Architecture of Wireless Networks for IoT

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Organisation

Evaluation

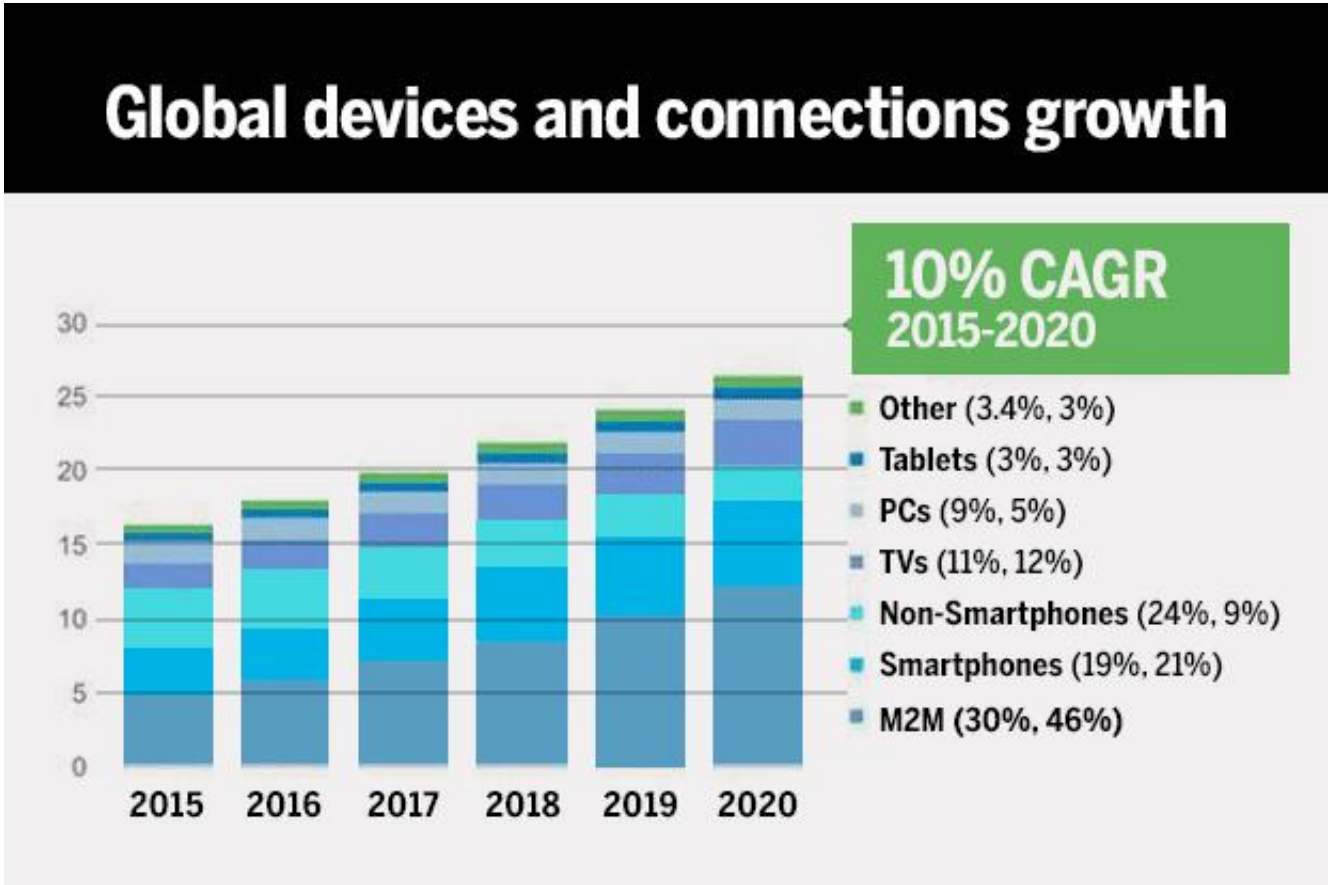
- Labs and Quiz → 50%
  - Quiz → 25%
  - Lab → 25%
- Project → 50%
  - PoC →40%
  - Presentation →10%

Organization and objectives

- Overview of available Wireless Local and Personnel Area Networks (WLAN, WPAN)
  - Wifi, Bluetooth, NB-IoT, SigFox, LoRa, 6LowPAN.etc
- Contiki Os and Zolertia ReMote (tools)
  - IEEE 802.15.4 communications (Broadcast and Unicast)
  - IPv6- 6LowPAN
  - Wireless Sensor Networks (WSN)
- Applications and Quality of Service (QoS)
- **Two main objectives**
  - Have a good command and advantages of each solution
  - To be able to develop IoT applications

Introduction

Evolution of number of devices by user
Five to ten wearable by user

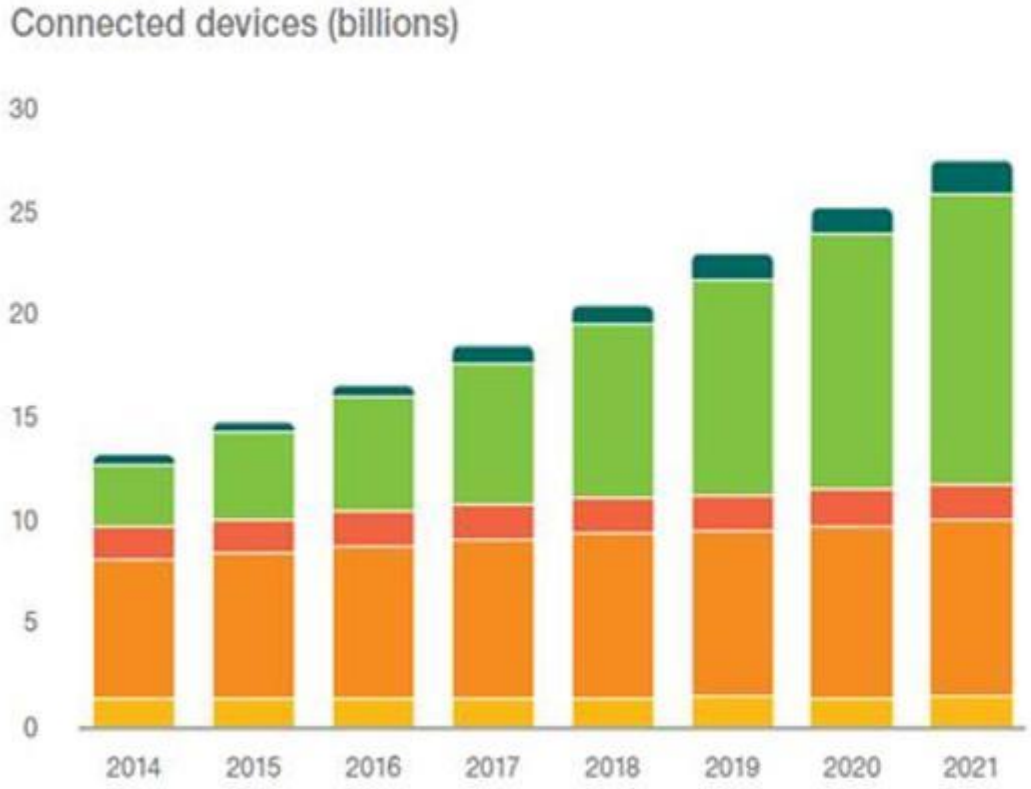


Network World.com

Compound Annual Growth Rate

Annual Growth Rate by wireless networks

THE INTERNET OF THINGS

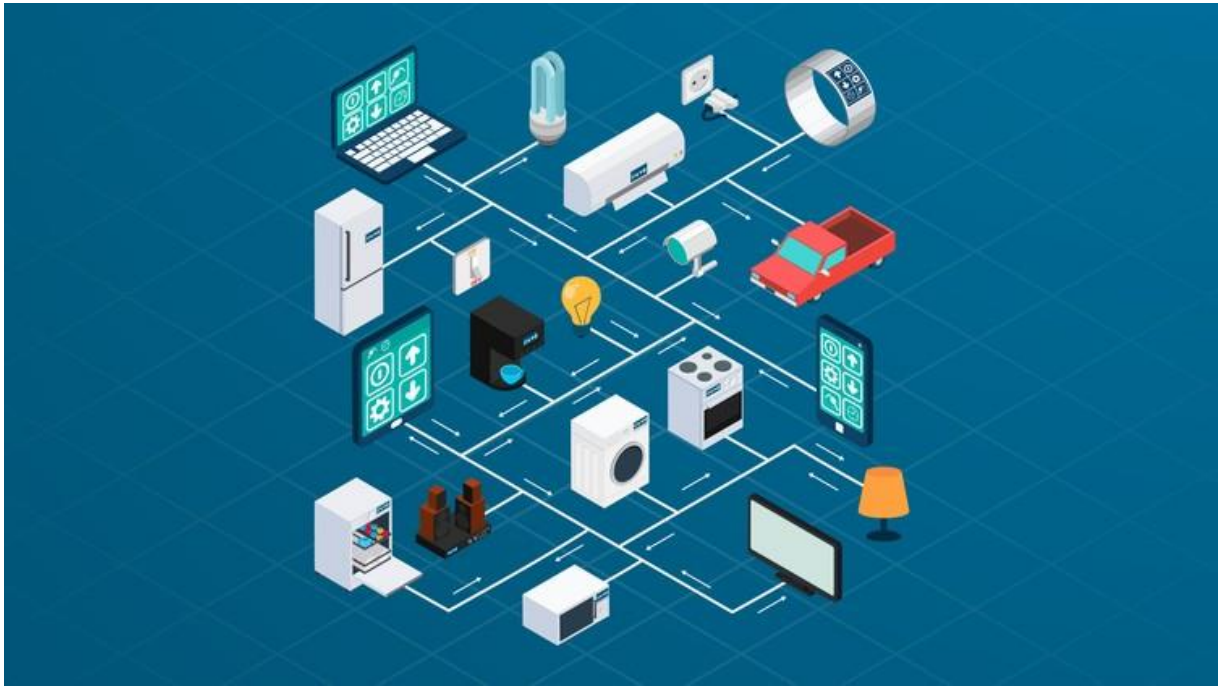


	15 billion	28 billion	CAGR 2015–2021
Cellular IoT	0.4	1.5	27%
Non-cellular IoT	4.2	14.2	22%
PC/laptop/tablet	1.7	1.8	1%
Mobile phones	7.1	8.6	3%
Fixed phones	1.3	1.4	0%

https://www.forbes.com

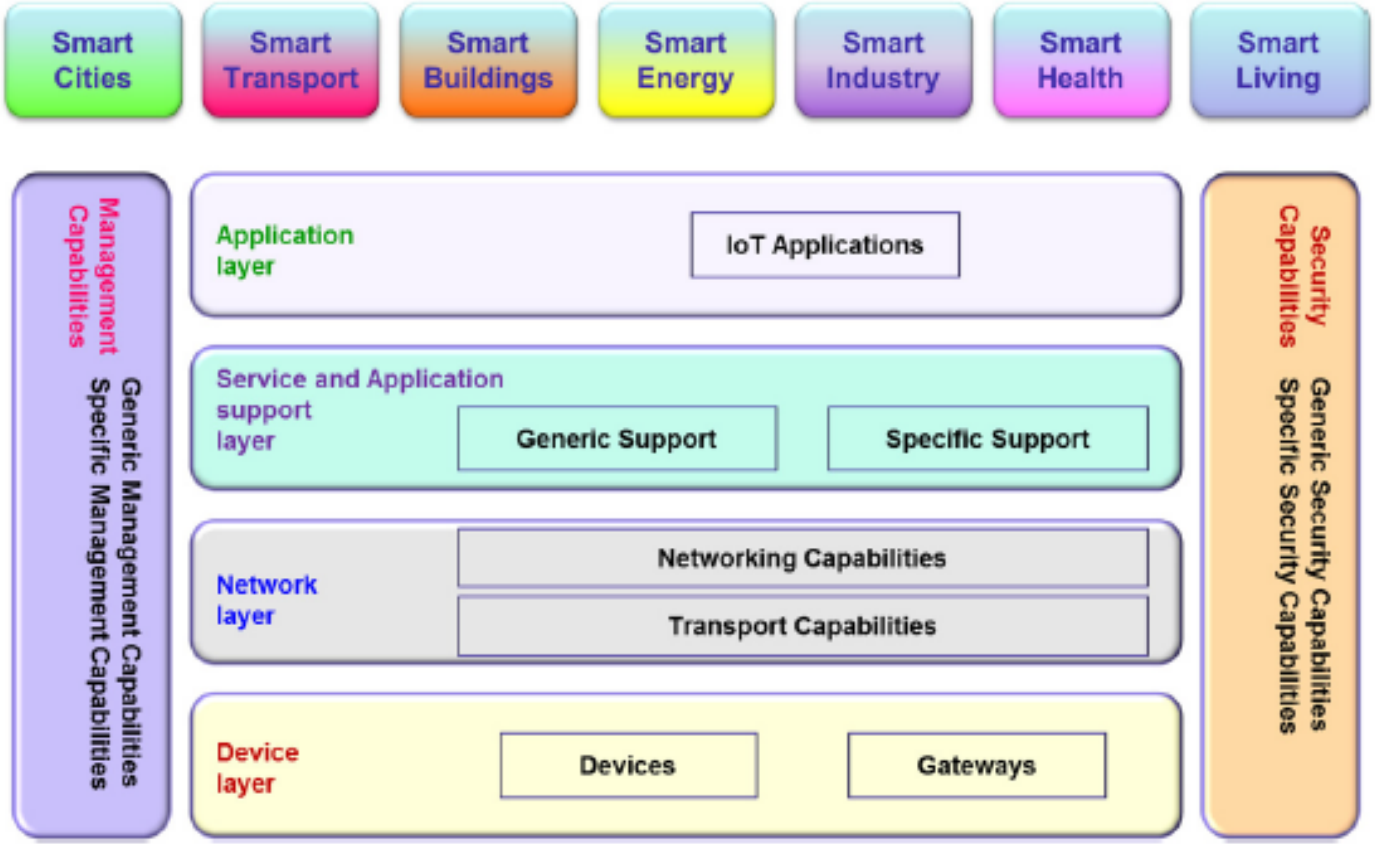
Introduction

Internet of Things (IoT) is a global infrastructure for the **information society**, enabling **advanced services** by interconnecting (physical and virtual**)** **things** based on existing and evolving **interoperable information and communication technologies. [ITU]**

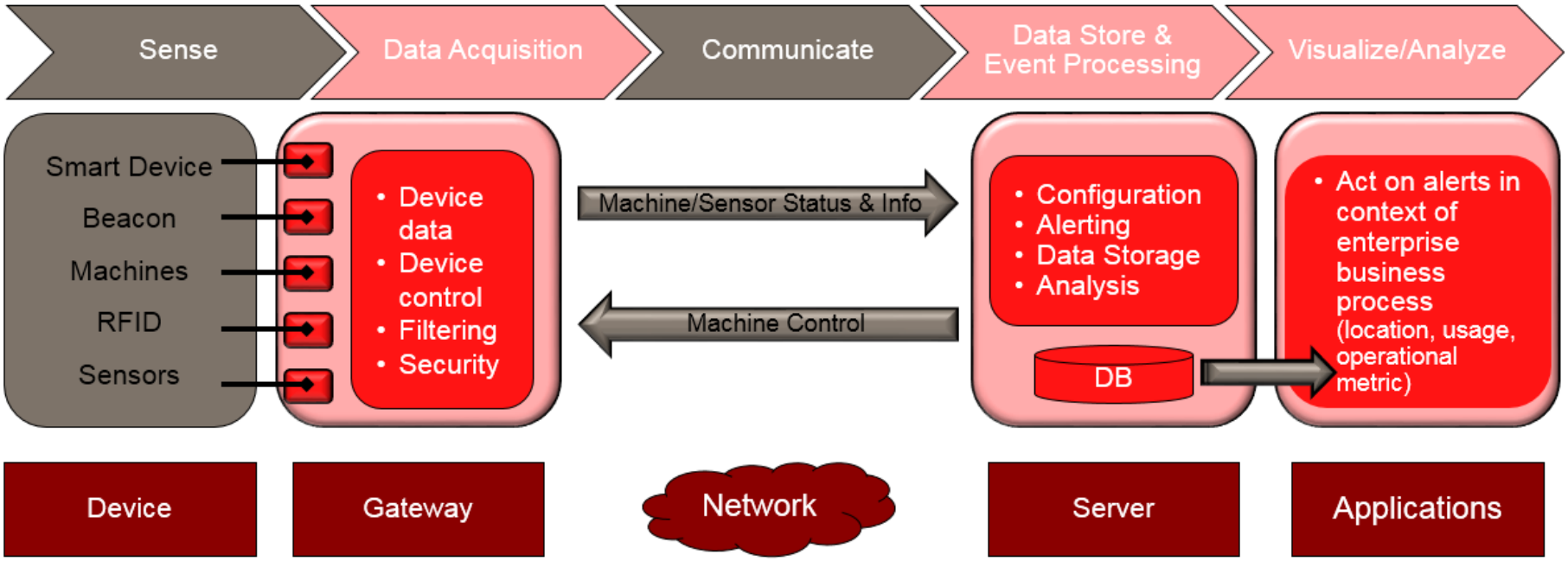


Introduction

IoT Layered Architecture and applications



Architecture IoT-Machine to Machine



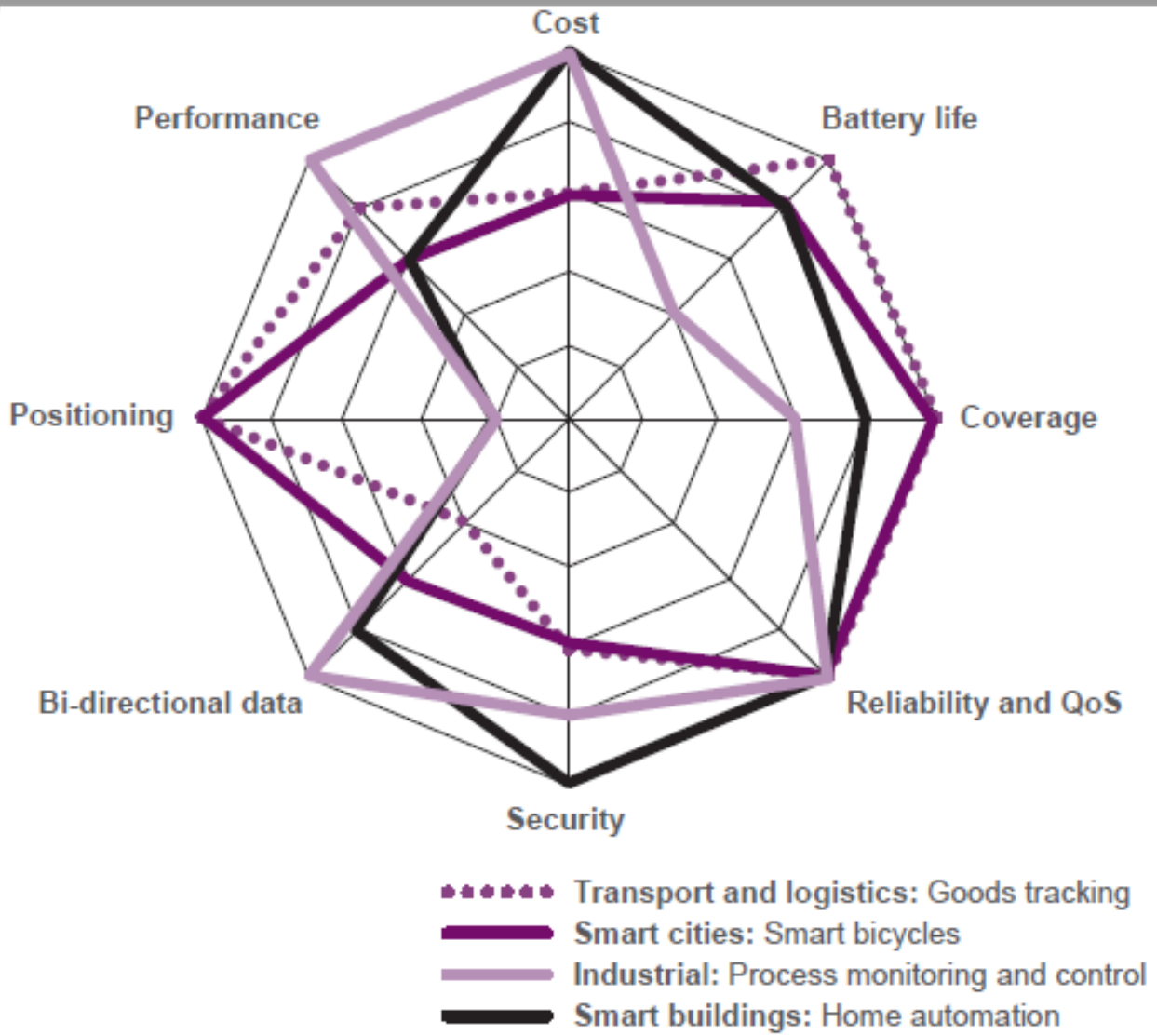
IOT requirements

Critical IoT
- Releability
- Availability
- Low Latency

→ 5G and LTE-M

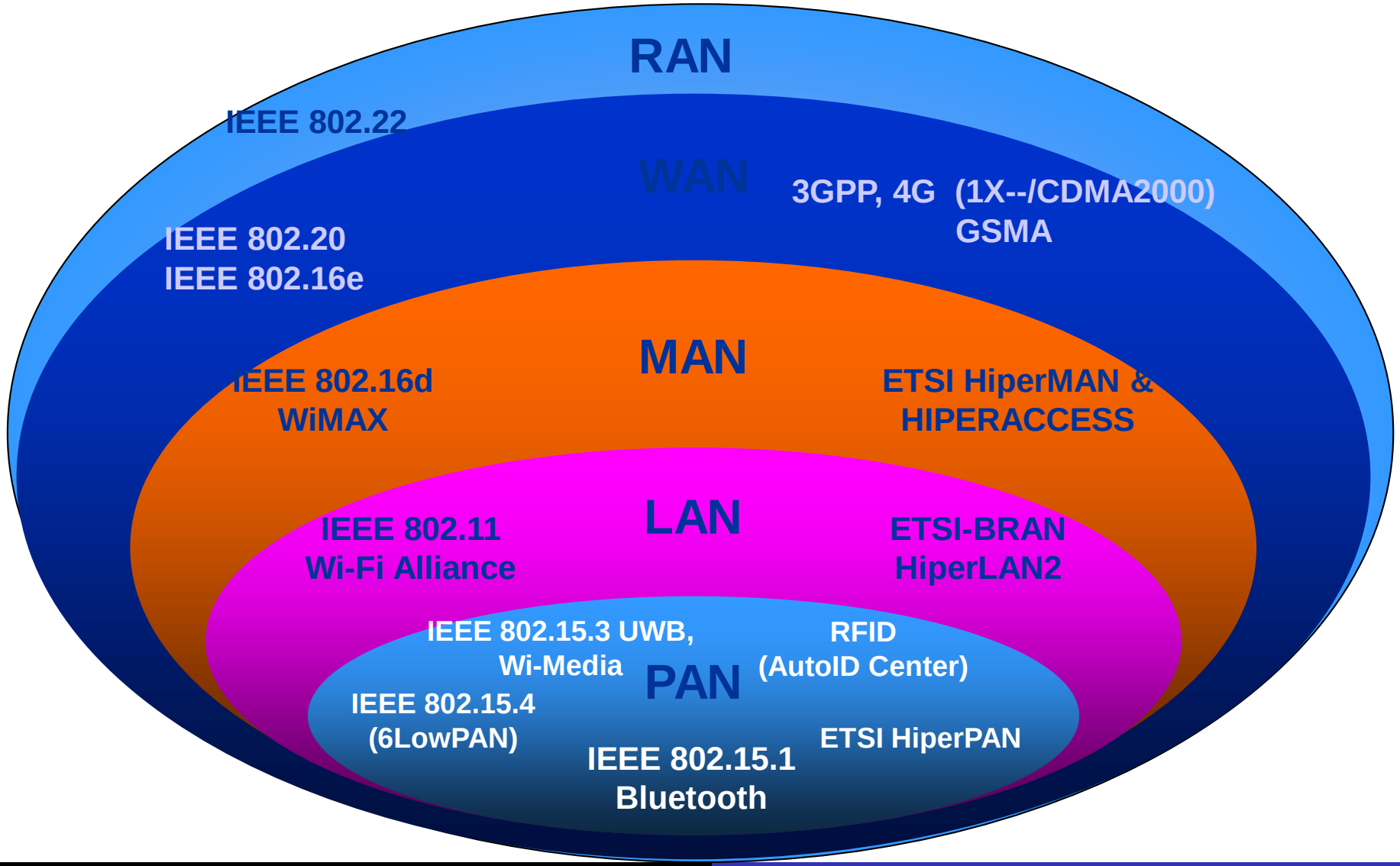
Massive IoT
- Device Cost
- Battery Life time
- Scalability
- Diversity

→ ZigBee, NFC, RFID



www.ericsson.com

Classification of Wireless Networks



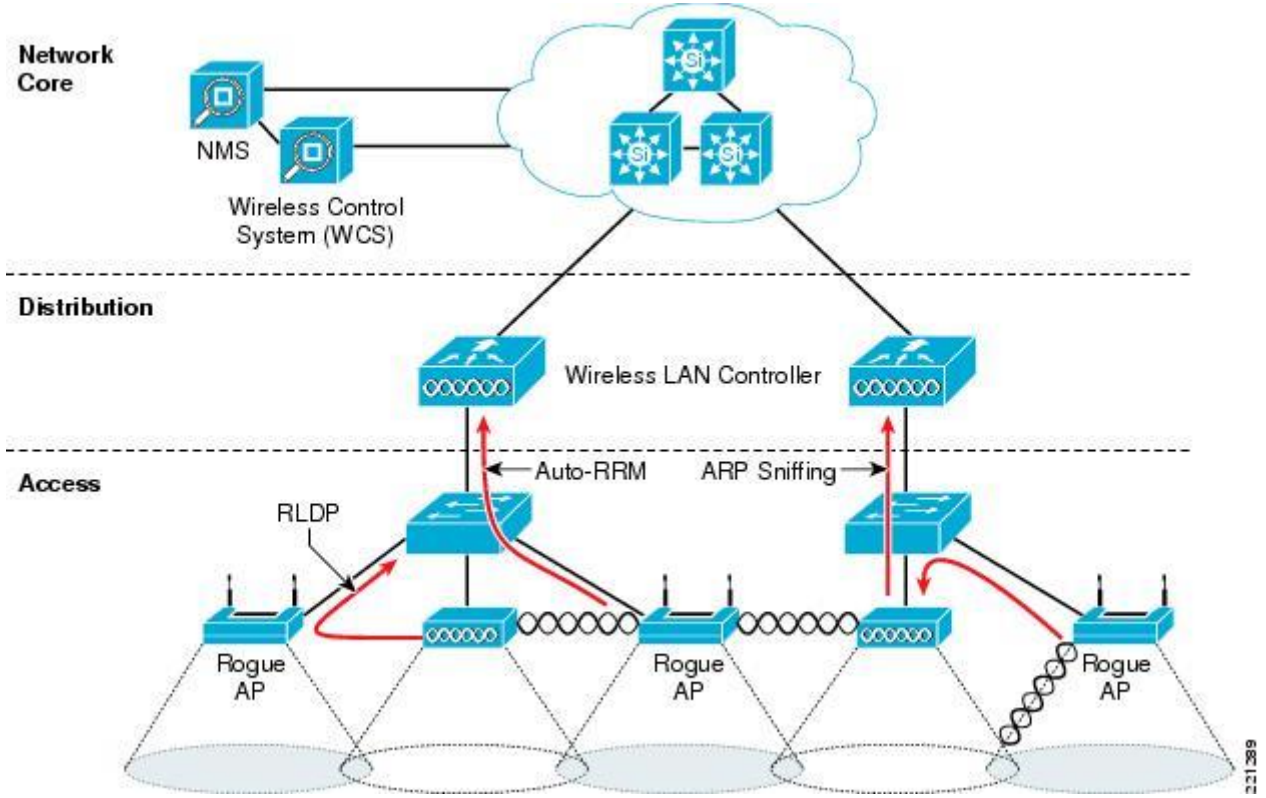
WiFi – IEEE 802.11

Réseaux Locaux sans Fil (Wireless Local Area Networks) WLAN

- IEEE 802.11 standard for MAC and Physical layer of Network
  - Point to point communications via an Access Point (AP)
- The objectives of the network AP
  - **Access to network** ressources (*e.g. Access to Ethernet Network)*
  - **Distribution (***backhaul* or Bridge between Wireless and Wired network)

WiFi – IEEE 802.11

Architecture of WiFi networks

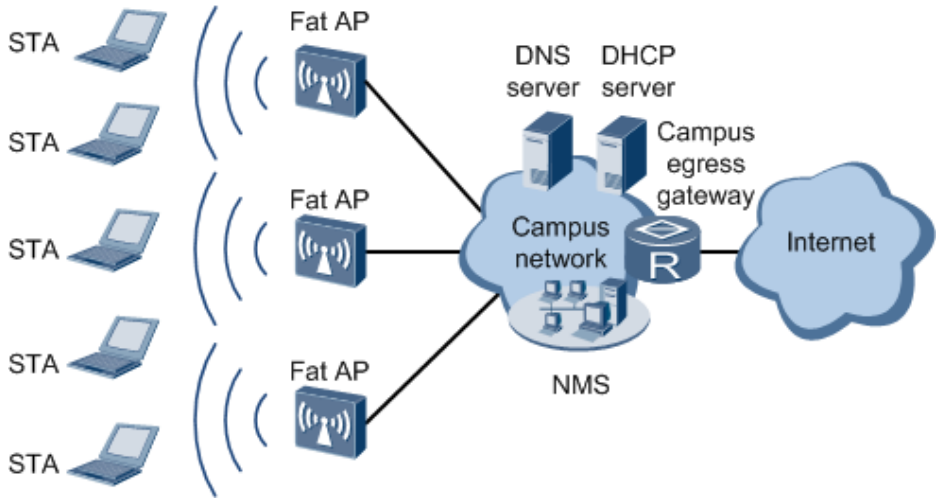


WiFi – IEEE 802.11

Architecture

Le même model OSI des réseaux filaires

	7	Application
	6	Présentation
	5	Session
User application	4	Transport
Software, Firmware	3	Réseau
Hardware	2	Liaison
	1	Physique



(a) Infrastructure

(b) Ad Hoc

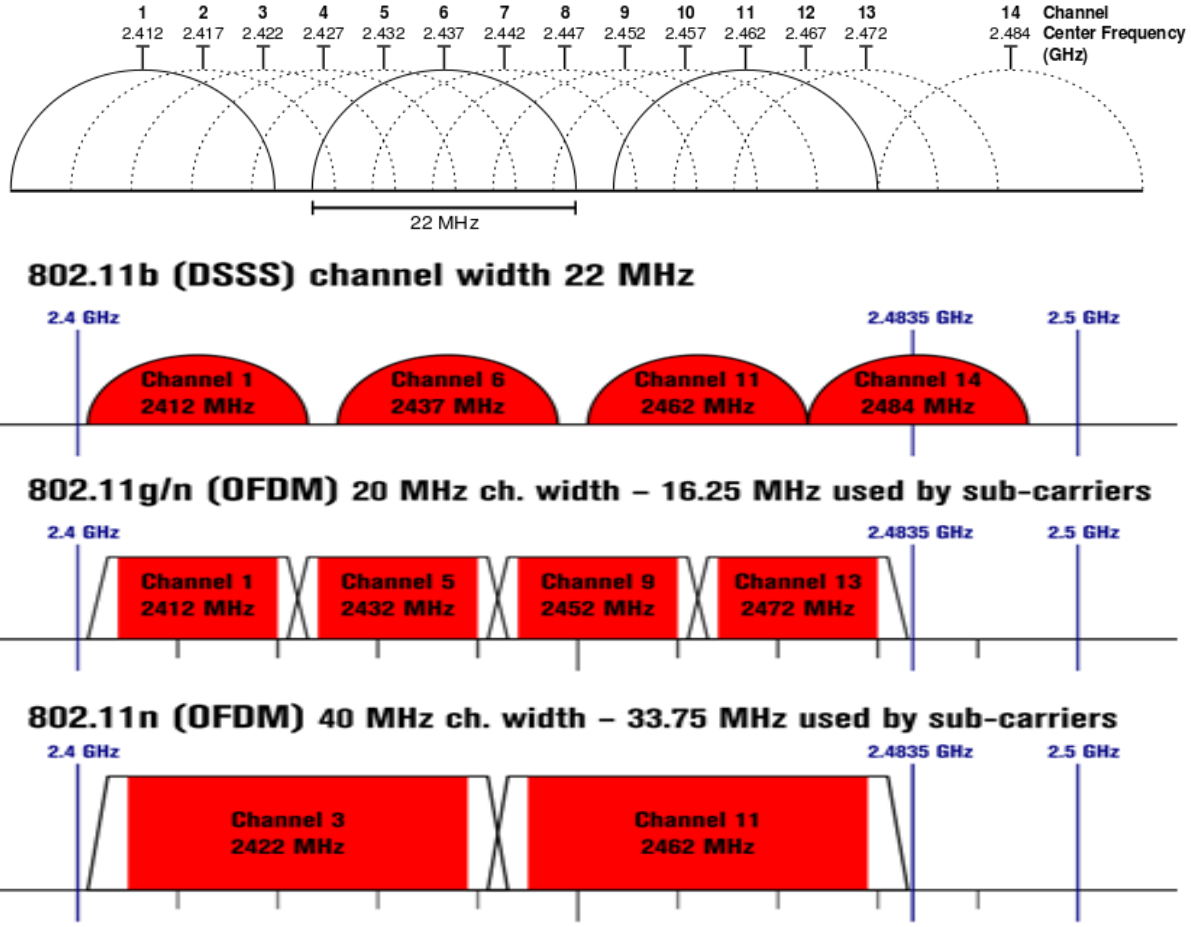
Independent BSS (Basic Service Set)

WiFi – IEEE 802.11

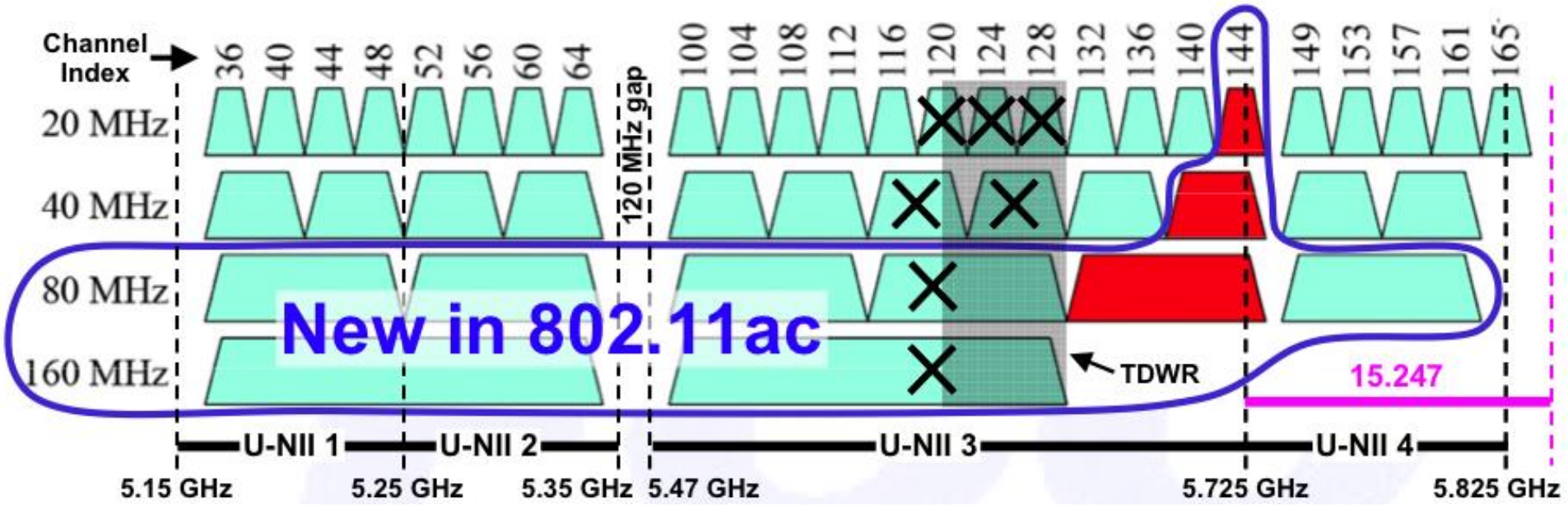
- 802.11x, amendements
  - 802.11b, data rate up to **11 Mbps** (**2,4 GHz ISM band**)
  - 802.11a, data rate up to **54 Mbps** (**5 GHz** ISM band)
  - 802.11g, data rate up to **54 Mbps** (**2,4 GHz** ISM band)
  - 802.11n, data rate up to **600 Mbps** with MIMO (dual bands 2,4 and 5 GHz ISM)
  - 802.11ac, data rate up to **6,7 Gbps** (dual bands **2,4 GHz and 5 GHz**)
  - 802.11ah for IoT, data rate up to 78 Mbps (915 MHz band in USA)
  - 802.11p for V2X, data rate up to 27 Mbps (5,8 GHz ISM band)

WiFi – IEEE 802.11

Install on your SmartPhone the Wifi Analyzer APPlication.
Now you can see the occupancy of Wifi channels in the 2,4 GHz frequency band



WiFi – IEEE 802.11

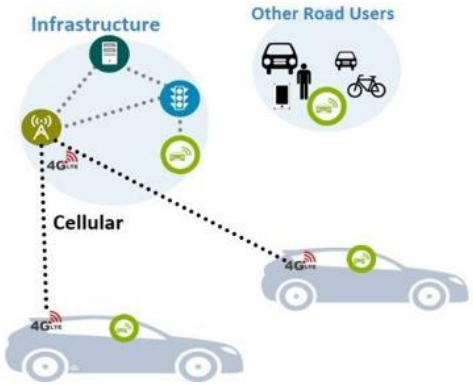


Wifi drawbacks :

- Energy consumption
- Point to point communication via an Access Point

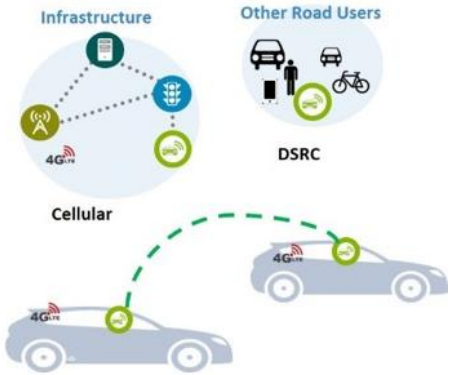
WiFi for V2X – IEEE 802.11p

Cellulaire
LTE



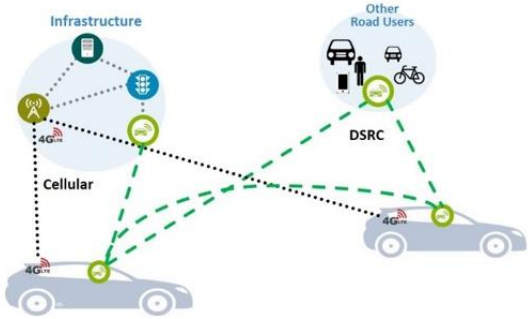
- Request sent to the base station (*eNodeB*)
- eNodeB allocates the ressources for vehicles

IEEE 802.11p
(DSRC, ITS-G5)



- Communication through messages diffusion
- Carrier Sense and Multiple Access of vehicles to the resources

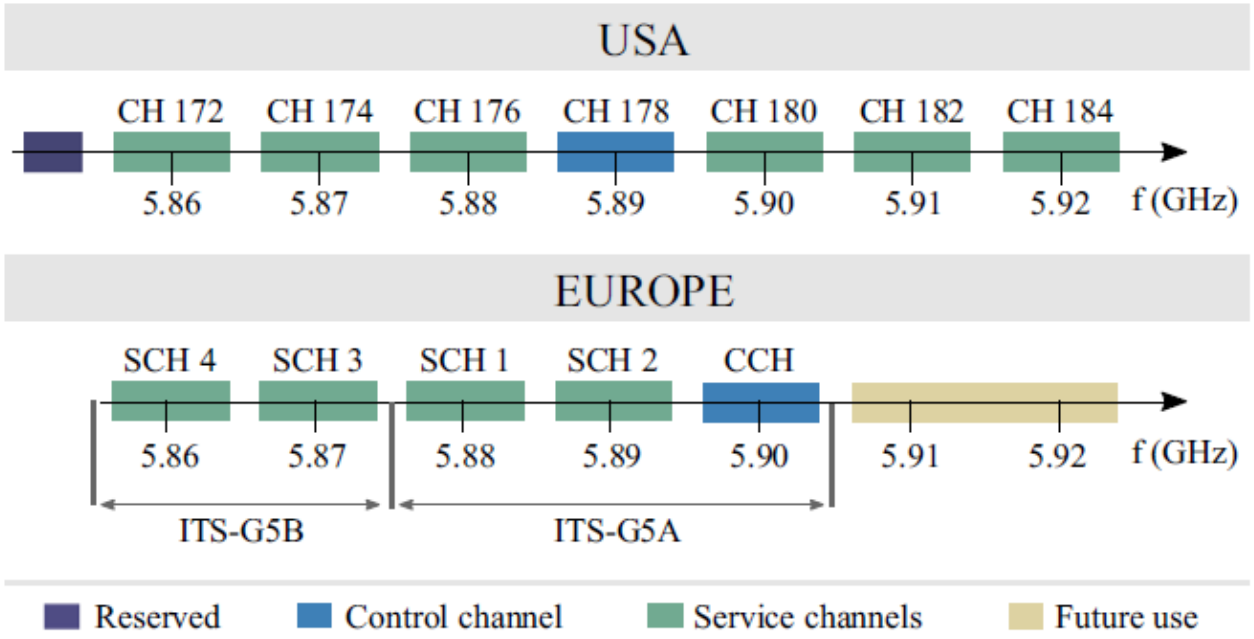
Co-existence de plusieurs technologies
LTE-V & 5G



- 5G
- Interconnexion of *Everything*

WiFi for V2X – IEEE 802.11p

Channel utilization



- OFDM scheme
  - BPSK, QPSK, 16QAM, 64 QAM
- 52 subcarriers
- Channel capacity 5MHz, 10MHz and 20MHz

Bluetooth

- Known as **IEEE 802.15.1** base on Ericson research
- Low power consumption (15ma for transmit, 1uA for sleep)
  - Coin cell battery for energy supply

- Exchange small packets (opposed to streaming)
- Connect → Transmit → Disconnect → Sleep
- GFSK Modulation
- Only up to 1 Mbps, 2 and 3 Mbps
- **2,4 GHz**, **ISM band**, **40 channels**
  - 3 Advertising channels
  - 37 Data channels
- Adaptive Frequency Hopping
- 24 bits for CRC
- Output power → 10 mW (10 dBm)

Bluetooth (Master/Slave actions)

Across platform, Bluetooth is not easy to remember

Once a device has been slaved, (paired) Only the master can set it free. **Users tend to forget which device it was paired with.**

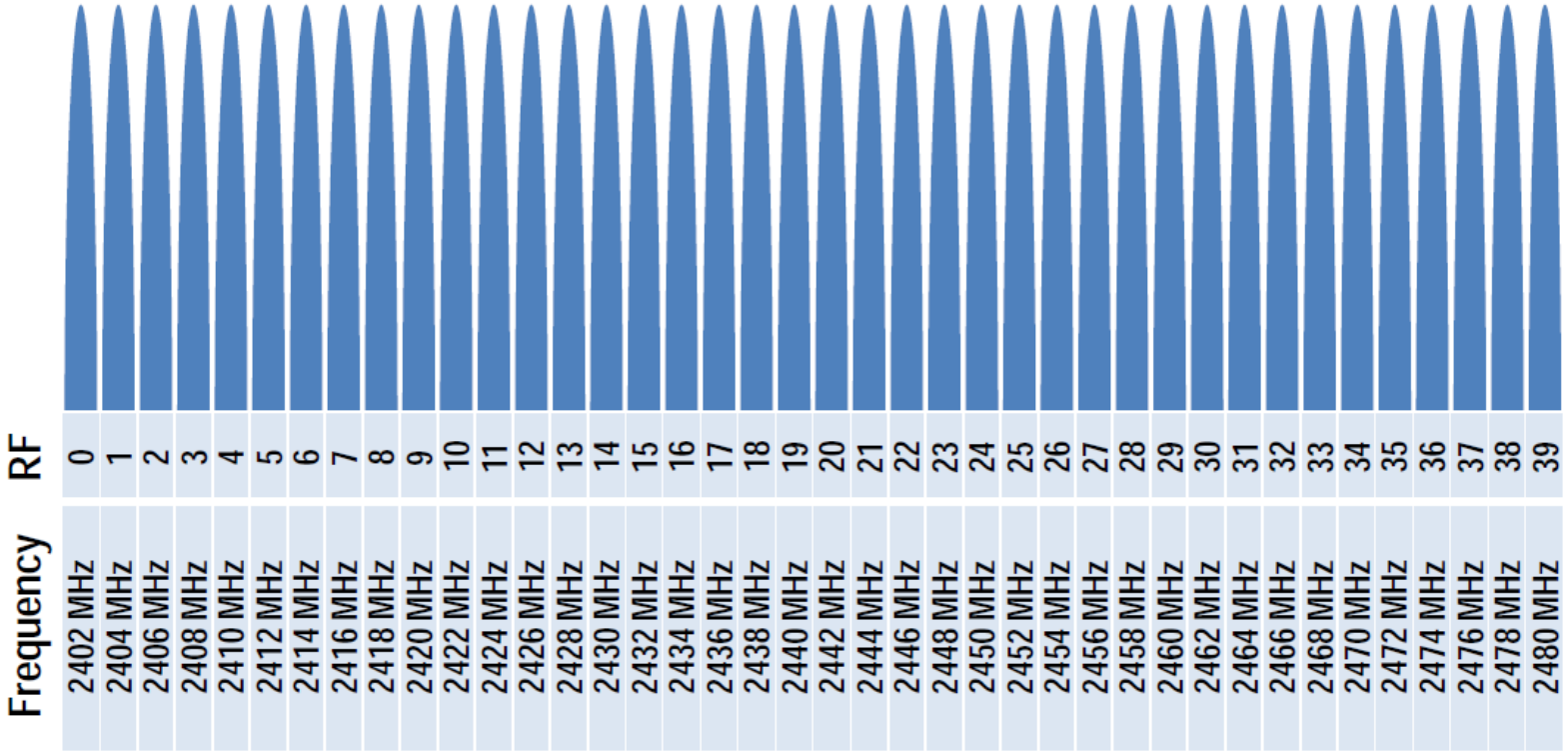
The three Bluetooth output power classes up to Bluetooth 2.0

Power Class	Transmission Power Level (mW)	Advertised Range (m)
1	100	100
2	2.5	10
3	1	1

Physical Channels

2.4 GHz ISM band

$$f = 2402 + 2 \cdot k \text{ MHz}$$



Bluetooth (Master/Slave actions)

State Machine

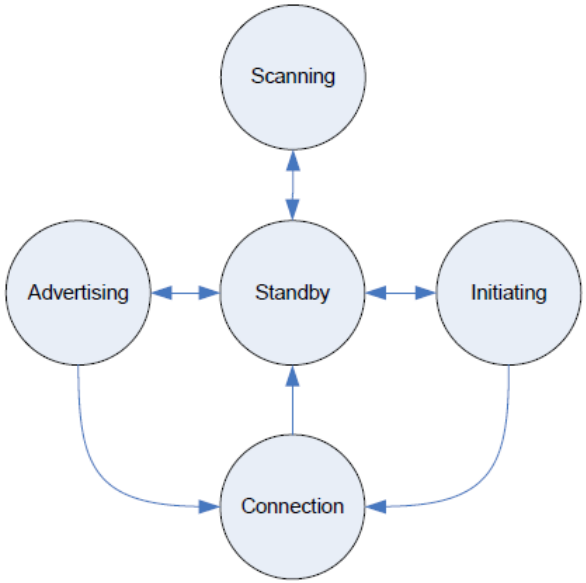
The operation of the Link Layer can be described in terms of a state machine with the following five states:

Master

- Can have multiple slaves
- Determines when slaves listen
- Determines frequency hopping algorithm
- Sends connection determination at connection request, but can update parameters after connection
- If received packet from slave, no need to respond

Slave

- Only one master
- If received packed from master, must respond



Bluetooth Low Energy (BLE)

Term	Introduced	Means
BR	1.1 (2002)	Basic Rate(1Mb/s)
EDR	2.0 (2004)	Enhanced Data Rate (2-3Mb/s)
HS	3.0 (2010)	High Speed (Alternate MAC/PHY)
LE	4.0 (2010)	Low energy (1 Mb/s ultra Low power)
Bluetooth Smart	4.0	LE only radio
Bluetooth Smart Ready	4.0	BR/EDR and LE dual radio

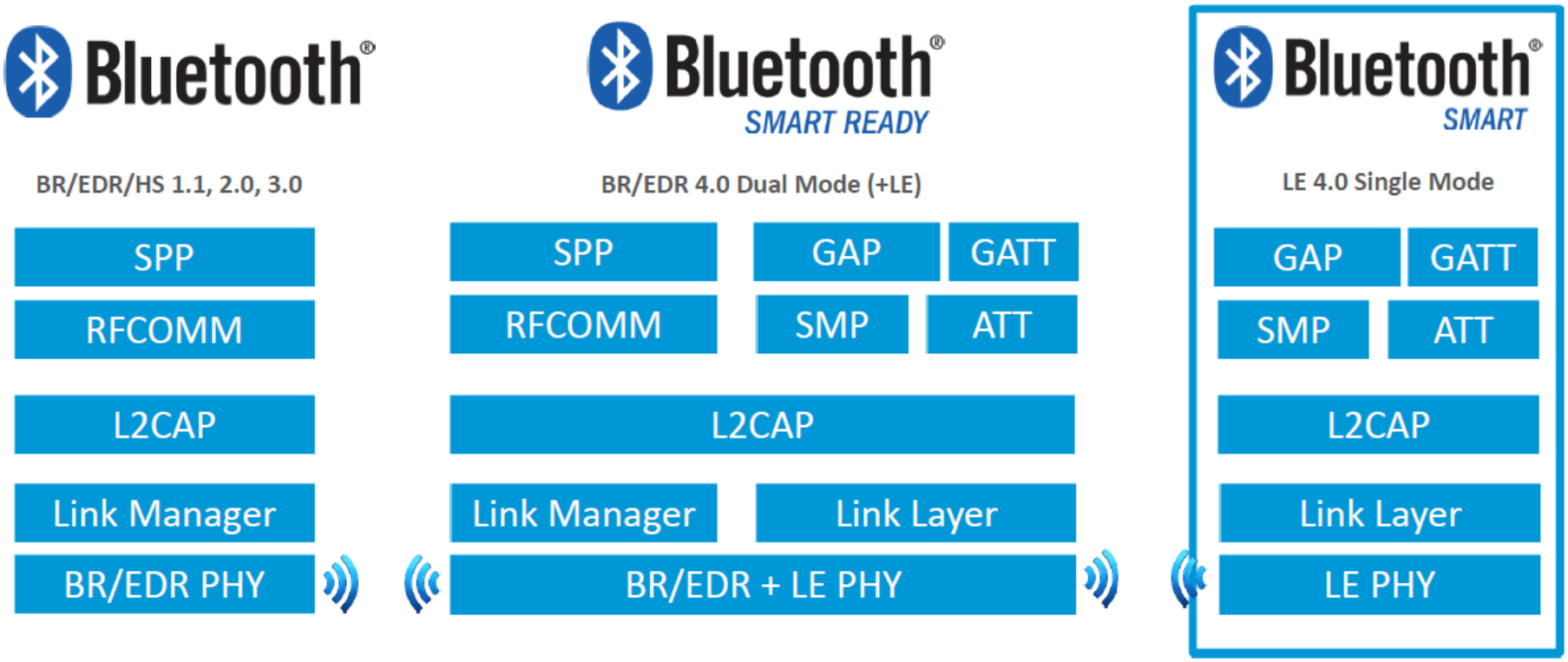
Nordic semiconductor

Bluetooth Low Energy (BLE)

RFCOMM : Radio Frequency Communication is a reliable stream-based protocol as TCP. It emulates **RS-232.**
L2CAP : Logical Link Control And Adaption Protocol. Packet based protocol with varying levels of reliability. 672 bytes< Packet size < 65,535 bytes
SCO: (Synchronous Connection Oriented) Best effort packet based protocol used to transmit voice **64 kb/s**

HCI Host **C**ontroler **I**nterface
It defines how a computer interacts and communicates with a local Bluetooth controler

Bluetooth Low Energy (BLE)

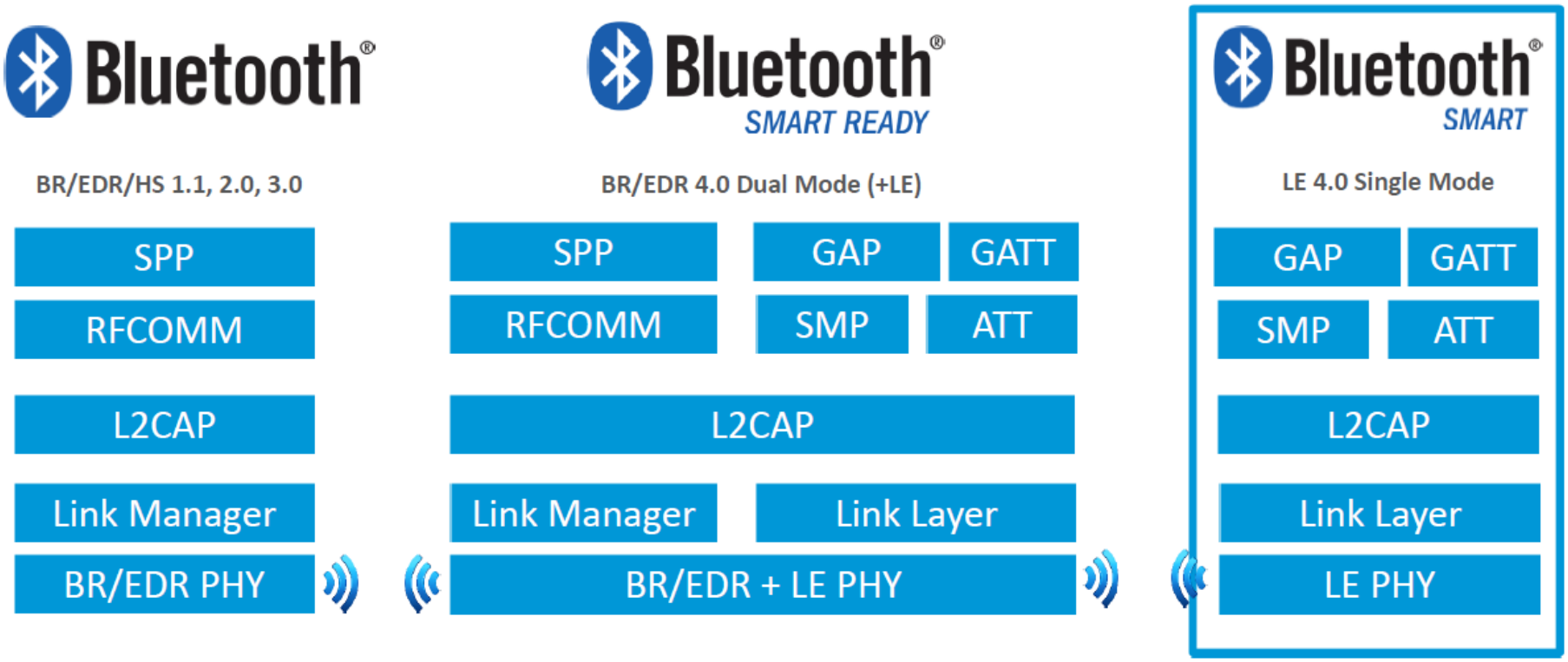


SPP: Serial Port Profile. It replaces the existing RS-232 with payload capacity equal to 128 bytes.

SMP : Security manager Protocol. It is role is to establish pairing, authentication and encryption between devices.

ATT: Attribute protocol. It defines the procedures and formats of services and their characteristics.

Bluetooth Low Energy (BLE)



GATT: Generic Attribute Profile manages different types of profile. **BLE it manages the devices connections to one central device.**
GAP Generic Access Profile. It is what makes your device visible to the outside world, and determines how two devices can (or can't) interact with each other.

SigFox - LPWAN

LPWAN : Low Power Wide Area Network → **proprietary LPWAN**

- Ultra Low Power
- Ultra Long Range

SigFox operates as a global network covers a given area as cellular network

- 1100 base station in France
- Chips compatible with SigFox protocols
- Simple to install (no pairing compared to BLE)
- Cost effectiveness
- GPS tracker is functional with SigFox devices

SigFox - LPWAN

How to communicate

1) Detect Something to send (the hard step)
2) Power on the communication module
3) Send
4) Message is picked up by the network
5) Data is received on your server

Proprieties :

- Send an AT command (couple of code) Up to 12 bytes
- Receive an HTTP request on a application server
- Unlicensed frequency band (**868 MHz**)
- Maximise energy efficiency (Tx in two seconds, 25mW: 14dBm)
- In theory, base stations cover **up to 200 km.** In reality, it depends on topography (in a city like Paris, coverage not exceed **5 km**)

SigFox - LPWAN

Proprieties :

- 7 messages/ hour with 100 bits/s
- No ACK messages
- Example of payload
  - GPS coordinates (lat x lng) : 6 bytes
  - Temperature : 2 bytes
  - State reporting: 1 byte
- Messages are signed with a key unique to the device
- Messages are scrambled or encrypted
- No keys exchanged over the network

Security

How to prototype ?

- Arduino, Rasberry PI, Atmel etc

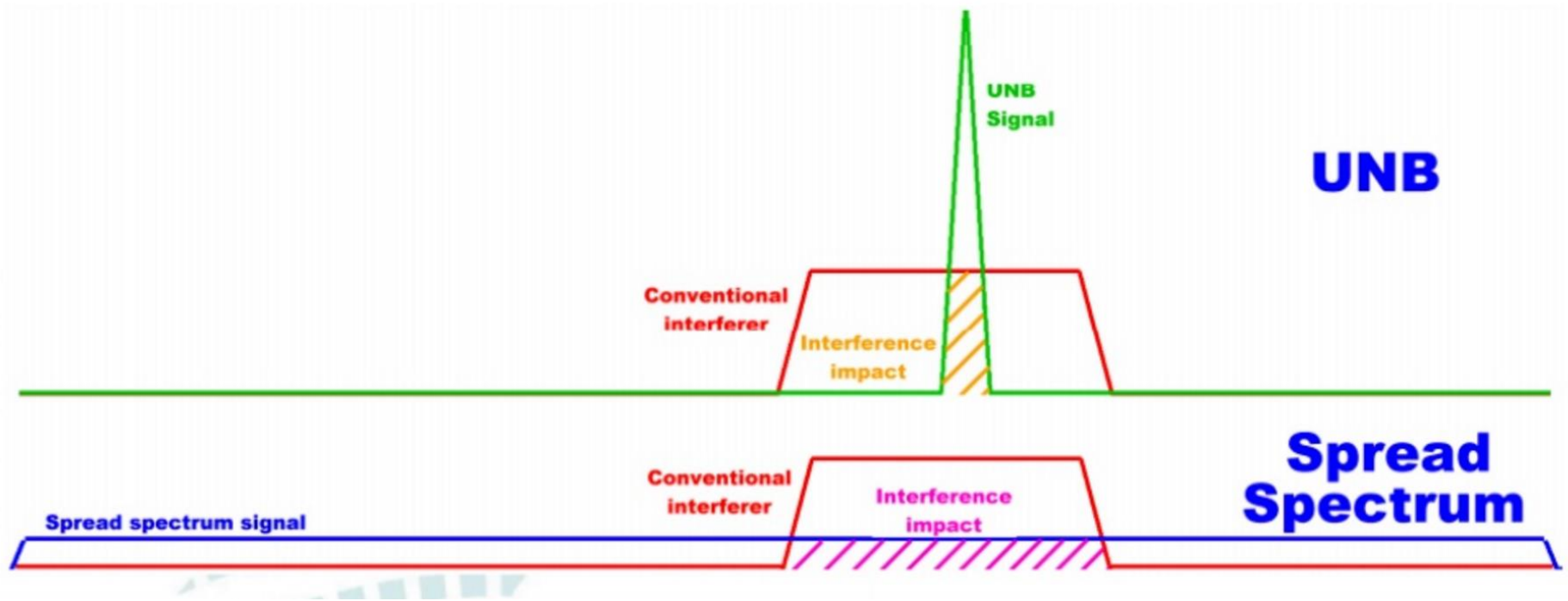
Easy to start but not industrial.

Sources SigFox

SigFox - LPWAN

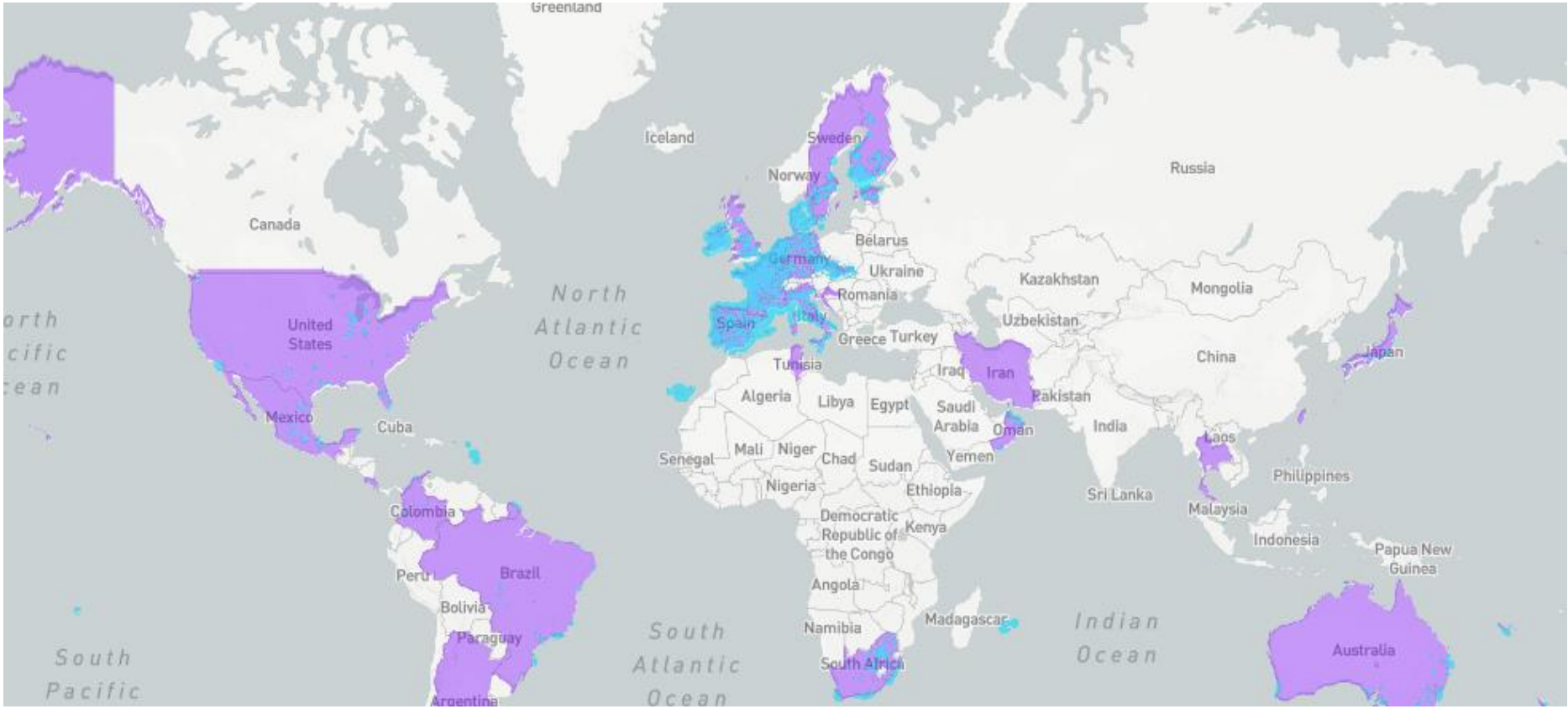
Ultra **N**arrow **B**and **– UNB**

- Europe 868 MHz
- USA 902 Mhz



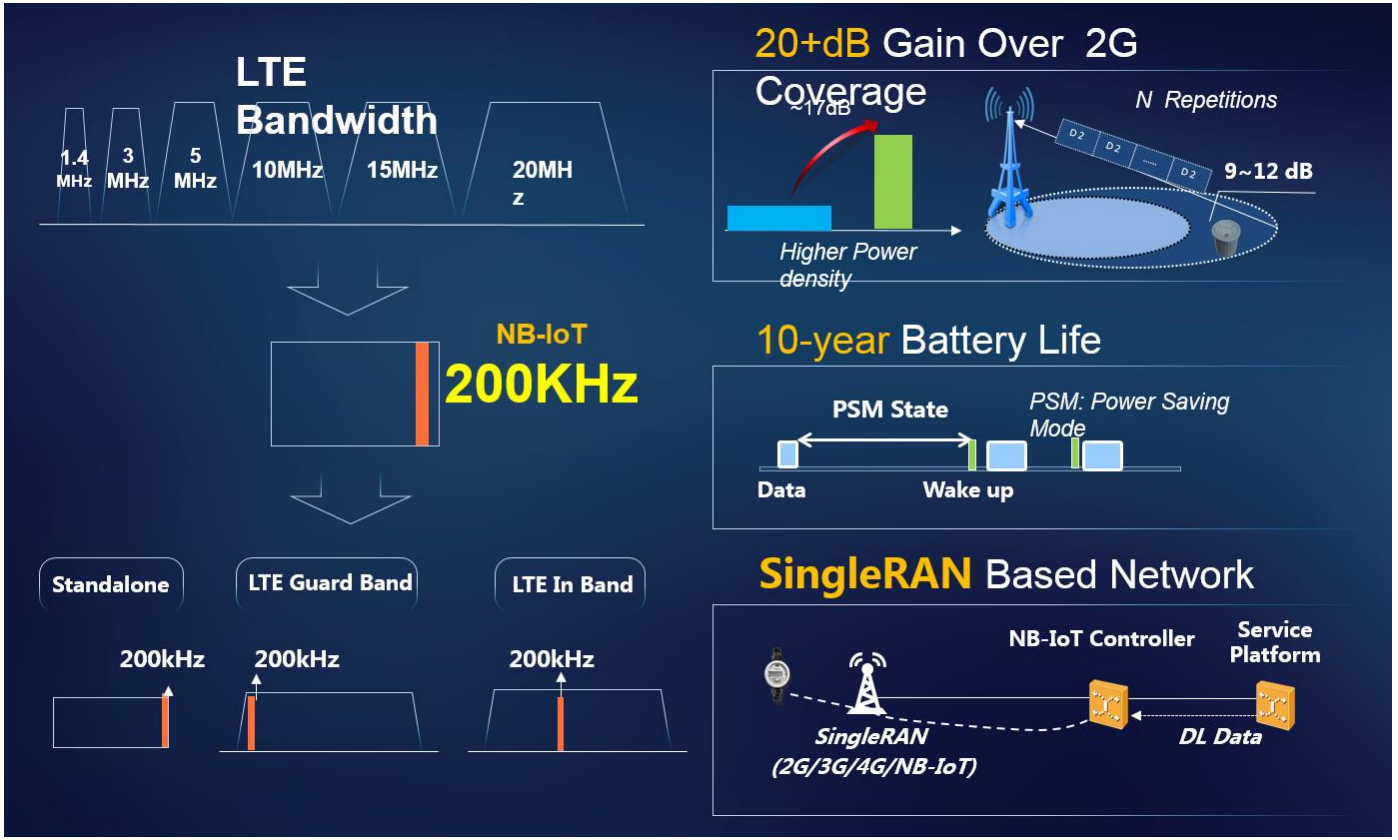
SigFox - LPWAN

Radio coverage



NarrowBand IoT (NB-IoT)

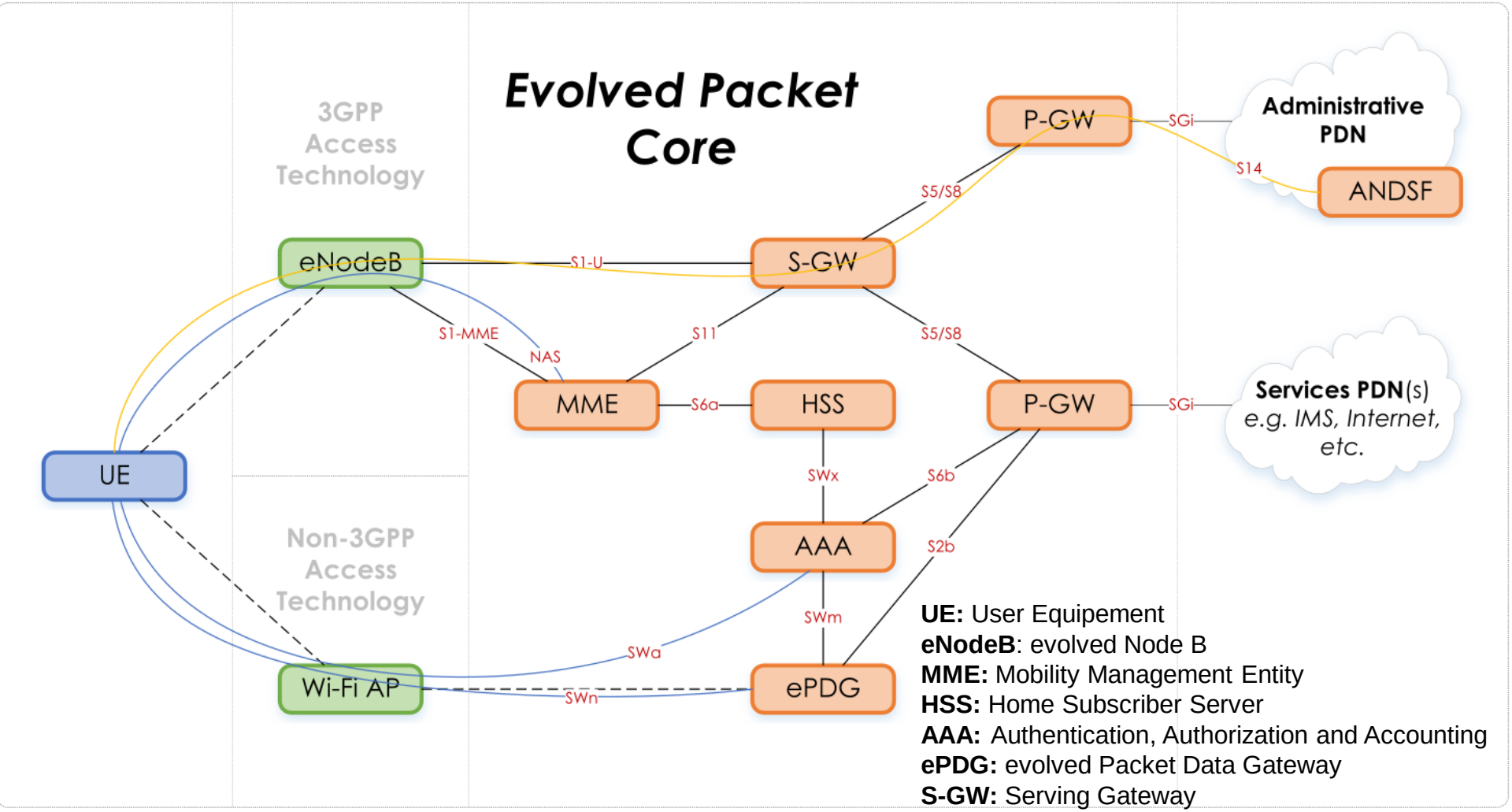
Low Power Wide Area Network (LPWAN) radio technology standard using cellular telecommunications bands.



NarrowBand IoT (NB-IoT)

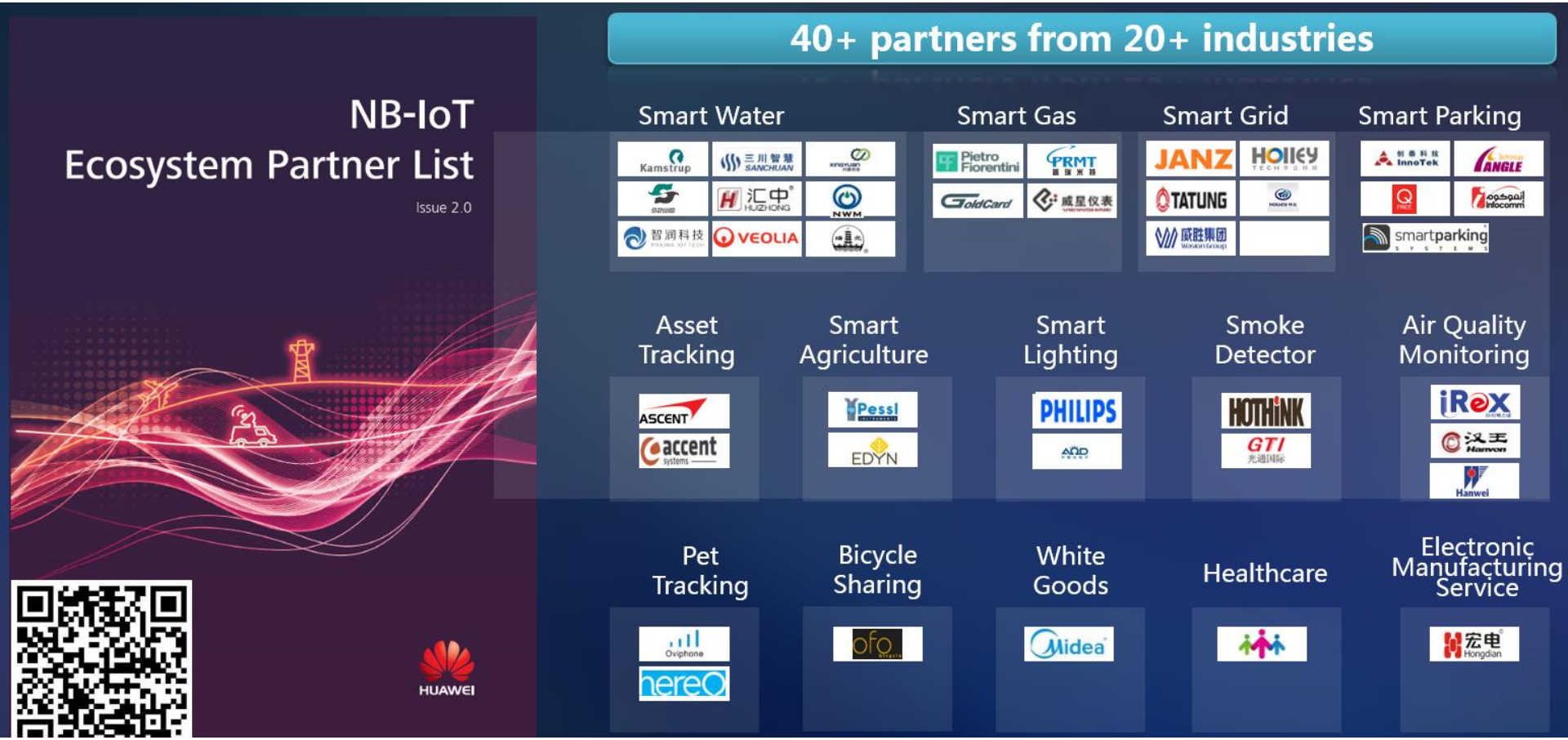
	LTE Cat.1	LTE Cat.0	LTE Cat.M	EC-GSM	NB-LTE*	NB-CIoT
Spectrum	LTE In-Band, Greenfield			GSM In-Band, Greenfield	Greenfield	Greenfield
Release Date/Commercialization	2009	2014	2015/2016	2016/2017	*2016/2017*	*2016/2017*
3GPP Release	Rel-8	Rel-12	Rel-13	Rel-13	*Rel-13/14*	*Rel-13/14*
Peak Data Rate	DL: 10Mbps	DL: 1Mbps	DL: 1Mbps	DL: 74kbps	*DL: 128kbps?*	DL: 32kbps
	UL: 5Mbps	UL: 1Mbps	UL: 1Mbps	UL: 74kbps	*UL: 64kbps?*	UL: 48/14.7kbps
System Bandwidth	20MHz	20MHz	1.4MHz	200kHz	200kHz	200kHz
LPWA Network	No	No	No	Yes	Yes	
Link Budget Target	140dB	140dB	155dB	164dB	*164dB*	164dB
Network Upgrade	No Need	SW Upgrade	To be determined	Yes (HW/SW?)	Yes (HW/SW?)	New Network Clean Slate overlaid with GSM network

LTE Architecture



UE: User Equipement
eNodeB: evolved Node B
MME: Mobility Management Entity
HSS: Home Subscriber Server
AAA: Authentication, Authorization and Accounting
ePDG: evolved Packet Data Gateway
S-GW: Serving Gateway
P-GW: Packet Gateway
ANDSF: Access Network Discovery and Selection Function

LPWAN – NB-IoT

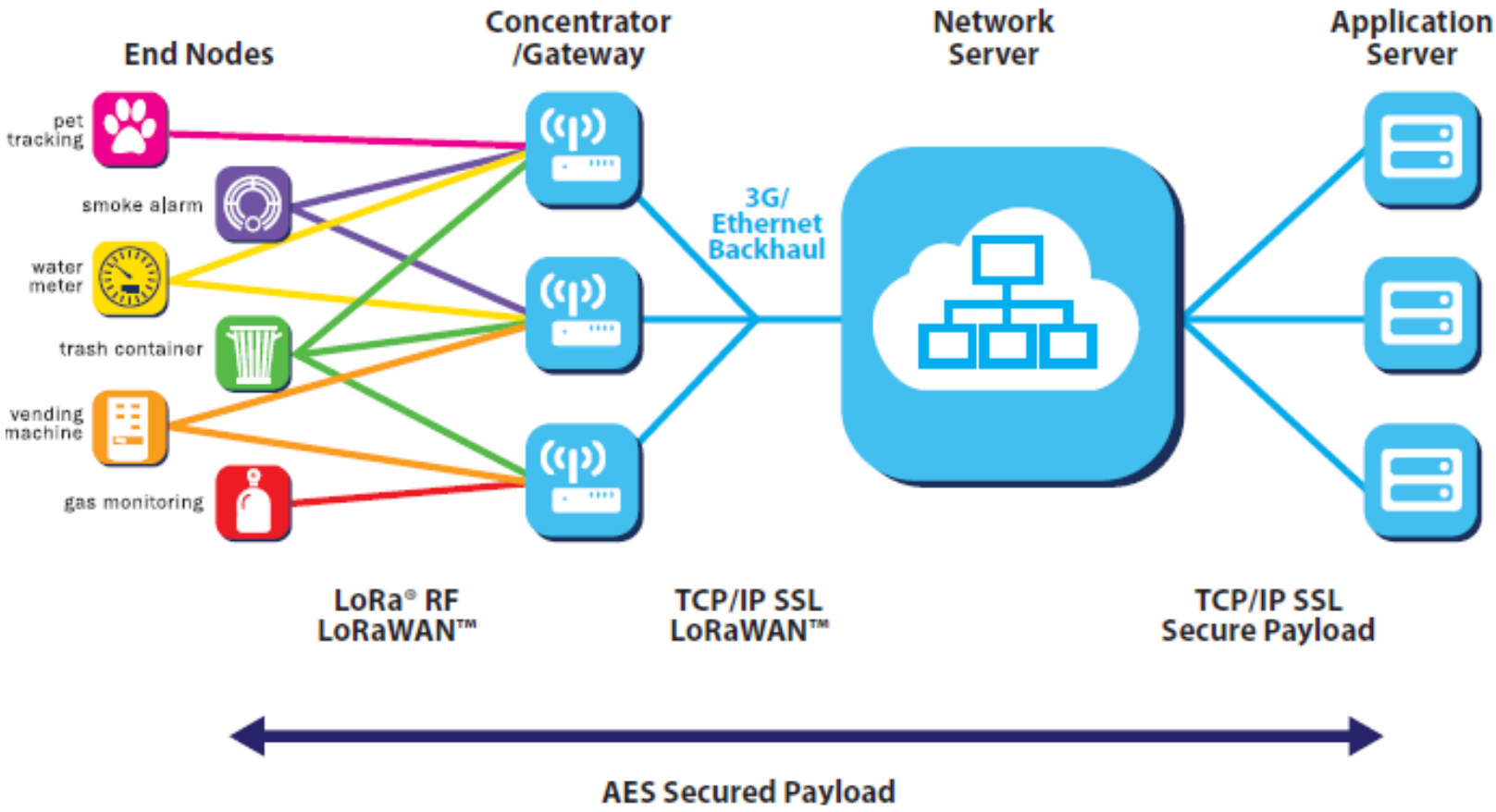


Source Huawei

Long Range IoT – LoRa

LPWAN : Low Power Wide Area Network → **proprietary LPWAN**

Network architecture



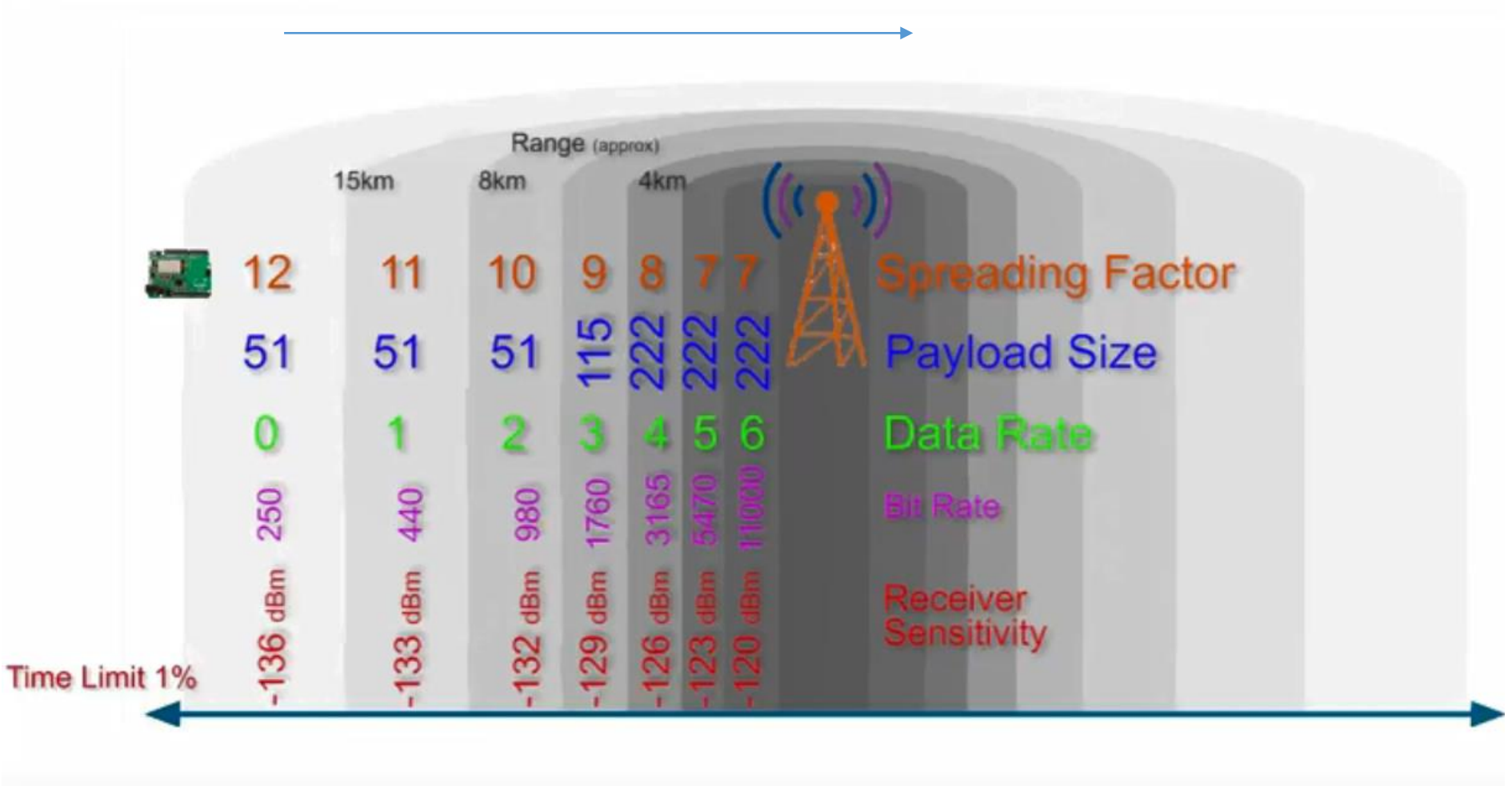
Long Range IoT – LoRa

Proprieties :

- Up to **290 kbps**
- **868 MHz** in Europe
- **902 MHz** In USA
- Output power is up to **20 dBm** for Tx
- Modulation **Frequency Shift Keying** (FSK) with **C**hirp **S**pread **S**pectrum (CSS)
- LoRa Physical layer inherits its proprieties from RADAR technology and **IEEE802.15.4a**
- **Spread Factor concept** is introduced to find the tradeoff between output power and data rate

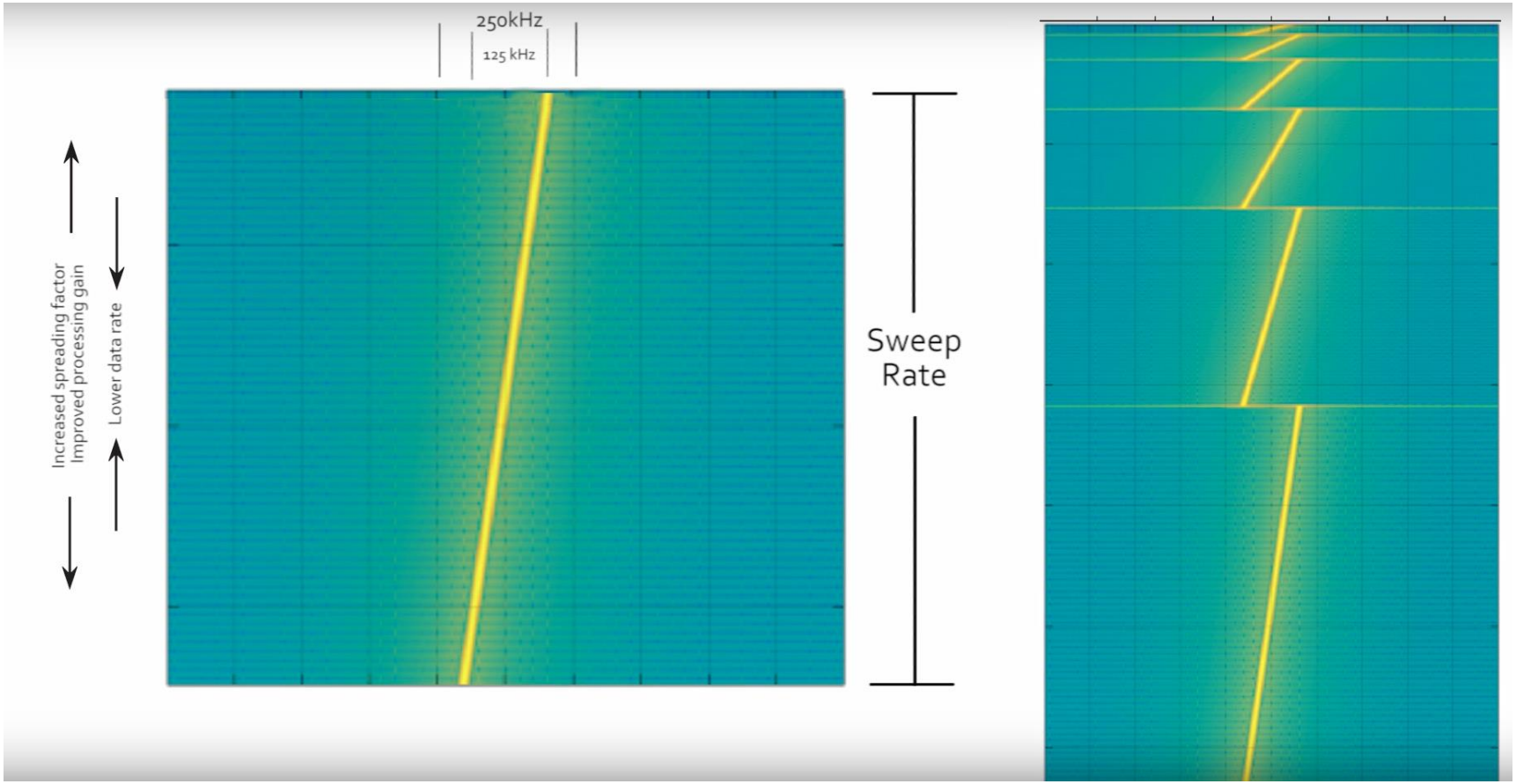
Long Range IoT – LoRa

Spread factor concept



Long Range IoT – LoRa

LoRa Chirp Spreading

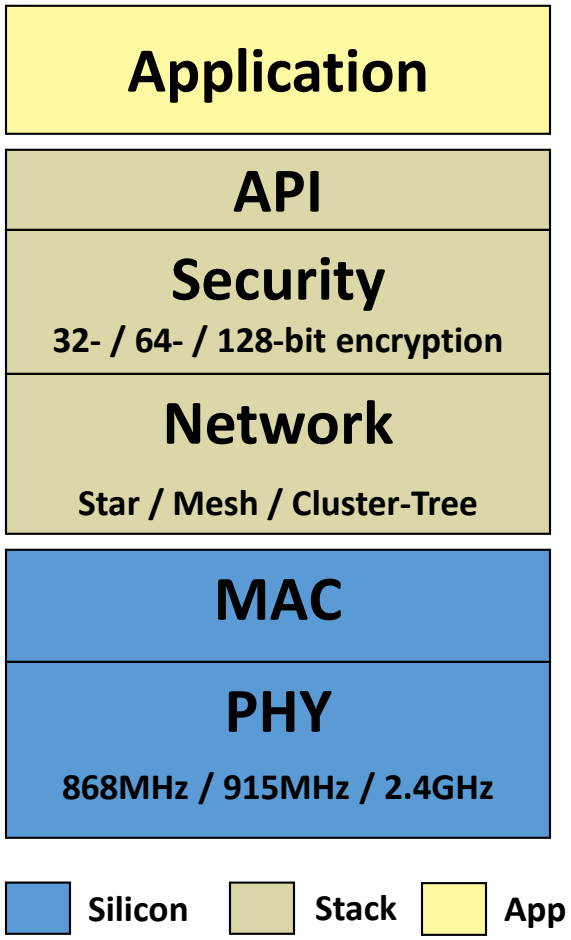


Long Range IoT – LoRa

LoRa device classes

CLASS NAME	INTENDED USAGE
A (« all »)	**Battery powered sensors**, or actuators with no latency constraint Most energy efficient communication class. Must be supported by all devices
B (« beacon »)	**Battery powered actuators** Energy efficient communication class for latency controlled downlink. Based on slotted communication synchronized with a network beacon.
C (« continuous »)	**Mains powered actuators** Devices which can afford to listen continuously. No latency for downlink communication.

IEEE 802.15.4 – 6LowPAN



Customer

ZigBee Alliance

IEEE 802.15.4

"the software"

Network, Security & Application layers

Brand management

IEEE 802.15.4

"the hardware"

Physical & Media Access Control layers

IEEE 802.15.4 – 6LowPAN

Proprieties

- Older and **better established than Bluetooth**
- Key advantage: mesh networking capabilities
- IEEE 802.15.4 **stack is heavier** than BLE
- **Higher energy consumption** than **BLE**
- Lower rates than BLE: **250 kb/s** (**2.4GHz**), **40 kb/s** (**915MHz**), **20 Kb/s** (**868 MHz**)
- Longer range than Bluetooth (**up to 300m**)
- Key applications: **smart grids**, **monitoring and surveillance**, **healthcare**, **M2M**
- PHY supports operation in multiple **ISM frequencies** (over **26 channels**)
- **OQPSK, BPSK, DQPSK** modulations

IEEE 802.15.4 – 6LowPAN

Frequency bands and channels

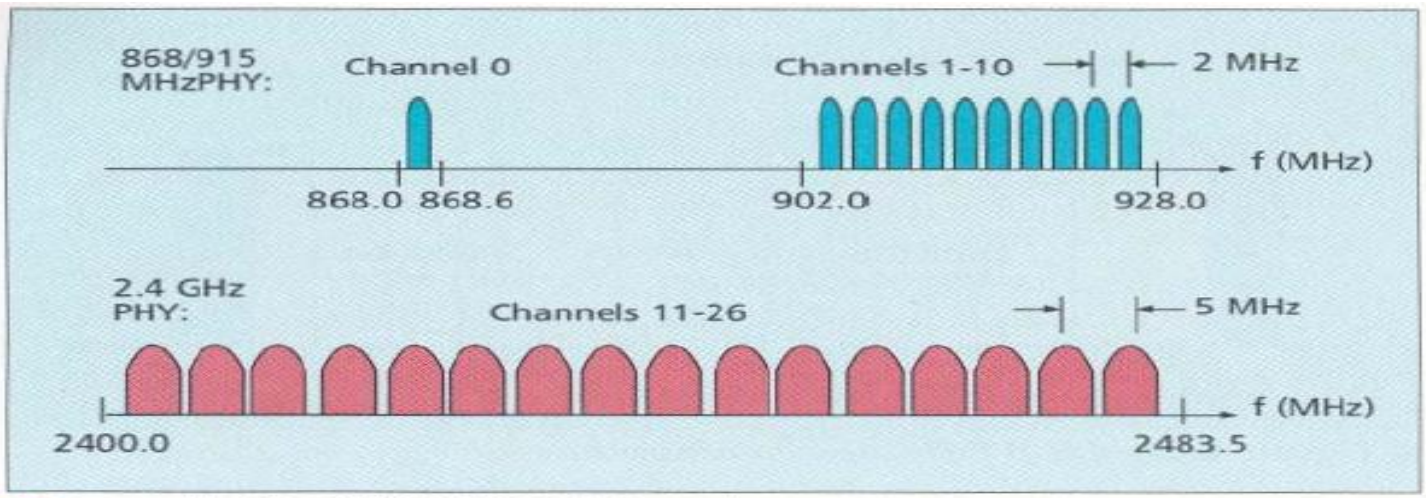


Figure 5. *The IEEE 802.15.4 channel structure.*

Channel number	Channel center frequency (MHz)
$k = 0$	868.3
$k = 1, 2, \ldots, 10$	$906 + 2(k - 1)$
$k = 11, 12, \ldots, 26$	$2405 + 5(k - 11)$

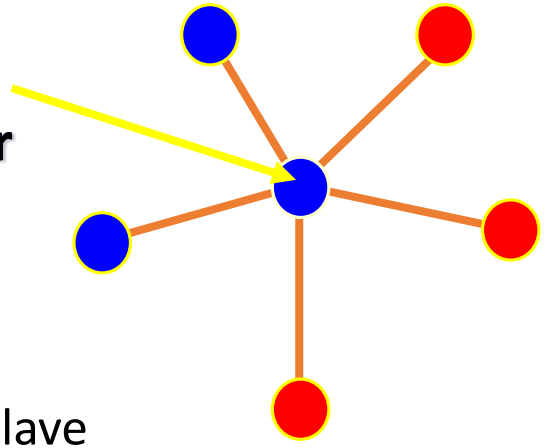
Table 2. *IEEE 802.15.4 channel frequencies.*

Sources IEEE 802.15.4 standard

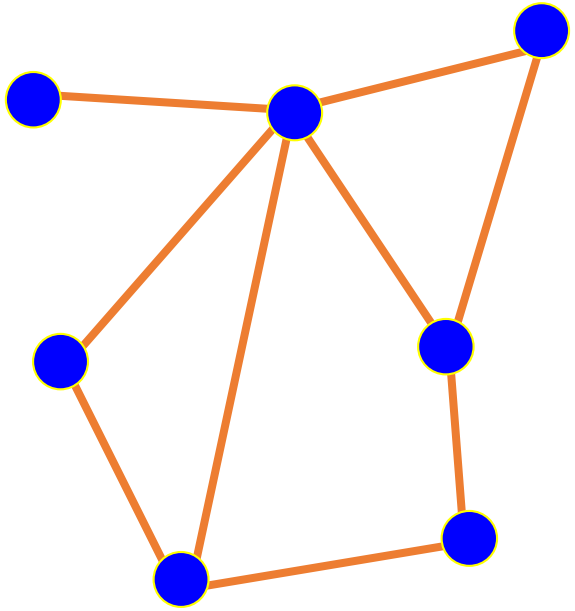
IEEE 802.15.4 – 6LowPAN

Deux topologies : Etoile et Mesh

Network coordinator



Master/slave



Point to point

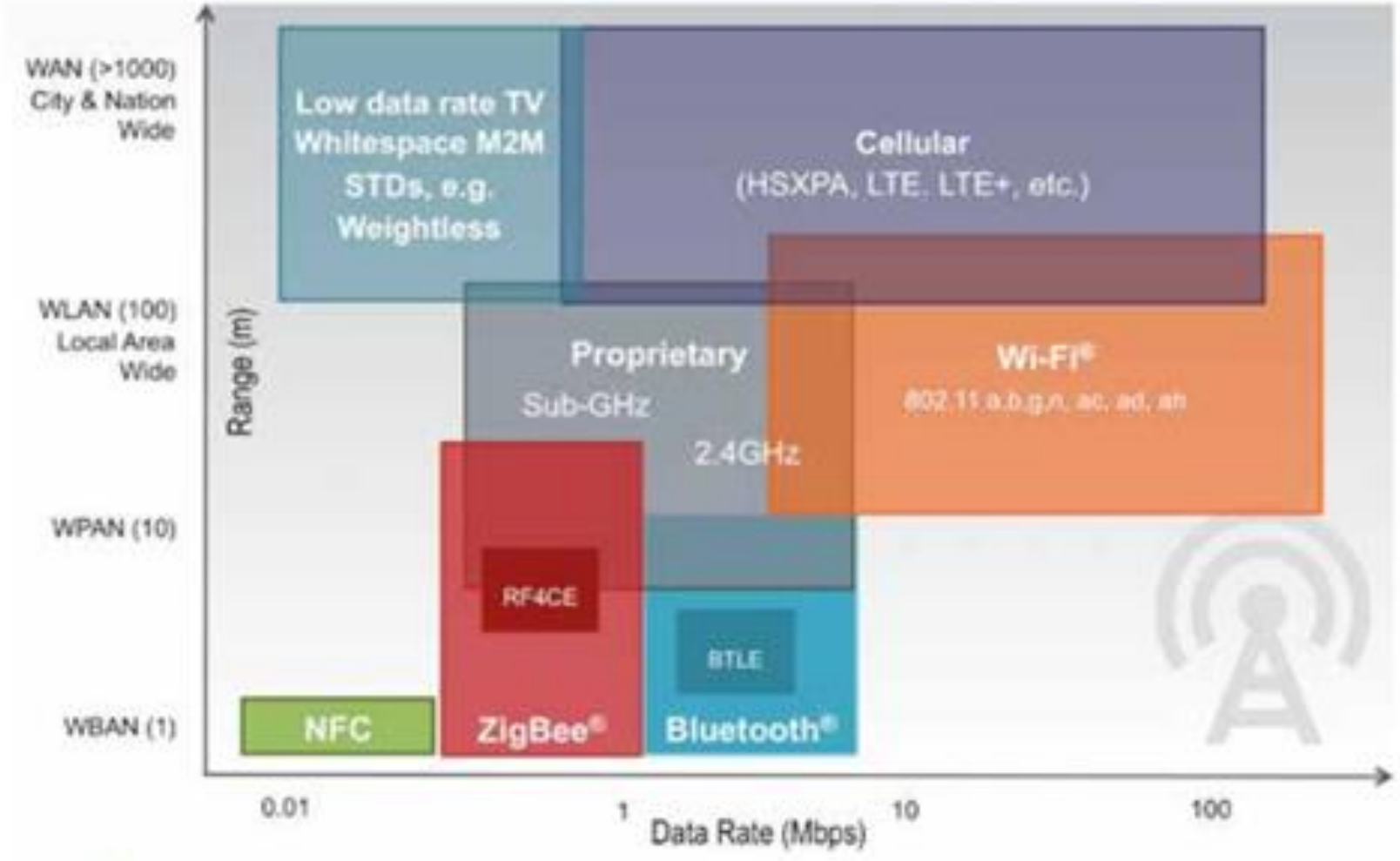
Full Function Device (FFD)

Reduced Function Device (RFD)

Communications Flow

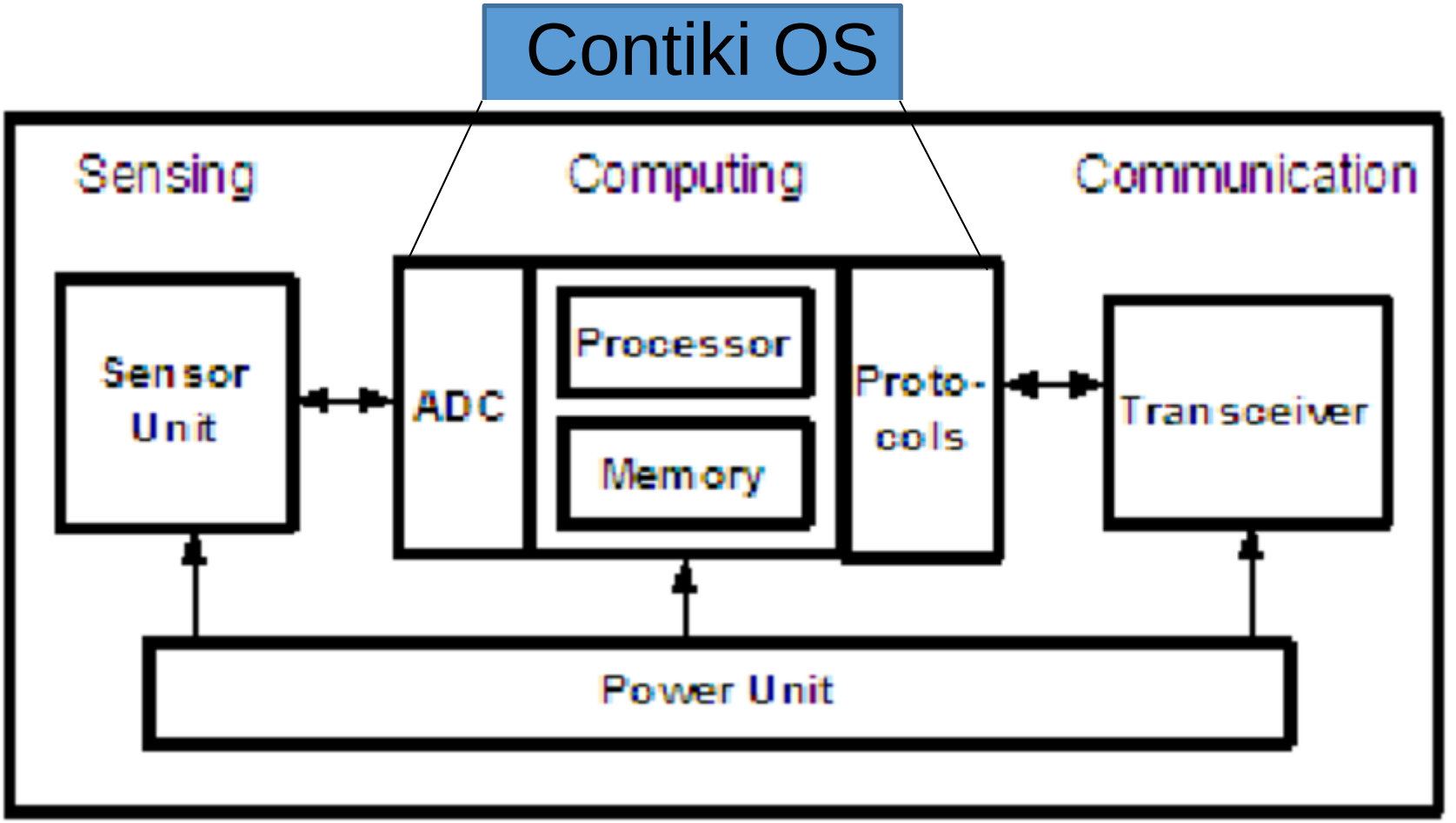
Wireless Communications

Wireless communications solutions



http://eu.mouser.com/

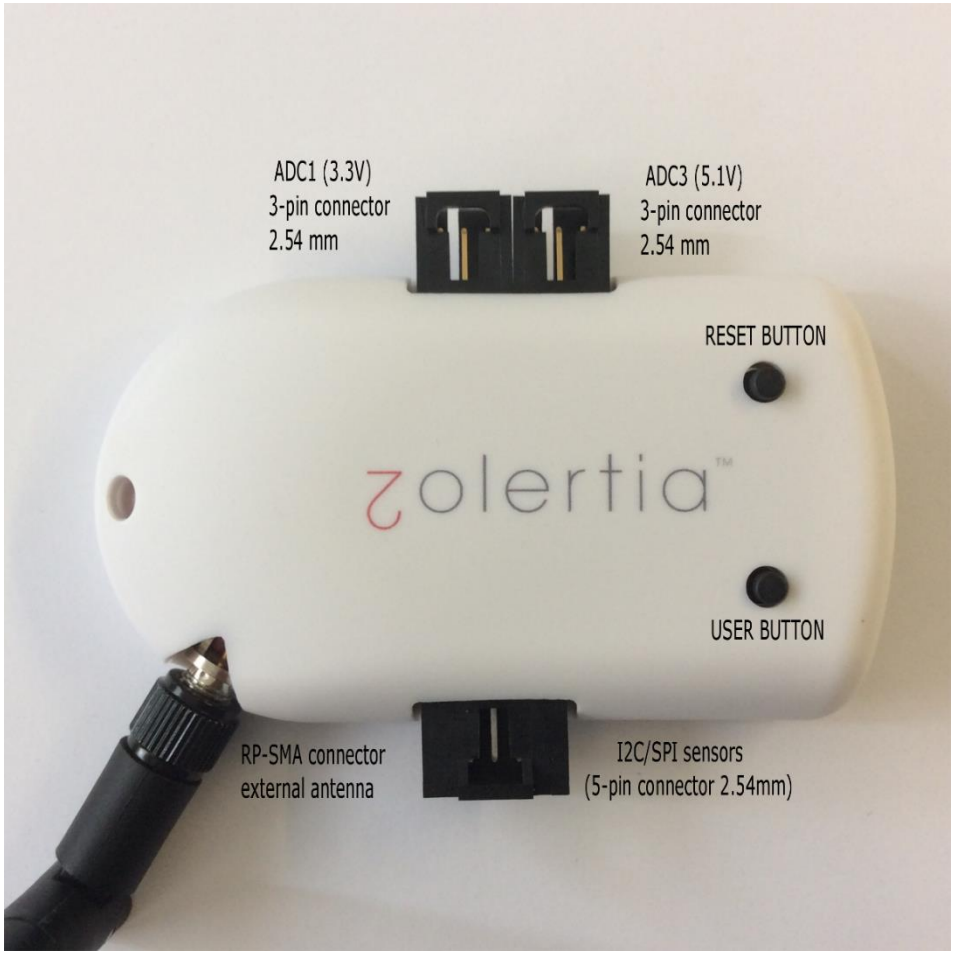
Hardware Architecture of Wireless Sensor Networks



Hardware Architecture of Wireless Sensor Networks

Platform offered by Zolertia

- Zolertia **RE-Mote hardware**



Software configuration

- Vmware Player
- Virtual Box
  - VM Ubuntu
- Linux Native
  - Ubuntu 14.04, 16.04
  - Debian, etc