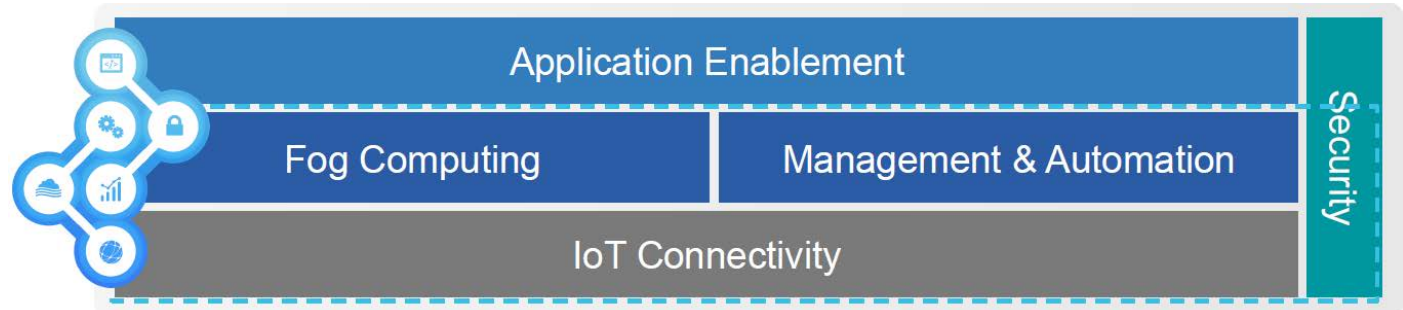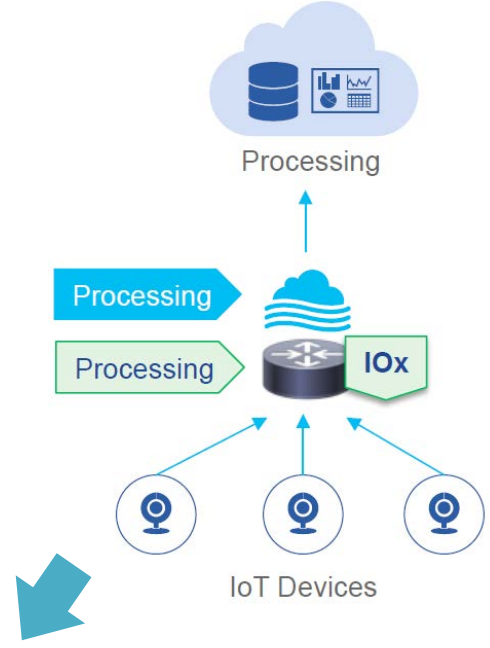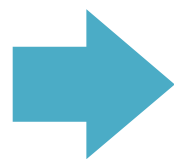
- **Tactile Internet** is able to deliver **remote physical experiences** globaly
  - Design a **higly responsive and adaptive mobile network**
- Robots lack a sense of touch
  - **35% margin of error in the cancer surgery**
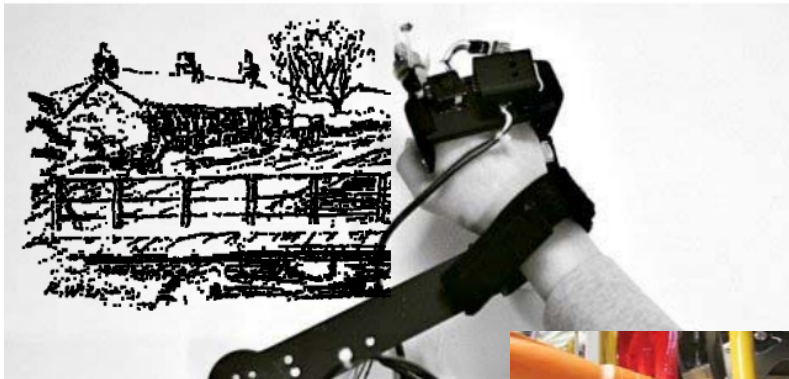
- **IoT enablers**
  - LPAWAN communication technologies, artificial inteligence, machine learning

- **More industrial devices are living on the edge**
  - Edge devices or intelligent gateways that collect, aggregate, filter, and relay data

- **The birth of digital twins**
  - Simulation, testing, and optimization in a virtual environment before committing actual resources

- **IoT leverages augmented and virtual reality (AR/VR)**

- **IoT messaging technologies and protocols**
  - LoRaWAN, Sigfox, 3GPP NB-IoT
  - MQTT, CoAP

- **Stronger cybersecurity eases IoT concerns**

- **5G vision: a unifying connectivity fabric**

5G

Enhanced mobile broadband
- Multi-Gbps data rates
- Extreme capacity
- Uniformity
- Deep awareness

Mobile devices — Networking

Mission-critical services
- Ultra-low latency
- High reliability
- High availability
- Strong security

Automotive — Robotics — Health

Massive Internet of Things
- Low cost
- Ultra-low energy
- Deep coverage
- High density

Wearables — Smart cities — Smart homes

Unified design for all spectrum types and bands from below 1GHz to mmWave
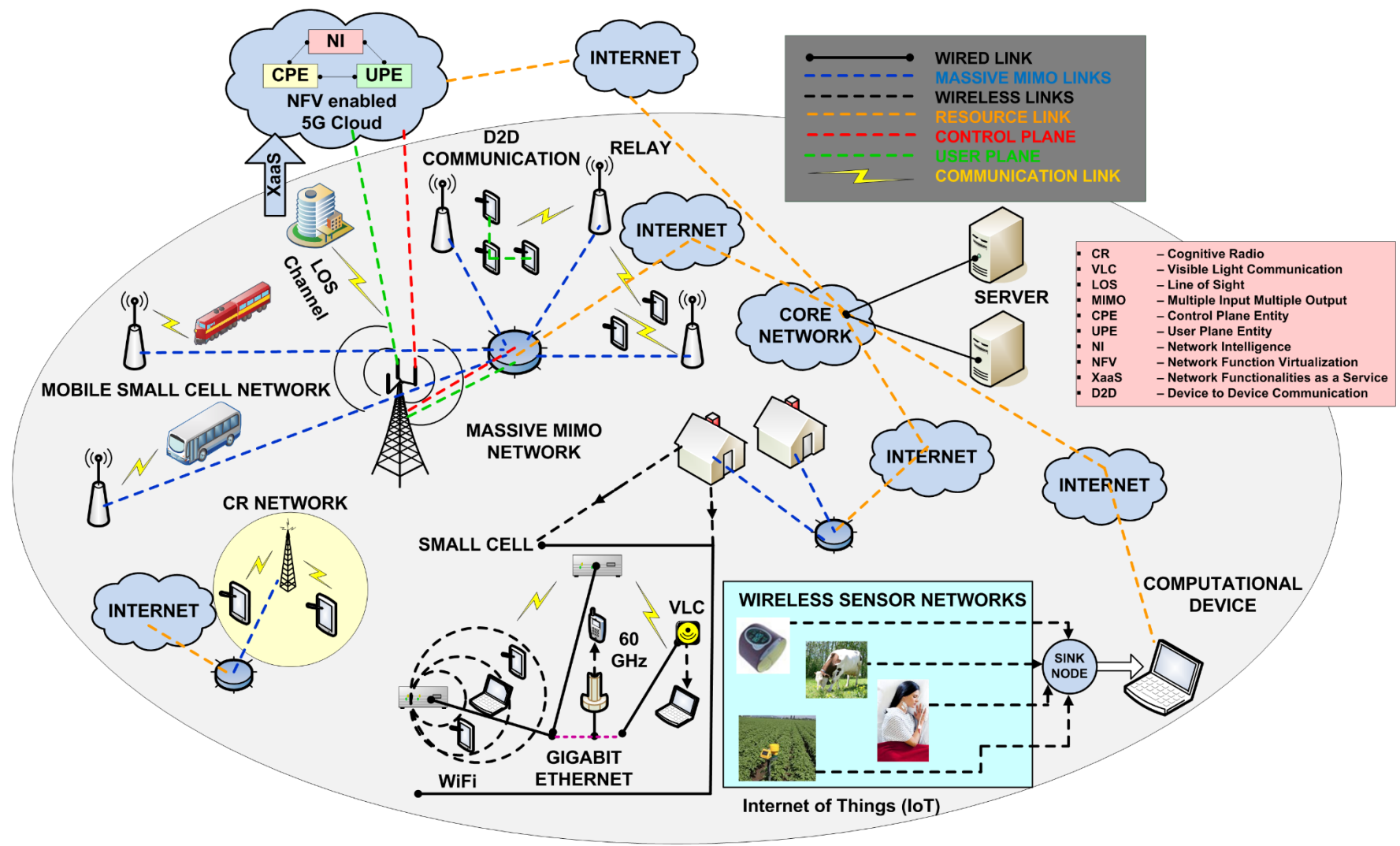
- Scalable **5G** deployments **with multi-connectivity**

- Fully leveraging 4G LTE and WiFi investments for a **seamless user experience (QoE)**

Small cell

5G / 4G / 3G/ Wi-Fi multimode device

Macro

5G Carrier aggregation

5G above 6GHz

5G below 6GHz

4G LTE, LTE Unlicensed and Wi-Fi

5G below 6GHz

4G LTE

5G above 6GHz

Wi-Fi

4G below 6GHz

4G/5G below 6GHz

4G/5G Macro

4G Macro

5G NR radio access designed to utilize LTE anchor for mobility management (non-standalone) or operate stand-alone with new multi-access 5G NextGen Core Network (NGCN)

- **Scalability to address diverse services and devices**
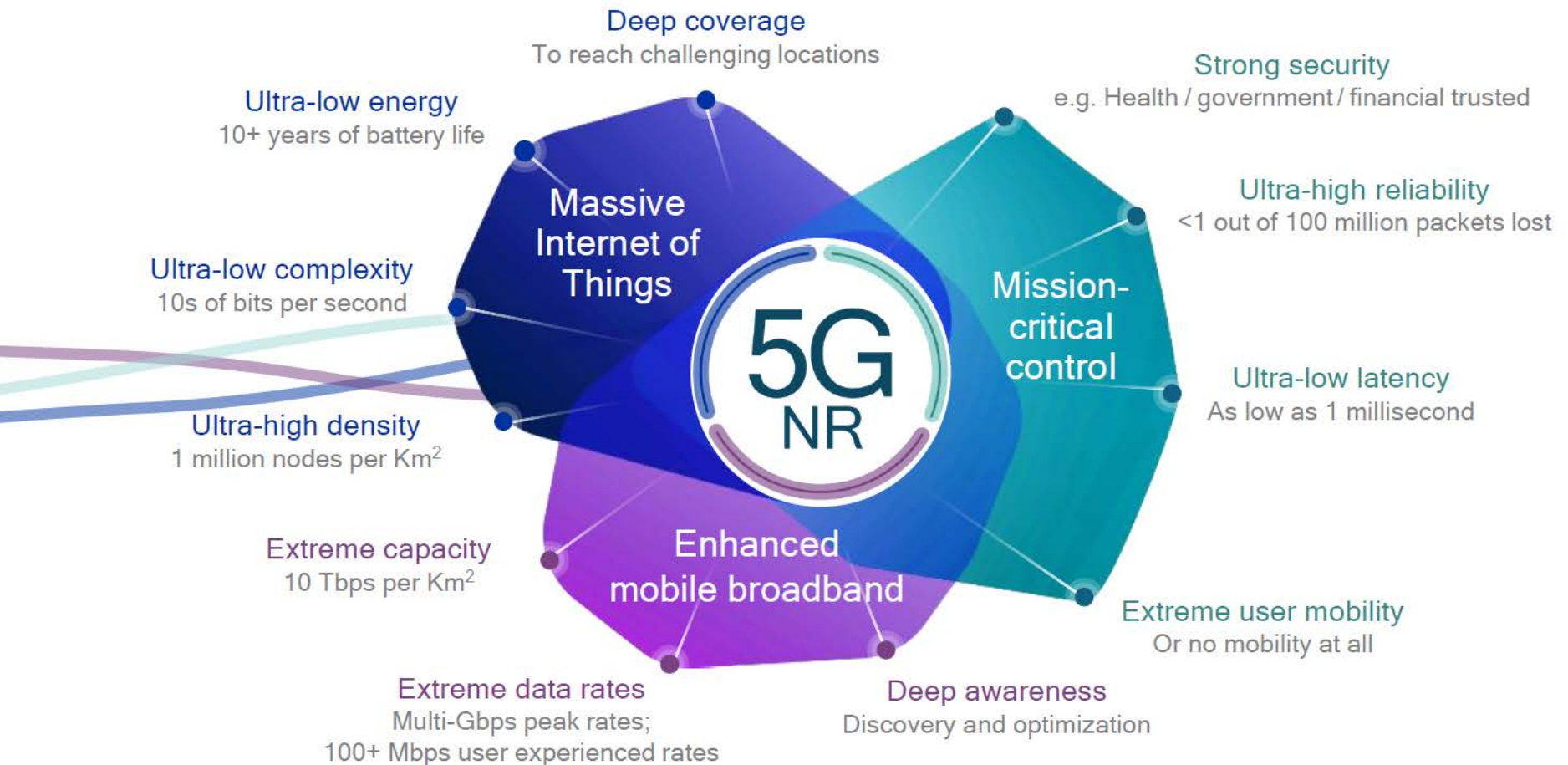
- Mostly sub-3 GHz with some operators now testing / deploying in 3.5 GHz band (CBRS in the US)
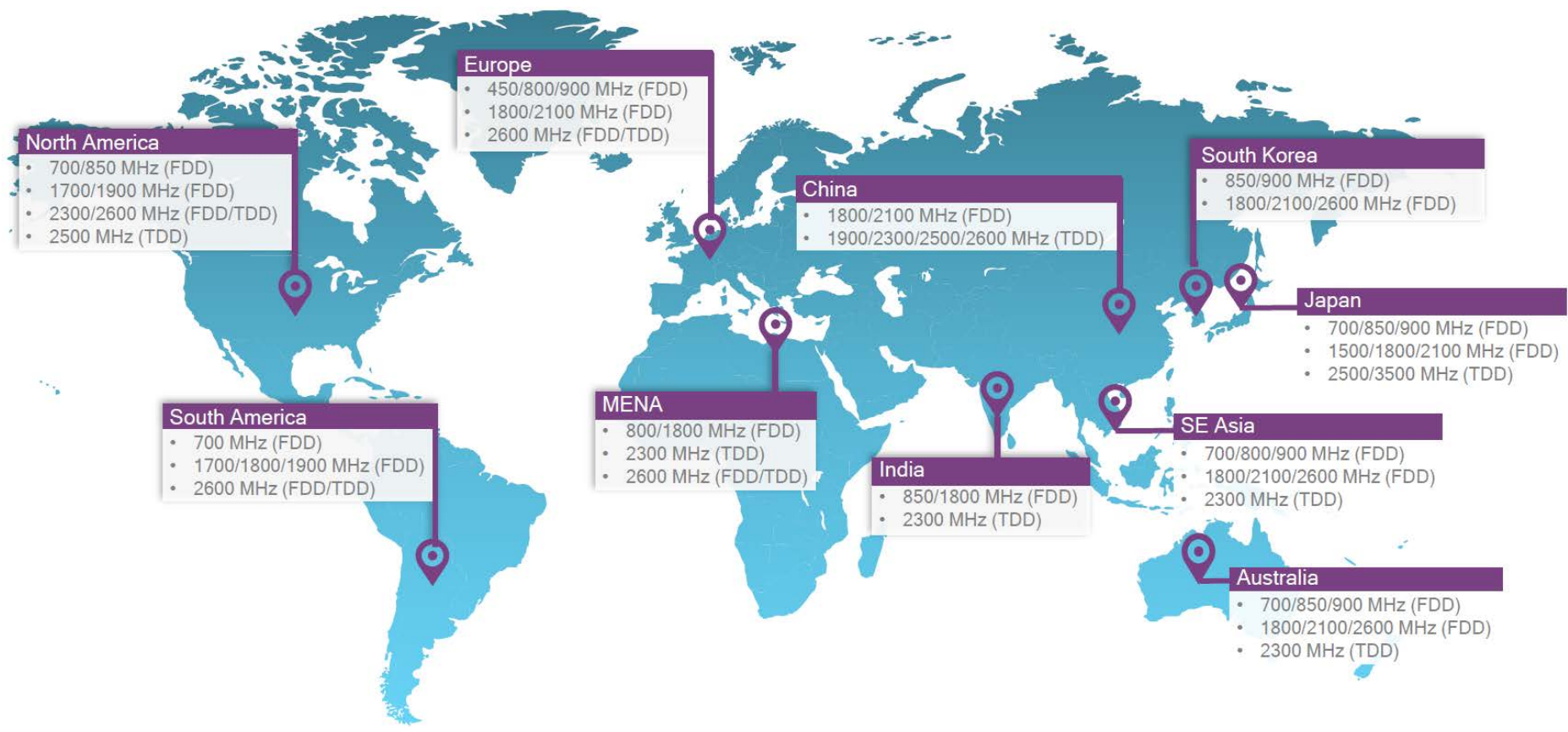

Europe
- 450/800/900 MHz (FDD)
- 1800/2100 MHz (FDD)
- 2600 MHz (FDD/TDD)

North America
- 700/850 MHz (FDD)
- 1700/1900 MHz (FDD)
- 2300/2600 MHz (FDD/TDD)
- 2500 MHz (TDD)

South Korea
- 850/900 MHz (FDD)
- 1800/2100/2600 MHz (FDD)

China
- 1800/2100 MHz (FDD)
- 1900/2300/2500/2600 MHz (TDD)

Japan
- 700/850/900 MHz (FDD)
- 1500/1800/2100 MHz (FDD)
- 2500/3500 MHz (TDD)

South America
- 700 MHz (FDD)
- 1700/1800/1900 MHz (FDD)
- 2600 MHz (FDD/TDD)

MENA
- 800/1800 MHz (FDD)
- 2300 MHz (TDD)
- 2600 MHz (FDD/TDD)

India
- 850/1800 MHz (FDD)
- 2300 MHz (TDD)

SE Asia
- 700/800/900 MHz (FDD)
- 1800/2100/2600 MHz (FDD)
- 2300 MHz (TDD)

Australia
- 700/850/900 MHz (FDD)
- 1800/2100/2600 MHz (FDD)
- 2300 MHz (TDD)

- **New spectrum sharing paradigms**

- Can enable **more efficient utilization** of, and access to, scarce resources

- **Legislation** updates are required

Licensed spectrum
Exclusive use
Example: 2.1 GHz

Shared spectrum
New shared spectrum paradigms
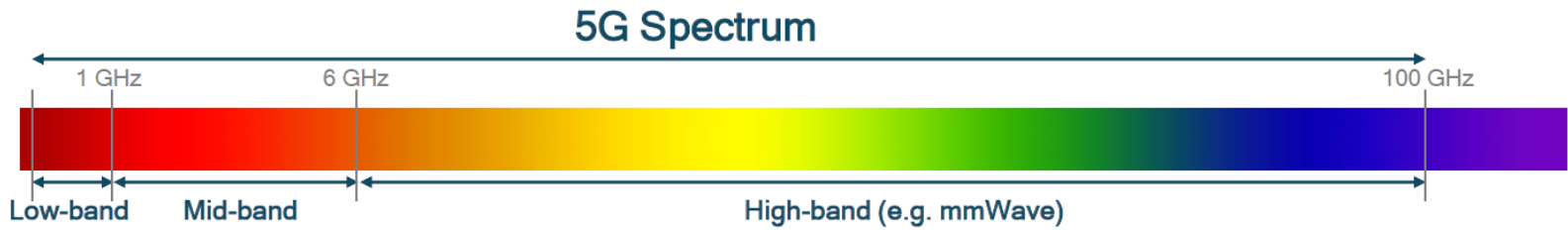Example: 2.3 GHz Europe / 3.5 GHz USA

Unlicensed spectrum
Shared use
Example: 2.4 GHz global / 5 GHz global

5G SHARED SPECTRUM

- The FCC is driving key spectrum initiatives to **enable 5G**

- **Accross low-band, mid-band, and high-band including mmWave**

5G Spectrum

| 1 GHz | 6 GHz | | 100 GHz |

Low-band **Mid-band** **High-band (e.g. mmWave)**

Low-band
Broadcast Incentive Auction

- First stage auction opened up 126 MHz in 600 MHz band, auction failed to close with clearing cost set at $88.4B

- Second stage auction opens up 114 MHz, auction will begin on 9/13

- Spectrum availability timing aligns with 5G

Mid-band
Citizens Broadband Radio Service

- Opening up 150 MHz in 3.5 GHz band

- 3-tier spectrum sharing with incumbents, PAL[1], and GAA[2]

- CBRS Alliance formally launched to drive an LTE-based ecosystem
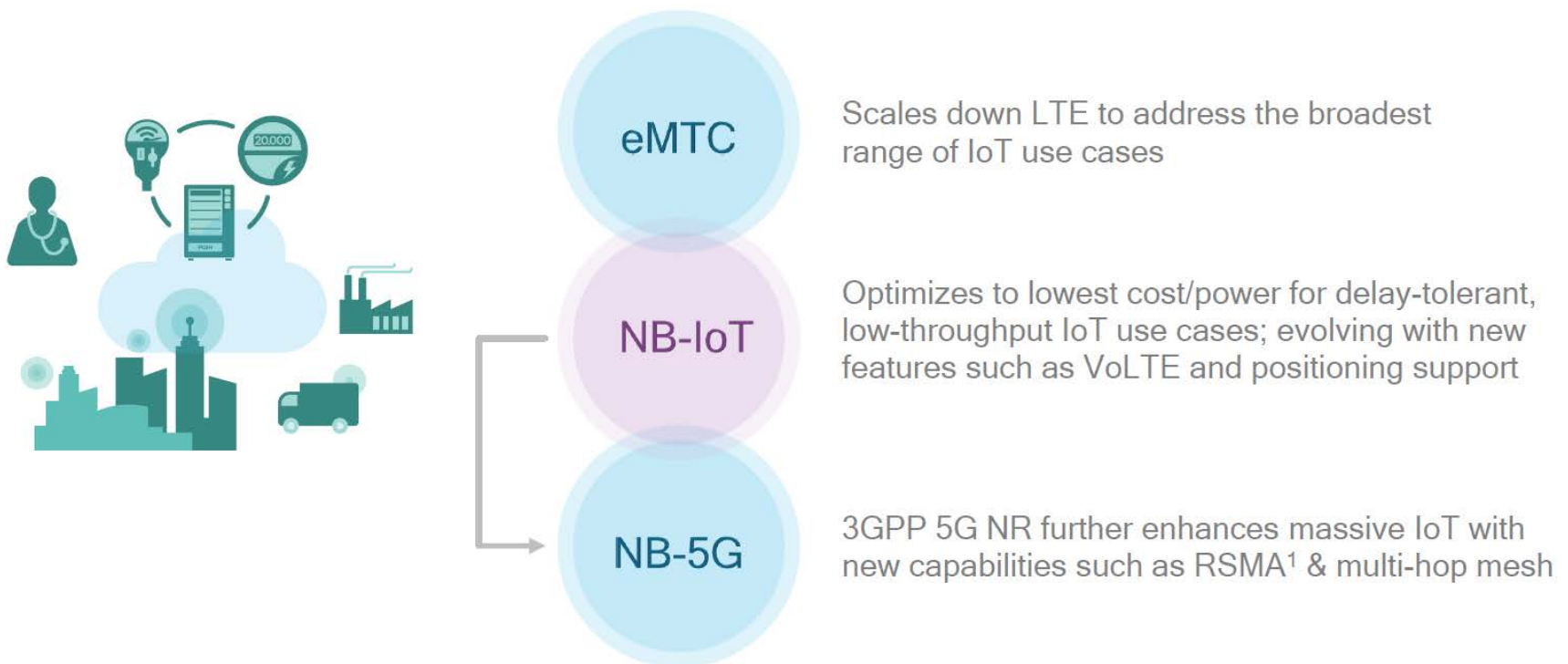
High-band
Spectrum Frontiers Ruling[3]

- Opening up 11 GHz in multiple mmWave bands

- 70% of newly opened spectrum is shared or unlicensed

- Unanimously approved by FCC with additional candidate bands identified for IMT-2020

- Power **efficient**; Low **complexity**; **Long range**

- Low-Power Wide Area Network (LPWAN) technologies
  - **Unlicensed** frequency bands (e.g., 868 MHz)
    - LoRaWAN, SIGFOX
  - Suitable mostly for **less frequent** transmissions of **small data** size
  - Very **good** radio signal **penetration**

- **3GPP NB-IoT** is continuing to evolve beyond Release 13
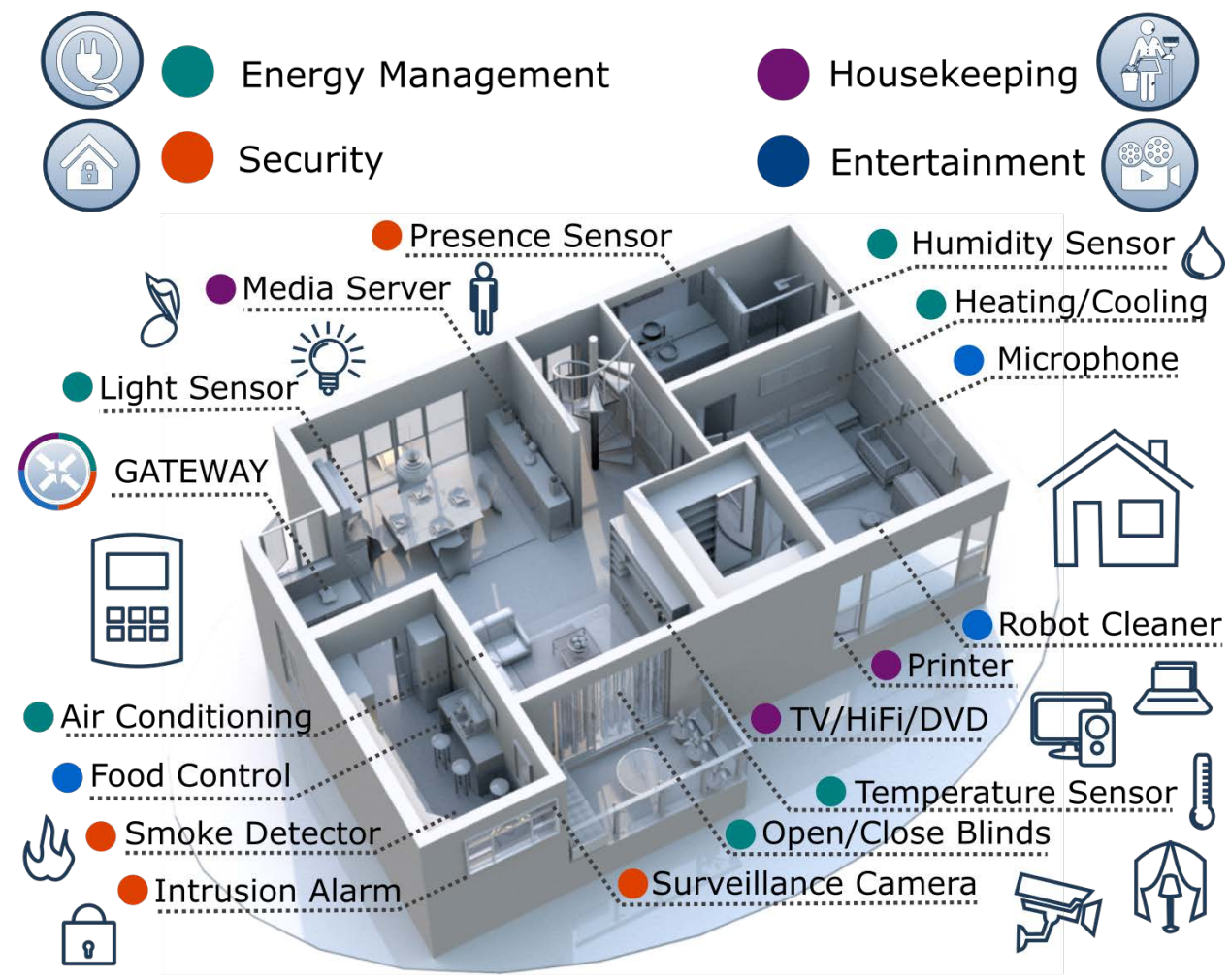 - Standardized cellular-based LPWAN solution

eMTC
Scales down LTE to address the broadest range of IoT use cases

NB-IoT
Optimizes to lowest cost/power for delay-tolerant, low-throughput IoT use cases; evolving with new features such as VoLTE and positioning support

NB-5G
3GPP 5G NR further enhances massive IoT with new capabilities such as RSMA[1] & multi-hop mesh

- IoT communication technologies enables new services and business models in utilities
  - **Online** measurement and control

- Governmental-controlled segment
  - **State critical infrastructure**
  - Specific (law-defined) requirements

- Careful evaluation of **suitable communication technology** according to the specific requirements of different Smart Grid services

- **Smart Grid**

  - Complex system of energy consumption / production units

  - Interconnection of all components

    - Specific traffic models in each segment

 - **It is not only about smart metering!**

- Constantly growing number of **communication-capable devices** deployed in our homes
  - Across most of the domains of our living

- **High diversity** of (often proprietary) technologies and solutions

- Energy Management
- Security
- Housekeeping
- Entertainment

- Presence Sensor
- Media Server
- Light Sensor
- GATEWAY
- Air Conditioning
- Food Control
- Smoke Detector
- Intrusion Alarm
- Humidity Sensor
- Heating/Cooling
- Microphone
- Robot Cleaner
- Printer
- TV/HiFi/DVD
- Temperature Sensor
- Open/Close Blinds
- Surveillance Camera

SMART MULTI-PURPOSE HOME GATEWAY (SYMPHONY)

- **Proof-of-concept** project
- **Gateway-centric** smart home system orchestrating a variety of sensors and actuators via different communication technologies
- Cellular connection as main communication channel outside the home
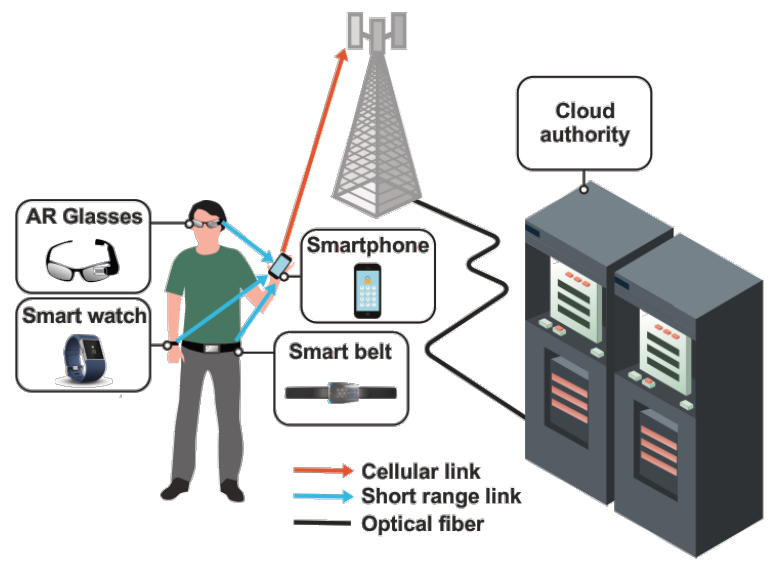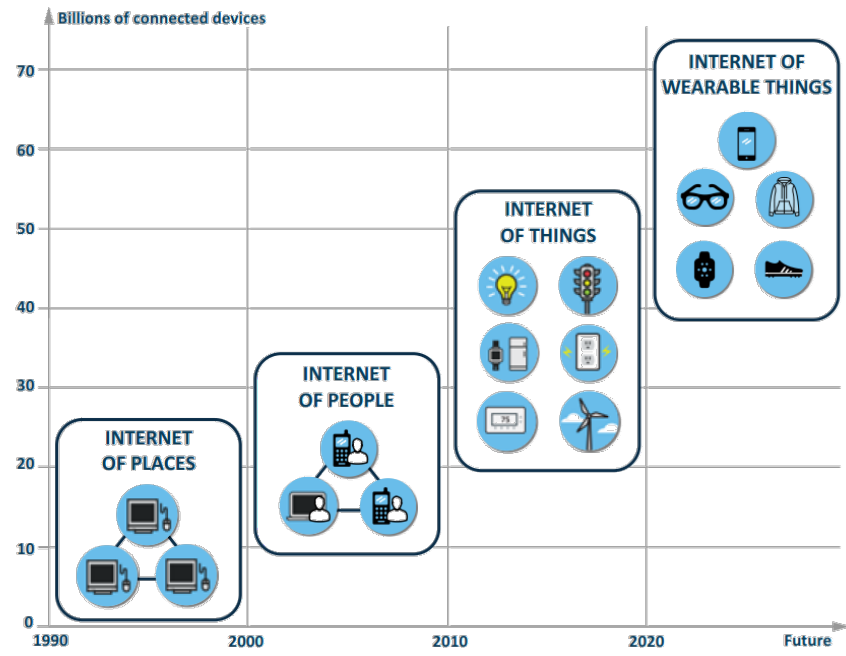- Interoperability needs to implemented as middleware
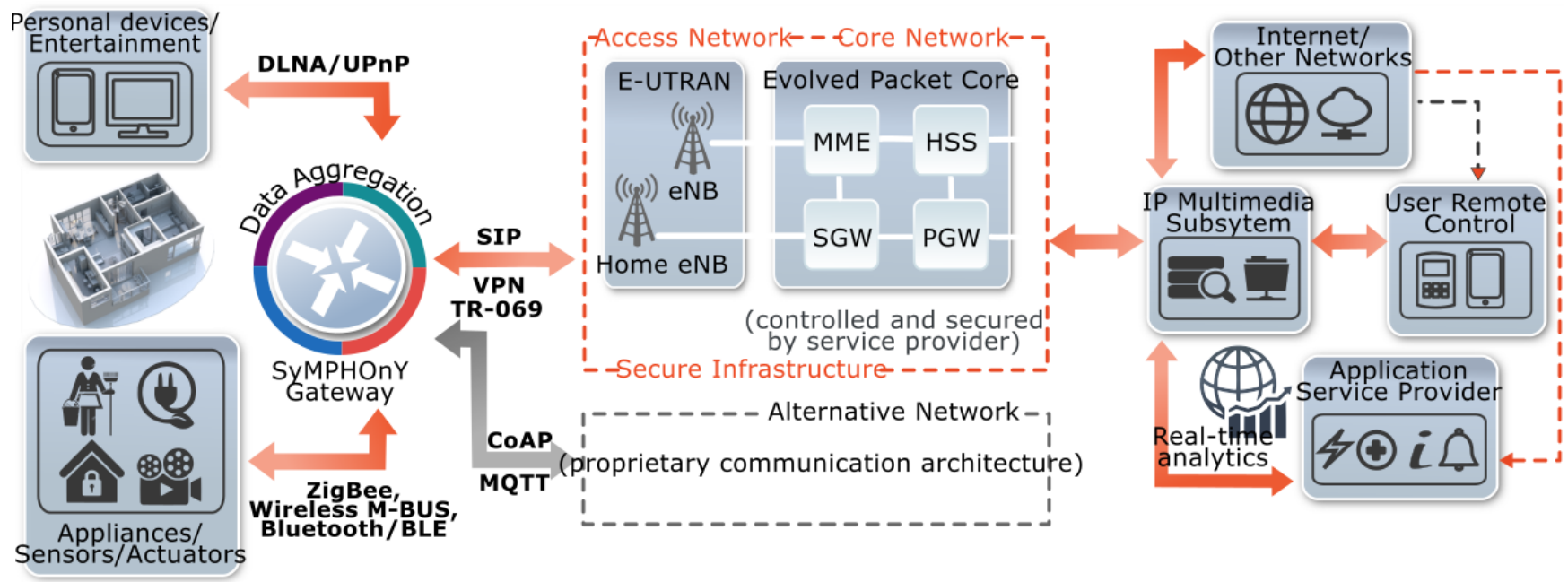
- **Industry 4.0**
  - Digitalization and automatization of all production processes
    - Automotive halls, logistic warehouses
 - Increasing efficiency
  - Reducing costs

Processing system
- per-item monitoring
- fast roaming
- RFID-like paging

Remote operator
AR/stereo 3D video

Monitoring system
- massive access
- small data
- low cost, disposable

Operator-controlled machinery
- real-time AR
- positioning
- collision avoidance

Self-driving transport
- local P2P communications
- positioning
- collision avoidance

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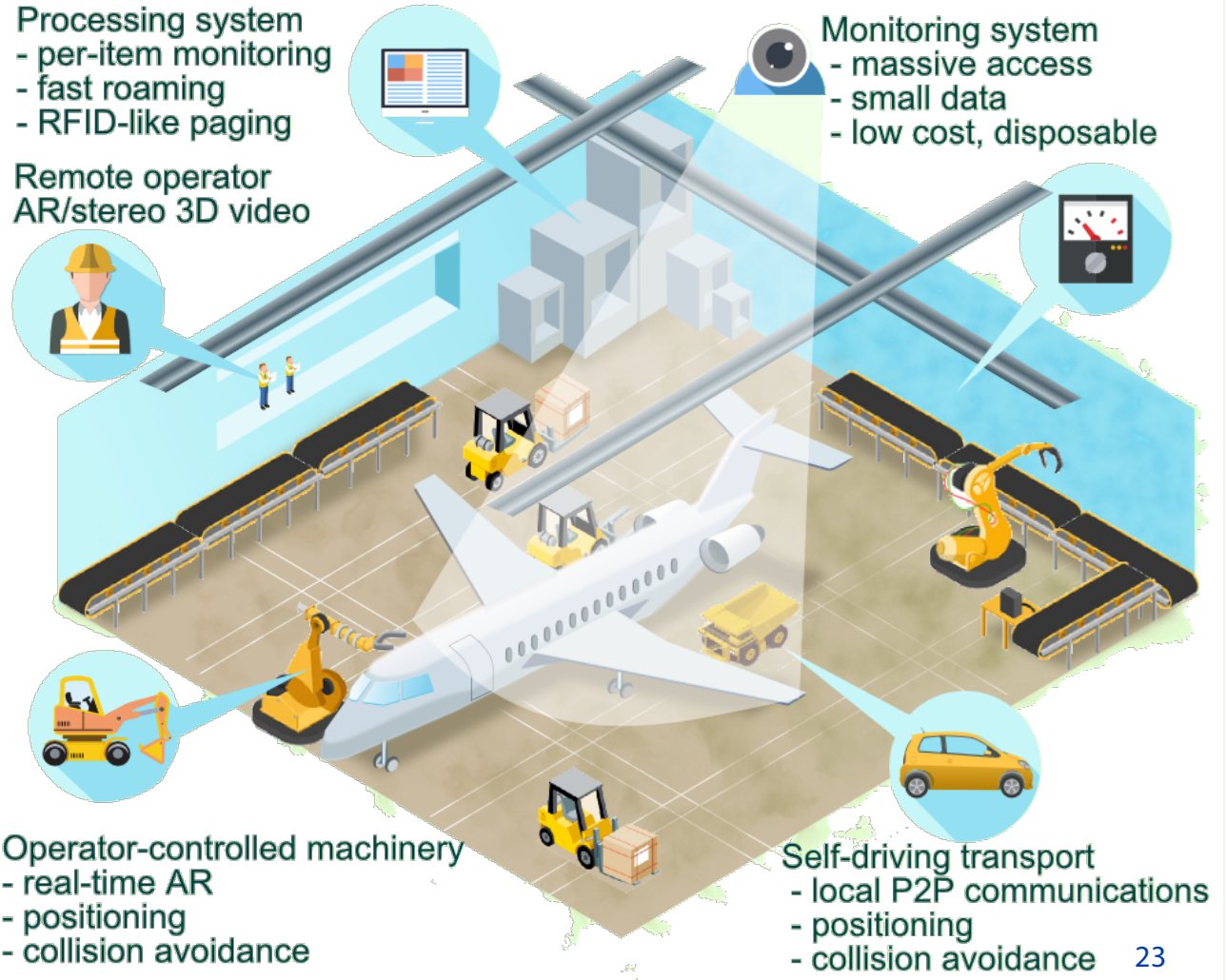
WEARABLES

- Emerging IoT segment enabling **cIoT and iIoT applications** as well
  - Electronic appliances (gadgets) worn directly on human body or in its vicinity

- Specific transmission requirements
  - **Up to Gb/s transmission speed**, ultra-low delay, high energy efficiency, **good user experience**
    - Variety of short range technologies
      – mmWave technologies
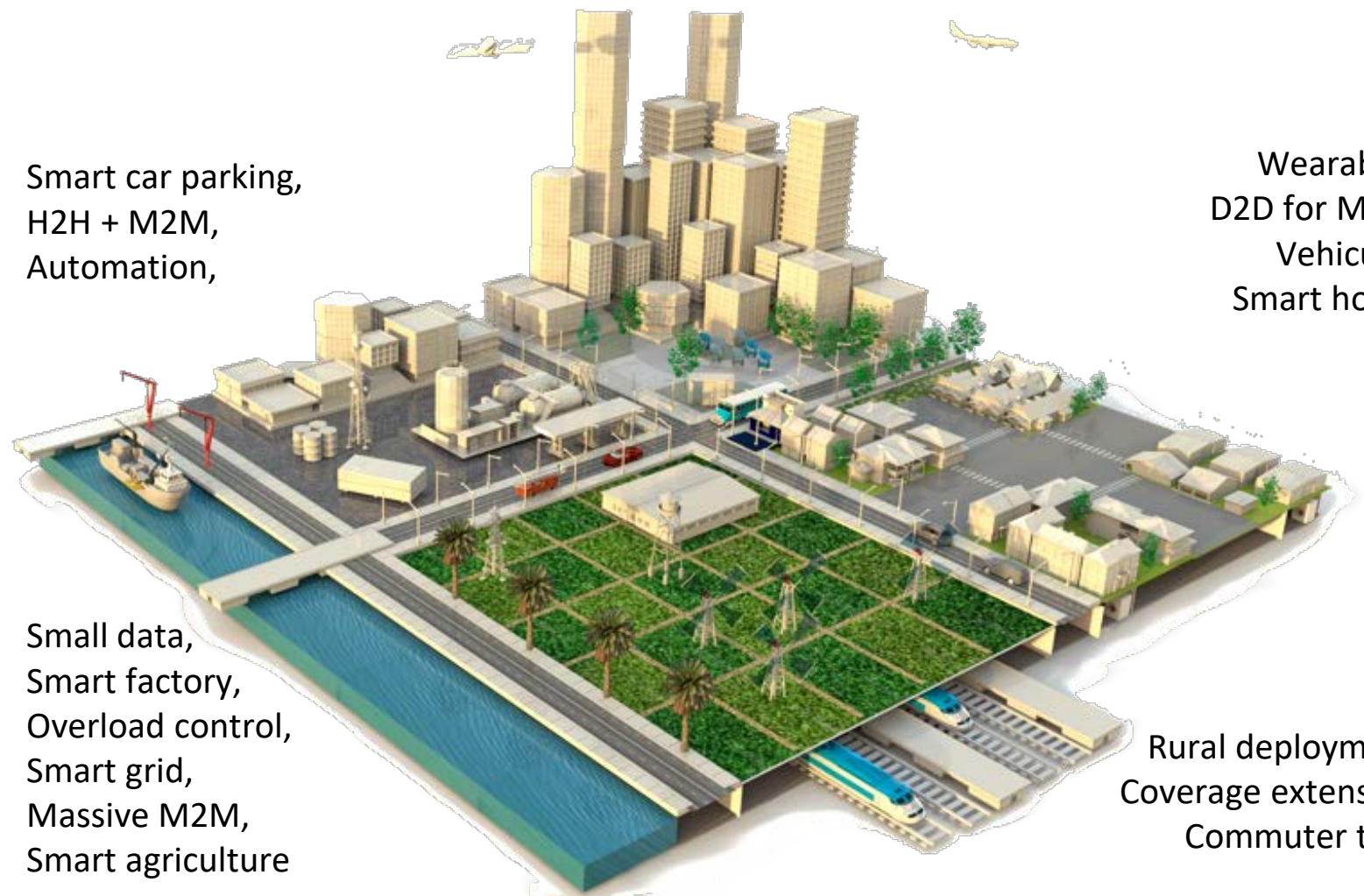
Smart car parking,
H2H + M2M,
Automation,

Wearables,
D2D for M2M,
Vehicular,
Smart home,

Small data,
Smart factory,
Overload control,
Smart grid,
Massive M2M,
Smart agriculture

Rural deployment,
Coverage extension,
Commuter train

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- Currently, we live in the **world of apps**

- **State-of-the-art technologies** are already **mature enough** to support novel applications

- True **smart applications** and services should work **without human interaction** and awareness

- Challenges to be solved:
  - Technology interoperability
  - Service integration
  - Proper legislation and policies
  - User experience
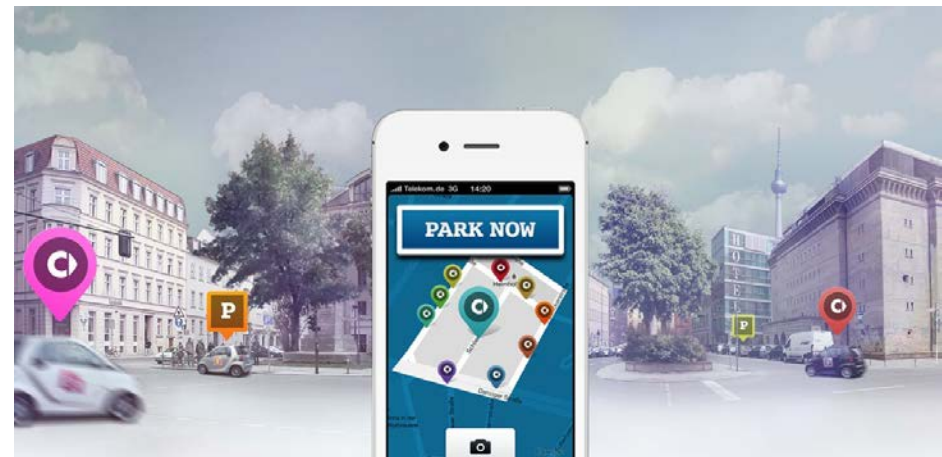
Source: Mario Morales, IDC

- We are **on the road** and we already know what 5G will be about!

- 5G is coming to change our **way of thinking** about communication technologies
  ◦ Still too **many challenges** and open issues in all aspects to be solved

- **(industrial) IoT** is the main driver for deployment of 5G wireless networks
  ◦ Tactile Internet
  ◦ Augmented / virtual reality
  ◦ Machine learning

Thank you for your attention.

Brno University of Technology,

Faculty of Electrical Engineering and Communication,

Department of Telecommunication

hosek@feec.vutbr.cz