



Introduction to the Internet of Things

Overview & Standardization



T. Bejaoui



**Overview of
the Ecosystem**

Standardization



Scope

IoT's?

Spectrum Ranges

Spectrum Availability

Going forward



Internet of Things – IoTs?



IoT? (Some Industry Definitions)

- *A network connecting (either wired or wireless) devices, or ‘things’, that is characterized by autonomous provisioning, management, and monitoring. The IoT is innately analytical and integrated **(IDC)***
- *IoT is the next evolution of the Internet, connecting the unconnected people, processes, data, and things in your business today **(Cisco)***
- *IoT devices as those capable of two-way data transmission (excluding passive sensors and RFID tags). It includes connections using multiple communication methods such as cellular, short range and others. **(GSMA)***
- *Sensors & actuators connected by networks to computing systems. These systems can monitor or manage the health and actions of connected objects and machines. Connected sensors can also monitor the natural world, people, and animal” **(McKinsey)***



IoT? (IEEE)

“An IoT system is a network of networks where, typically, a massive number of objects, things, sensors or devices are connected through communications and information infrastructure to provide value-added services via intelligent data processing and management for different applications (e.g. smart cities, smart health, smart grid, smart home, smart transportation, and smart shopping).”

-- IEEE Internet of Things Journal



IoT?

➤ **Resolution ITU-R 66** (*recognizing “c”*)

IoT is a concept encompassing various platforms, applications, and technologies implemented under a number of radio communication services

➤ **ITU-T Recommendation [Y.2060 renamed as Y.4000]**

A global infrastructure for the information society, enabling advanced services by interconnecting (physical & virtual) things based on existing and evolving interoperable information and communication technologies



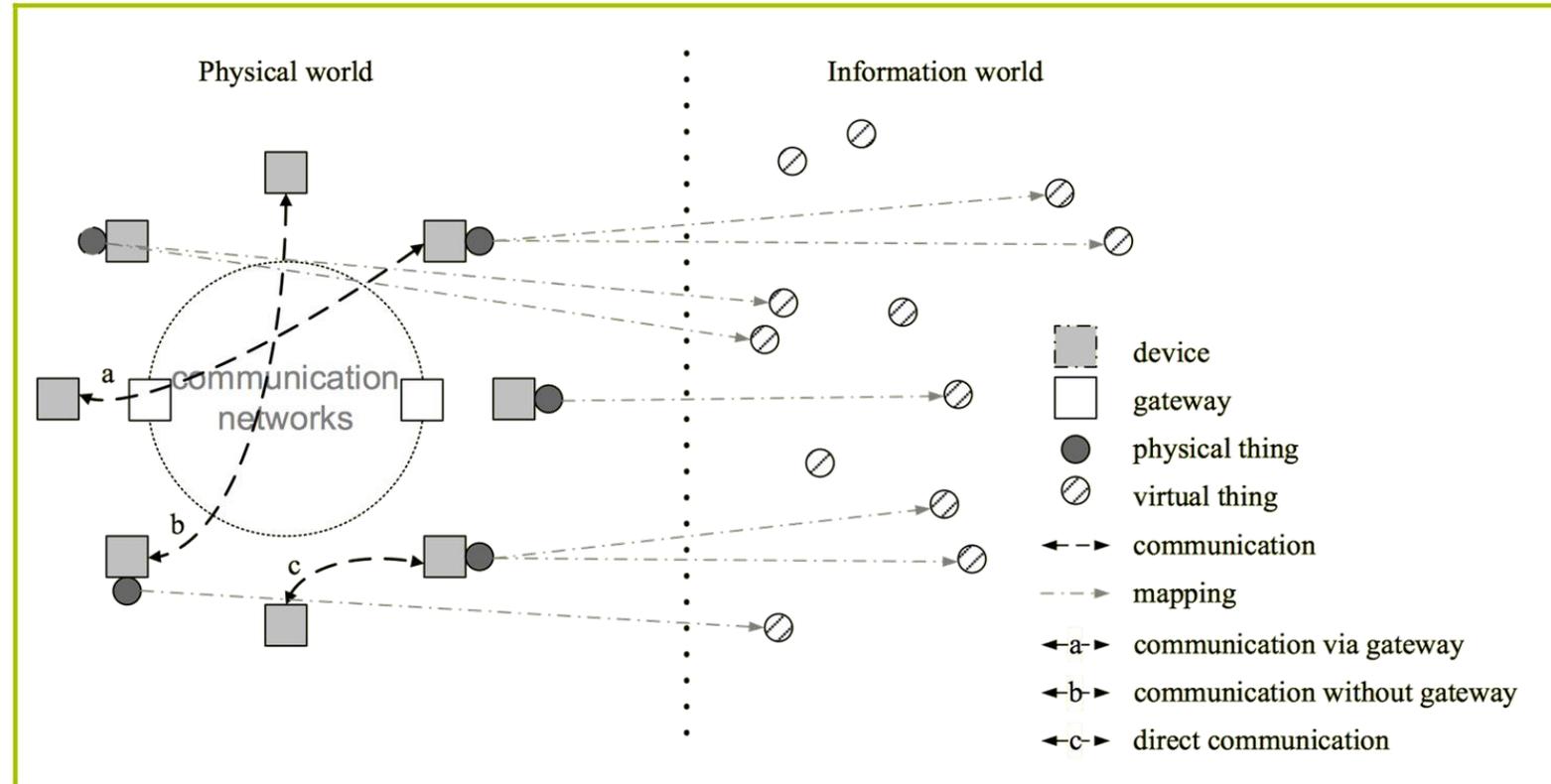
Internet of Things - ITU Definition

➤ Physical things

- Exist in the physical world and are capable of being sensed, actuated and connected.
- Examples: industrial robots, goods and electrical equipment.

➤ Virtual things

- Exist in the information world and are capable of being stored, processed and accessed.
- Examples: Multimedia content, application software.



Source: Recommendation ITU-T Y.2060



Why IoT?

- **Open platforms**
 - Designed to make building and deploying applications easier, faster, secure and more accessible for everyone.

- **Allows**
 - To create the low-power, wide-area sensor and/or actuator network (WASN) systems for Machine Type Communications (MTC), Smart cities and Ubiquitous Sensor Networks (USN) applications.

- **Contributes**
 - To socio economic development such as in Agriculture, health sector and many more.

- **Efficient Management**
 - Manage utilities efficiently such as smart power, water grids, and transport management



Characteristics (IoT v/s Cellular)

➤ **IoT communications are or should be:**

- Low cost,
- Low power,
- Long battery duration,
- High number of connections,
- Different bitrate requirement,
- Long range,
- Low processing capacity,
- Low storage capacity,
- Small size devices,
- Simple network architecture and protocols



IoT?

➤ **Wireless Technologies**

➤ **Diversity of IoT application requirements:**

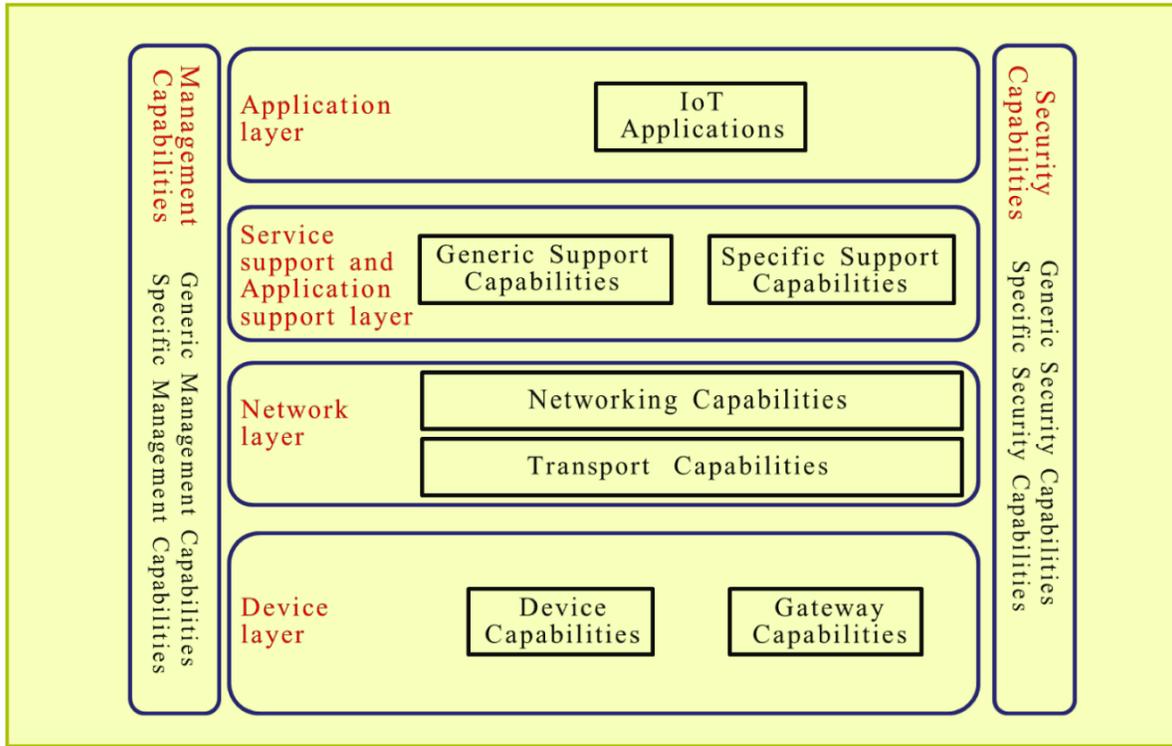
- Varying bandwidth requirements (how much information is sent)
- Long-range vs short-range
- Long battery life
- Various QoS requirements

IoT and cloud technologies are the two unstoppable forces promoting digital capabilities

Spectrum needs to be made available in a range of frequency bands to cater for various cases

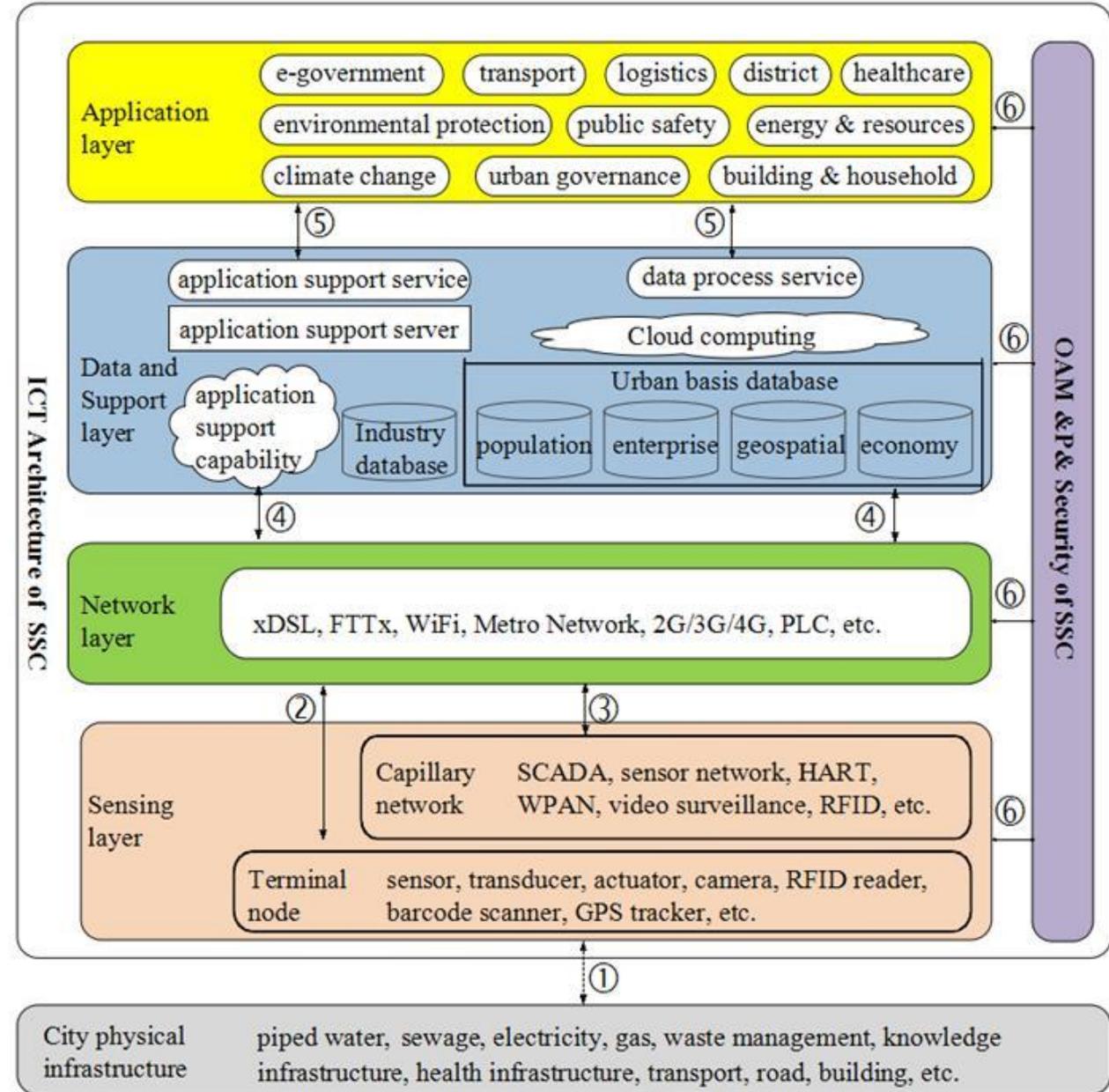


IoT reference model



Source: Recommendation ITU-T Y.2060

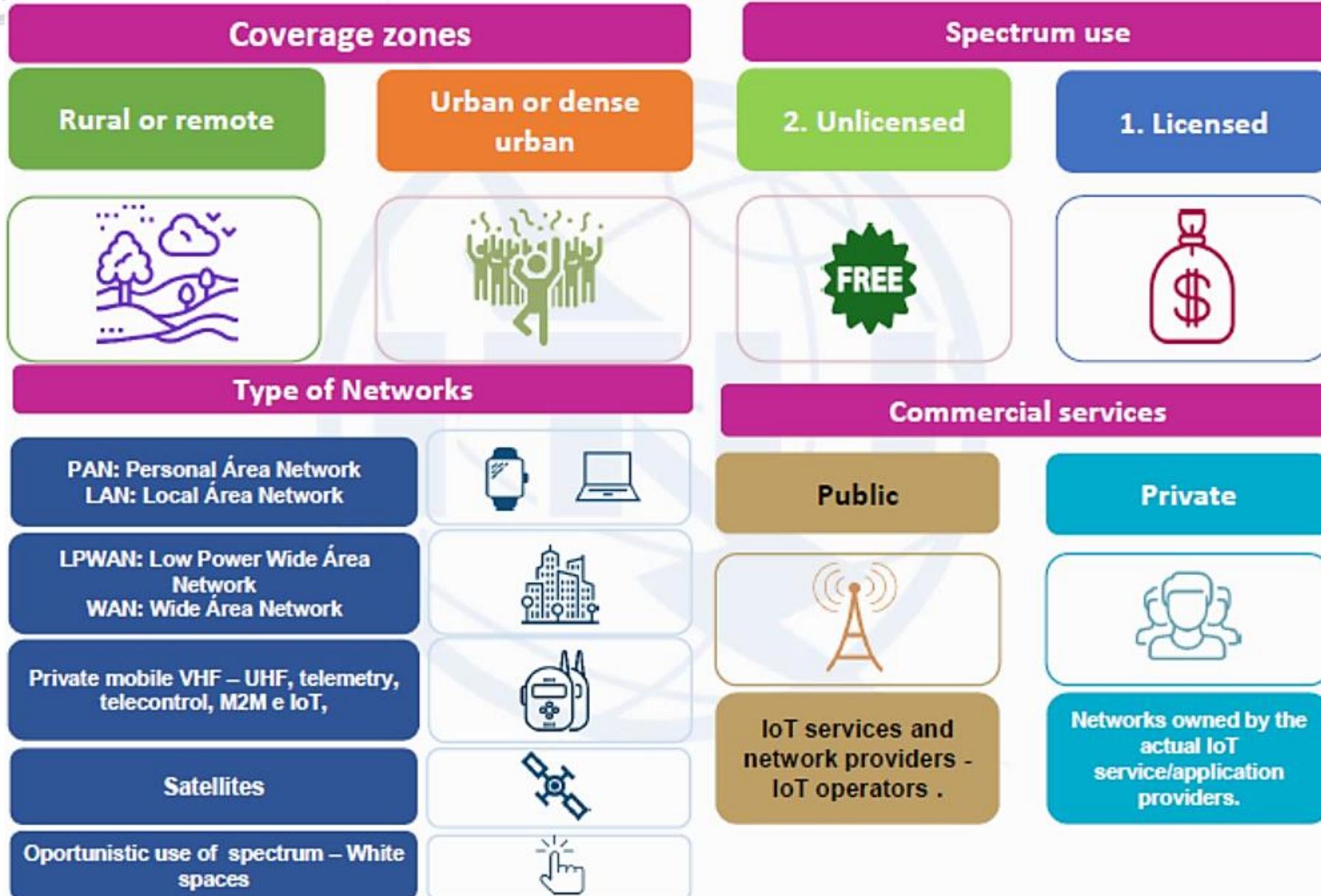
In IoT solutions supporting FC part of the application processing is executed directly at IoT objects and only when needed. More complex and resource-consuming tasks are transferred to higher level units (FC units) or directly to the cloud.



A multi-tier SSC (smart sustainable city) ICT architecture from communication view
 Source: ITU-T Focus Group on Smart Sustainable Cities: Overview of smart sustainable cities infrastructure



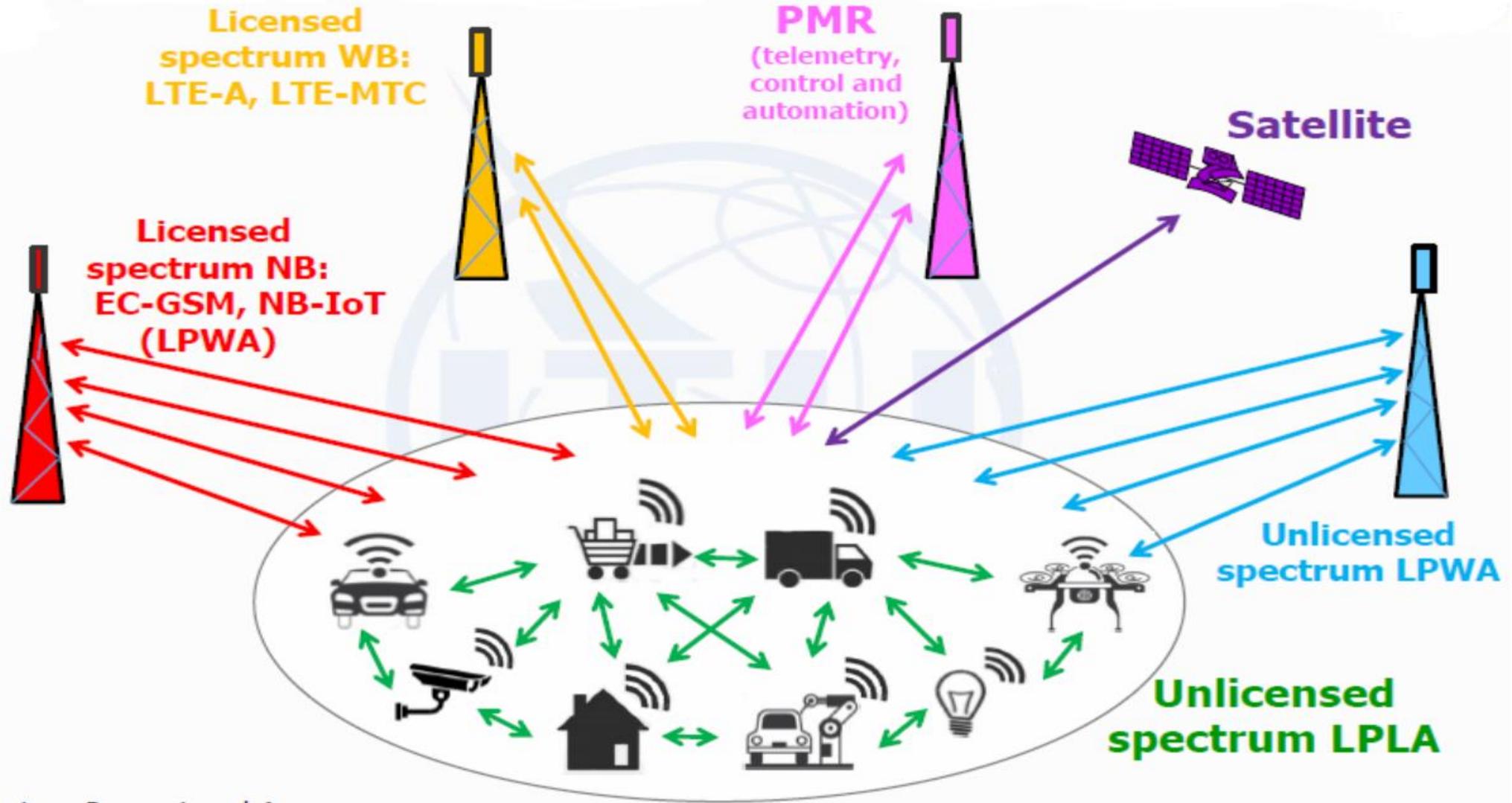
IoT Usage Cases



Source: ITU Workshop on Spectrum Management for Internet of Things Deployment, 22 November 2016, Geneva



IoT Connectivity Options



LPLA: Low Power Local Area
LPWA: Low Power Wide Area

Source: ITU Workshop on Spectrum Management for Internet of Things Deployment, 22 November 2016, Geneva



The Three-Layer IoT Architecture

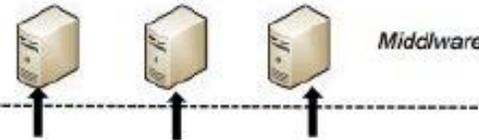
Smartphone applications

E-health applications

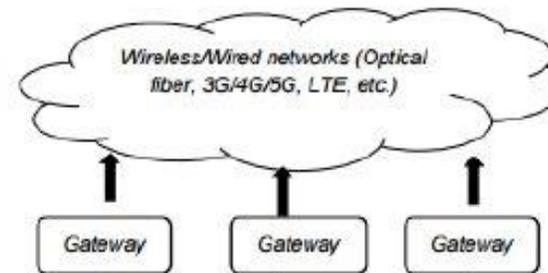
Power management applications



Application Layer



Network Layer

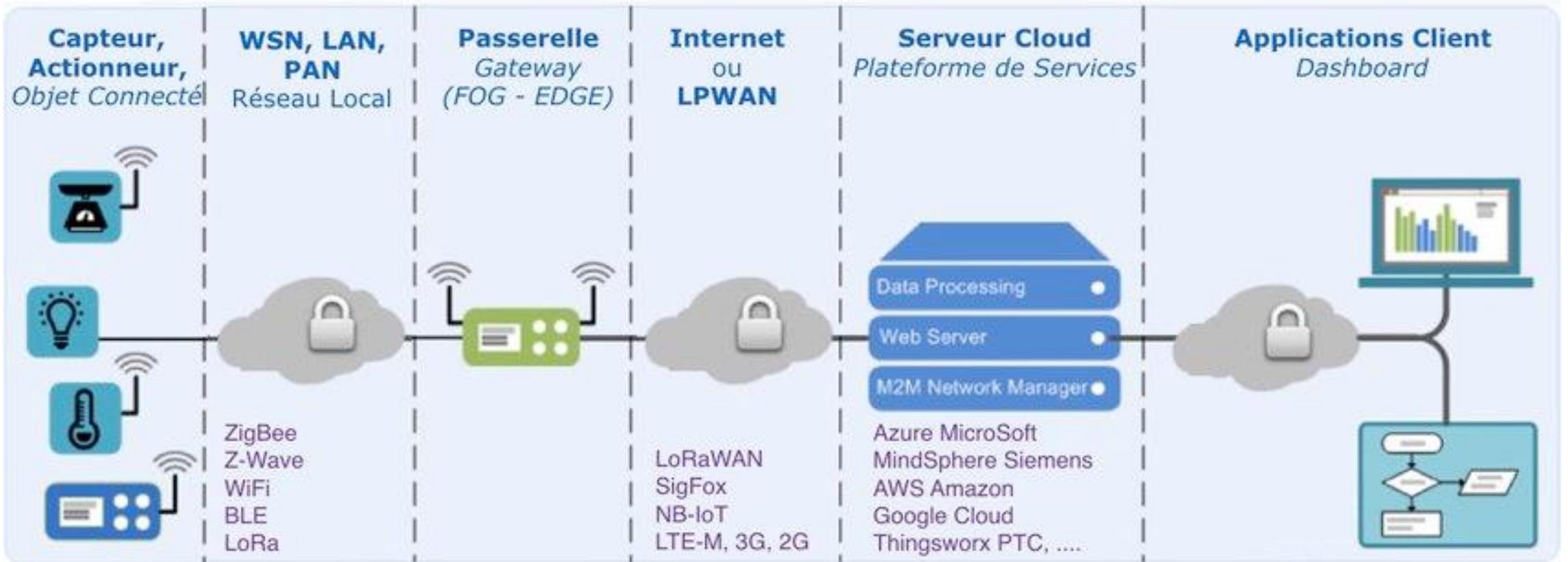


Perception Layer



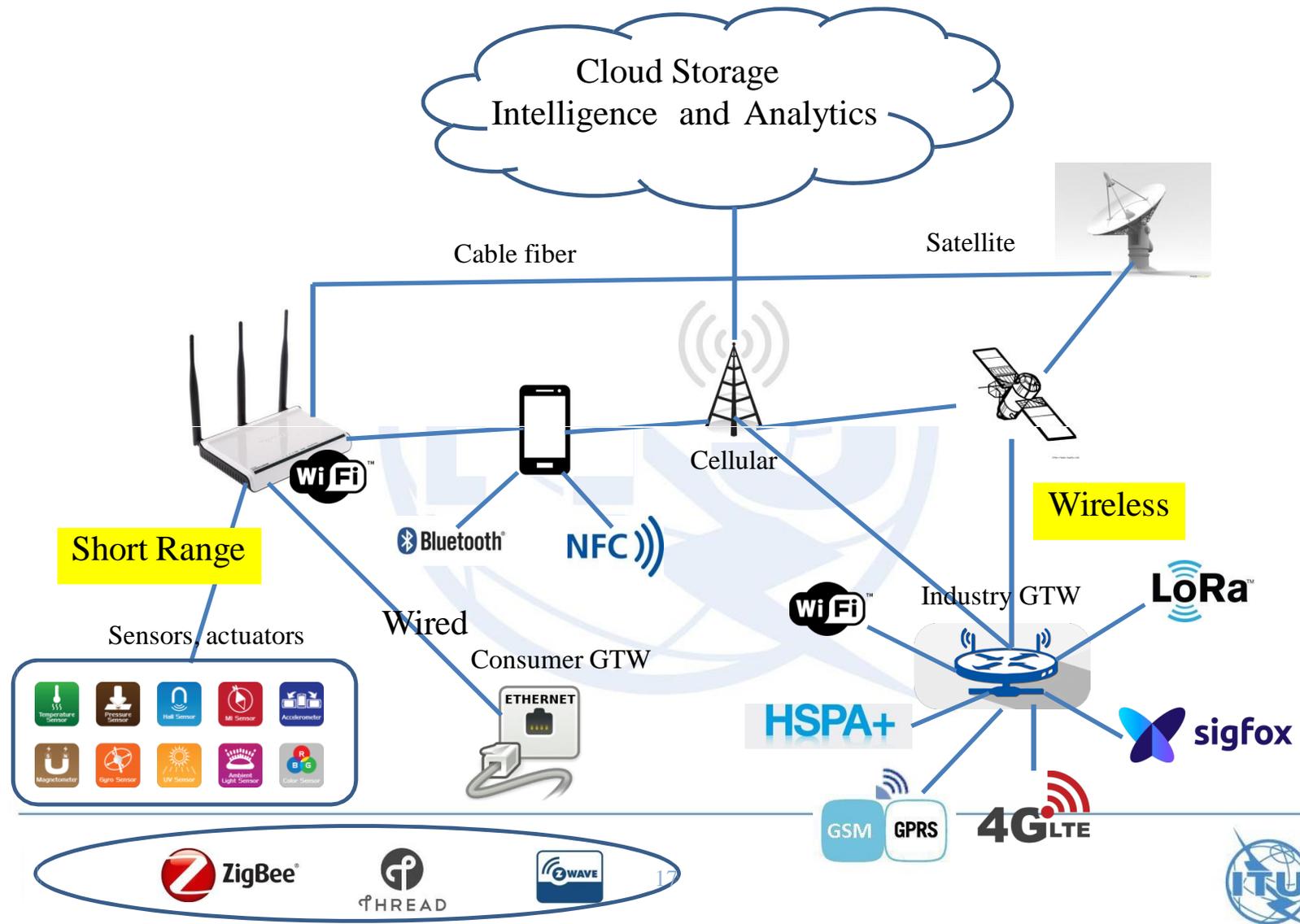


Modèle d'architecture IoT à 6 niveaux





IoT: General Architecture?

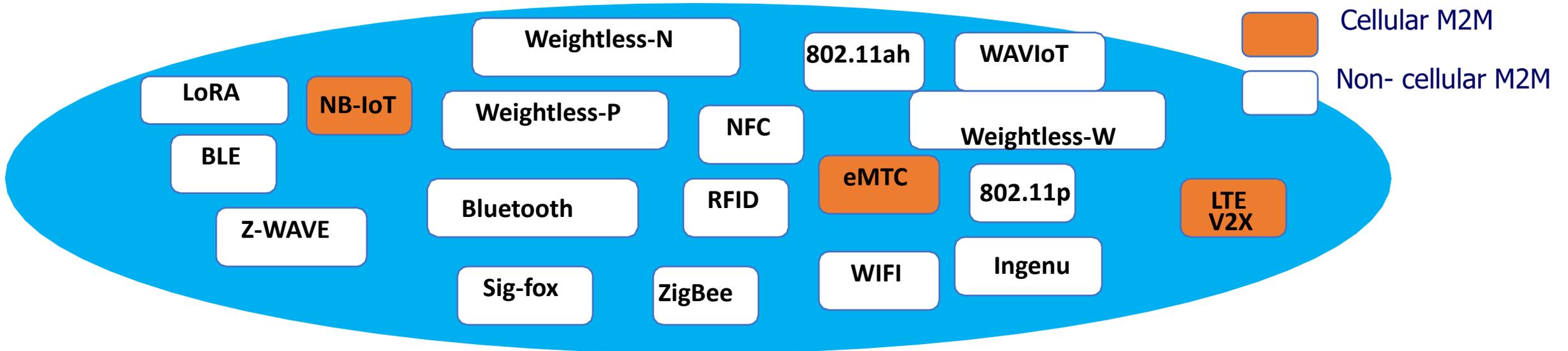




IoT Technical Solutions

Study in ITU under **WRC-19 agenda item 9.1, issue 9.1.8** (Machine Type Communication - MTC)

Studies on the technical and operational aspects of radio networks and systems, as well as spectrum needed, including possible harmonized use of spectrum to support the implementation of narrowband and broadband machine-type communication infrastructures





Spectrum Needs of IoT

- **What are the spectrum needs of IoT?**
 - Determined by each application's throughput requirements, but also latency
 - *For a given spectral efficiency (b/s/Hz), the lower the latency requirements the larger the bandwidth needed to send a given amount of data*
 - While many IoT applications might not need high speed connections and/or have very stringent latency requirements, some do (e.g. remote surgery)

- **In what frequency bands?**
 - Determined by each IoT application's range and coverage requirements, but also bandwidth needs of the applications
 - Range and coverage requirements also depend on deployment scenarios
 - *Point-to-point, mesh, broadcast, multi-cast, etc.*



Spectrum Licensing for IoT

Spectrum for MTC/IoT applications

Unlicensed spectrum

- *Low cost /no license fees*
Regulatory limits (EIRP restrictions)
- **Non-guaranteed QoS**

- All devices can have access to spectrum, subject to compliance with technical conditions as specified in regulations
- Short range and delay-tolerant applications are typical use cases

Licensed spectrum

- *Better Interference management*
- *Network Security*
- *Reliability*

Mobile operator Network

Reuse cellular infrastructure and device eco-system for M2M/ IoT apps

- IMT spectrum can be used for supporting NB-IoT, eMTC and LTE-V2N (eNB-to-vehicle)
- MBB spectrum can also be used for M2M/IoT

Dedicated Network

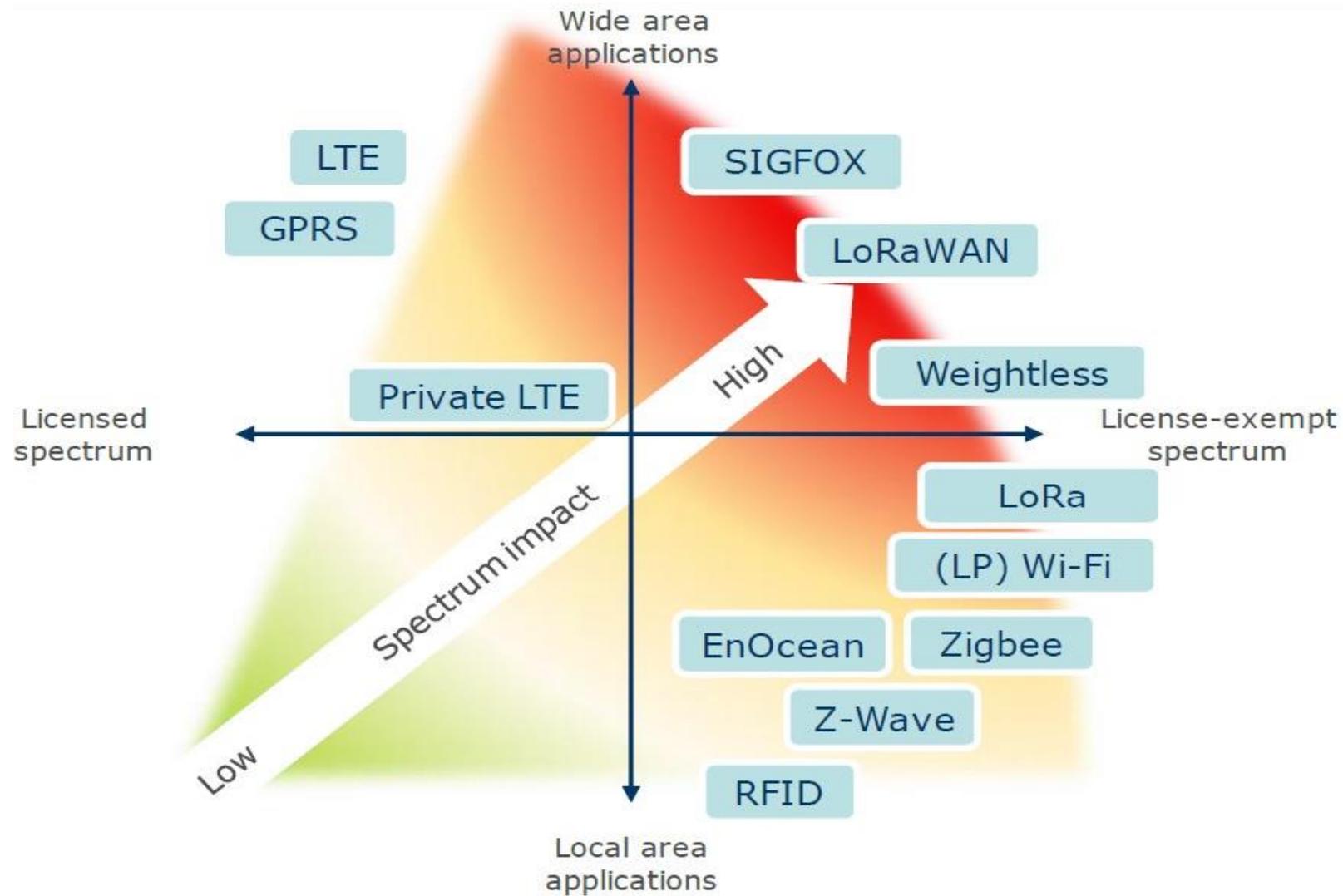
Private network customized for specific M2M/IoT apps.

Example: In **China** New bands for M2M:

- 5 905 -5 925 MHz for LTE-V2X trials
- 2 x 2.3 MHz in 800MHz can be used for NB-IoT

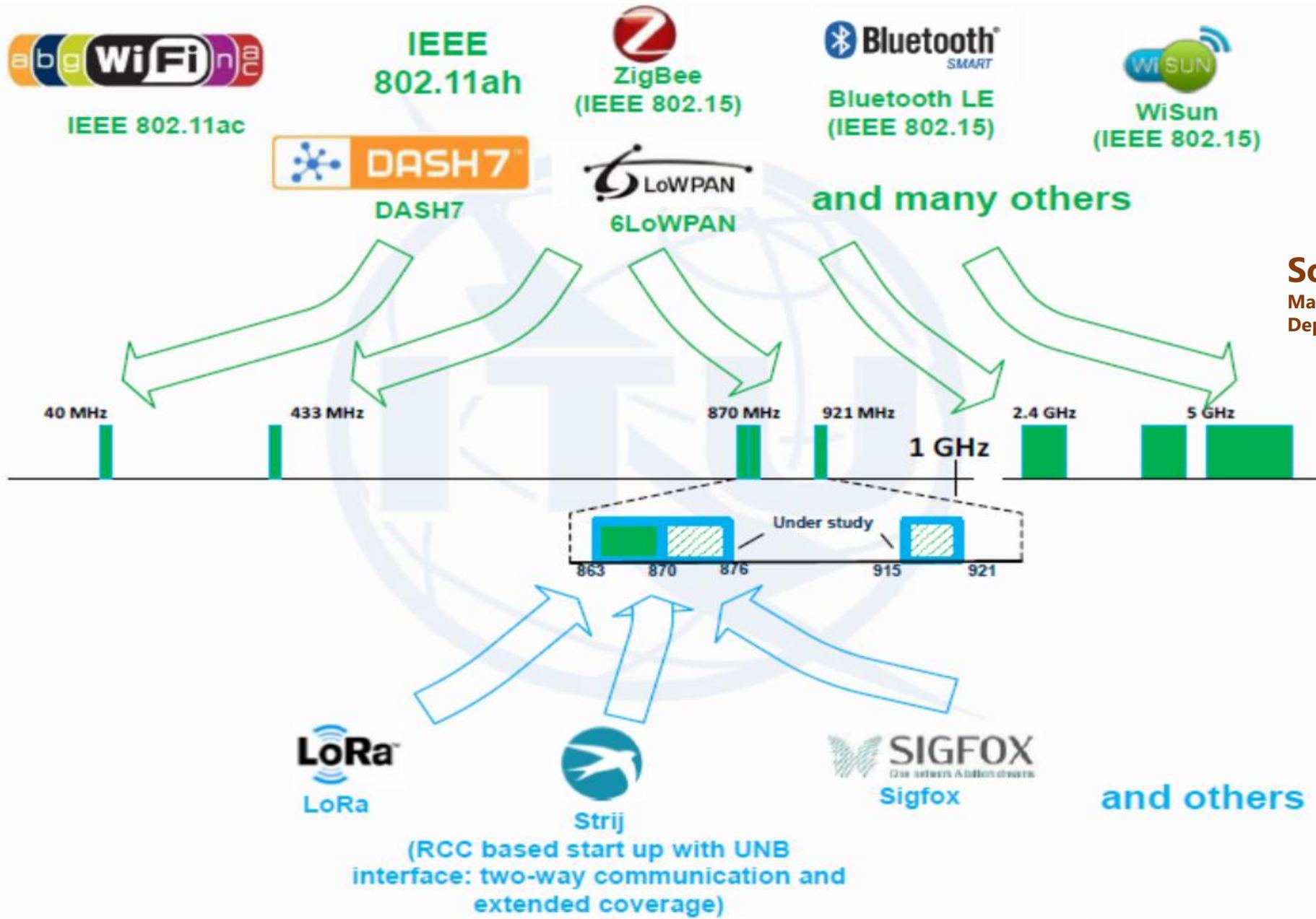


IoT technologies summary





Spectrum usage for IoT - SRDs

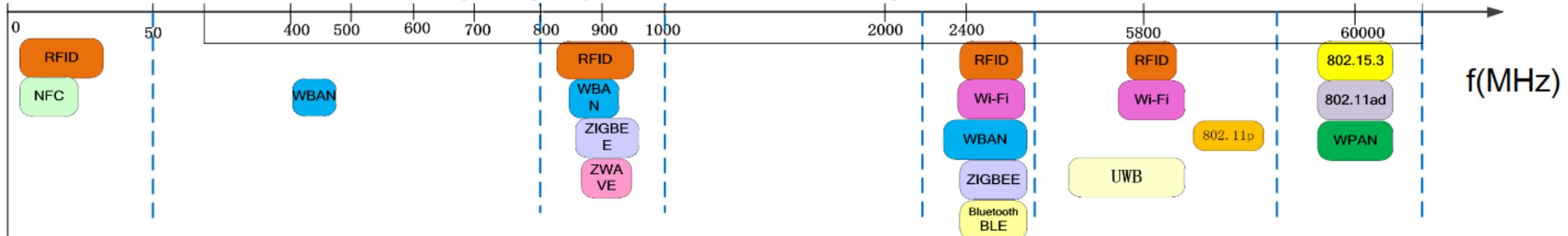


Source: ITU Workshop on Spectrum Management for Internet of Things Deployment, 22 November 2016, Geneva



Spectrum usage for IoT - SRDs

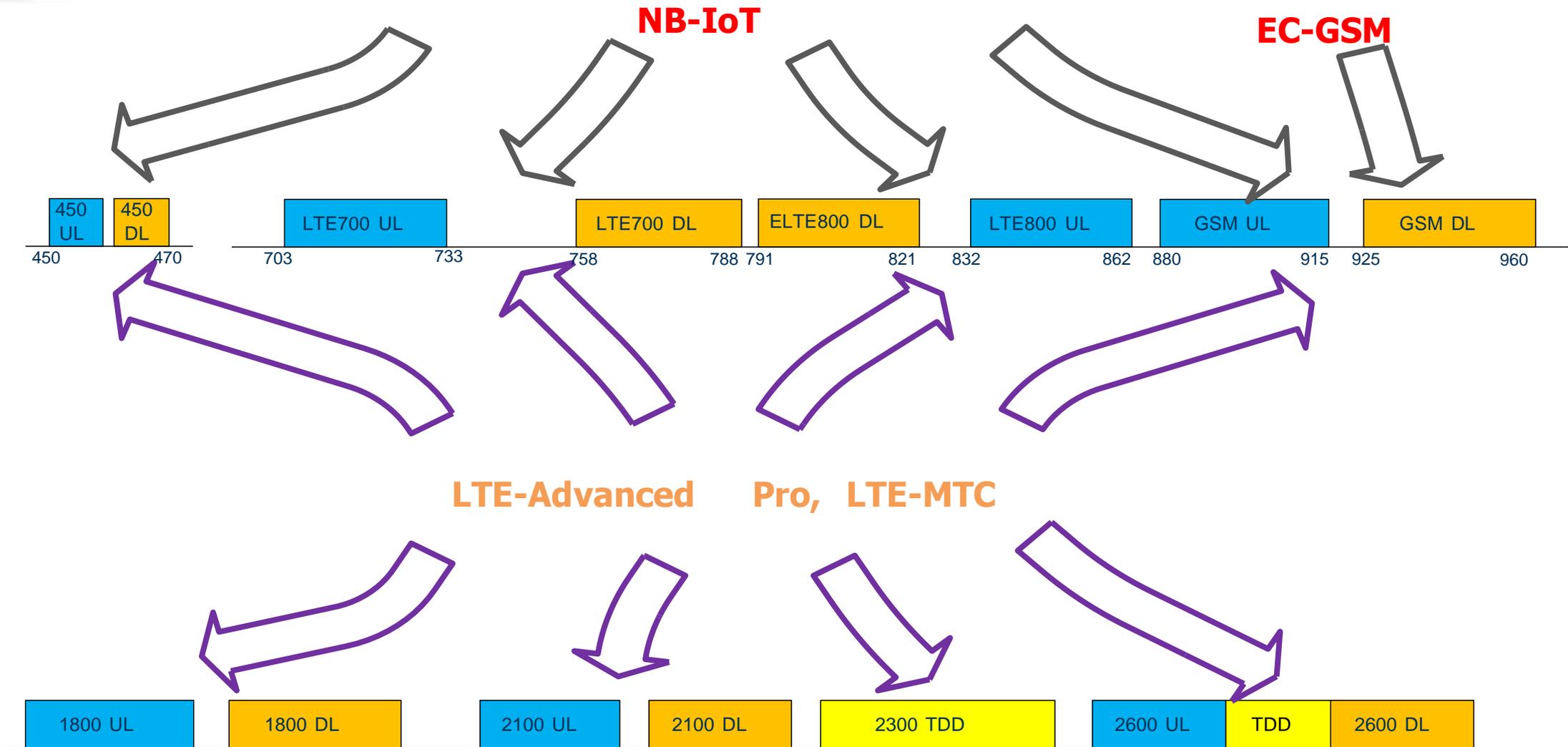
Some widely deployed SRD technologies in Sub 6GHz bands



Source: ITU Workshop on Spectrum Management for Internet of Things Deployment, 22 November 2016, Geneva



IoT deployments in Licensed Spectrum





Spectrum Needs of IoT

M2M

Radiocommunication Technologies

Technology	Spectrum band
NB-IoT	MBB bands
eMTC	MBB bands
Sigfox	868MHz
LTE-V2X	MBB bands (Uu)
	5.8,5.9GHz (PC5)
Bluetooth	2.4GHz
ZigBee	868/2450MHz
RFID	13.56/27.12/433/ 860MHz ...
NFC	13.56MHz
Z-WAVE	868 MHz
Ingenu	2.4GHz

Frequency range

- Sub-1 GHz band are most suitable for efficient provision of wide area coverage;

Authorization

- Sharing spectrum with unlicensed authorization to achieve low cost and low power requirements
- Licensed (exclusive) spectrum is more suitable for wide area coverage and/or higher reliability requirements for delay sensitive applications



IMT- Identified Spectrum



Definition

➤ Res. ITU-R 56-1: *Naming for International Mobile Telecommunications*

Since ITU is the internationally recognized entity that has sole responsibility to define and to recommend the standards and frequency arrangements for IMT systems, with the collaboration of other organizations such as standard development organizations, universities, industry organizations and with partnership projects, forums, consortia and research collaborations, therefore the RA-15 debated especially on naming of IMT systems.

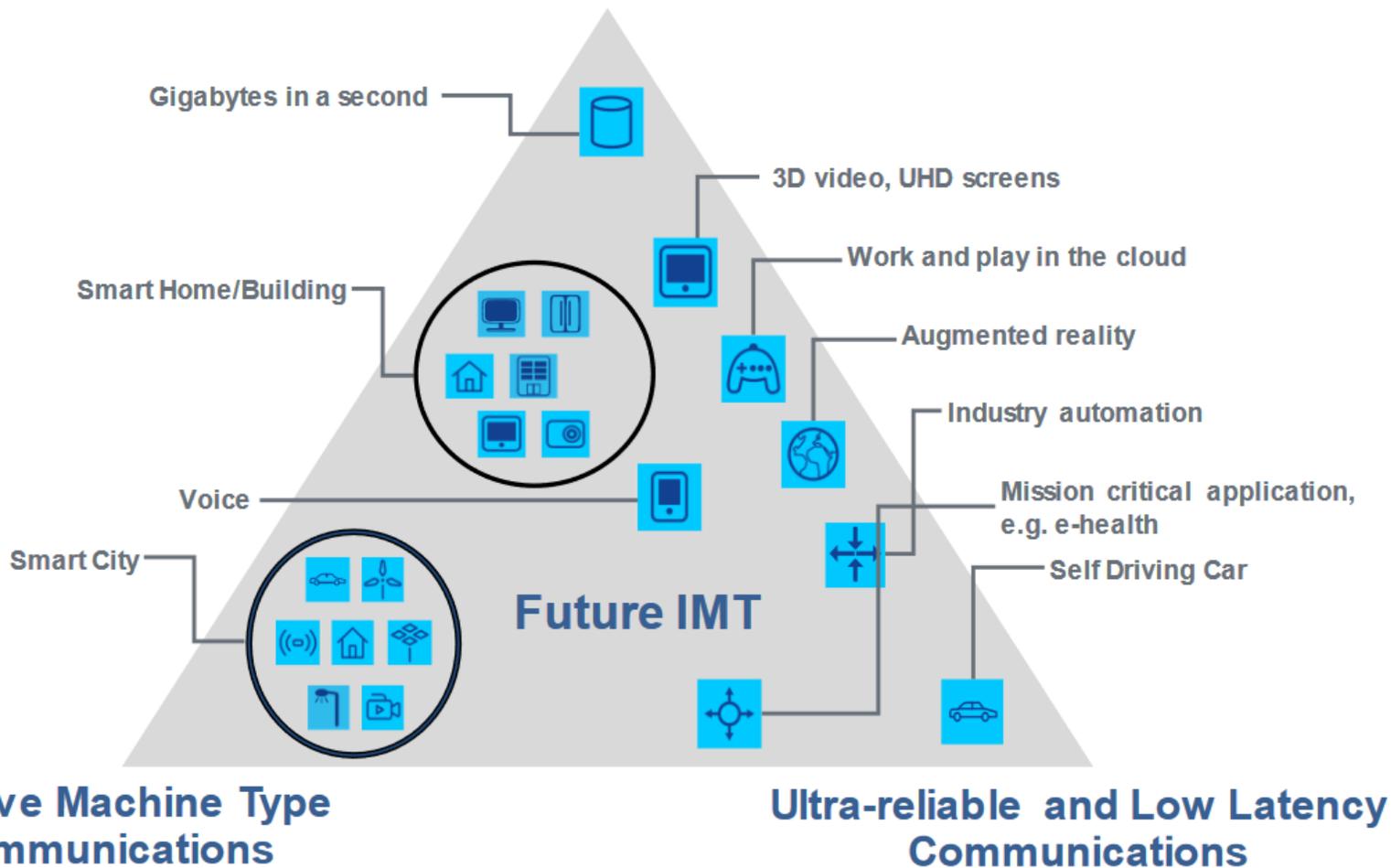
- *the existing term **IMT-2000** continues to be relevant and should continue to be utilized;*
- *the existing term **IMT-Advanced** continues to be relevant and should continue to be utilized;*
- *However for systems, system components, and related aspects that include new radio interface(s) which support the new capabilities of systems beyond IMT-2000 and IMT-Advanced, the term “**IMT-2020**” be applied*
- *In addition it was resolved that the term “IMT” would be considered the root name that encompasses all of IMT-2000, IMT-Advanced and IMT-2020 collectively.*





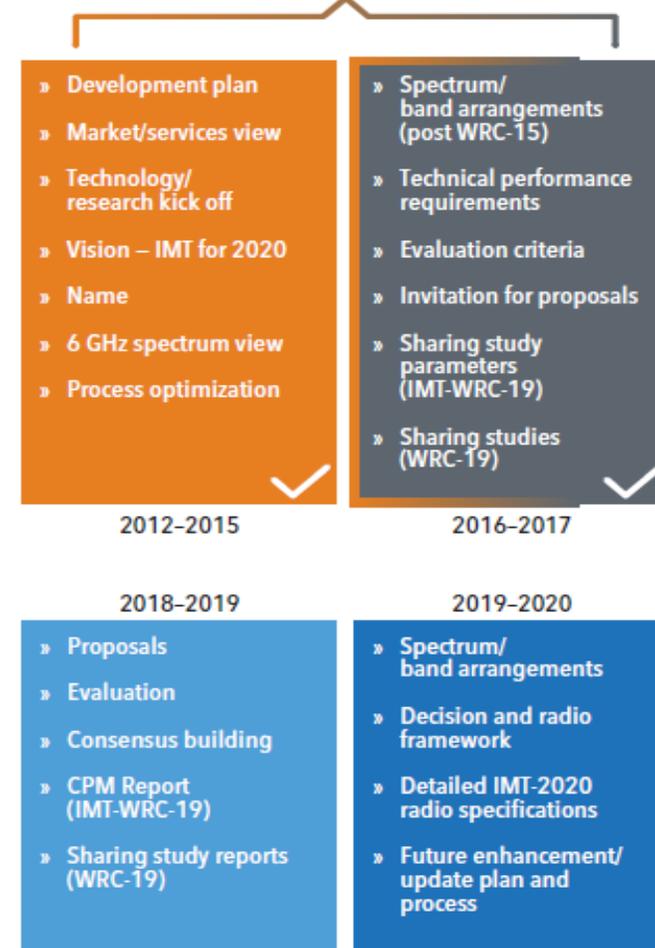
IMT Supports IoT

Enhanced Mobile Broadband



IMT-2020 standardization process

Setting the stage for the future: vision, spectrum, and technology views

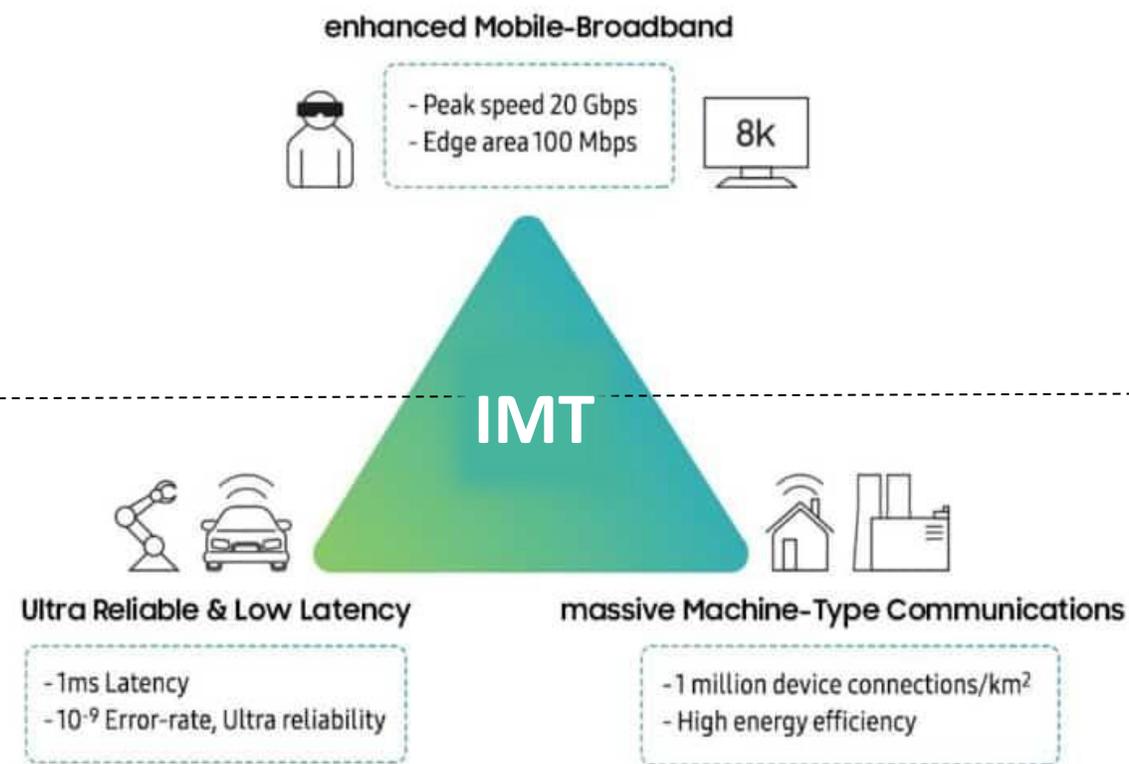


Defining the technology²⁹

Source: Forging paths to IMT-2020 (5G), Stephen M. Blust, Chairman, ITU Radiocommunication Sector (ITU-R) Working Party 5D, Sergio Buonomo, Counsellor, ITU-R Study Group 5, ITU News, 02/2017



Understanding IMT applications



Consumer – Fixed wireless

Business

Some 5G use cases and challenges

Latency, Reliability, Throughput, Density, Speed, Flexibility

Autonomous vehicles	1	L.R.T.D.S.F	
Smart traffic management	2	L.R.T.D.S.F	
Emergency networks	3	L.R.T.D.S.F	
Factory automation	4	L.R.T.D.S.F	
High speed rail	5	L.R.T.D.S.F	
Short lived massive outdoor	6	L.R.T.D.S.F	
Internet of Things	7	L.R.T.D.S.F	
Any media anywhere	8	L.R.T.D.S.F	
Remote medical	9	L.R.T.D.S.F	
Smart city/ Grids	10	L.R.T.D.S.F	
Virtual reality	11	L.R.T.D.S.F	
Fixed wireless access	12	L.R.T.D.S.F	

Source: Forging paths to IMT-2020 (5G), Stephen M. Blust, Chairman, ITU Radiocommunication Sector (ITU-R) Working Party 5D, Sergio Buonomo, Counsellor, ITU-R Study Group 5, ITU News, 02/2017



Recalling WRC-15 outcomes





Outcomes of WRC-15

Mobile Broadband (MBB)

(agenda Item 1.1 and 1.2)





Outcomes of WRC-15

➤ New spectrum Identified

WRC - 15				
Band (MHz)	Bandwidth (MHz)	R1	R2	R3
470 – 608	138		some	
608 – 698	84		some	
1427 – 1452	25	any	any	any
1452 – 1492	40	some	any	any
1492 – 1518	26	any	any	any
3300 – 3400	100	some	some	some
3600 – 3700	100		some	
4800 – 4990	190		some	some
	New BW 709			



Outcomes of WRC-15

Spectrum for IMT

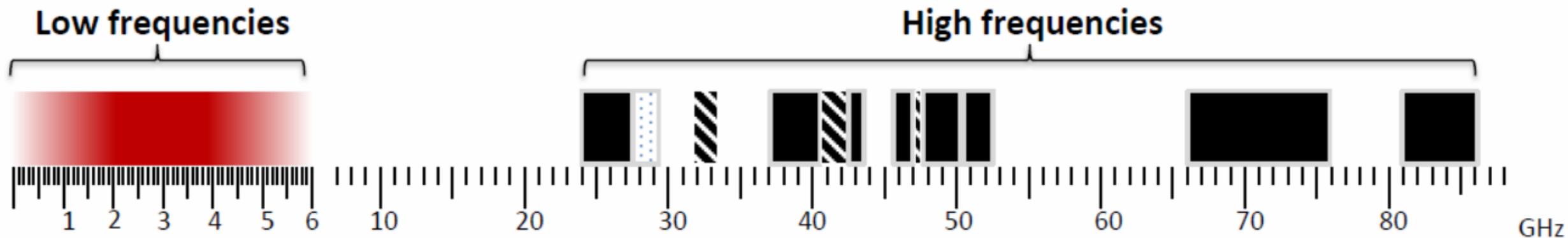
Band (MHz)	Footnotes identifying the band for IMT			Bandwidth
	Region 1 or parts thereof	Region 2 or parts thereof	Region 3 or parts thereof	
450-470		5.286AA		20
470-698	-	<u>5.295, 5.308A</u>	5.296A	228
694/698-960	<u>5.317A</u>	<u>5.317A</u>	5.313A, 5.317A	262
1 427-1 518	<u>5.341A, 5.346</u>	<u>5.341B</u>	5.341C, 5.346A	91
1 710-2 025		5.384A, 5.388		315
2 110-2 200		5.388		90
2 300-2 400		5.384A		100
2 500-2 690		5.384A		190
3 300-3 400	<u>5.429B</u>	<u>5.429D</u>	5.429F	100
3 400-3 600	<u>5.430A</u>	<u>5.431B</u>	5.432A, 5.432B, 5.433A	200
3 600-3 700	-	<u>5.434</u>	-	100
4 800-4 990	-	<u>5.441A</u>	5.441B	190
Total Bandwidth	1,886			
<i>(Regional allocations vary and therefore totals can be different for a specific region)</i>				



Going Forward



IMT spectrum requirements and WRC-19



- In scope of WRC-19, already allocated to Mobile Service
- ▨ In scope of WRC-19, require allocation to Mobile Service
- Not in scope of WRC-19, but allocated to Mobile Service
- In scope of previous WRCs



BB applications in MS

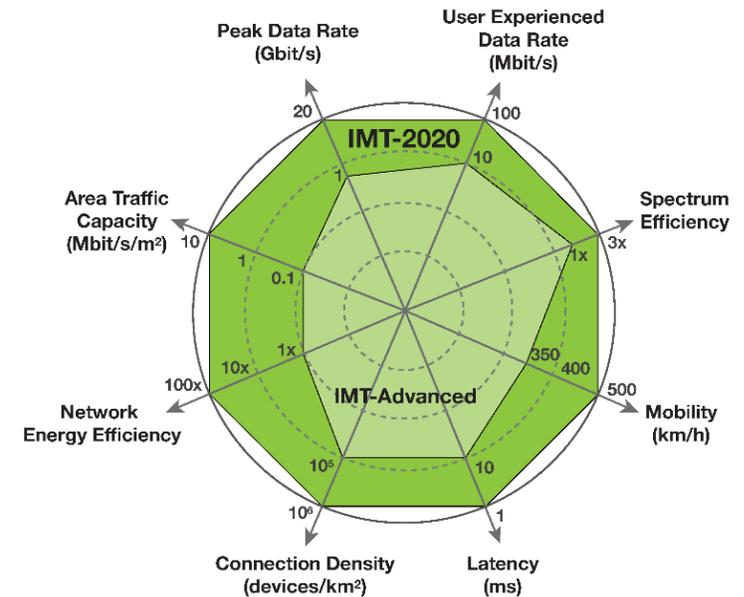
(WRC-19 Agenda item 1.13 and 1.16)

➤ The following bands, which are already allocated to mobile, will be studied with a view to an IMT-2020 identification:

- 24.25 – 27.5 GHz
- 37 – 40.5 GHz
- 42.5 – 43.5 GHz
- 45.5 – 47 GHz
- 47.2 – 50.2 GHz
- 50.4 – 52.6 GHz
- 66 – 76 GHz
- 81 – 86 GHz

➤ The following bands will also be studied, although they do not currently have global mobile allocations: Res. 238 (WRC-15)

- 31.8 – 33.4 GHz
- 40.5 – 42.5 GHz
- 47 - 47.2 GHz





Overlapping Bands in WRC-19 Agenda Items

1.6 – NGSO FSS Res. 159 (WRC-15)	1.13 – IMT Res. 238 (WRC-15)	1.14 – HAPS Res. 160 (WRC-15)	9.1 (9.1.9) – FSS Res. 162 (WRC-15)
	24.25 - 27.5	24.25 - 27.5 (Reg. 2)	
37.5 - 39.5 (s-E*)	37 - 40.5	38 - 39.5 (globally)	
39.5 - 42.5 (s-E*)	40.5 - 42.5		
47.2 - 50.2 (E-s*)	47.2 - 50.2		
50.4 - 51.4 (E-s*)	50.4 - 52.6		51.4 - 52.4 (E-s*)

- E-s: Earth-to-space; s-E: space-to-Earth.
- **All bands in GHz**

Studies to **address mutual compatibility & sharing feasibility** among the **services/applications** for which **allocation/identification is envisaged** under the corresponding Res. relating to the AI in the overlapping bands



Future Spectrum need estimation for IMT

(24.25 GHz - 86 GHz)

Deployment scenarios	Indoor hotspot	Dense urban		Urban macro
		Micro	Macro	
Frequency range	24.25-86 GHz	24.25-43.5 GHz	<6 GHz	<6 GHz

Deployment scenario	Micro	Indoor hotspot
Total spectrum needs for 24.25-86 GHz	14.8-19.7 GHz*	
Spectrum needs for 24.25-43.5 GHz	5.8-7.7 GHz	9-12 GHz
Spectrum needs for 45.5-86 GHz	—**	

* Considering the coexistence between multiple network operators (e.g. the guard band(s) may be required in the case of multiple network operators scenarios), the total spectrum needs are expected to be increased.

** The division in this table regarding frequency ranges and deployment scenarios is just an indicative example on how spectrum needs could be distributed for different spectrum sub-ranges within 24.25-86 GHz and different deployment scenarios. This table should not be understood nor used to exclude any possible IMT-2020 deployment options in the range 45.5-86 GHz.



Some 5G Deployments strategies

Regulator	Low (1 GHz)	Medium (<6GHz)	High (mmWave)
FCC	600MHz auctioned – T-Mobile using for 5G	3.5GHz band to be shared under CBRS	28GHz available; 64GHz for unlicensed
Ofcom	700MHz spectrum available by 2020	3.5GHz cleared; 3.7GHz under consultation	26GHz to be repositioned for mobile data
MISP (KOR)	700MHz and 1.3GHz to be freed up in 2018	3.5GHz to be allocated	28GHz – 1GHz available; 38GHz to be allocated
MIIT (CHN)	800MHz for NB-IoT	3.3GHz, <u>3.5GHz</u> , 4.4GHz, 4.9GHz being considered	26GHz and 40GHz reallocation underway
MIC (JPN)	700MHz assigned for LTE	3.4GHz & 4.4-4.9GHz under review, 3.5GHz done	27.5-29.5GHz to be reassigned for mobile BB
	For coverage – mobile BB and massive IoT	3.5GHz has wide support – for eMBB and mission-critical apps	26 – 28GHz has wide support – high density and high capacity

3.5GHz IMT vs FSS will be evaluated and coordinated with neighbouring countries



IoT and regulatory issues

- Licensed Vs Non Licensed spectrum
- Area of license
- Numbering
- Standardization
- Infrastructure sharing
- Access to data and open IOT platforms
- Data analytics
- Mobile data roaming
- Consumer protection
- Quality of Service
- USO
- Taxation

One world, one global SIM: How ITU-allocated 'global IMSI ranges' support IoT and M2M connectivity

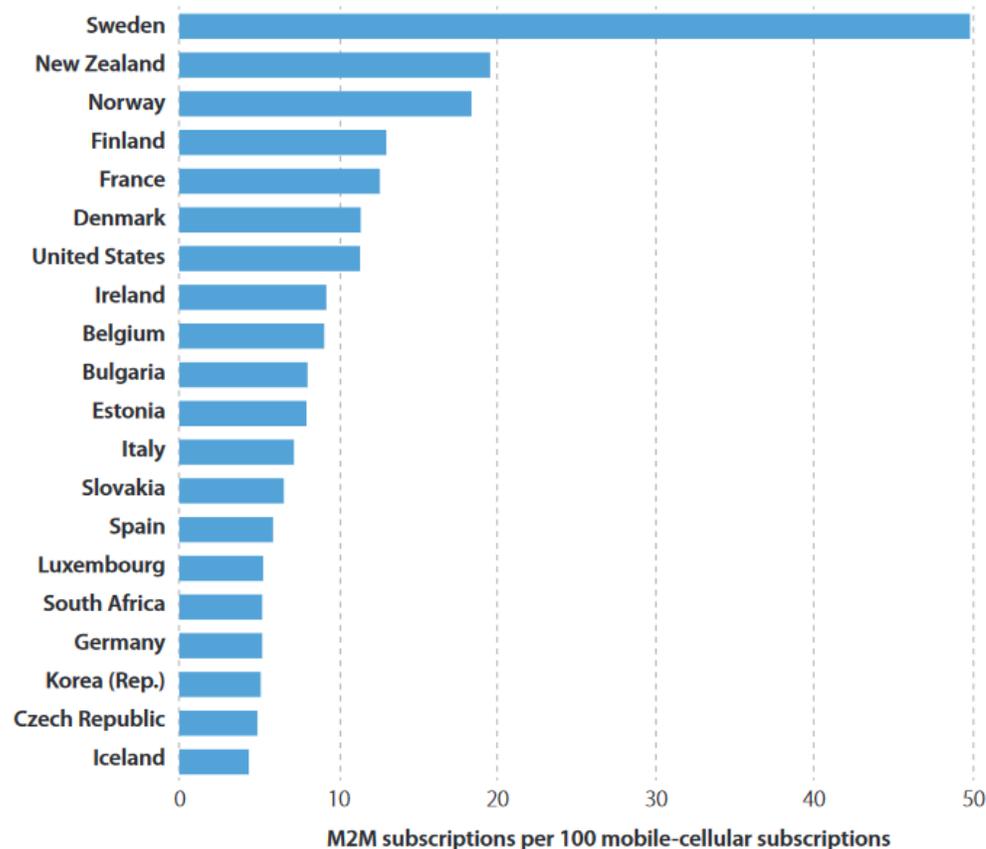
<https://news.itu.int/one-world-one-global-sim/>

! Global International Mobile Subscriber Identity (IMSI) ranges are signified by the shared Mobile Country Code '**901**', a code without ties to any particular country.



Conclusion

- IoTs are in early stage of deployment
 - Some operators already provided services
- Spectrum requirements vary with usage cases
 - Could be Unlicensed or Licensed.
- IMT supports numerous applications including support for IMT services



Based on available data, there were 22 mobile-cellular subscriptions for each machine-to-machine (M2M) subscription worldwide at the beginning of 2015.

The countries with the highest M2M penetration rates are highly industrialized, advanced economies, including the Northern European countries of Sweden, Norway, Finland and Denmark

Source: ITU. Note: Data refer to early 2015.



**Overview of
the Ecosystem**

Standardization



Scope

IoT Design and Planning requirements

Short Range IoT Solutions

Long Range IoT Solutions

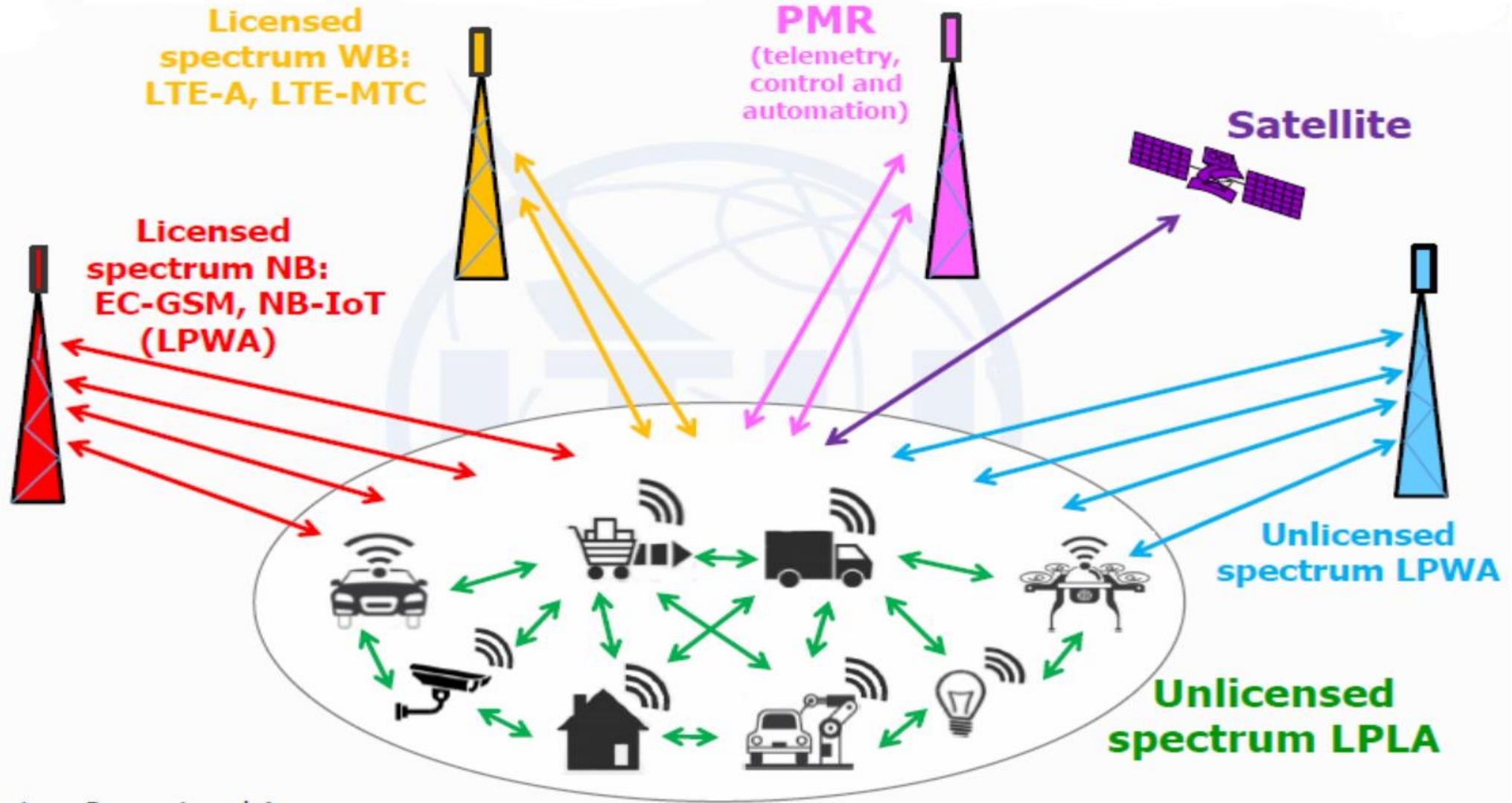
IMT2020 (5G Supporting) IoT

Examples from of current IoT Market

- Regulation
- Pricing
- Future analysis and issues



IoT Connectivity Options



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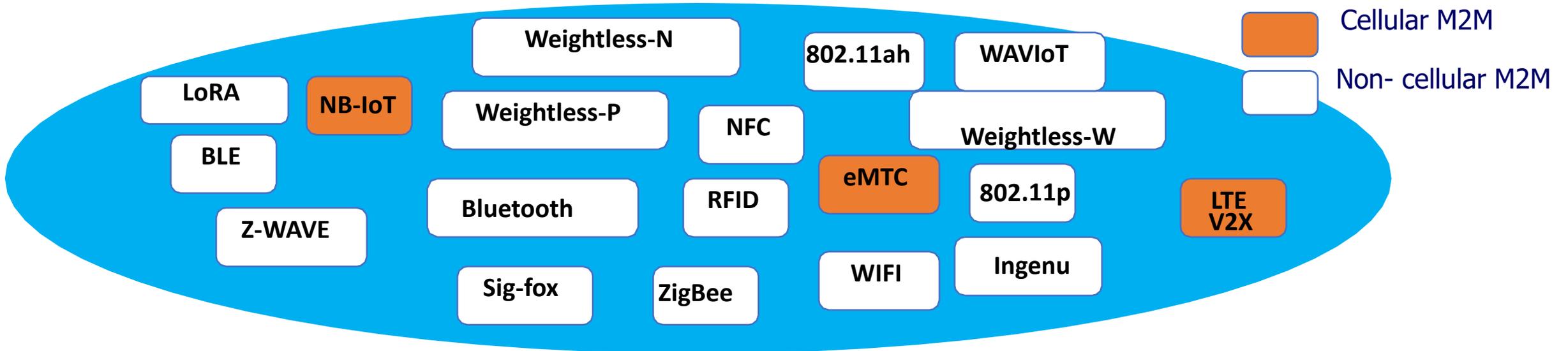
Source: ITU Workshop on Spectrum Management for Internet of Things Deployment, 22 November 2016, Geneva



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Studies on the technical and operational aspects of radio networks and systems, as well as spectrum needed, including possible harmonized use of spectrum to support the implementation of narrowband and broadband machine-type communication infrastructures





IoT: 4 layer Model

Integrated Applications



Information Processing



Network Infrastructure



Sensing and Identification





IoT: Reference Model

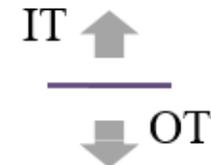
Levels

- 7 Collaboration & Processes
(Involving People & Business Proces)
- 6 Application
(Reporting, Analytics, Control)
- 5 Data Abstraction
(Aggregation & Access)
- 4 Data Accumulation
(Storage)
- 3 Edge Computing
(Data Element Analysis & Transform)
- 2 Connectivity
(Communication & Processing Units)
- 1 Physical Devices & Controlle
(The "Things" in IoT)



The model is based on "Integrated Security & Management"

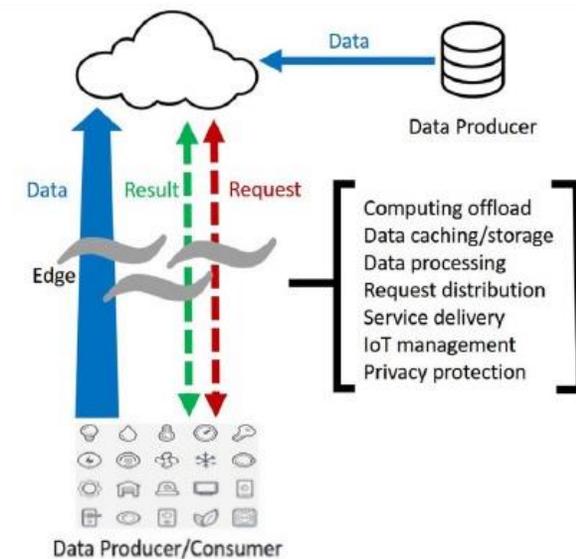
Data at Rest



Data in Motion

The model is based on "Information Flow"

In IoT solutions supporting Fog Com putting (FC) part of the application processing is executed directly at IoT objects and only when needed. More complex and resource-consuming tasks are transferred to higher level units (FC units) or directly to the cloud.





IoT design requirements

IoT Network	Impact on IoT Systems Design
Scale	Tens of thousand sensors in a given site; or millions distributed geographically More pressure on application architectures, network load, traffic types, security, non-standard usage pattern
Heterogeneous end-points	Vast array of sensors, actuators, and smart devices – IP or non-IP Diverse data rate exchange, form factor, computing and communication capabilities, legacy protocols
Low Capex and Opex requirement	May be deployed before activation, maybe or cannot-be accessed once deployed <ul style="list-style-type: none">• Low numbers of gateways Link budget: e.g: UL: 155 dB (or better), DL: Link budget: 153 dB (or better)• Devices deliver services with little or no human control, difficult to correct mistakes, device management is key
Criticality of services	Human life critical (Healthcare), Critical infrastructure (Smart Grid) Stringent latency (10ms for SG) and reliability requirements, may challenge/exceed network capabilities of today
Intrusiveness	Things with explicit intent to better manage end-users (eHealth, Smart Grid) Issues of Privacy become major obstacles
Geography	Movement across borders Issues of numbering for unique identification

Source: ITU CoE training on BB networks planning, Bangkok, Sep 2017



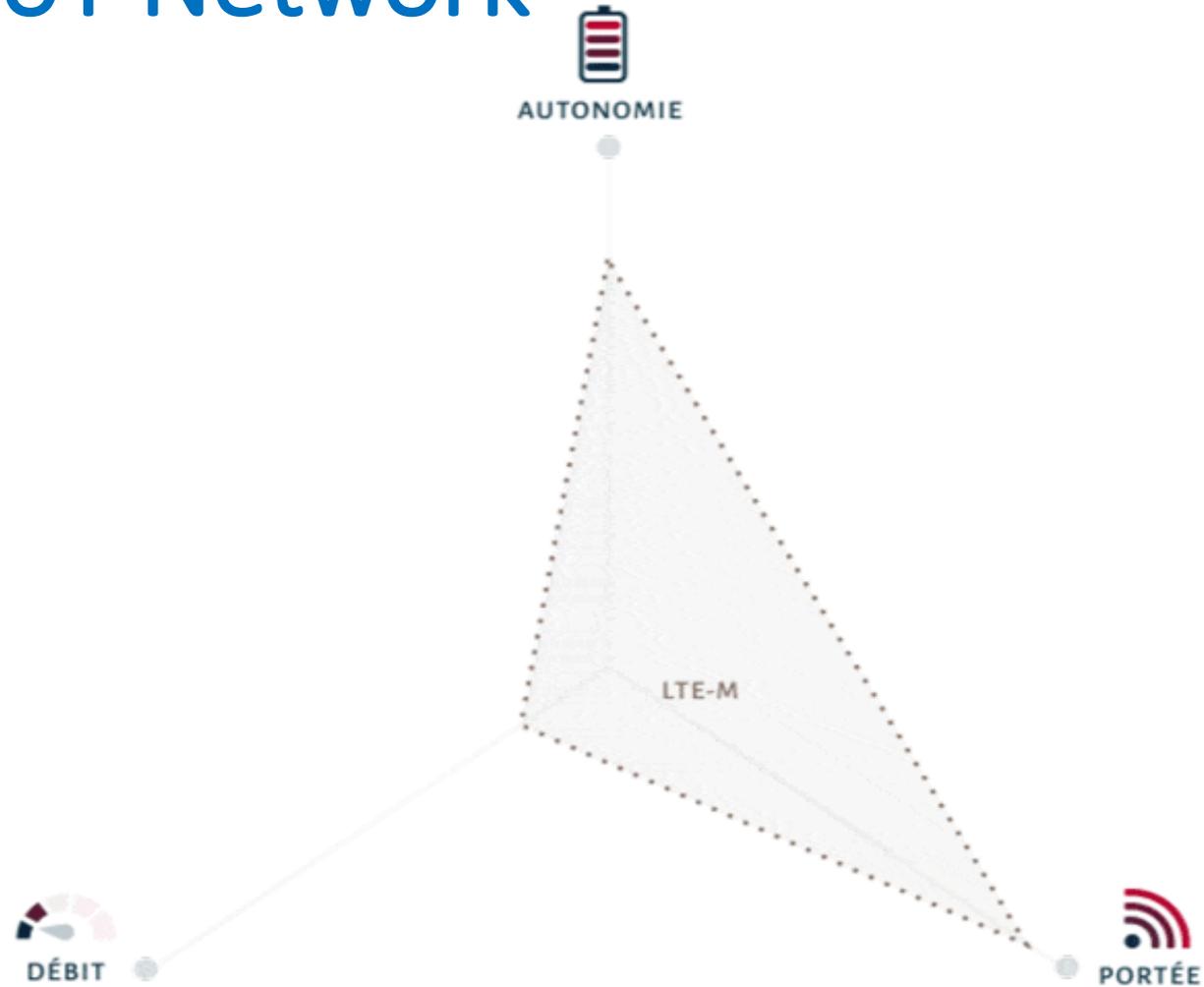
IoT network connectivity requirements

IoT Network	Impact on IoT Systems Design
Resource-constrained endpoints	Severely resource constrained (memory, compute) Cost motivation: compute/memory several orders of magnitude lower, limited remote SW update capability, light protocols, security
Low Power	Some end-point types may be mostly 'sleeping' and awakened when required <ul style="list-style-type: none">• Sensors cannot be easily connected to a power source• Reduced interaction time between devices and applications (some regulations state duty cycle of no more than 1%)• Idle mode most of the time (energy consumption of around 100 μW). Connected mode just for transmission (mA)• < 100 MHz clock frequency• Embedded memory of few Mb
Embedded	Smart civil infrastructure, building, devices inside human beings Sensors deployed in secure or hostile operating conditions, difficult to change without impacting system, Security
Longevity	Deployed for life typically, have to build-in device redundancy Very different lifetime expectancy, rate of equipment change in IoT business domains much lower than ICT Industry
High Sensitivity on reception	Gateways and end-devices with a high sensitivity around -150 dBm/-125 dBm with Bluetooth lower than -95 dBm in cellular

Source: ITU CoE training on BB networks planning, Bangkok, Sep 2017



Choose your IoT Network



CHOISIR VOTRE RÉSEAU IOT

un compromis entre débit, portée et consommation d'énergie



IoT Technical Solutions

➤ Fixed & Short Range

- RFID
- Bluetooth
- Zigbee
- WiFi
-

➤ Long Range technologies

- Non 3GPP Standards (LPWAN)
- 3GPP Standards



Short Range IoT Solutions

- RFID
- Bluetooth
- ZigBee
- WiFi



RFID: Radio Frequency Identification



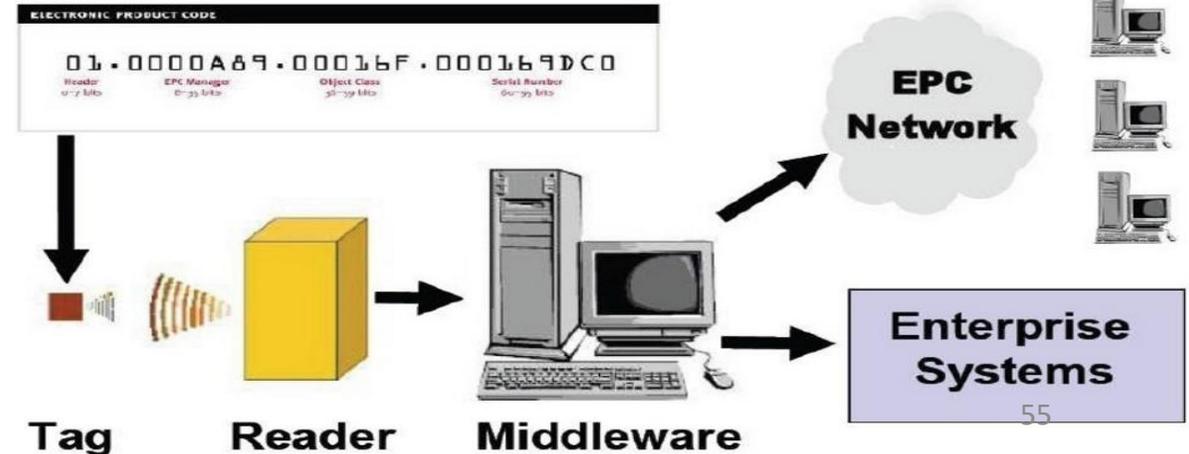
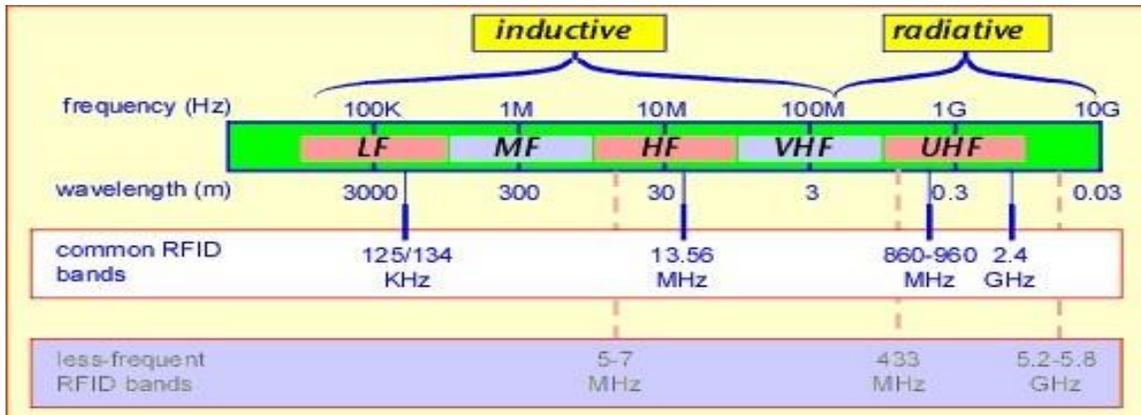
➤ Appeared first in 1945

➤ Features:

- Identify objects, record metadata or control individual target
- More complex devices (e.g., readers, interrogators, **beacons**) usually connected to a host computer or network
- Radio frequencies from 100 kHz to 10 GHz

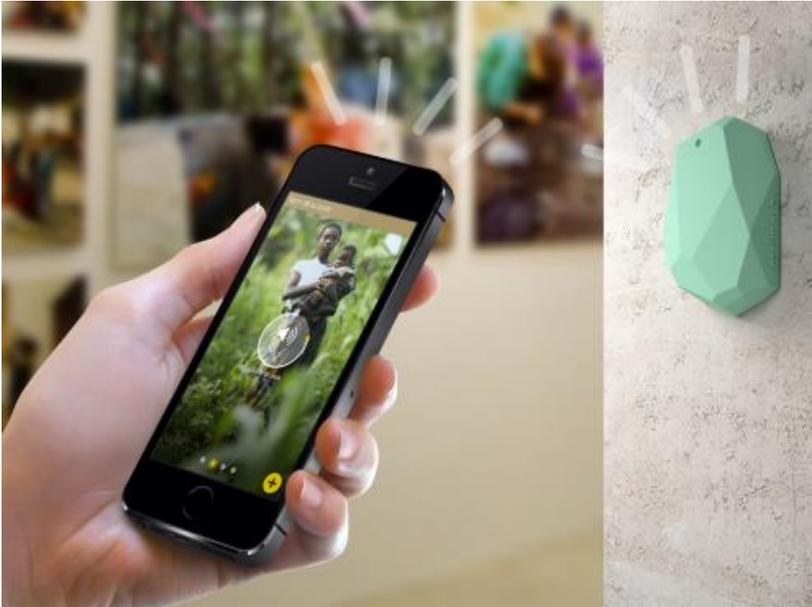
➤ Operations:

- Reading Device called Reader (connected to backend network and communicates with tags using RF)
- One or more tags (embedded antenna connected to chip based and attached to object)





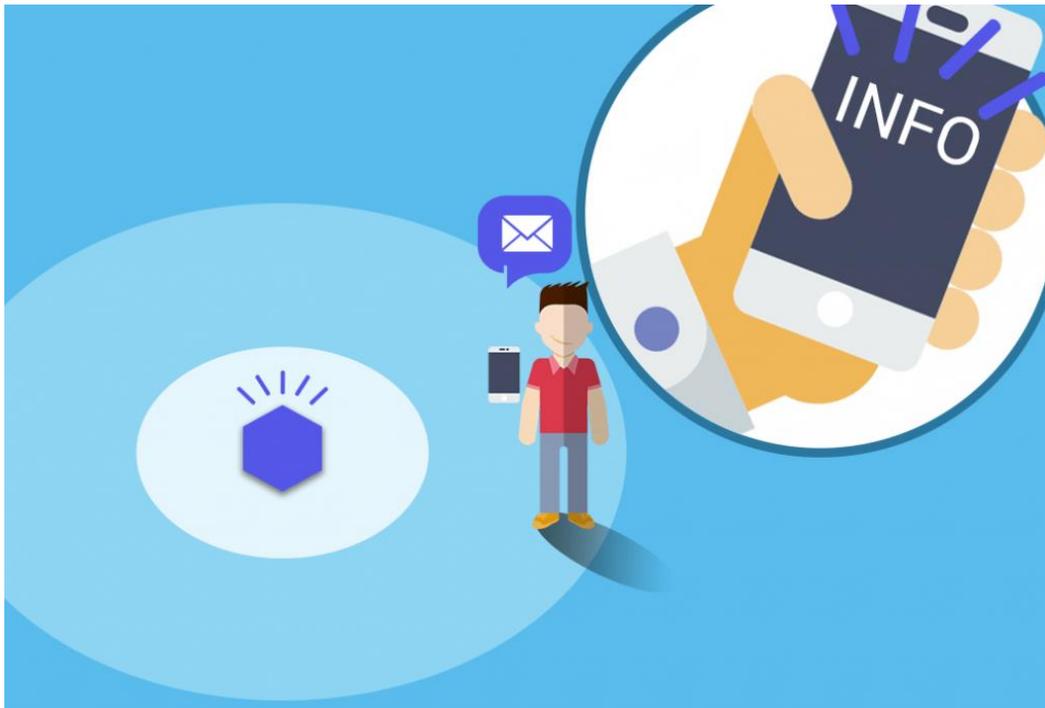
Les Beacons



- **QU'EST-CE QUE LES BEACONS ?**
- Un **beacon** est une petite balise **bluetooth** low energy (BLE) qui émet une **onde radio** à faible portée (environ 100 mètres) et qui ne consomme que très peu d'énergie. Cette onde est captée par les **smartphones** qui peuvent alors recevoir différents contenus (push notifications, messages, médias ,etc...)
- Le premier beacon a été créé en 2013 par Apple, c'est le **iBeacon**.
- Un deuxième type apparaît en 2014 : c'est le **Altbeacon** créé par Radius Network.
- Enfin, en 2015, Google sort ses beacons **Eddystones**
- Chaque beacon est composé d'une batterie, d'un micro contrôleur, d'une antenne, d'un module radio et de capteurs et comporte un UUID (Universal Unique Identifier) permettant de l'identifier.



Les Beacons Immobiliers



LES BEACONS IMMOBILES

- Les beacons peuvent être utilisés de façon immobile, c'est-à-dire qu'ils sont placés dans des endroits et définissent des zones.
- Lorsqu'un utilisateur entre dans la zone, des informations peuvent être poussées sur son smartphone.
- Ce type d'utilisation est fréquent dans :
 - le tourisme
 - le commerce connecté (couponing, pushmarketing...)
 - l'industrie
 - les visites culturelles (musées, expositions...)



Les Beacons Mobiles

LES BEACONS MOBILES

- Les beacons peuvent être utilisées de façon mobile, c'est-à-dire qu'ils bougent avec l'utilisateur.
- Lorsque l'utilisateur s'éloigne trop du smartphone, le signal est rompu et une alerte peut être envoyée sur le téléphone.





Bluetooth – IEEE 802.15.1



➤ Features:

- Low Power wireless technology
- Short range radio frequency at 2.4 GHz ISM Band
- Wireless alternative to wires
- Creating PANs (Personal area networks)
- Support Data Rate of 1 Mb/s (data traffic, video traffic)
- Uses Frequency Hopping spread Spectrum

➤ Bluetooth 5:

- 4x range, 2x speed and 8x broadcasting message capacity
- Low latency, fast transaction (3 ms from start to finish) Data Rate 1 Mb/s: sending just small data packets



Class	Maximum Power	Range
1	100 mW (20 dBm)	100 m
2	2,5 mW (4 dBm)	10 m
3	1 mW (0 dBm)	1 m



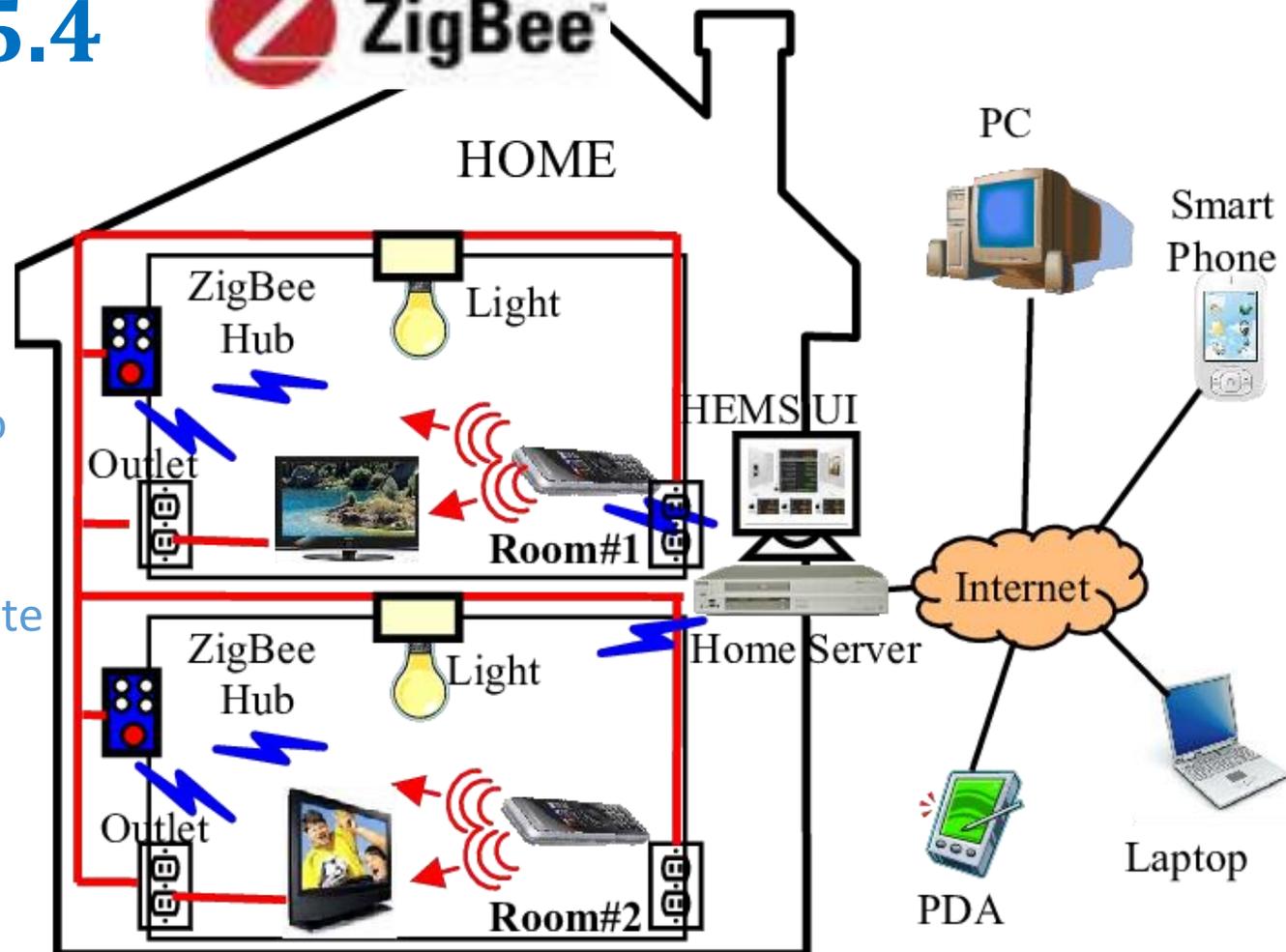
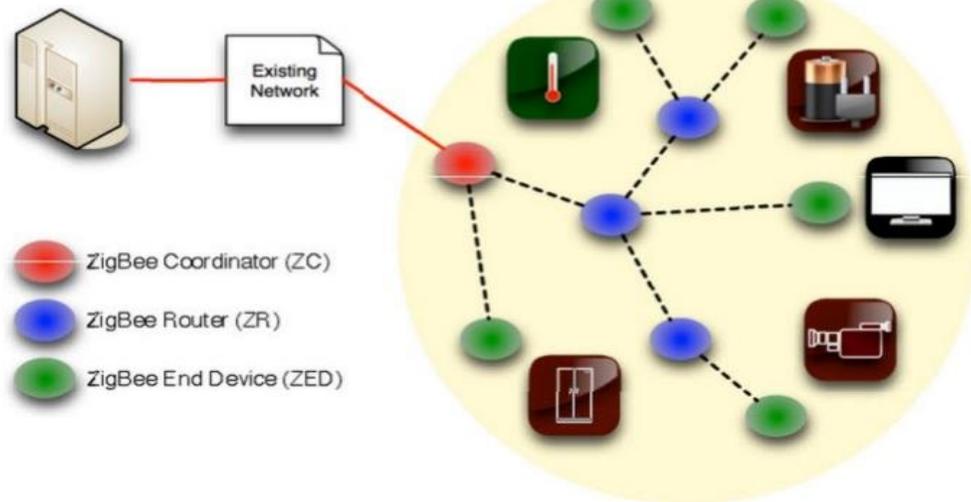
ZigBee - IEEE 802.15.4



Operations:

- **Coordinator:** acts as a root and bridge of the network
- **Router:** intermediary device that permit data to pass to and through them to other devices
- **End Device:** limited functionality to communicate with the parent nodes

— Wired Connection
 - - - Wireless Connection



Low cost and available



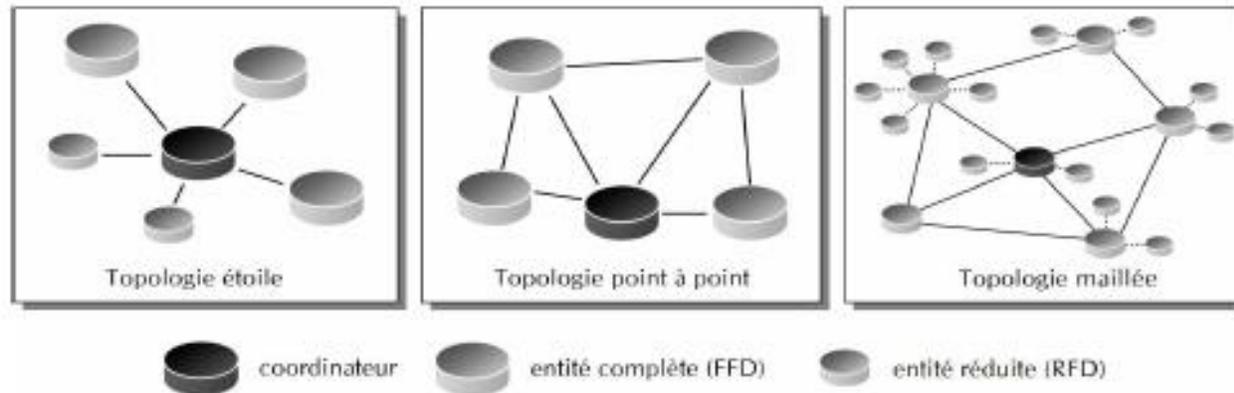
ZigBee

- ZigBee ou IEEE 802.15.4 permet d'obtenir des liaisons sans fil à très bas prix, à courte portée et à une très faible consommation énergétique (LPWPAN) → adaptée pour être intégrée dans de petits appareils électroniques, interconnecter des unités embarquées ayant des contraintes énergétiques importantes comme les capteurs.
- Portée max : quelques centaines de mètres
- Faible débit : 250 kbps max.
- Différence % à PAN se situe au niveau de l'utilisation du médium : optimisé pour une faible utilisation du médium partagé par tous, par exemple 0,1% du temps (somnolence).



ZigBee

- IEEE 802.15.4 prévoit deux topologies : étoile *ou point à point*
- la couche réseau de ZigBee permet la création de réseaux maillés (*mesh*) grâce à un routage automatique



- ZigBee peut travailler sur 3 bandes de fréquences : 868MHz (Europe), 915MHz (Amérique du nord) et 2,4GHz (Mondial).
- Deux couches physiques différentes (PHY), une pour le 868/915MHz (PHY868/915) et une seconde pour le 2,4GHz (PHY2450) mettant en oeuvre une modulation à spectre étalé



WiFi



- **Wireless Alternative to Wired Technologies**
- **Standardized as IEEE 802.11 standard for WLANs**

Standard	Frequency bands	Throughput	Range
WiFi a (802.11a)	5 GHz	54 Mbit/s	10 m
WiFi B (802.11b)	2.4 GHz	11 Mbit/s	140 m
WiFi G (802.11g)	2.4 GHz	54 Mbit/s	140 m
WiFi N (802.11n)	2.4 GHz / 5 GHz	450 Mbit/s	250 m
IEEE 802.11ah	900 MHz	4 Gbit/s	100 M
IEEE 802.11ac	900 MHz	7 Gbit/s	100 M

Home & Building Automation

- Bringing intelligence, convenience and lifestyle



Smart Energy

- Adding power awareness to products and helping to save energy



Multimedia

- Wireless audio streaming and advanced remote controls



Security and Safety

- Improving remote control and home monitoring



Industrial M2M Communication

- Internet enhanced M2M communication using existing Wi-Fi infrastructure



Small Size | Low Cost | Low Power



WiFi HaLow



A new low-power, long-range version of Wi-Fi that bolsters IoT connections

Wi-Fi HaLow is based on the **IEEE 802.11ah** specification

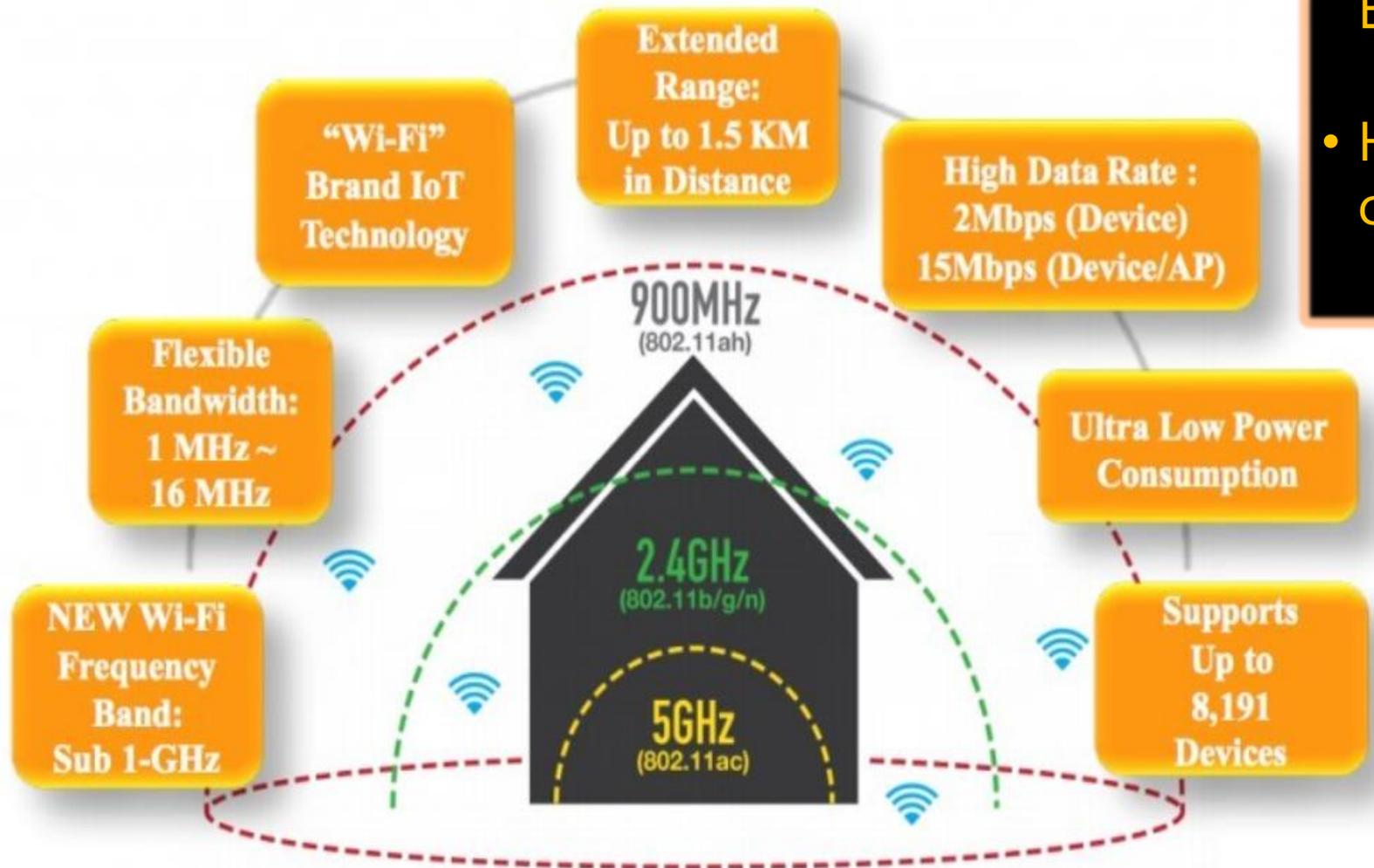
Wi-Fi HaLow will operate in the unlicensed wireless spectrum in the 900MHz band

Its range will be nearly double today's available Wi-Fi (1 kilometer)

- More flexible
- The protocol's low power consumption competes with Bluetooth
- Higher data rates and wider coverage range



WiFi HaLow



- More flexible
- The protocol's low power consumption competes with Bluetooth
- Higher data rates and wider coverage range

Picture Source: Newracom

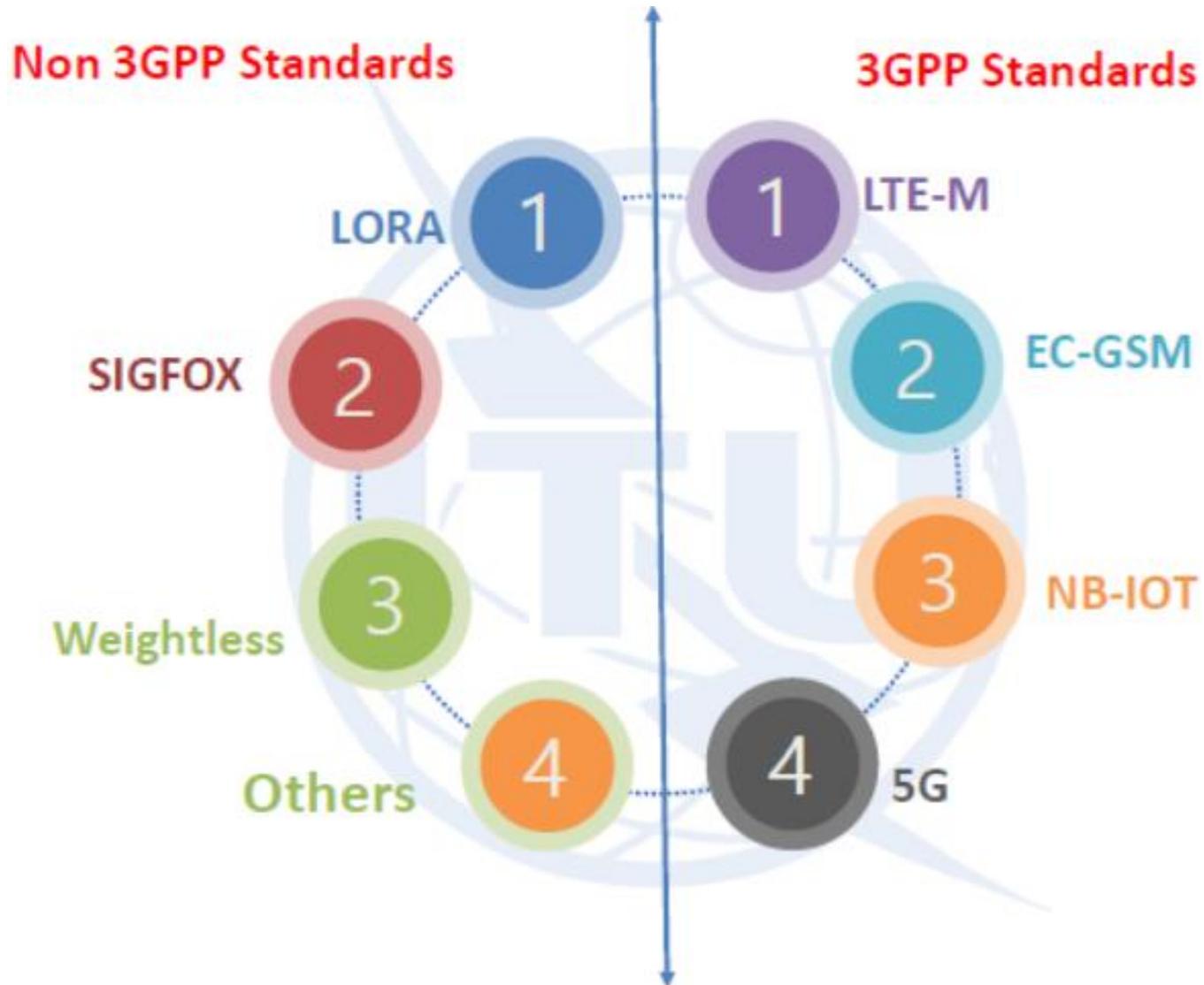


Long Range IoT Solutions

- Non 3GPP
- 3GPP

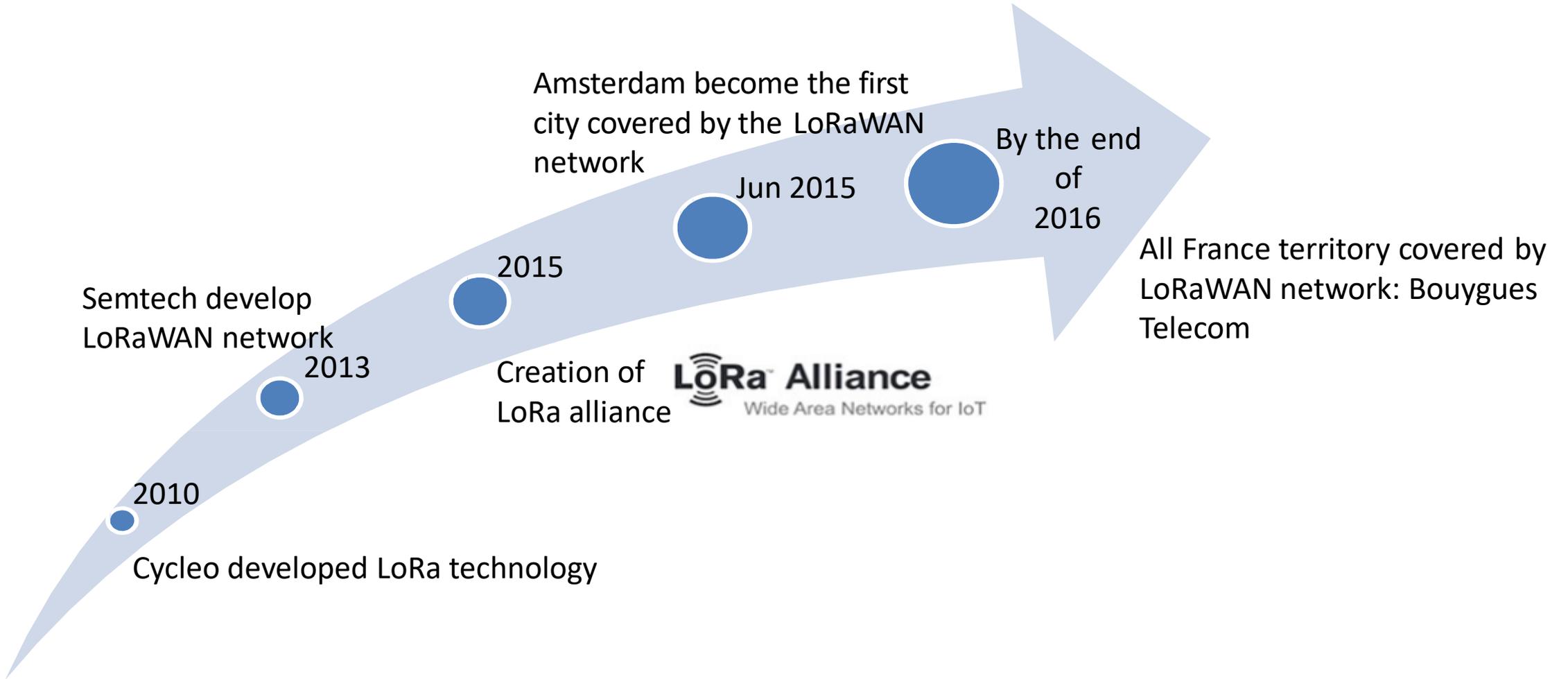


IoT Long Range Technical Solutions





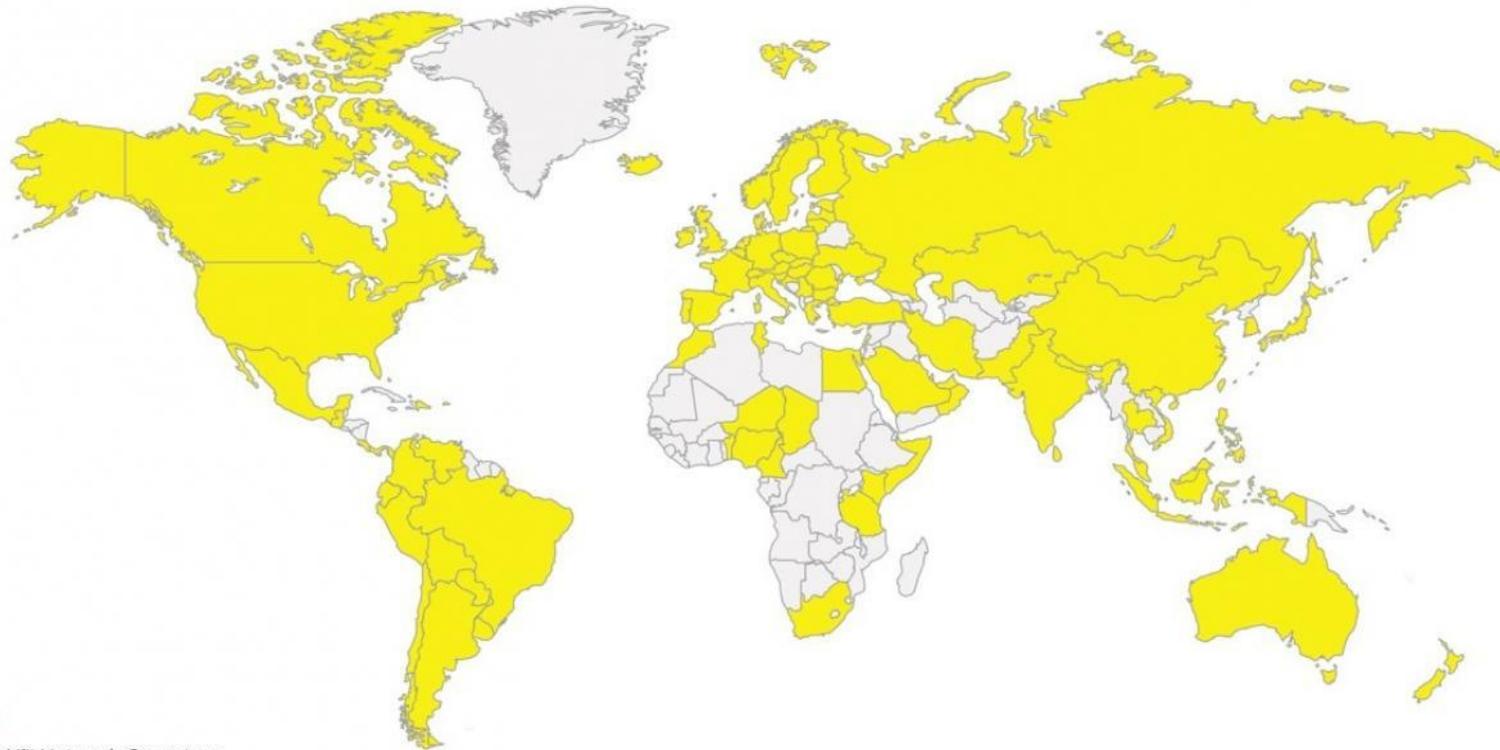
LORA





LoRaWAN Network Coverage

LoRaWAN™ NETWORK COVERAGE



100+
LoRaWAN™ Network Operators

100+ Countries With LoRaWAN Deployments

December 2018

All information contained herein is current at time of publishing - LoRa Alliance is not responsible for the accuracy of information presented



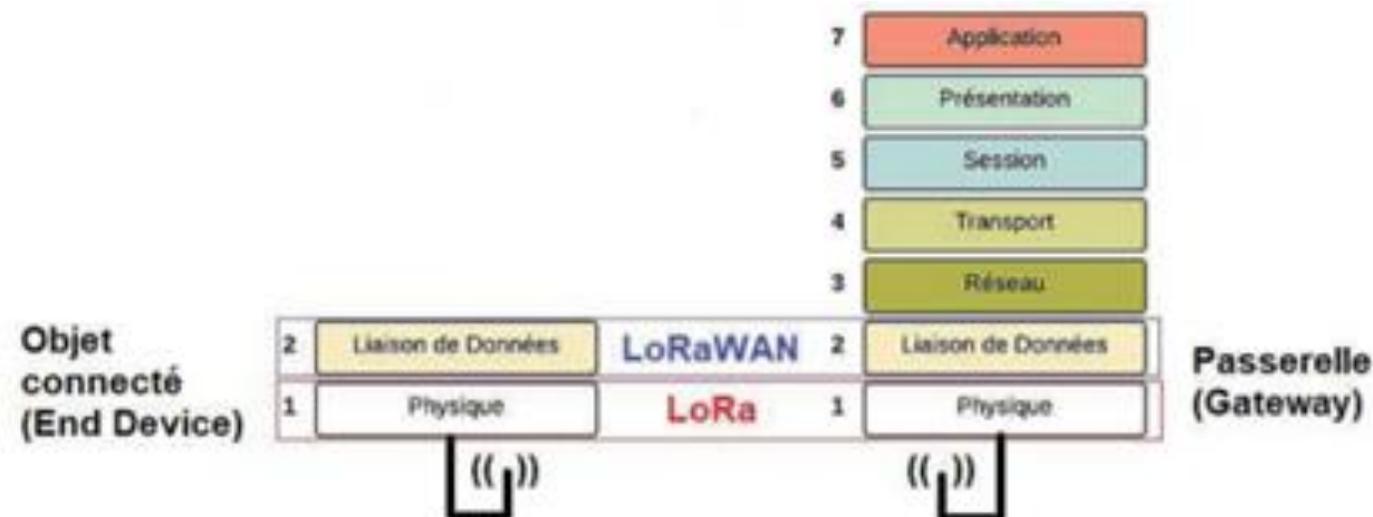
LORA - Features

- **LoRaWAN is a Low Power Wide Area Network**
- **Modulation:** a version of Chirp Spread Spectrum (CSS) with a typical channel bandwidth of 125KHz
- **High Sensitivity:** End Nodes: Up to -137 dBm, Gateways: up to -142 dBm
- **Long range:** up to 15 Km
- **Strong indoor penetration:** With High Spreading Factor, Up to 20dB penetration (deep indoor)
- **Robust** Occupies the entire bandwidth of the channel to broadcast a signal, making it robust to channel noise
- **Resistant to Doppler effect multi-path and signal weakening.**



LoRa versus LoRaWAN (1)

- La technologie LoRaWAN a été développée par la start up grenobloise Cycléo. Cette dernière a été rachetée en 2012 par l'entreprise californienne Semtech qui détient désormais les droits exclusifs sur la technologie LoRa.
- La technologie LoRa, aussi parfois appelée **LoRa RF**, désigne l'interface radio du réseau de communications sans fil (couche physique), alors que l'appellation LoRaWAN, parfois désignée également par le terme LoRa MAC désigne le protocole de communication. D'où la modélisation du réseau de communications LoRaWAN associant un objet communicant au serveur de réseau





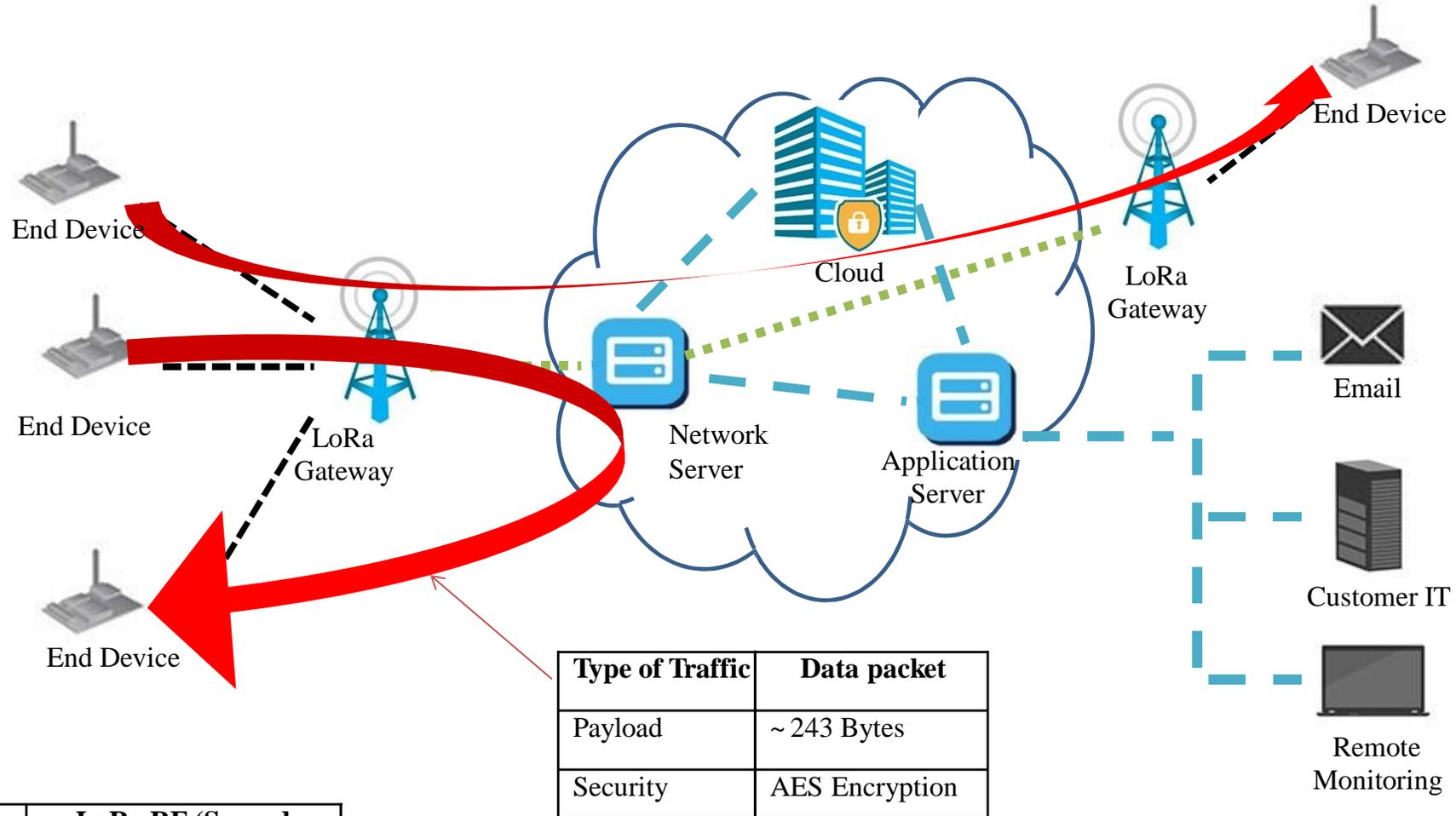
LoRa versus LoRaWAN (2)

En résumé, on peut conclure que :

- LoRa, qui est l'abréviation de **Long Range**, désigne l'interface radio « longue portée » assurant le transit des informations bidirectionnelles entre les objets connectés et la ou les passerelle(s)
- LoRaWAN, qui signifie **Long Range Wide Area Network**, désigne l'ensemble du réseau de communications, depuis chacun des objets connectés jusqu'au serveur.



LORA - Architecture



Modulation	LoRa RF (Spread Spectrum)
Range	~ 15 Km
Throughput	~ 50 Kbps



LORA – Device Classes

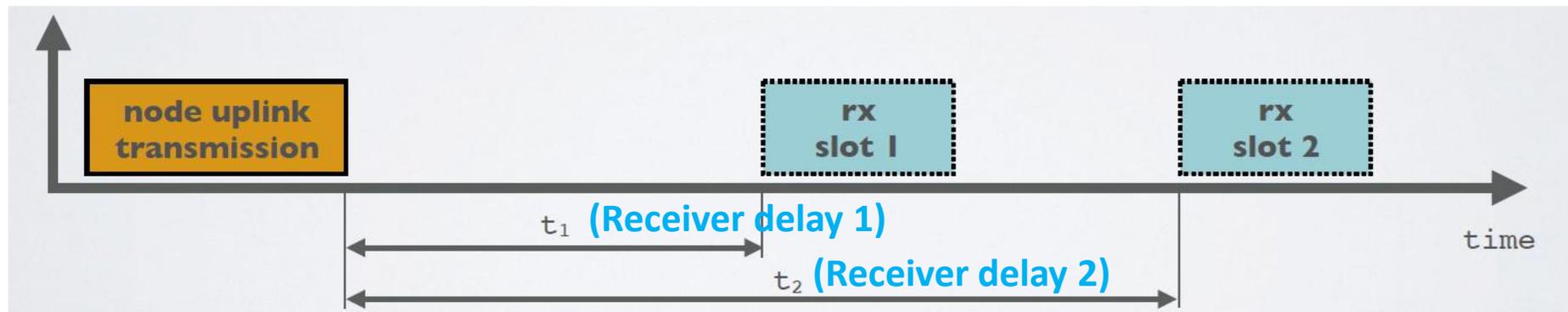
Classes	Description	Intended Use	Consumption	Examples of Services
A (« all »)	Listens only after end device transmission	Modules with no latency constraint	The most economic communication Class energetically. Supported by all modules. Adapted to battery powered modules	<ul style="list-style-type: none">• Fire Detection• Earthquake Early Detection
B (« beacon »)	The module listens at a regularly adjustable frequency	Modules with latency constraints for the reception of messages of a few seconds	Consumption optimized. Adapted to battery powered modules	<ul style="list-style-type: none">• Smart metering• Temperature rise
C (« continuous »)	Module always listening	Modules with a strong reception latency constraint (less than one second)	Adapted to modules on the grid or with no power constraints	<ul style="list-style-type: none">• Fleet management• Real Time Traffic Management

Any LoRa object can transmit and receive data



Fonctionnement en classe A

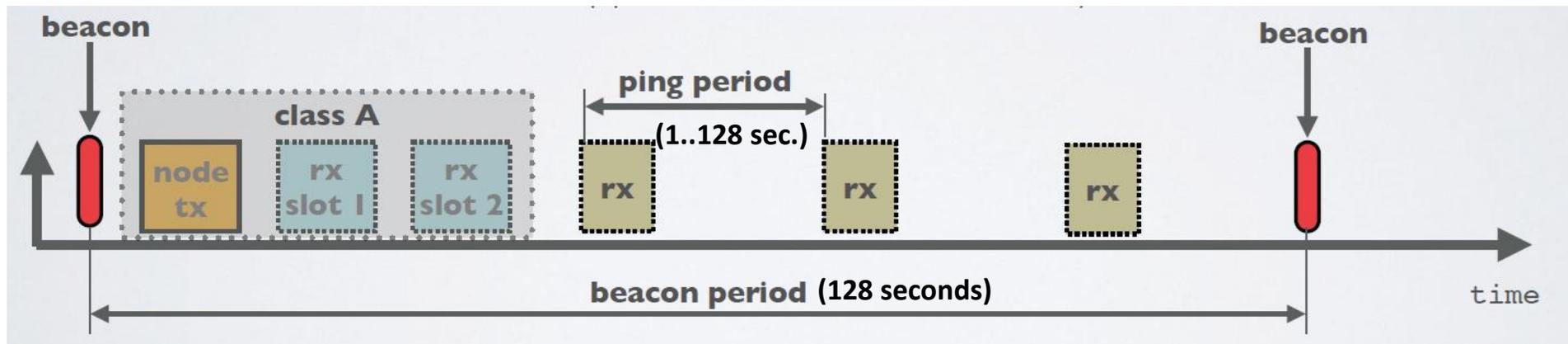
- Un node peut transmettre un message **n'importe quand**
- Une réponse peut être transmise pas la passerelle après les temps t_1 ou t_2 , généralement 1s et 2s.





Fonctionnement en classe B

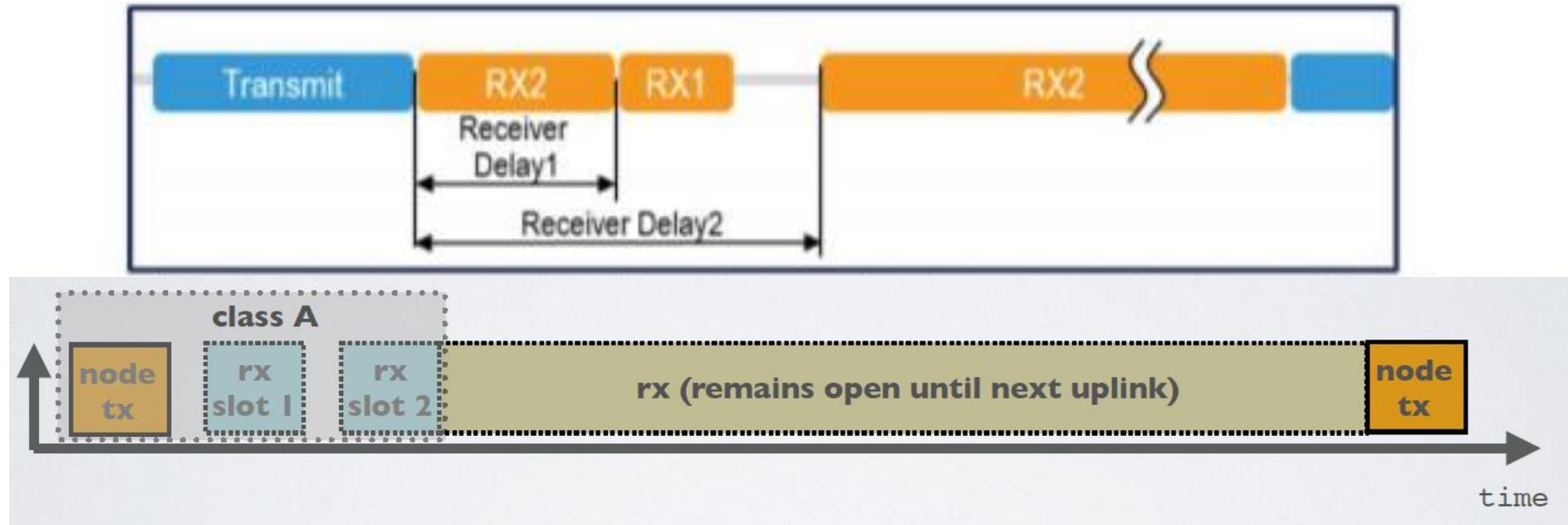
- Même fonctionnalités que la classe A
- Le node peut recevoir plusieurs réponses.
- **Le échanges commencent lorsque la passerelle transmet une balise (beacon)**
- Dans ce cas, il est possible, entre la transmission de 2 données successives de la part de l'objet connecté, d'insérer, à intervalles de temps réguliers, davantage de fenêtres pendant lesquelles le serveur peut transmettre ses données à l'objet connecté. Dans ce mode de fonctionnement, c'est toujours l'objet connecté qui a l'initiative de la transmission de données, mais ensuite, c'est le serveur qui devient prioritaire, et peut, toutes les 128 secondes, par l'intermédiaire d'un signal de synchronisation (Beacon) poursuivre l'émission de données à l'attention de l'objet connecté pour 128 secondes supplémentaires.





Fonctionnement en classe C

- Même fonctionnalités que la classe A
- Pour cette configuration, le serveur, entre deux transmissions consécutives de l'objet connecté, a la possibilité de renvoyer des données de façon continue.
- Le node écoute durant toute la période entre deux transmissions. **Cela induit une plus grande consommation**





Sélection de la classe

- Compte tenu du fait que dans un module LoRa, c'est l'étage RF qui est le plus énergivore, il est clair que plus celui-ci est sollicité pendant de longues durées (ces durées pendant lesquelles le module RF transmet ou reçoit une donnée sont désignées en anglais par l'expression TOA pour Time On Air), plus sa consommation énergétique sera élevée.
- C'est pourquoi les modules LoRa configurés en classe A ou B peuvent être alimentés par pile, alors que ceux configurés en classe C doivent recourir à une alimentation délivrée par des panneaux solaires.



Architecture LoRa

le LoRa n'est pas un réseau LPWAN car ne dispose pas d'une architecture en étoile mais permet seulement une communication pair à pair. On parlera donc de technologie LoRa et non de "protocole LoRa" car l'essentiel du LoRa se situe dans la transmission de messages à longue distance ;

il n'implémente aucun protocole hiérarchique et reste un moyen bas niveau de transmission de données sans-fil à longue portée.

Le LoRa s'impose comme une technologie peu propriétaire. Il n'y a aucun abonnement, aucune limite de message par jour et la longueur d'un message n'est pas limitée.

- Le réseau est de type pair à pair, il n'existe aucune hiérarchie dans le réseau. L'architecture du réseau ne permet donc pas d'avoir un concentrateur de données comme le Sigfox qui a adopté une hiérarchie en étoile. Il est donc impossible d'obtenir avec un réseau LoRa, un système de supervision central.
- Les communications ne sont pas du tout sécurisées. L'émetteur et le destinataire sont identifiés par un IDentifiant (ID) donné dans la trame qui n'est pas cryptée.



Concept Radio

La portée et la qualité d'une liaison radio dépendent de très nombreux facteurs.

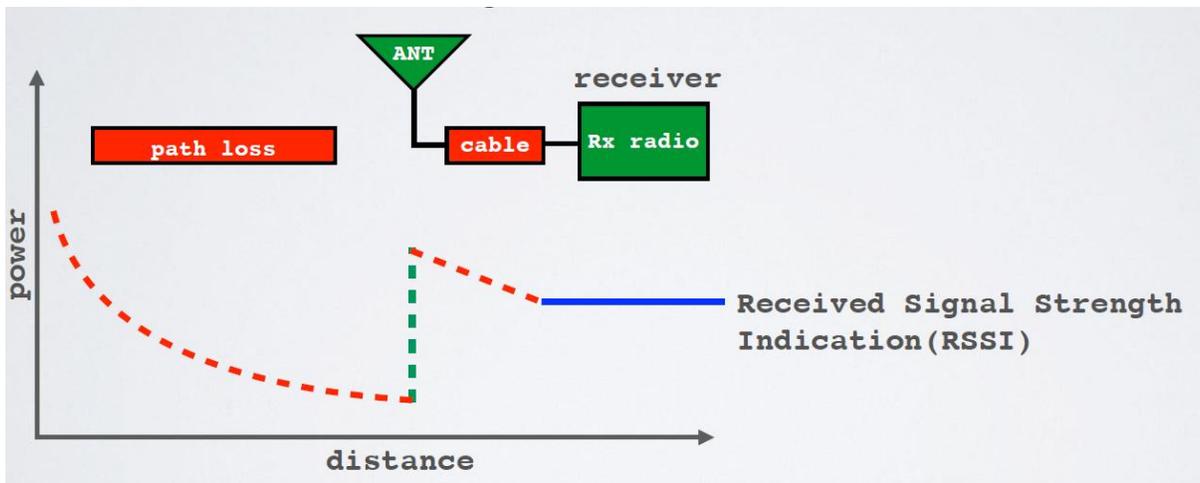
En particulier:

- Le RSSI
- Le SNR
- Le SF
- La BW



RSSI

- Received Signal Strength Indication (RSSI)
- Indication de l'intensité du signal reçu (Puissance PR)



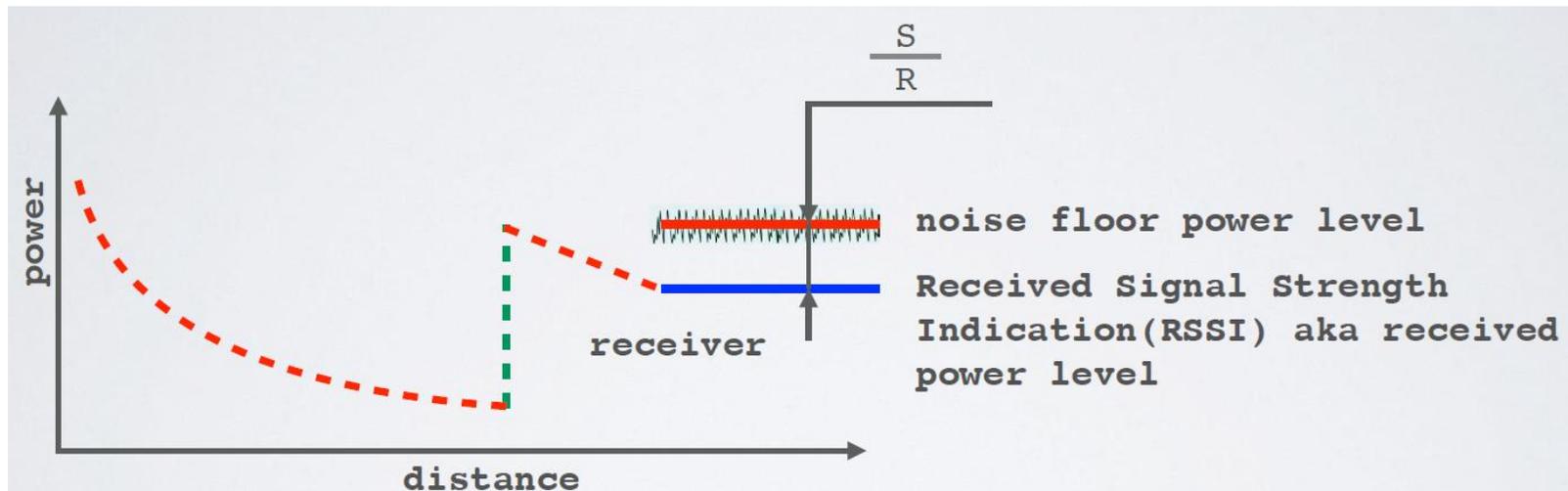
Le RSSI est mesuré en dBm et est toujours négatif
Un RSSI de 0 correspond à une réception maximale

Sur LoRa le RSSI est compris entre
-30dBm et -120dBm



SNR

- Signal to Noise Ratio (SNR) ou Rapport signal/bruit
- C'est le rapport entre la puissance du signal reçu et le niveau du bruit. Plus ce rapport est grand et plus il sera facile d'extraire le signal du bruit.
- La technologie LoRa permet de démoduler un signal sous le niveau de bruit. (-7.5dBm à -20dBm sous le bruit)





Sensibilité

On appelle Sensibilité, la puissance P_R minimale (ou RSSI minimal) qui doit être présente sur le récepteur.

Si le RSSI reçu est en dessous de la sensibilité, alors le signal est indétectable par le récepteur.



Exigences

- Les valeurs RSSI, Sensibilité, SNR, ... sont données en décibel

- Un signal pourra être reçu convenablement si les deux conditions suivantes sont remplies :
 - 1 . Le RSSI est supérieur à la sensibilité du récepteur.

 - 2 . Le SNR ne passe pas en dessous d'un certain seuil qui rendrait le signal impossible à démoduler.



Exercice

Un émetteur transmet à une puissance de 13dBm en utilisant une antenne dont le gain est de 2dB. Les pertes dans l'air sont de 60 dB.

L'antenne réceptrice qui possède un gain de 2dB est reliée à un récepteur dont la sensibilité est de -80 dBm.

Question: Le signal pourra-t-il être reçu ?

Réponse:

La puissance reçue est de $13 + 2 - 60 + 2 = -43$ dBm et $-43 > -80$ (sensibilité)

Donc oui, le signal pourra être reçu



Transmission radio et propagation

$$P_{(\text{dBm})} = 10 \cdot \log_{10}(1000 \cdot P_{(\text{W})} / 1\text{W}) = 10 \cdot \log_{10}(P_{(\text{W})} / 1\text{W}) + 30$$

alors

$$1\text{W} = 30\text{dBm}$$

Exercice : Le Talkie-Walkie a une puissance d'émission de 2W. Quelle est la puissance d'émission exprimées en dBm ?

Réponse :

$$1\text{ mW} \times 10 \times 10 \times 10 \times 2 = 2\text{ W}$$

$$0\text{ dBm} + 10 + 10 + 10 + 3 = 33\text{dBm}$$



Transmission radio et propagation (1)

Comment améliorer le bilan de transmission?

- La première idée serait d'émettre plus fort (augmenter PE). Ceci est possible dans une certaine mesure, car les puissances d'émission sont limitées.
 - En LoRa, la puissance d'émission maximum sur la bande 868 Mhz est de 14 dBm (25 mW).
- La seconde possibilité est d'améliorer la sensibilité du récepteur. Les concepteurs de modules LoRa s'efforcent de l'améliorer jusqu'aux limites technologiques actuelles.
- Au final, ce qui compte, c'est surtout la différence entre la puissance PE et la sensibilité du récepteur. C'est ce qu'on appelle le **Link Budget**.
- En LoRa, le Link Budget est d'environ 157 dB
- En LTE (4G), le Link Budget est d'environ 130 dB.



Transmission radio et propagation (2)

Distance de transmission en LoRa

- Affaiblissement en espace libre

$$FSPL = 20 \log_{10}(d) + 20 \log_{10}(f) + 20 \log_{10}\left(\frac{4\pi}{c}\right) - G_t - G_r$$

- En avril 2020, le record du monde de distance en transmission LoRa a été battu. Il est de 832 km pour une puissance de 25 mW / 14 dBm (puissance maximale autorisée en Europe).



Modulation LoRa

➤ La modulation LoRa

la modulation LoRa utilise l'étalement de spectre pour transmettre ses informations. Mais au lieu d'utiliser des codes d'étalement (CDMA), elle utilise une méthode appelée Chirp Spread Spectrum.

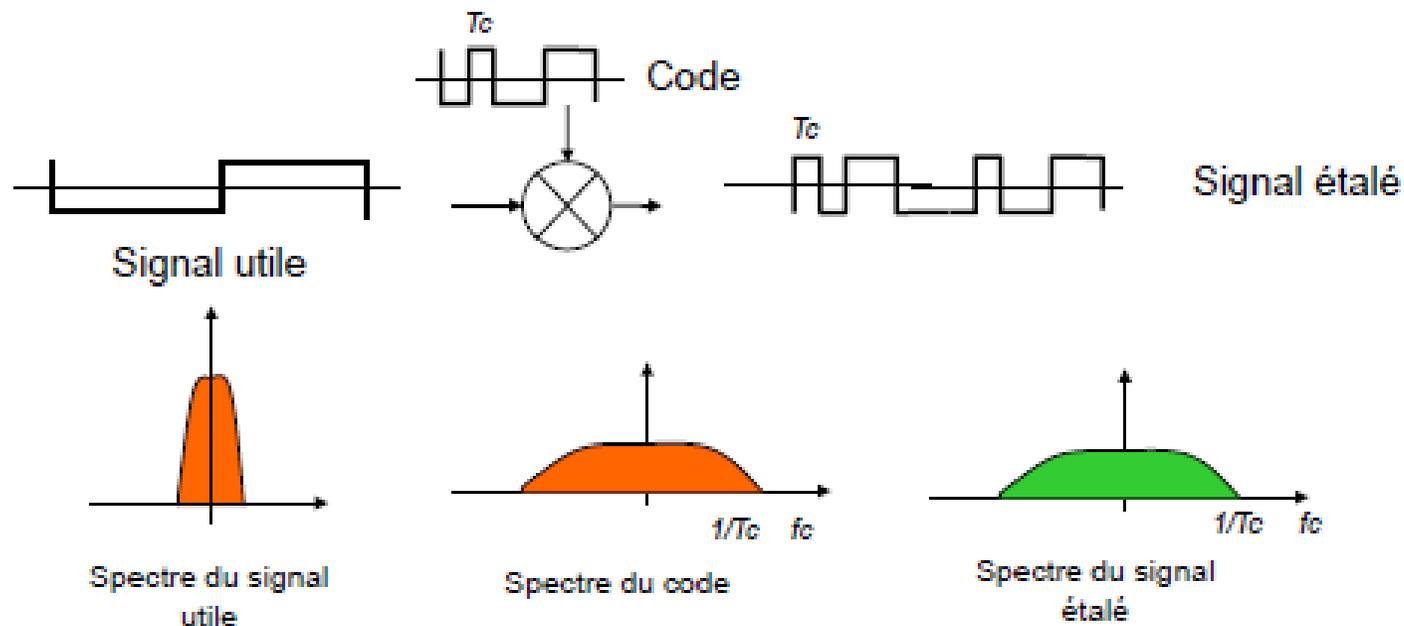
La finalité est toujours la même : avoir plusieurs transmissions dans le même canal. La conséquence sur le spectre est aussi la même : cela provoque un étalement du spectre.

- Les transmissions sont numérisées dites à étalement de spectre
- L'étalement de spectre rend le signal moins sensible aux fluctuations sélectives en fréquences
- Le signal est transmis sur une bande de fréquences beaucoup plus large que la bande de fréquences nécessaire



Étalement de Spectre

- A l'émission : étalement du spectre par multiplication du signal utile par un code

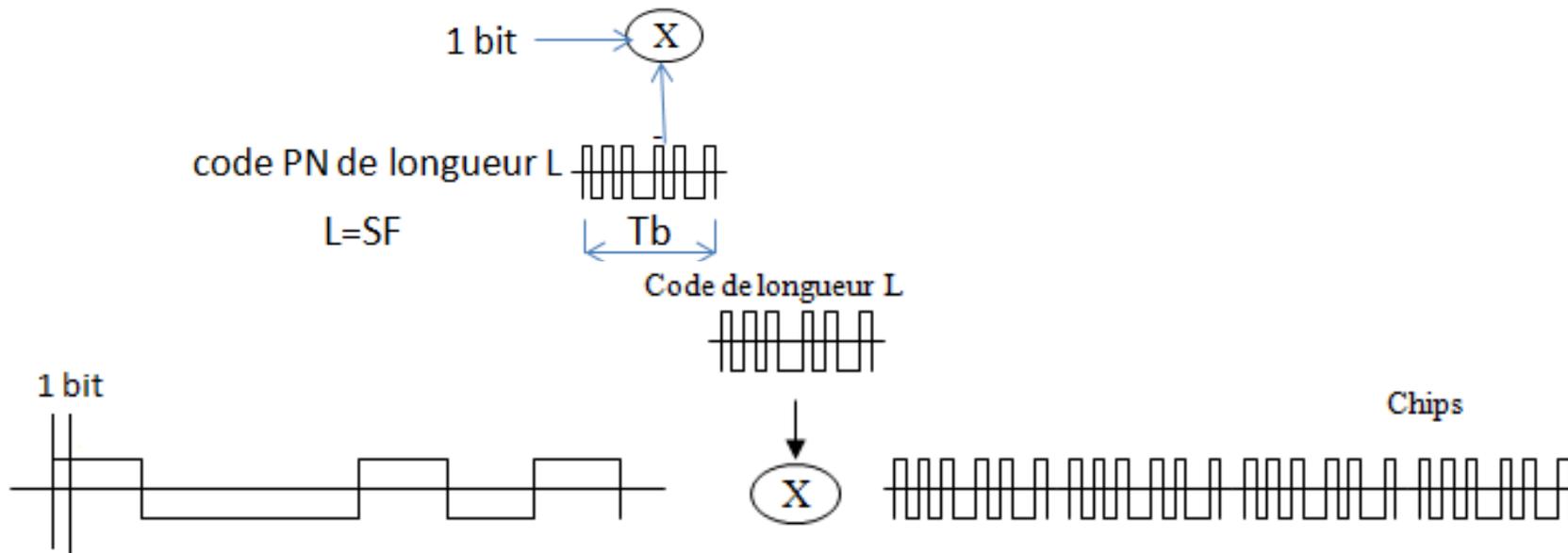


- La séquence du code, constituée de N éléments appelés « Chips » est unique pour chaque utilisateur, et constitue la clé de codage
- La longueur L du code est appelée « Facteur d'étalement SF (Spreading Factor) »



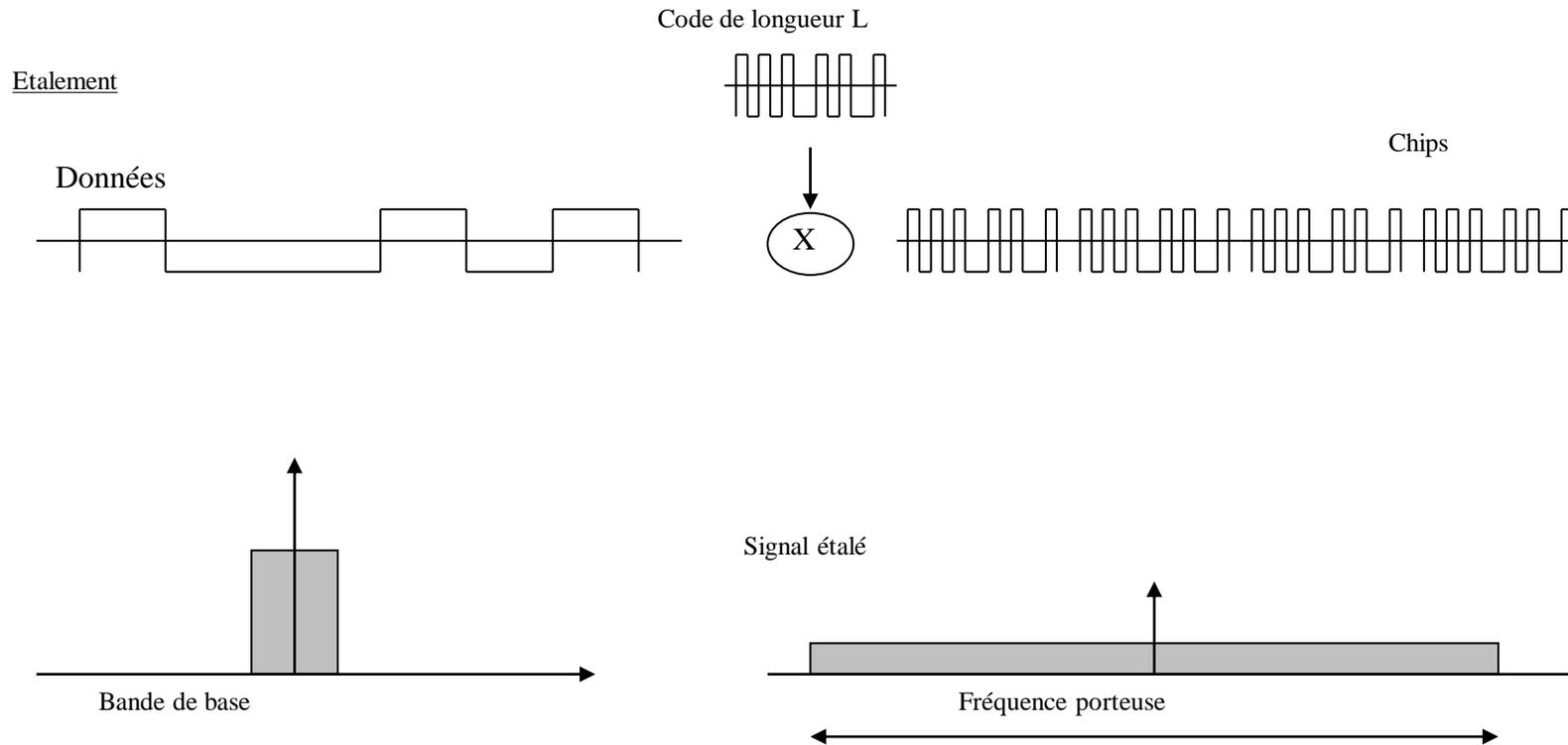
Étalement de Spectre

- Si chaque symbole a une durée T_b , on a 1 chip toutes les T_b/SF secondes. Le nouveau signal modulé a un débit SF fois plus grand que le signal initialement envoyé par l'utilisateur et utilisera donc une bande de fréquence SF fois plus étendue :





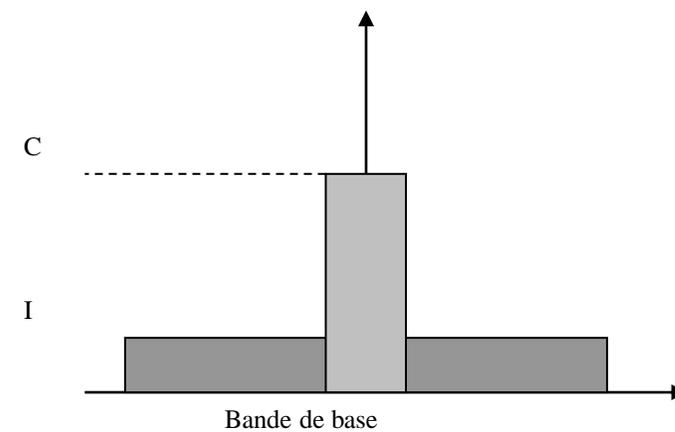
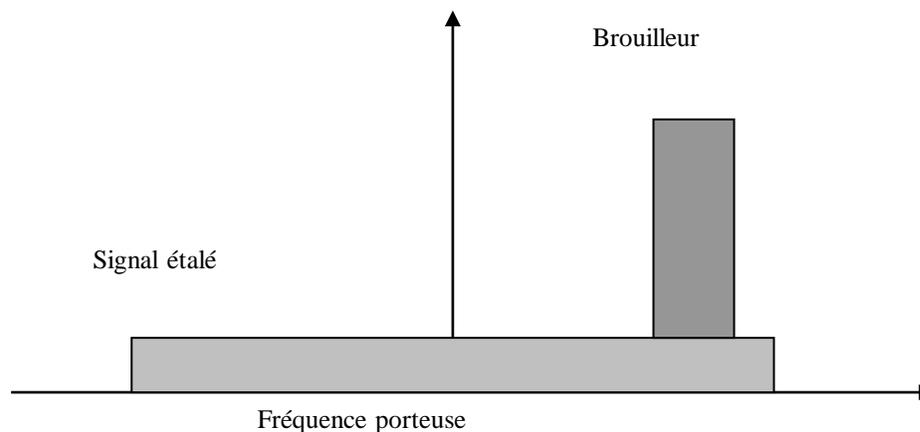
Étalement de Spectre





Désétalement de spectre

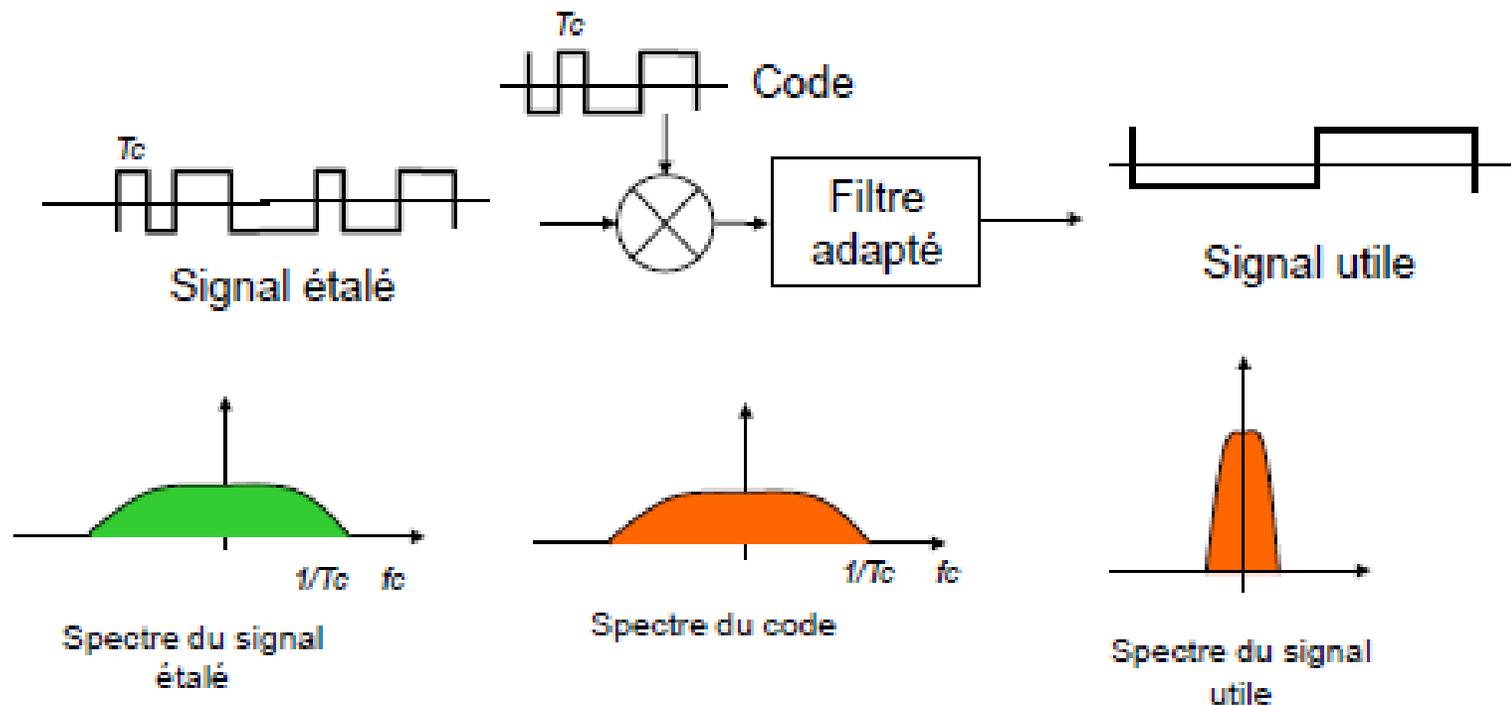
- Pour récupérer l'information, le récepteur doit effectuer la même opération: il génère la même séquence d'étalement et la multiplie au signal reçu; les données codées par cette séquence sont restaurées (puissance spectrale augmentée) alors que les données des autres utilisateurs restent étalées et les brouilleurs dus au canal sont étalés, non corrélés au signal utile.
- Ceci permet de diminuer le niveau de bruit pour le signal en bande de base : plus l'étalement est important, plus les interférences sont éliminées.





Désétalement de spectre

- A la réception : désétalement par un filtre adapté





Les codes d'étalement

- Chaque utilisateur possède un code, il est donc nécessaire de n'avoir aucune interférence entre ceux-ci.
- Pour cela, nous utilisons des codes orthogonaux



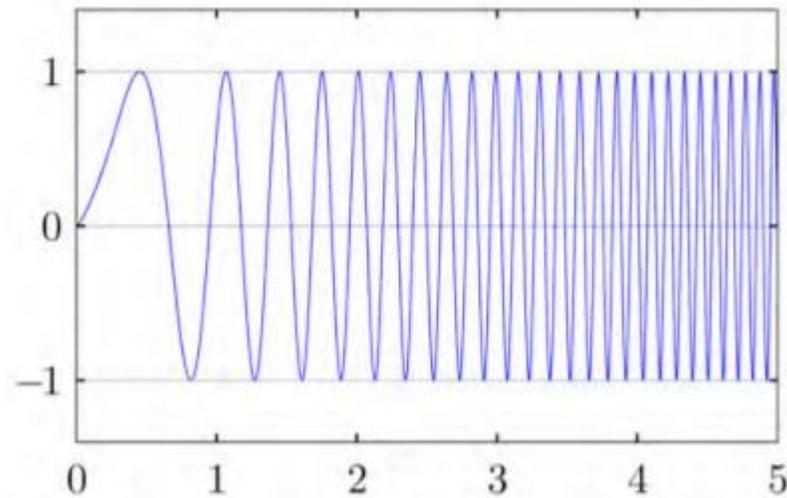
Les spécificités techniques

- La technologie LoRa s'appuie sur les bandes ISM, dont la répartition des fréquences et les réglementations varient suivant la région du monde.
- Les deux fréquences principalement utilisées sont le 868 MHz en Europe et 915 MHz en Amérique du nord.
- Cette couche physique repose sur une alternative à la **Spread Spectrum Modulation, ou Modulation à étalement de spectre (SSM)**, nommé **Chirp Spread Spectrum (CSS)** qui étale le signal de base sur un domaine fréquentiel donné **afin d'augmenter considérablement la bande passante** dans le but **d'accroître la résistance aux interférences, réduire la consommation énergétique et intégrer un code correcteur d'erreur.**



Chirp Spread Spectrum Modulation

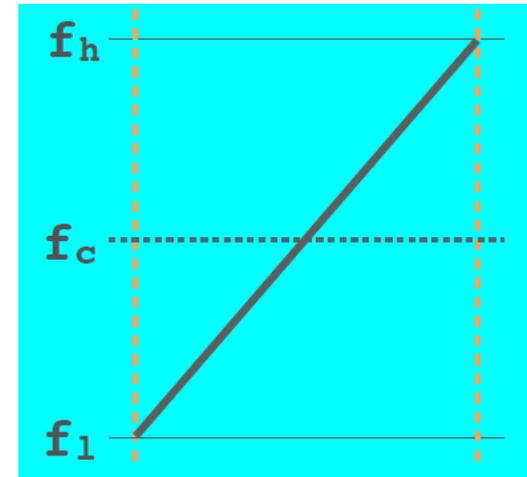
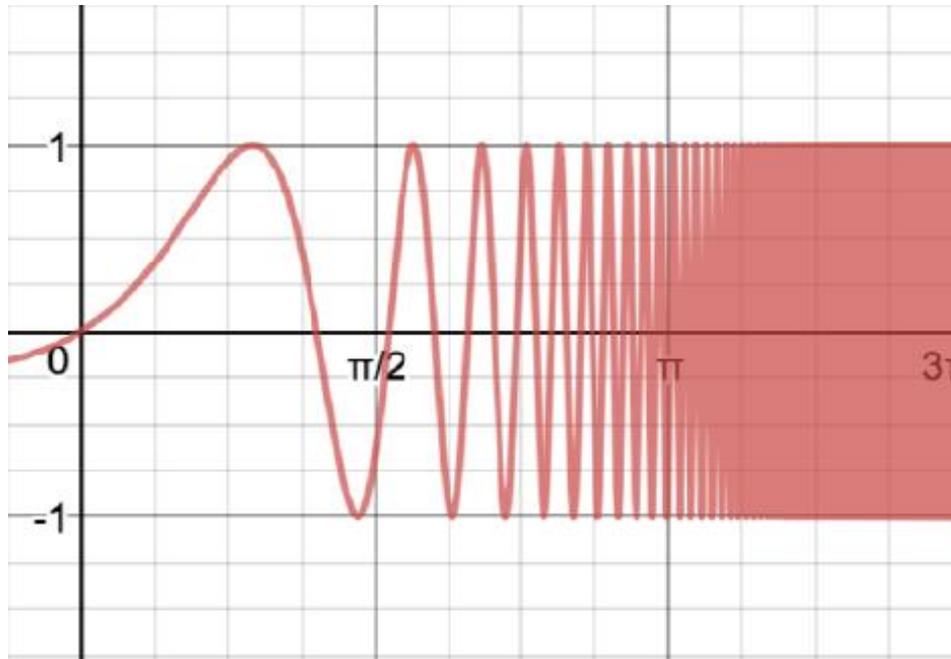
- Ce type de modulation, très utilisé pour des applications radar dans le passé est désormais répandu pour les communications bas débit.
- Le CSS forme des symboles appelés chirp dont l'amplitude est constante et la fréquence croît ou décroît dans le temps.



Représentation temporelle d'un Chirp



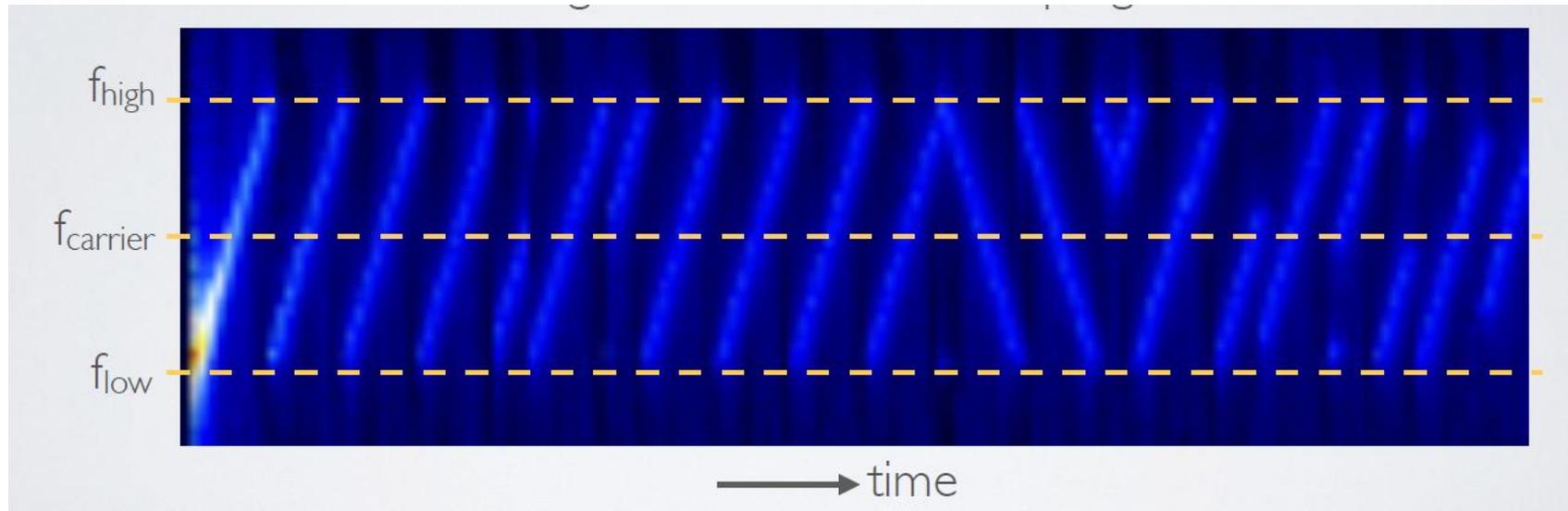
Modulation de fréquence et modulation LoRa



La modulation LoRa est une modulation de fréquence appliquée aux transmissions numériques. Contrairement à la FSK qui possède deux fréquences, une pour le 0 logique et une pour le 1. LoRa repose sur des sauts de fréquences qui représentent des motifs (des groupes de bits). La modulation est adaptative



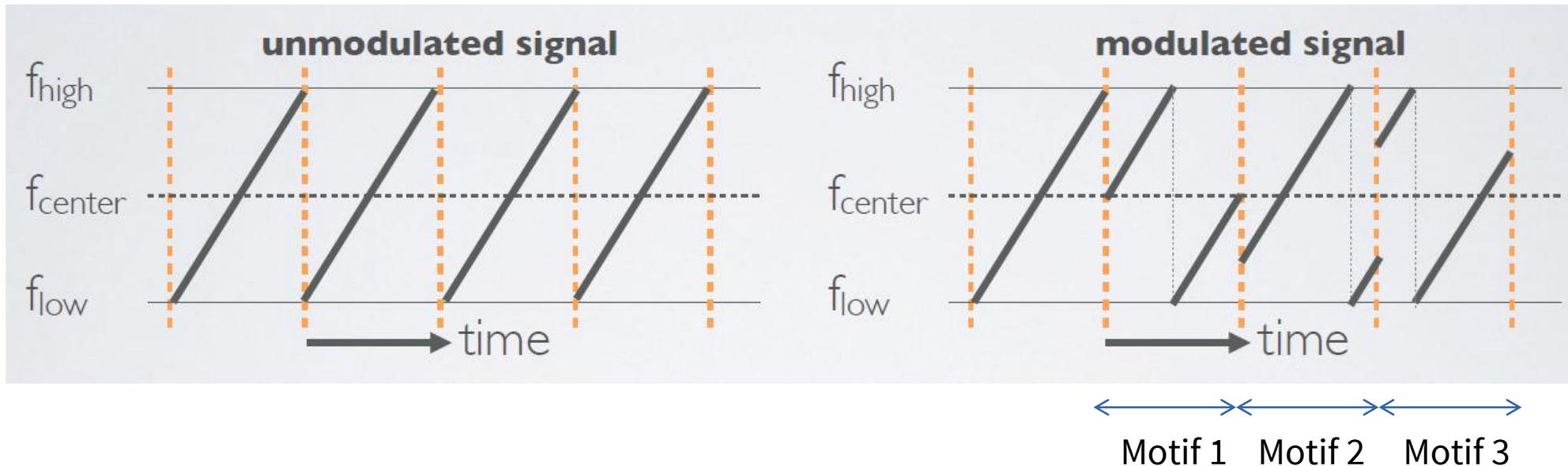
Modulation LoRa



On voit ici les sauts de modulations montante ou descendantes représentant les motifs



Modulation LoRa

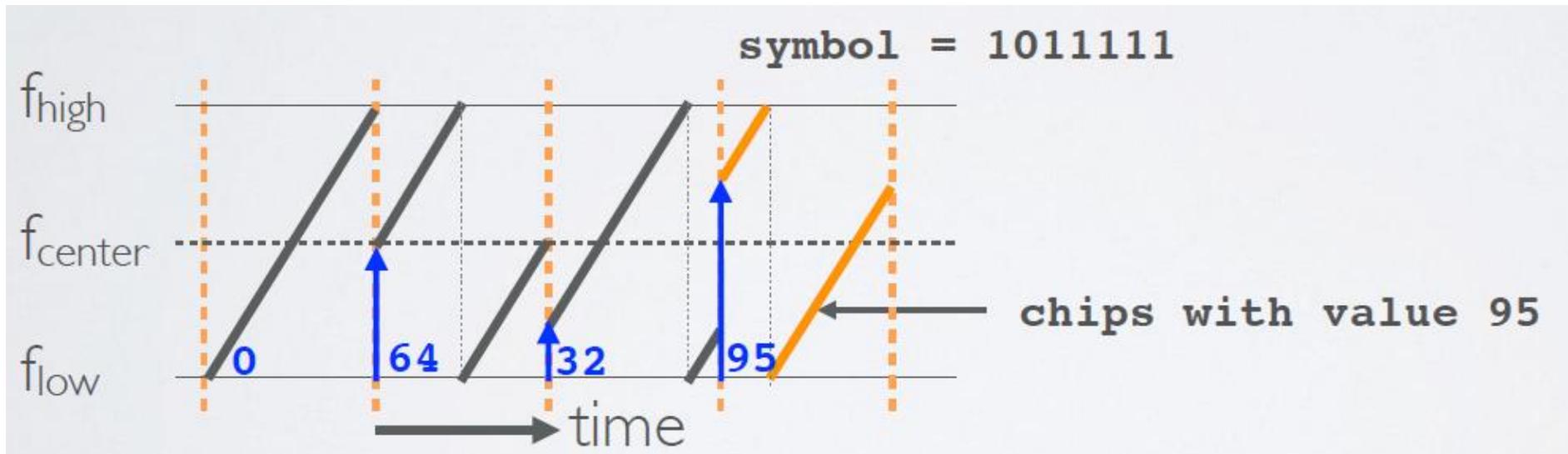


Chaque motif est représenté par une fréquence de début d'étalement.
Arrivée à f_{high} , la fréquence bascule sur f_{flow} pour rejoindre la fréquence de départ du motif



Modulation LoRa

- Par exemple si le motif est : 1011111 (95 en décimal)
- Le motif peut être codé avec 7 valeurs (7 bits) (SF=7)
- La variation de fréquence est divisée en 2^{SF} pas = $2^7 = 128$ pas ou chips.





Fréquence/Bande Passante

La fréquence de départ est la fréquence centrale du canal **moins** la Bande Passante divisée par deux.

La fréquence de fin est la fréquence centrale du canal **plus** la Bande Passante divisée par deux :

- La fréquence centrale est appelée le canal.
- La bande passante est la largeur de bande occupée autour du canal.

Pour faciliter la représentation de ce symbole, on utilise plutôt un graphique Temps/Fréquence de la forme suivante :



Exercice

On considère une émission sur la fréquence centrale 868 Mhz avec une Bande Passante de 125 kHz. Donner la fréquence de début et la fréquence de fin du symbole (sweep ou chirp).

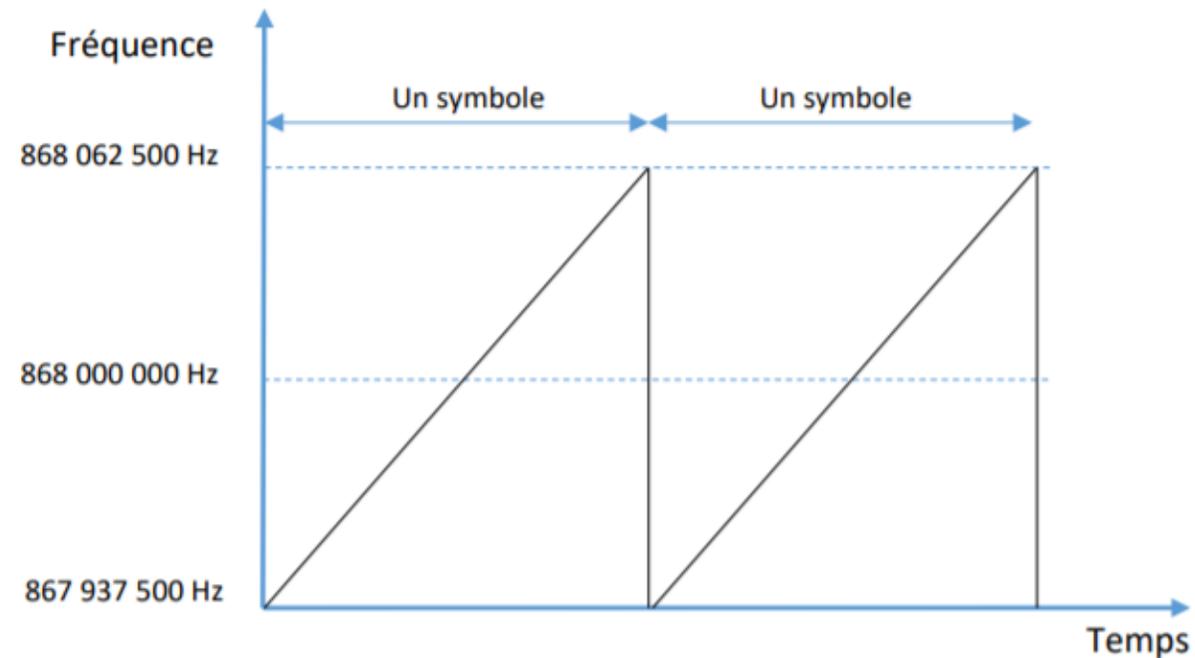
Réponse :

- Fréquence de début : 867 937 500 Hz
- Fréquence de fin : 868 062 500 Hz



Représentation d'un symbole

- Pour faciliter la représentation de ce symbole, on utilise plutôt un graphique Temps/Fréquence de la forme suivante :





Facteur d'étalement (Spreading Factor-SF)

En LoRa, chaque symbole représente un certain nombre de bits transmis. La règle est la suivante :

Nombre de bits transmis dans un symbole = Spreading Factor

Par exemple, si la transmission utilise un *Spreading Factor* de 10 (**SF10**), alors **un symbole représente 10 bits**.

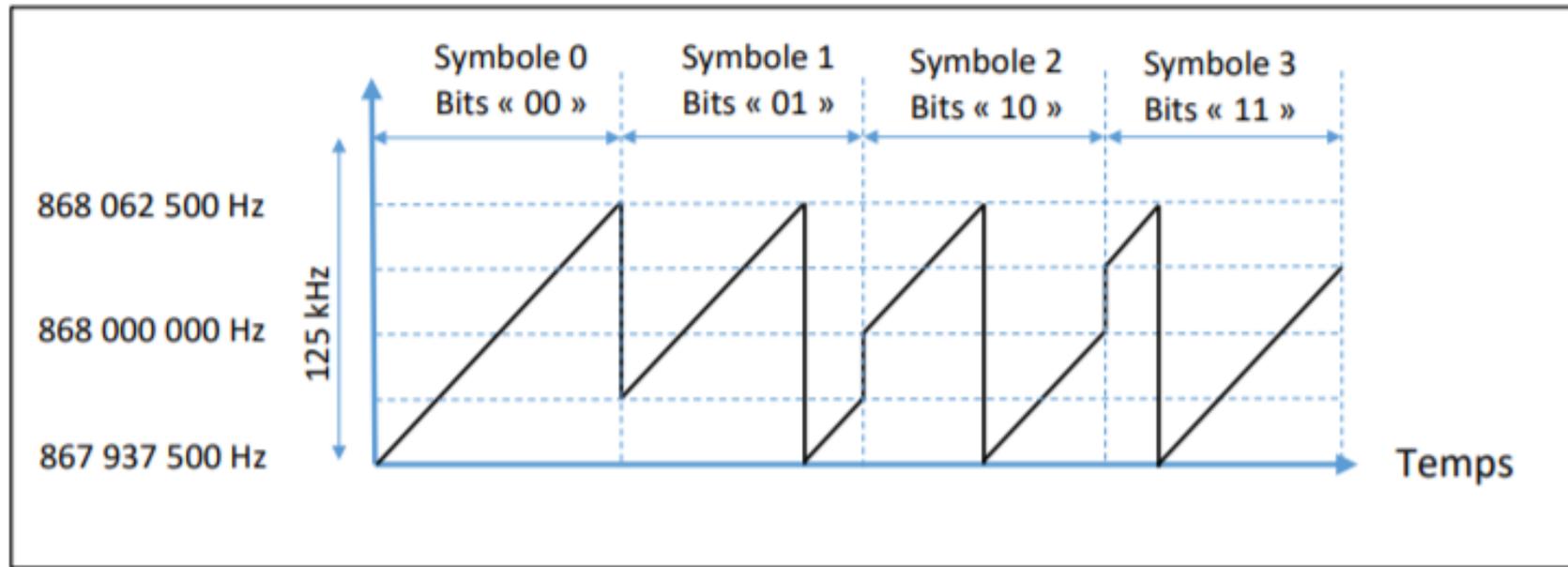
C'est-à-dire qu'à l'émission, les bits sont regroupés par paquet de **SF** bits, puis chaque paquet est représenté par un symbole particulier parmi 2^{SF} formes de symboles possibles.



Facteur d'étalement (Spreading Factor-SF)

Exemple

- un exemple théorique d'une modulation en SF2 à 868 Mhz, sur une bande passante de 125 kHz. Chaque symbole représente donc 2 bits.



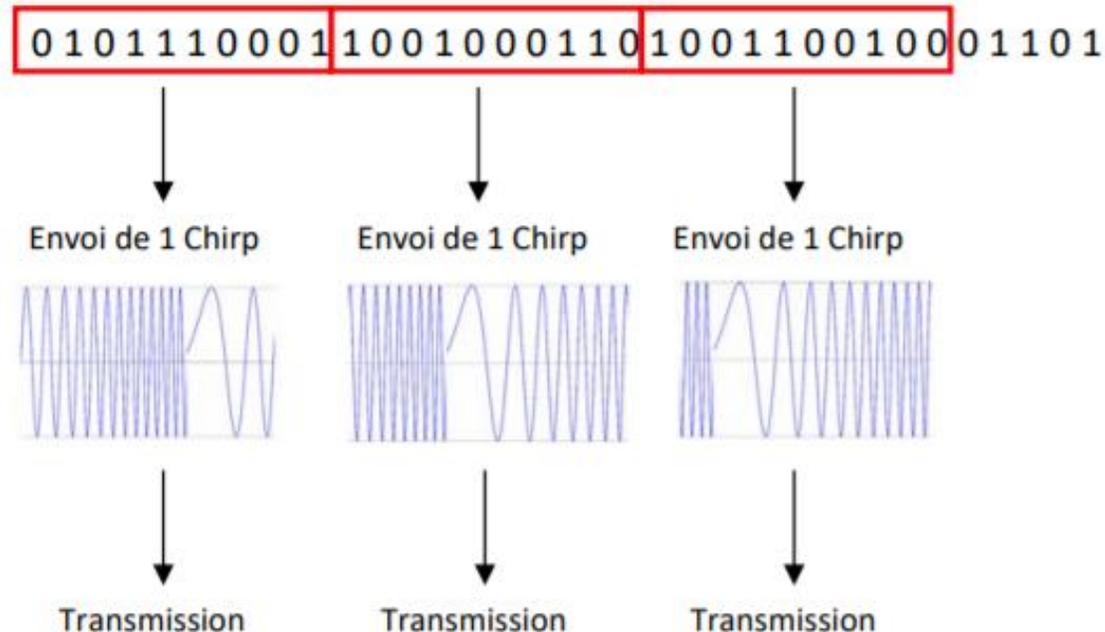
Symboles émis en Modulation LoRa (Cas SF=2)



Facteur d'étalement (Spreading Factor-SF)

Exemple

- On considère la suite binaire suivante :
0 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 0 1 1 0 1 0 0 1 1 0 0 1 0 0 0 1 1 0 1
- ■ Le Spreading Factor utilisé est SF10 Nous regroupons donc les bits par paquet de 10. Chaque paquet de 10 bits sera représenté par un symbole (sweep) particulier. Il y a 1024 symboles différents pour coder les 1024 combinaisons binaires possibles (2^{10}).





Facteur d'étalement (Spreading Factor-SF) Durée d'émission d'un symbole et débit

En LoRa, la durée d'émission de chaque symbole (Chirp) dépend du Spreading Factor utilisé.

Plus le SF est grand et plus le temps d'émission sera long.

Pour une même bande passante, le temps d'émission d'un symbole en SF8 est deux fois plus long que le temps d'émission d'un symbole en SF7.

Ainsi de suite jusqu'à SF12.



Facteur d'étalement (Spreading Factor-SF) Temps d'émission d'un Symbole

Le temps d'émission d'un symbole (T_{symbole}) est inversement proportionnel à la bande passante :

$$T_{\text{symbole}} = \frac{2^{SF}}{\text{Bandwidth}}$$

Exemple: Temps d'émission d'un symbole pour une bande passante de 125 Khz:

Spreading Factor	Temps d'émission d'un symbole
SF7	1,024 ms
SF8	2,048 ms
SF9	4,096 ms
SF10	8,192 ms
SF11	16,384 ms
SF12	32,768 ms



Facteur d'étalement (Spreading Factor-SF)

Débit binaire

Chaque symbole comprend SF bits, le débit binaire est égale alors :

$$D_b = SF \cdot \frac{\text{Bandwidth}}{2^{SF}}$$

- Plus le Spreading Factor sera élevé, plus le débit binaire sera faible.
- Plus la Bande Passante sera élevée, plus le débit binaire sera élevé.

En LoRa, la **bande passante** peut prendre **deux valeurs** : **125 kHz** et **250 kHz**. Une dernière valeur à **500 kHz** est disponible uniquement en Amérique du nord



Facteur d'étalement (Spreading Factor-SF)

Exercice

On considère les deux cas suivants :

- cas 1 (SF7, 125 kHz)
- cas 2 (SF12, 125 kHz)

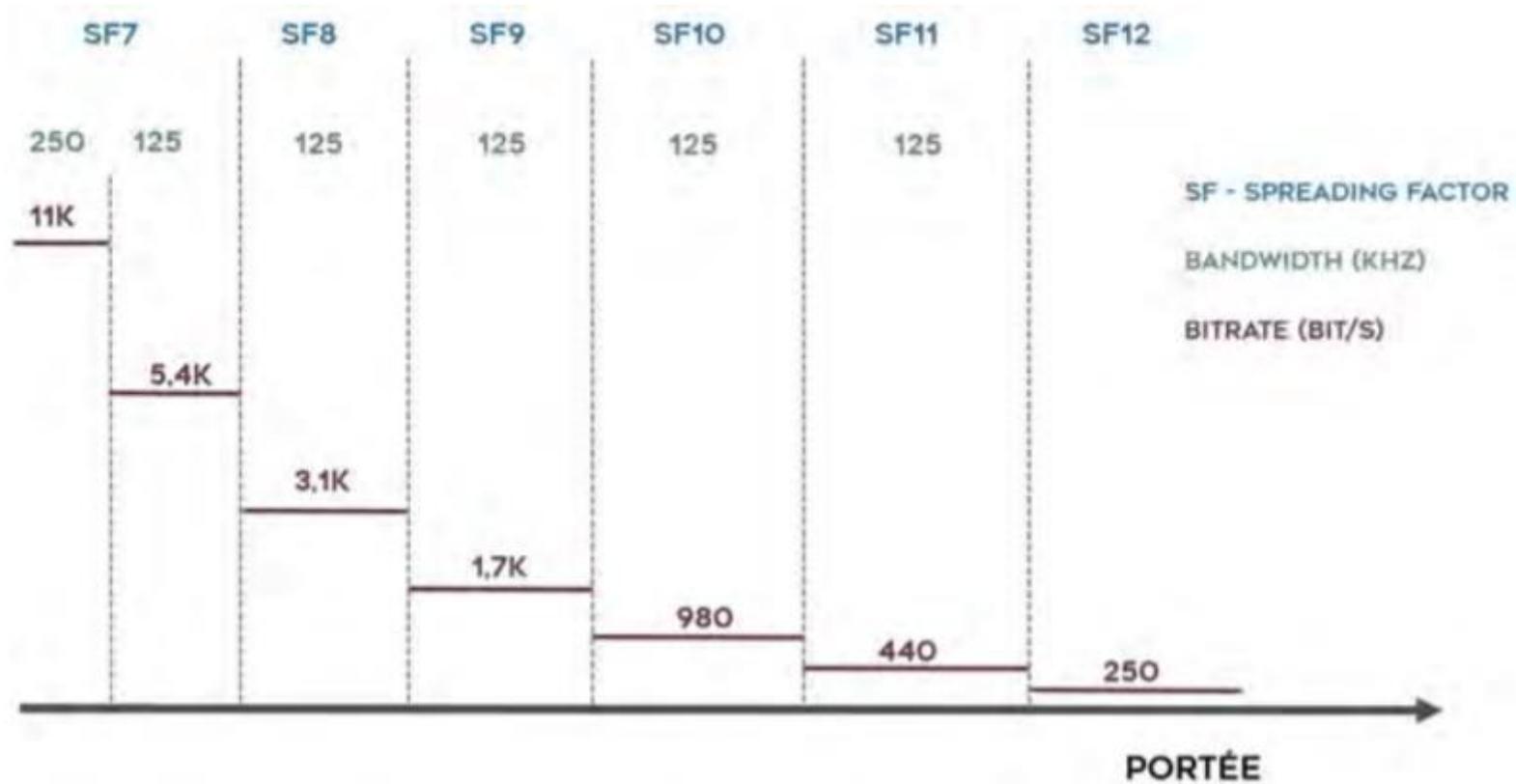
Donner le débit binaire correspondant

Réponse :

- **Cas 1 : Pour SF7, 125 kHz → Débit = 6,836 kbps**
- **Cas 2 : Pour SF12, 125 kHz → Débit = 366 bps**



Facteur d'étalement (Spreading Factor-SF) Relation entre SF et Débit





Facteur d'étalement (Spreading Factor-SF)

Relation entre SF et Débit

Data Rate (DR)	Spreading Factor (SF)	Bande Passante	Débit Physique (bit/s)
1	SF11	125KHz	440
2	SF10	125KHz	980
3	SF9	125KHz	1760
4	SF8	125KHz	3125
5	SF7	125KHz	5470
6	SF7	250KHz	11000



Facteur d'étalement (Spreading Factor-SF) Coding Rate

Le **Coding Rate** représente le code de correction. C'est un ratio qui augmentera le nombre de bits à transmettre afin de réaliser de la détection / correction d'erreurs.

Dans le cas d'un $CR = 4 / 8$, il y aura 8 bits transmis réellement à chaque fois que nous souhaitons transmettre 4 bits.

Dans cet exemple, cela provoque une transmission d'un nombre de bits multiplié par 2.

$$CR = 4/4+n , n \in \{1, 2, 3, 4\}$$

$$BitRate = SF * \frac{BW}{2^{SF} * CR}$$



Facteur d'étalement (Spreading Factor-SF) Coding Rate

Exercice :

Avec un CR de 4 / 5:

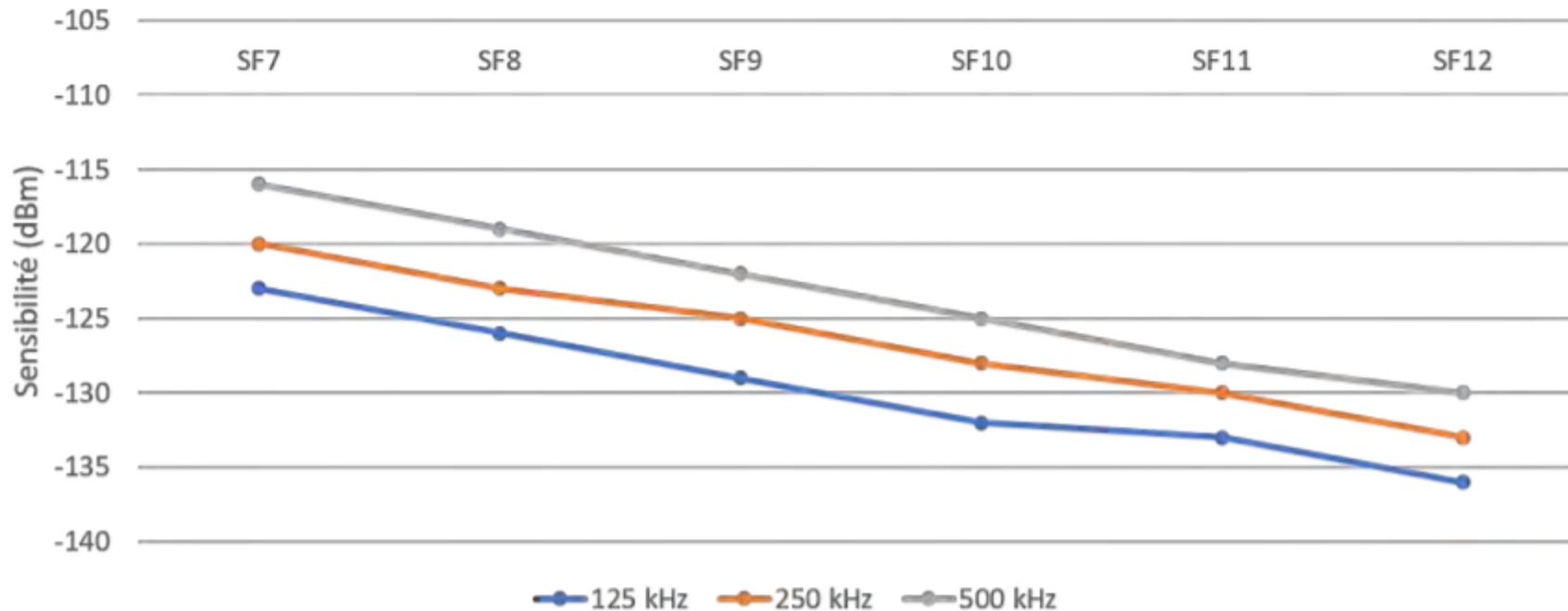
Donner le débit binaire correspondant pour SF7, 125 kHz, et pour SF12, 125 kHz

Réponse :

- **Cas 1** : Pour SF7, 125 kHz et CR4/5 → Débit = 6.836 kbps / 1.25 = 5469 bps
- **Cas 2** : Pour SF12, 125 kHz et CR4/5 → Débit = 366 bps / 1.25 = 293 bps



Sensibilité en fonction du SF



Sensibilités du dispositif LoRa Semtech SX1276 - Source : Semtech



Format d'un paquet LoRa

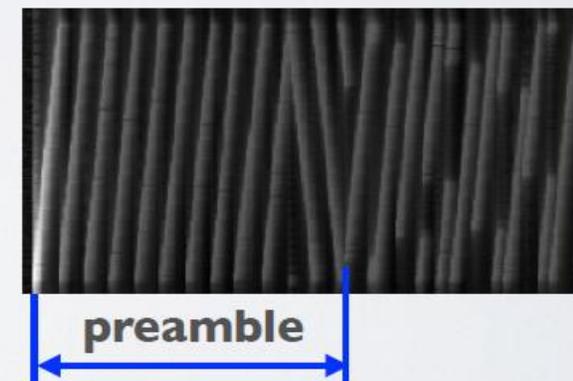
La détection d'erreur est optionnelle

Le Payload Length également mais il faudra que la longueur du message soit fixe et connu du récepteur

Explicit header mode



Implicit header mode





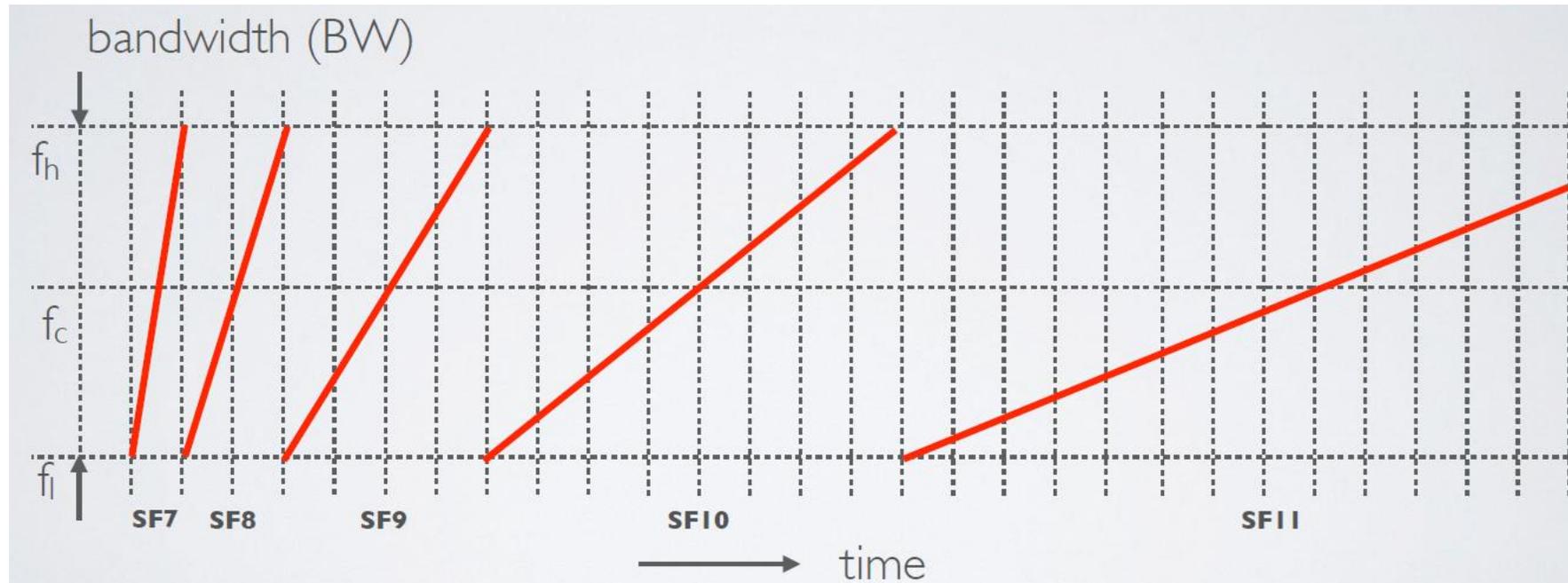
Time on Air (TOA)

La portée est inversement proportionnelle à la vitesse de modulation.

La modulation est auto-adaptative.

Il est nécessaire de réduire la vitesse de modulation si la distance augmente et donc d'augmenter le TOA.

Cela a pour conséquence de diminuer le débit binaire (bits/sec)





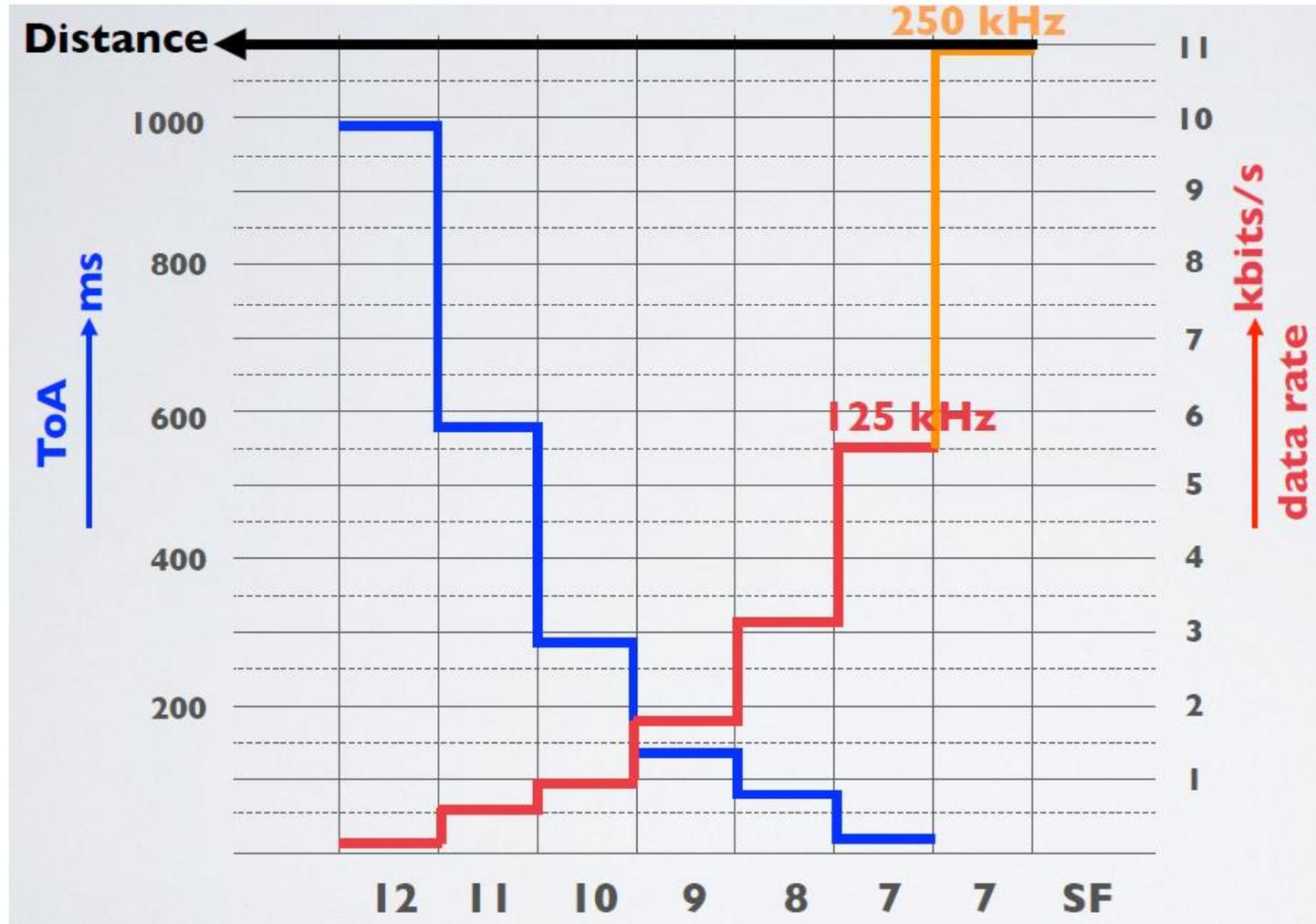
SF & TOA

- Exemple :
- Préambule = 8bits
Explicite header activé
CRC activé
Charge (payload)=10 octets
CR=1
BW=125KHz

Spreading Factor	Time on Air (ms)
7	41
8	72
9	144
10	289
11	578
12	991

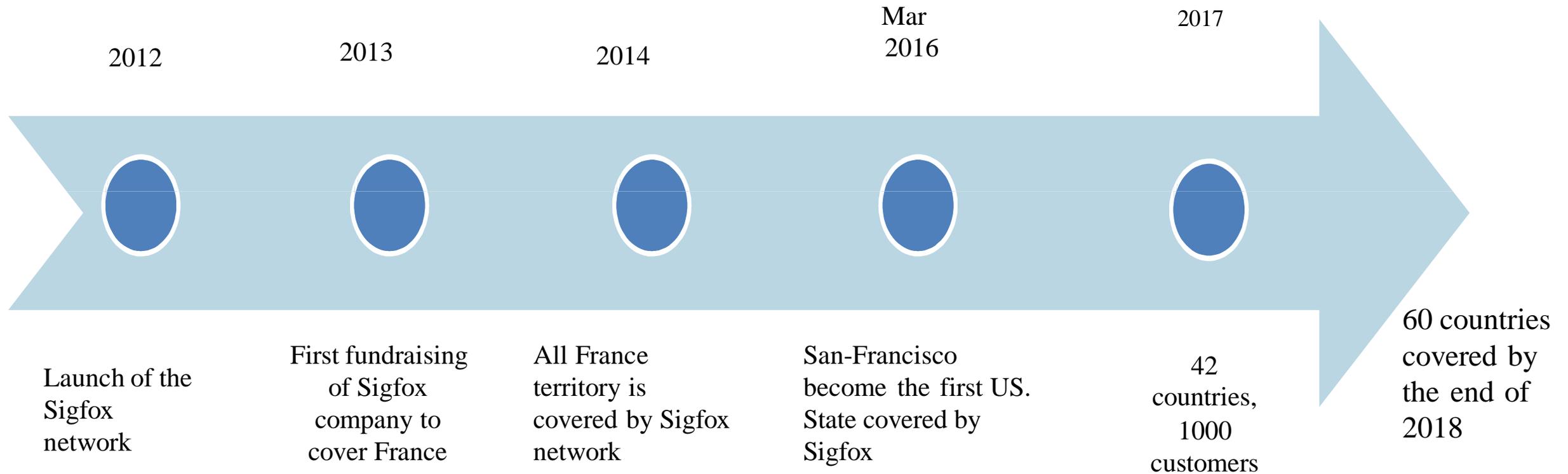


Time On Air vs Data Rate / Spreading Factor





Sigfox – Development





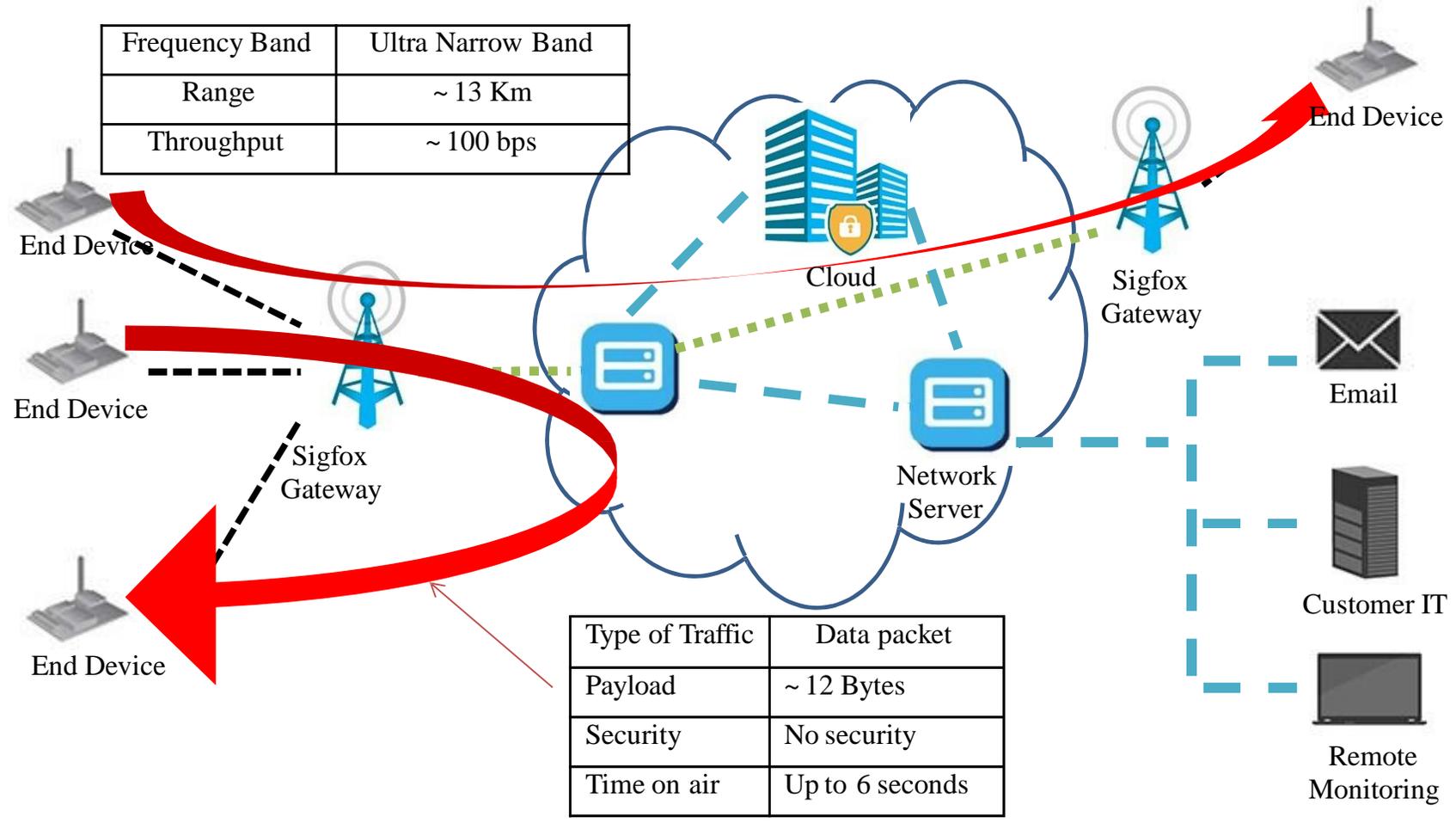
Sigfox – Overview

- First LPWAN Technology (BPSK based transmission)
- The physical layer based on an Ultra-Narrow band wireless modulation
- **Proprietary system**
- Low throughput (~100 bps)
- Low power
- Extended range (up to 50 km)
- 140 messages/day/device
- Subscription-based model
- Cloud platform with Sigfox –defined API for server access
- **Roaming capability**
- Takes very narrow parts of spectrum and changes the phase of the carrier radio wave to encode the data





Sigfox - Architecture



Frequency Band	Ultra Narrow Band
Range	~ 13 Km
Throughput	~ 100 bps

Type of Traffic	Data packet
Payload	~ 12 Bytes
Security	No security
Time on air	Up to 6 seconds



LoRa vs. Sigfox

- **Sigfox** est prévu pour envoyer 140 messages de 12 octets à 300 bauds par jour et recevoir 4 messages par jour.
LoRa envoie des messages plus longs (5KO) et sans limitation.
- **LoRa** optimise dynamiquement le lien entre l'objet (node) et la passerelle (gateway) ce qui permet des portées plus grandes (plus de 15Km en plaine)
- Le protocole **LoRa** est sous licence Semtech mais s'appuie sur un réseau « libre »
- **Sigfox** utilise les réseaux privés des opérateur téléphoniques
- **LoRa** et **Sigfox** utilise en Europe la bande des 868MHz



LoRa vs. Sigfox

- La radio LoRa repose sur une transmission à étalement de spectre.
Faible amplitude mais spectre large.
- La radio Sigfox repose sur une transmission sur un **spectre de fréquences très étroit (Ultra Narrow Band)** mais avec plus de puissance.



Weightless - Overview



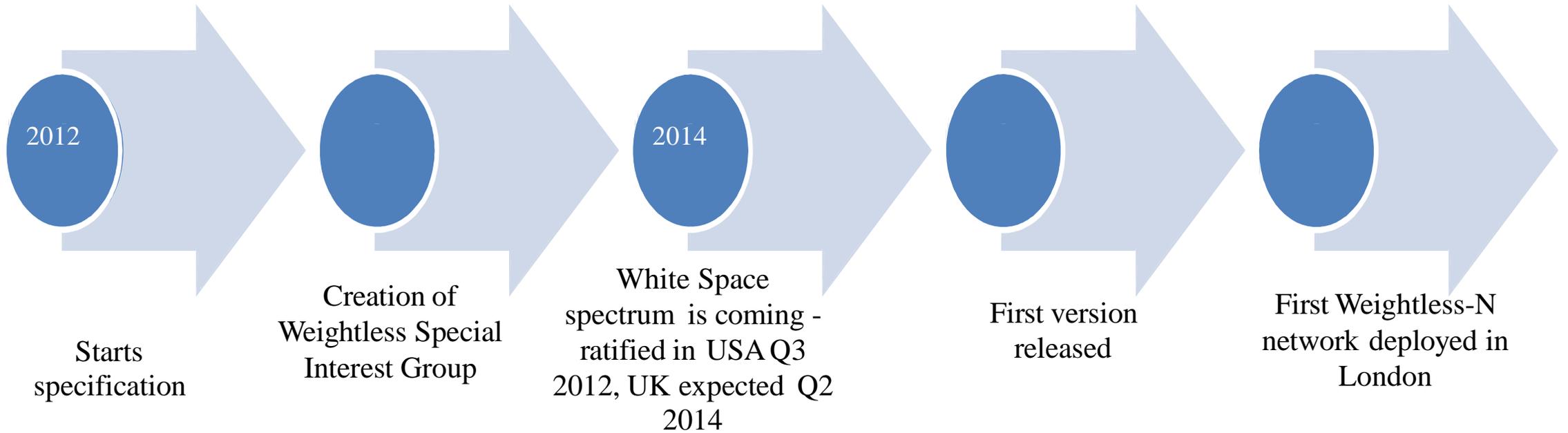
- Low cost technology to be readily integrated into machines
- Operates in an unlicensed environment where the interference caused by others cannot be predicted and must be avoided or overcome.
- Ability to operate effectively in unlicensed spectrum and is optimized for M2M.
- Ability to handle large numbers of terminals efficiently.

Frequency Band	Narrow Band
Range	~ 13 Km
Throughput	~ 10 Mbps

Type of Traffic	Data packet
Payload	~ 200 Bytes
Security	AES Encryption



Weightless – Development





Weightless – Versions

	Weightless-N	Weightless-P	Weightless-W
Communication	1-way	2-ways	2-ways
Range	5Km+	2Km+	5Km+
Battery life	10 years	3-8 years	3-5 years
Terminal cost	Very low	Low	Low-medium
Network cost	Very low	Medium	Medium
Data Rate	Up to 10 Mbps	Up to 100 Kbps	Up to 200 Kbps



RPMA – Overview



- **Random Phase Multiple Access (RPMA) technology is a low-power, wide-area channel access method used exclusively for machine-to-machine (M2M) communication**
 - Uses the popular 2.4 GHz band
 - Offer extreme coverage and High capacity
 - Allows handover (channel change) with Excellent link capacity
- **RPMA is a Direct Sequence Spread Spectrum (DSSS) using**
- Convolutional channel coding, gold codes for spreading
- 1 MHz bandwidth
- TDD frame with power control in both open and Closed Loop Power Control





RPMA – Development



2008



RPMA was developed by On-Ramp Wireless to provide connectivity to oil and gas actors

September
2015



it was renamed Ingenu, and targets to extend its technology to the IoT and M2M market

2016



RPMA was implemented in many places
Austin, Dallas/Ft. worth,
Houston, TX, Phoenix, AZ,
....

2017



RPMA will be introduced in many others countries: Los Angeles, San Francisco-West Bay, CA, Washington, D C, Baltimore, MD, Kansas City



EnOcean



- **Ultra low power radio technology based on miniaturized power converters**
 - Power is generated by harvesting energy from motion, light or temperature (e.g. pressure on a switch or by photovoltaic cell)
 - These power sources are sufficient to power each module to transmit wirelessly and have battery-free information.

- **Frequencies:**
 - 868 MHz for Europe and 315 MHz for the USA

- **EnOcean Alliance**
 - By 2014 = more than 300 members (Texas, Leviton, Osram, Sauter, Somfy, Wago, Yamaha ...)



ZWave



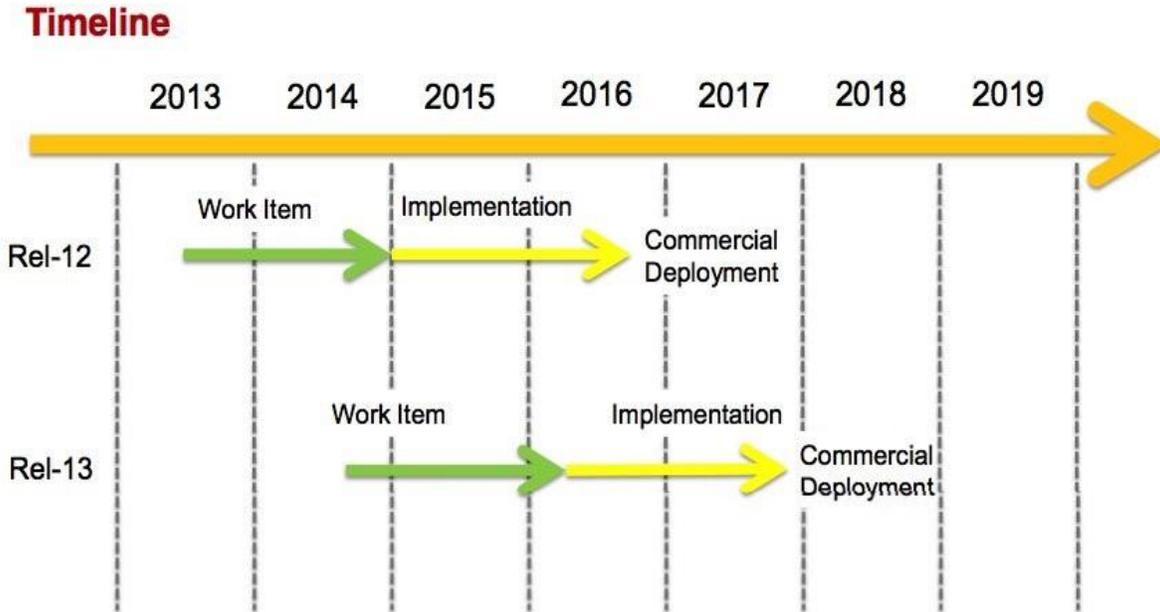
- **Low power radio protocol**
- **Home automation (lighting, heating, ...) applications**
- **Low-throughput: 9 and 40 kbps**
- **Battery-operated or electrically powered**
- **Frequency range: 868 MHz in Europe, 908 MHz in the US**
- **Range: about 50 m (more outdoor, less indoor)**
- **Mesh architecture possible to increase the coverage**
- **Access method type CSMA / CA**
- **Z-Wave Alliance: more than 100 manufacturers**



LTE-M - Overview



- Evolution of LTE optimized for IoT
- Low power consumption and autonomous
- Easy Deployment
- Interoperability with existing LTE networks
- Coverage upto 11 Km
- Max Throughput ≤ 1 Mbps



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- ✓ First released in Rel.1 in 2 Q4 2014
- ✓ Optimization in Rel.13
- ✓ Specifications completed in Q1 2016
- ✓ Available since 2017



LTE to LTE-M

3GPP Releases	8 (Cat.4)	8 (Cat. 1)	12 (Cat.0) LTE-M	13 (Cat. 1,4 MHz) LTE-M
Downlink peak rate (Mbps)	150	10	1	1
Uplink peak rate (Mbps)	50	5	1	1
Number of antennas (MIMO)	2	2	1	1
Duplex Mode	Full	Full	Half	Half
UE receive bandwidth (MHz)	20	20	20	1.4
UE Transmit power (dBm)	23	23	23	20

Release 12

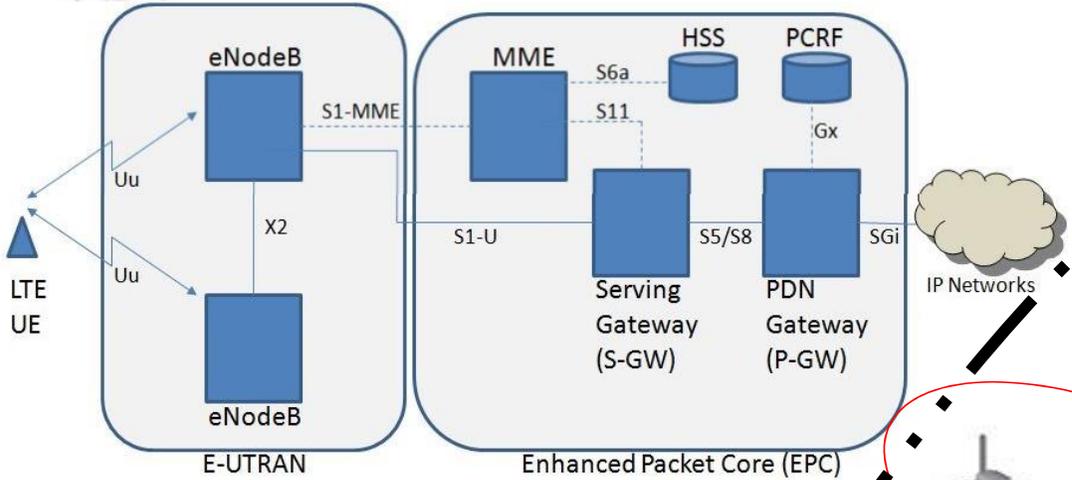
- New category of UE (“Cat-0”): lower complexity and low cost devices
- Half duplex FDD operation allowed
- Single receiver
- Lower data rate requirement (Max: 1 Mbps)

Release 13

- Reduced receive bandwidth to 1.4 MHz
- Lower device power class of 20 dBm
- 15dB additional link budget: better coverage
- More energy efficient because of its extended discontinuous repetition cycle (eDRX)

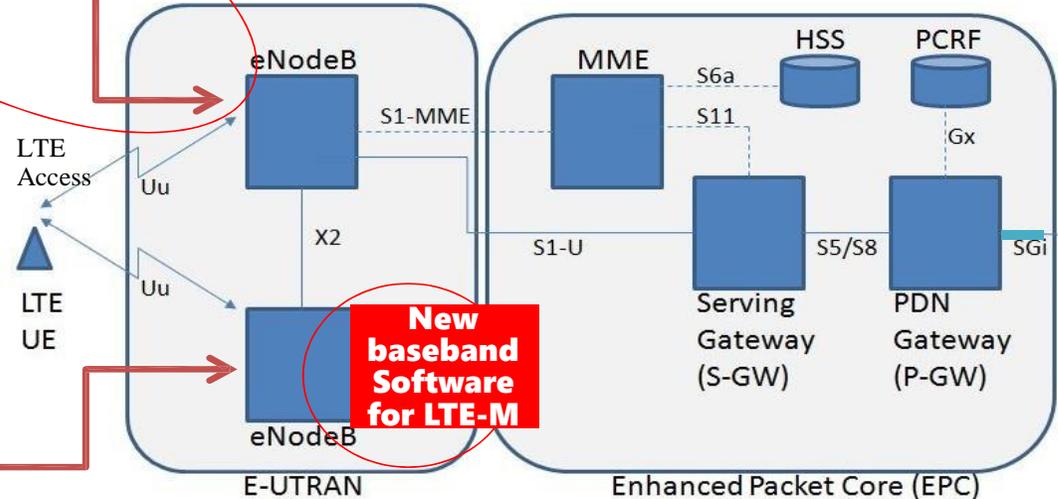


LTE to LTE-M - Architecture

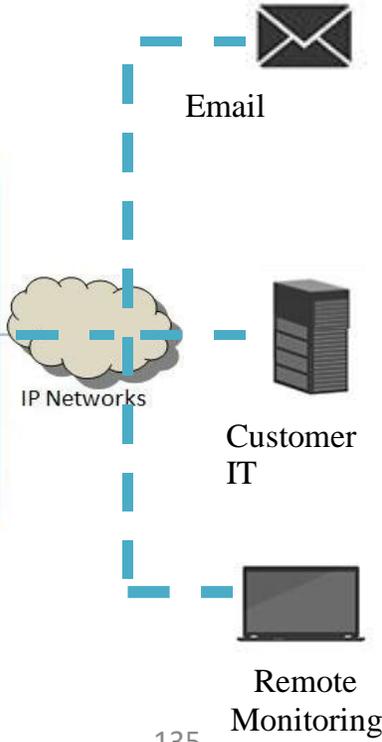


Frequency Band	Narrow Band
Access	LTE-M
Range	~ 11 Km
Throughput	~ 1 Mbps

Present LTE Architecture



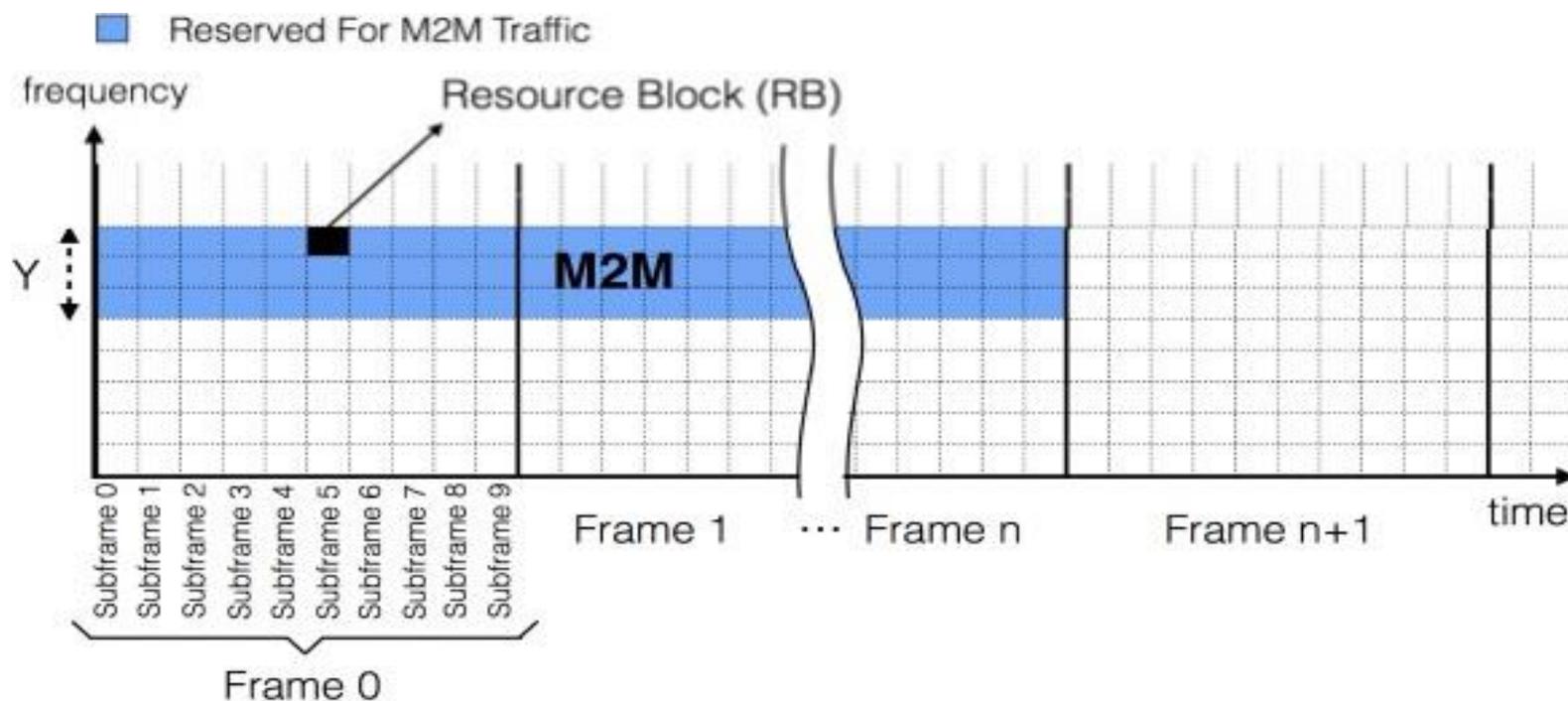
Enhancement for LTE-M





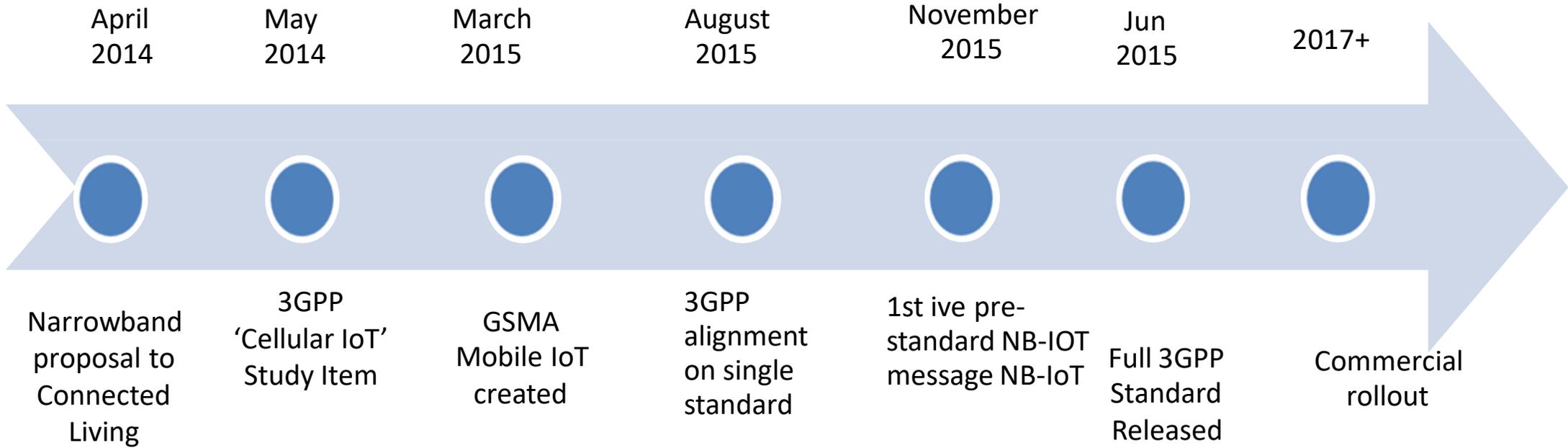
LTE-M

- Licensed Spectrum
- Frequency Bands: 700-900 MHz for LTE
- Some resource blocks are allocated to IoT on LTE bands





NB-IoT





NB-IoT

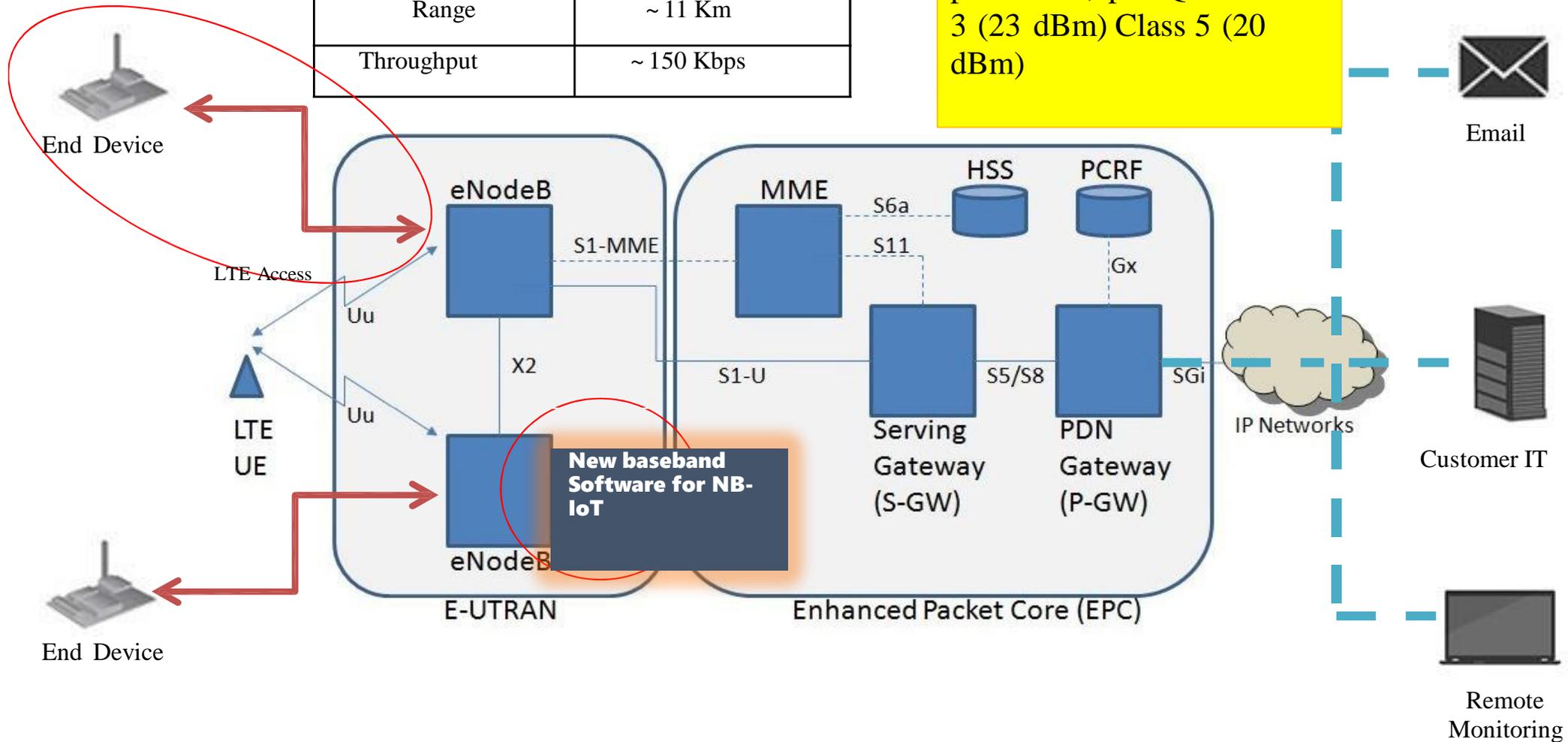
- **Uses LTE design extensively** e.g. DL: FDMA, UL: SC-FDMA
- **Lower cost** than eMTC (Narrow band: supports 180 KHz channel)
- **Extended coverage:** 164 dB maximum coupling loss or link budget (at least for standalone) in comparison to GPRS link budget of 144dB and LTE of 142.7 dB
- **Low Receiver sensitivity** = -141 dBm
- **Long battery life:** 10 years with 5 Watt Hour battery (depending on traffic and coverage needs)
- **Support for massive number of devices:** at least 50.000 per cell
- **3 modes of operation:**
 - **Stand-alone:** *stand-alone carrier, e.g. spectrum currently used by GERAN (GSM Edge Radio Access Network) systems as a replacement of one or more GSM carriers*
 - **Guard band:** *unused resource blocks within a LTE carrier's guard-band*
 - **In-band:** *resource blocks within a normal LTE carrier*



NB-IoT - Architecture

Frequency Band	Ultra Narrow Band
Range	~ 11 Km
Throughput	~ 150 Kbps

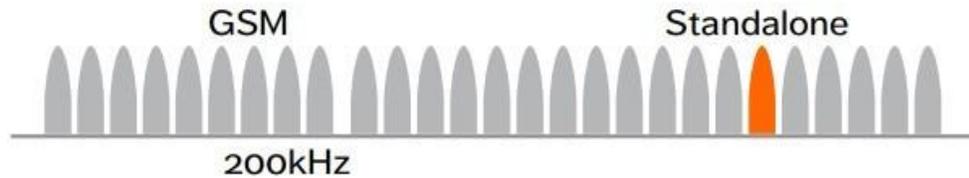
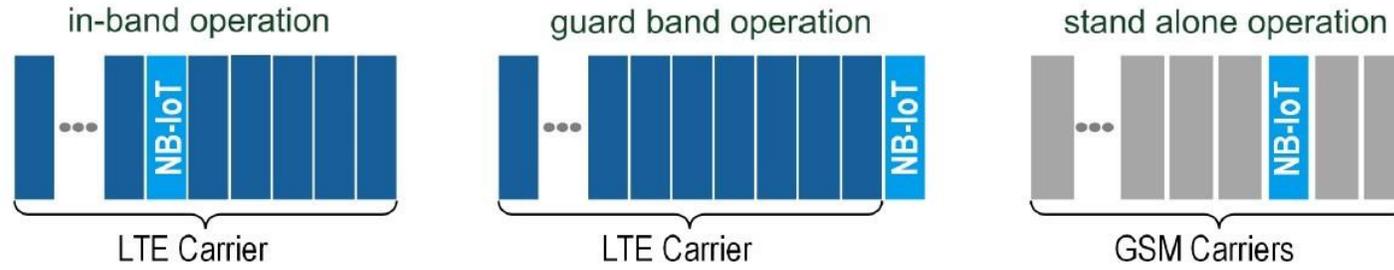
HD-FDD
p/2 BPSK, p/4 QPSK Class 3 (23 dBm) Class 5 (20 dBm)



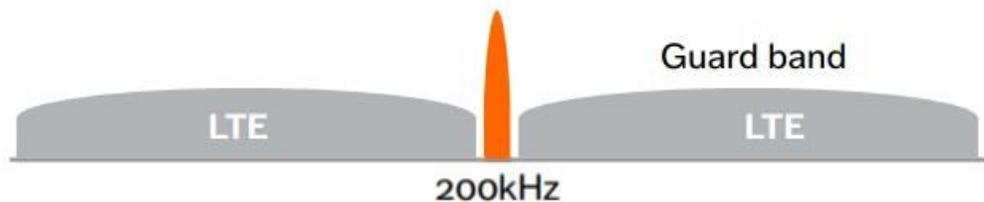


NB-IoT – Spectrum & Access

Designed with a number of deployment options for licensed GSM, WCDMA or LTE spectrum to achieve efficiency



Stand-alone operation
Dedicated spectrum.
Ex.: By **re-farming GSM channels**



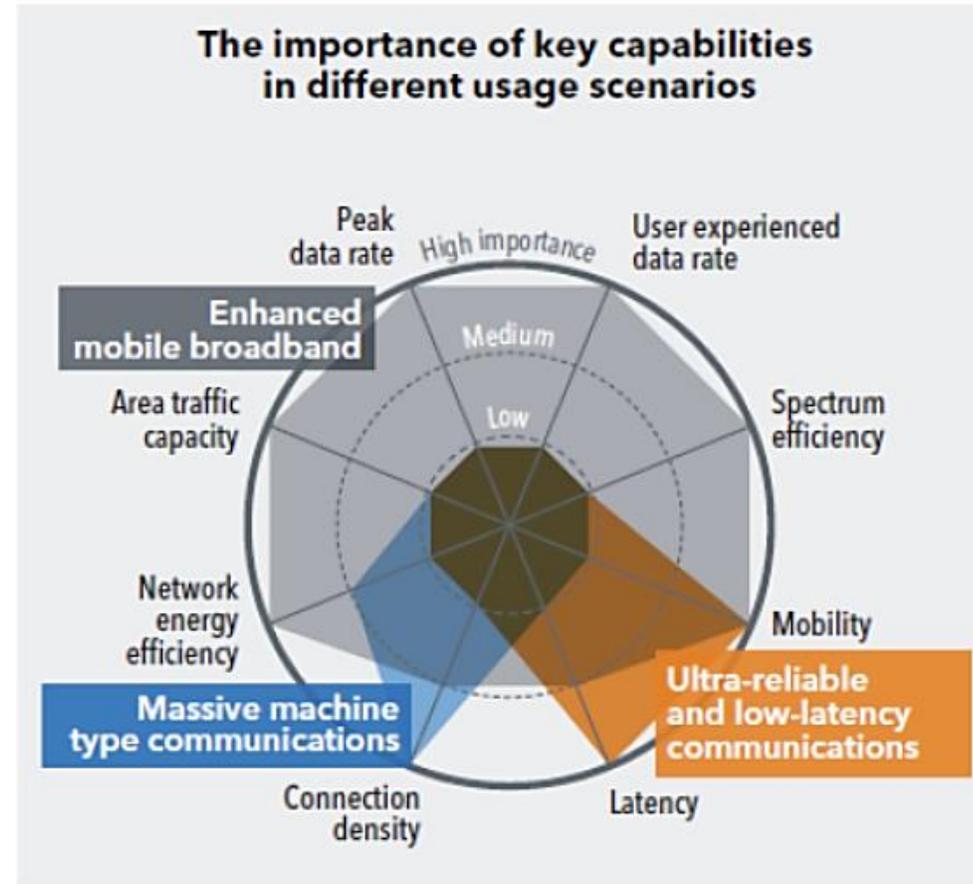
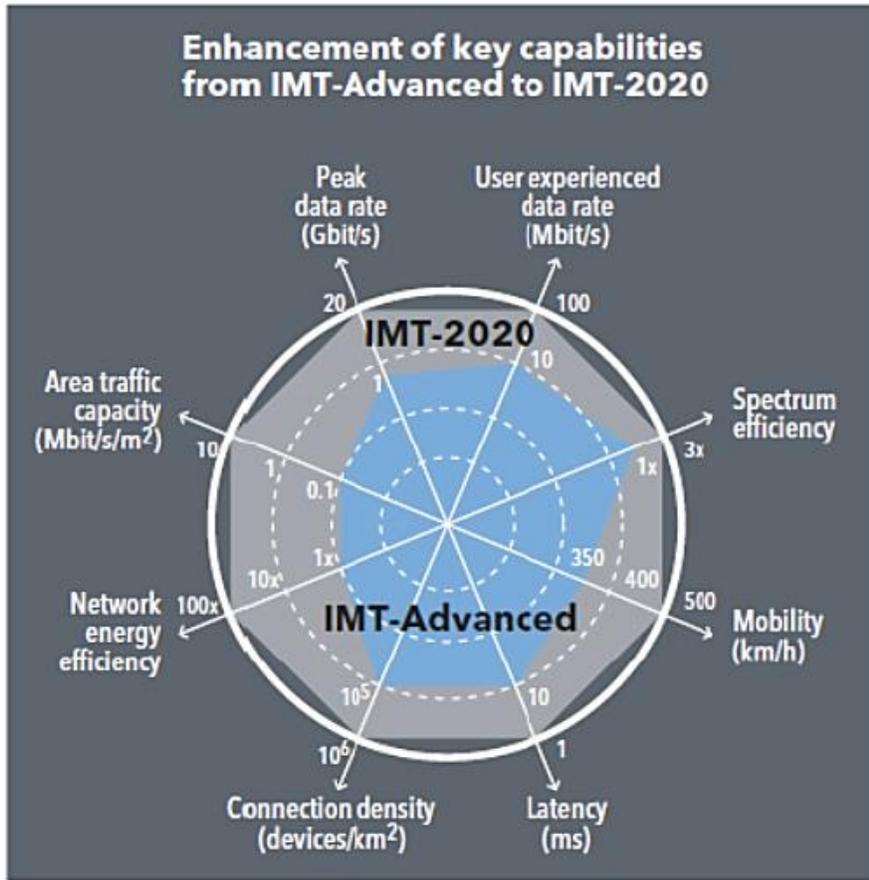
Guard band operation
Based on the unused RB within a LTE carrier's **guard-band**



In-band operation
Using **resource blocks** within a normal LTE carrier



IMT 2020 (5G) Supporting IoT



The values in the figures above are targets for research and investigation for IMT-2020 and may be revised in the light of future studies. Further information is available in the IMT-2020 Vision (**Recommendation ITU-R M.2083**)



IMT-2020 (5G) Network slicing to Supports IoT



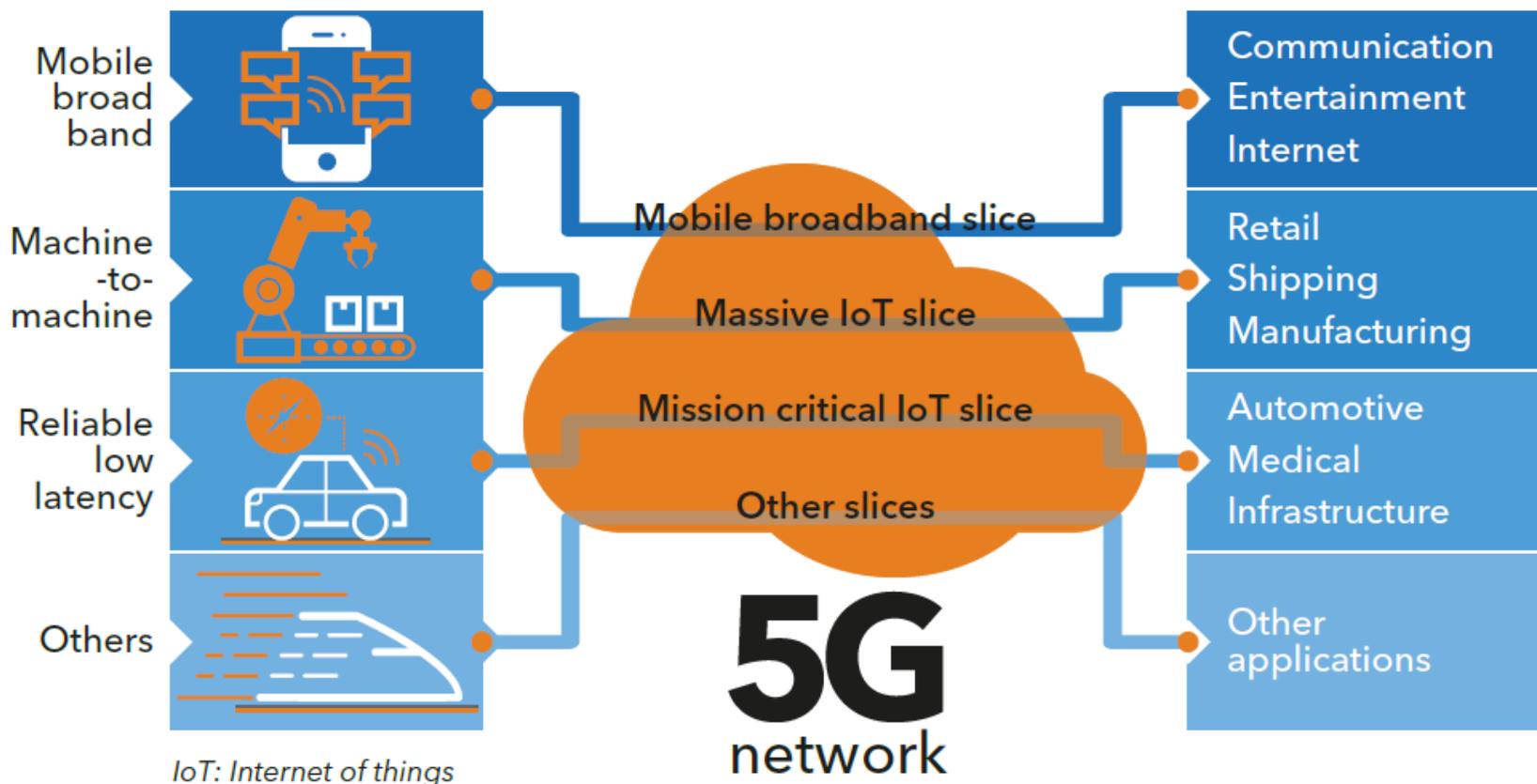
4G networks do not enable the range of services that the future requires. 5G will be faster and more flexible.

4G
network

Source: Forging paths to IMT-2020 (5G), Stephen M. Blust, Chairman, ITU Radiocommunication Sector (ITU-R) Working Party 5D, Sergio Buonomo, Counsellor, ITU-R Study Group 5, ITU News, 02/2017

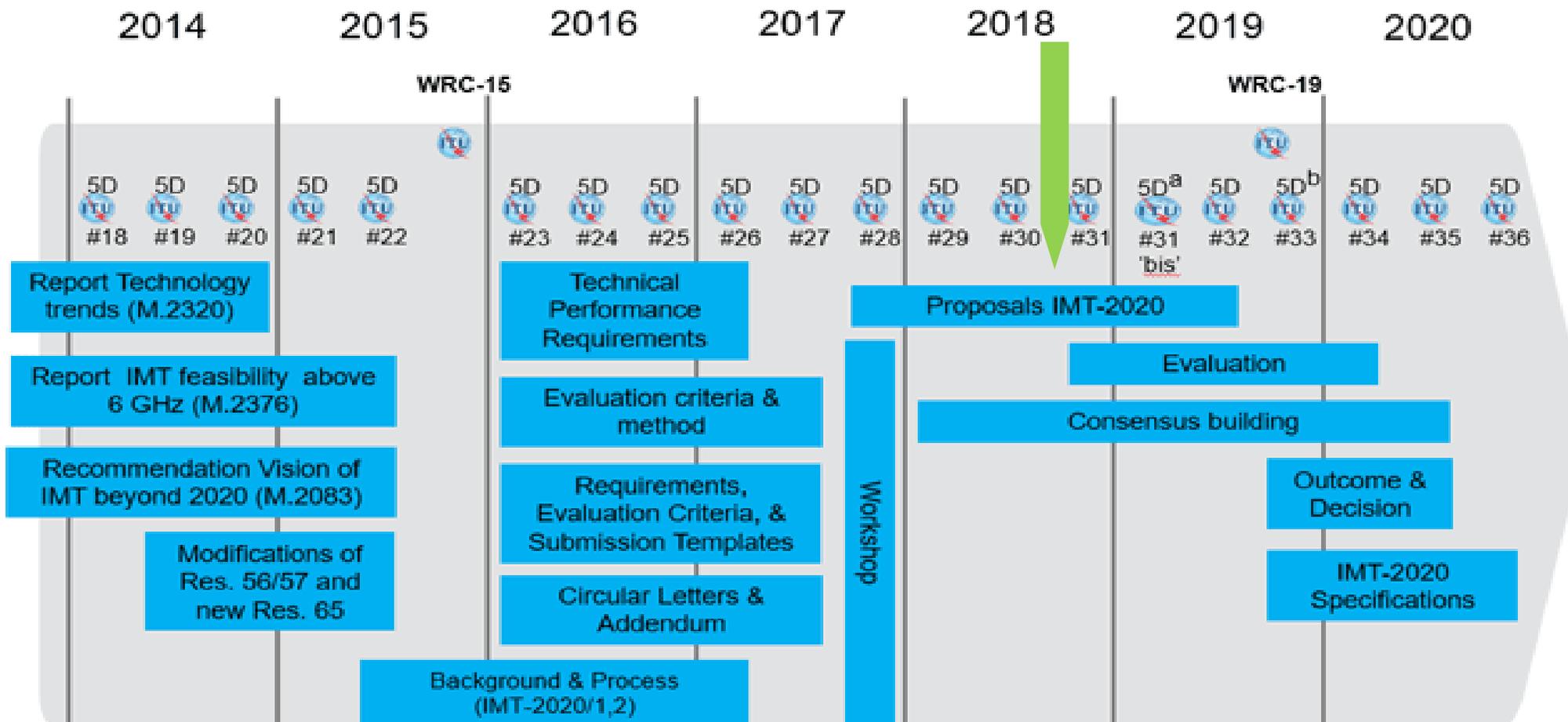
5G network slicing

5G network slicing enables service providers to build virtual end-to-end networks tailored to application requirements.





IMT-2020 (5G) – Detailed Timeline and Process in ITU



(a) – five day meeting, (b) – focus meeting on Evaluation (Technology)

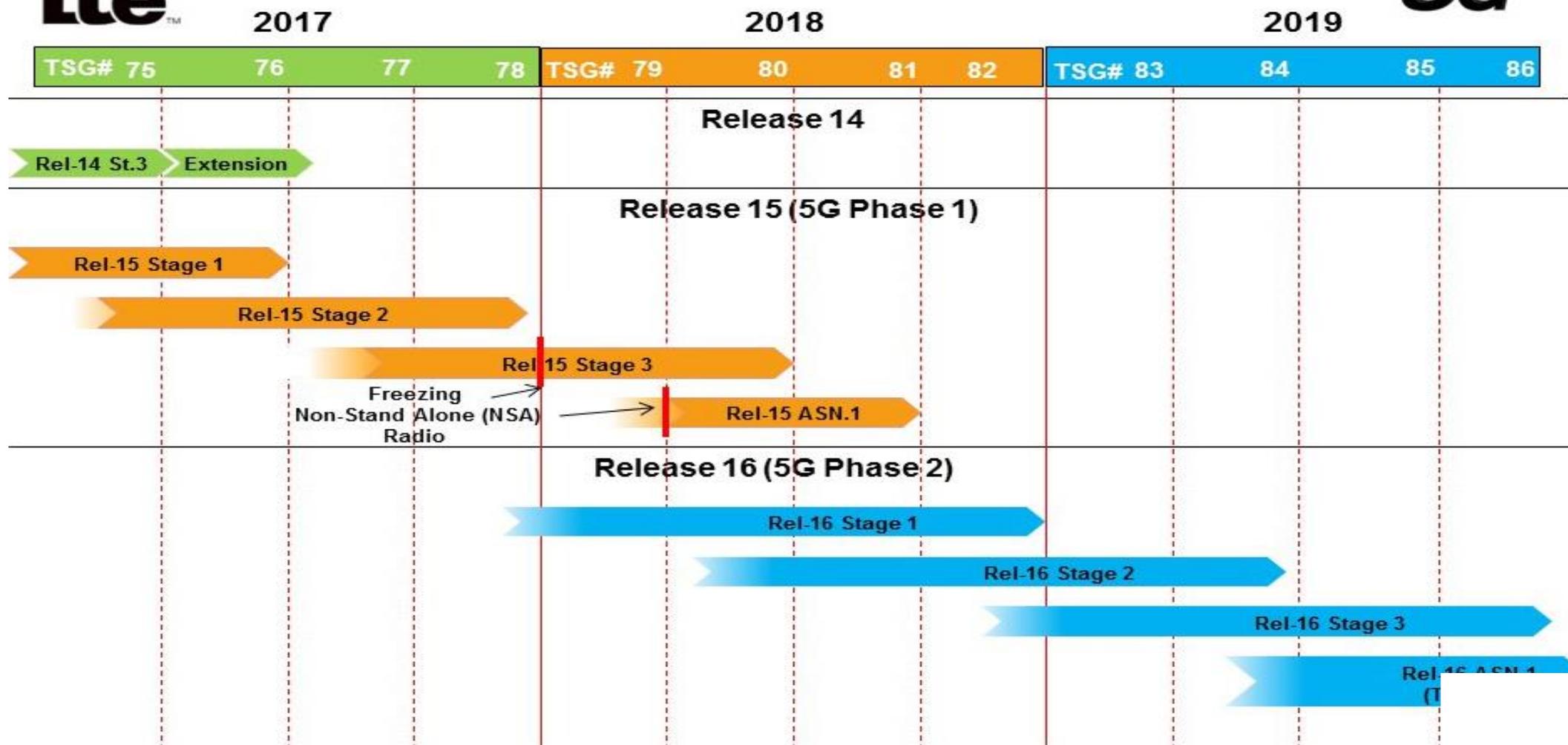
Note: While not expected to change, details may be adjusted if warranted.



5G and 3GPP Releases evolution



3GPP Ongoing Releases

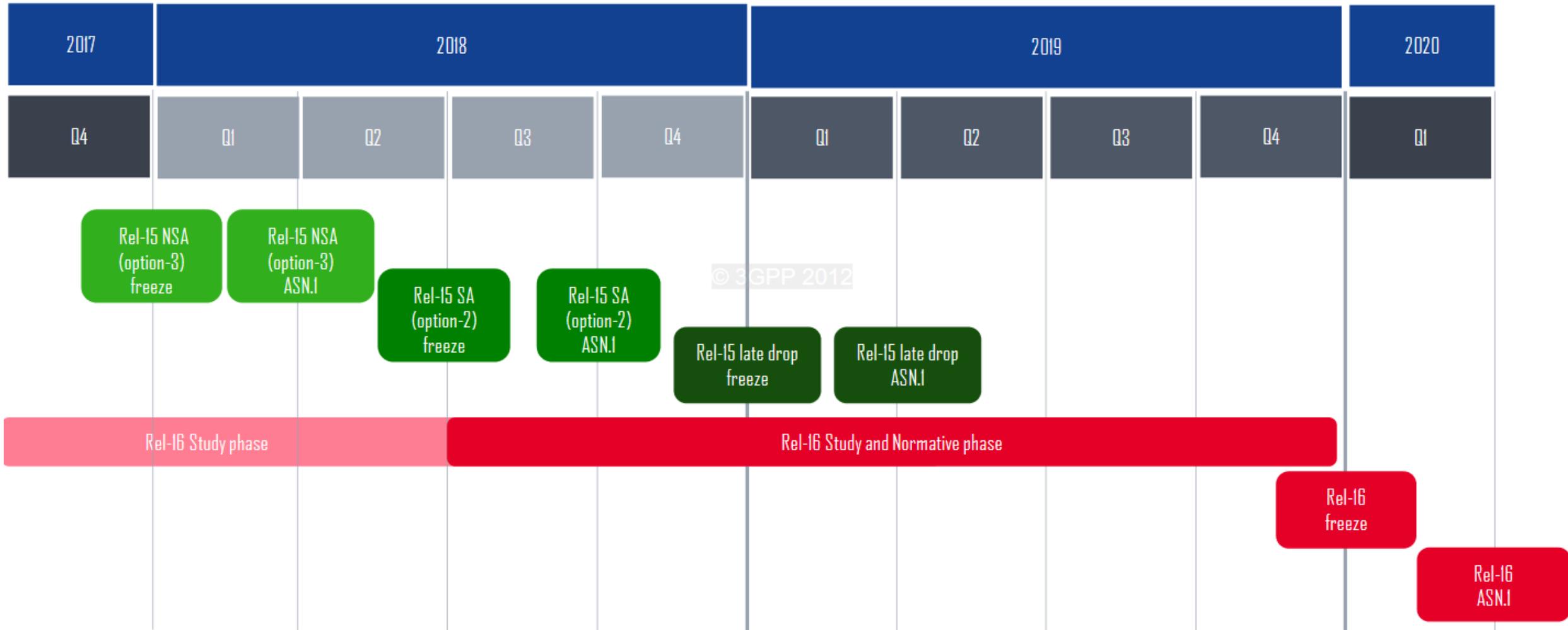


Source: http://www.3gpp.org/images/articleimages/ongoing_releases_900px.JPG

Your Logo

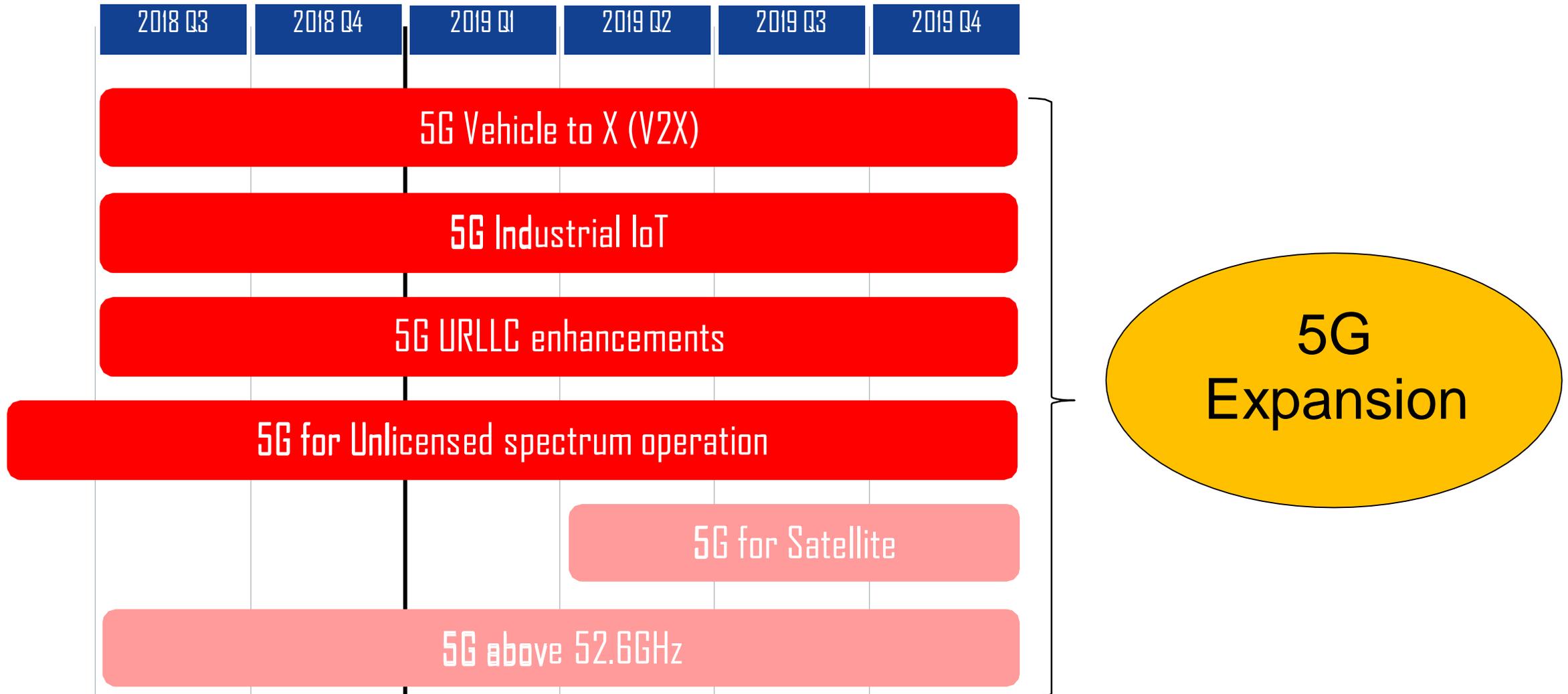


3GPP Release 16 - Timeline





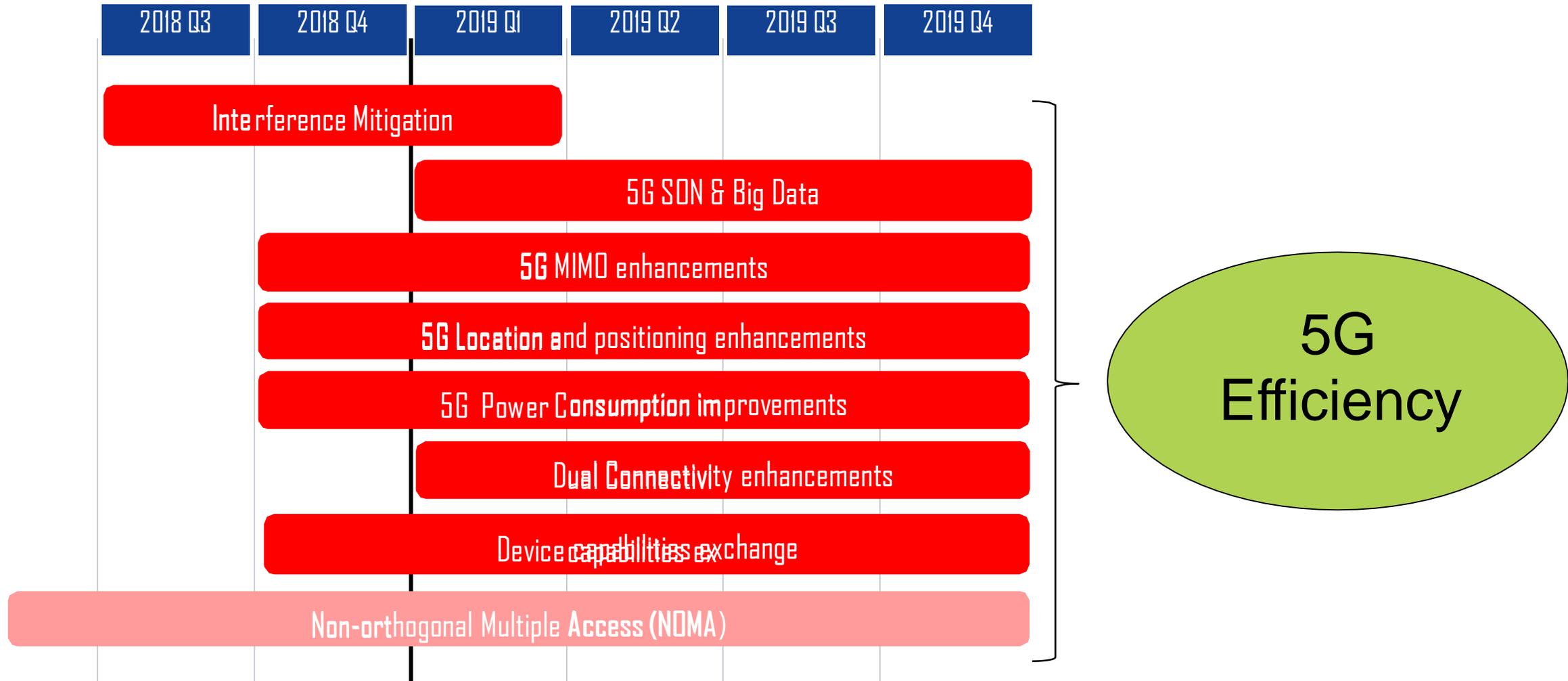
3GPP Release 16 – 5G expansion



Source: [http://www.3gpp.org/ftp/Information/presentations/presentations_2018/RAN80_webinar_summary\(brighttalk\)extended.pdf](http://www.3gpp.org/ftp/Information/presentations/presentations_2018/RAN80_webinar_summary(brighttalk)extended.pdf)



3GPP Release 16 – 5G Efficiency





Examples from of current IoT Market

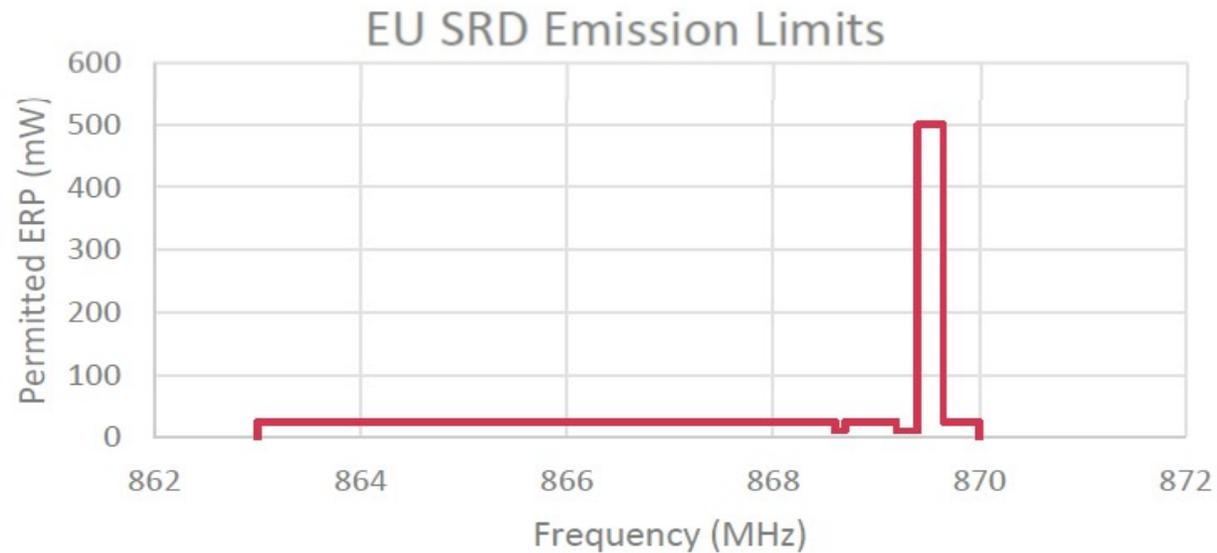
- Regulation
- Pricing
- Future analysis and issues



Regulations: Example

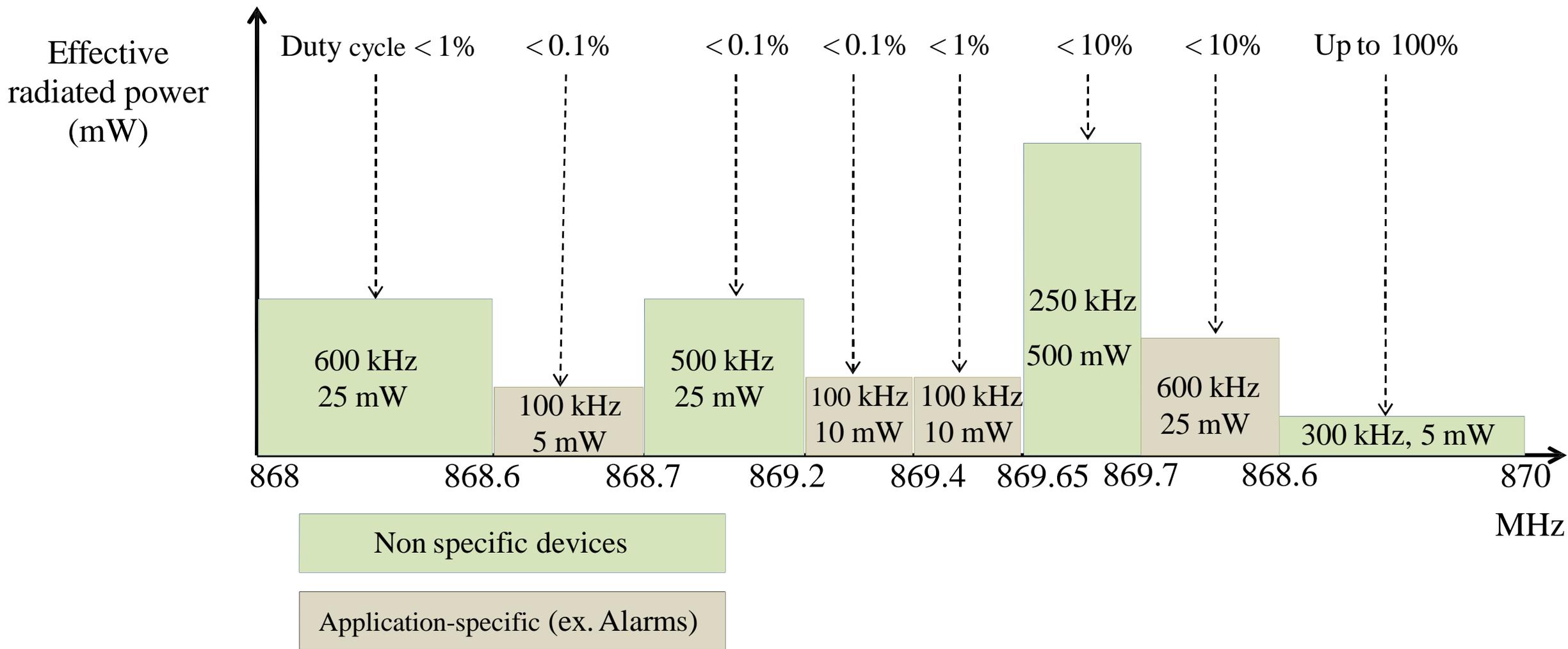
ARCEP- France

Link	Activity rate	Power
DL	10%	25 mW
UL	1%	500 mW





Regulations: Example Tunisia





Infrastructure Capex Estimates: 5G Example

CAPEX for scenario 1 – **Large dense city**

Item	Value
Total CAPEX (USD millions)	55.5
Number of small cell sites	1 027
Cost per square km (USD millions)	3.7
CAPEX per site (USD thousands)	54.1

CAPEX for scenario 2 – **Small less dense city**

Item	Value
Total CAPEX (USD millions)	6.8
Number of small cell sites	116
Cost per square km (USD millions)	2.3
CapEx per site (USD thousands)	58.6

Small cell distance	Scenario 1	Scenario 2
RAN equipment (antenna, street cabinet, base station electronics, battery backup and network maintenance modules)	25%	24%
Implementation costs (design and planning costs, site upgrade costs, permit costs and civils costs to lay street cabinets)	50%	46%
Fibre (provision of 144 fibre along the route of activated street assets)	25%	30%
MER (single rack and termination equipment)	<0.1%	<0.1%



Chipset Costs

LoRAWAN	NB-IoT	LTE-M
<p>1. MICROCHIP Interface: UART Stack / MAC: LoRaWAN Stack implementation: Microchip proprietary Price: \$14.27 @ single unit \$10.90 @ 1000 units</p> <p>2. MULTITECH Interface: UART Stack / MAC: LoRaWAN Stack implementation: MultiTech proprietary (XBEE compatible) Price: ~\$30 @ single unit</p>	<p>1. NB-IoT Quectel BC95 3GPP Rel-13 Interfaces SIM/USIM 1 Transmission 100bps Price: \$ 40,00</p> <p>2. Digi XBee Cellular NB-IOT Up to ~60Kbps Downlink, 25Kbps Uplink 1 antenna design, 200 mW (23 dBm) Band 20 (800MHz) Band 8 (900MHz) \$30-60 Single unit</p> <p>3. Quectel Module GSM/GPRS/UMTS/HSPA/NB-IoT \$ 68,00Single unit</p>	<p>Digi International XBee™ Cellular LTE-M Embedded Modem</p> <p>200mW (23dBm) Tx power 3.0V to 4.3V supply voltage Up to 384kbps RF throughput Up to 1Mbps DL or UL speed NB-IoT Ready with a future over-the-air update</p> <p>\$ 69Single unit</p>





Market solution Pricing: NB-IoT Example



➤ 2017

- The NB-IoT access entry package is available from **EUR 199** Includes a *6-month activation of up to 25 SIM-cards with 500 KB per SIM pooled in Germany's NB-IoT network*. As a further optional add-on – a private APN with IPsec-key encryption is available.
- The NB-IoT Access & Cloud of Things entry package is available from **EUR 299** and additionally includes direct access to Deutsche Telekom's Cloud of Things platform for device and data management.

<https://www.telekom.com/en/media/media-information/archive/first-narrowband-iot-service-packages-launched-in-germany-497494>

➤ IN 2018

- Europe's first data flat rate for the Internet of Things with joint offering by Deutsche Telekom and 1NCE, designed especially for business customers. It provides connectivity for devices using low data volumes in the Internet of Things (or IoT). The prepaid rates can now be booked from the 1NCE webshop.
- For a one-off price of **10 Euros**, customers receive a industrial IoT eSIM card with a data volume of **500 MB** and **250 SMS** messaging for use in the Internet of Things.

<https://www.telekom.com/en/media/media-information/archive/pay-once-use-over-ten-years-533898>



Market Pricing: LoraWan Example



2017

Price Plan	Data Allowance* (Frequency of communication)	Monthly Flat Rate (VAT Excluded)	Examples of Services	Note
Band IoT 35	100KB	KRW 350	Metering and monitoring services (e.g. Advanced Metering Infrastructure (AMI), environmental monitoring, water leakage monitoring, etc.)	- Discount benefits for long-term contracts: Ranging from a 5% discount for two-year contracts to a 20% discount for 5 year-contracts - Multi-line discount: Ranging from a 2% discount for those using 500 lines to a 10% discount to those who use 10,000 lines
Band IoT 50	500KB	KRW 500		
Band IoT 70	3MB	KRW 700	Tracking services (e.g. locating tracking	
Band IoT 100	10MB	KRW 1,000	For people/things, asset management, etc.)	
Band IoT 150	50MB	KRW 1,500	Control service (e.g. safety management, lighting control, shared parking, etc.)	
Band IoT 200	100MB	KRW 2,000		

*Data usage exceeding the data allotment provided will be charged at KRW 0.005 per 0.5KB.



Market Pricing: Sigfox Example



Network subscription charges: S\$1 per device per month, which comes with a data plan for up to 140 messages per day.

Qualified channel partners who commit to volume can ultimately enjoy subscription charges from as low as **S\$1 per device per year**.

<https://www.unabiz.com/unabiz-announces-iot-connectivity-from-1-per-year/>



Market Pricing: LTE-M Example

LTE-M

**One rate -
unlimited data
for \$30/year***

LTE-M provides nationwide, carrier grade security with optimized features designed specifically for IoT applications. *Price is exclusive of taxes and fees. Terms and Conditions provided in frequently asked questions below.

LTE-M Button

Starting at
**34.99 per
device**

The AT&T LTE-M Button is a programmable button using the AT&T nationwide LTE-M network and will be supported by AWS IoT 1-click. Price includes up to 1500 clicks or 36 months, whichever comes first. Price is exclusive of taxes and fees. Terms and conditions may apply.



AT&T



Market Pricing: Outcome Based Pricing

Source: GSMA Intelligence

Examples of OBP in three sectors

Sector – IoT application	Utility-based pricing	Outcome-based pricing
 <p>Industrial predictive maintenance</p>	Enterprise pays for real-time, secure, high-bandwidth connectivity.	Using equipment behaviour patterns, a jointly determined outcome could be the number of successful field engineer visits.
 <p>Automotive usage-based insurance risk management</p>	Enterprise pays for real time and roaming connectivity.	Using insights from aggregated driving behaviour, an insurance company can develop an average risk score that allows it to more accurately detect insurance fraud.
 <p>Utilities critical infrastructure monitoring</p>	Enterprise pays for private networks to collect equipment data from low-power sensors.	The supplier is paid if the utility achieves x% reduction in unscheduled grid blackouts.

OBP differs from traditional pricing:

instead of charging by traffic/volume or number of devices, it sets pricing for enterprise clients based on achieving jointly determined outcomes.

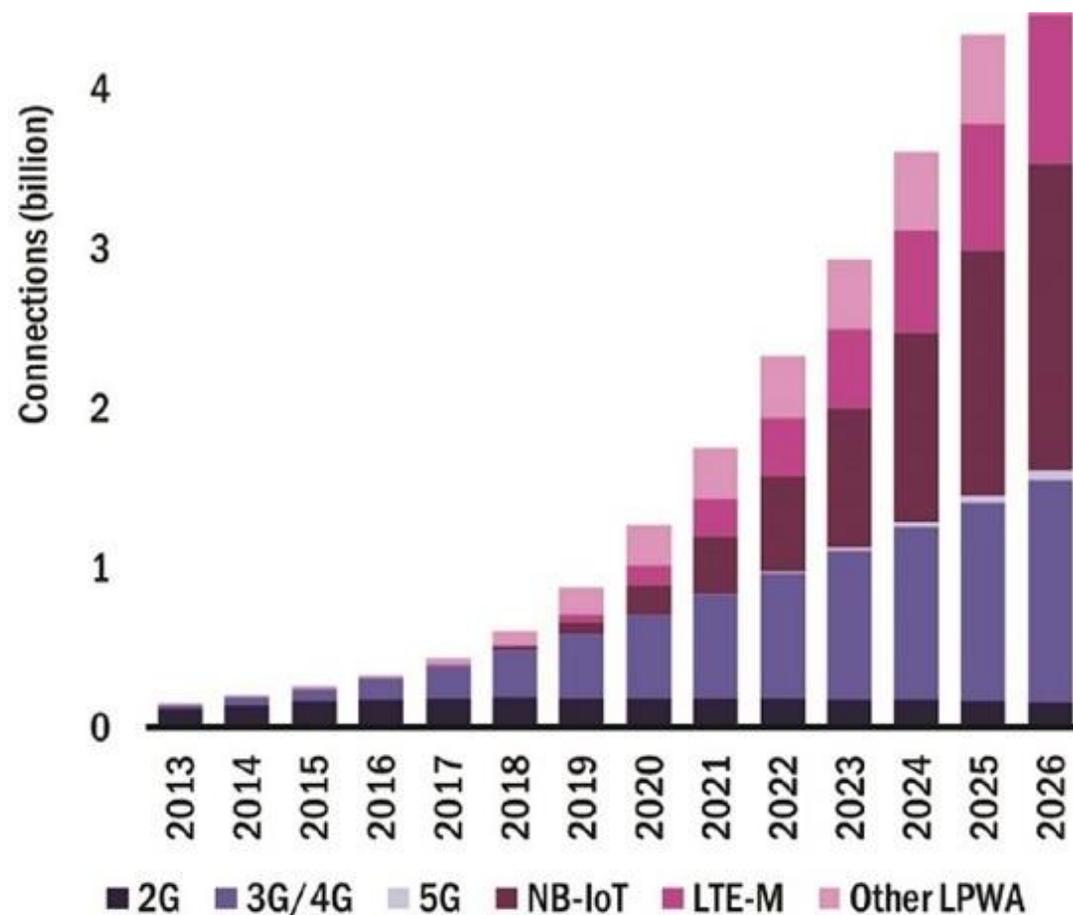
OBP attempts to drive service providers to deliver on results but also encourages sharing of the investment burden between enterprises and service providers.



Some Facts and forecasts

Analysis Mason:

- 3G and 4G will capture a 27% market share in 2026
- 5G will constitute just over 1% of the total connections in 2026, but this will be the average across all application groups. For automotive and embedded SIMs specifically, 5G will have a 4% share of the total connections.

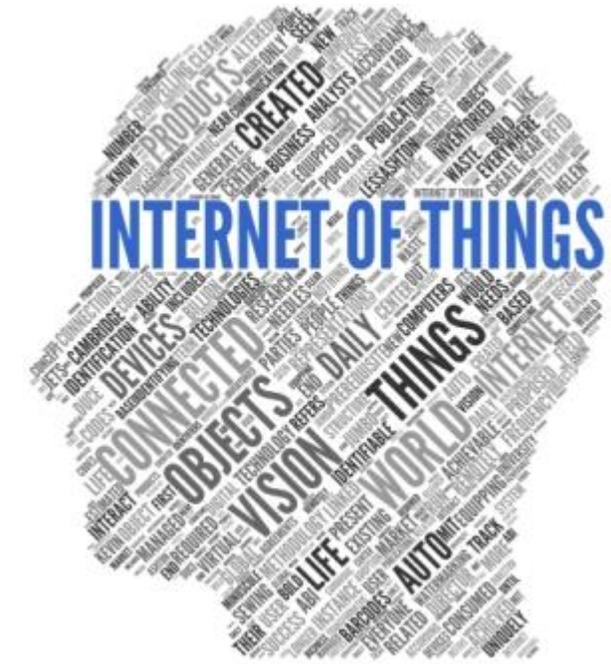


NB-IoT will be the dominant network for IoT in 2026
(Analysys Mason)



Future Issues of IoT

- ❖ Data Ownership
- ❖ Rights around derivative use of data
- ❖ Dynamic decision rights (change in consent)
- ❖ Consumer awareness
- ❖ Privacy rights
- ❖ Cybersecurity
- ❖ Liability (decision made by AI: health, transportation)
- ❖ Accuracy
- ❖ Public profit sharing
- ❖ Preventing oligopolies (Large tech companies taking over)
- ❖ Fairness (Some may not be able to afford)
- ❖ Disposal of electronic waste





References



ITU

**“Committed to
connecting the
WORLD”**