WSCF 2019

Introduction to the LoRaWAN standard

Germán Capdehourat

Cyber Physical Systems Workshop

“From robots and drones to smart cities and industry 4.0, a connected world”

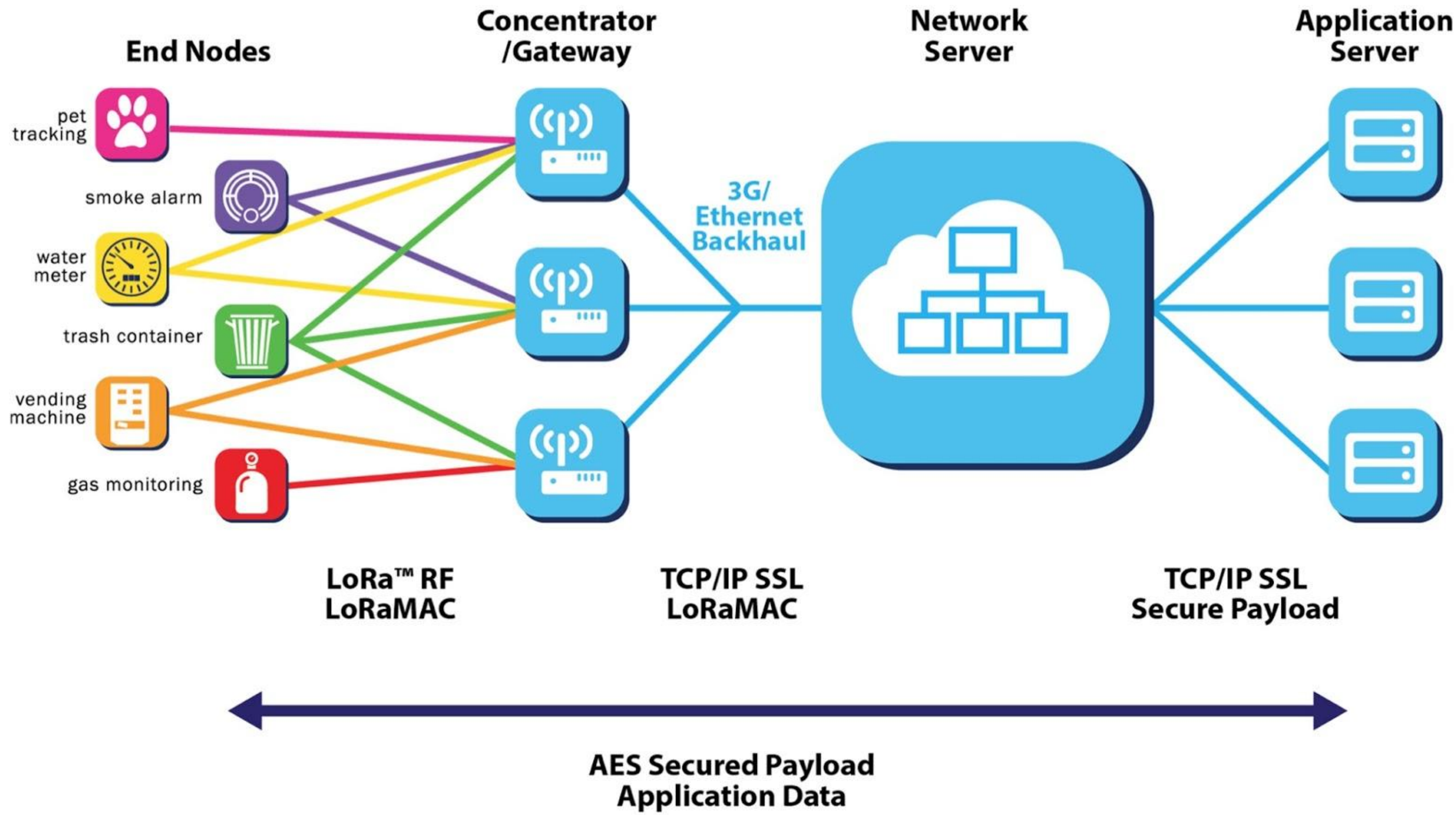
November 18th, Montevideo, Uruguay

FACULTAD DE INGENIERIA
UNIVERSIDAD DE LA REPUBLICA
URUGUAY

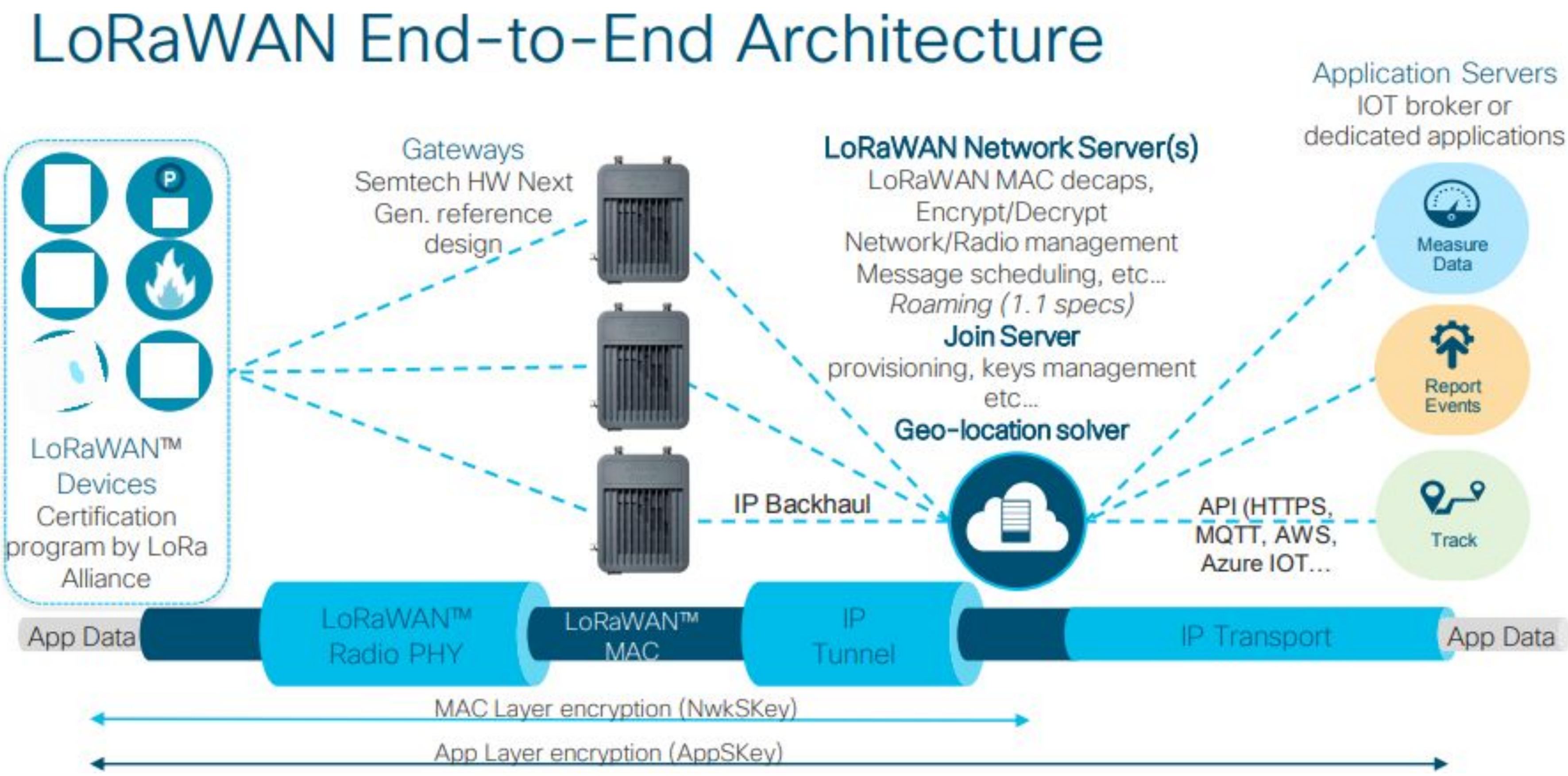
Agenda

- LoRaWAN Network Architecture.
- Nodes, Gateways and Network Server.
- Frequency bands and channels.
- Physical layer (RF) and medium access.
- LoRaWAN Frame Structure.
- Nodes Configuration: ABP/OTAA Provisioning.
- Security, ADR y geolocalization.
- Gateway and Network Server Configuration.
- Design Example of a LoRaWAN Network.

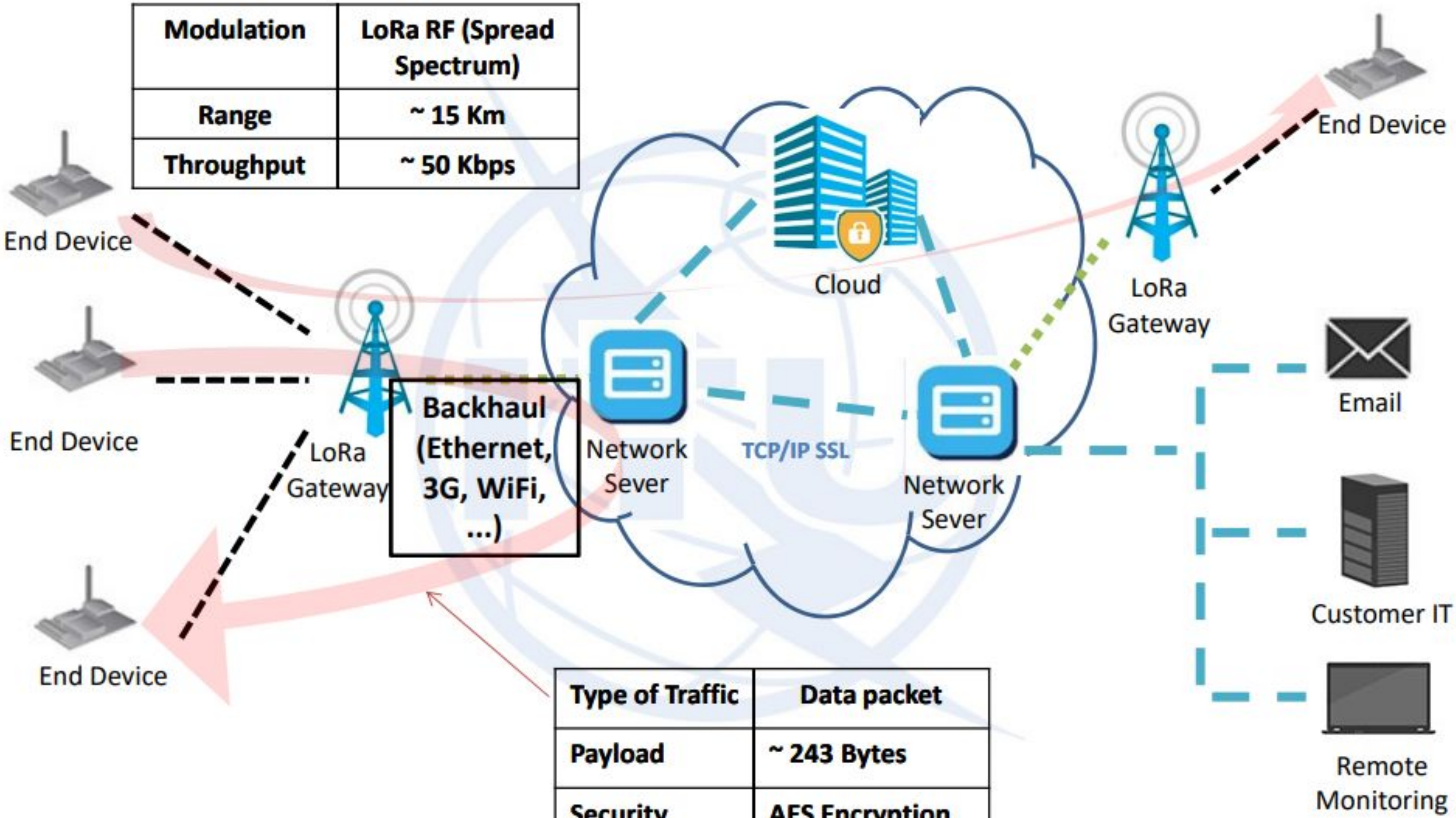
Network Architecture



Network Architecture



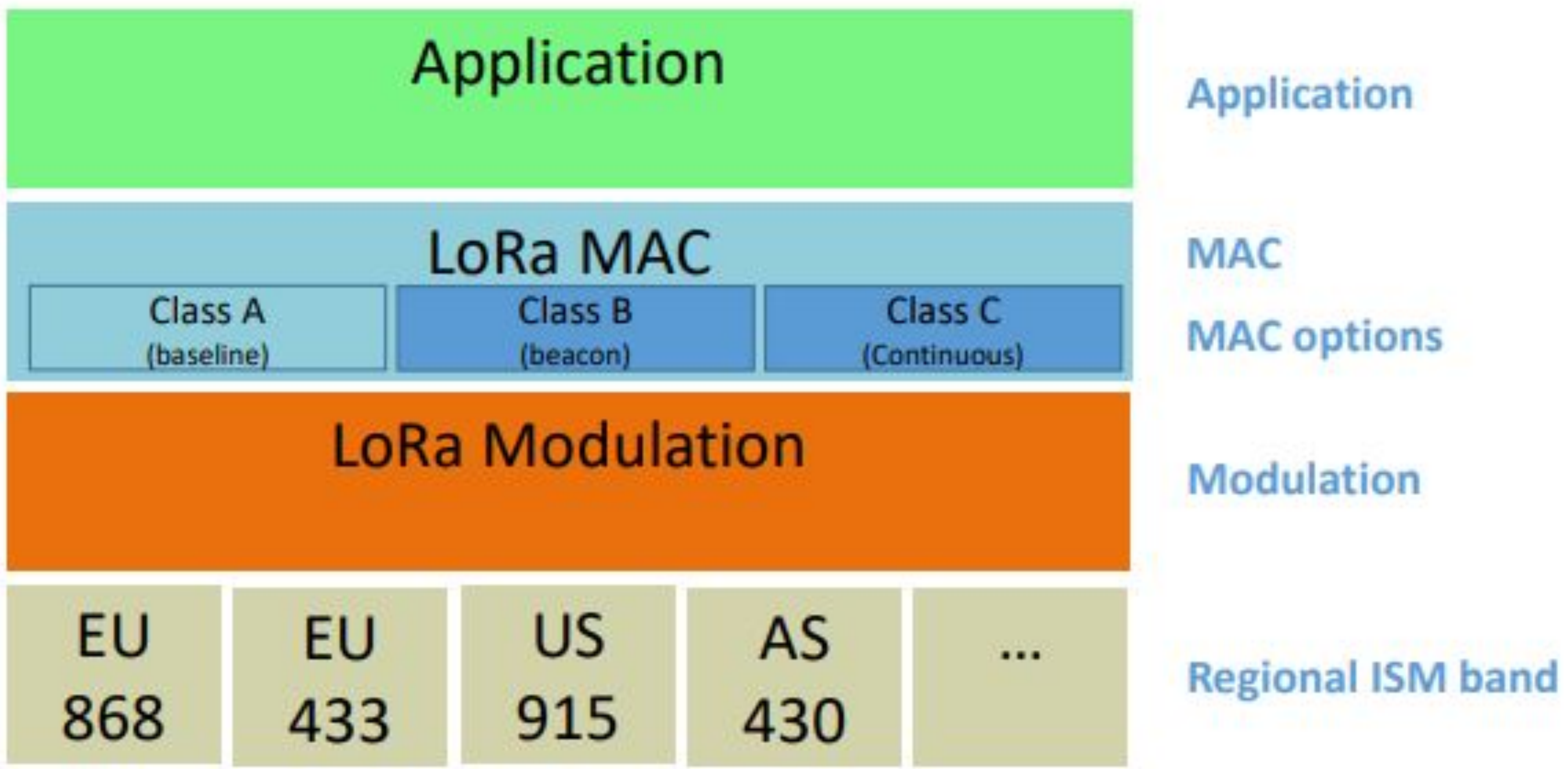
Network Architecture



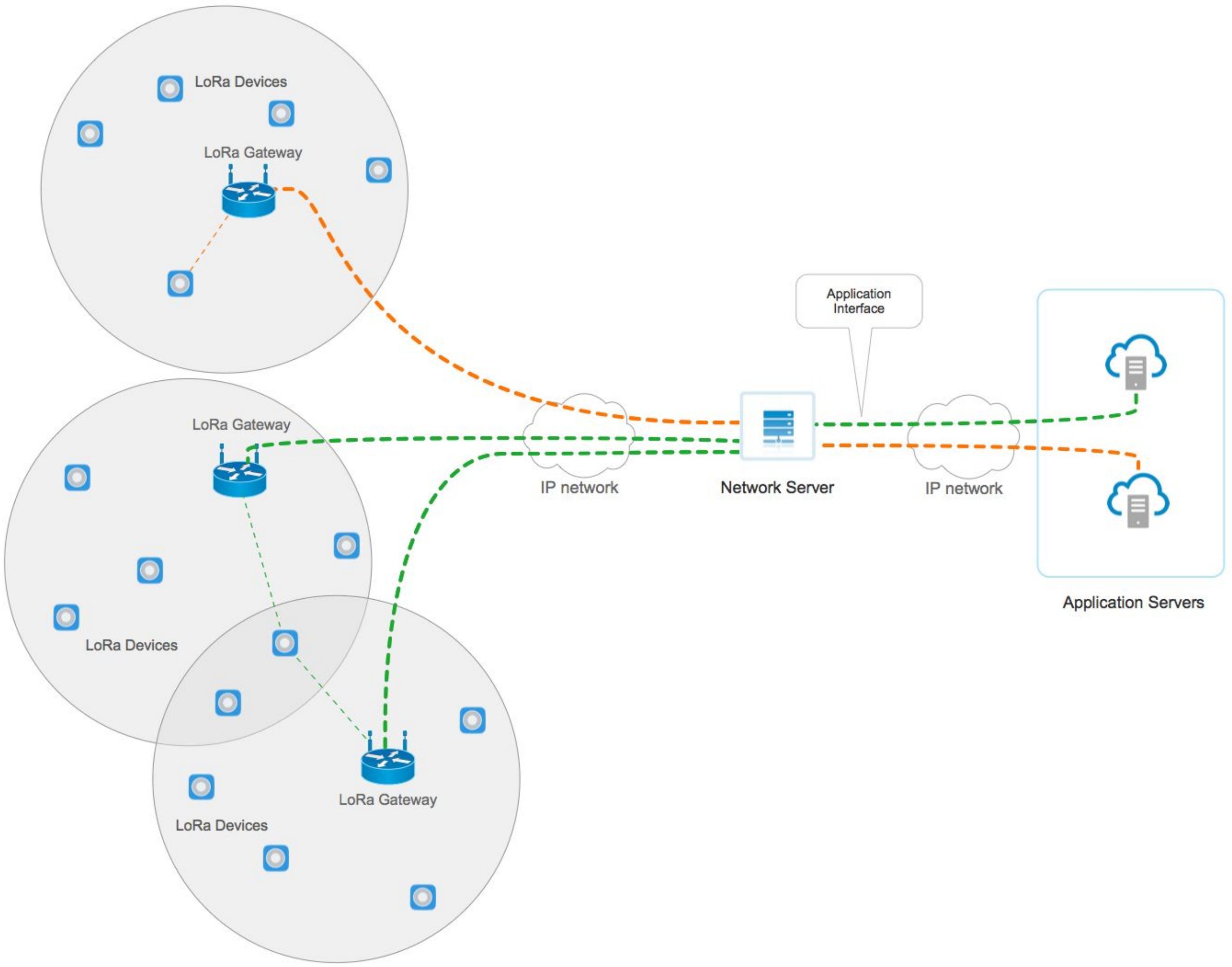
Modulation	LoRa RF (Spread Spectrum)
Range	~ 15 Km
Throughput	~ 50 Kbps

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

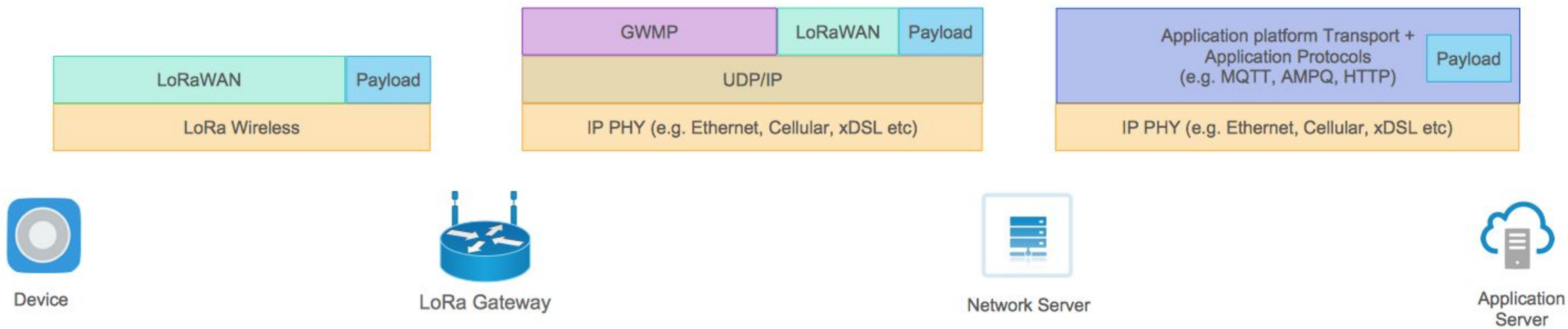
Network Layers



Network Layers

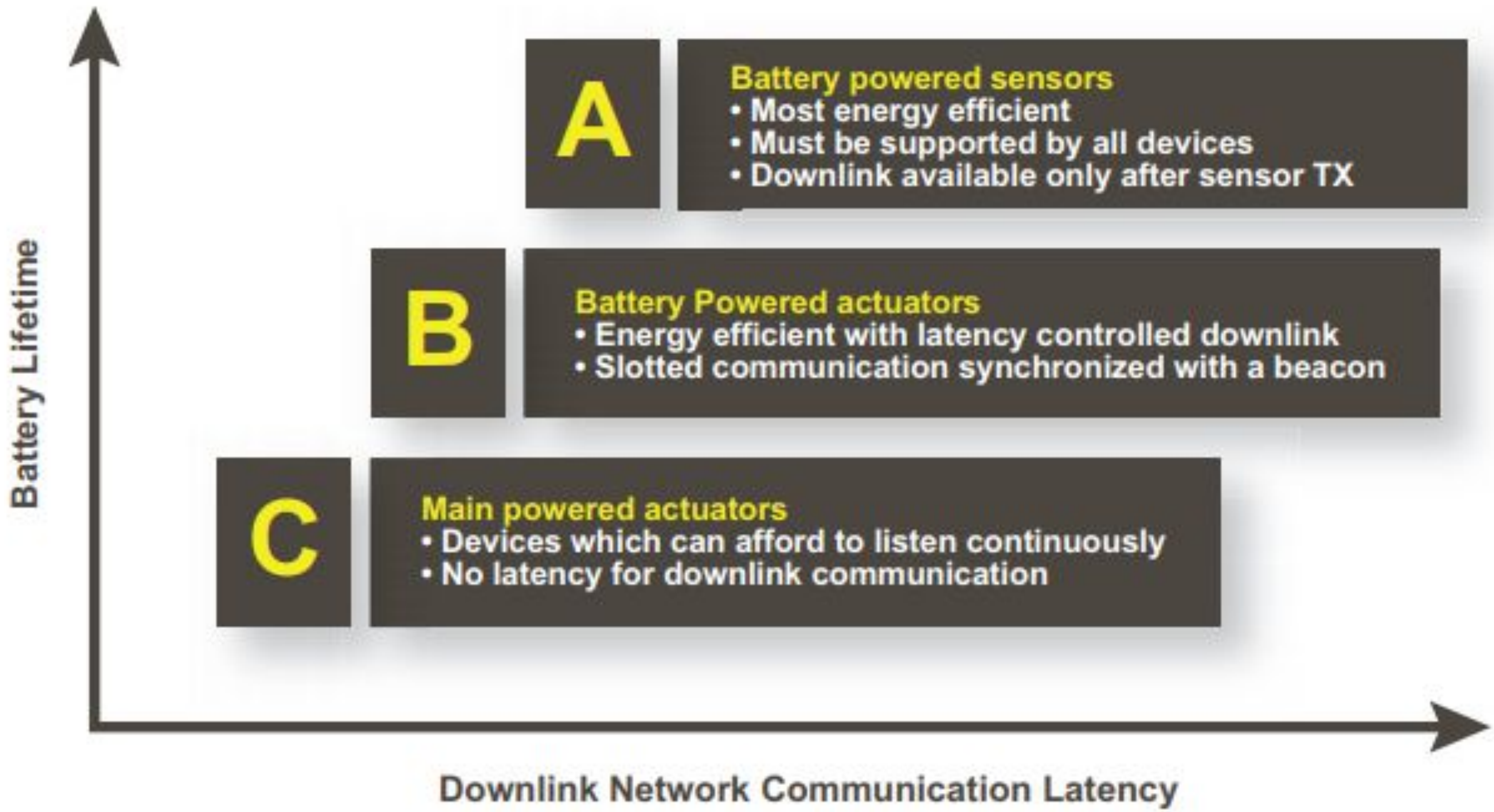


Network Layers

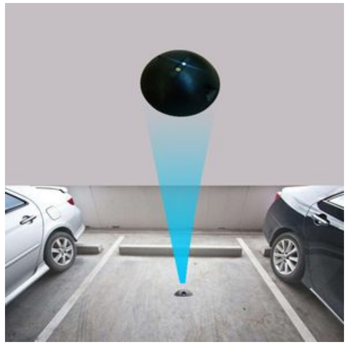


- LoRa is the physical layer protocol between end nodes and gateways.
- The LoRaWAN specification defines:
  - MAC layer for node-gateway communication.
  - Network/Transport layer for node-network server communication.

End Nodes


A
Battery powered sensors
• Most energy efficient
• Must be supported by all devices
• Downlink available only after sensor TX
B
Battery Powered actuators
• Energy efficient with latency controlled downlink
• Slotted communication synchronized with a beacon
C
Main powered actuators
• Devices which can afford to listen continuously
• No latency for downlink communication
Battery Lifetime
Downlink Network Communication Latency

End Nodes

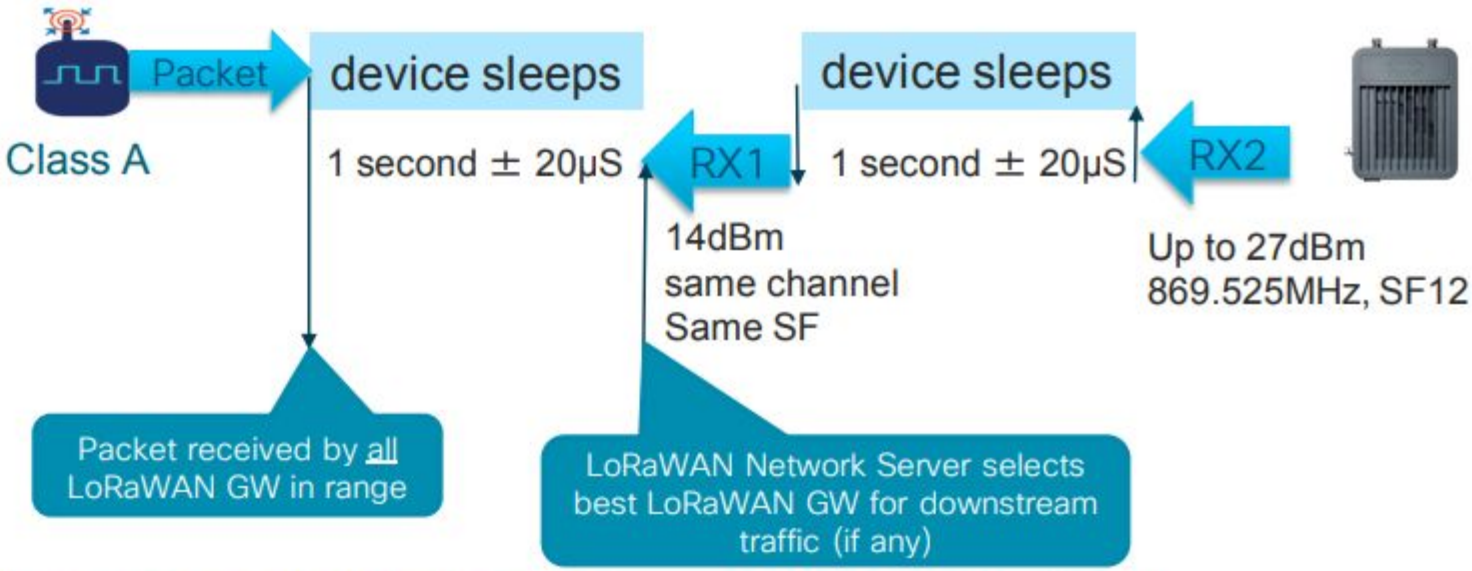


End Nodes

- Low power sensors or actuators.
- Asynchronous communication with an ALOHA-based scheme (when they have something to transmit they just do it).
- All end nodes must support Class A.
- The support of Class B and C is optional.
- All support bidirectional communication.
- The difference between them is:
  - downlink latency.
  - energy consumption.

End Nodes - Class A

LoRaWAN Class A Devices



Class A: bi-directional (default: must be supported by all devices)

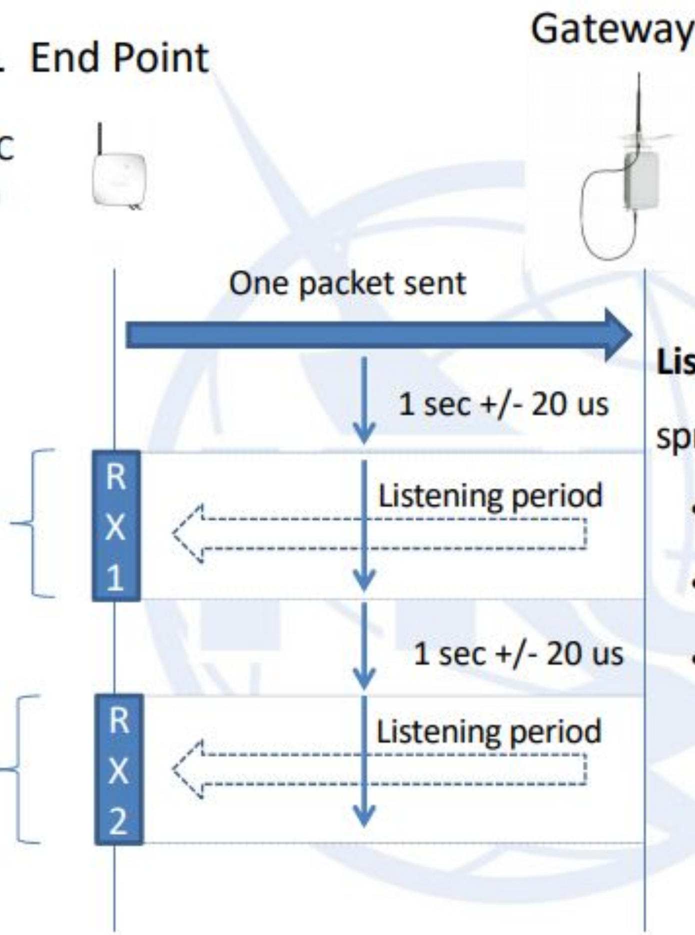
- Most energy efficient communication class
- Class A must initiate a Tx before listening on Rx windows
- Can switch to Class B or C

End Nodes - Class A

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

1st receive window

2nd receive window



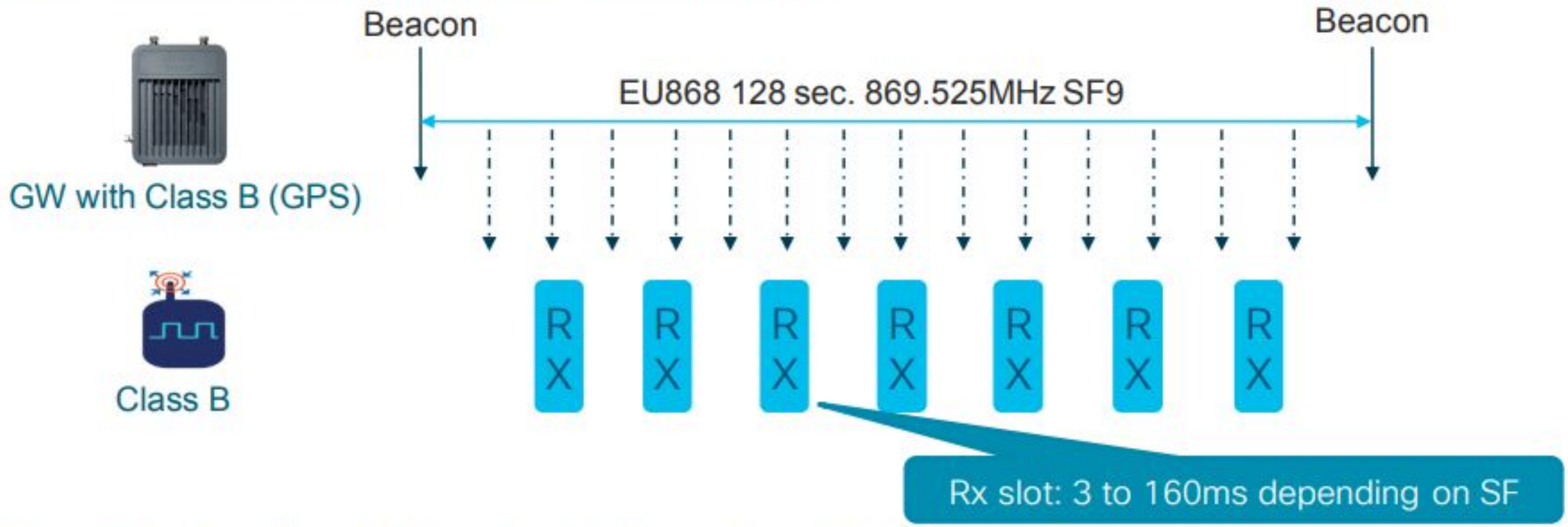
Listening period: varies according to the spreading factor SF

- 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

End Nodes - Class B

LoRaWAN Class B Devices

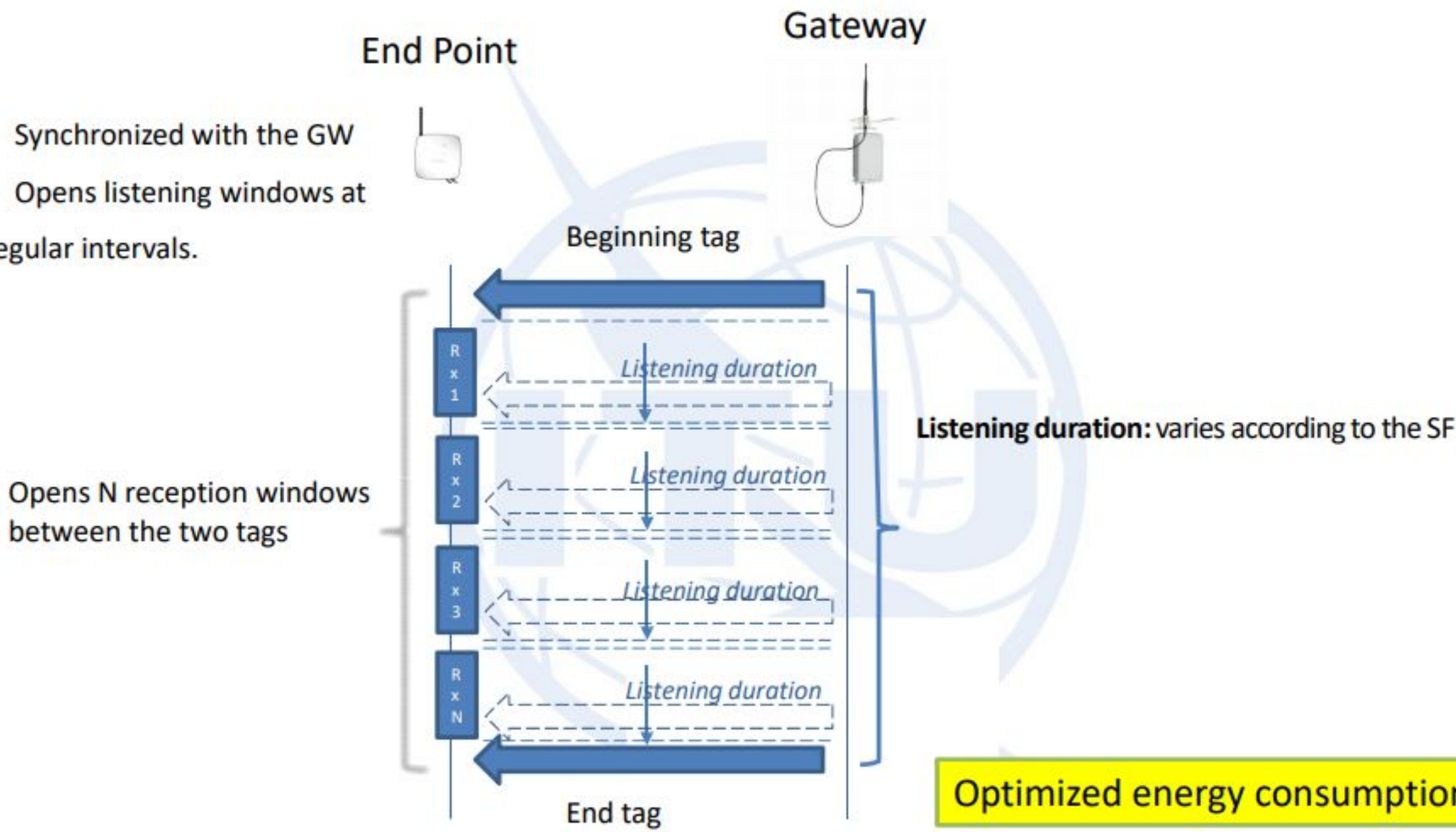


Class B Bi-directional with scheduled receive slots (Beacons)

- Energy efficient communication class for latency controlled downlink.
- Slotted communication synchronized with a network beacon (from gateways).
- Network may send downlink packet to node at any Rx slot
- Node may implements Class A, then switch to Class B, if application firmware supports it

End Nodes - Class B

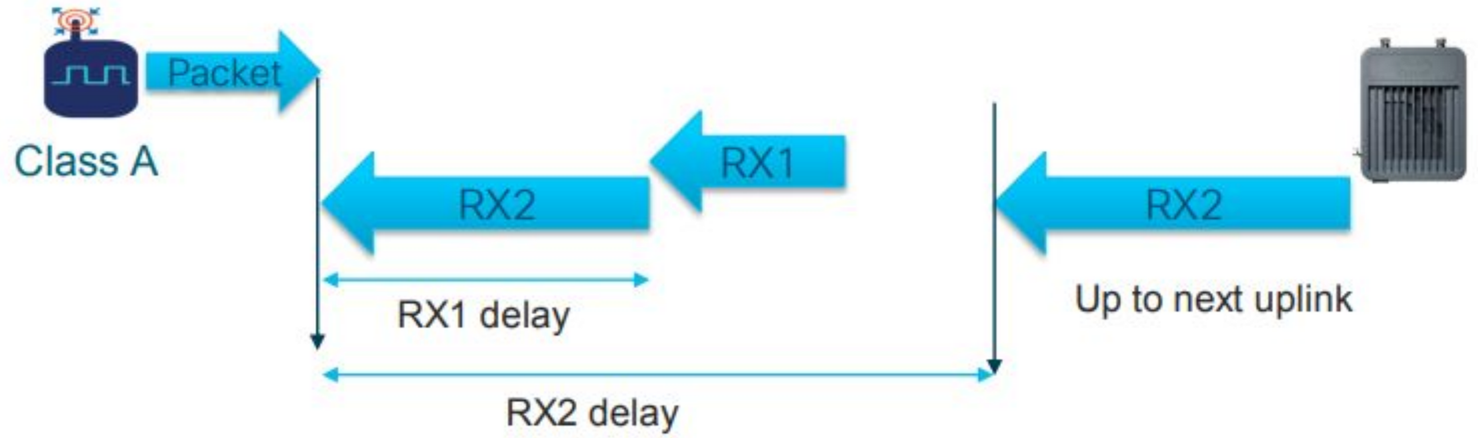
- Synchronized with the GW
- Opens listening windows at regular intervals.



Optimized energy consumption

End Nodes - Class C

LoRaWAN Class C Devices

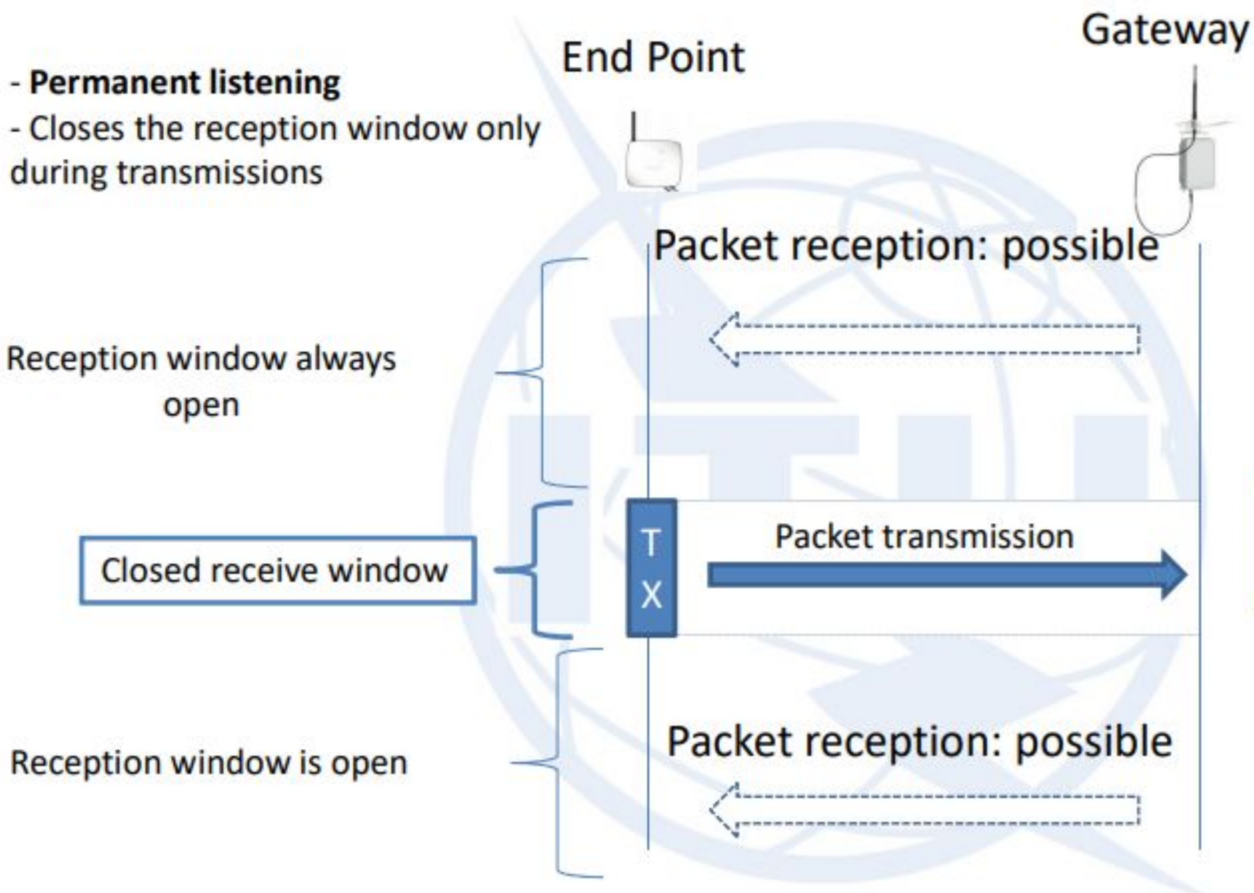


Class C: bi-directional with "Continuous Rx"

- Powered devices which can afford to listen continuously.
- No latency for downlink communication.
- Implements Class A RX1 window plus...Continually listens on RX2 channel, only closed when Transmitting

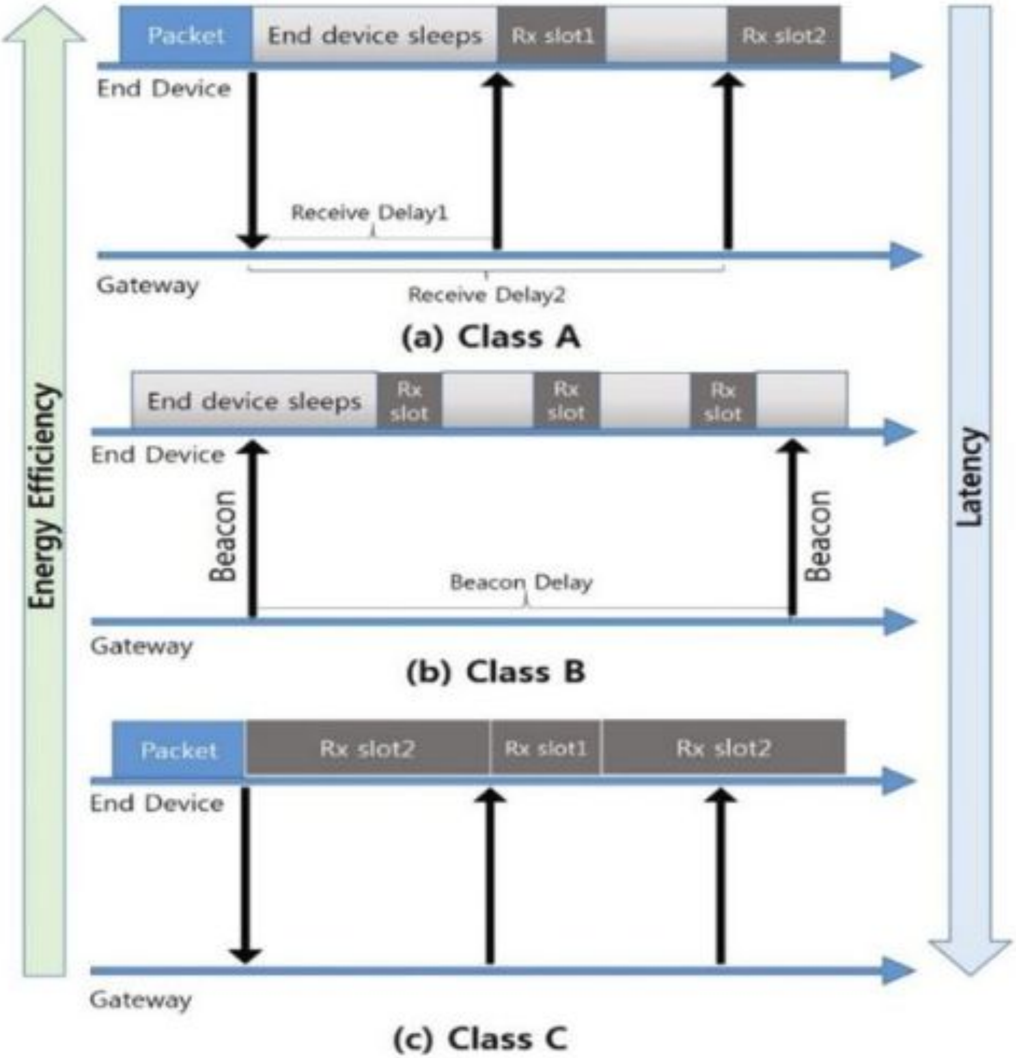
End Nodes - Class C

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



Adapted to devices on the power grid

End Nodes Summary



Gateways

- Equivalent to Base Stations in cellular networks or Access Points in Wi-Fi networks.
- They act as concentrators, forwarding the packets from the nodes to the network server.
- The communication with the nodes is wireless, through the LoRa physical layer.
- The communication with the network server is an IP connection (3G / 4G, Ethernet or fiber).
- Multiple gateways can receive the same packet from a certain node (overlapping coverage).

Gateways

Types of Gateways

- Just like Base Stations or APs, gateways can be for indoor or outdoor.
- SCG (Single-Channel Gateways): they can only receive packages on one channel and one SF at a time. They do not comply with the LoRaWAN standard.
- MSG (Multiple-Channel Gateways): they can listen and receive packages on several channels simultaneously (typically 8), even with different SF and rates.

Network server

- Centralized entity that manages the entire network.
- Network Server functions:
    - Filter duplicate packets (received by multiple gateways).
    - Perform the security check.
    - Send ACK to gateways.
    - Adaptive Data Rate (ADR).
    - Packet routing, GW selection.

Network server

LORIOT

orbiwise

THE THINGS NETWORK

LoRaServer

senet
Connecting the IoT Revolution

everynet

Actility
Connecting with intelligence

ThingPark by actility

ResIOT™

LoRaWAN History

- LoRa Alliance and first standard
  - Created by different companies from the industry.
  - Version 1.0 released in June 2015.
  - Open standard (similar to 802.11).
- Currently two versions 1.0.X (current is 1.0.3) and 1.1 (add handover between networks).
- Main standard documents:
  - LoRaWAN specification.
  - LoRaWAN regional parameters.

Frequency Bands US902-928

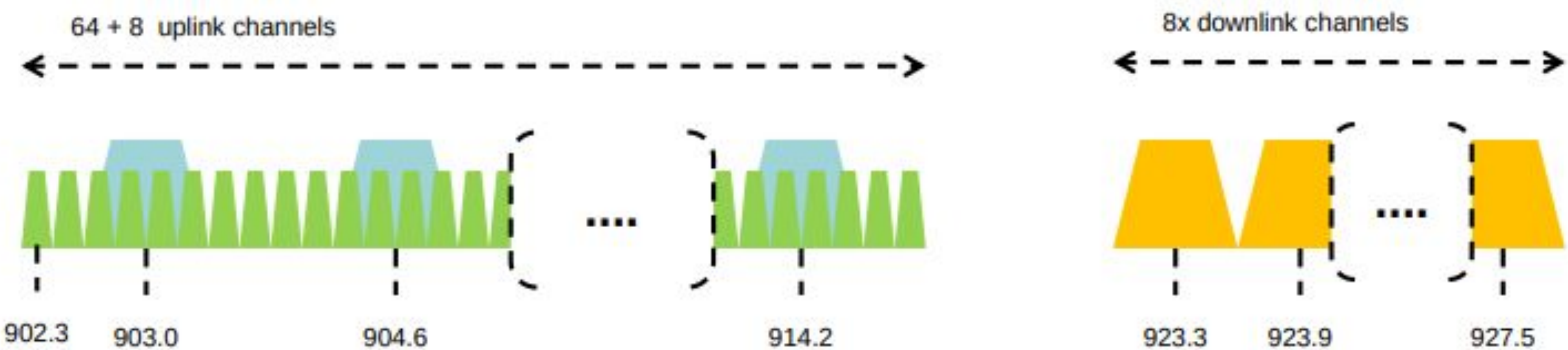


Figure 1: US902-928 channel frequencies

Frequency Bands AU915-928

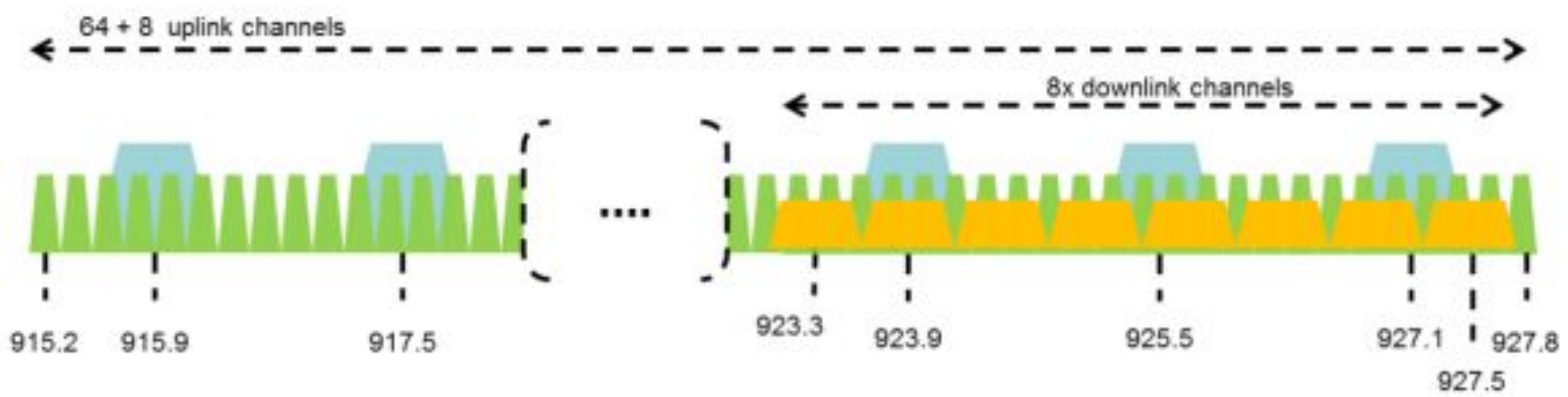


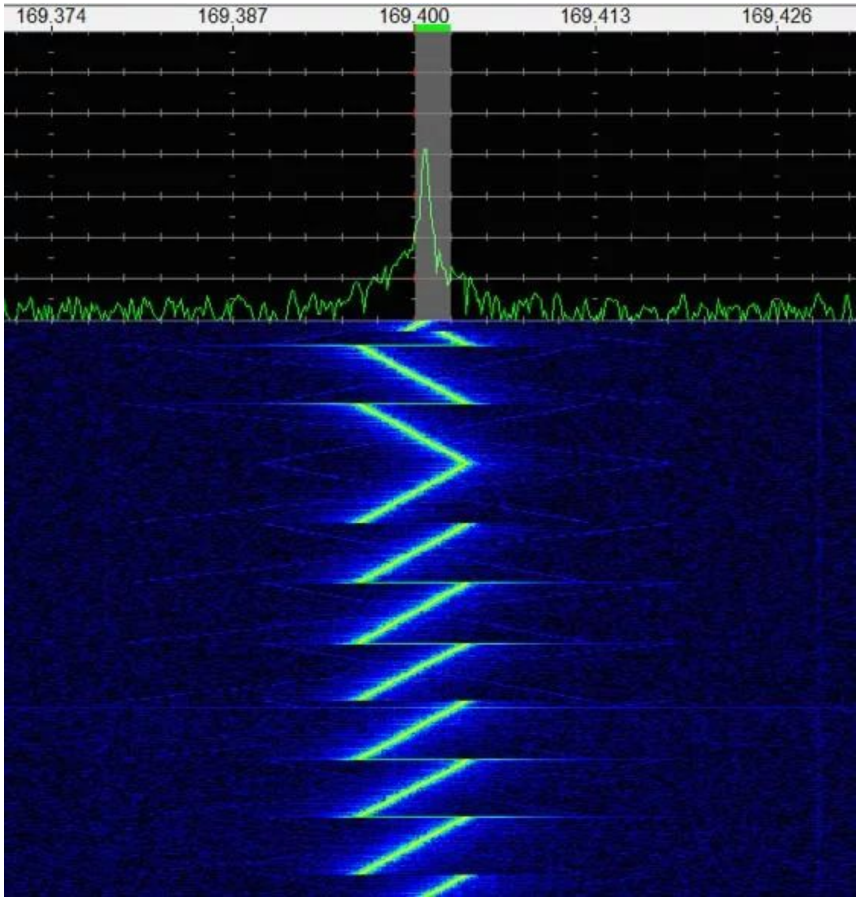
Figure 2: AU915-928 channel frequencies

Data Rates - AU915-928

DataRate	Configuration	Indicative physical bit rate [bit/sec]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF8 / 500 kHz	12500
7	RFU	
8	LoRa: SF12 / 500 kHz	980
9	LoRa: SF11 / 500 kHz	1760
10	LoRa: SF10 / 500 kHz	3900
11	LoRa: SF9 / 500 kHz	7000
12	LoRa: SF8 / 500 kHz	12500
13	LoRa: SF7 / 500 kHz	21900
14..15	RFU	

Table 35: AU915-928 Data rate table

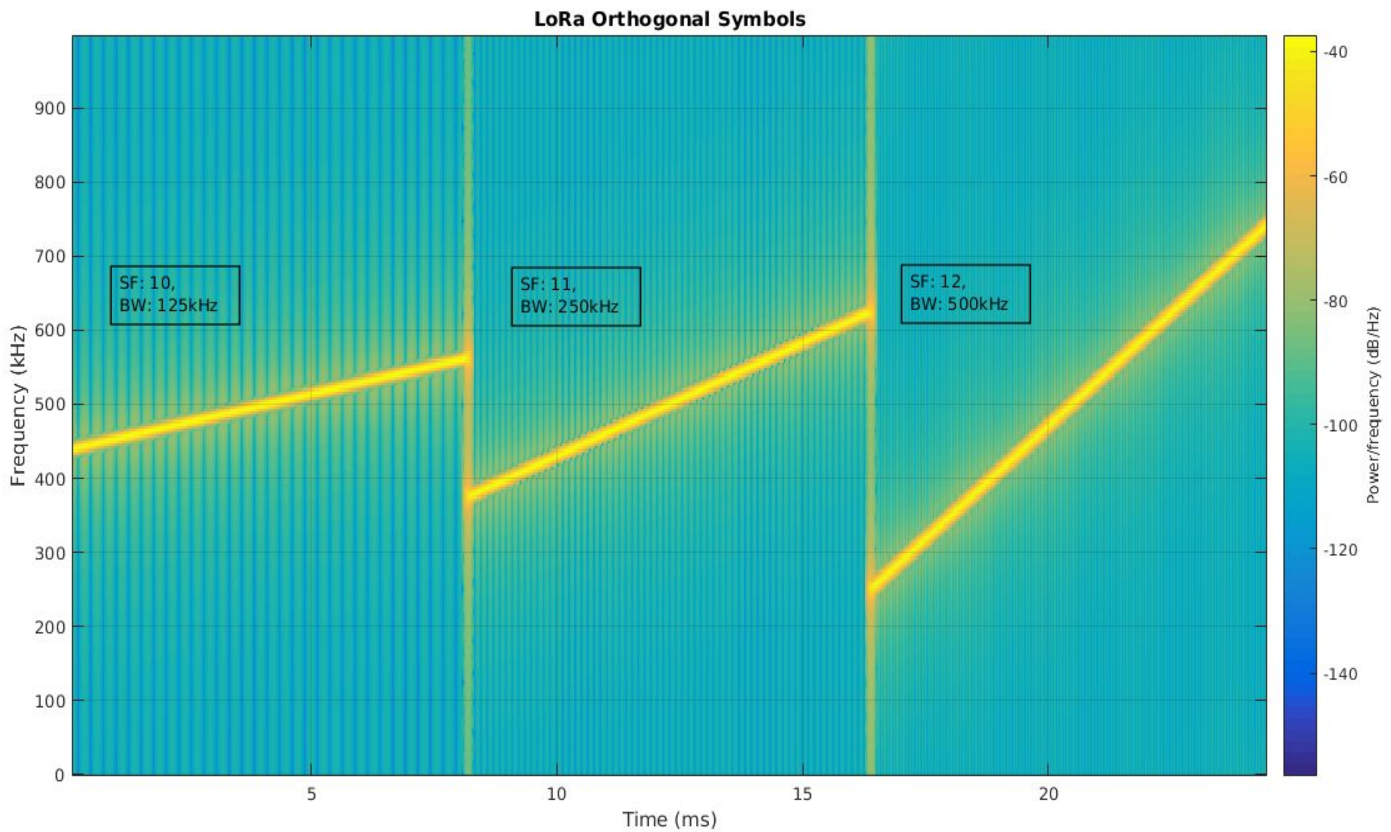
Physical Layer (RF)



- CSS: Chirp Spread Spectrum.

Physical Layer (RF)

- Spreading Factor (SF).

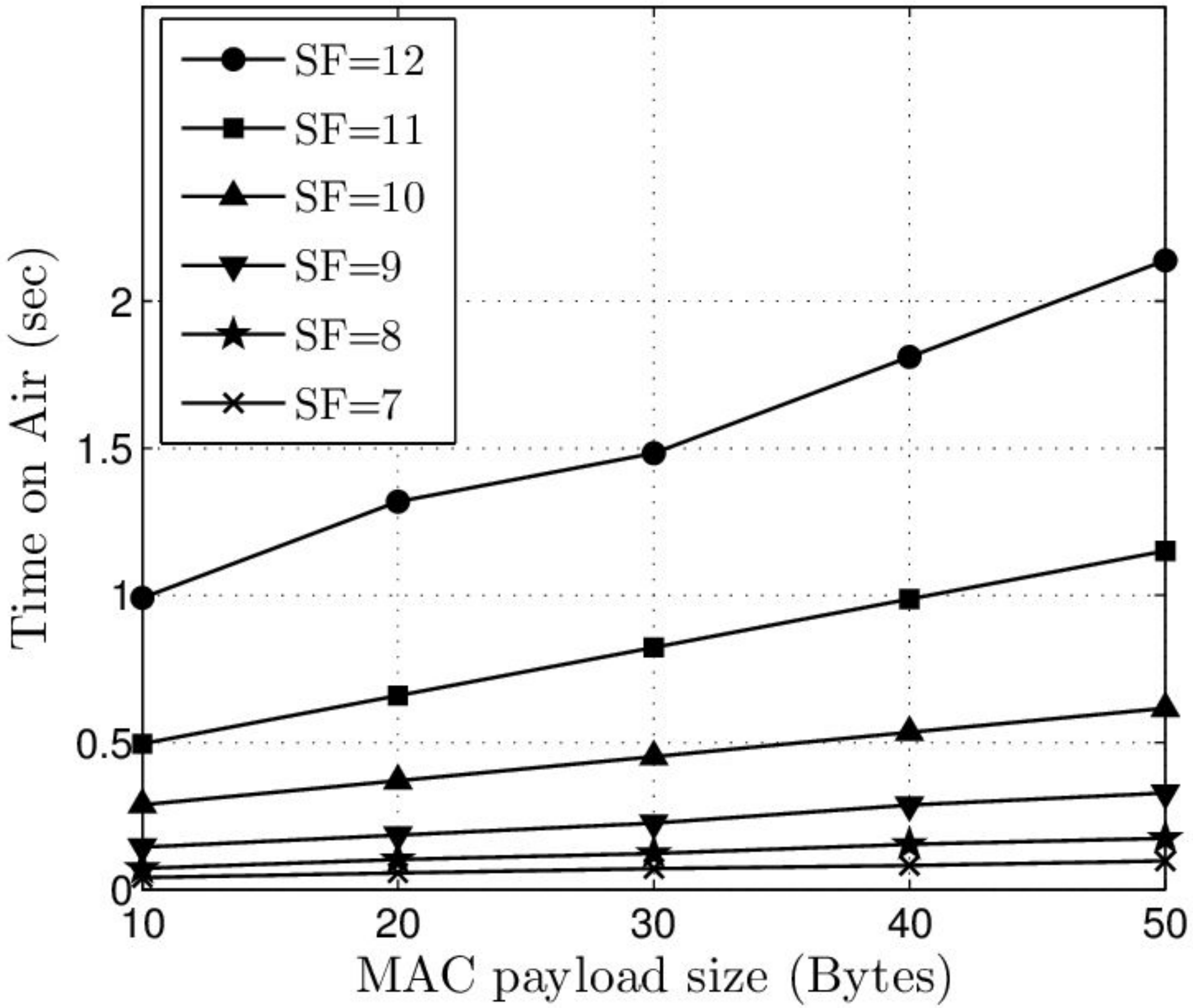


Physical Layer (RF)

Table 3: Semtech SX1276 LoRa receiver sensitivity [dBm] [24].

SF BW	6	7	8	9	10	11	12
125kHz	-118	-123	-126	-129	-132	-133	-136
250kHz	-115	-120	-123	-125	-128	-130	-133
500kHz	-111	-116	-119	-122	-125	-128	-130

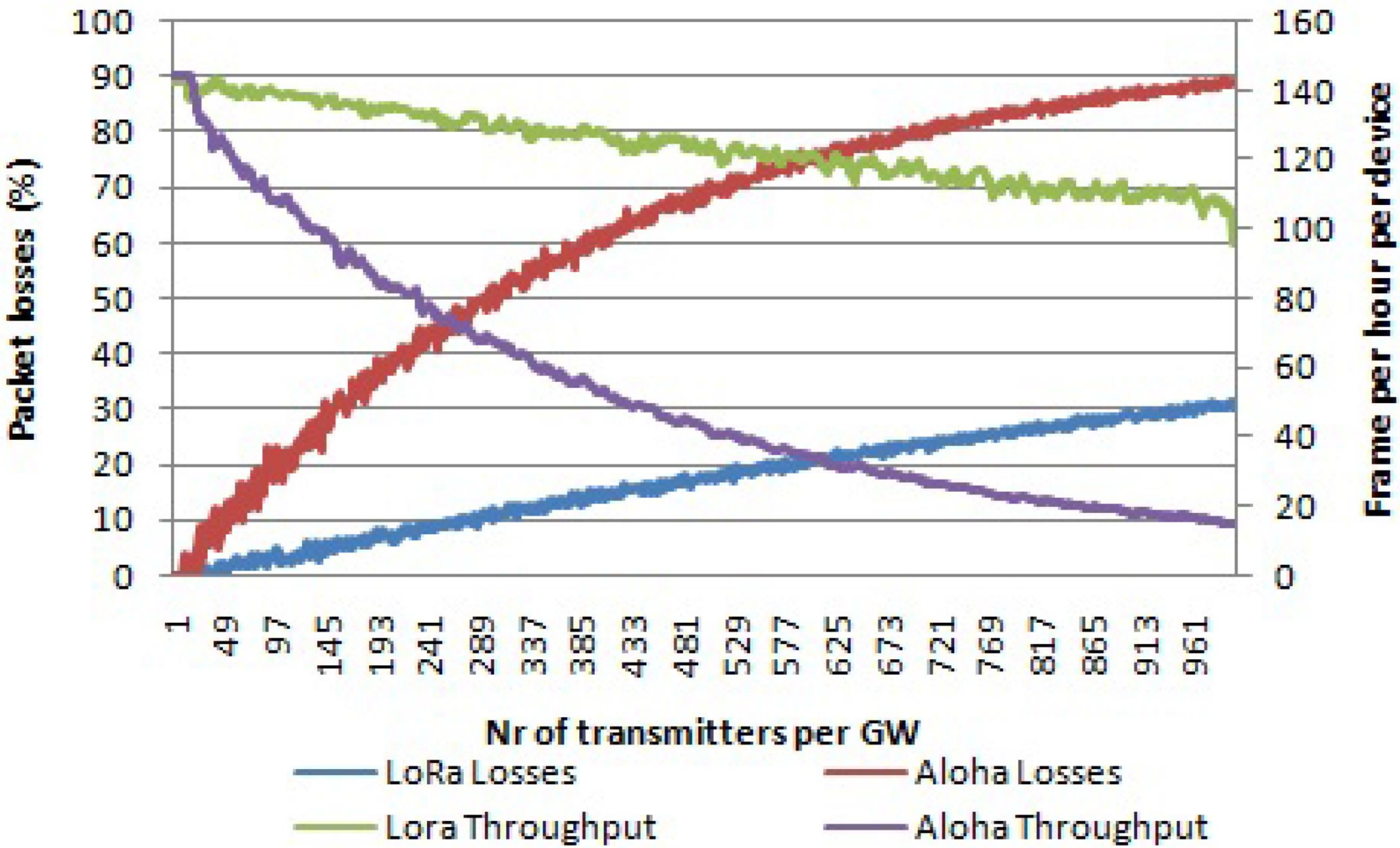
Physical Layer (RF)



Medium Access (MAC)

- MAC is ALOHA-based, so very efficient from the point of view of energy consumption.
- Control plane packets are reduced and allows asynchronous nodes.
- Problem: does not scale well.
- As the number of nodes trying to transmit simultaneously increases, the time to achieve it increases.
- Potential problem in "peak hours".

Medium Access (MAC)



Frame Structure

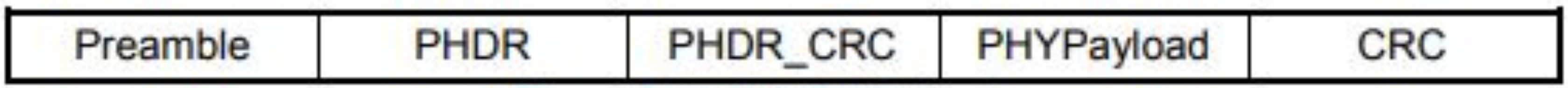


Figure 2: Uplink PHY structure

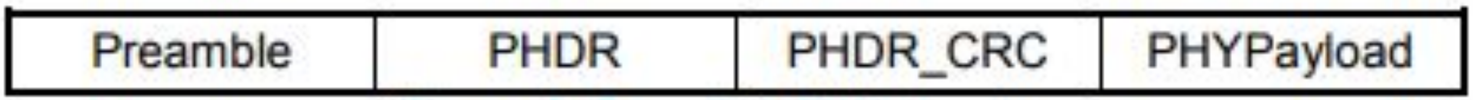


Figure 3: Downlink PHY structure

- Preamble: time and frequency synchronism.
- PHDR y PHDR_CRC: PHY header and the correspondent CRC.
- PHYPayload: physical layer payload.
- CRC: payload integrity protection.

Types of Frames

MType	Description
000	Join-request
001	Join-accept
010	Unconfirmed Data Up
011	Unconfirmed Data Down
100	Confirmed Data Up
101	Confirmed Data Down
110	Rejoin-request
111	Proprietary

Table 1: MAC message types

- 4 types for data (Up, Down, w/o ACK).
- 3 for activation with OTAA.

Frame Structure

Radio PHY layer:

Preamble	PHDR	PHDR_CRC	PHYPayload	CRC*

Figure 5: Radio PHY structure (CRC* is only available on uplink messages)

PHYPayload:

MHDR	MACPayload	MIC

or

MHDR	Join-Request or Rejoin-Request	MIC

or

MHDR	Join-Accept[2]

Figure 6: PHY payload structure

MACPayload:

FHDR	FPort	FRMPayload

Figure 7: MAC payload structure

FHDR:

DevAddr	FCtrl	FCnt	FOpts

Figure 8: Frame header structure

Frame Structure

- MHDR (MAC header) defines the type of message and the LoRaWAN standard version.
- MAC Payload includes the frame header (FHDR) followed by an optional field with the port (FPort) and other optional field for the frame payload (FRMPayload).
- The length of the MAC Payload layer payload is variable, since it depends on the data rate being used.

Frame Structure

- FHDR includes the node address (DevAddr), an 8 bits frame control (FCtrl) for the ADR (Adaptive Data Rate), two bytes for the frame counter (FCnt), and up to 15 bytes for different frame options (FOpts) used by the MAC layer commands.
- MIC (Message Integrity Code) authenticate each message with the LoRaWAN network server.

Frame Structure

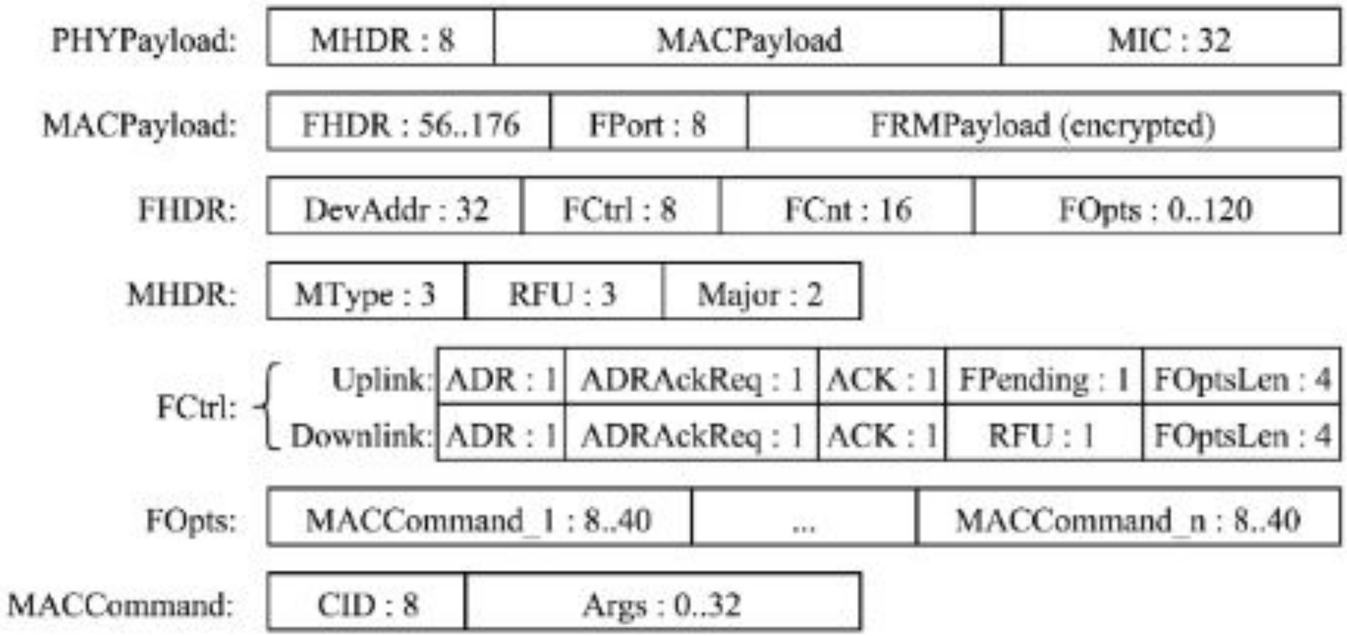


Figure 3.10 – LoRaWAN frame format. The sizes of the fields are in bits [33]

End Node Configuration

- Configure the frequency band and channels for the LoRaWAN connection.
- It is possible to change the transmission power.
- To activate the device on the network, there are two different mechanisms:
  - ABP - Activation by personalization.
  - OTAA - Over the air activation.
- In both cases, it is necessary to load certain information in the node previously.

End Node Configuration

- DevEUI (IEEE EUI64) - Global node identifier, analogous to MAC address in TCP/IP network.
- It is the recommended identifier for the network server to identify the nodes, regardless of the activation mechanism.
- OTAA devices - they must have it stored before they can be associated.
- For ABP it is not required to have it stored, but it is recommended that they also have it.

End Node Configuration

- End device address (DevAddr): 32-bit identifier of the node in the network.
- Seven bits are used as the network identifier, and the remaining 25 bits correspond to the node's network address.
- Comparable with an IP address for a TCP/IP device.

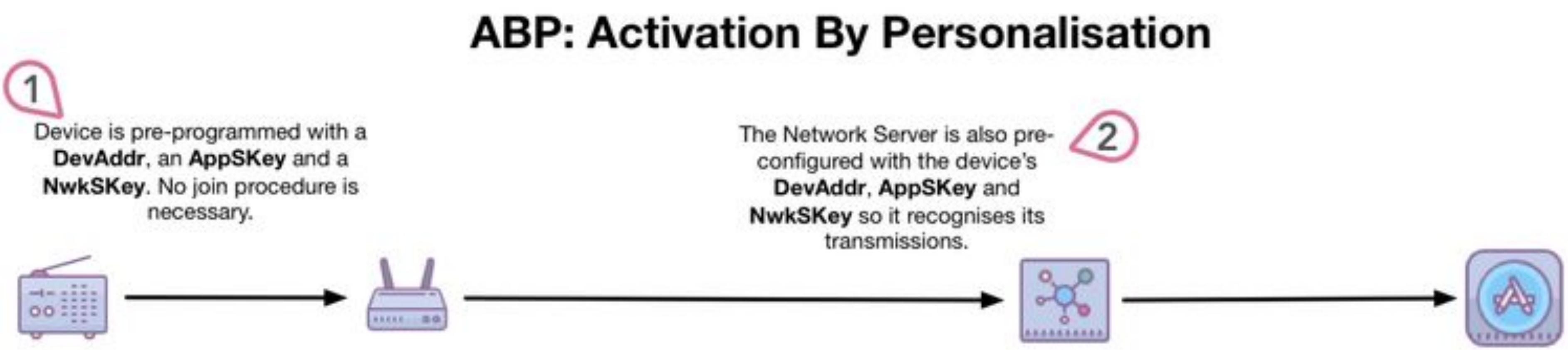
End Node Configuration

- AppEUI / JoinEUI (IEEE EUI64) - Global identifier of the application that identifies the Join Server that assists in the process of association and generation of session keys.
- OTAA devices - they must have it stored before they can be associated.
- Not required for devices that only support ABP.

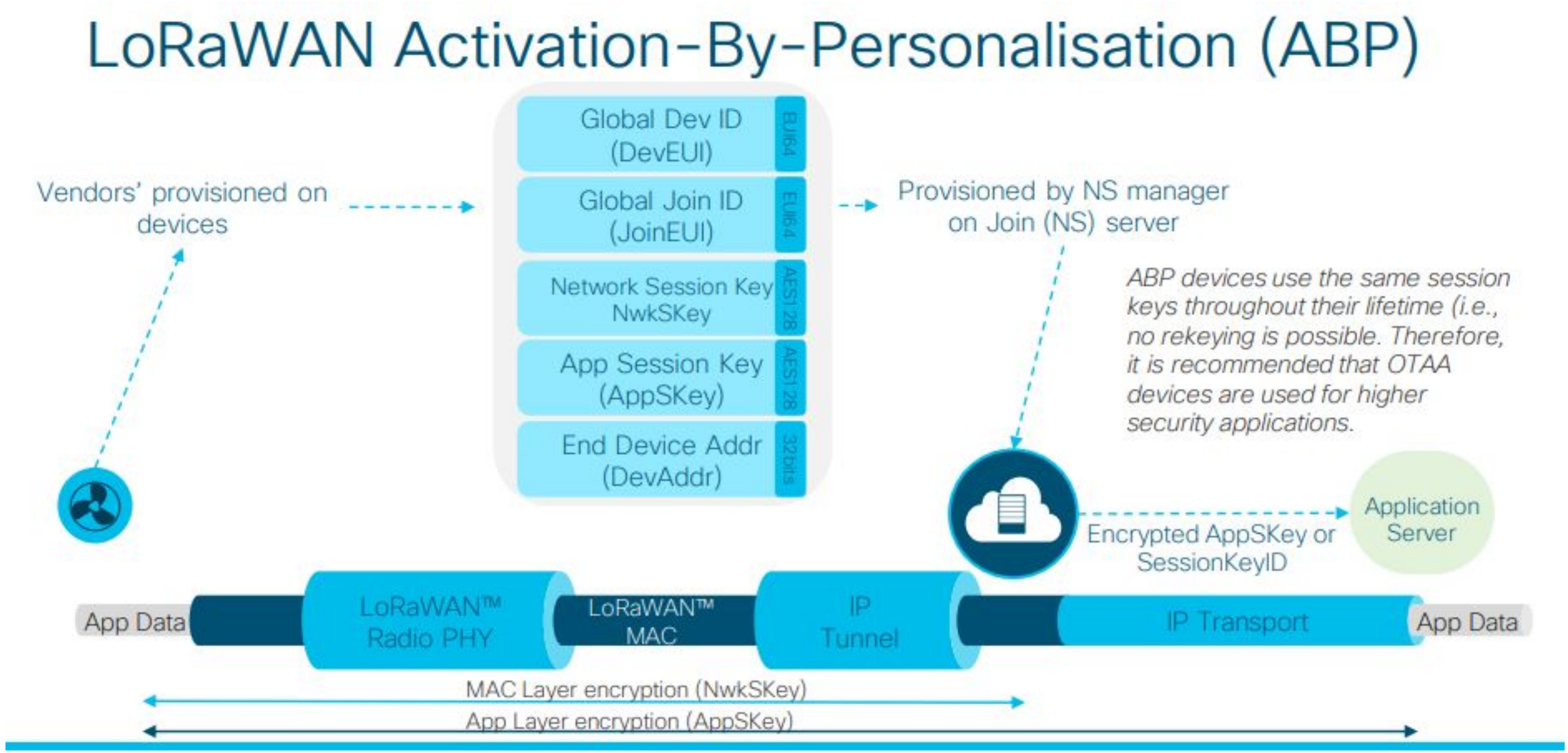
End Node Configuration

- Network session key (NwkSKey): 128-bit AES key used for authentication between network server and node, and to calculate and verify the MIC of all messages and ensure data integrity.
- Application session key (AppSKey): 128-bit AES key used by the network server and nodes to encrypt/decrypt the payload of all data messages.

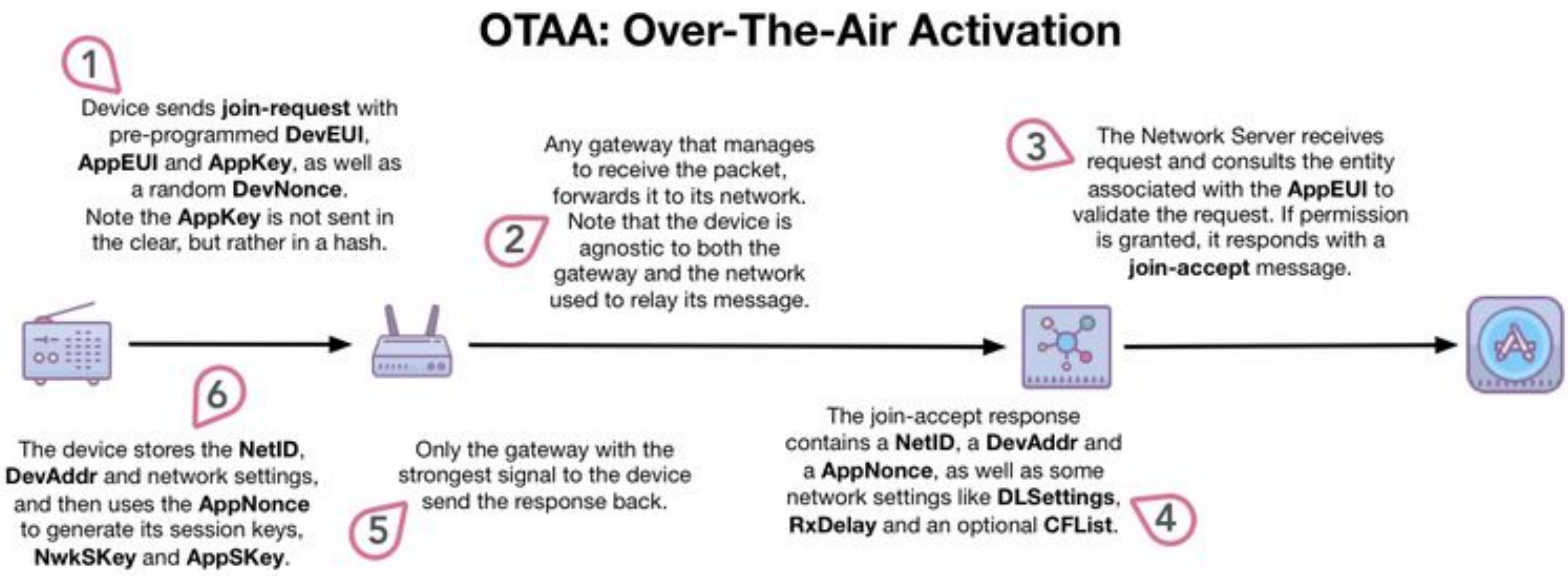
ABP Provisioning



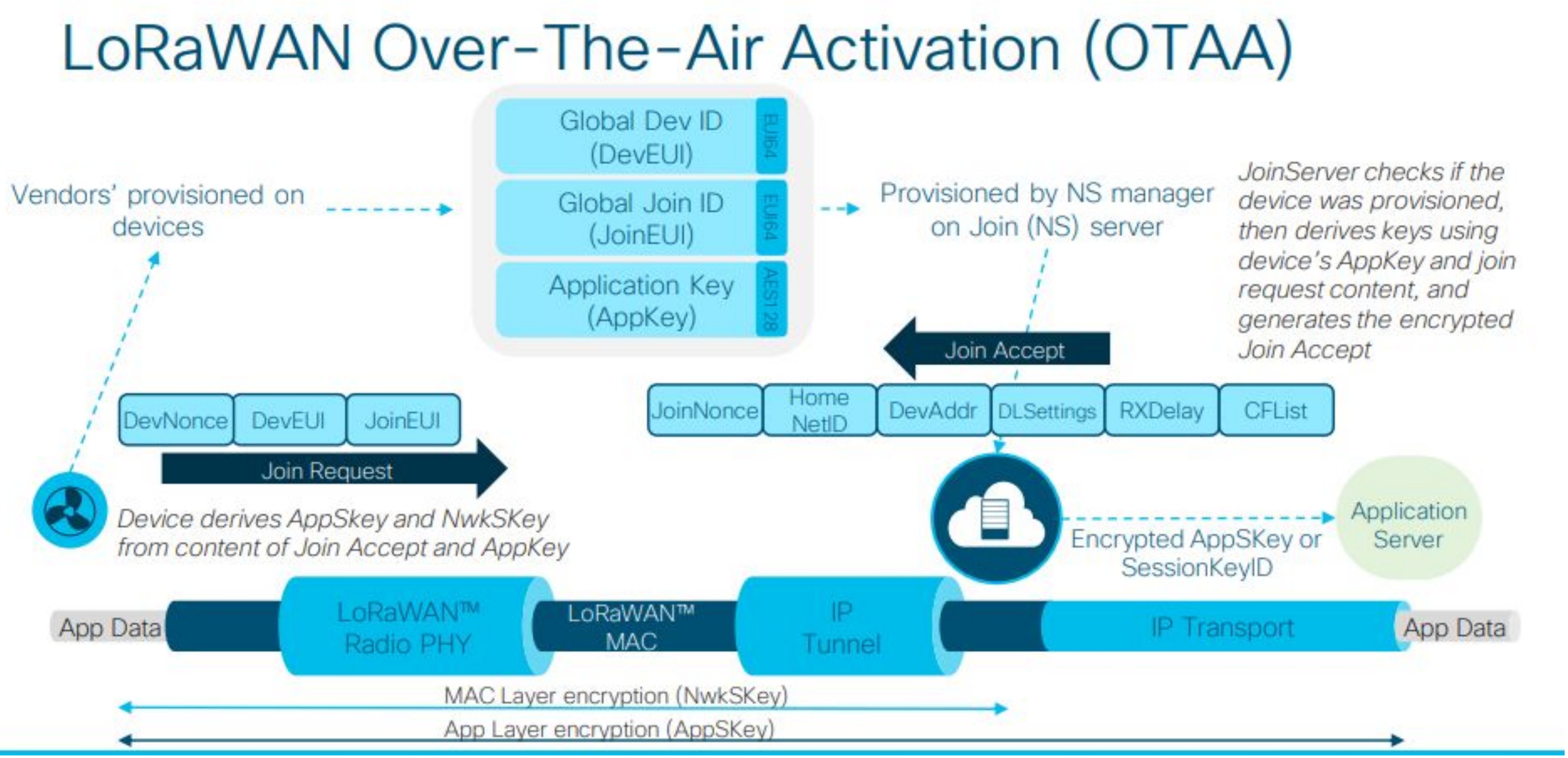
ABP Provisioning



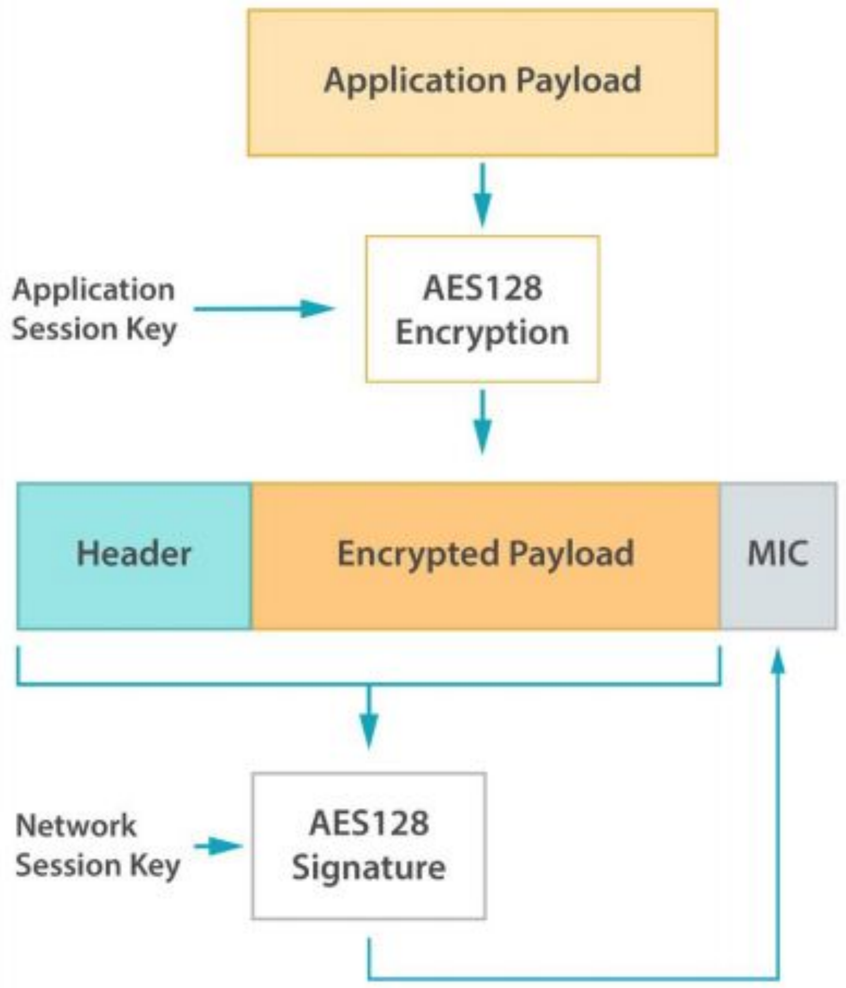
OTAA Provisioning



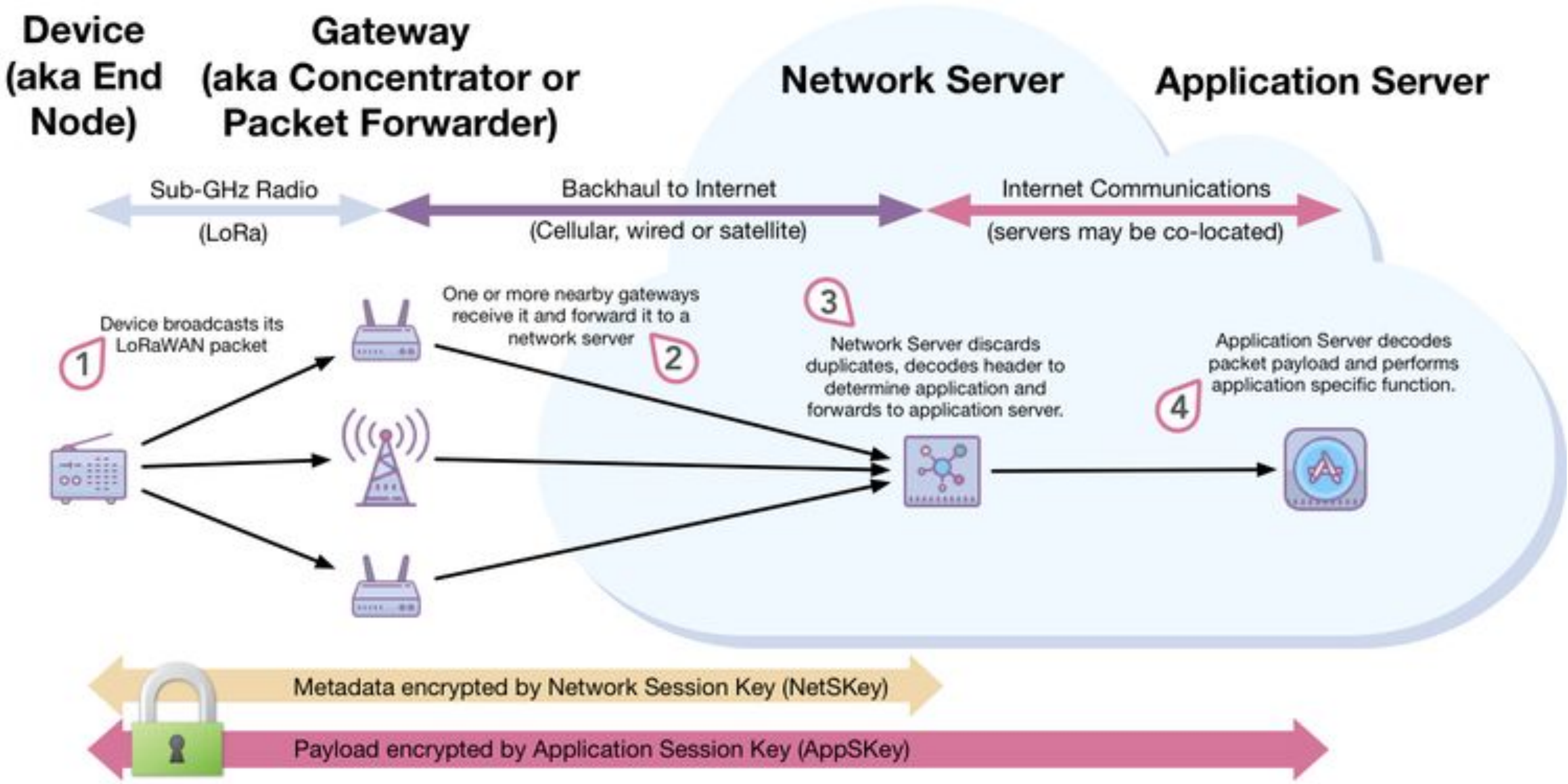
OTAA Provisioning



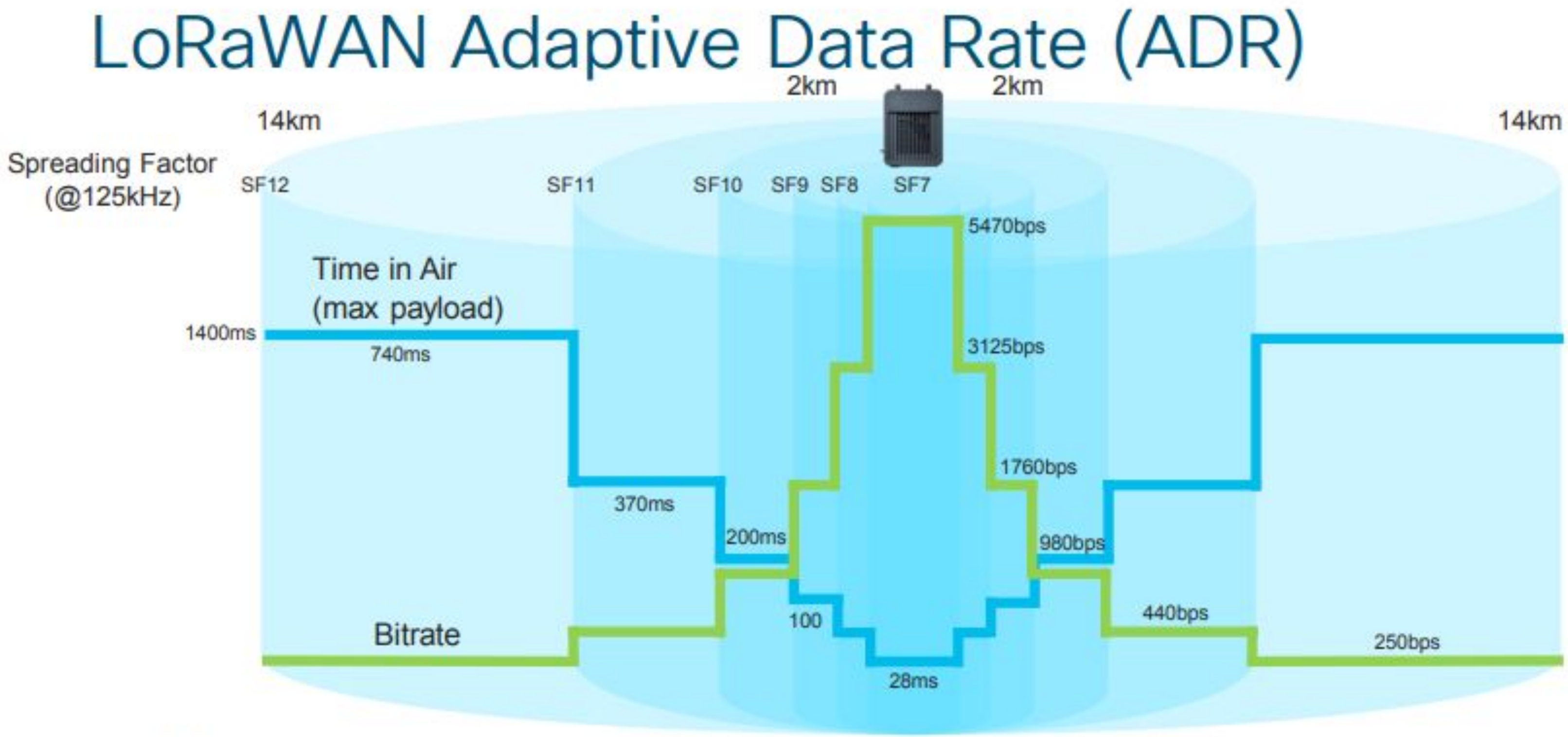
LoRaWAN Security



LoRaWAN Security



Adaptive Data Rate (ADR)



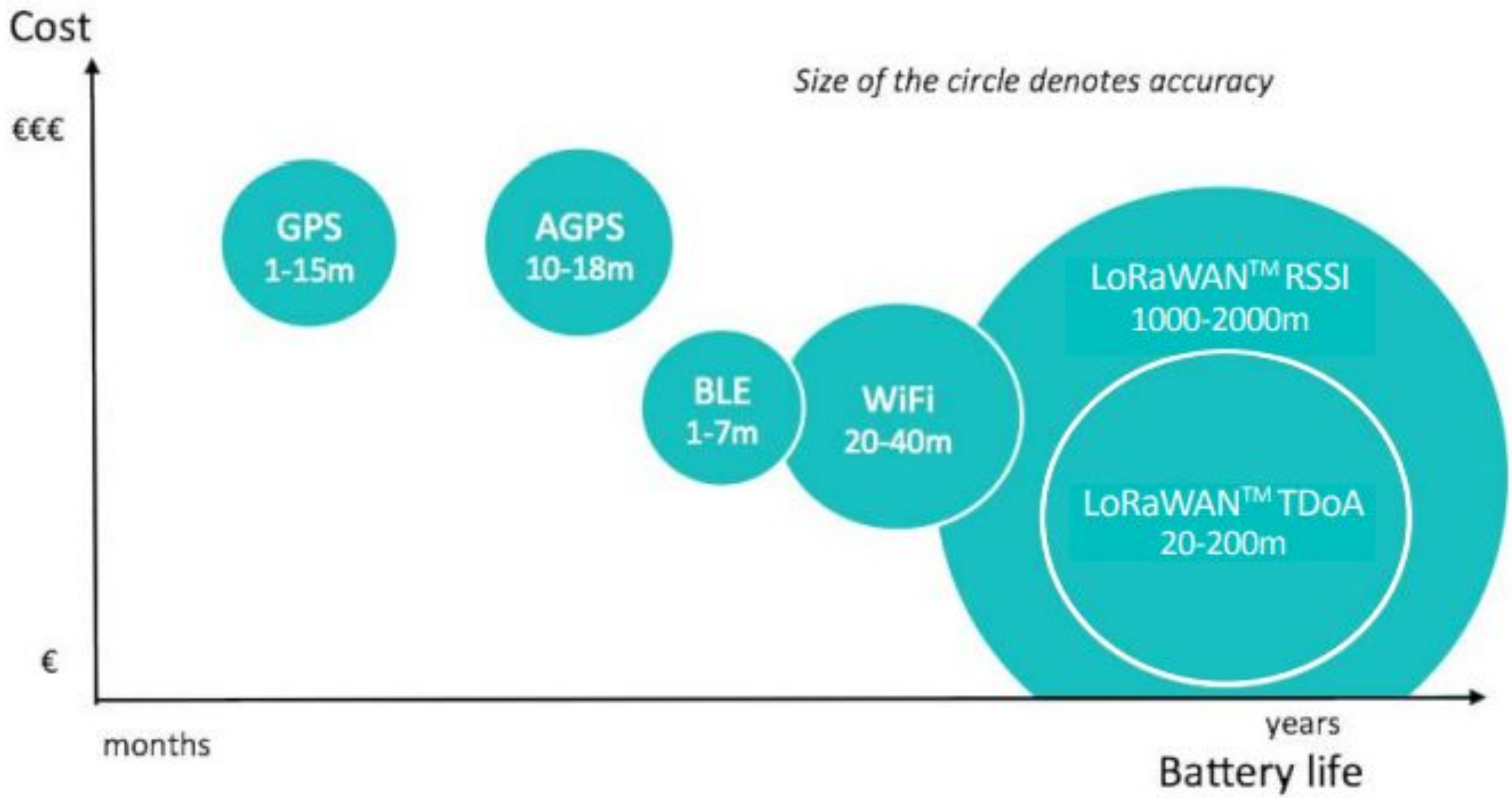
- ADR maximises battery life overall & network capacity
- ADR manages the data rate and RF output for each device

Adaptive Data Rate (ADR)

ADR, Spreading Factor and Payload

Spreading Factor	Data Rate (bit/s)	Time on Air (ms)	Maximum Payload Size	End-device sensitivity (dBm)
SF12	250	1400	59 bytes	-137
SF11	440	740	59 bytes	-135
SF10	980	370	59 bytes	-133
SF9	1760	200	123 bytes	-130
SF8	3125	100	250 bytes	-127
SF7	5470	28	250 bytes	-124

Geolocalization



- Low cost solution supported for any sensor (GWs must be properly geolocated).

Gateway Configuration

- Configure the frequency band and channels for the LoRaWAN connection.
- It is possible to set the transmission power.
- For the backhaul interface, standard IP network configuration is required.
- The URL/IP of the network server must be indicated.
- Other options regarding the treatment of packets.

Network Server Configuration

- For the backhaul interface, standard IP network configuration is required (addressing, DNS, etc).
- The frequency band must be indicated (e.g. in Lora server: AU_915_928).
- Enable ADR and configure available channels.
- Device parameters according to node class.
- Backend connections with applications (e.g. MQTT, IoT platforms, etc.).

Design Example

Use case

Assumptions

- Big City
- **Public LoRaWAN Network Dimensioning**
- Number of devices increase every year
- Total Bandwidth: **1 MHz**

- **LoRa SX1301 Chipset**
- **Bandwidth: 125 KHz**
- **8 channels**
- **Central Frequency: 868 MHz**
- CRC enabled
- Low data rate optimization enabled

Design Example

Service and End Device Modeling

Modeling of:
- End devices (type, technology used, …)
- Sensors
- Other connected things

→ Modeling the services

❖ *Fleet Management:* The end device can send a packet in the network every **30 second** to track a vehicle

❖ *Logistic*: an end device can send a packet in the network every **5 min** to report his occupation state

❖ *Water meter*: can send a packet **once a day** to inform the water consumption

Design Example

Traffic Modeling

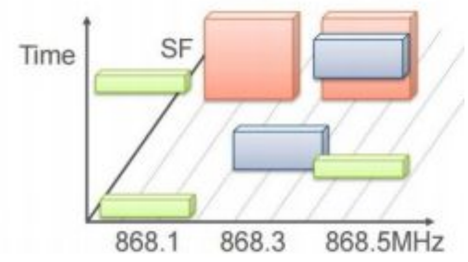
Several parameters to consider depending on the technology

Packet size

Change according the services

Number of available channels

More channels ➔ More simultaneous connections



Throughput

Determine the time on Air ➔ Packets inter-arrival time

Gateway Capacity

Gateway capacity (packets/day, maximum throughput, ...)

Design Example

Traffic Modeling

Services	Packet transmission frequency (per hour)
Sensor	1
Metering	0,04
Alarm	1/365/24
Tracking Logistic	2
Vehicle Tracking	6
Traffic Control	60
Agriculture	1
Wearables	2
Home Automation	0,50

Design Example

Gateway Capacity

Lora Gateway **Capacity**: given in terms of **number of packets per day**.

LoRa Packet
(maximum size: 256 bytes)

Preamble	Payload	CRC
Up to 5 bytes	Min: 2 bytes	Up to 2 bytes

Payload Size (byte)	Spreading Factor	Symbol Rate	Programmed Preamble (Symbol)	Preamble Duration (ms)	Coding Rate	Number of payload Symbol	Payload Duration (ms)	Duration of packet (ms)	Single Gateway with 8 channels Capacity (Packets per day)
10	7	0,98	6	10	2	32	32	43	1 997 041
10	8	0,49	6	20	1	23	47	68	1 268 797
5	9	0,24	6	41	2	14	57	99	869 845
15	10	0,12	6	83	4	40	327	411	209 888
15	11	0,06	6	167	1	23	376	544	158 600
10	7	0,98	6	10	4	40	40	51	1 679 104
15	8	0,49	6	20	1	33	67	88	975 434
12	9	0,24	6	41	3	29	118	160	537 420
12	10	0,12	6	83	1	23	188	272	317 199

Design Example

IoT Applications with Different Characteristics

Example Applications	Data volume	Quality of Service	Amount of signaling	Time sensitivity	Mobility	Server initiated Communication	Packet switched only
Smart energy meters	low	low	intermediate	very low	no	yes	yes
Red charging	low	low	low	low	yes	no	yes
eCall	very low	very high	very low	very high	yes	no	no
Remote maintenance	low	low	high	high	no	yes	yes
Fleet management	low	low	very high	intermediate	yes	yes	no
Photo frames	intermediate	low	high	low	no	yes	yes
Assets tracking	low	low	very high	high	yes	yes	no
Mobile payments	intermediate	low	high	very high	yes	no	yes
Media synchronisation	high	low	high	intermediate	yes	yes	yes
Surveillance cameras	very high	very high	low	very high	no	yes	yes
Health monitoring	high	high	high	very high	yes	yes	yes

very low | low | intermediate | high | very high

Design Example

First Year

Gateway **Capacity: 1 500 000 packets per day**

Services	Packet transmission frequency (at BH)	End devices Number	Number of packets per day for one device	Burstiness Margin	Security Margin	Number of packets
Sensor	1	200	24	20%	10%	152 064
Metering	0,04	100,00	1	20%	10%	132
Alarm	0,00	100,00	1	20%	10%	132
Tracking Logistic	2	100	48	20%	10%	304 128
Vehicle Tracking	6	70	144	20%	10%	1 916 007
Traffic Control	10	150	240	20%	10%	11 404 800
Agriculture	1	200,00	24	20%	10%	152 064
Wearables	0,5	1000,00	12	20%	10%	190 080
Home Automation	0,5	300	12	20%	10%	57 024
Total Packets per day						14 176 431

Number of Gateways: **10**

Design Example

Second Year Gateway **Capacity: 1 500 000 packets per day**

Services	Packet transmission frequency (at BH)	End device Number	Number of packets per day for one device	Burstiness Margin	Security Margin	Number of packet
Sensor	1	400	24	20%	10%	304 128
Metering	0,04	200	1	20%	10%	264
Alarm	0,00	200	1	20%	10%	264
Tracking Logistic	2	200	48	20%	10%	608 256
Vehicle Tracking	6	140	144	20%	10%	3 832 013
Traffic Control	10	300	240	20%	10%	22 809 600
Agriculture	1	400	24	20%	10%	304 128
Wearables	0,5	2000	12	20%	10%	380 160
Home Automation	0,5	600	12	20%	10%	114 048
Total Packets per day						28 352 861

Number of Gateways: **19**

Design Example

Third Year

Services	Packet transmission frequency (at BH)	End device Number	Number of packets per day for one device	Burstiness Margin	Security Margin	Number of packets
Sensor	1	800	24	20%	10%	608 256
Metering	0,04	400	1	20%	10%	528
Alarm	0,00	400	1	20%	10%	528
Tracking Logistic	2	400	48	20%	10%	1 216 512
Vehicle Tracking	6	300	144	20%	10%	8 211 456
Traffic Control	10	600	240	20%	10%	45 619 200
Agriculture	1	800	24	20%	10%	608 256
Wearables	0,5	3000	12	20%	10%	570 240
Home Automation	0,5	1200	12	20%	10%	228 096
Total Packets per day						57 063 072

Number of Gateways: **39**

References

- LoRaWAN standard documentation:
  - LoRaWAN specification v1.1
  - LoRaWAN regional parameters v1.1
- Master Thesis, Lisbon Superior Engineering Institute: "IoT Network – Design and Implementation", Diciembre 2018.
- Cisco Live 2019 LoRaWAN presentation: LoRaWAN for IOT Enterprises services.
- IoT Course presentation from ITU: "IoT Network Planning", Diciembre 2016.

THE END

Thank you.
Any questions?

gcapde@fing.edu.uy