Session 3: IoT Standards

ITU Asia-Pacific Centre of Excellence Training
On
"Traffic engineering and advanced wireless network planning"

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Objectives

- Provide the main characteristics and features of IoT services and present IoT present systems and standards

I. Introduction

II. LPWAN Architecture

III. IoT Short Range and Long Range Systems

IV. State of Art

I. Introduction

Internet of things (IoT) [ITU-T Y.2060]: *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*.

NOTE 1 (from [ITU-T Y.2060]) – From a broad perspective, the IoT can be perceived as a vision with technological and societal implications.

NOTE 2 (from [ITU-T Y.2060]) – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, *whilst ensuring that security and privacy requirements are fulfilled.*

IETF’s definition of “things”

“In the vision of IoT, ‘things’ are very various such as computers, sensors, people, actuators, refrigerators, TVs, vehicles, mobile phones, clothes, food, medicines, books, etc. These things are classified as three scopes:

- **People**,
- **Machine** (for example, sensor, actuator, etc.)
- **Information** (for example, clothes, food, medicine, books, etc.).

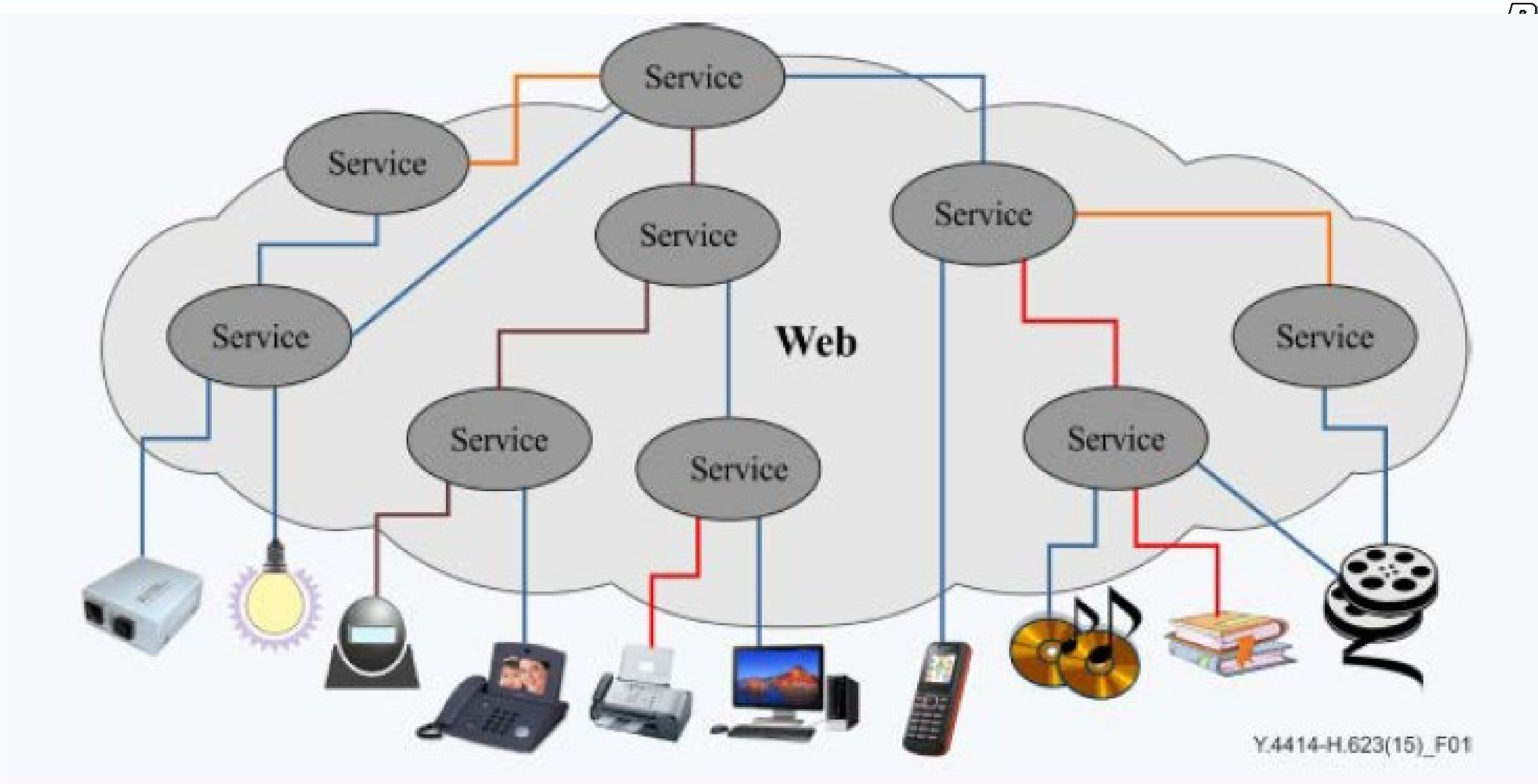
These ‘things’ should be identified at least by one unique way of identification for the capability of addressing and communicating with each other and verifying their identities. In here, if the ‘thing’ is identified, we call it the ‘object.’”

IEEE definition of IoT

“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

General Concept of Web of Things



*Source: Recommendation ITU-T **Y.4414/H.623 (11/2015)***

Technically, IoT consists in the direct digital and standardized identification (IP @, smtp, http protocols …) of a physical object through a wireless communication system.

IoT Specificities versus Cellular

IoT communications are or should be:

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

IoT Specificities

- **Low power**,
- **Low cost** (network and end devices),
- **Short** range (first type of technologies) or **Long** range (second type of technologies),
- **Low bit rate** (≠ broadband!),
- **Long battery** duration (years),
- Located in **any area** (deep indoor, desert, urban areas, moving vehicles …)

Quiz 1 – Introduction to IoT

1. IoT corresponds to which phase of Internet evolution?
2. What is the definition of IoT by ITU?
3. What are the characteristics of IoT?
4. What is the impact of IoT networks low power feature on the planning?
5. What is the impact of IoT networks long battery life feature on the planning?

II. LPWAN Architecture

IoT 4 layers model

Integrated Applications

Information Processing

Network Infrastructure

Sensing and Identification

IoT reference model

Levels

7 **Collaboration & Processes**
(Involving People & Business Processes)

6 **Application**
(Reporting, Analytics, Control)

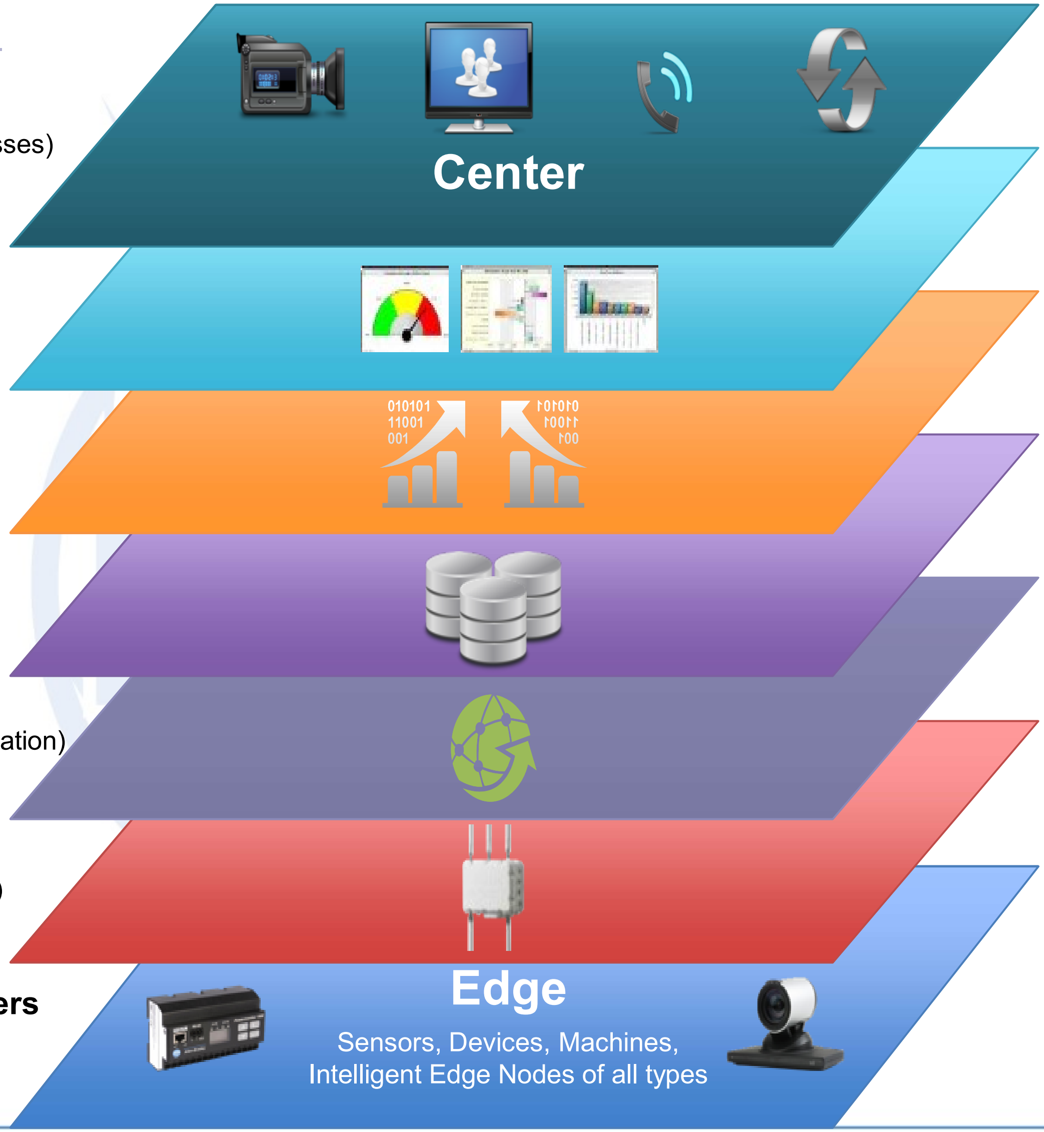
5 **Data Abstraction**
(Aggregation & Access)

4 **Data Accumulation**
(Storage)

3 **Edge Computing**
(Data Element Analysis & Transformation)

2 **Connectivity**
(Communication & Processing Units)

1 **Physical Devices & Controllers**
(The "Things" in IoT)



The model is based on **"Integrated Security & Management"**

Data at Rest

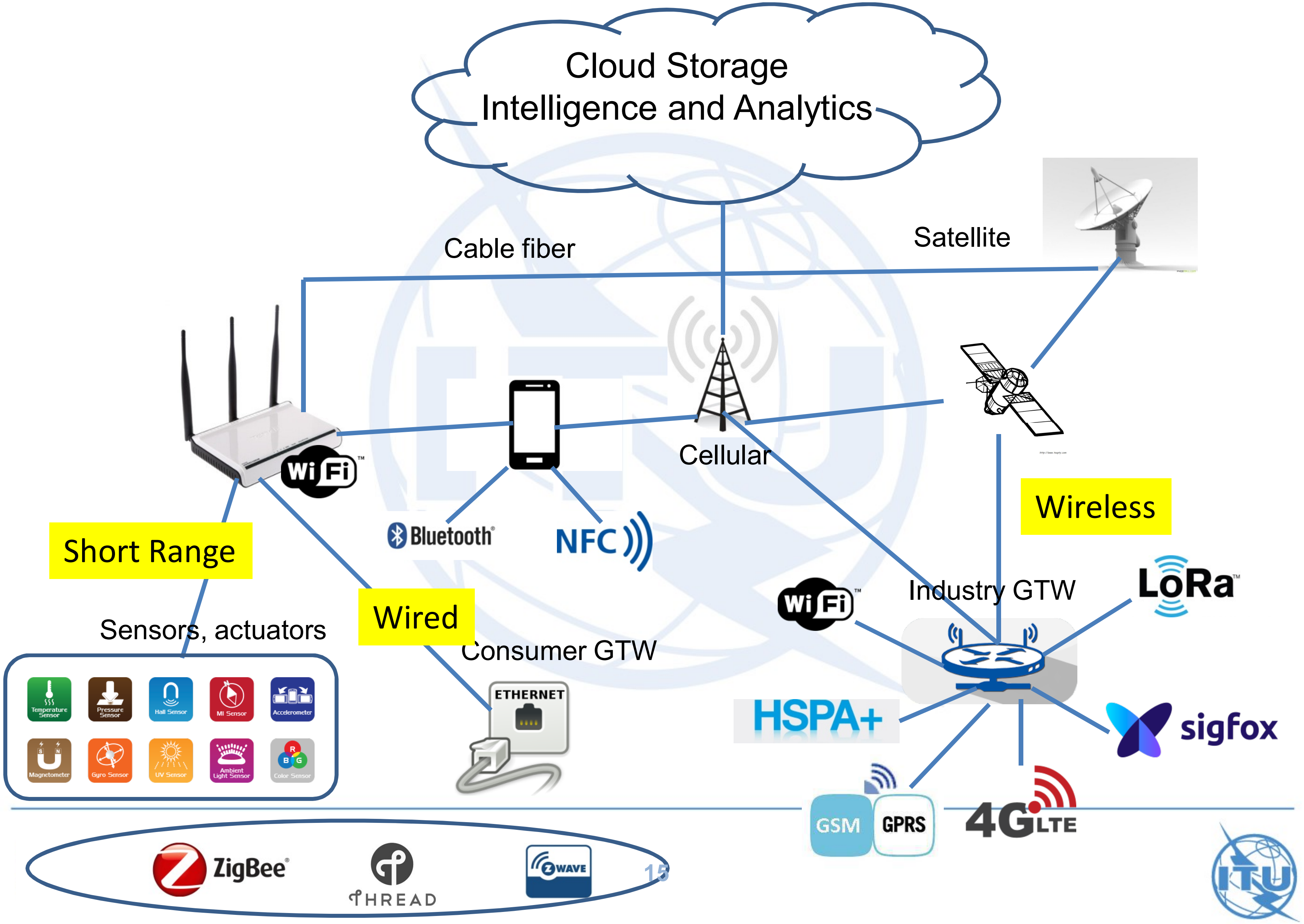
IT

OT

Data in Motion

The model is based on **"Information Flow"**

IoT network general architecture



IoT and Fog Computing (FC)

- Transmission of all data to the cloud for: *processing* and *analysis*

➔ **Large bandwidth** and communication procedure very ***inefficient***, **energy-hungry** or even critical in case of scarce available bandwidth resources or massive concurrent accesses,

➔ Introduces ***unacceptable latencies*** in the decision making process.

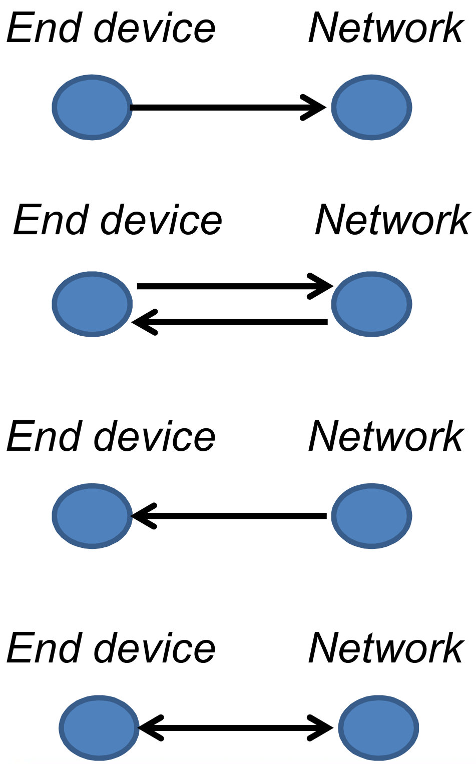
⇒ **Fog Computing** complements the **Cloud Computing** by ***moving storage and computation close to end-devices*** also taking advantage of relationships in space and time among collected information.

⇒ FC relies on *local highly performing computational units* meant to collect, store and process data acquired by IoT objects.

⇒ 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.

Things classification

- Things/Objects differentiate according to:
  - The **range** (short, medium, long)
  - The **type of interaction** with the system (i.e., service type):



- ***Alarm*** (transmission initiated by the end-device only, according to the events, bursty traffic),
- ***Measurements*** (triggered either by the end-device or by the system),
- ***Control*** (transmissions initiated by the system),
- ***Combination*** of these.

The device can:

- **Publish** or **Subscribe**
- Be **online** or **offline**
- Manage messages of **different formats**
- Have different **types of communication channels**
- Have **one channel** or **several data streams**

Quiz 2 – IoT networks architecture

1. What are the 4 layers of an IoT network?
2. What are the main components of an IoT network?
3. How fog computing is related to IoT?
4. What are the different types of objects in IoT?
5. What are the operations an object (i.e., end-device) can achieve?
6. What kinds of IoT networks can be distinguished?

III. IoT Short Range and Long Range Systems

Summary

A. Fixed & Short Range

B. Long Range technologies

1. Non 3GPP Standards (LPWAN)
2. 3GPP Standards

A. Fixed & Short Range

i. RFID

ii. Bluetooth

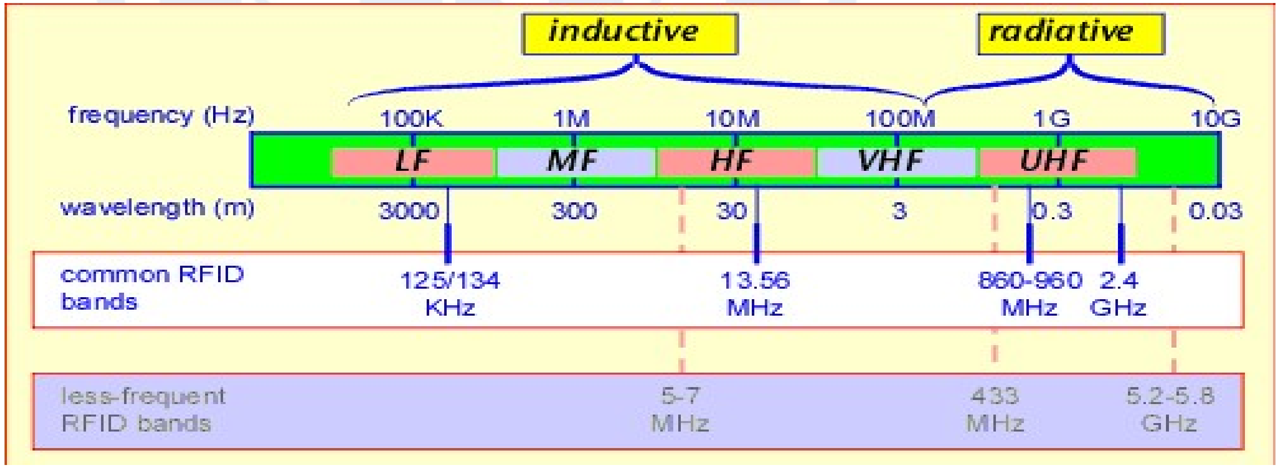
iii. Zigbee

iv. WiFi

i. RFID

- 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
- *Operating*: reading device called a reader, and one or more tags

RFID Frequencies



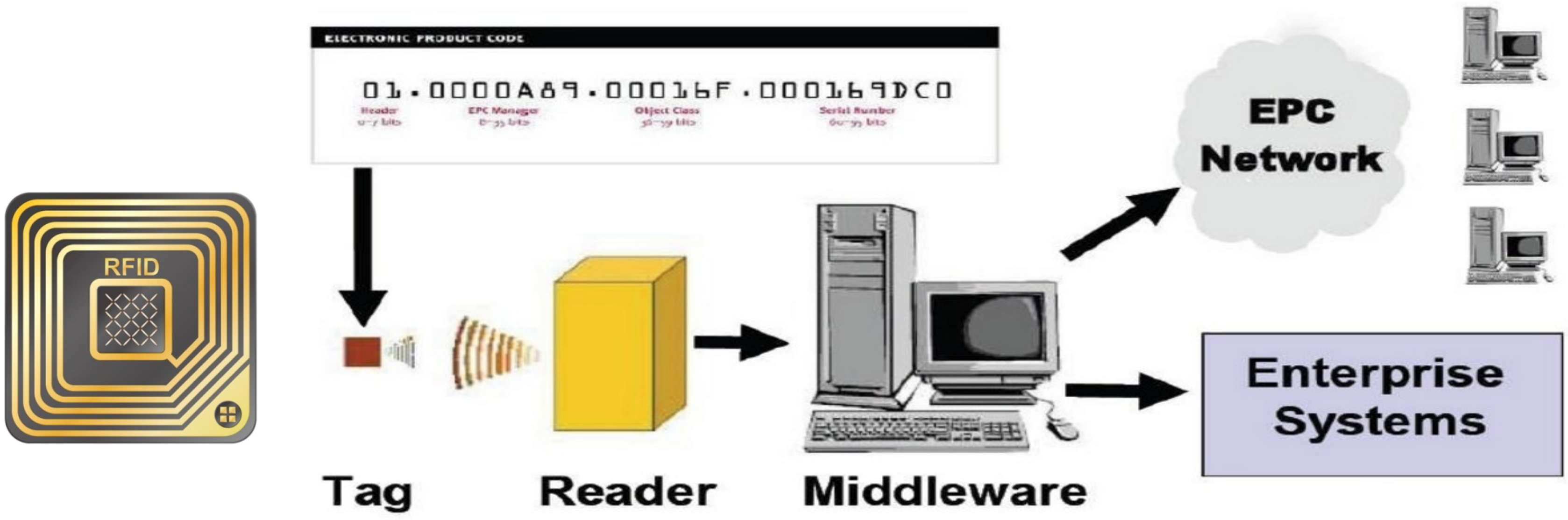
How does it work?

Tag

- Microchip connected to an antenna
- Can be attached to an object as his identifier

Reader

- RFID reader communicating with the **RFID tag** through radio waves



ii. Bluetooth

- **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

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

Bluetooth Low Energy

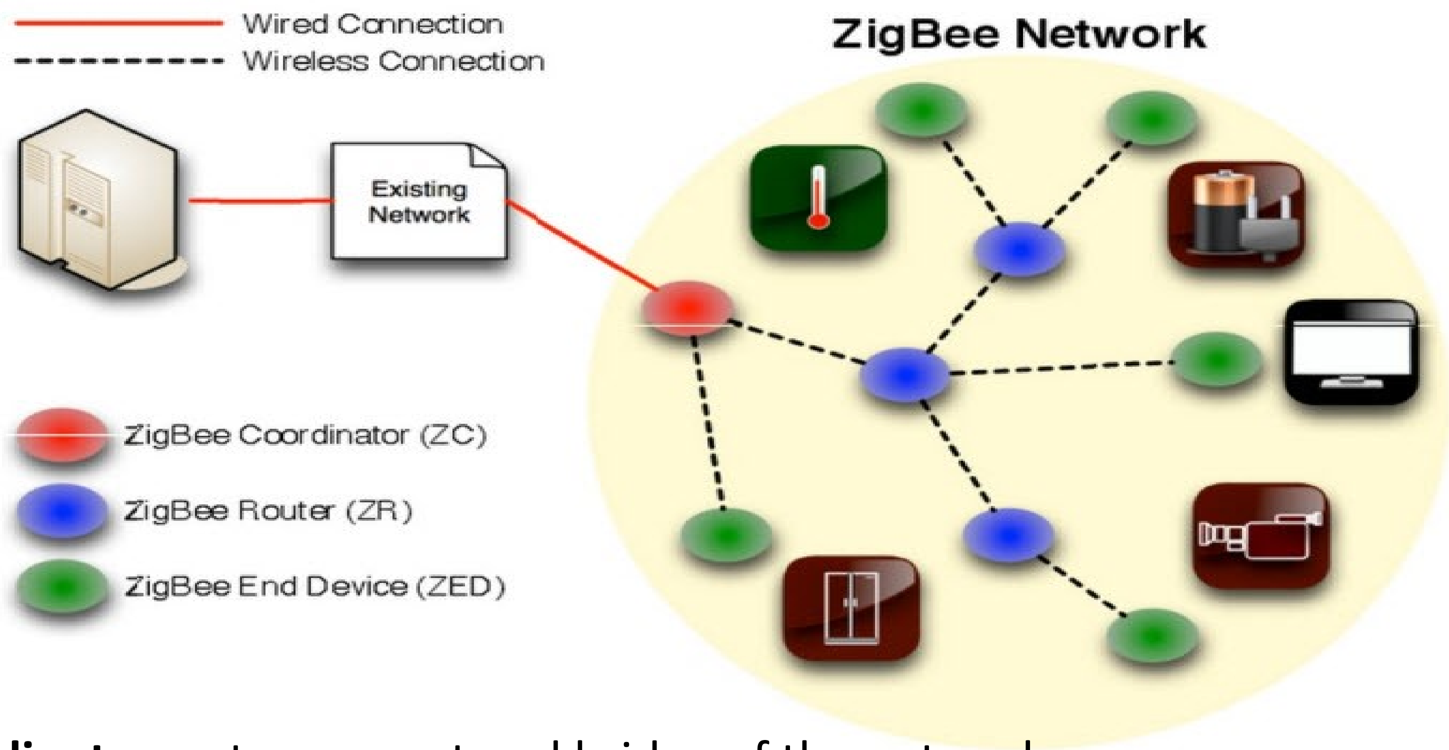
- Enables IoT features
- Lowest cost and Easy to implement
- Discovery & connection improvements
- Low latency, fast transaction (3 ms from start to finish)
- Data Rate 1 Mb/s: sending just small data packets
- **Bluetooth 5**: 4x range, 2x speed and 8x broadcasting message capacity.

Range	~ 150 m
Output Power	~ 10mW(10 dBm)
Max current	15 mA
Modulation	GFSK at 2.4 GHz
Sleep current	~ 1 µA

Low cost, available, ready to go.

iii. ZigBee

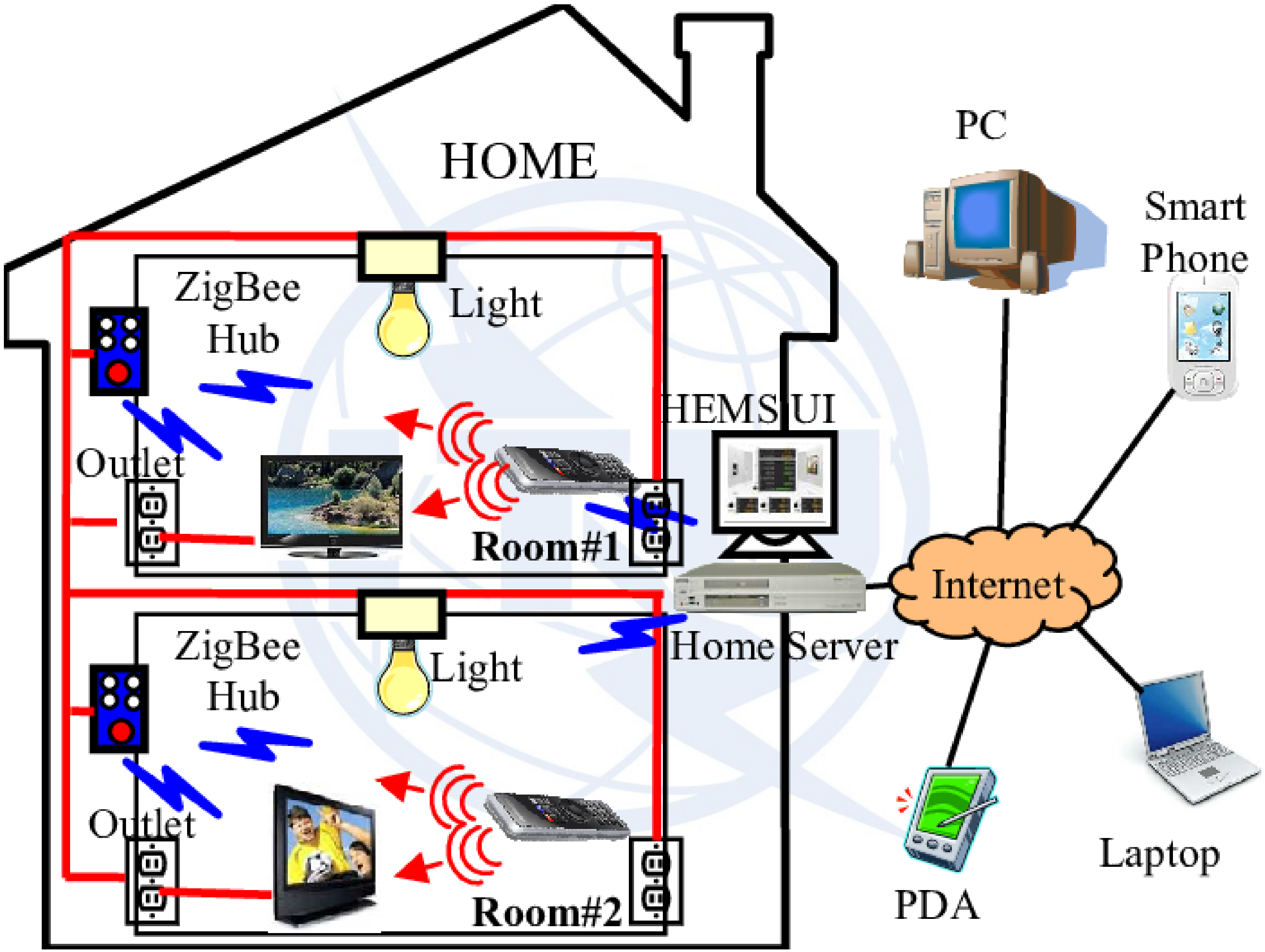
ZigBee



- **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

Low cost, available, ready to go.

ZigBee


HOME
ZigBee Hub
Light
Outlet
Room#1
HEMS UI
ZigBee Hub
Light
Outlet
Room#2
Home Server
PC
Smart Phone
Internet
PDA
Laptop

iv. WiFi

- Wireless technology
- Alternative to Wired Technologies
- IEEE 802.11 standard for WLANs

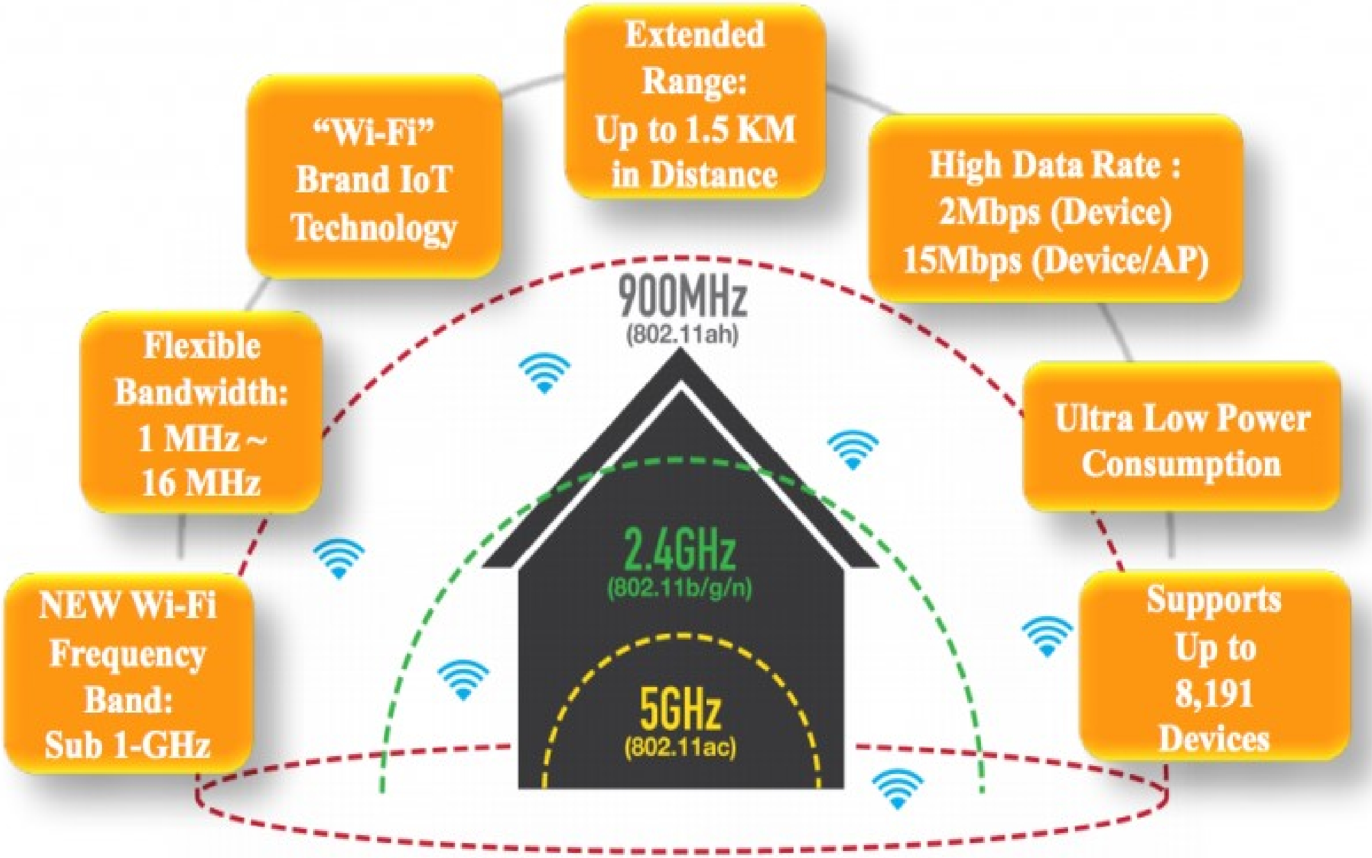
Standard	Frequency bands	Throughput	Range
WiFi a (802.11a)	5 GHz	54 Mbit/s	10 m
WiFi B (802.11b)	2.4 GHz	11 Mbit/s	140 m
WiFi G (802.11g)	2.4 GHz	54 Mbit/s	140 m
WiFi N (802.11n)	2.4 GHz / 5 GHz	450 Mbit/s	250 m
IEEE 802.11ah	900 MHz	8 Mbit/s	100 M

WiFi HaLow

- A new low-power, long-range version of **Wi-Fi** that bolsters **IoT** connections, it will be available in 2018
- Wi-Fi HaLow is based on the pending IEEE 802.11ah specification
- Wi-Fi HaLow will operate in the unlicensed wireless spectrum in the 900MHz band
- It will easily penetrate walls and barriers thanks to the propagation capabilities of low-frequency radio waves.
- Its range will be nearly double today's available Wi-Fi (1 kilometer)

- WiFi is longer range than Bluetooth and ZigBee
- More flexible
- Closer to networks

WiFi Halow main characteristics



WiFi-based IoT Devices

Quiz 3 – Short range IoT systems

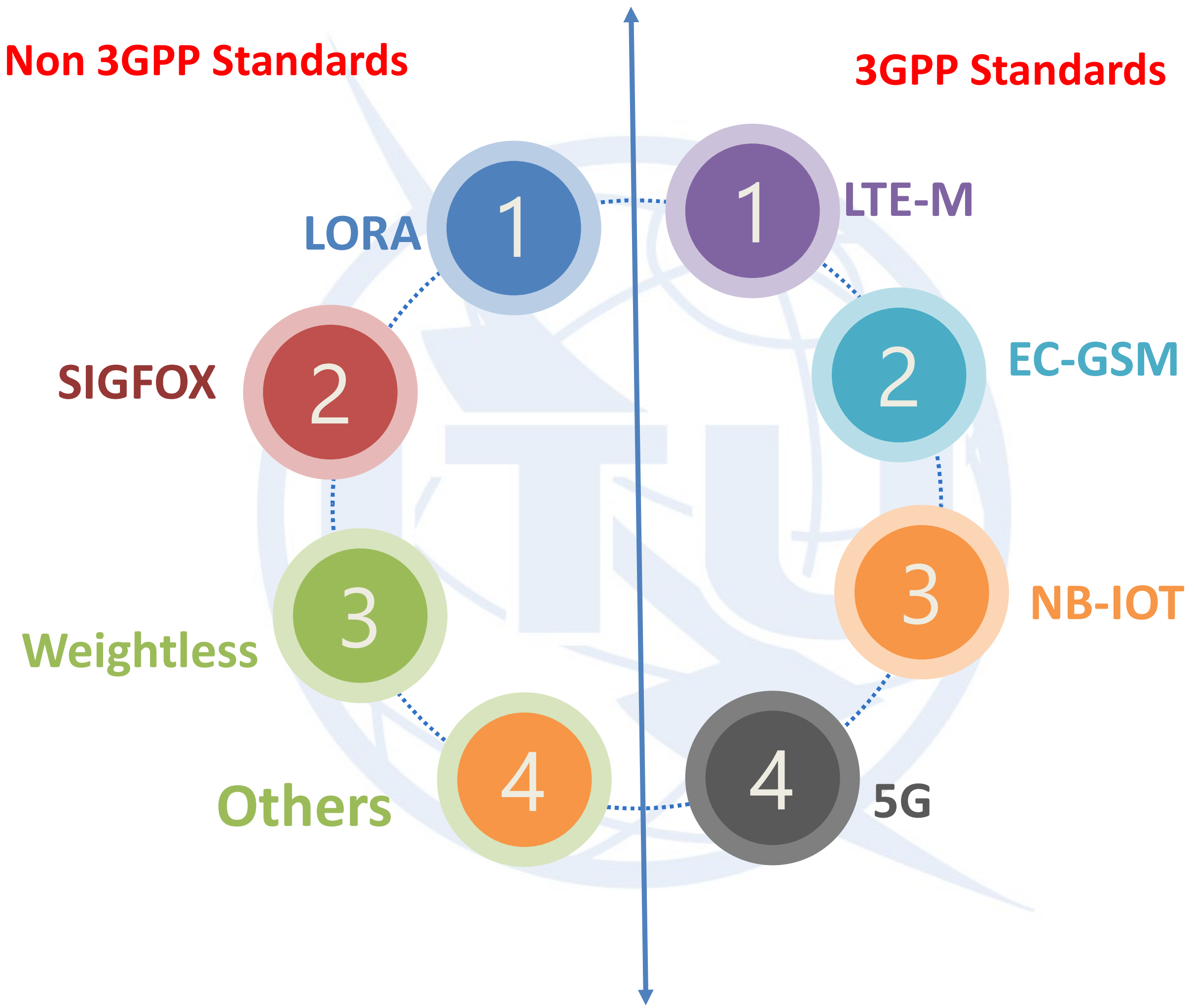
1. What are the main 2 technologies used for IoT short range?
2. What are the main changes introduced in existing short range system to allow IoT communications?
3. What are the main advantage of using existing systems?
4. What are the offered bitrates with these systems?
5. What are the maximum ranges these systems can offer?

Summary

A. Fixed & Short Range

B. Long Range technologies

1. Non 3GPP Standards (LPWAN)
2. 3GPP Standards


Non 3GPP Standards
3GPP Standards
1
LORA
2
SIGFOX
3
Weightless
4
Others
1
LTE-M
2
EC-GSM
3
NB-IOT
4
5G

Wide-area M2M technologies and IoT

Carrier frequency		Technology	Channel bandwidth	Representative data rate	Link budget target or max. range
Licensed cellular		LTE Cat. 0	20 MHz	DL: 1 Mb/s UL: 1 Mb/s	140 dB
		LTE Cat. M	1.4 MHz	DL: 1 Mb/s UL: 1 Mb/s	155 dB
		NB-IoT	200 kHz	DL: 128 kb/s UL: 64 kb/s	164 dB
		EC-GSM	200 kHz	DL: 74 kb/s UL: 74 kb/s	164 dB
Unlicensed	2.4 GHz	Ingenu RPMA	1 MHz	UL: 624 kb/s DL: 156 kb/s	500 km line of sight
	Sub-1 GHz	LoRa chirp spread spectrum	125 kHz	UL: 100 kb/s DL: 100 kb/s	15 km rural 5 km urban
	Sub-1 GHz	Weightless-N	200 Hz	UL: 100 b/s	3 km urban
	Sub-1 GHz	Sigfox	160 Hz	UL: 100 b/s	50 km rural 10 km urban

H. S. Dhillon et al., "*Wide-Area Wireless Communication Challenges for the Internet of Things*," IEEE Communications Magazine, February 2017

B. Non 3GPP Standards (LPWAN)

i. LoRaWAN

ii. Sigfox

iii. Weightless

iv. RPMA

v. Others

LPWAN REQUIREMENTS

Long battery life

Support for a **massive number of devices**

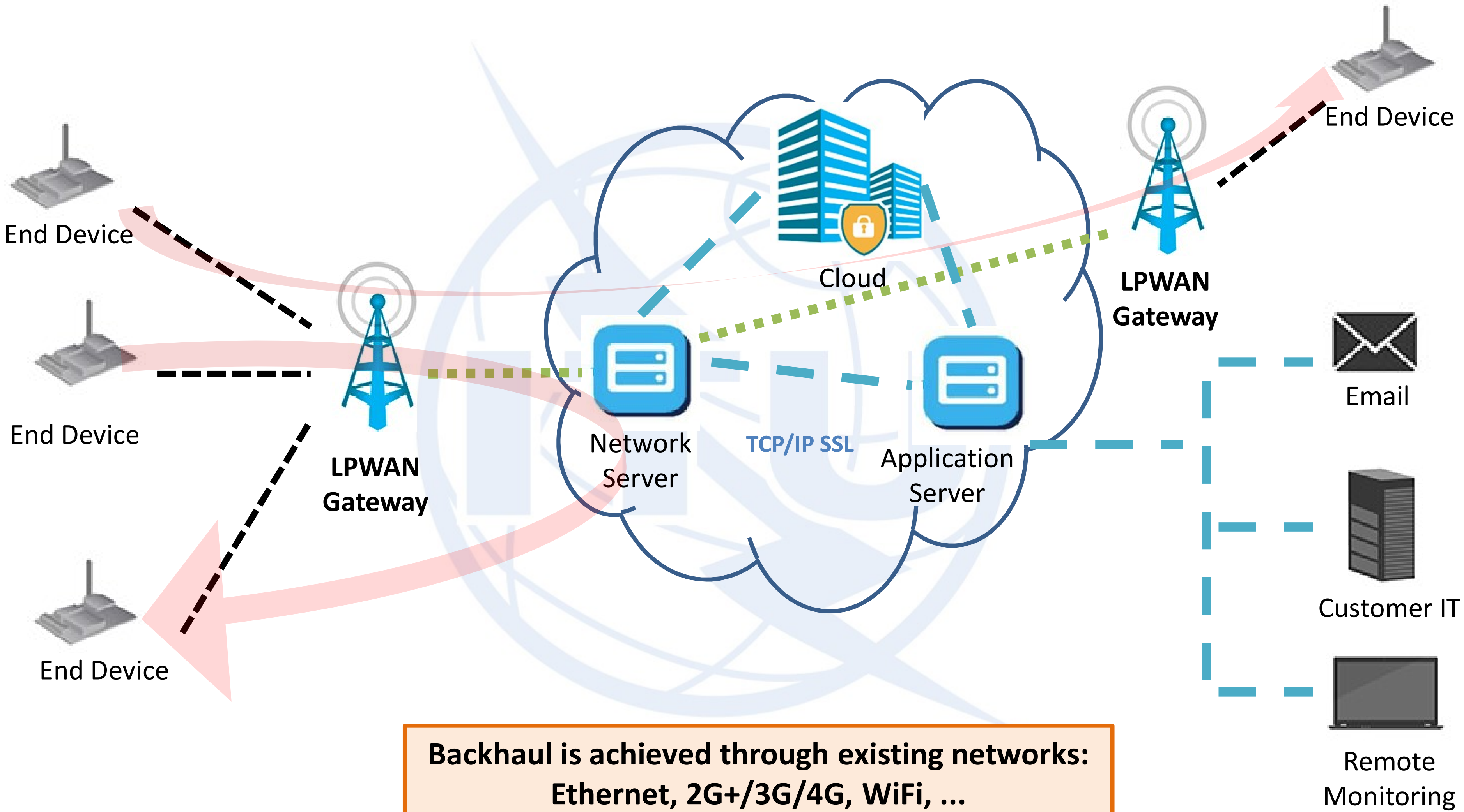
LPWAN

Low device cost

Extended coverage (**10-15 km** in rural areas, **2-5 km** in urban areas)

Low cost and **easy deployment**

General architecture of LPWAN



Backhaul is achieved through existing networks: Ethernet, 2G+/3G/4G, WiFi, ...

i. LoRaWAN

Roadmap

2010
Cycleo developed LoRa technology

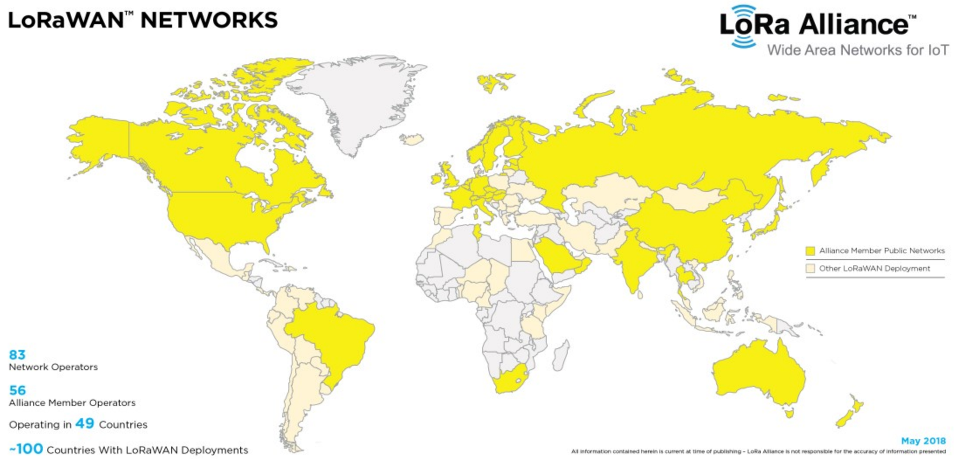
2013
Semtech develop LoRaWAN network

2015
Creation of LoRa alliance

Jun 2015
Amsterdam become the first city covered by the LoRaWAN network

2016
All France territory covered by LoRaWAN network:Bouygues Telecom

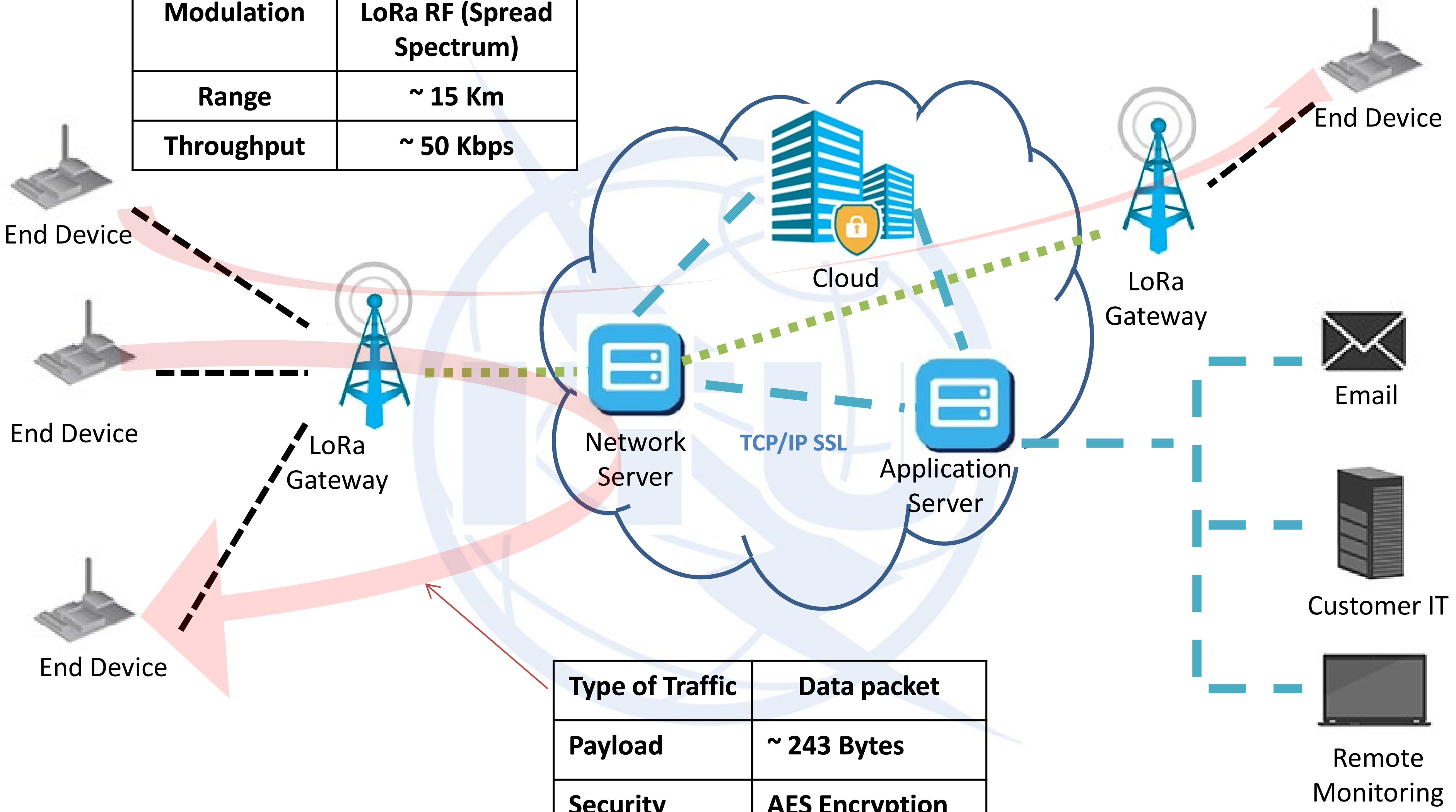
LoRa Alliance
Wide Area Networks for IoT



- LoRaWAN is a *Low Power Wide Area Network*
- LoRa 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 communication (up to **15 Km**)
- Strong indoor penetration: With High Spreading Factor, Up to **20dB** penetration (**deep indoor**)
- 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.

Architecture

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



Type of Traffic	Data packet
Payload	~ 243 Bytes
Security	AES Encryption

Spectrum (Influence of the Spreading Factor)

Far with obstacles:

➔ **High sensitivity** required

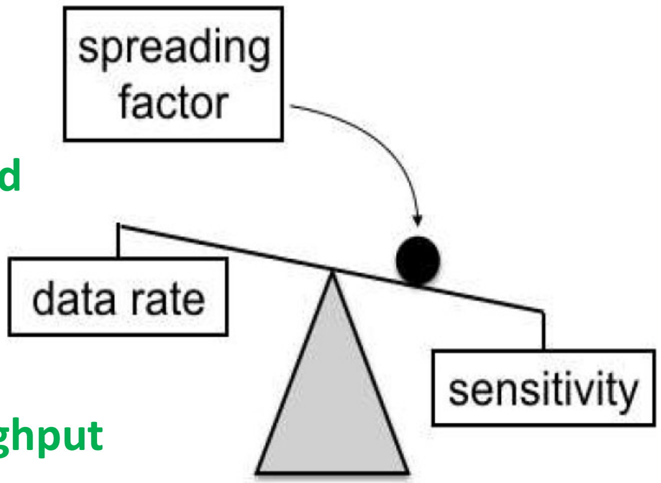
➔ The network **increases** the SF (*Spreading Factor*) ➔

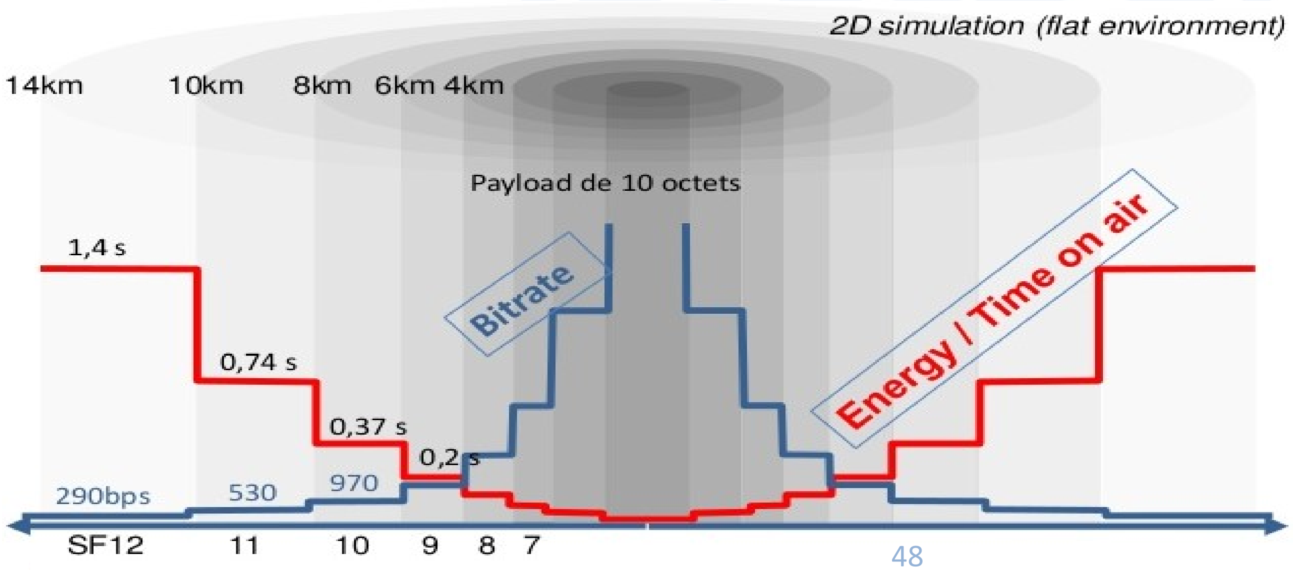
Throughput decreases but **the connection is maintained**

Close:

➔ **Low sensitivity** sufficient

➔ **Decrease** of SF (SPREADING FACTOR), **increase of throughput**



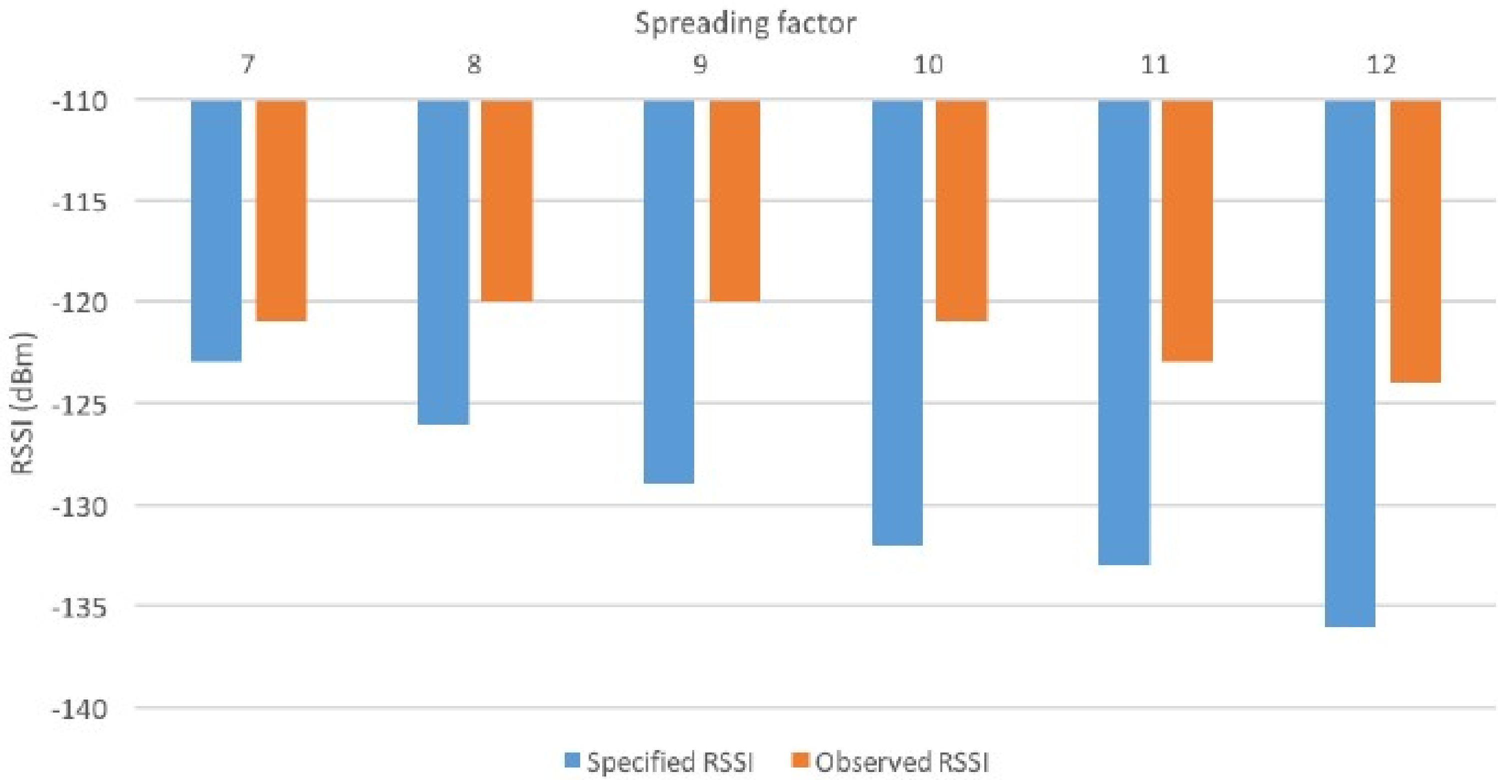


Adaptive throughput

ADR: *Adaptive Data Rate*

RSSI and SF versus BW

BW \ SF	7	8	9	10	11	12
125 kHz	−123	−126	−129	−132	−133	−136
250 kHz	−120	−123	−125	−128	−130	−133
500 kHz	−116	−119	−122	−125	−128	−130



SF, bitrate, sensitivity and SNR for a 125 kHz channel

Spreading factor	Bitrate (bit/sec)	Sensitivity (dBm)	LoRa demodulator SNR
7 (128)	5 469	-124 dBm	-7.5 dB
8 (256)	3 125	-127 dBm	-10 dB
9 (512)	1 758	-130 dBm	-12.5 dB
10 (1024)	977	-133 dBm	-15 dB
11 (2048)	537	-135 dBm	-17.5 dB
12 (4096)	293	-137 dBm	-20 dB

SF and repetition can be either **manual** (i.e., determined by the end-device) or **automatic** (i.e., managed by the network)

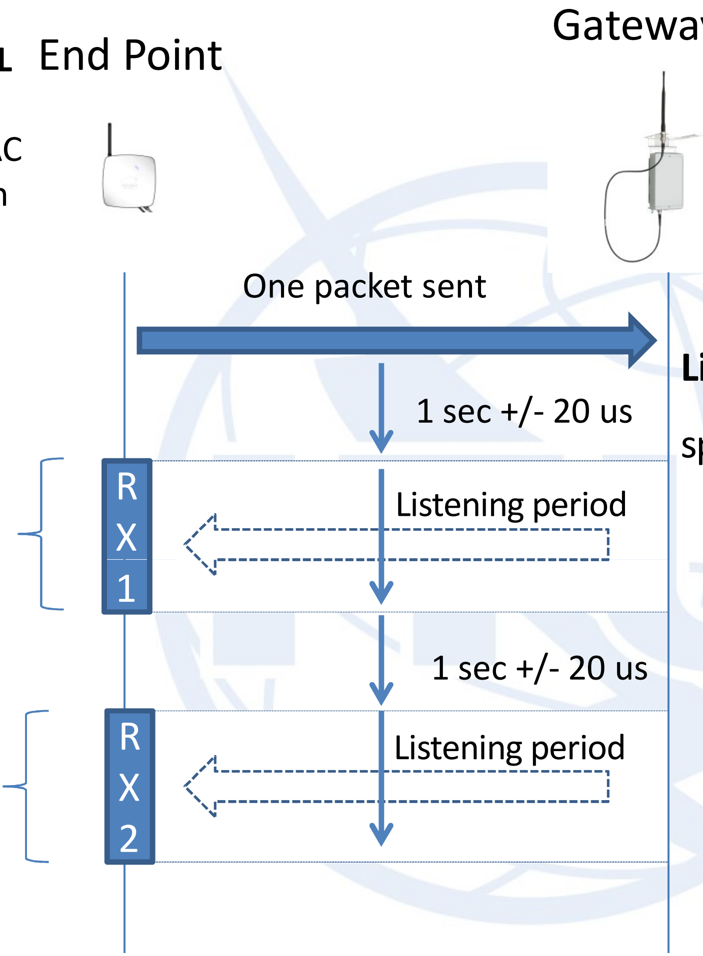
LoRaWAN: device classes

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**	• **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**	• **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**	• **Fleet management** • **Real Time Traffic Management**

➔ Any LoRa object can transmit and receive data

Class A

Open **2 windows for DL reception** (acknowledgments, MAC commands, application commands...) **after sending a packet**



1st receive window

2nd receive window

Listening period: varies according to the spreading factor SF

- 5.1 ms at SF7 (outdoor and close devices)
- 10.2 ms at *SF8 …*
- 164 ms at SF12 (deep-indoor or far devices)

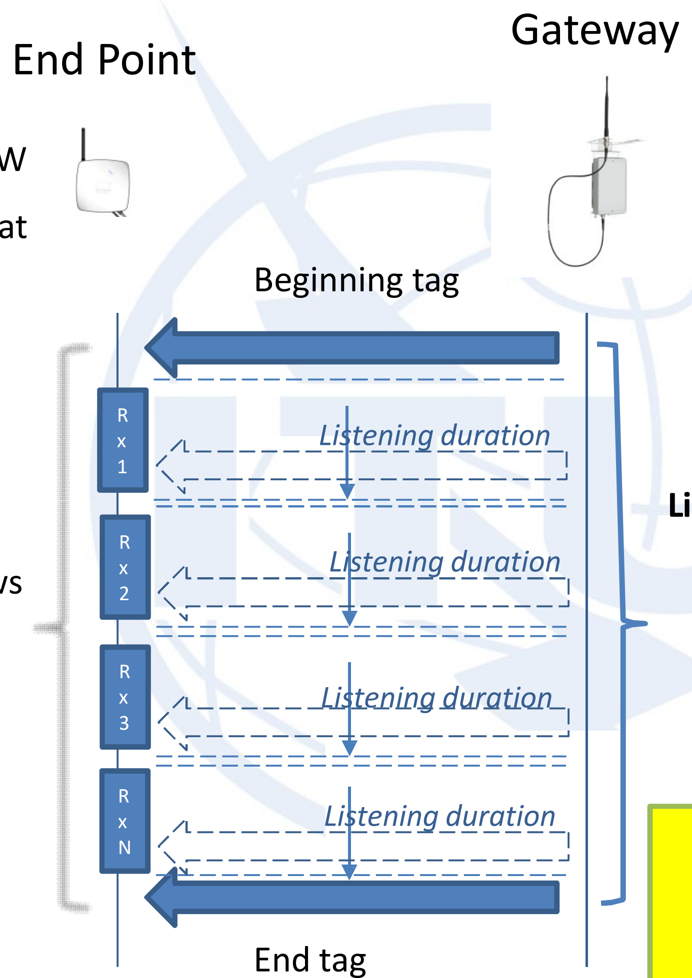
- Very economic energetically
- Communication triggered by the end device

Class B (Synchronized mode)

- **Synchronized** with the GTW
- **Opens listening windows** at

regular intervals.

Opens N reception windows between the two tags

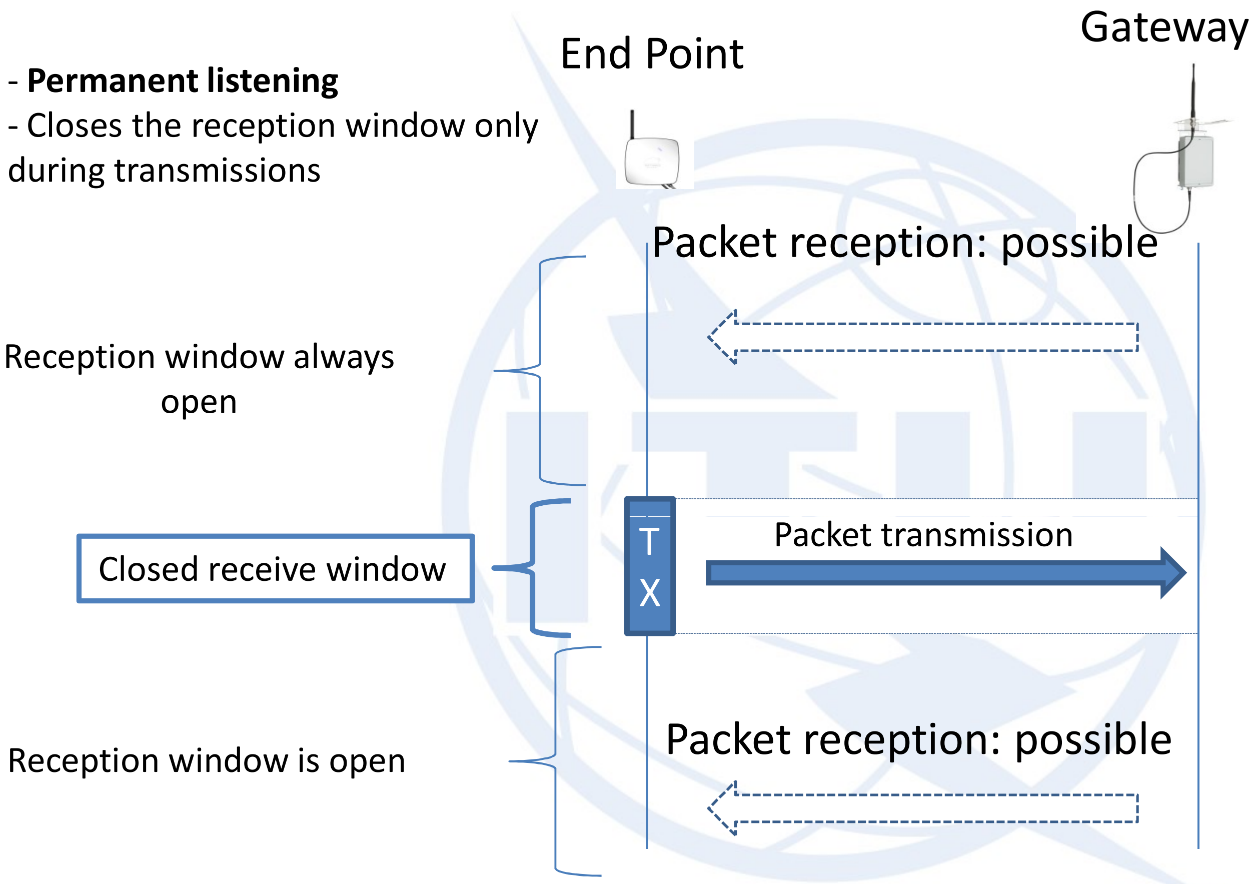


Listening duration: varies according to the SF

- Optimized energy consumption
- Communication initiated by the GTW

Class C

- **Permanent listening**
- Closes the reception window only during transmissions



Adapted to devices on the power grid

- **End-device address (*DevAddr*):**

Network identifier	network address of the end-device
7 bits	**25 bits**

- **Application identifier (*AppEUI*):** A global application ID in the IEEE EUI64 address space that uniquely **identifies the owner of the end-device**.
- **Network session key (*NwkSKey*):** A key used by the network server and the end-device to calculate and verify the message integrity code of all data messages to ensure data integrity.
- **Application session key (*AppSKey*):** A key used by the network server and end-device to encrypt and decrypt the payload field of data messages.

LORA Vs GSM

Lora network	GSM network
DevAddr	**TMSI**
DEVEUI	**IMEI**
Gateway EUI	**GUI**
AppEUI	**IMSI**
Network identifier	**PLMN**
NwkSKey, AppSKey	**A5/1 algorithm**
Network server	**Core network**

ii. Sigfox

Roadmap

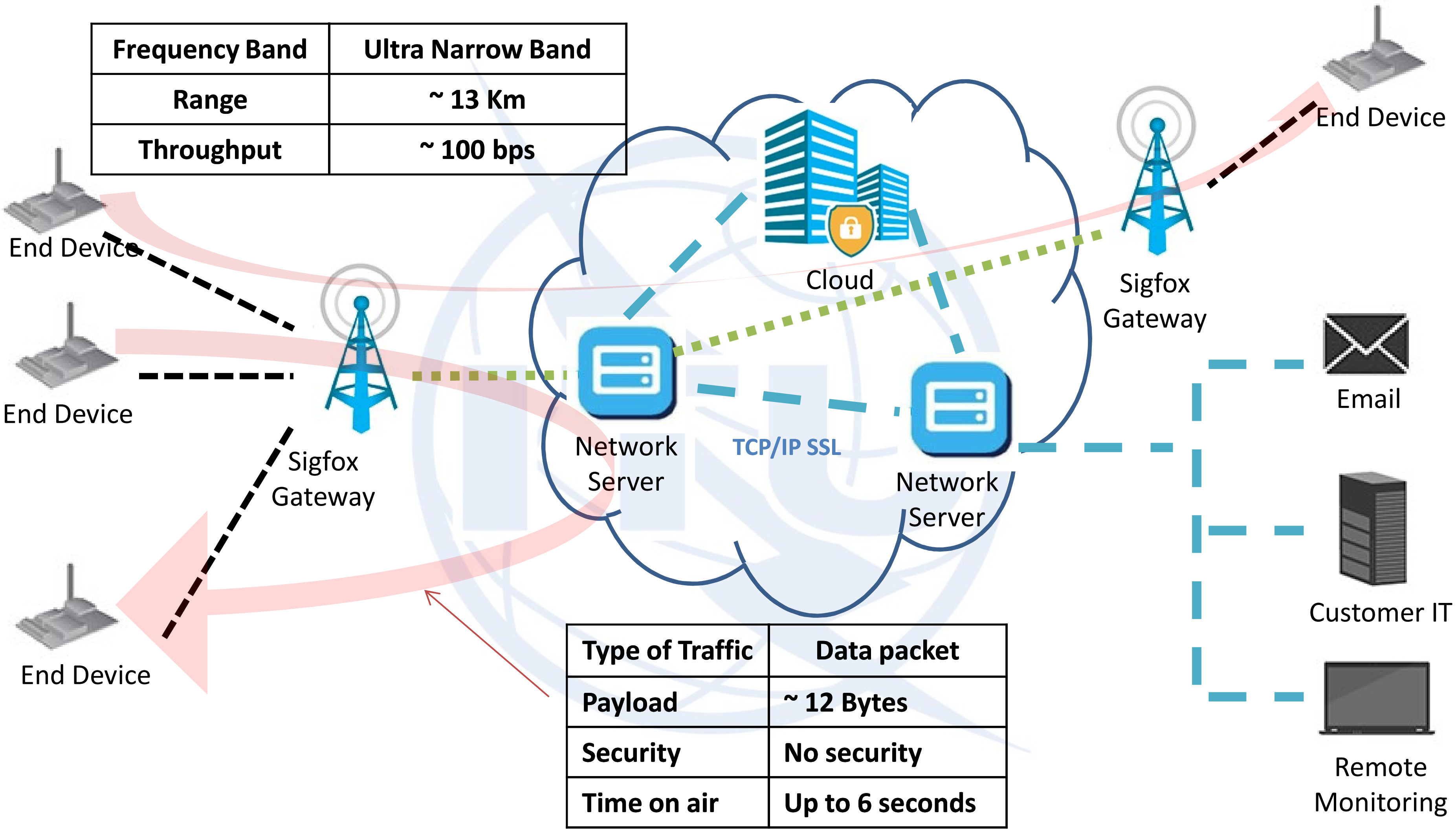
- **2012** — Launch of the Sigfox network
- **2013** — First fundraising of Sigfox company to cover France
- **2014** — All France territory is covered by Sigfox network
- **Mars 2016** — San-Francisco become the first US. State covered by Sigfox
- **2017** — 42 countries, 1000 customers

Sigfox Overview

- **First LPWAN** Technology
- 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**

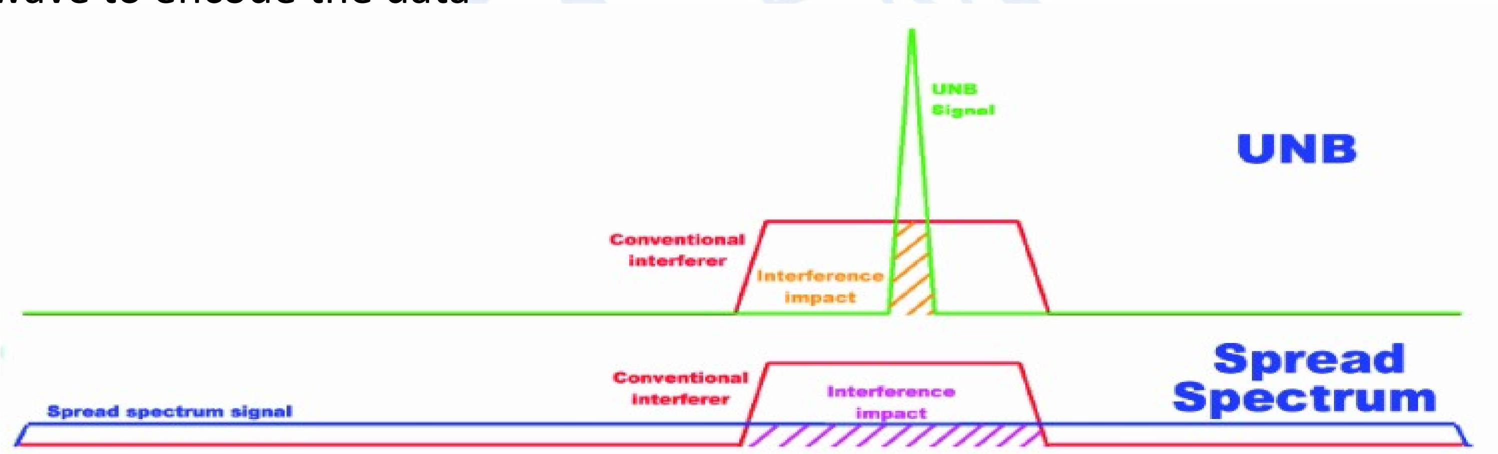
Architecture

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

- **Narrowband** technology
- Standard radio transmission method: binary phase-shift keying (**BPSK**)
- Takes very narrow parts of spectrum and changes the phase of the carrier radio wave to encode the data

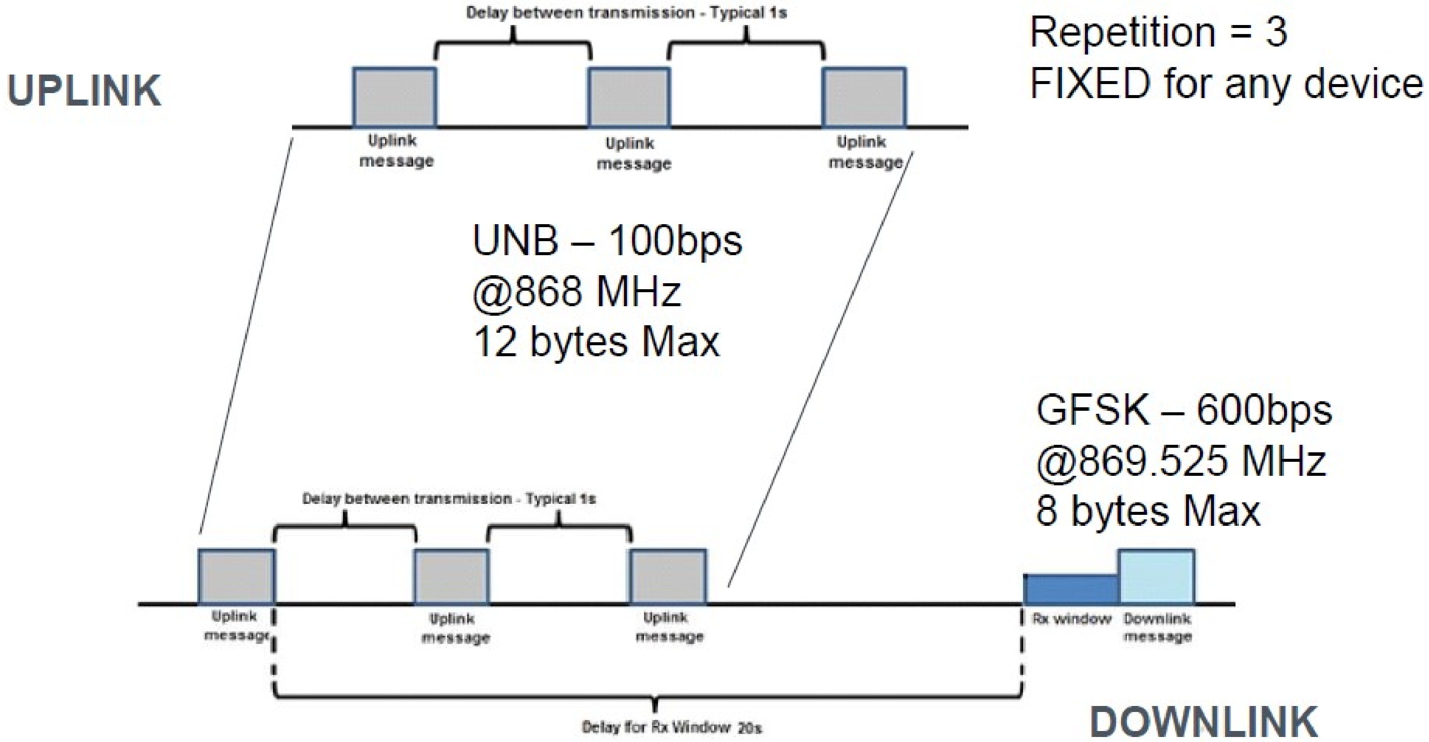


Frequency spectrum:

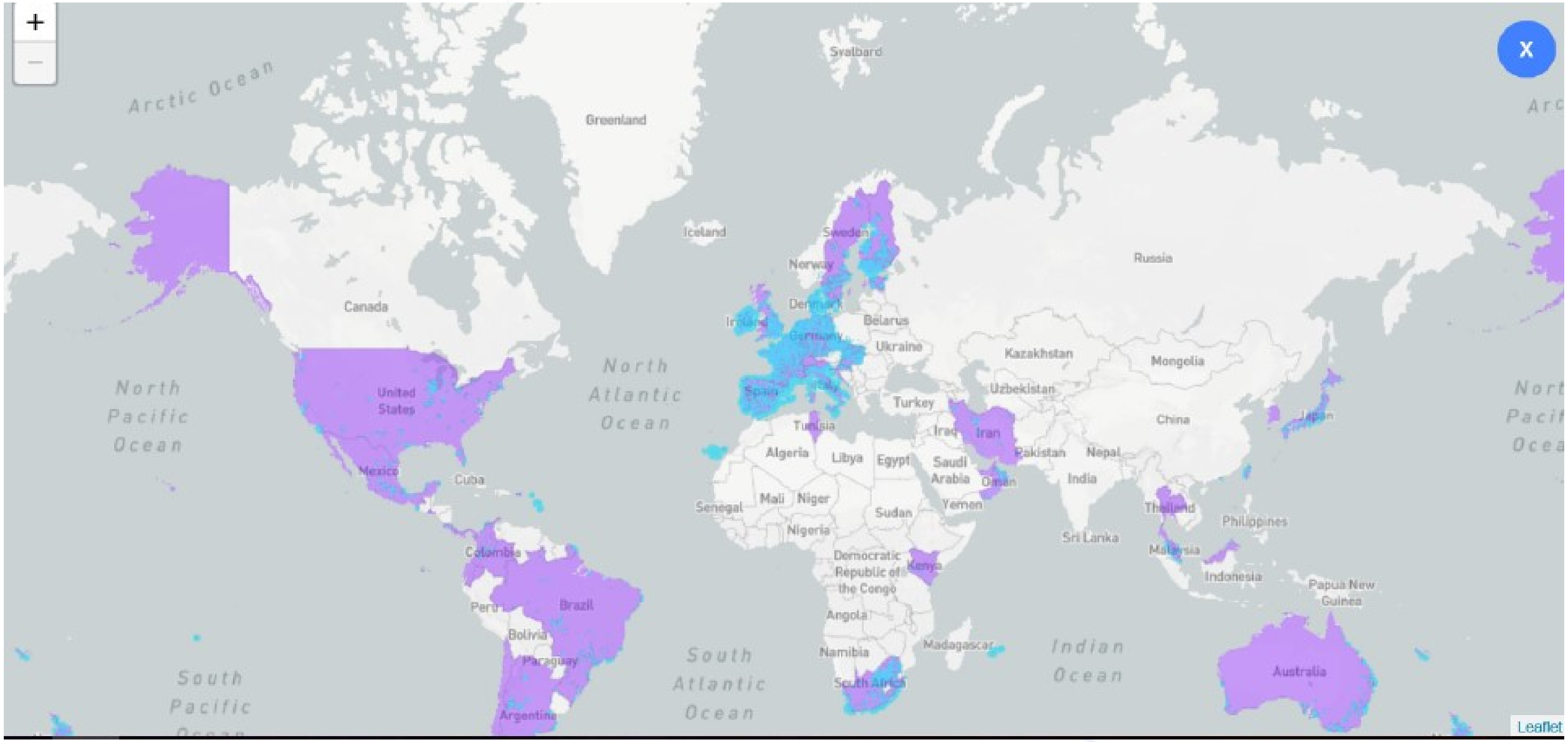
- 868 MHz in Europe
- 915 MHz in USA

Sigfox transmission

- Starts by an **UL transmission**
- Each message is transmitted 3 times
- A **DL message** can be sent (option)
- Maximum payload of **UL messages** = 12 data bytes
- Maximum payload of **DL messages** = 8 bytes



Current state



iii. Weightless

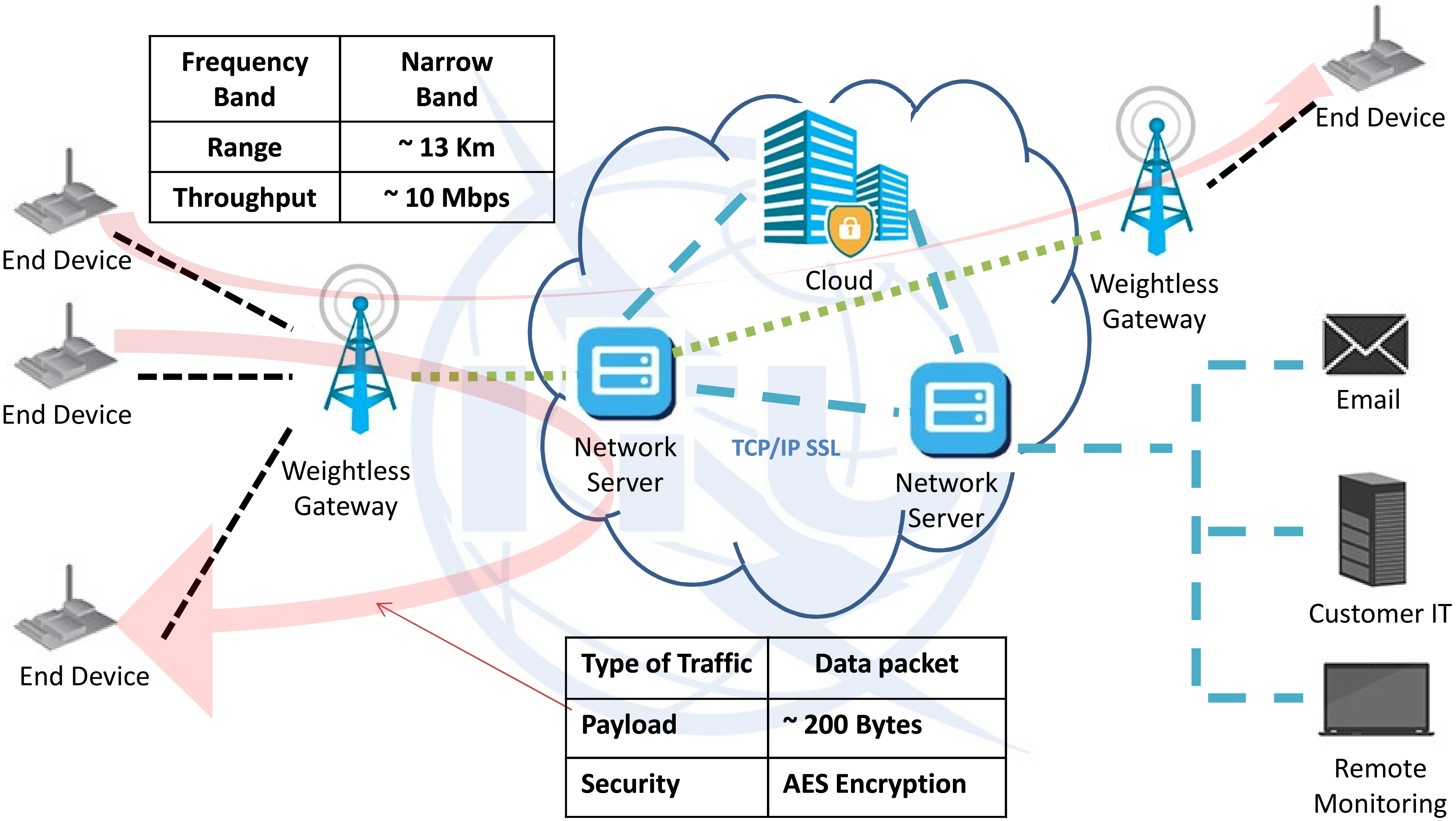
WEIGHTLESS Overview

- **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.

Roadmap

- **2012** — Starts specification
- **2012** — Creation of ***Weightless Special Interest Group***
- **2014** — **White Space spectrum** is coming - ratified in USA Q3 2012, UK expected Q2 2014
- **May 2015** — First version released
- **Jun 2015** — First Weightless-N network deployed in London

Architecture



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

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

	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

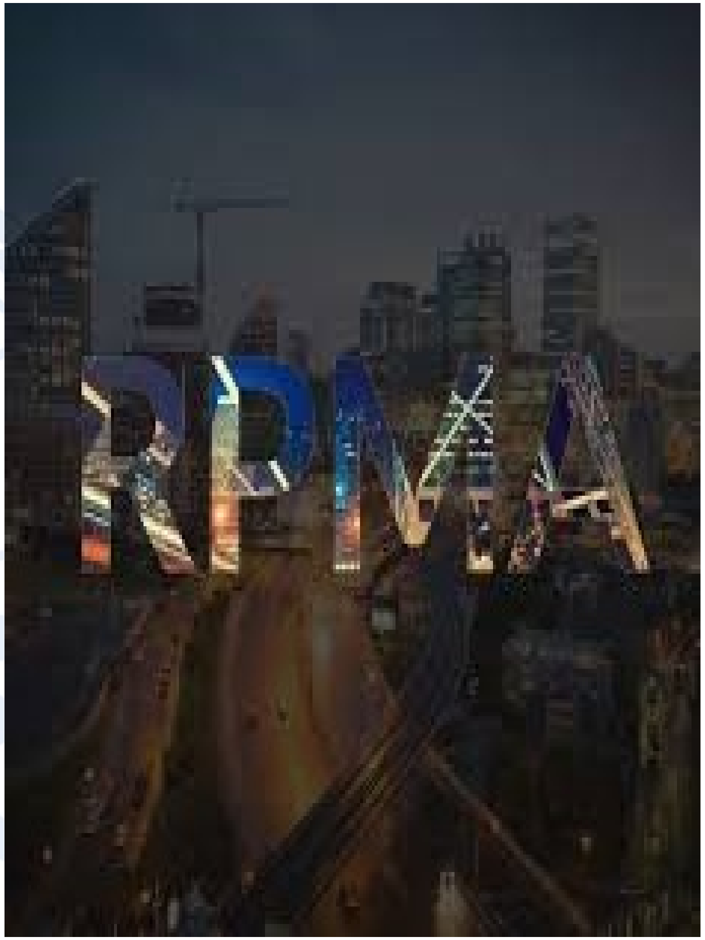
iv. RPMA

Roadmap

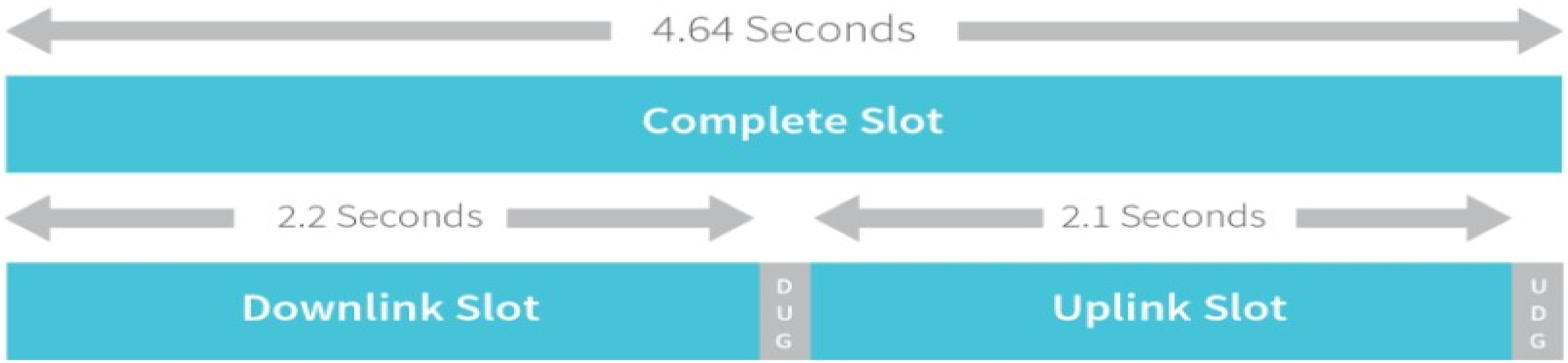
INGENU

2008	September 2015	2016	2017
RPMA was developed by On-Ramp Wireless to provide connectivity to oil and gas actors	it was renamed Ingenu, and targets to extend its technology to the IoT and M2M market	RPMA was implemented in many places Austin, Dallas/Ft. worth, Hostton,TX,Phenix,AZ, ….	RPMA will be invaded in many others countries: Los Angeles, San Franscisco-West Bay,CA,Washington,DC, Baltimore,MD, Kanasas City

- Random Phase Multiple Access (RPMA) technology is a low-power, wide-area channel access method used exclusively for machine-to-machine (M2M) communication
- RPMA uses the popular 2.4 GHz band
- Offer extreme coverage
- High capacity
- Allow handover (channel change)
- Excellent link capacity



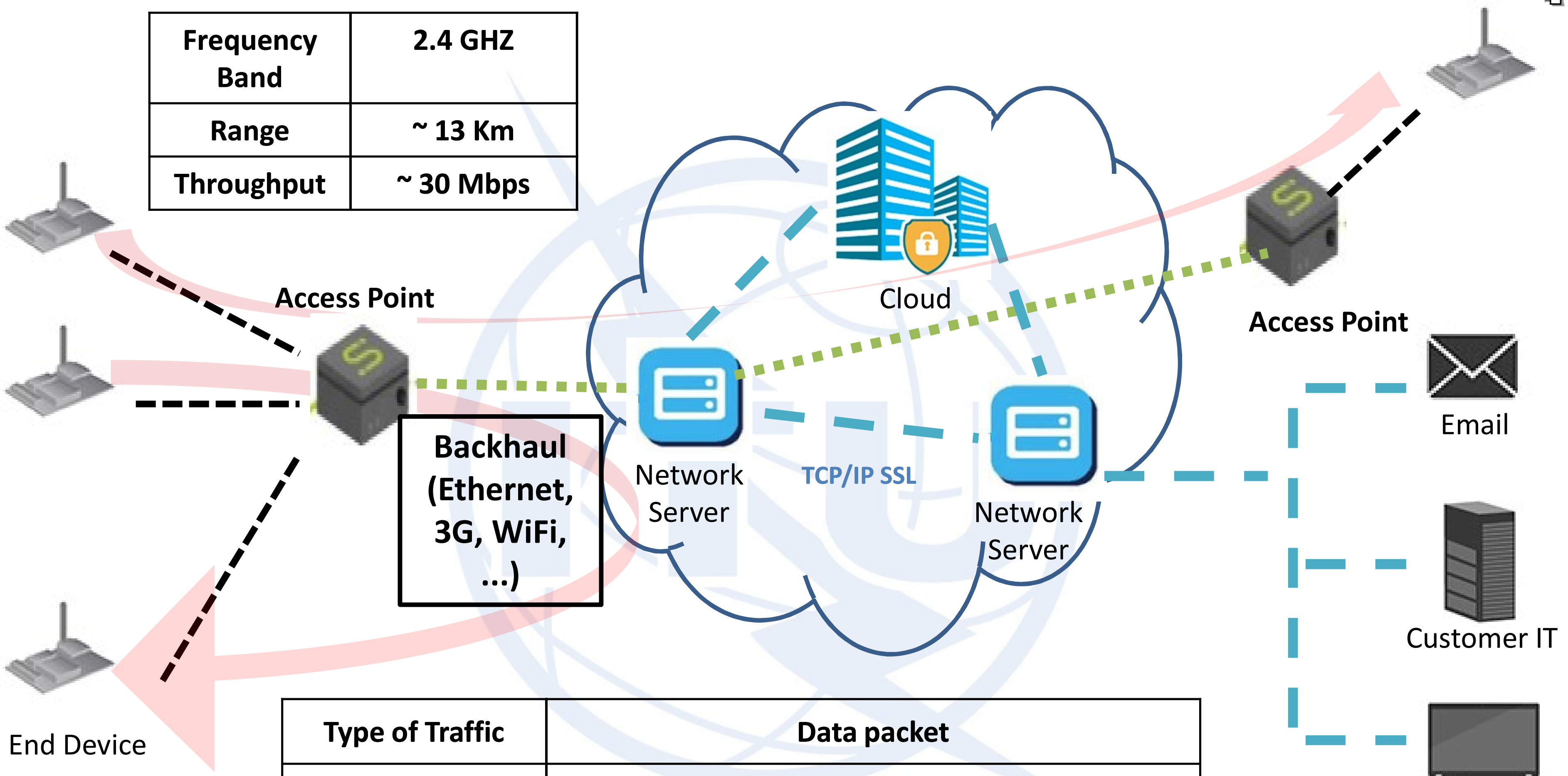
- RPMA is a Direct Sequence Spread Spectrum (DSSS) using:
  - Convolutional channel coding, gold codes for spreading
  - 1 MHz bandwidth
  - Using **TDD frame** with power control:
    - **Closed Loop Power Control:** the access point/base station measures the uplink received power and periodically sends a one bit indication for the endpoint to turn up transmit power (1) or turn down power (0).
    - **Open Loop Power Control:** the endpoint measures the downlink received power and uses that to determine the uplink transmit power without any explicit signaling from the access point/base station.



TDD frame

INGENU RPMA architecture

Frequency Band	2.4 GHZ
Range	~ 13 Km
Throughput	~ 30 Mbps



Type of Traffic	Data packet
Payload	~ 16 Bytes (one end point) ~ 1600 Bytes (for 1000 end points
Security	AES Encryption

❖Uplink Subslot Structure Supporting Flexible Data Rate

Step 1: Choose Spreading factor from 512 to 8192
Step 2: randomly select subslot
Step 3: Randomly select delay to add to subslot start from 0 to 2048 chips

v. Others

EnOcean

- Based on **miniaturized power converters**
- **Ultra low power** radio technology
- Frequencies: 868 MHz for Europe and 315 MHz for the USA
- Power from pressure on a switch or by photovoltaic cell
- These power sources are sufficient to power each module to transmit wireless and battery-free information.
- EnOcean Alliance in 2014 = more than 300 members (Texas, Leviton, Osram, Sauter, Somfy, Wago, Yamaha ...)

Green.Smart.Wireless.
enocean®

- 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 in

Quiz 4 – LPWAN

1. What are the main 2 IoT non-3GPP networks?
2. What are the main characteristics of LPWAN?
3. What are the 3 classes defined in LoRaWAN?
4. What is the particular SigFox model proposed for the users?
5. How many times a SigFox message is transmitted?
6. What multiple access technique is used in LoRa and SigFox?
7. What is the advantage of this multiple access technique in LPWAN communications?

Thank you!