L’edificio in rete: tecnologie low-power ed efficientamento energentico

Prof. Nicola Cordeschi

21-03-2023

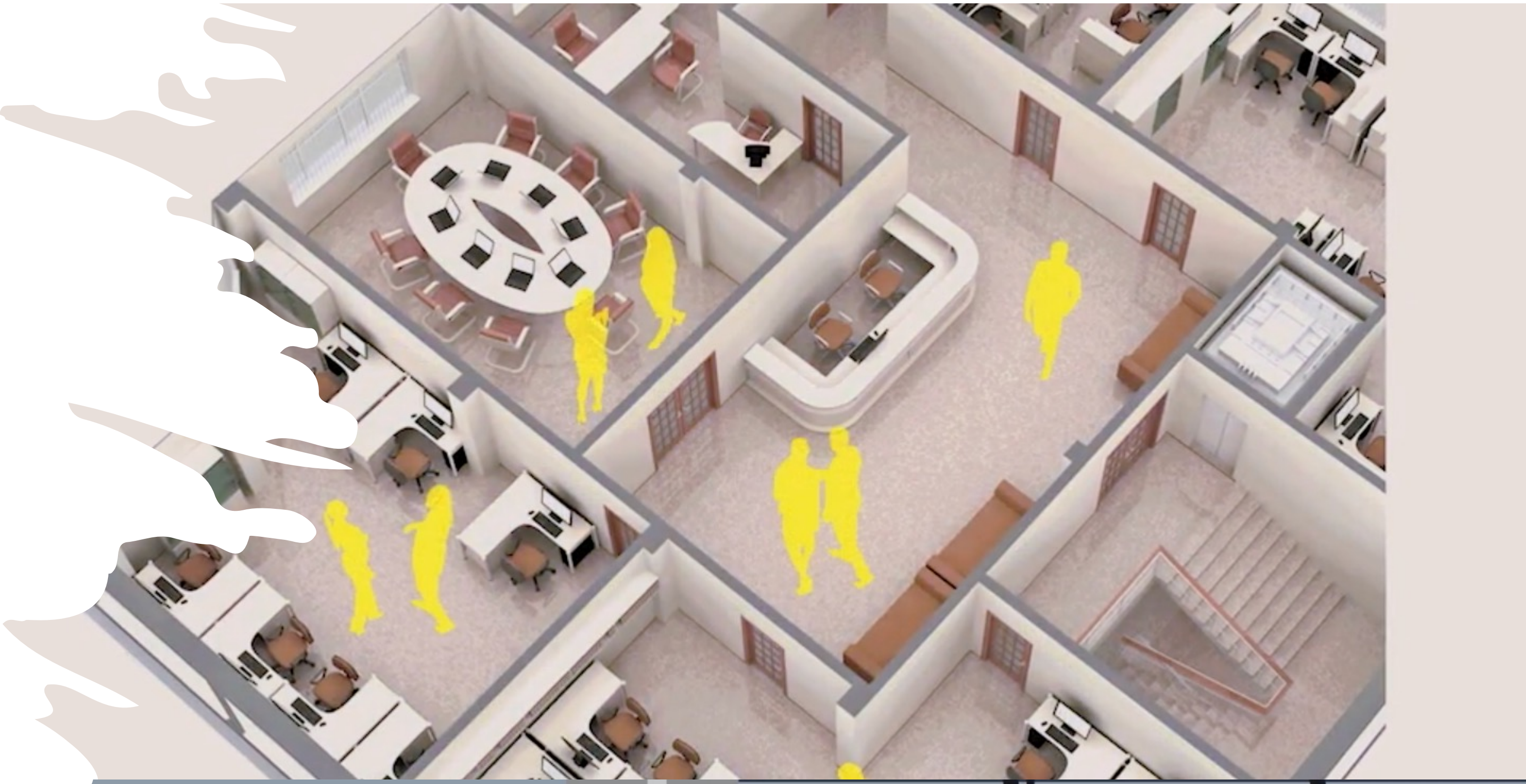
Outline

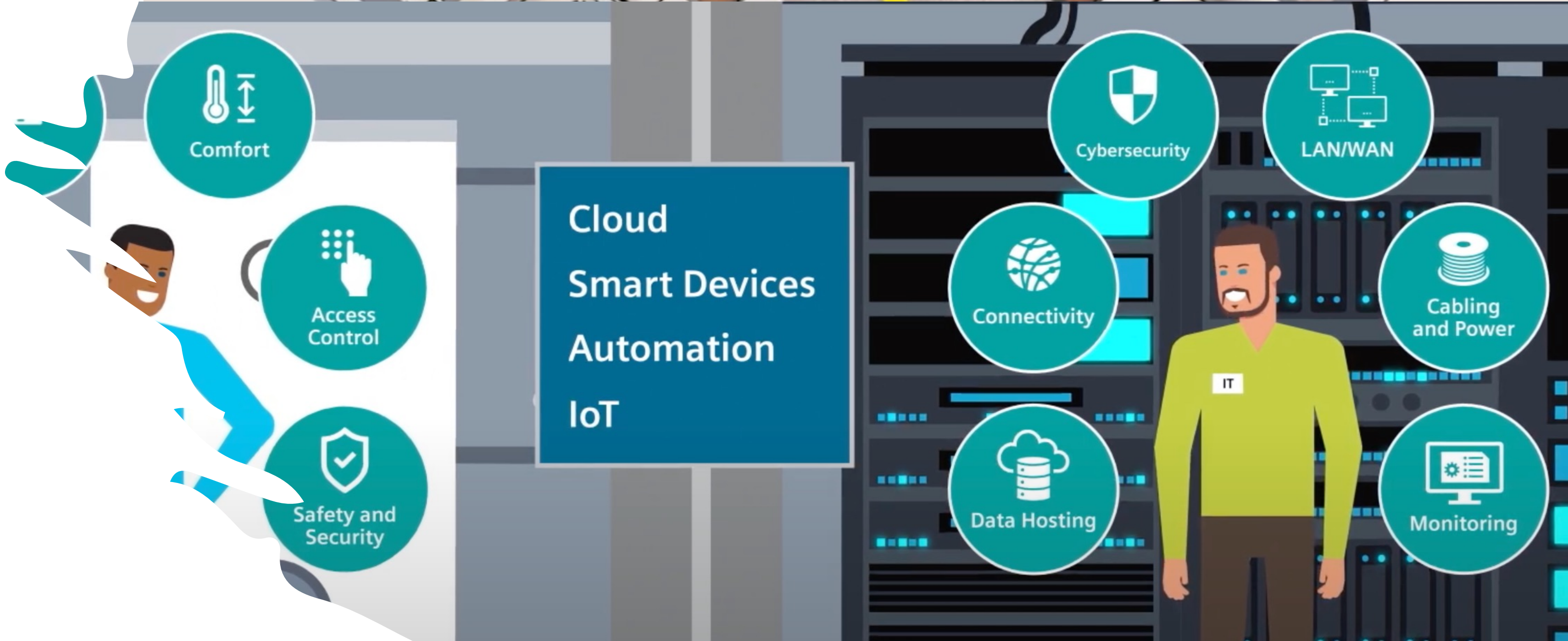
- Smart Buildings and IoT
- IoT Market and Ecosystem
- IoT Technology Overview:
  - *Short-range*
  - *LPWA*

Smart Buidings

Smart Building, Energy-management, IoT

- A building's operations consist of various systems:
- heating, ventilation, air conditioning, lighting, and security.
- Energy management, video surveillance, access management, and environmental monitoring are part of the related requirements.



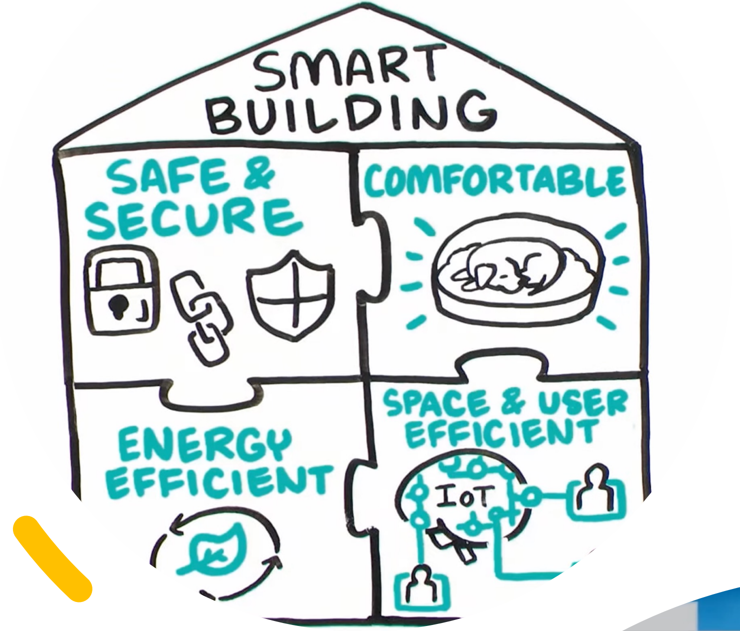


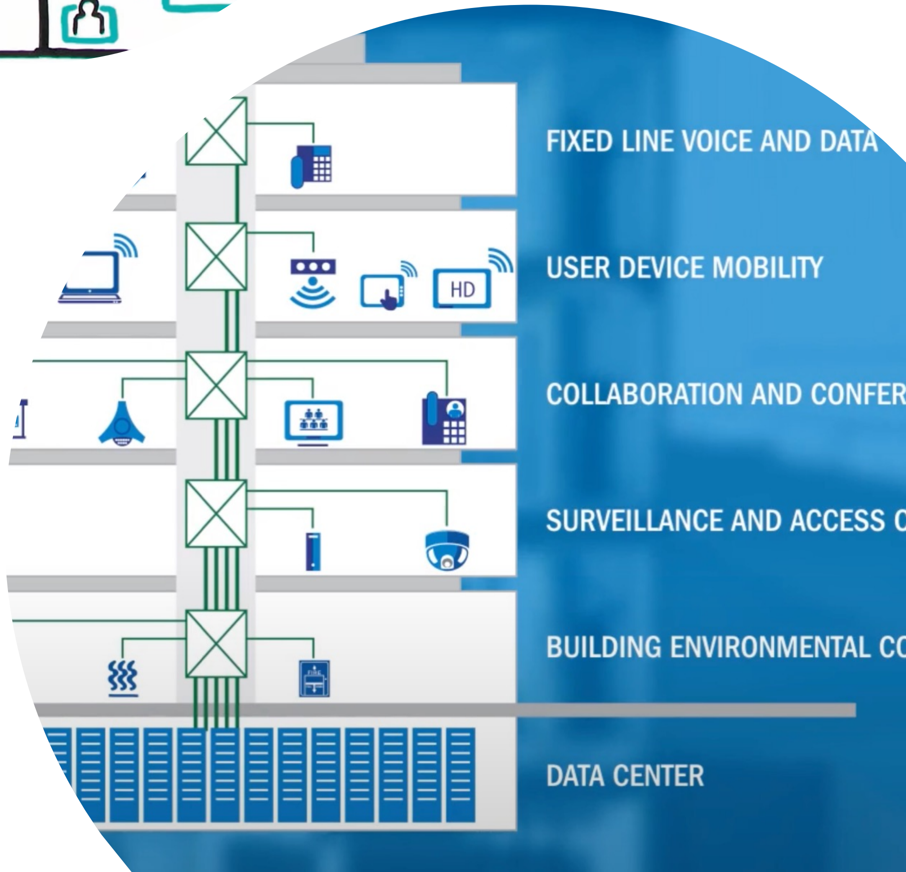
Smart Building, Energy-management, IoT

- In the modern age, a wide range activity is required for commercial buildings. According to the **UN Global Status Report 2017**:
  - "**36 percent of energy use and nearly 40 percent of the carbon emissions in the world come from buildings**."

- An energy management and control system has a crucial role in the optimization of energy consumption without compromising comfort or performance

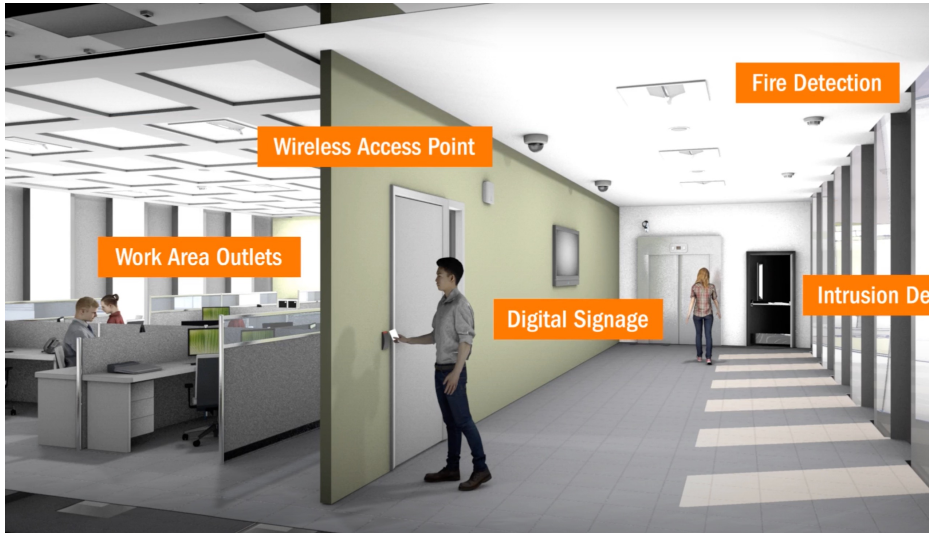
- **Any structure can be converted to a smart building** through the use of automated processes to control its operations.





Smart Building, Energy-management, IoT

- The **real value of IoT** in comparison to the traditional control systems of a building are related to:
    - **Real-time monitoring and** the possibility of **adjustments**, with the use of *sensors*, *actuators*, and microchips as well as *data collection* and *cloud* computing,
    - IoT by wireless sensor networks (WSN) provides more **flexibility**
    - **Economically justifiable**



Smart Building, Energy-management, IoT

- The **real value of IoT** in comparison to the traditional control systems of a building are related to:
  - **Real-time monitoring and** the possibility of **adjustments**, with the use of *sensors*, *actuators*, and microchips as well as *data collection* and *cloud* computing,
  - IoT by wireless sensor networks (WSN) provides more **flexibility**
  - **Economically justifiable**

TABLE I. POTENTIAL FOR ENERGY SAVINGS FOR DIFFERENT SENSORS [10].

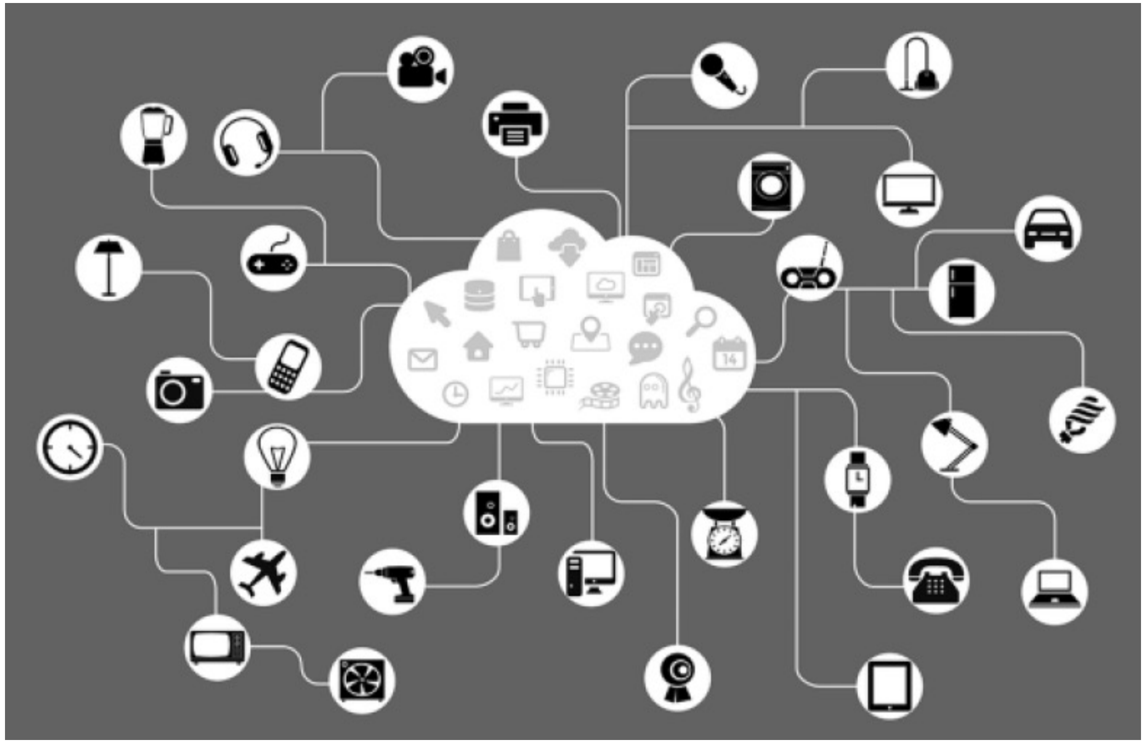
System	Technology	Energy Savings
Lighting	Advanced lighting controls	45%
Lighting	Web-based lighting management system	20-30% above controls savings
Window shading	Automated shade system	21-38%
Window shading	Switchable film	32-43%
Window shading	Smart glass	20-30%
Building automation	Building automation System (BAS)	10-25% whole building
Analytics	Cloud-based energy information system	5-10% whole building

IoT Market

IoT definition and IoT Market(s): a Mindset shift

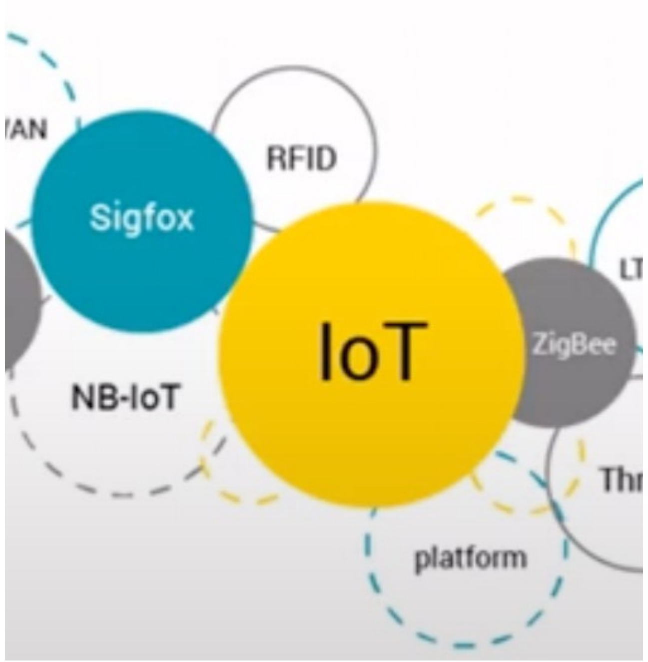
The Internet of Things (IOT) is the system of Connected Computing Devices, Machines, Sensors, Animals, People, Objects (ex. Lights & Meters) with UIDs (unique identifiers - say unique names) that have the ability to transfer, Compute, Analyze data over a network without requiring human-to-human or human-to-computer interaction.

	Traditional Mindset	IoT Mindset
Customer needs	Answer to existing needs in a reactive manner	Address emerging needs in a predictive manner
Offering	Stand-alone produce that becomes obsolete over the time	Product refreshes thanks to over the air updates
Path to profit	Sell the next product/device	Enabling recurrent revenues



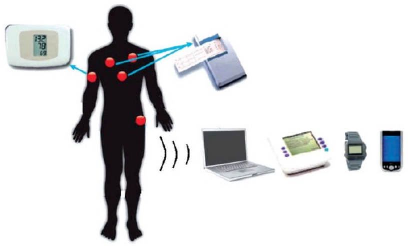
Further IoT Definitions…

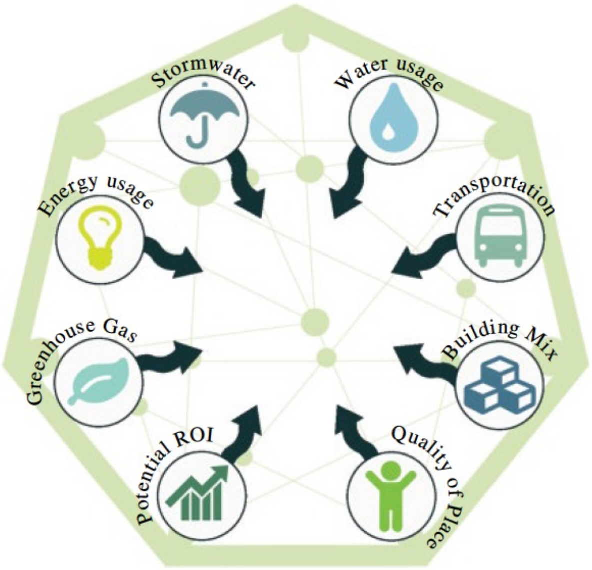
- **IEEE (2015)**: "Broadly speaking, the Internet of Things is a system consisting of networks of sensors, actuators, and smart objects whose purpose is to interconnect 'all' things, including everyday and industrial objects, in such a way as to make them intelligent, programmable, and more capable of interacting with humans and each other"
- **National Institute of Standards and Technology (NIST)**: *"Cyber-physical systems (CPS)—sometimes referred to as the Internet of Things (IoT)—involves connecting smart devices and systems in diverse sectors like transportation, energy, manufacturing and healthcare in fundamentally new ways. Smart Cities/ Communities are increasingly adopting CPS/IoT technologies to enhance the efficiency and sustainability of their operation and improve the quality of life."*
- **Internet Engineering Task Force (IETF)**: "The basic idea is that IoT will connect objects around us (electronic, electrical, non-electrical) to provide seamless communication and contextual services provided by them."
- **International Telecommunications Union (ITU)**: a network that is available anywhere, anytime, by anything and anyone
- **Organization for the Advancement of Structured Information Standards (OASIS)**: "System where the Internet is connected to the physical world via ubiquitous sensors."
- **European Telecommunications Standards Institute (ETSI)**: "the communication between two or more entities that do not necessarily need any direct human intervention."

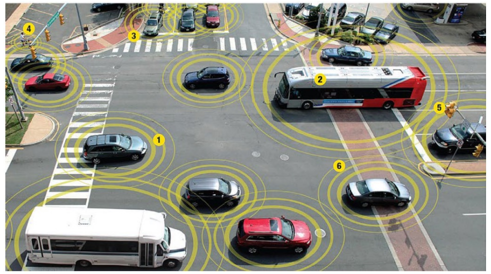


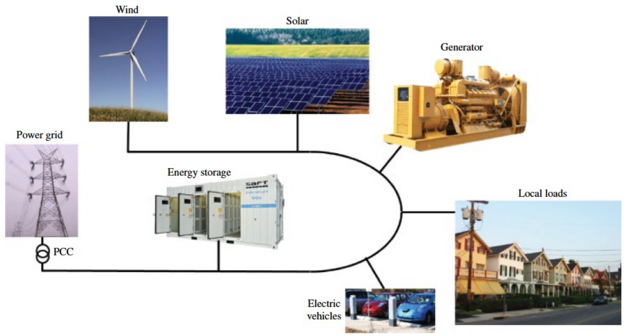
IoT use-cases

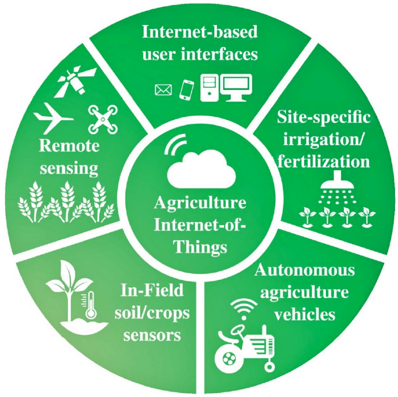
- Smart City
- Internet of Vehicles
- Internet of Drones
- Smart Grid
- Smart Health
- Smart Home
- Smart Agriculture
- Smart Ship
- Industrial IoT
- Etc…

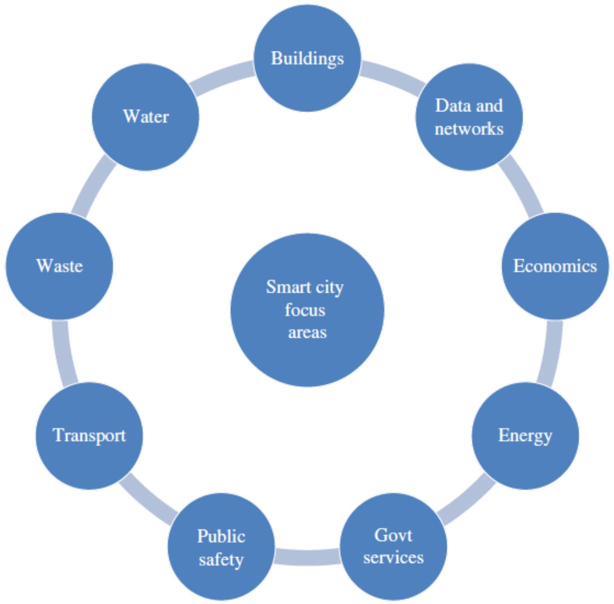


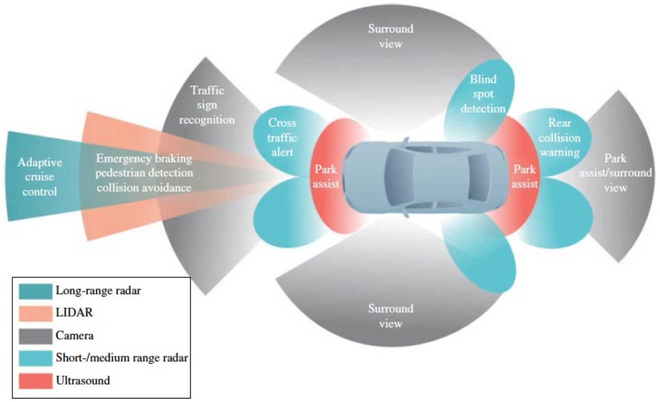




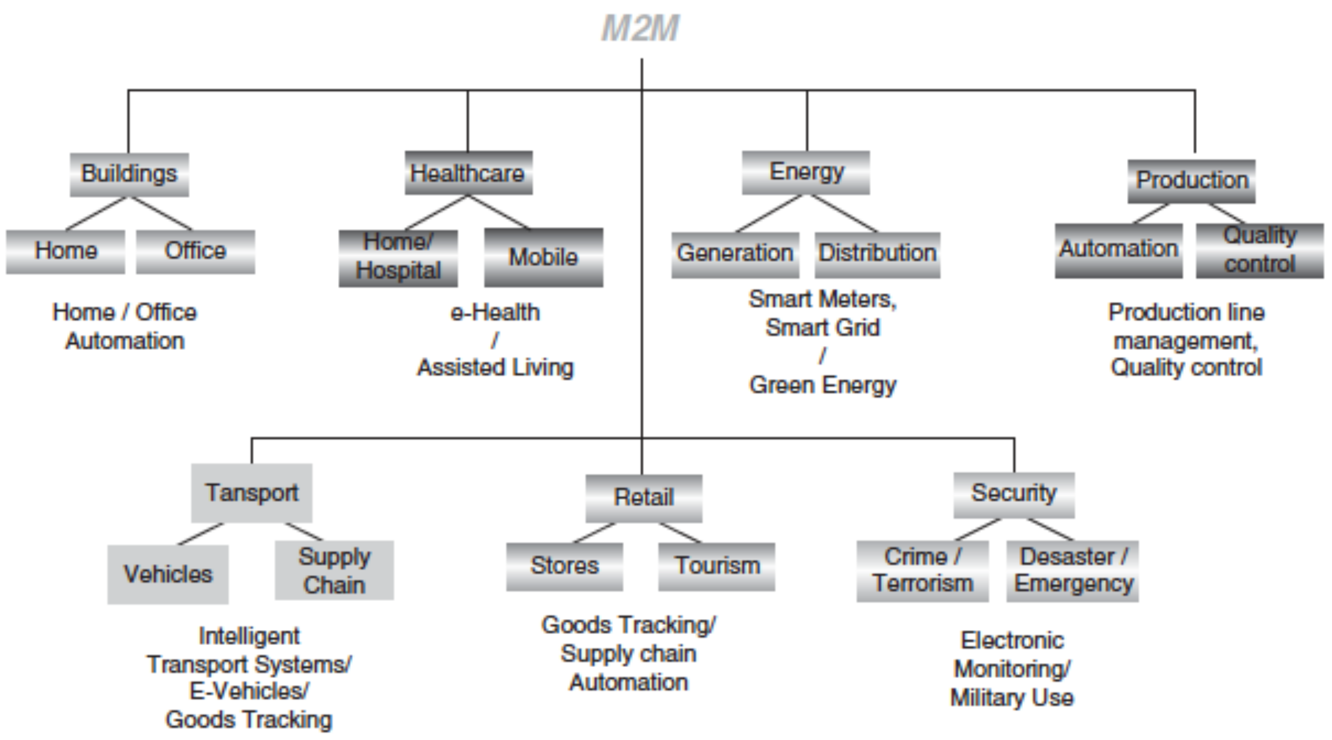


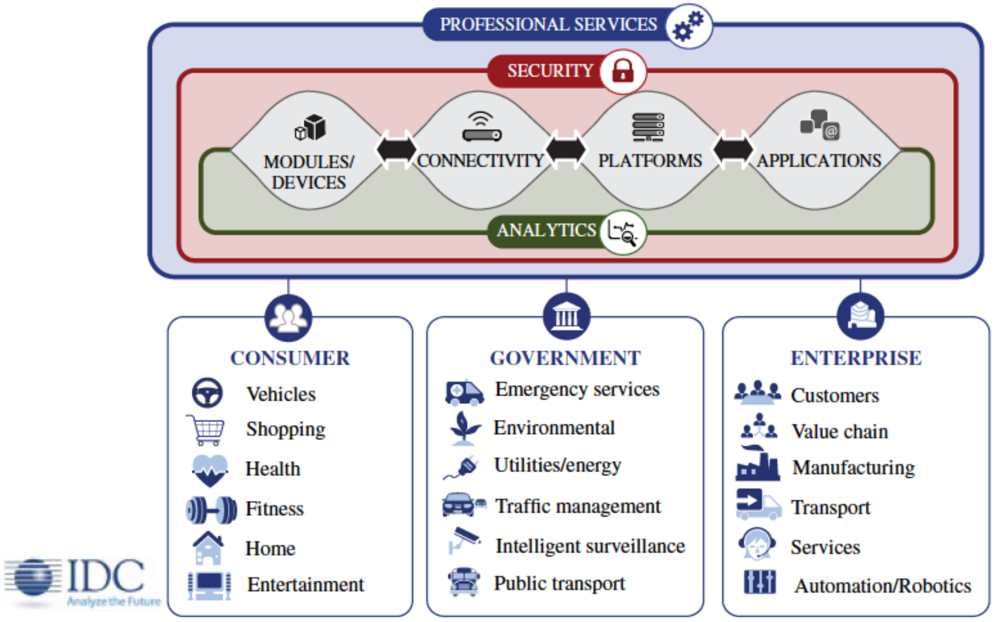






Application Taxonomy and Ecosystem



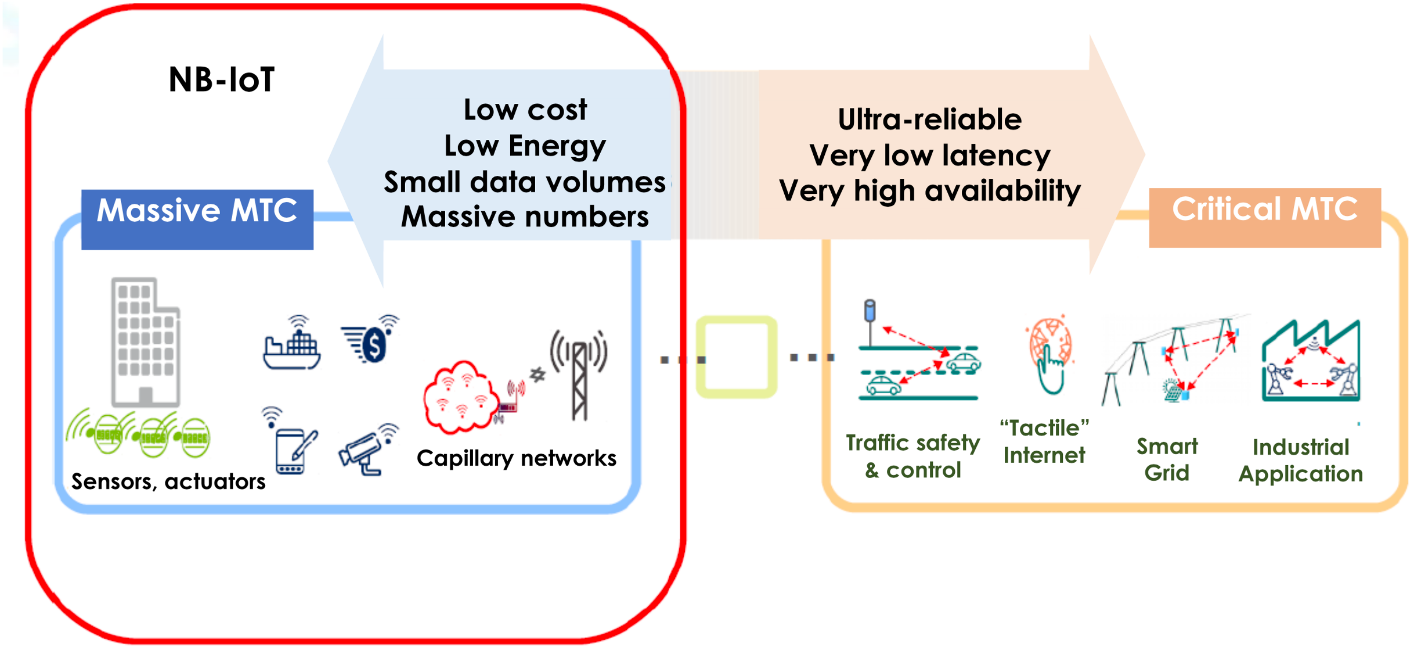


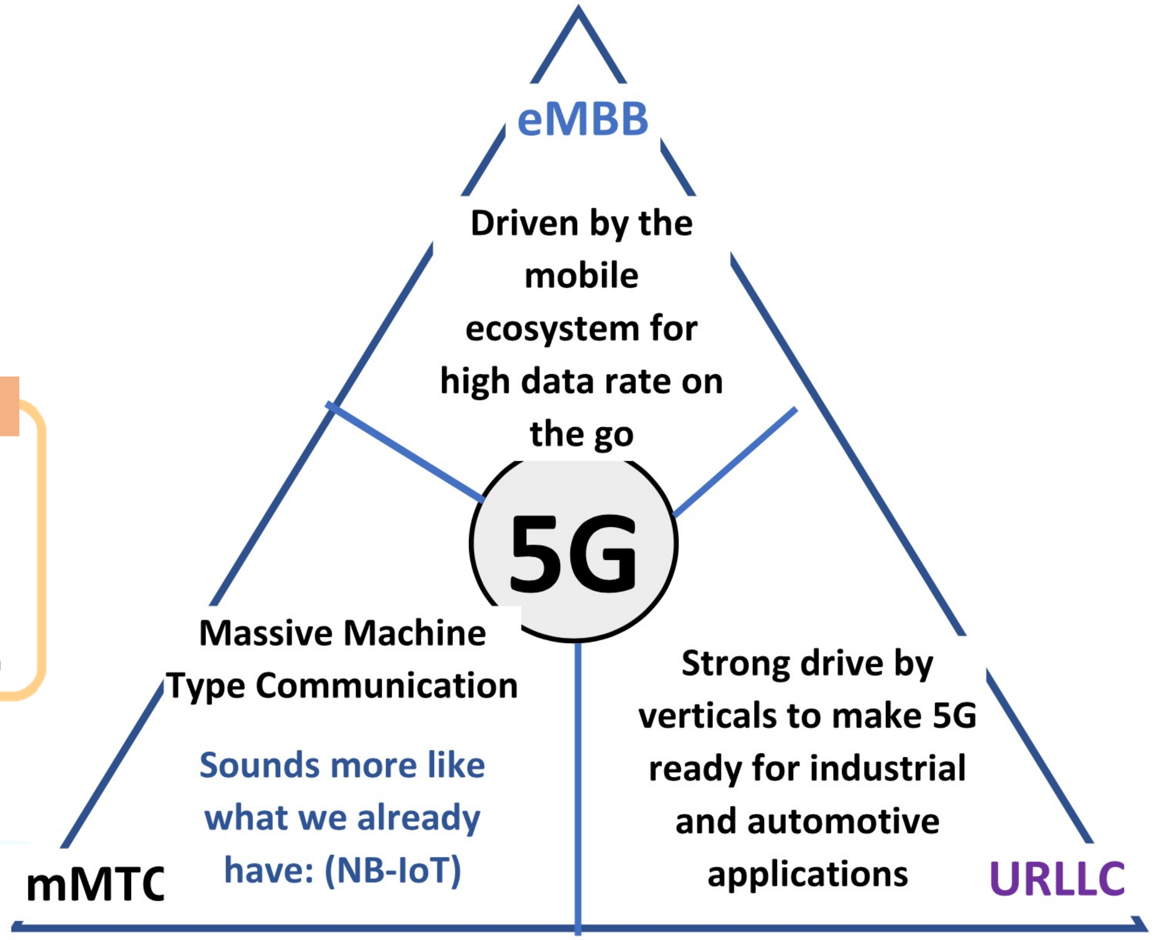
	ITS	e-Health	Surveillance	Smart Meters
Mobility	Vehicular	Pedestrian/ vehicular	None	None
Message size	Medium	Medium?	Large	Small (few kB)
Traffic pattern	Regular/ irregular	Regular/ irregular	Regular	Regular
Device density	High	Medium	Low	Very high (up to 10,000 per cell)
Latency requirements	Very high (few milliseconds)	Medium (seconds)	Medium (<200 ms)	Low (up to hours)
Power efficiency requirements	Low	High (battery power devices)	Low	High (battery-powered meters)
Reliability	High	High	Medium	High
Security requirements	Very high	Very high	Medium	High

Courtesy: A. Maeder, NEC Laboratories Europe.

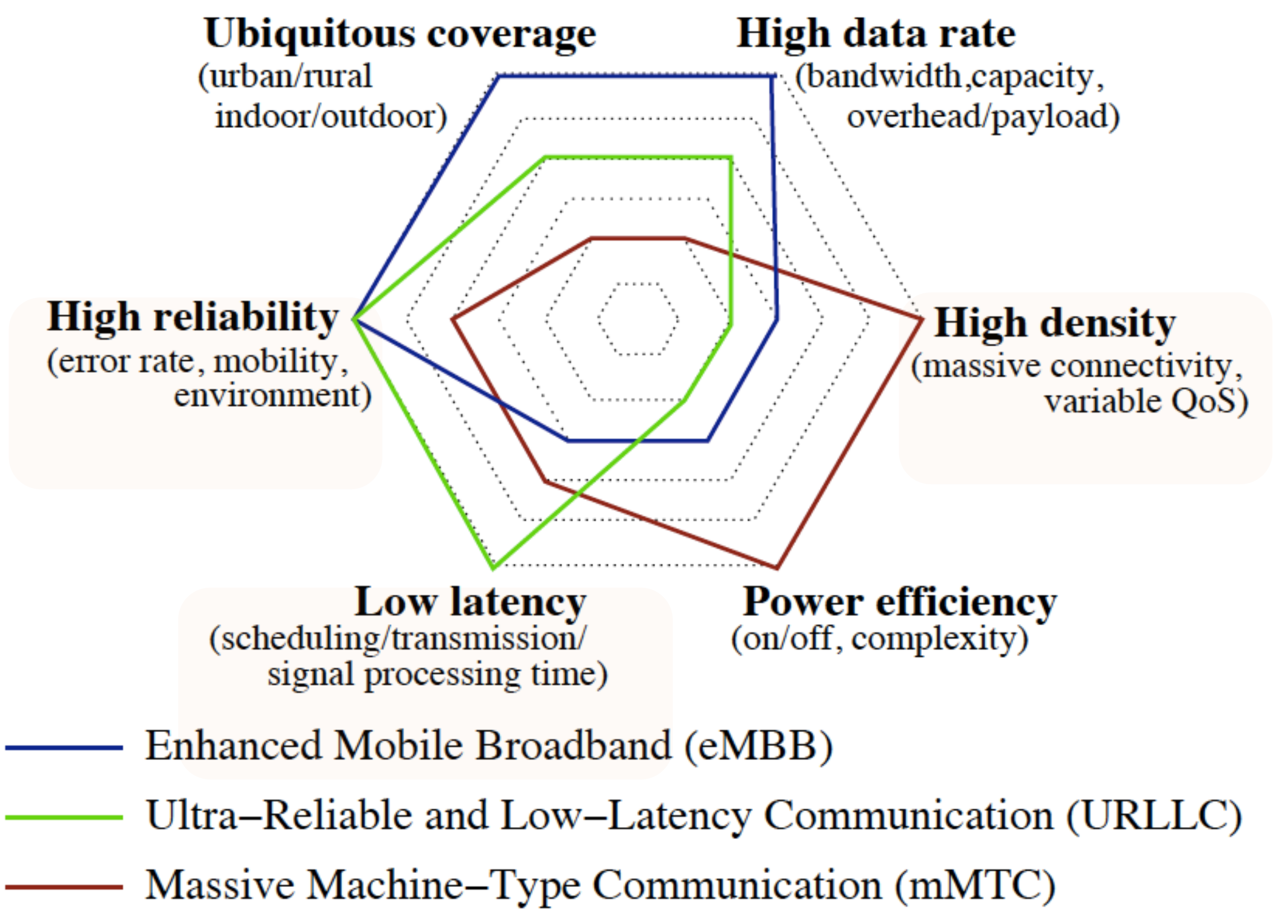
5G technologies: three main pillars

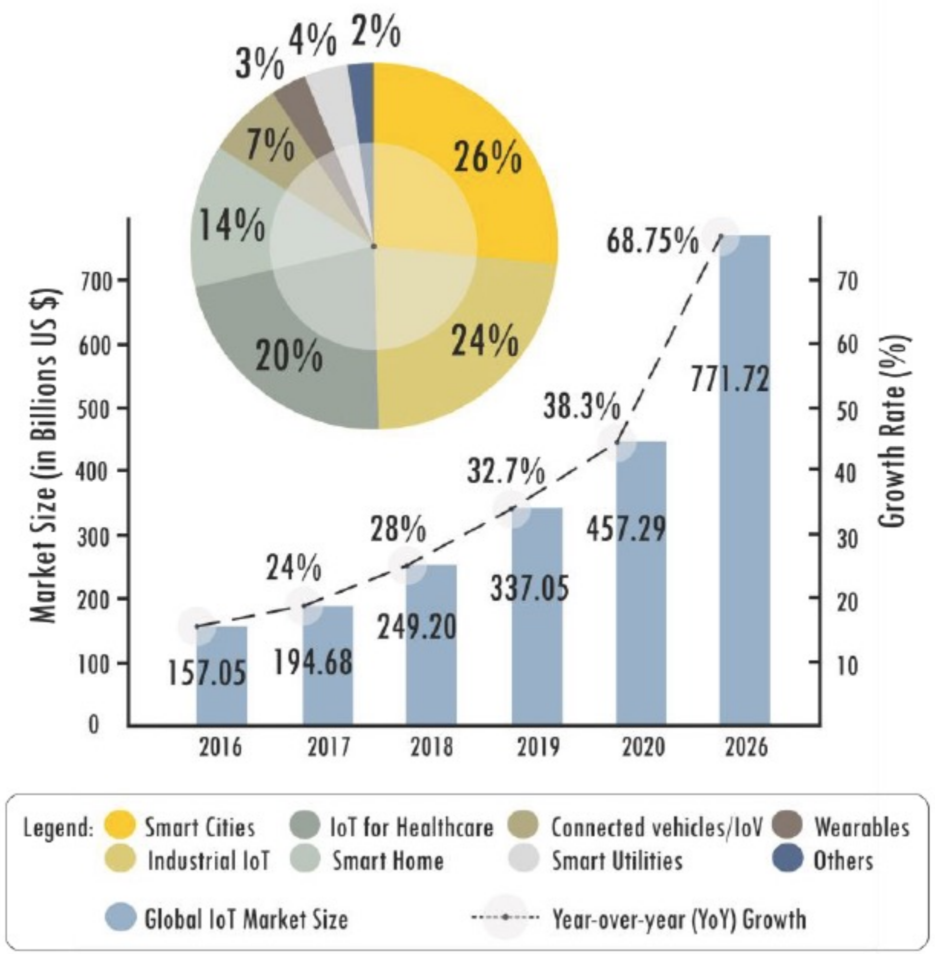
- Enhanced Mobile Broadband (eMBB)
- Ultra Reliability Low Latency Communication(URLLC)
- massive Machine Type Communication (mMTC)





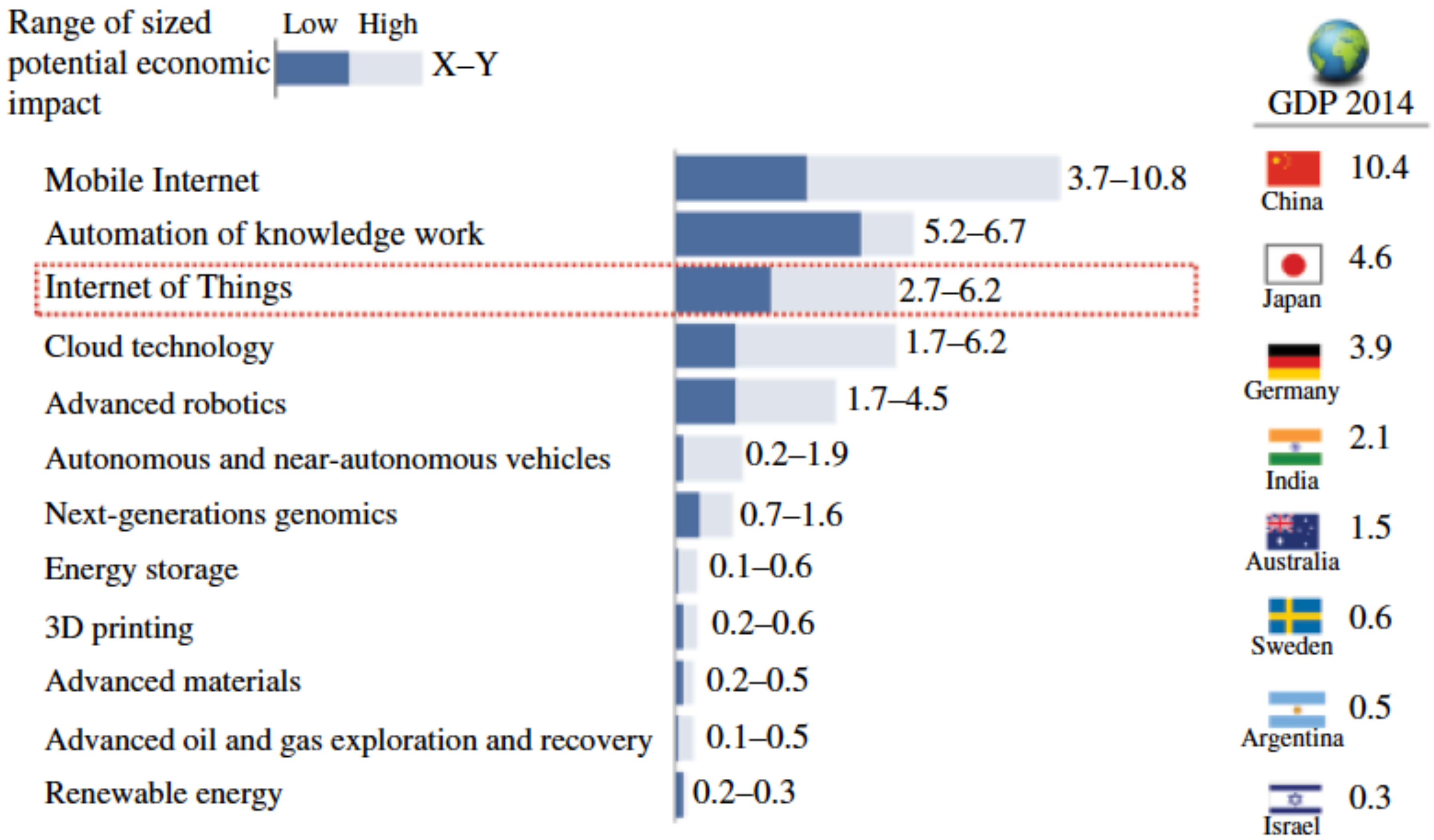
IoT for URLLC AND mM2M Communications





Potential economical impact of sized IoT Applications

IoT Economic Impacts by 2025



Economic impact of the 12 most significant disruptive technologies by 2025, in US$ trillions per year and countries' current GDP in 2014

5G and the eMBB KPIs trend…

What about IoT for Smart Buildings and mMTC?

Totally different metrics, totally different numbers:

- Sporadic Traffic
- Massive number of devises
- Low-power consumption and maintenance
- Low-cost

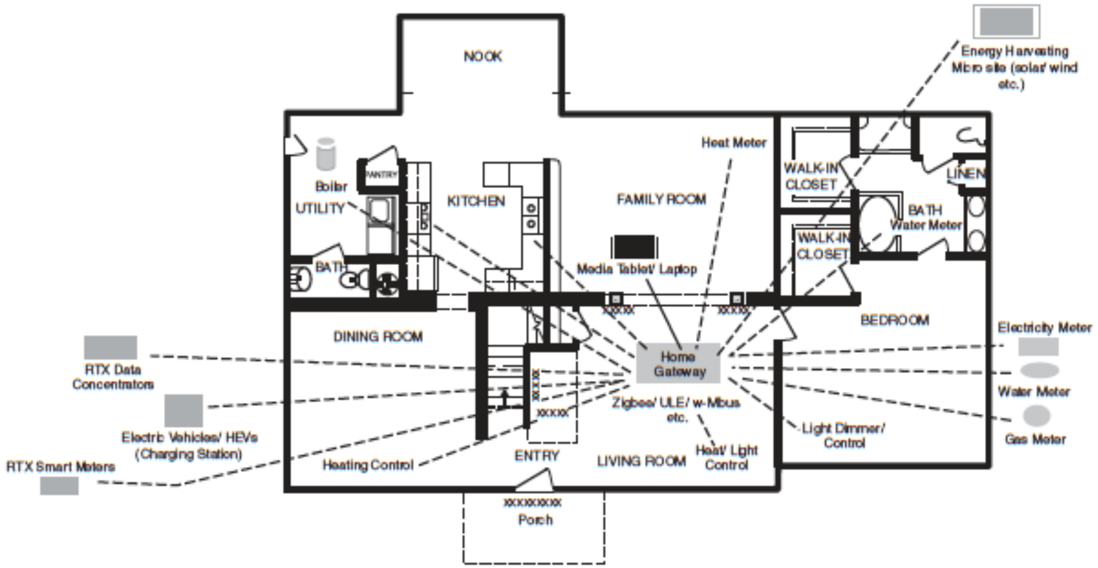
	5G	Beyond 5G	6G
Application types	• eMBB •URLLC •mMTC	• Reliable eMBB •URLLC •mMTC •Hybrid (URLLC + eMBB)	New applications: • MBRLLC • mURLLC • HCS • MPS
Device types	• Smartphones • Sensors • Drones	• Smartphones • Sensors • Drones •XR equipment	• Sensors and DLT devices • CRAS • XR and BCI equipment • Smart implants.
Spectral and energy efficiency gains[1] with respect to today's networks	10x in bps/Hz/m^2/Joules	100x in bps/Hz/m^2/Joules	1000x in bps/Hz/m^3/Joules (volumetric)
Rate requirements	1 Gb/s	100 Gb/s	1 Tb/s
End-to-end delay requirements	5 ms	1 ms	< 1 ms
Radio-only delay requirements	100 ns	100 ns	10 ns
Processing delay	100 ns	50 ns	10 ns
End-to-end reliability requirements	99.999 percent	99.9999 percent	99.99999 percent
Frequency bands	• Sub-6 GHz • MmWave for fixed acces.	• Sub-6 GHz • MmWave for fixed access	• Sub-6 GHz • MmWave for mobile acces • Exploration of higher frequency and THz bands (above 300 GHz) • Non-RF (e.g., optical, VLC, etc.)
Architecture	• Dense sub-6 GHz small base stations with umbrella macro base stations. • MmWave small cells of about 100 m (for fixed access).	• Denser sub-6 GHz small cells with umbrella macro base stations • < 100 m tiny and dense mmWave cells	• Cell-free smart surfaces at high frequency supported by mmWave tiny cells for mobile and fixed access. • Temporary hotspots served by drone-carried base stations or tethered balloons • Trials of tiny THz cells.

[1] Here, spectral and energy efficiency gains are captured by the concept of area spectral and energy efficiency.

The IoT Overturn…

TABLE 1. Most common LPWAN technologies.

Unlicensed	Licenced
LoRa	NB-IoT
SigFox	LTE-M(LTE Cat-M1)
Symphony Link	NB-Fi (Narrowband Fidelity)
iFrogLab	LTE-MTC
ThingPark Wireless	UNB (Ultra Narrow Band)
Ingenu [6]	WEIGHTLESS-P [5]



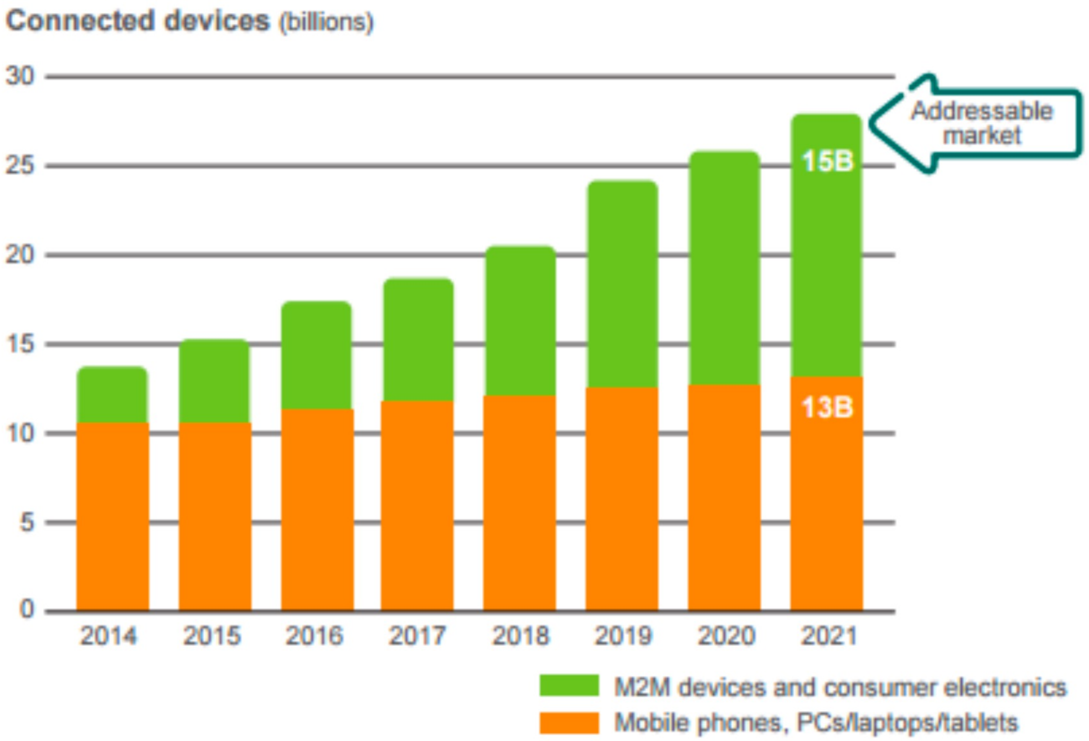
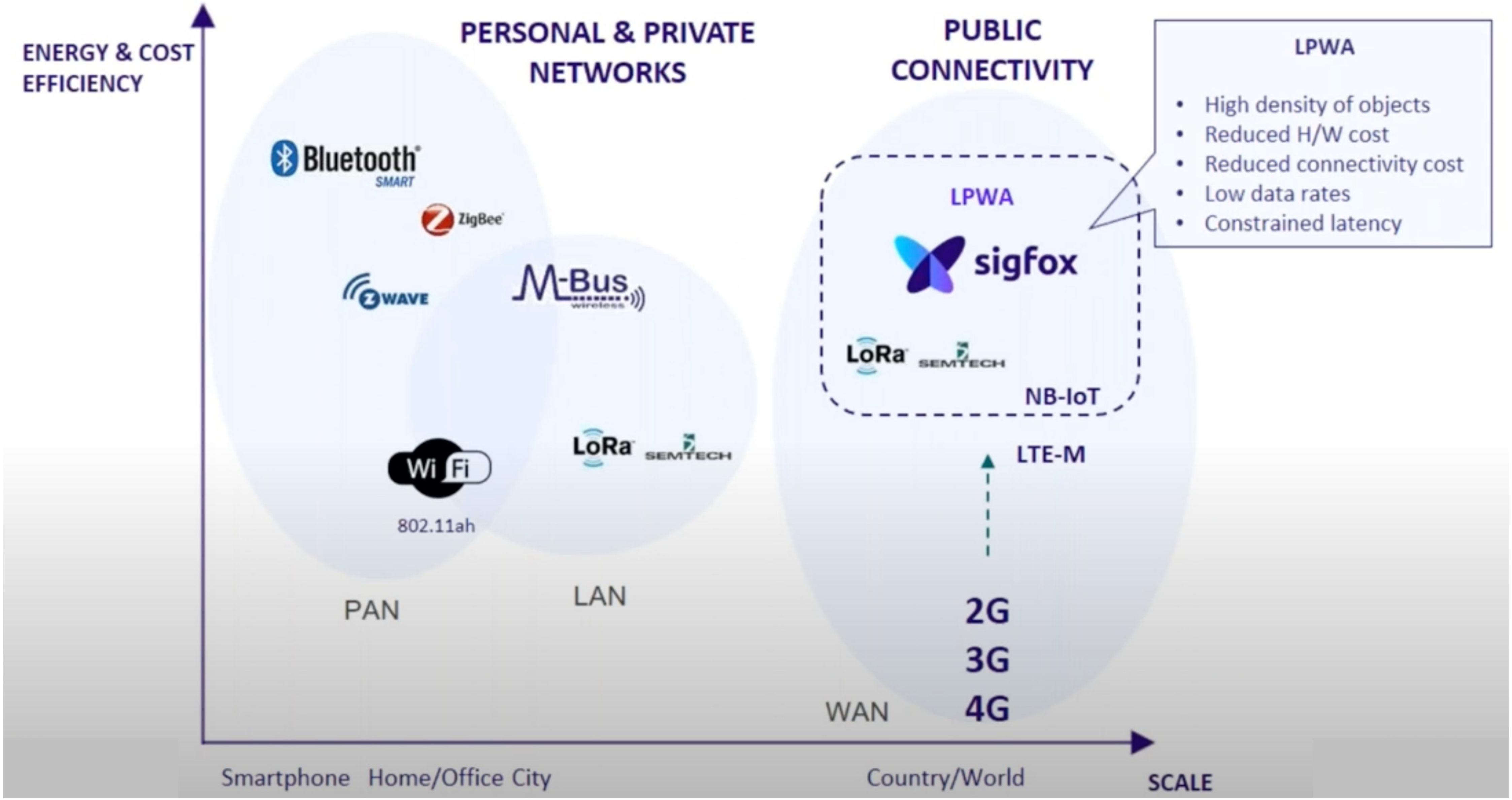


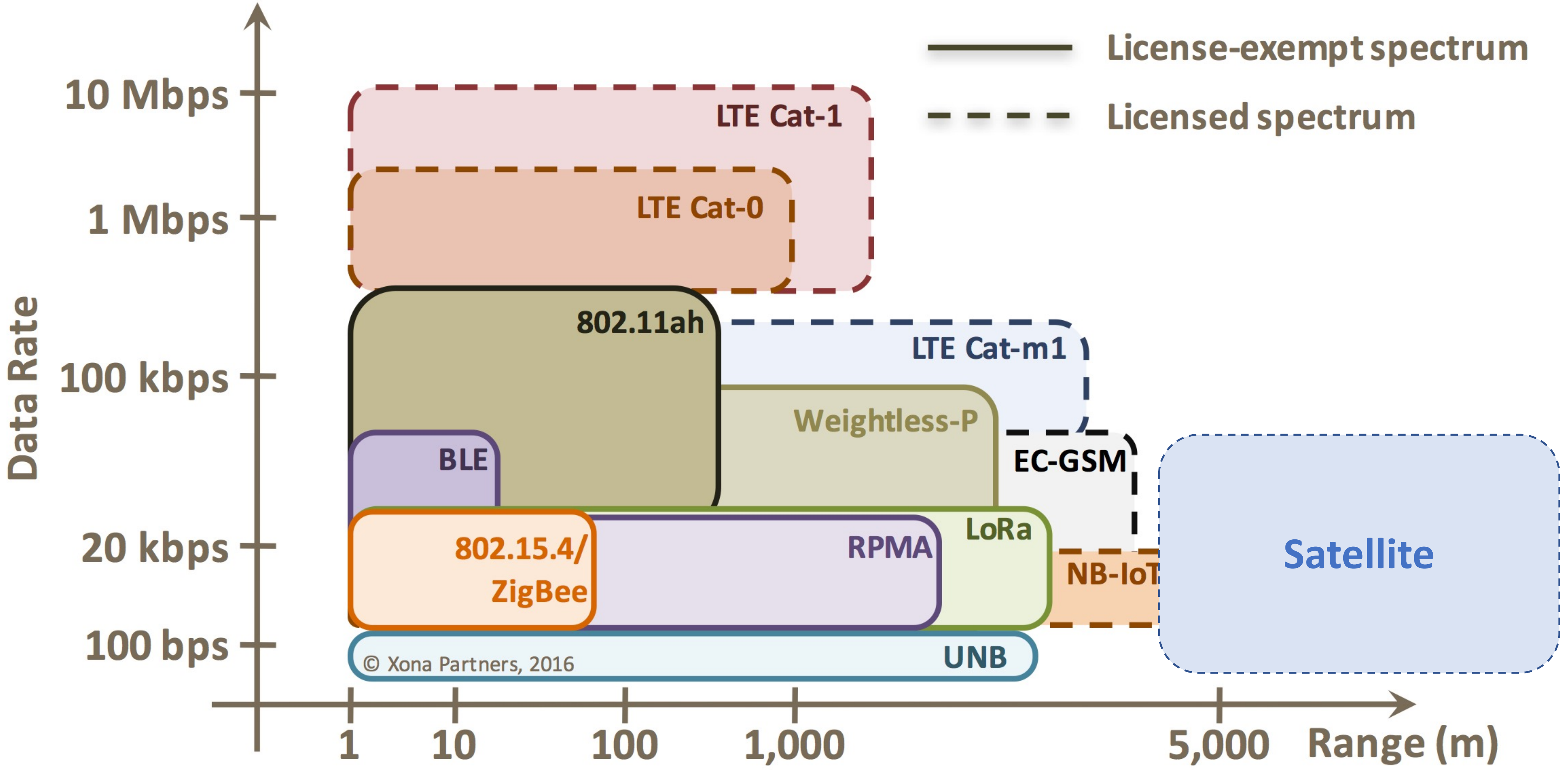
FIGURE 1. Expected growth in number of connected devices [23].

IoT Technologies

Some currently available IoT wireless technologies

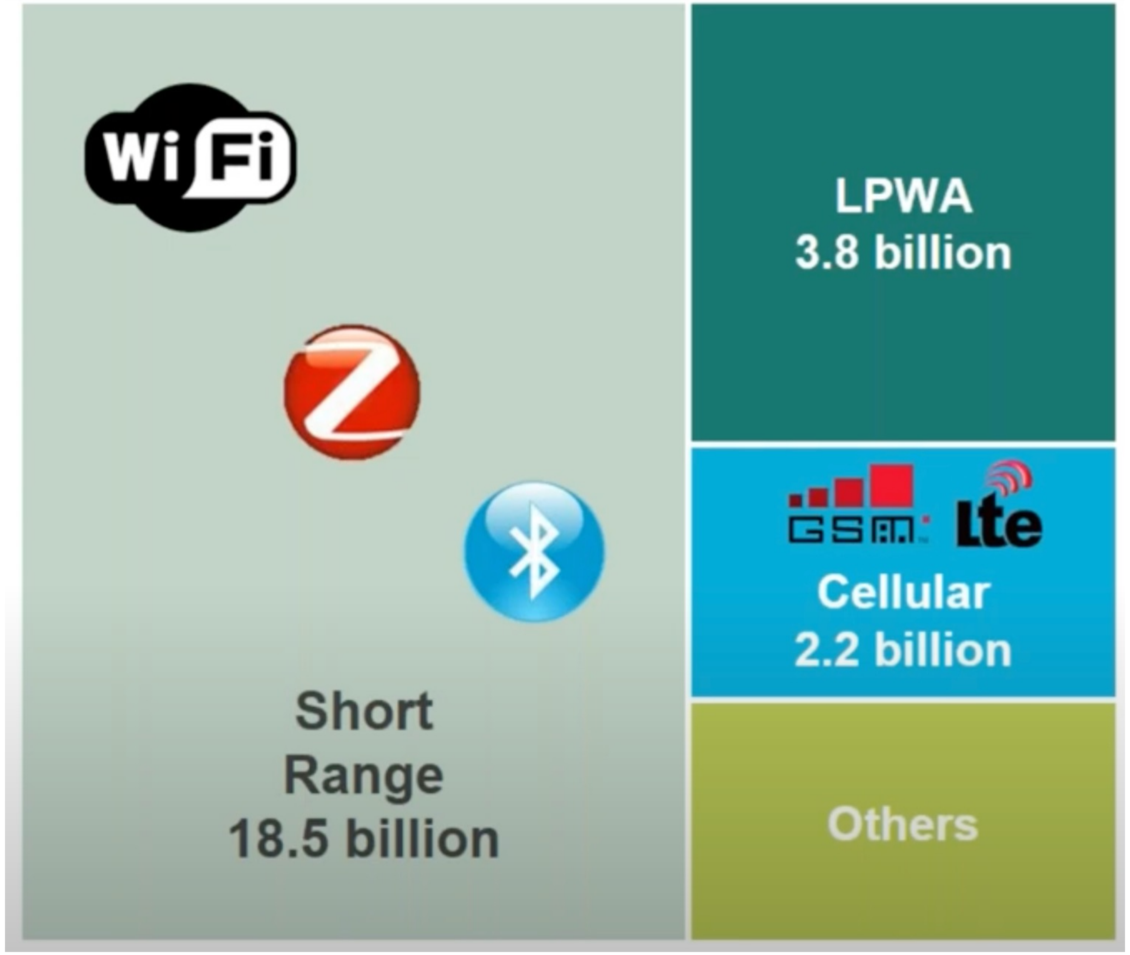


Some currently available IoT wireless technologies



https://community.arm.com/iot/b/blog/posts/the-great-iot-connectivity-race

Some currently available IoT wireless technologies



- LPWA will represent 20 to 25% of the IoT connectivity market by 2025
- Why so many IoT technologies?
- How to properly compare and choose the 'right one'?
- Different KPIs fot different IoT applications

Fields & Applications: one size cannot fit all !!!

- **WiFi and BT (BLE)** are widely adopted for personal devices
- **Cellular** technology fits high data throughput associated application.
- **LPWAN** offers multi-year battery lifetime and sensors support. Small amount of data transmission is involved.

Local Area Network Short Range Communication	**L**ow **P**ower **W**ide **A**rea (LPWAN) Internet of Things	**Cellular Network** Traditional M2M
40%	**45%**	**15%**
Well established standards In building	Low power consumption Low cost Positioning	Existing coverage High data rate
Battery Live Provisioning Network cost & dependencies	High data rate Emerging standards	Autonomy Total cost of ownership
Bluetooth 4.0 / ZigBee / WiFi	LoRa	GSM / 3G+ / H+ / 4G

Spectrum and Duty-Cycle Regulations

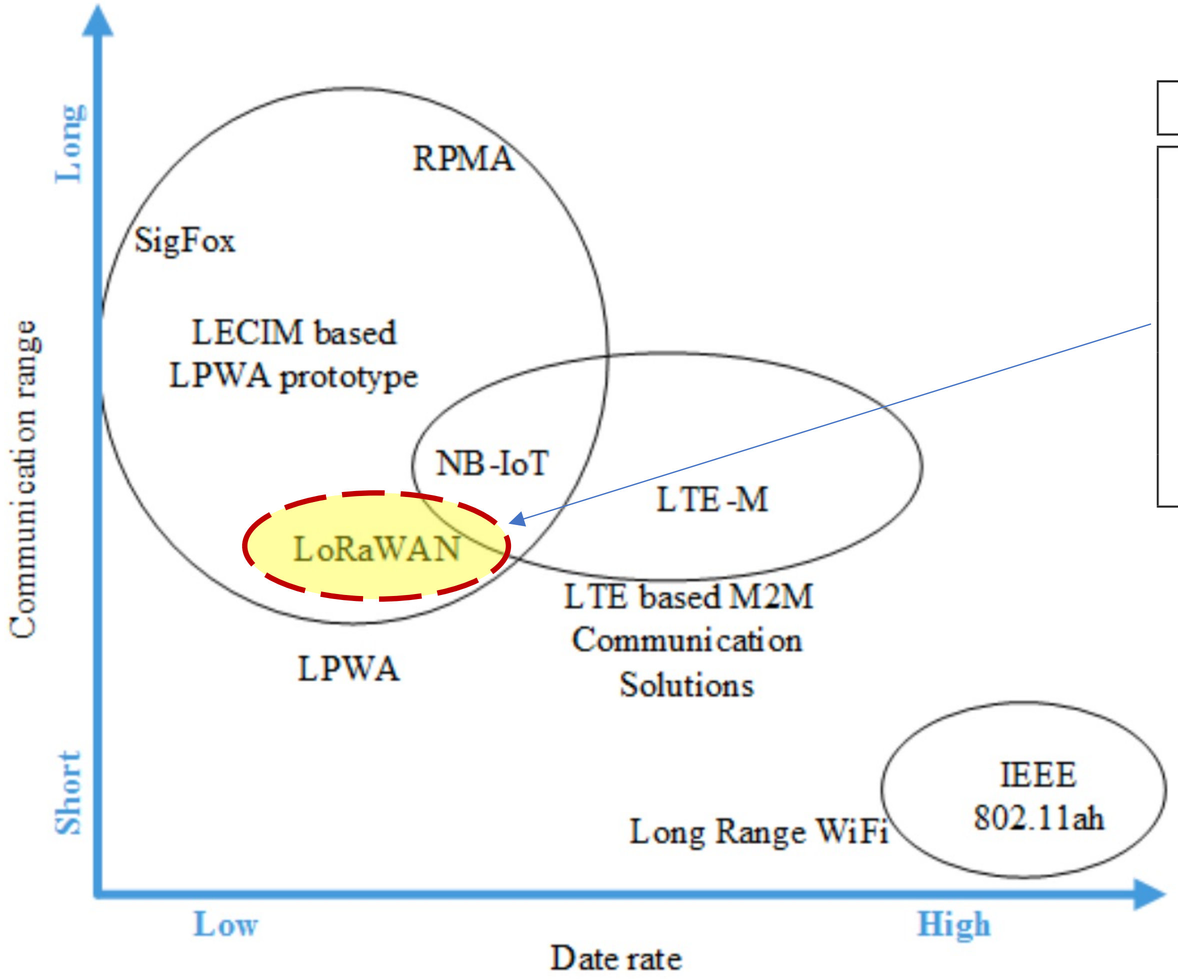


TABLE III
TRANSMIT POWER AND DUTY CYCLE REGULATIONS PER SUB-BAND FOR THE EU868 BAND [56]

Frequency	Transmit Power	Duty Cycle
863 – 865 MHz	25 mW ERP	$\leq$ 0.1% or LBT
865 – 868 MHz	25 mW ERP	$\leq$ 1% or LBT
868 – 868.6 MHz	25 mW ERP	$\leq$ 1% or LBT
868.7 – 869.2 MHz	25 mW ERP	$\leq$ 0.1% or LBT
869.4 – 869.65 MHz	500 mW ERP	$\leq$ 10% or LBT
869.7 – 870 MHz	5 mW ERP	No requirement
869.7 – 870 MHz	25 mW ERP	$\leq$ 1% or LBT

$$FSPL = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2$$

d in meters, *f* in Hertz

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) - 147.55$$

ITU Industrial, Scientific and Medical (ISM) radio band

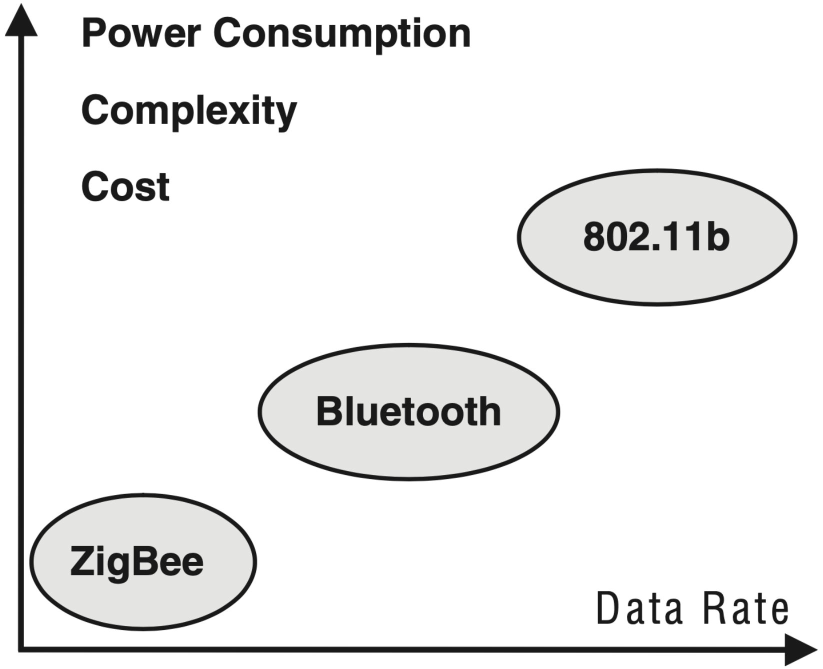
Frequency range		Center frequency	Bandwidth	Type	Availability	Licensed users
863 MHz	870 MHz	866.5 MHz	7 MHz	B(?)	Europe (?)	Short range devices, RFID (?). UHF
13.553 MHz	13.567 MHz	13.56 MHz	14 kHz	B	Worldwide	FIXED & Mobile services except Aeronautical mobile (R) service
26.957 MHz	27.283 MHz	27.12 MHz	326 kHz	B	Worldwide	FIXED & MOBILE SERVICE except Aeronautical mobile service, CB Radio
40.66 MHz	40.7 MHz	40.68 MHz	40 kHz	B	Worldwide	Fixed, Mobile services & Earth exploration-satellite service
902 MHz	928 MHz	915 MHz	26 MHz	B	Region 2 only (with some exceptions)	FIXED, Mobile except aeronautical mobile & Radiolocation service; in Region 2 additional Amateur service
2.4 GHz	2.5 GHz	2.45 GHz	100 MHz	B	Worldwide	FIXED, MOBILE, RADIOLOCATION, Amateur & Amateur-satellite service
5.725 GHz	5.875 GHz	5.8 GHz	150 MHz	B	Worldwide	FIXED-SATELLITE, RADIOLOCATION, MOBILE, Amateur & Amateur-satellite service
24 GHz	24.25 GHz	24.125 GHz	250 MHz	B	Worldwide	AMATEUR, AMATEUR-SATELLITE, RADIOLOCATION & Earth exploration-satellite service (active)
6.765 MHz	6.795 MHz	6.78 MHz	30 kHz	A	Subject to local acceptance	FIXED SERVICE & Mobile service
433.05 MHz	434.79 MHz	433.92 MHz	1.74 MHz	A	only in Region 1, subject to local acceptance	AMATEUR SERVICE & RADIOLOCATION SERVICE, additional apply the provisions of footnote 5.280. For Australia see footnote AU.
61 GHz	61.5 GHz	61.25 GHz	500 MHz	A	Subject to local acceptance	FIXED, INTER-SATELLITE, MOBILE & RADIOLOCATION SERVICE
122 GHz	123 GHz	122.5 GHz	1 GHz	A	Subject to local acceptance	EARTH EXPLORATION-SATELLITE (passive), FIXED, INTER-SATELLITE, MOBILE, SPACE RESEARCH (passive) & Amateur service
244 GHz	246 GHz	245 GHz	2 GHz	A	Subject to local acceptance	RADIOLOCATION, RADIO ASTRONOMY, Amateur & Amateur-satellite service

- **Possible allocation strategies**: primary, secondary, exclusive or shared utilization

- **Type A**: designated for ISM applications (subject to special authorization by the administrator)
- **Type B:** *also* designated for ISM applications. Other services operating within these bands must accept harmful interference

Short-range IoT Technologies

Main Short-Range Technologies



	Data Rate	Typical Range	Application Examples
ZigBee	20 to 250 Kbps	10–100 m	Wireless Sensor Networks
Bluetooth	1 to 3 Mbps	2–10 m	Wireless Headset Wireless Mouse
IEEE 802.11b	1 to 11 Mbps	30–100 m	Wireless Internet Connection

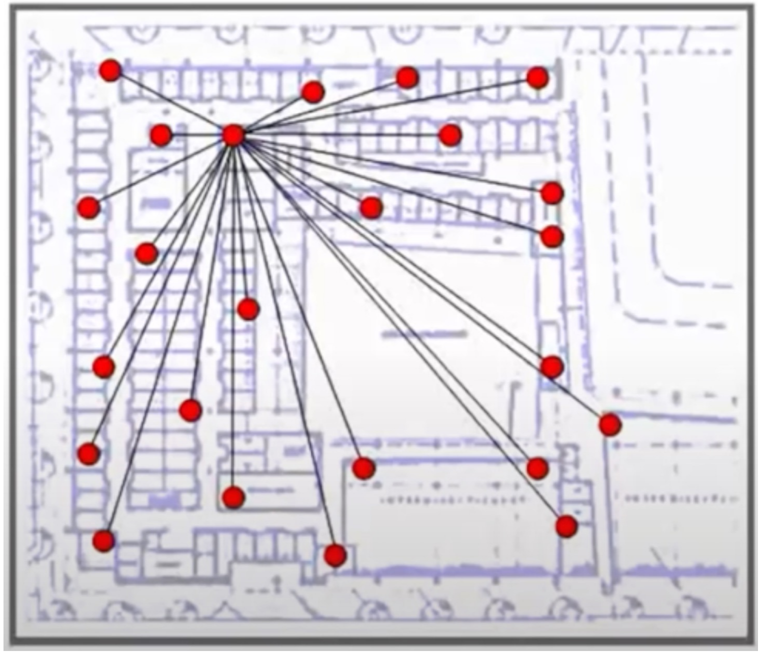
IEEE 802.11 Family (Wi-Fi)

Wi-Fi generations

Generation	IEEE standard	Maximum throughput	Adopted	Radio frequency GHZ
Wi-Fi "0"*	802.11	2Mbit/s	1997	2.4
Wi-Fi "1"*	802.11b	11Mbit/s	1999	2.4
Wi Fi "2"*	802.11a	54Mbit/s	1999	5
Wi-Fi "3"*	802.11g	54Mbit/s	2003	2.4
Wi-Fi 4	802.11n	600Mbit/s	2008	2.4/5
Wi-Fi 5	802.11ac	6.8Gbit/s	2014	5
Wi-Fi 6	802.11ax	10Gbit/s	2019	2.4/5
Wi-Fi 6E	802.11ax	10Gbit/s	2020	6
Wi-Fi 7	802.11be	46Gbit/s	2024	1–7.25 (2.4/5/6)

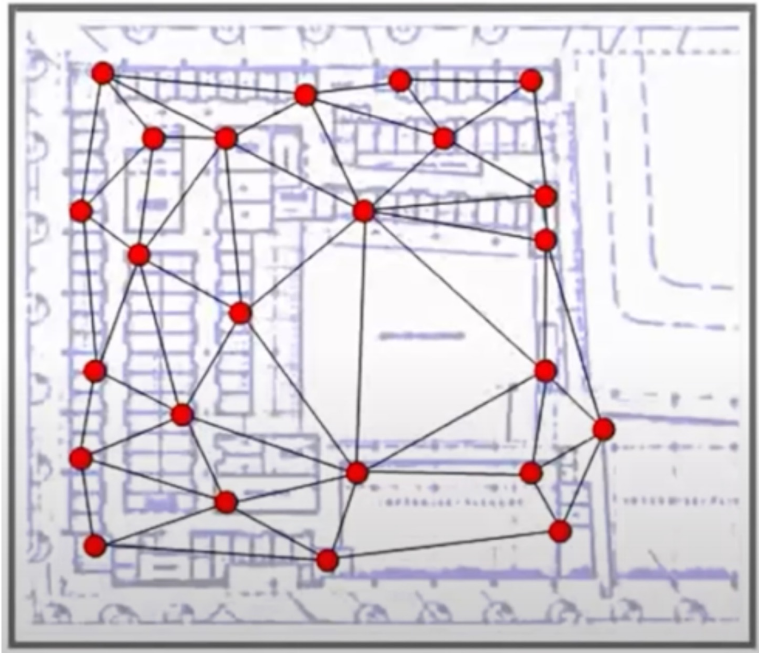
*non-official designation

IoT topologies



Star Network (e.g. 802.11)

Infrastructure in place, some designated devices always act as routers in the network



Mesh Network (e.g. ZigBee)

Route selected dynamically based on the network connectivity (ad-hoc), appropriate for multisensor monitoring and control applications

Short-Range Technologies

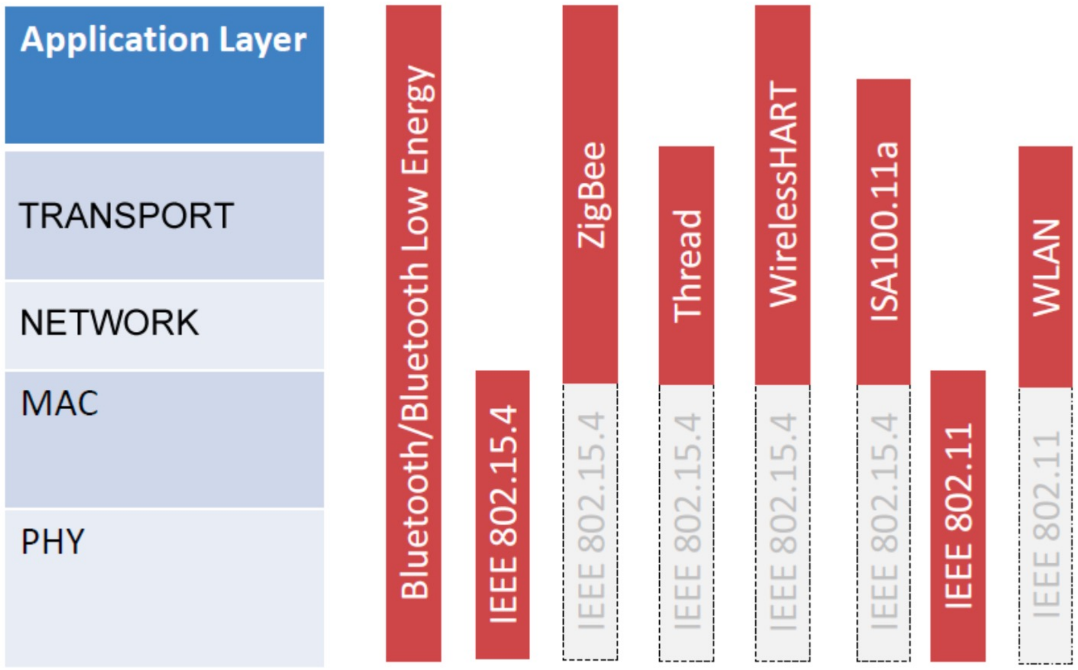
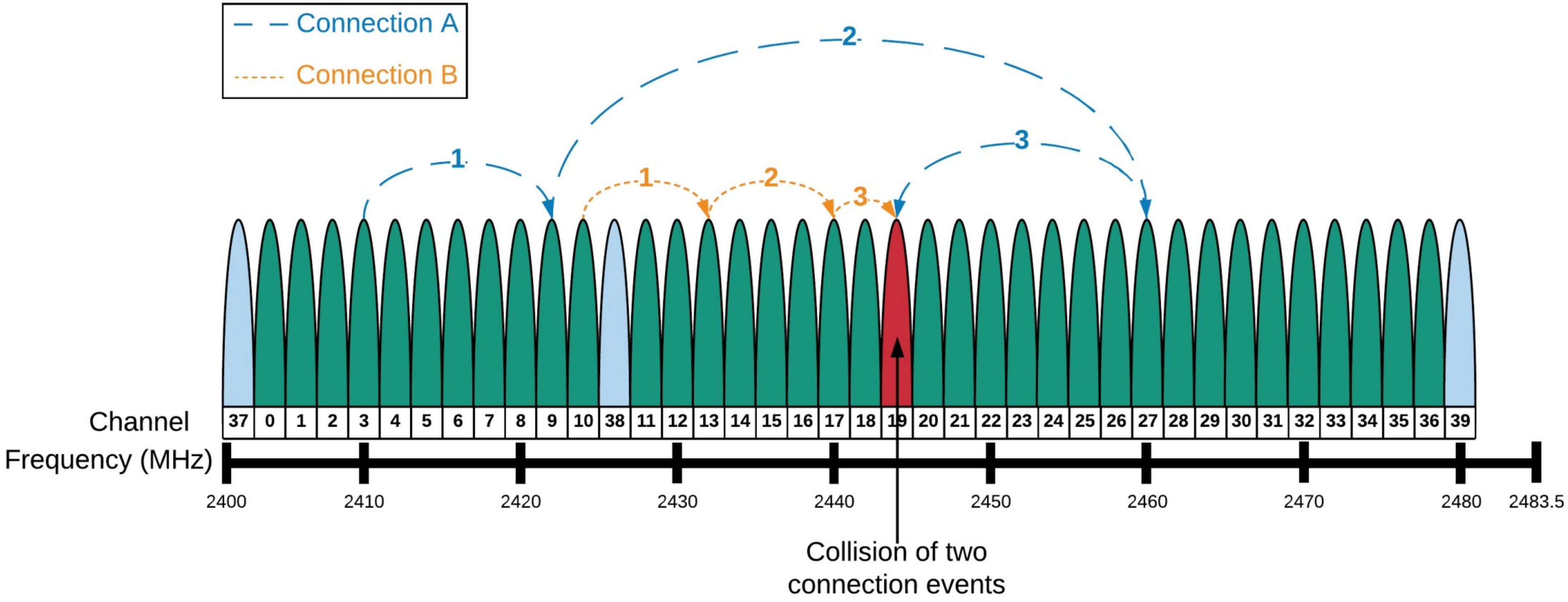


Table 12.3 Comparison of Zigbee and Bluetooth

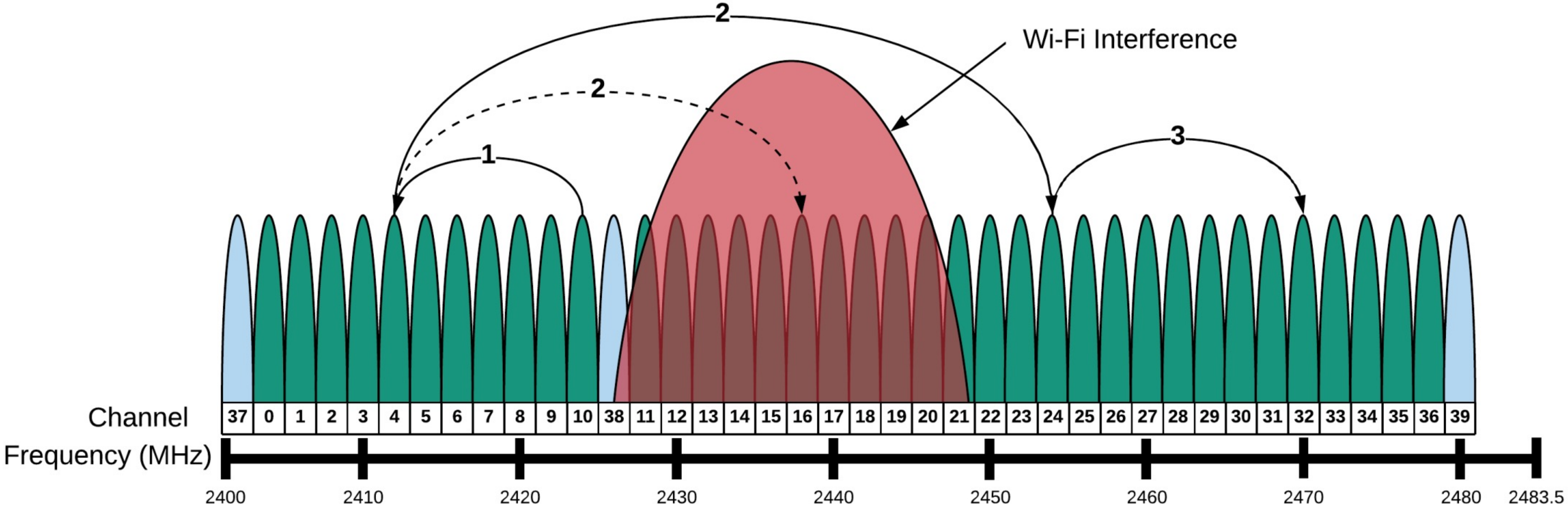
	Bluetooth	**Zigbee**
Transmission scheme	FHSS (frequency hopping spread spectrum)	DSSS (direct sequence spread spectrum)
Modulation	GFSK (Gaussian frequency shift keying), $\pi/4$ Quadrature and 8 angle phase shift keying	O-QPSK (offset quadrature phase shift keying) or BPSK (binary phase shift keying)
[a]Frequency band	2.4 GHz	2.4 GHz, 915 MHz, 868 MHz
Raw data bit rate	1, 2, 3 Mbps	250, 100, 40, or 20 kbps (depends on frequency band and modulation)
Power output	Maximum 100, 2.5, or 1 mW, depending on class	Minimum capability 0.5 mW; maximum as allowed by local regulations
Minimum sensitivity	−70 dBm for 0.1% BER	−85 dBm (2.4 GHz) or −92 dBm (915/868 MHz) for packet error rate <1%
Network topology	Master-slave 8 active nodes, no fixed limit for LE	Star or peer to peer up to 64k active nodes

[a] *IEEE 802.15.4 also offers additional frequency bands, specifically for China and Japan and for UWB (ultra-wideband), and other modulation types.*

Coexistence at 2.4 GHz

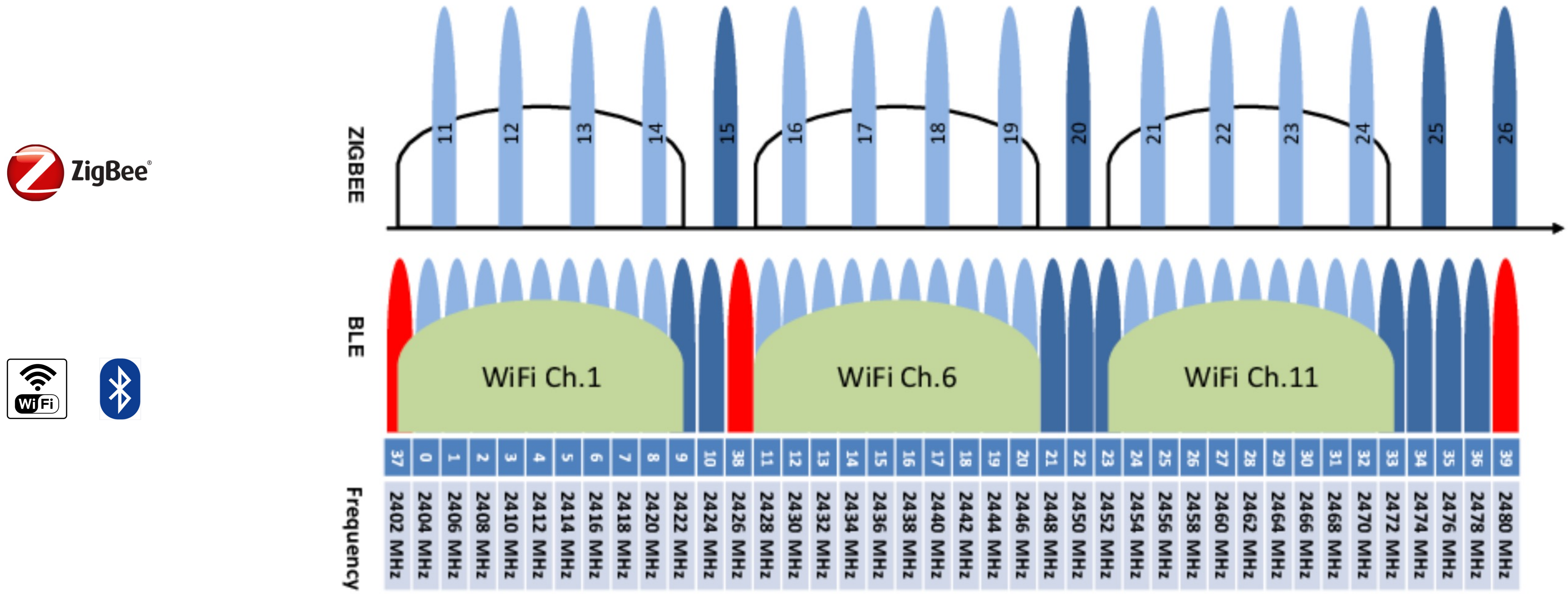


AFH disabled all channels that are interfered with by a nearby Wi-Fi network. The second connection event would normally happen on channel 16 but is instead redirected to channel 24.



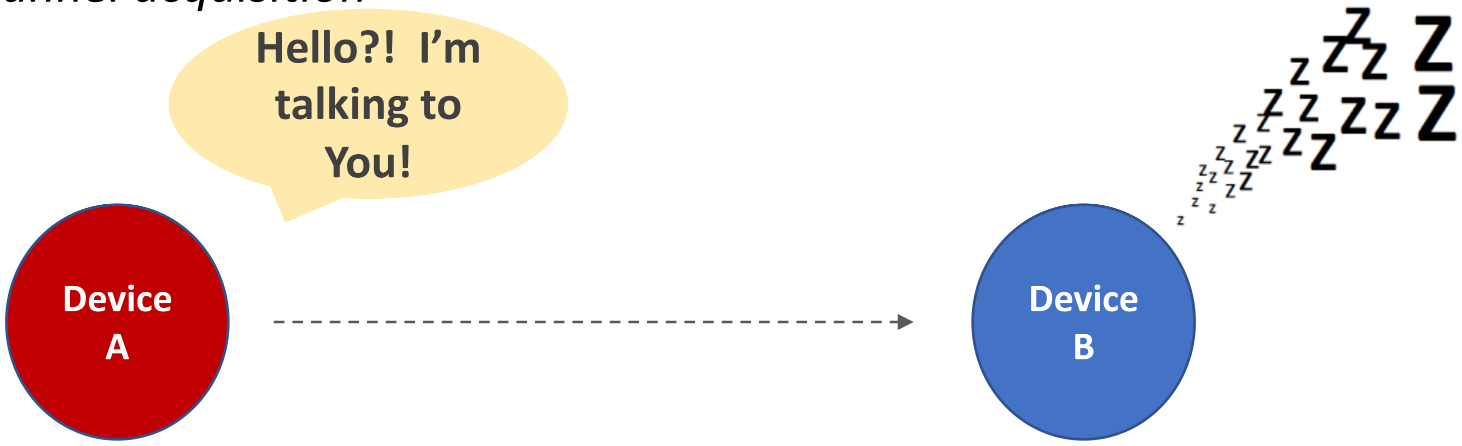
Coexistence at 2.4 GHz

Note: The effects of IEEE 802.15.4 on WLAN can effectively be ignored. Bluetooth however has a significant effect on WLAN throughput.



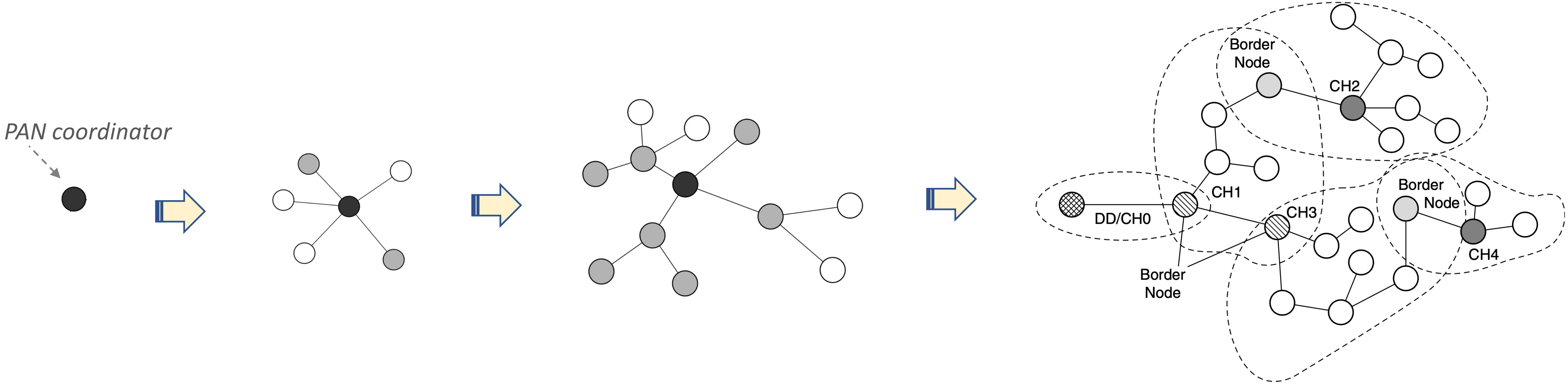
Power Saving MAC Algorithms for IoT

- In IoT, Devices sleep most of the time
- What if we send data to a sleeping device?
- Ok going to sleep, but need to be awake when data is sent to you
- Need some way to:
  - coordinate *when/how nodes sleep*
  - Coordinate *channel acquisition*



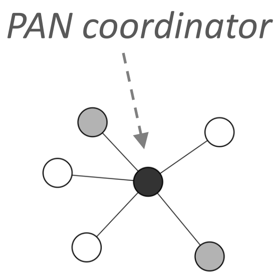
The ZigBee example

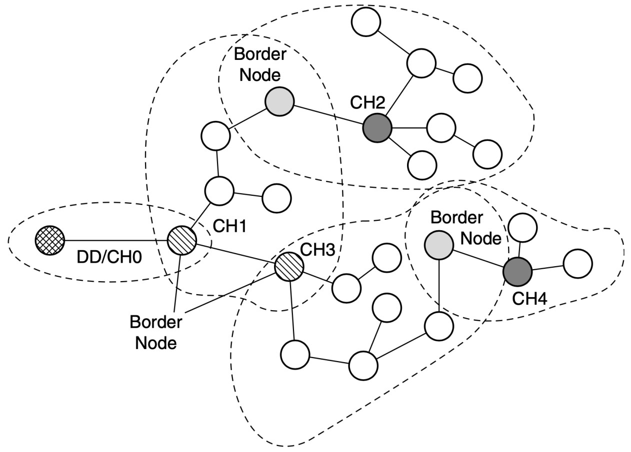
- **Self-Forming Network**
  - in mesh networks, the first FFD device that starts communicating establishes itself as the PAN coordinator (i.e., ZigBee coordinator)
  - Other devices join the network by sending association requests
  - *Association* and *Disassociation* services are provided by IEEE 802.15.4

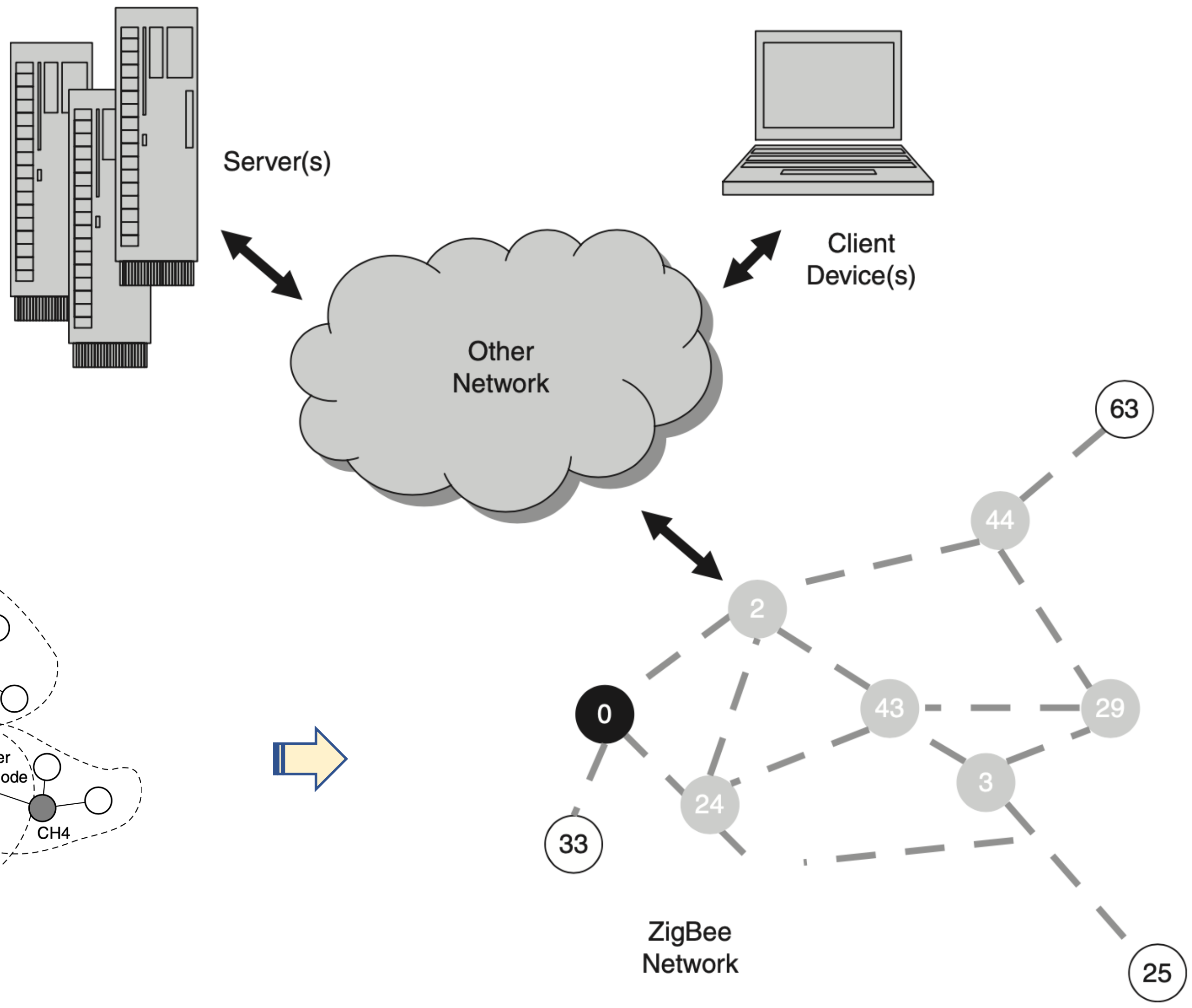


802.15.4/ZigBee Gateway

- A ZigBee gateway provides the interface between a ZigBee network and another network using a different standard

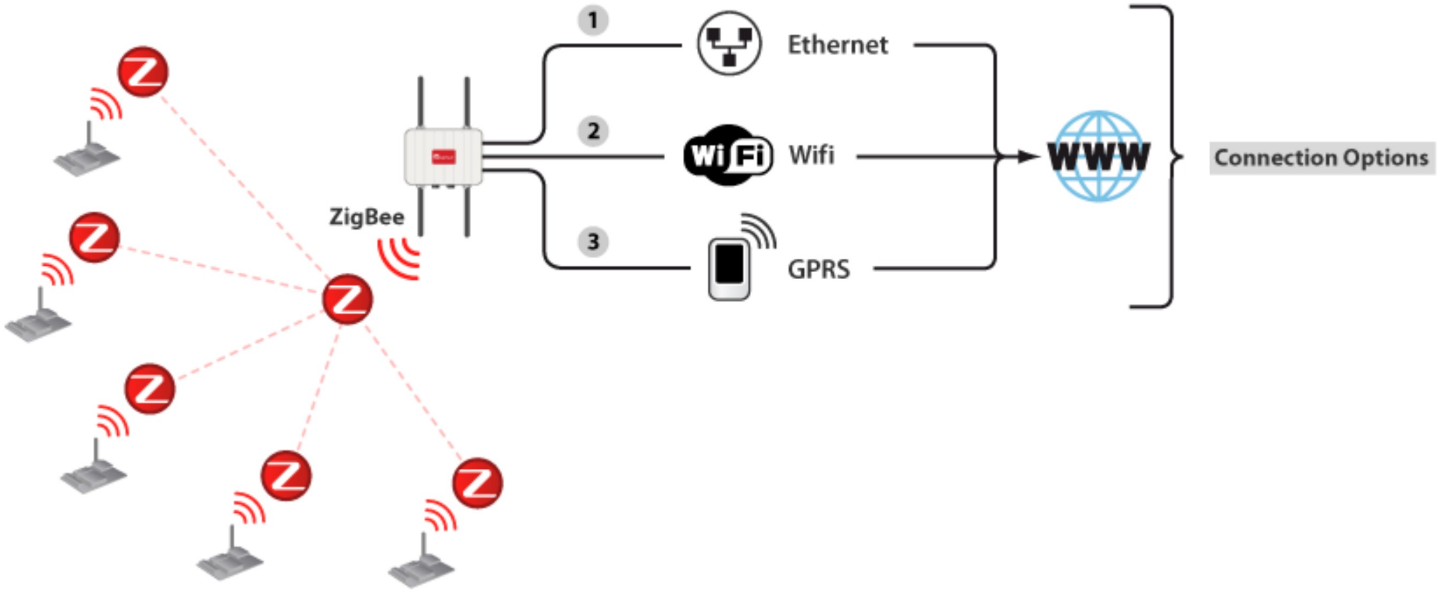




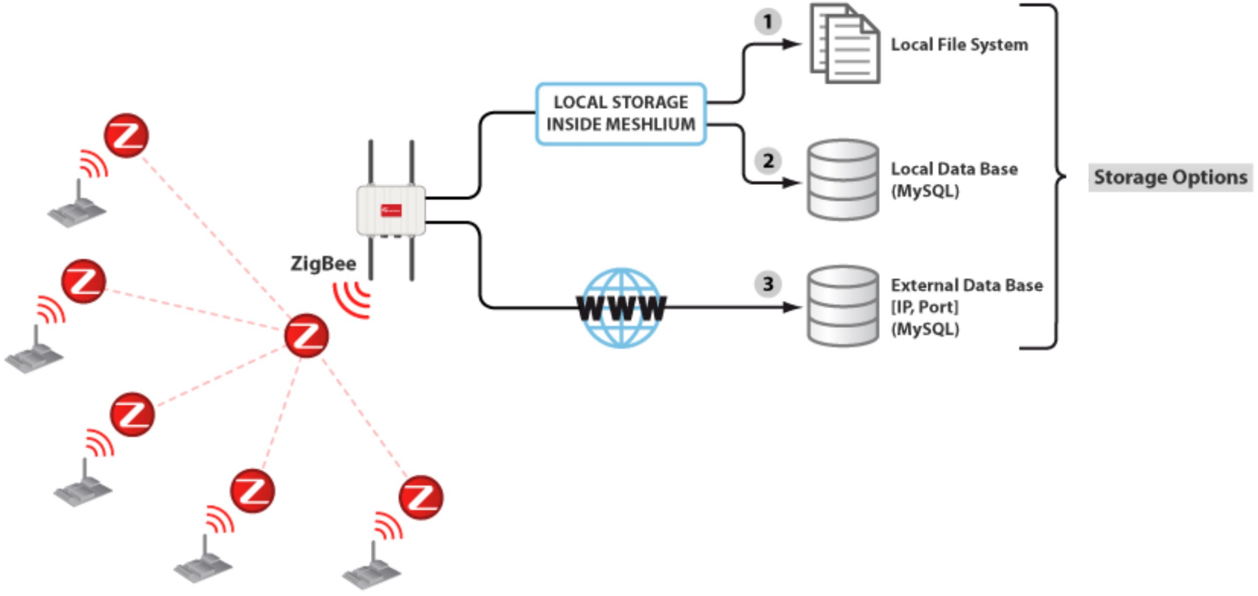


802.15.4/ZigBee Gateway

- a ZigBee gateway can implement both
  - the ***ZigBee protocol***
  - the ***Internet protocol***



- Translate ZigBee packets to Internet protocol packet format, and vice versa *(works in OSI model's all layer)*



LPWAN Tecnologies

Different Key requirements for LPWAN

LPWAN is a type of wide area network which connects devices over *large areas* and allows *long range* communication at a *lower bit rate, low cost and greater power efficiency (Low Power).* LPWAN supports a large number of devices over wide areas in comparison to cellular services. Examples of LPWAN are NBIOT, LORA, Sigfox etc.

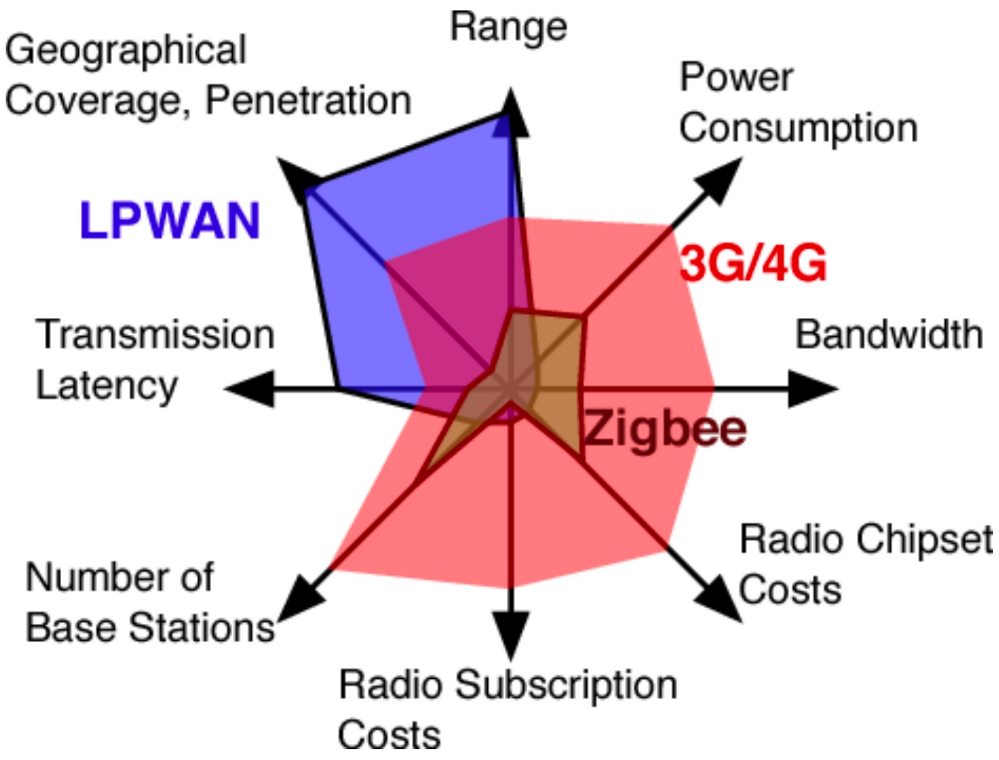


FIGURE 1. **Comparison between LPWAN and cellular technologies [24].**

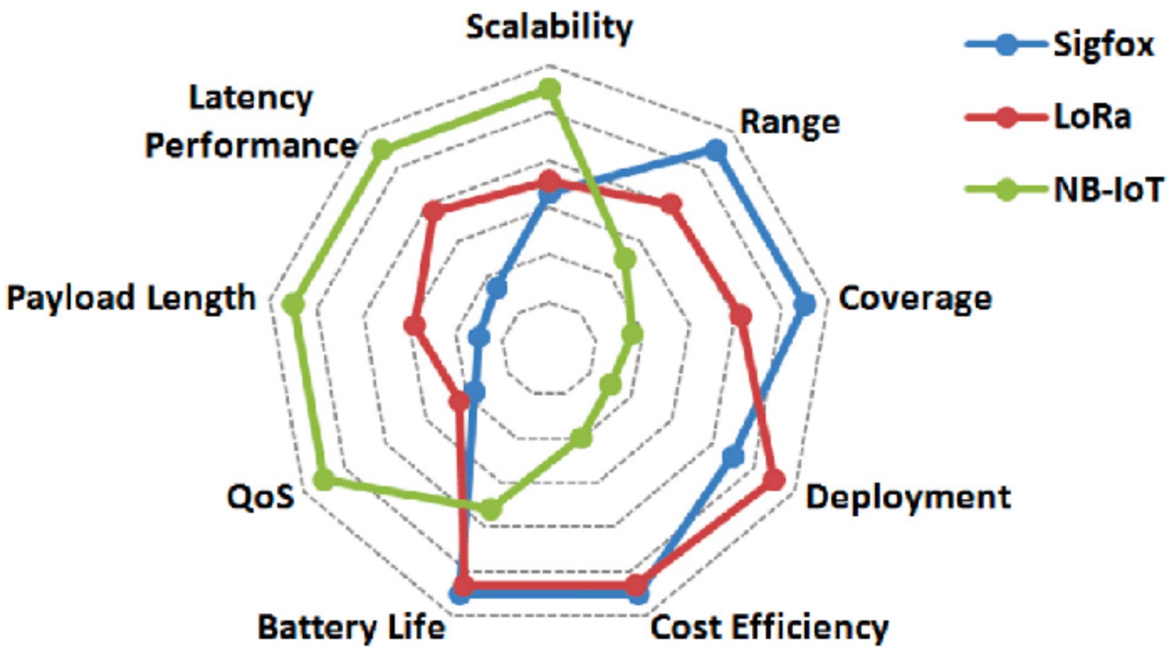


FIGURE 2. **Comparison between LPWANs technologies [29].**

Different Key requirements for LPWAN

LPWAN is a type of wide area network which connects devices over *large areas* and allows *long range* communication at a *lower bit rate, low cost and greater power efficiency (Low Power).* LPWAN supports a large number of devices over wide areas in comparison to cellular services. Examples of LPWAN are NBIOT, LORA, Sigfox etc.

TABLE 2. Major properties of LPWAN technologies.

Main Properties
Long range of communication
Low power consumption
Low data rate
Low cost of device and deployment
Simplified network topology and deployment
Full coverage
Network scalability for the capacity upgrade

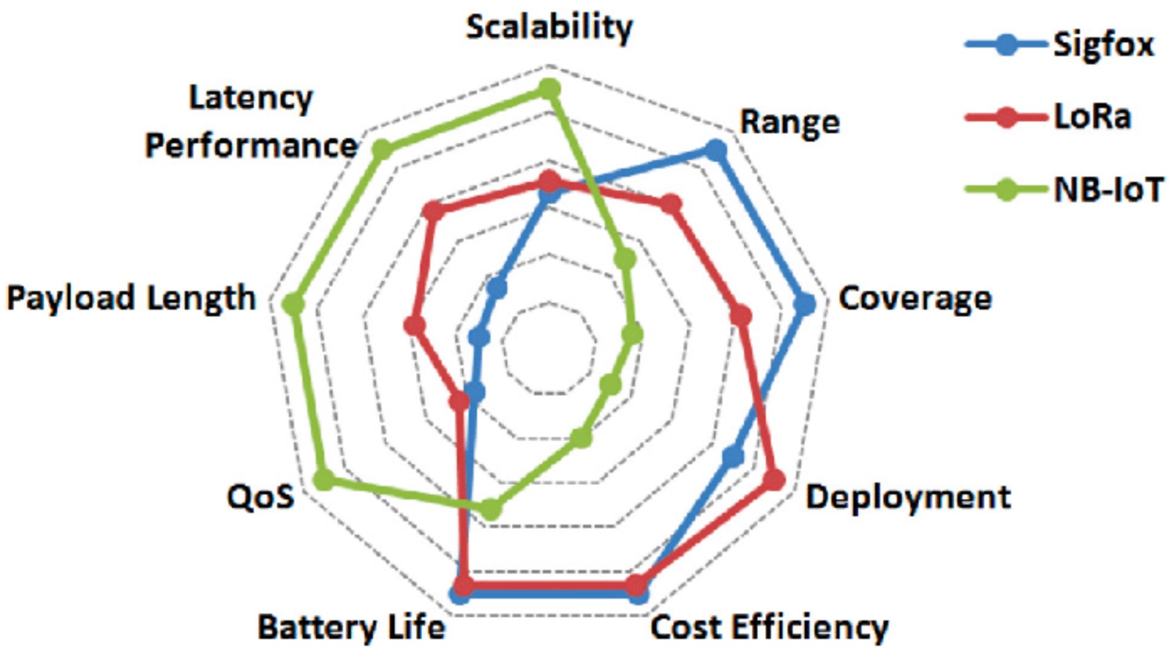


FIGURE 2. Comparison between LPWANs technologies [29].

LPWAN Performance Comparison

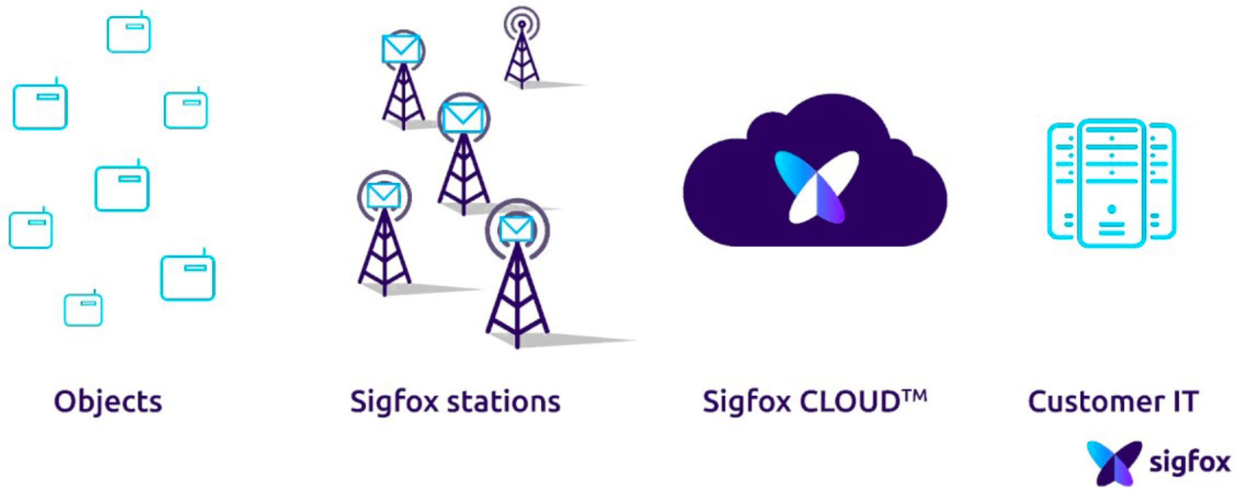
	NB-IoT NB-IoT	WIFI	BLUETOOTH	SIGFOX	LoRa	LTE-M/ (eMTC) (Rel 13) eMTC	EC-GSM (Rel. 13)	ZIGBEE Pro	5G (targets)
Coverage Area	<15 km 164 dB	17-30+ (meters)	1-10+ (meters)	<12km 160 dB	<10 km 157 dB	<10 km 156 dB	<15 km 164 dB	1-100+ (meters)	**<12km 160 dB**
Spectrum Bandwidth	Licensed 7-900MHz 200 kHz shared	2.4 GHz 802.11	2.4 GHz 802.15.1	Unlicensed 900MHz 100kHz	Unlicensed 900MHz <500kHz	Licensed 700MHz-900MHz 1.4 MHz shared	Licensed 800MHz-900MHz shared	2.4G 802.15.4	Licensed 700MHz-900MHz shared
Rate	<50 kbps	150Mbps	1Mbps	<100bps	<10 kbps	<1 Mbps	10 kbps	250kbps	<1 Mbps
Terminal cost	4.00$ (2015) 2-3$ (2020)	4.00$ (2016)	4.00$ (2016)	4.00$ (2015) 2.64$ (2020)	4.00$ (2015) 2.64$ (2020)	5.00$ (2015) 3.30$ (2020)	4.5$ (2015) 2.97$ (2020)	3.00$ (2016)	<2$
Network Reforming	Small to moderate	None	None	Large	Large	Small	Moderate (LTE reuse)	None	Requires 5G NWs

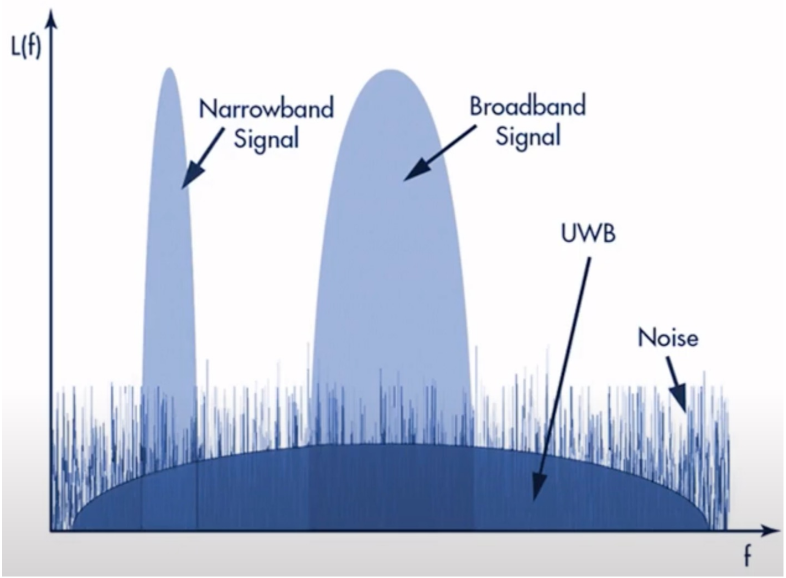
FIGURE 2. **Performance Comparison of some common IoT Technologies [3], [23] and [17].**

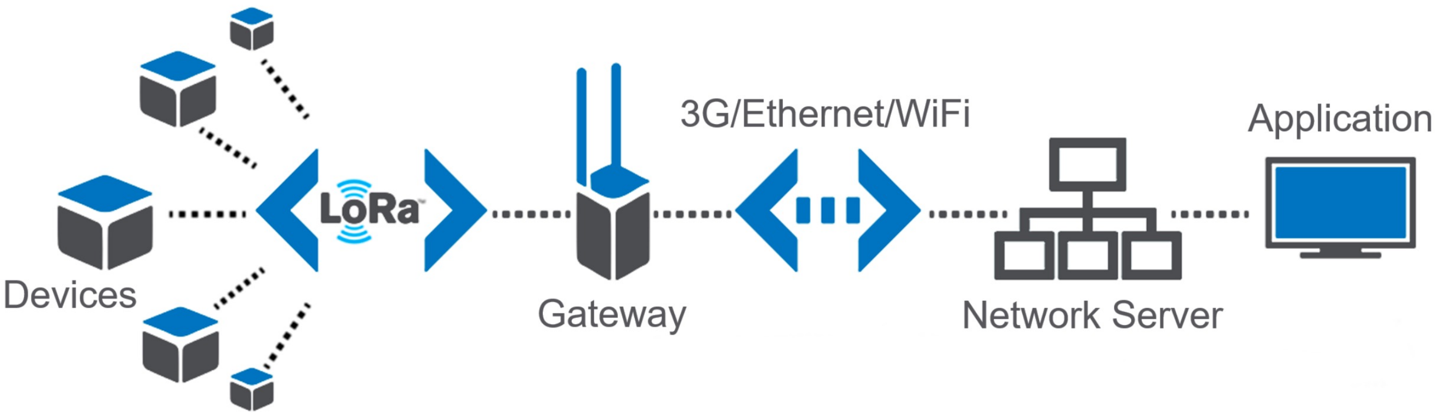
Sigfox/LoRaWAN/NB.IoT Comparison

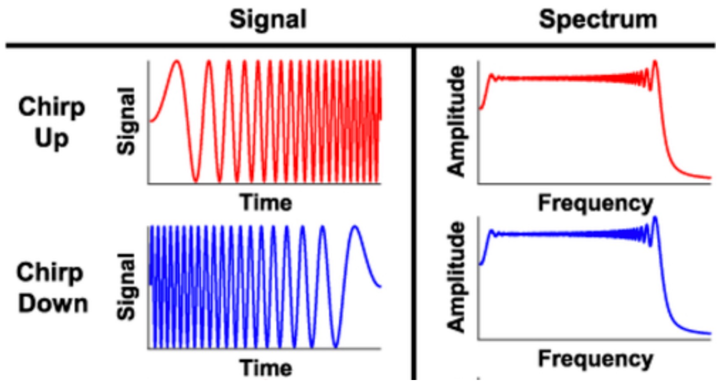
Parameter	LTE Cat 1	LTE-M	NB-IoT	LoRa	Sigfox
Spectrum	Licensed	Licensed	Licensed	Unlicensed	Unlicensed
Bandwidth	20 MHz	1.4 MHz	180 KHz	125/250 Khz	100 Hz
Data Transfer	Full Duplex	Full & half Duplex	Half Duplex	Half Duplex	Half Duplex
Frequency	Cellular Band	Cellular Band	Cellular Band 800 MHz	Sub Ghz	Sub Ghz
Max Data Rate(UL)	10 Mbps	1 Mbps	250 Kbps	50 kbs	100 kb/s
Max Coupling	144 dB	155 dB	164 dB	157 dB	160 dB
Expected Module Cost	< 10$	<10$	<5$	<4$	<4$
Expected Battery Life	3-5 Years	5-10 Years	10+ Years	12+ Years	12+ Years
Sim Card	Yes	Yes	Yes	No	No
Modulation		QPSK	QPSK	CSS	BPSK
Latency	50–100 ms	10–15 ms	1.6–10 s	2–30 s	2–30 s
Device Transmit Power	23 dBm	20/23 dBm	14/20/23 dBm	20 dBm	20 dBm
Standard	3GPP Rel. 1	3GPP Rel. 13	3GPP Rel. 13	LoRa Alliance	Proprietary
Range	Medium	Medium	High(+)	V. High(+++)	V. High(++++)

Sigfox/LoRaWAN Technology Architectures

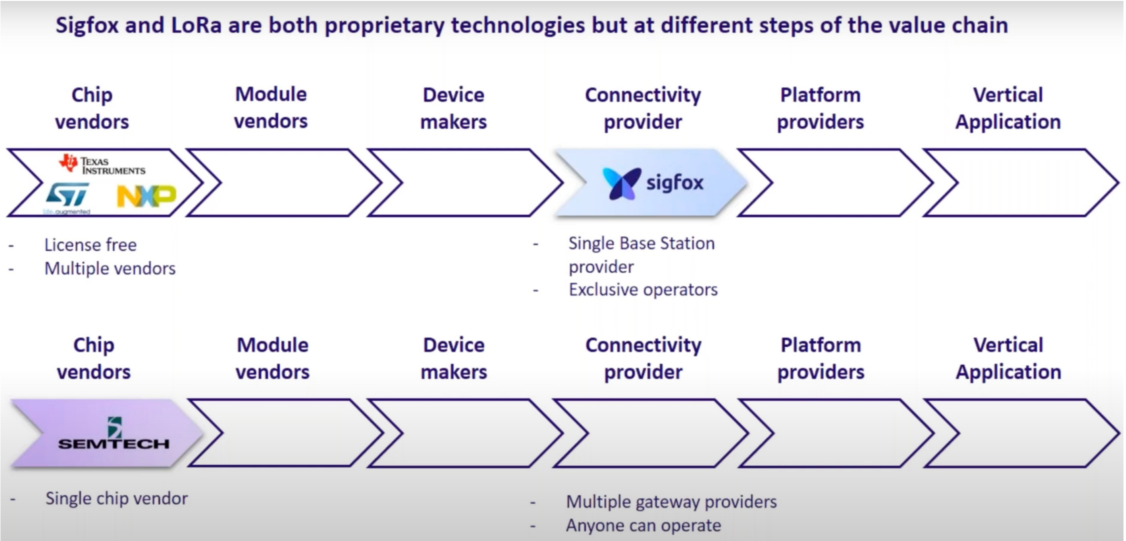








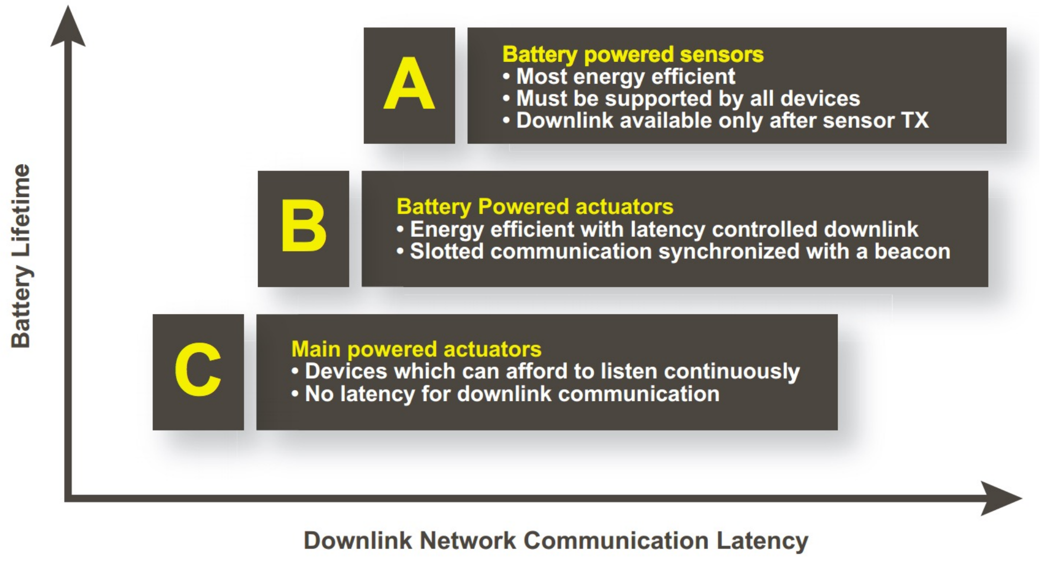
Sigfox/LoRaWAN Technology Architectures

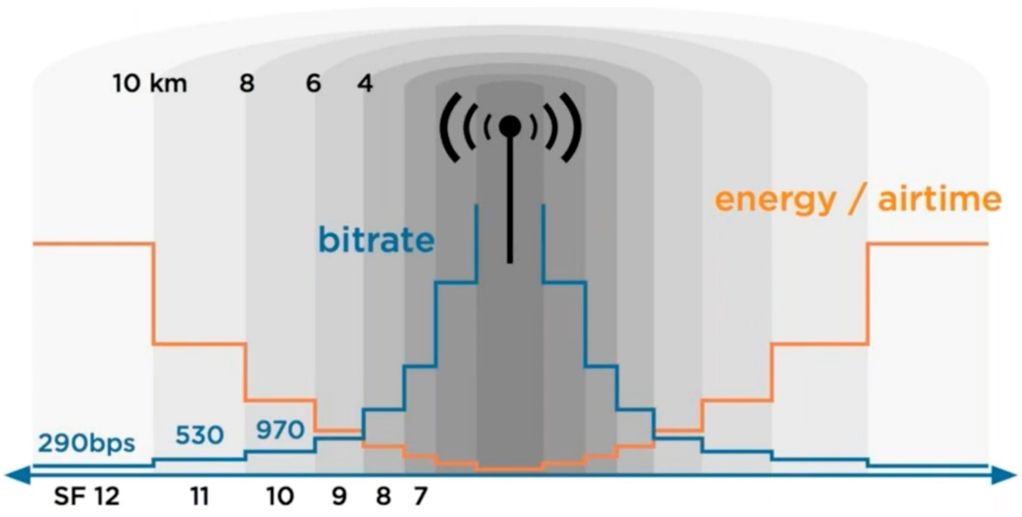


LoRaWAN	Sigfox
TTN operates a global, open source, free of charge network	Sigfox operates a global, propretary and chargeable network
TTN is based on community gateway. No strategic placement of gateways	Coverage is their biggest asset. Gateways are placed strategically to reach maximum coverage
No up-time guaranteed for community gateways nor for the network	Uptime of network guaranteed

LoRaWAN	Sigfox
Multi-channel LoRaWAN gateways are based on propretary chips	Sigfox gateways (or base stations) are SDR receivers
They listen only to 8 channels	They listen to the whole band
Gateway chips are propretary, the software is open source	Base stations are propretary (hard- and software)
You can build and deploy your own gateway, even 15$ single channel ones	You can buy a "Micro Node" which is then part of the Sigfox network

Some more details: Device classes, Link-Adaptation…





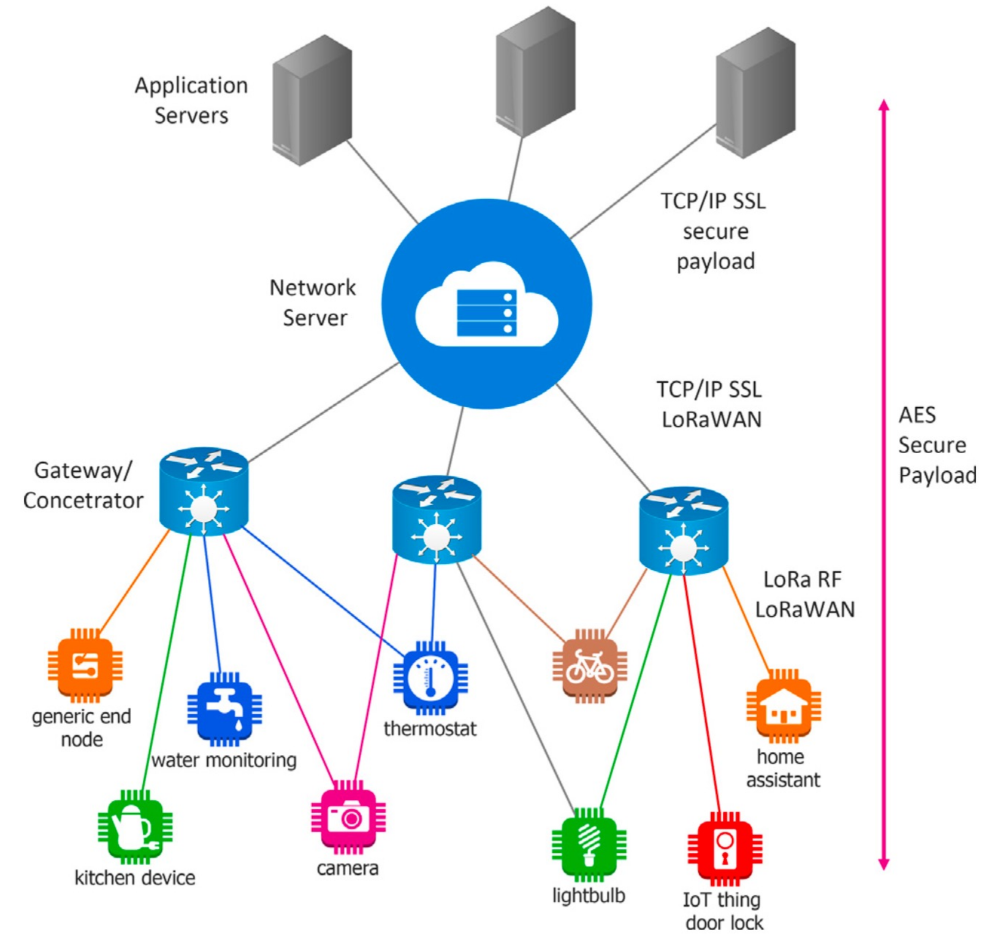
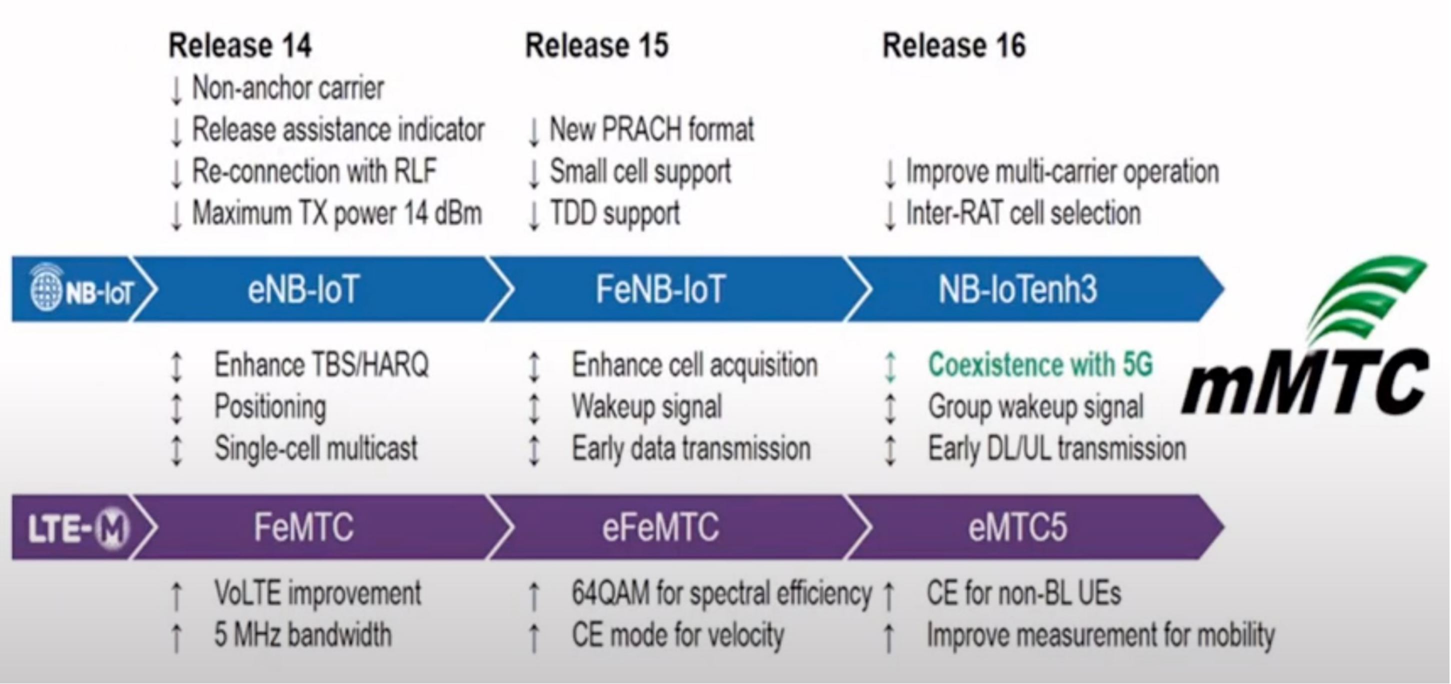
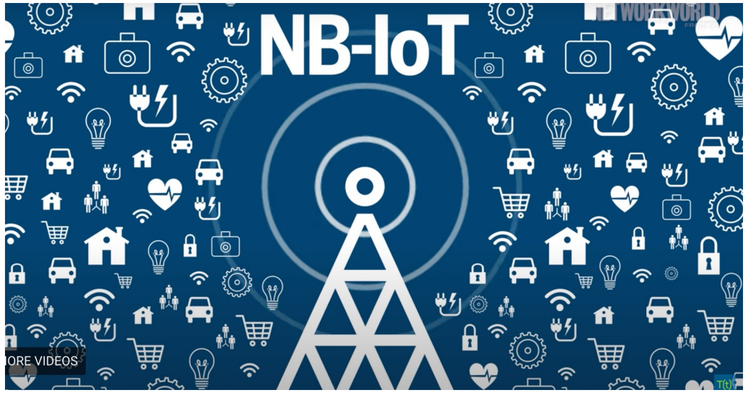
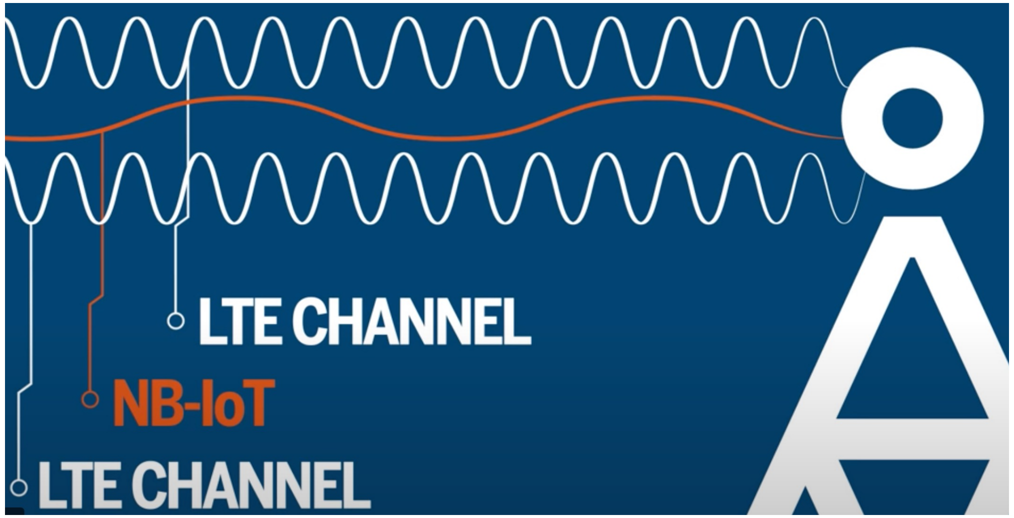


Fig. 1 Star-of-Stars: LoRaWAN Network Topology.

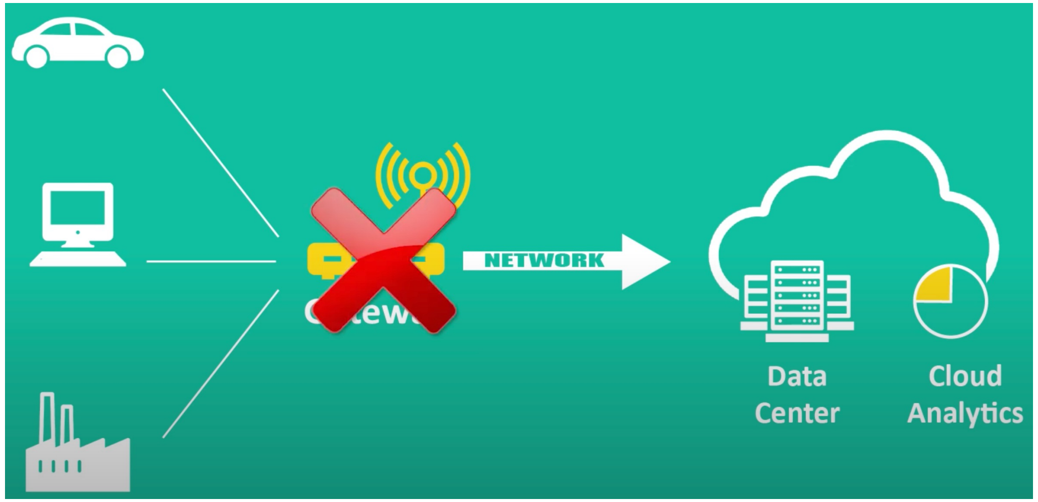
NB-IoT Technology Architectures (based on 3GPP LTE)

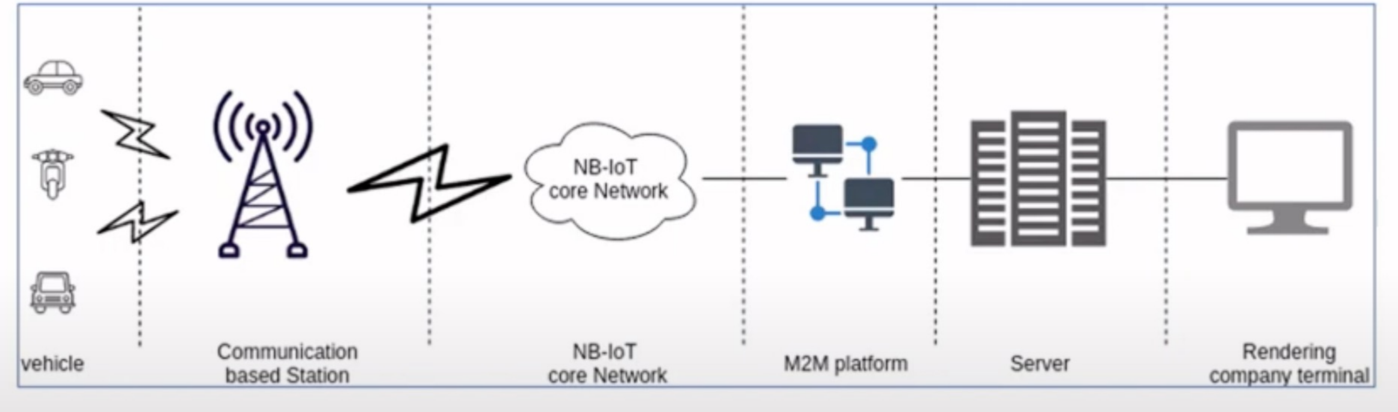




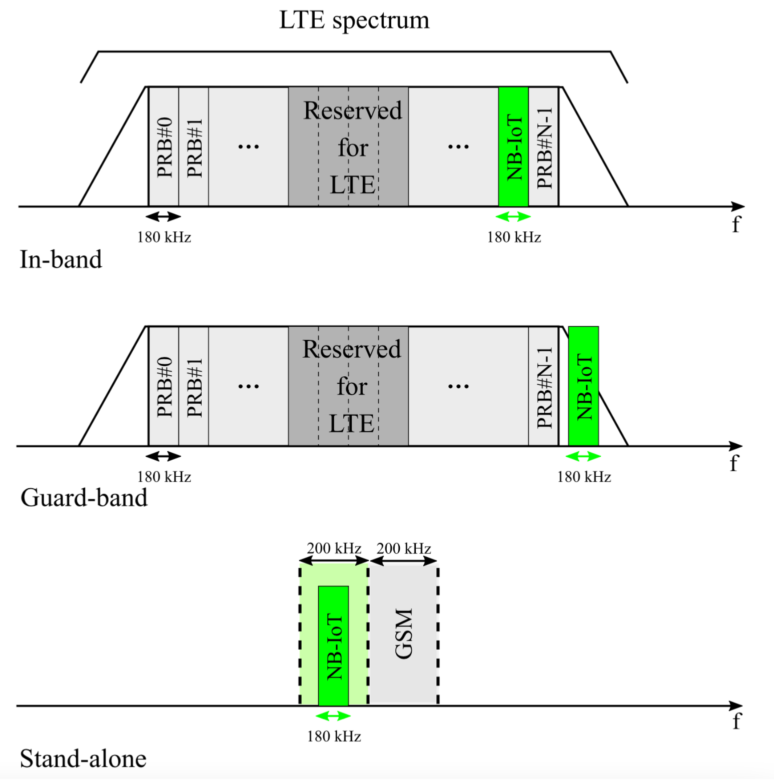


NB-IoT Technology Architectures (based on LTE)





NB-IoT



IoT and energy-efficiency: a huge world full of possibilities….

Questions & Answers

Thank you