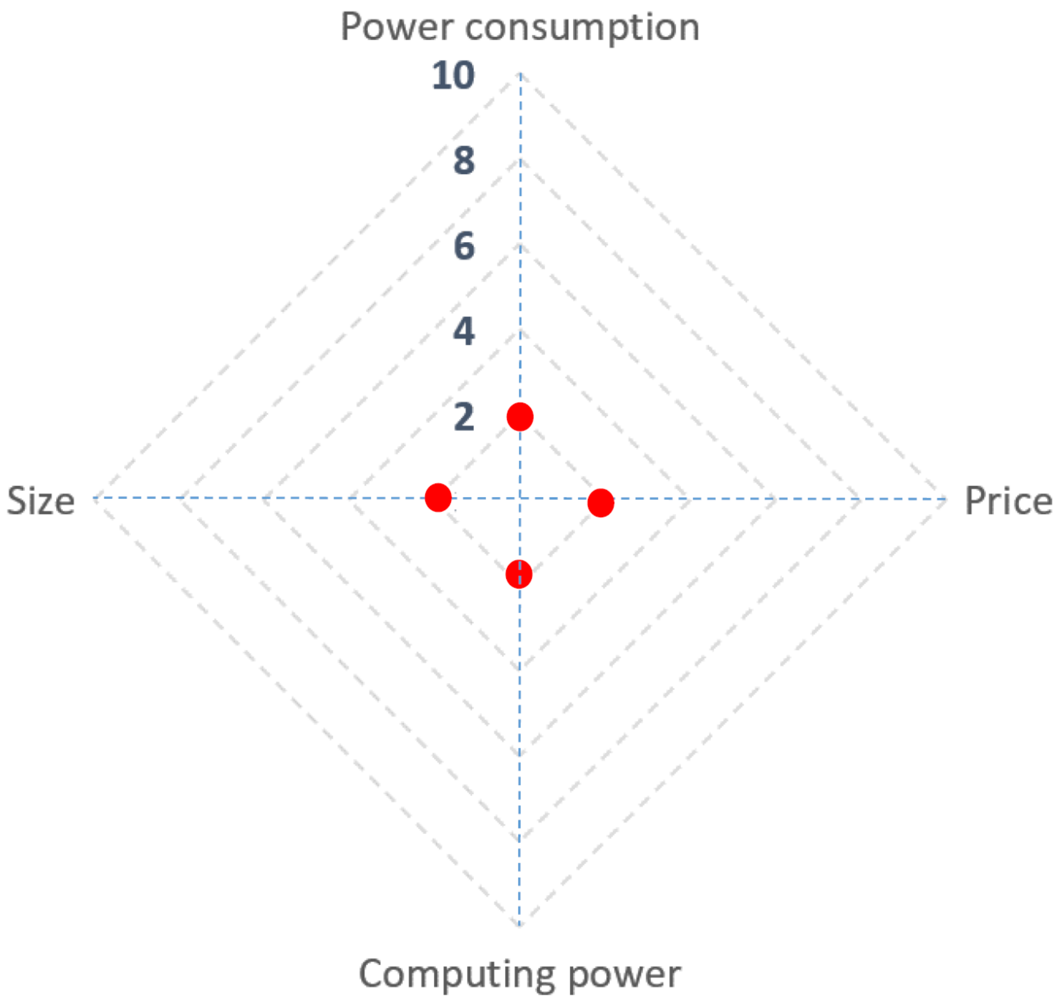
IoT Connectivity
LoRaWAN

Prof. Fouad HANNA, PhD.
fouad.hanna@heig-vd.ch

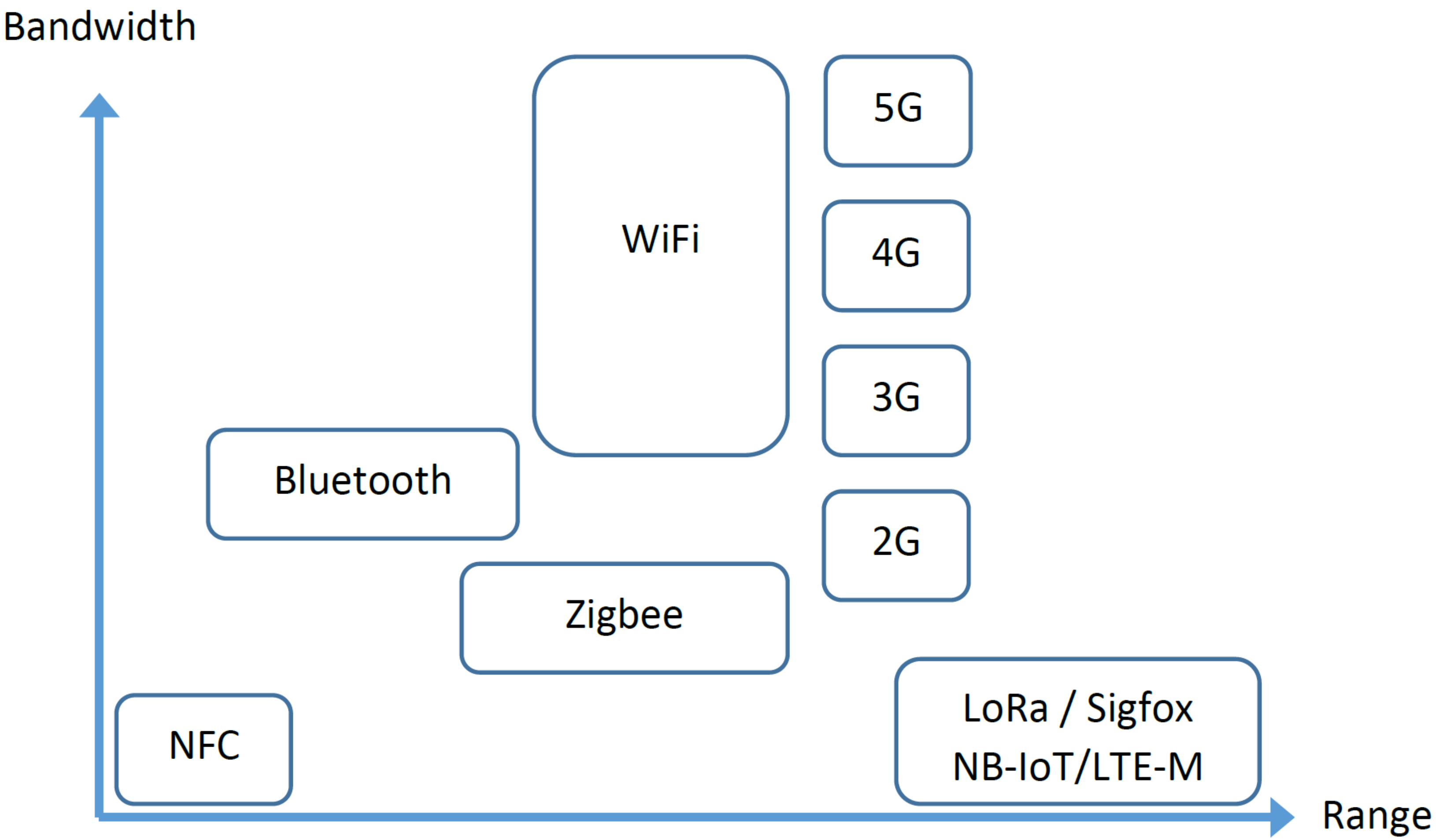
Table of contents

Radio transmission - media sharing

IoT device characteristics



IoT wireless protocols



Frequency bands

- Free frequency bands in Europe :
  - no need to ask for authorization
  - free of charge

Band	Examples of protocols
13.56 MHz	RFID HF, NFC
433 MHz	Walkie-talkie, remote control, LoRa
868 MHz	Sigfox, LoRa
2.4 GHz	Wi-Fi, Bluetooth, Zigbee
5 GHz	Wi-Fi

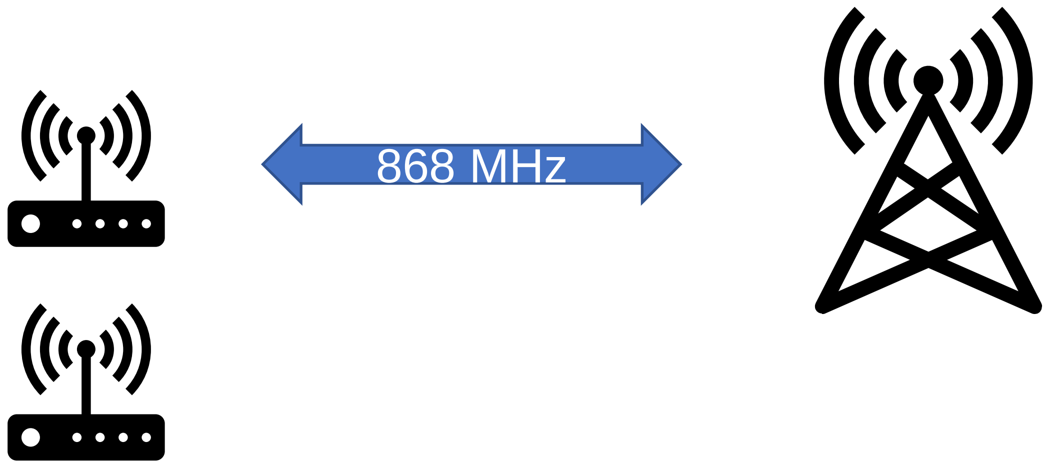
Free frequency bands

Frequency bands

- ❑ Lora in Europe : 868 MHz.

- ❑ 2 devices sending simultaneously + same frequency = collision ?

- ❑ Need for media sharing modes:
  - ❑ FDM (Frequency Division Multiplexing)
  - ❑ Spread Spectrum
  - ❑ Duty cycle

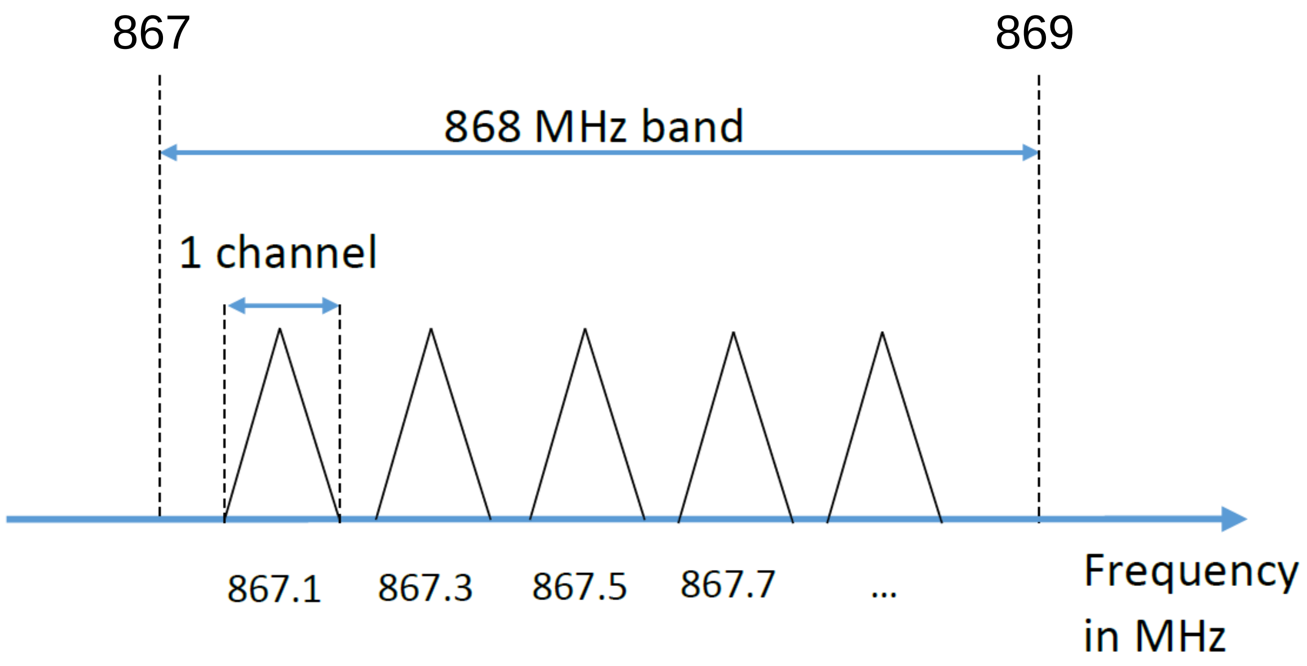


Media sharing - FDM (Frequency Division Multiplexing)

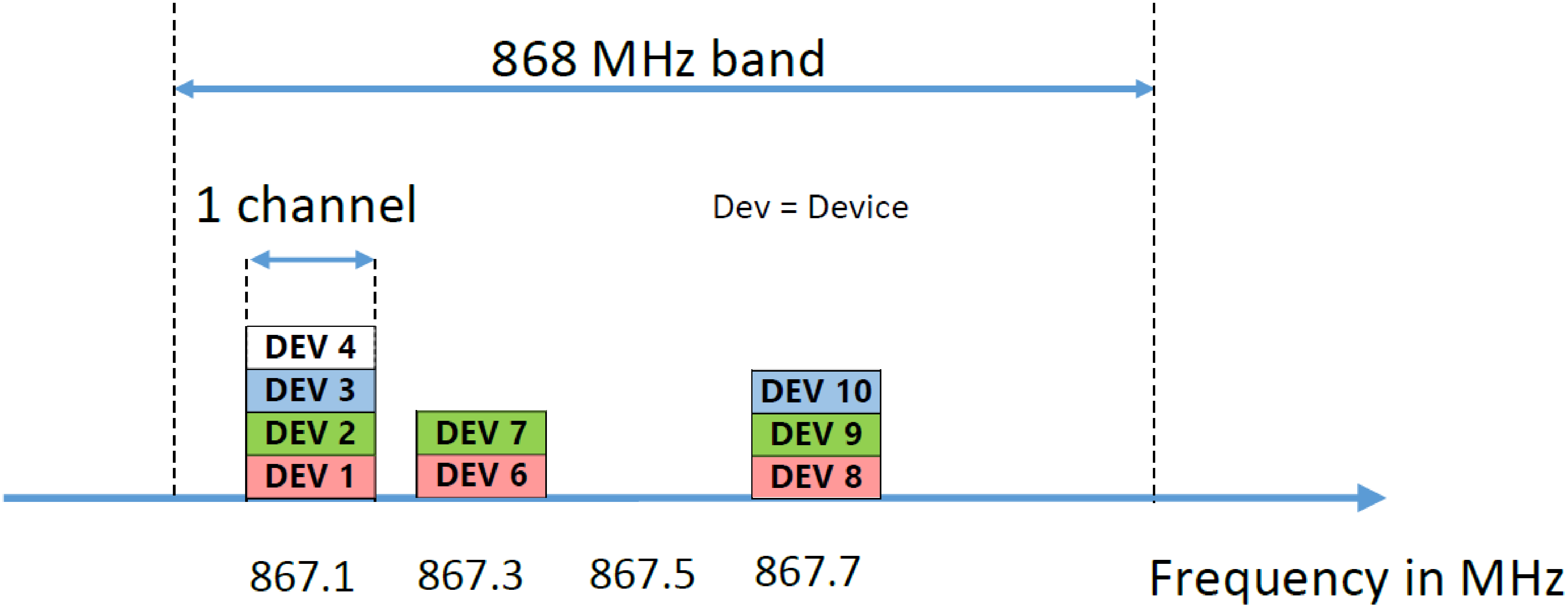
- Devices use frequency channels to separate their transmissions.

- Europe lora 868 frequency plan:
  - Officially called EU 863-870 MHz.
  - 8 channels uplink / downlink.
  - 1 channel downlink.
  - 867 MHz → 869 MHz (125 kHz / channel).

- Using only channels, 8 lora devices can talk simultaneously… is that enough ??



Media sharing – Spread Spectrum



Media sharing – Spread Spectrum

- End-devices transmit at the same time, on the same channel, but with a specific signal structure (with codes or symbols) .
- Most famous Spread Spectrum modulation methods use "codes“.
- Lora uses symbols instead (called Chirp), hence its name: Chirp Spread Spectrum (CSS) modulation.
- LoRaWAN uses 6 Spreading Factors SF 7 → 12.
- Using 8 channels + 6 SFs = 8 * 6 = 48 lora devices can talk simultaneously… is that enough ??

Media sharing – Duty cycle

2 time units every 10 time units, this device has a duty cycle of 20%.

- Time on Air (ToA): amount of time that a message take from sender to receiver (channel occupied).
- Duty cycle is the proportion of time during which a component, device, or system is operated.
  - expressed as a ratio or as a percentage
  - in Europe there is a 0.1% and 1.0% max duty cycle per day depending on the channel.

- Example: To respect the 1% duty cycle

ToA = 1s (big though) => after sending a message, we have to wait 99x1s = 99s before sending a new message.

- Now using channels + spread spectrum + duty cycle (1%, ToA 1s) : 8 * 6 * 100 = 4800 dev ☺

Spreading spectrum with codes

- Objectif: transmitting at the same time on the same channel.
- One spreading code per user.
- Two users cannot have the same code.
- Codes must have mathematical properties adapted to our objective: transmitting at the same time on the same channel. The matrix below gives four spreading codes
- The property of these codes is called "orthogonal".

Code user 0	1	1	1	1
Code user 1	1	-1	1	-1
Code user 2	1	1	-1	-1
Code user 3	1	-1	-1	1

Spreading spectrum with codes

- During transmission:
  - Each bit of the message is multiplied by its "Spreading Code": (1) x (2)
  - The result of the multiplication is transmitted: (3)
- During reception:
  - Each symbol received (4) is multiplied by the same "Spreading Code" (2).
  - The received message (6) is equal to the sum of the decoded symbols (5), divided by the number of symbols (here we have four symbols).

1	**User 1 message (bits)**	**1**	**0**	**1**
2	User 1 "Spreading Code"	**1 -1 1 -1**	**1 -1 1 -1**	**1 -1 1 -1**
3	Transmitted symbols = (1) x (2)	1 -1 1 -1	0 0 0 0	1 -1 1 -1
… transmission …				
4	User 1 "Spreading Code"	**1 -1 1 -1**	**1 -1 1 -1**	**1 -1 1 -1**
5	Decoded symbols = (3) x (4)	1 1 1 1	0 0 0 0	1 1 1 1
6	**Message received = Σ (5) / nbr_Symb**	**1**	**0**	**1**

Spreading spectrum with codes

1’	**User 2 message (bits)**	**0**	**1**	**0**
2’	User 2 "Spreading Code"	**1 1 -1 -1**	**1 1 -1 -1**	**1 1 -1 -1**
3’	Transmitted symbols = (1) x (2)	0 0 0 0	1 1 -1 -1	0 0 0 0
… transmission …				
4’	User 2 "Spreading Code"	**1 1 -1 -1**	**1 1 -1 -1**	**1 1 -1 -1**
5’	Decoded symbols = (3) x (4)	0 0 0 0	1 1 1 1	0 0 0 0
6’	**Message received = Σ (5) / nbr_Symb**	**0**	**1**	**0**

1’’	**User 3 message (bits)**	**1**	**1**	**0**
2’’	User 3 "Spreading Code"	**1 -1 -1 1**	**1 -1 -1 1**	**1 -1 -1 1**
3’’	Transmitted symbols = (1) x (2)	1 -1 -1 1	1 -1 -1 1	0 0 0 0
… transmission …				
4’’	User 3 "Spreading Code"	**1 -1 -1 1**	**1 -1 -1 1**	**1 -1 -1 1**
5’’	Decoded symbols = (3) x (4)	1 1 1 1	1 1 1 1	0 0 0 0
6’’	**Message received = Σ (5) / nbr_Symb**	**1**	**1**	**0**

Spreading spectrum with codes - Simultaneous transmissions

- On the receiver's antennas: The signal received is the addition of all symbols transmitted by all users (1, 2, 3).

3	Transmitted symbols User 1 = (1) x (2)	1 -1 1 -1	0 0 0 0	1 -1 1 -1
3’	Transmitted symbols User 2 = (1’) x (2’)	0 0 0 0	1 1 -1 -1	0 0 0 0
3’’	Transmitted symbols User 3 = (1’’)x (2’’)	1 -1 -1 1	1 -1 -1 1	0 0 0 0

1’’’	**∑ of the transmitted symbols (3 + 3’ + 3’’)**	**2 -2 0 0**	**2 0 -2 0**	**1 -1 1 -1**

Spreading spectrum with codes - Simultaneous transmissions

- Then, on each receiver:
  - Each signal received (1) is multiplied by the user's "Spreading code" (2, 2' or 2").
  - The message (4, 4’, 4") is equal to the sum of the decoded symbols (3, 3’, 3"), divided by the number of symbols (here we have four symbols). The message is equivalent to the one sent by each user.

1	**∑ of the transmitted symbols**	**2 -2 0 0**	**2 0 -2 0**	**1 -1 1 -1**

2	Code User 1	**1 -1 1 -1**	**1 -1 1 -1**	**1 -1 1 -1**
3	Decoding (1) x (2)	2 2 0 0	2 0 -2 0	1 1 1 1
4	**Message received (∑ (3)/ nbr_bits)**	**1**	**0**	**1**

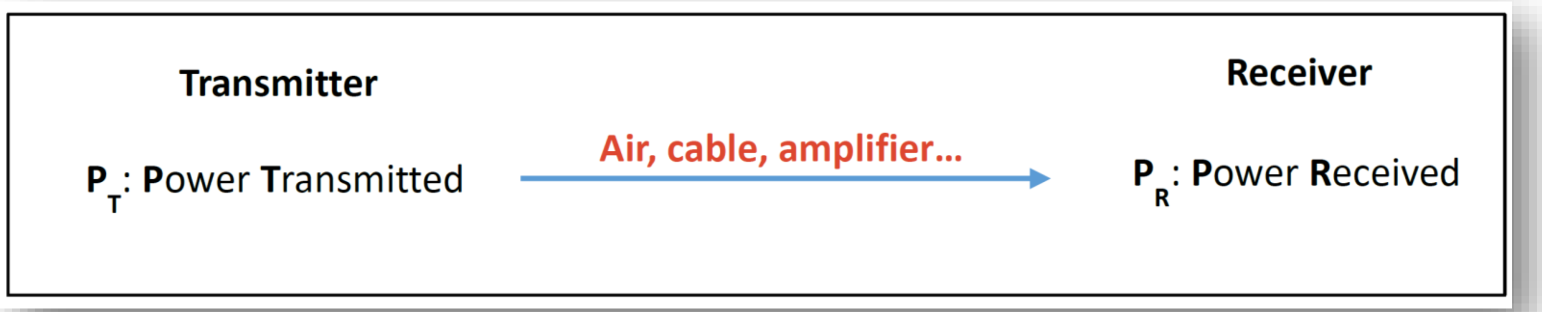
2’	Code User 2	**1 1 -1 -1**	**1 1 -1 -1**	**1 1 -1 -1**
3’	Decoding (1) x (2’)	2 -2 0 0	2 0 2 0	1 -1 -1 1
4’	**Message received (∑ (3’)/ nbr_bits)**	**0**	**1**	**0**

2’’	Code User 3	**1 -1 -1 1**	**1 -1 -1 1**	**1 -1 -1 1**
3’’	Decoding (1) x (2’’)	2 2 0 0	2 0 2 0	1 1 -1 -1
4’’	**Message received (∑ (3’’)/ nbr_bits)**	**1**	**1**	**0**

Radio transmission - propagation

The decibel (dB)

- When a signal spreads, the ratio between P_R and P_T can differ greatly.



- Cable → ratio ≈ 1
- Amplifier → ratio can be much higer
- Air loss transmission → ratio can be extremely low (billionth of a billionth).
- Dealing with such big and small numbers is not suitable + multiplying the gain of each transmission block is not convenient.
- Solution: use logarithmic formula → expressed in dB

The decibel (dB)

- ❑ dB: is a ratio between two powers: P_R and P_T.

$$Power\ ratio\ (dB) = 10.\log_{10}\frac{P_R}{P_T}$$

$$\frac{P_R}{P_T} = 10^{\frac{Power\ ratio\ (dB)}{10}}$$

dB < 0	dB = 0	dB > 0
attenuation ($P_R < P_T$)	Equality ($P_R = P_T$)	gain ($P_R > P_T$)

- ❑ Advantage of using dB:
  - ❑ Dealing with reasonable numbers
  - ❑ Use + and – for the overall calculation (instead of * and /)

The decibel (dB)

Power ratio in dB	Power ratio
+ 10 dB	Multiplication by 10
+ 3 dB	Multiplication by about 2
0 dB	Equality
-3 dB	Division by about 2
- 10 dB	Division by 10

Gain

Attenuation

- Exercise: for a transmission, we have a gain -6 dB. What is the power ratio of P_R and P_T?

$$\frac{P_R}{P_T} = 10^{\frac{Power\ ratio\ (dB)}{10}} = 10^{\frac{-6}{10}} = 0.25$$

The decibel (dB)

- Example: given the transmission below, what is the gain in dB?

P_R is 10^9 (billion) times weaker than P_T

$P_R = P_T / 10^9 = P_T / 10/10/10/10/10/10/10/10/10$

Gain (dB) ≡ -10-10-10-10-10-10-10-10-10 = -90 dB

-90 dB → attenuation

Measuring power in dBm (decibel-milliwatts)

- dBm is the power in comparison to 1 mW (milliwatts).
- 0 dBm ←→ 1 mW

$$Power\ (dBm) = 10.\log_{10}(Power\ (mW))$$

$$Power\ (mW) = 10^{\frac{Power\ (dBm)}{10}}$$

Measuring power in dBm (decibel-milliwatts)

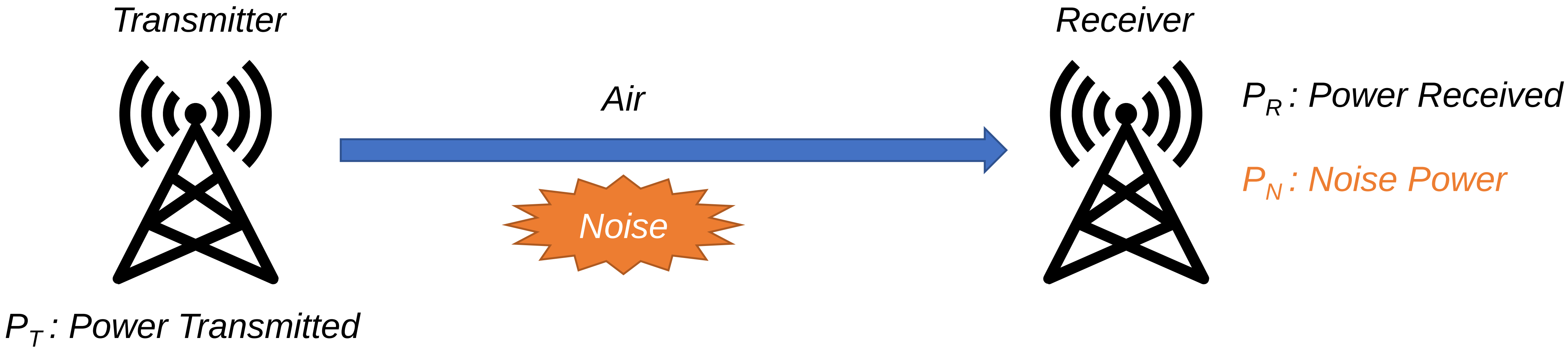
Power in dBm	Power in mW
+ 10 dBm	10 mW
+ 3 dBm	2 mW
0 dBm	1 mW
-3 dBm	0.5 mW
- 10 dBm	0.1 mW

- Exercise: A walkie-talkie has a transmission power of 2 W. Using the table above, find the transmission power in dBm.

2W = 2000 mW = 1 mW * 10 * 10 * 10 * 2

Power (dBm) = 0 dBm + 10 + 10 + 10 + 3 = **33 dBm**

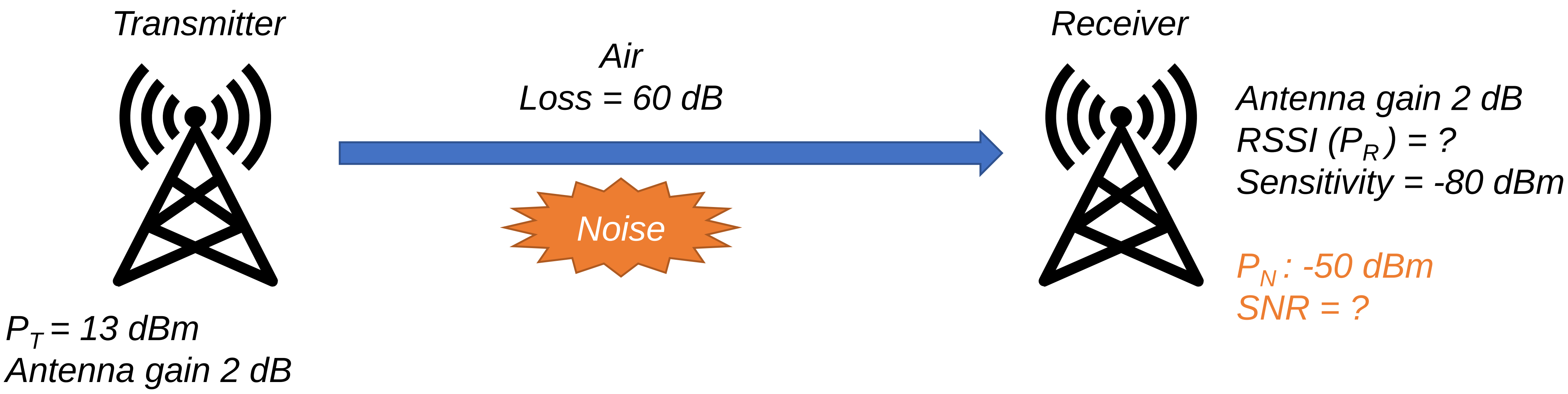
RSSI, sensitivity, SNR



- Received Signal Strength Indication (RSSI) = the power of the received signal P_R
- Sensitivity = minimum RSSI (or minimum P_R) that must be present at the receiver in order to retrieve the signal.
  - RSSI < sensitivity → the signal is undetectable
- Signal over Noise Ratio (SNR) = P_R / P_N , if P_R , P_N measured in watts

  = P_R - P_N , if P_R , P_N measured in dBm

RSSI, sensitivity, SNR



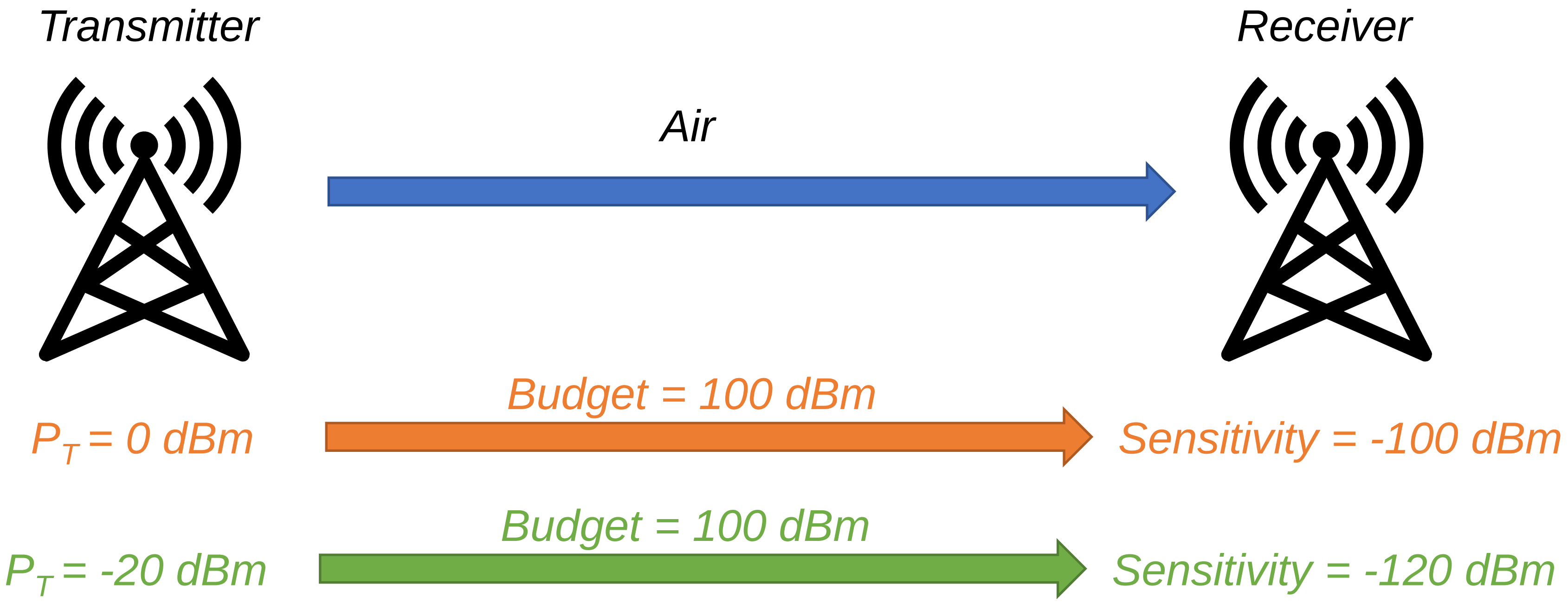
- Exercise: given the information above, find if the signal can be received (RSSI > Sensitivity) and calculate the SNR.

RSSI = 13 + 2 – 60 + 2 = -43 dBm > Sensitivity (-80 dBm) → signal can be received.

SNR = P_R - P_N = -43 – (-50) = -43 + 50 = +7 dB

Link budget

- $\text{Link budget} = P_T - \text{Sensitivity}$



- The two transmissions above have the same budget → same max distance.
  - In the first, the person is talking louder but the person listening hears less than the second case.
  - In the second, the person speaks less loudly but the person listening hears better than the first.

Link budget

- What to do if *RSSI (P_R) < Sensitivity* ?
  - Increase P_T : transmission power is limited by the specification (e.g. 868 MHz band max 14 dBm (25 mW)).
  - Improve the sensitivity of the receiver !

- → Once the link budget is spent along the transmission path, the signal is lost.

- In LTE (4G) we have a link budget of about 130 dBm.
- In LoRa, we have a link budget of about 157 dBm.
- Which one goes further ?

Example of reception on a LoRa gateway

```
"gateways":
    {
      "time": "2020-04-29T12:09:45.563621044Z",
      "channel": 0,
      "rssi": -13,
      "snr": 9.8
    }
```

- Good RSSI and very good SNR.
- Device positioned a few meters from the gateway !

Example of device documentation - Semtech SX1272

KEY PRODUCT FEATURES

- LoRa™ Modem
- 157 dB maximum link budget
- +20 dBm at 100 mW constant RF output vs. V supply
- +14 dBm high efficiency PA
- Programmable bit rate up to 300 kbps
- High sensitivity: down to -137 dBm

Max P_T power

- Max link budget = 20 – (-137) = 157 dBm.
- Respecting EU 868 limit: max link budget = 14 – (-137) = 151 dBm.

Example of device documentation - Semtech SX1276

KEY PRODUCT FEATURES

- LoRa™ Modem
- 168 dB maximum link budget
- +20 dBm - 100 mW constant RF output vs. V supply
- +14 dBm high efficiency PA
- Programmable bit rate up to 300 kbps
- High sensitivity: down to -148 dBm

- This device is more recent and has better sensitivity than the SX1272

→ better link budget

Example of device documentation - Semtech SX1276

SpreadingFactor (RegModemConfig2)	Spreading Factor (Chips / symbol)	LoRa Demodulator SNR
6	64	-5 dB
7	128	-7.5 dB
8	256	-10 dB
9	512	-12.5 dB
10	1024	-15 dB
11	2048	-17.5 dB
12	4096	-20 dB

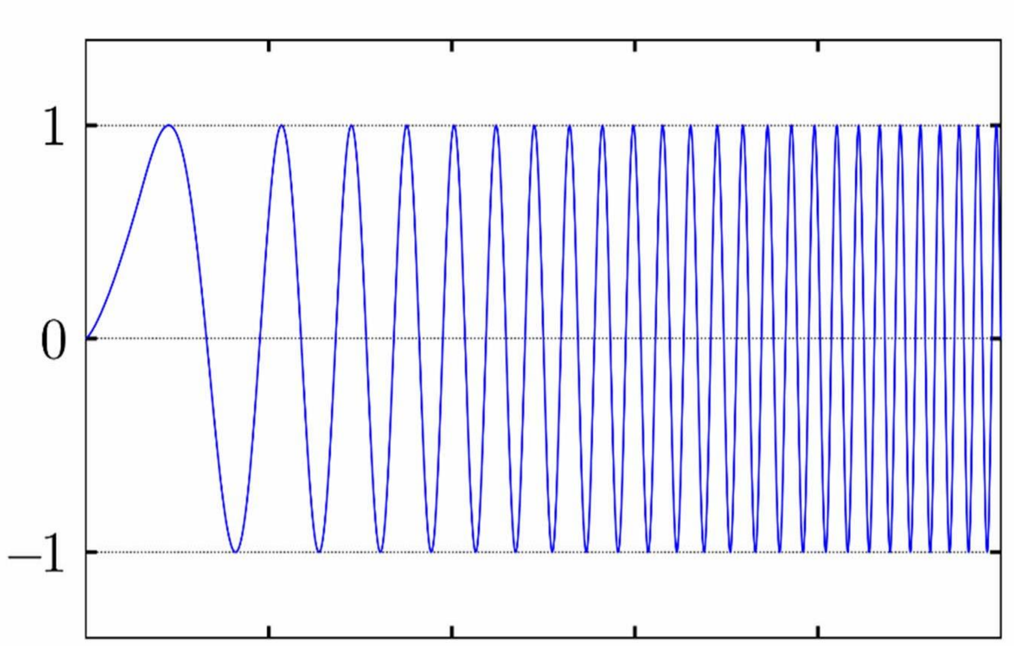
- SP8 → SNR -10 dB → noise 10 times the signal
- SP12 → SNR -20 dB → noise 100 times the signal
- Attention to the 2nd column: higher spreading factor → lower bit rate

Lora modulation

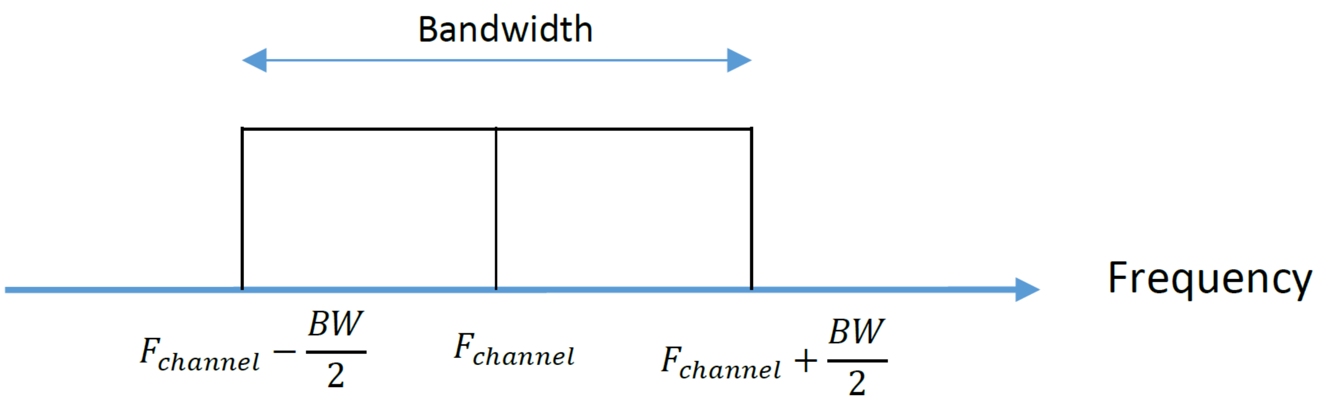
Chirp Spread Spectrum modulation

- ❑ LoRa modulation uses Spread Spectrum
  - ❑ Uses “Chirps” instead of “codes” → Chirp Spread Spectrum modulation
  - ❑ Same purpose: several transmissions at the same time on the same channel

- ❑ The Chirp:
  - ❑ The signal emitted by the LoRa modulation is a symbol
  - ❑ Basic form of Chirp is presented in the figure
  - ❑ Start frequency → End frequency



Chirp Spread Spectrum modulation



Spectrum of a LoRa transmission

- The channel ($F_{channel}$) is the center frequency
- The band occupied around $F_{channel}$ is the bandwidth
  - 125 kHz, 250 kHz or 500 kHz, depending on the region or the frequency plan

Chirp Spread Spectrum modulation

- ❑ Exercise: *A LoRa transmission uses the 868,1 MHz channel with a bandwidth of 125 kHz. Can you give the start and end frequency of the Chirp ?*

Start frequency: 868 100 000 – 125 000/2 = 868 037 500 Hz

End frequency: 868 100 000 + 125 000/2 = 868 162 500 Hz

- ❑ Exercise: *A LoRa transmission uses the 868.3 MHz channel with a bandwidth of 250 kHz. Can you give the start and end frequency of the Chirp ?*

Start frequency: 868 300 000 – 250 000/2 = 868 175 000 Hz

End frequency: 868 300 000 + 250 000/2 = 868 425 000 Hz

Chirp Spread Spectrum modulation

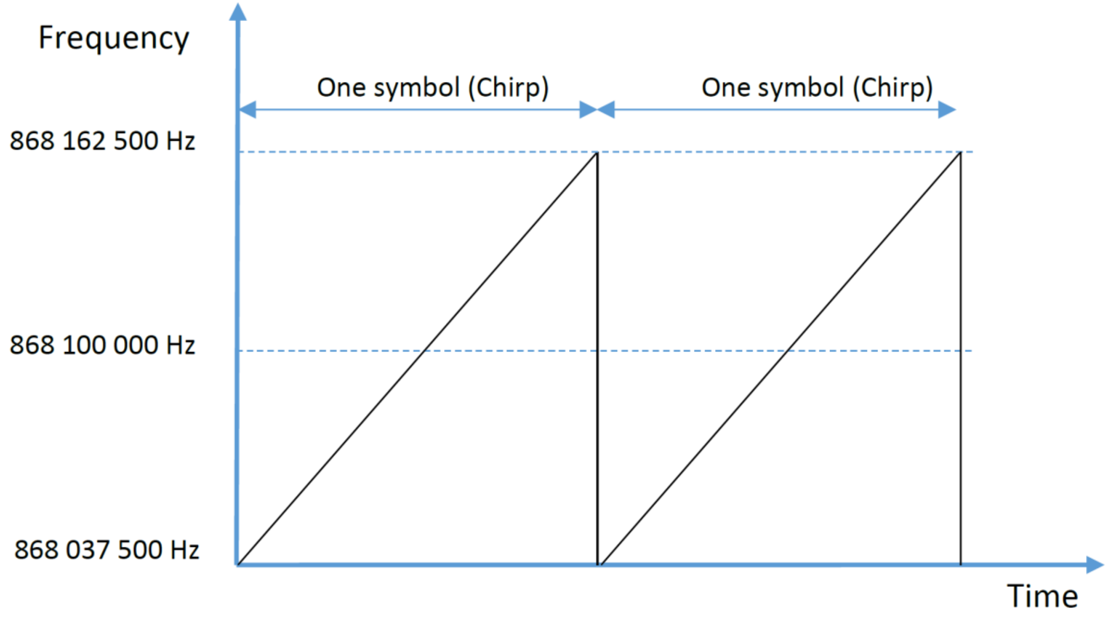
- ❑ Time-Frequency graph (Spectrogram) makes the representation easier to understand.

- ❑ In LoRa, each symbol represents a number of bits transmitted

Spreading Factor = Number of bits transmitted in a symbol

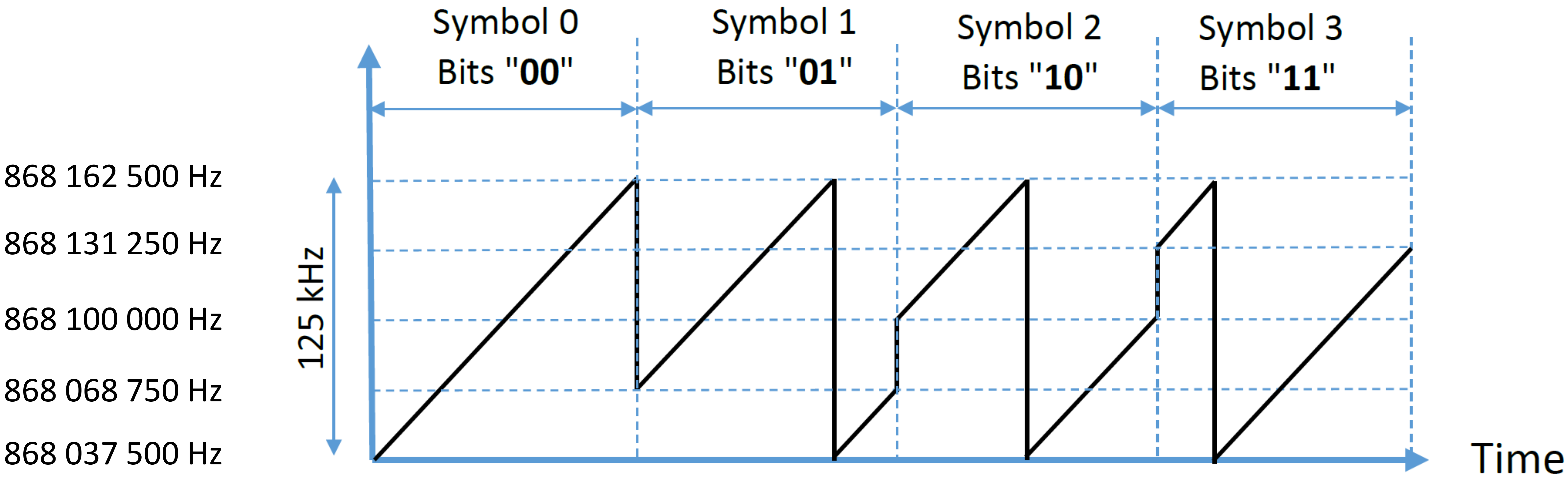
Ex. SF10, then one symbol represents 10 bits

- ❑ Bits are grouped together in packets of SF bits
- ❑ 2^{SF} possible forms of Symbols (packets)
- ❑ Between symbols, the only difference is the starting frequency.



Spectrogram of a LoRa transmission

Chirp Spread Spectrum modulation



Symbols transmitted in LoRa modulation in SF2 (theoretical case)

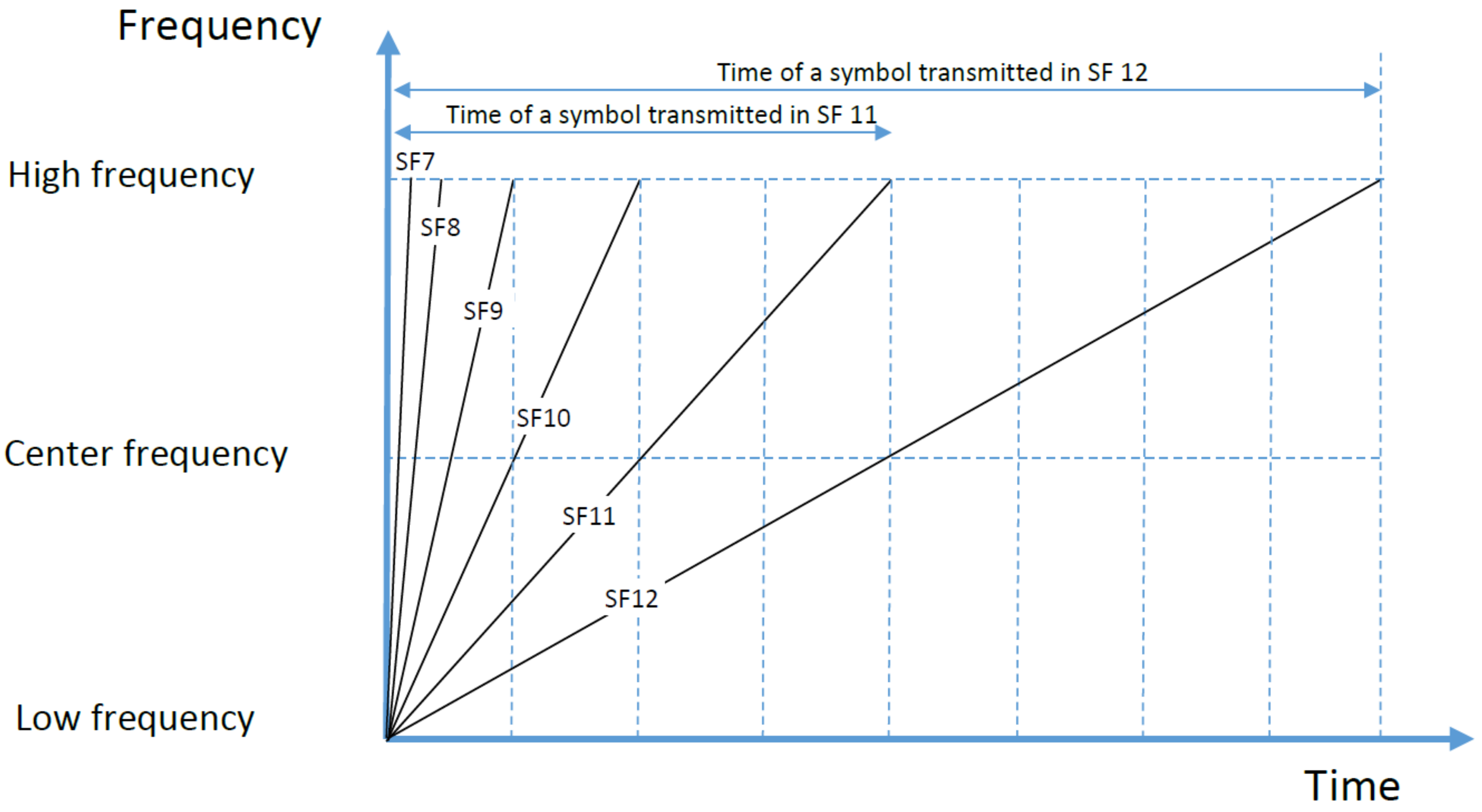
Symbol transmission time

- ❑ Higher SF → more bits per symbol → ~~higher~~ LOWER bit rate.
- ❑ Higher SF → higher Symbol Transmission Time

$$\boxed{T_{symbol} = \frac{2^{SF}}{Bandwidth}}$$

$$\boxed{Bit\,rate(bps) = SF * \frac{1}{T_{symbol}} = SF * \frac{Bandwidth}{2^{SF}}}$$

Symbol transmission time



Symbol transmission time

Symbol transmission time

Spreading Factor	Symbol transmission time (ms)	Bit rate (bps)
SF7	1.024	6836
SF8	2.048	3906
SF9	4.096	2197
SF10	8.192	1221
SF11	16.384	671
SF12	32.768	366

Symbol transmission time and bit rate comparison for BW125

Coding Rate

- ❑ The number of bits transmitted in order to carry out error detection and correction.
- ❑ Coding Rate is a ratio that represents the overhead of these supplementary bits.
- ❑ Affects the bit rate.
- ❑ Example:

CR = 4 / 8 → 8 bits are transmitted each time, whereas in reality we want to transmit 4 bits → overhead ratio = 2

CodingRate (RegModemConfig1)	Cyclic Coding Rate	Overhead Ratio
1	4/5	1.25
2	4/6	1.5
3	4/7	1.75
4	4/8	2

Overhead Ratio and Coding Rate

Coding Rate

$$Bit\ rate(bps) = SF\ * \frac{Bandwidth}{2^{SF}}\ /\ overhead\ CR$$

- ❑ Exercise: Using two cases (SF7, 125 kHz) and (SF12, 125 kHz) with a CR of 4/5, give the corresponding bit rate

CR = 4/5 → overhead = 5/4 = 1.25

Case 1: For SF7, 125 kHz and CR4/5 → bit rate = 6.836 kbps / 1.25 = 5469 bps

Case 2: For SF12, 125 kHz and CR4/5 → bit rate = 366 bps / 1.25 = 293 bps

Coding Rate

- The documentation of a LoRa transceiver gives the data rates according to
  - Spreading Factor
  - Bandwidth
  - Coding Rate

Bandwidth (kHz)	Spreading Factor	Coding rate	Nominal Rb (bps)	Sensitivity (dBm)
125	12	4/5	293	-136

Bit rate and LoRa transmission parameters

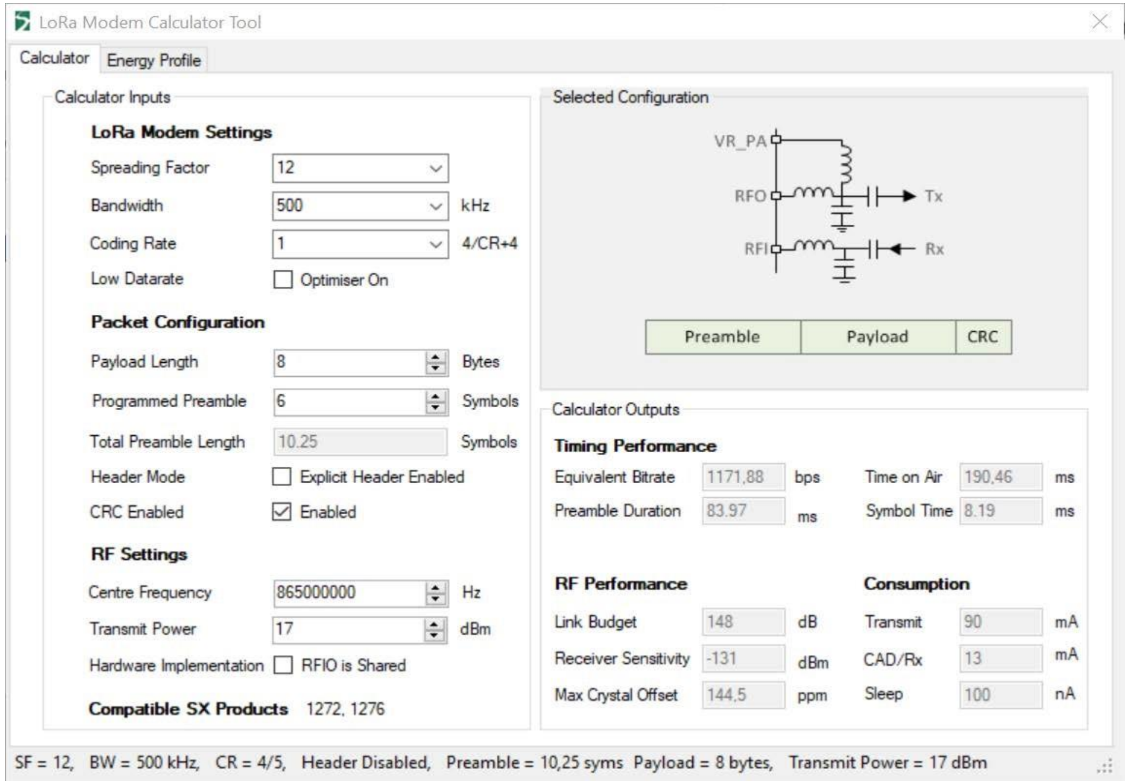
LoRa modem calculator

- ❑ Software provided by Semtech to simulate a LoRa transmission (ex. Calculator for SX1272)

https://semtech.my.salesforce.com/sfc/p/#E0000000JelG/a/2R000000HUhK/6T9Vdb3_ldnElA8drIbPYjs1wBbhlWUXej8ZMXtZXOM

- ❑ Online LoRa simulators exist also

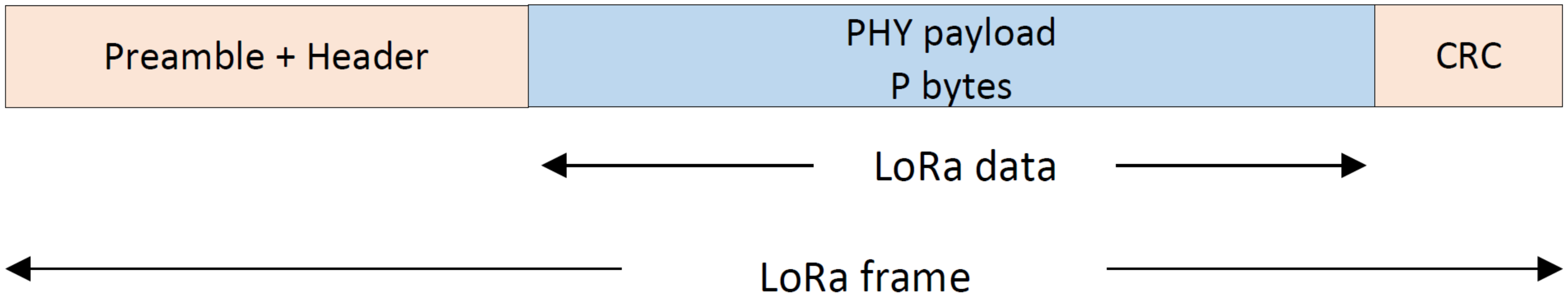
- ❑ Exercise: verify the bitrate "equivalent bitrate" value using the calculator



LoRa data frame and bitrate

- LoRa adds information to our payload (physical layer protocol).
  - A preamble allowing the receiver to synchronize with the transmitter

  LoRaWAN: preamble = 12.25 symbols (8 + 4.25 added by transceiver)
  - Optional headers after the preamble (information about payload size)
  - CRC field (frame integrity check) at the end



- LoRa data is called PHY payload

- This overhead should be taken into account when calculating the actual bitrate (PHY payload bitrate).

LoRa data frame and bitrate

- Time on Air: overall duration of a LoRa frame.

- Exercise: *find the PHY payload bitrate using data from the last exercise.*

Use the Lora modem calculator to get the Time on Air for each case.

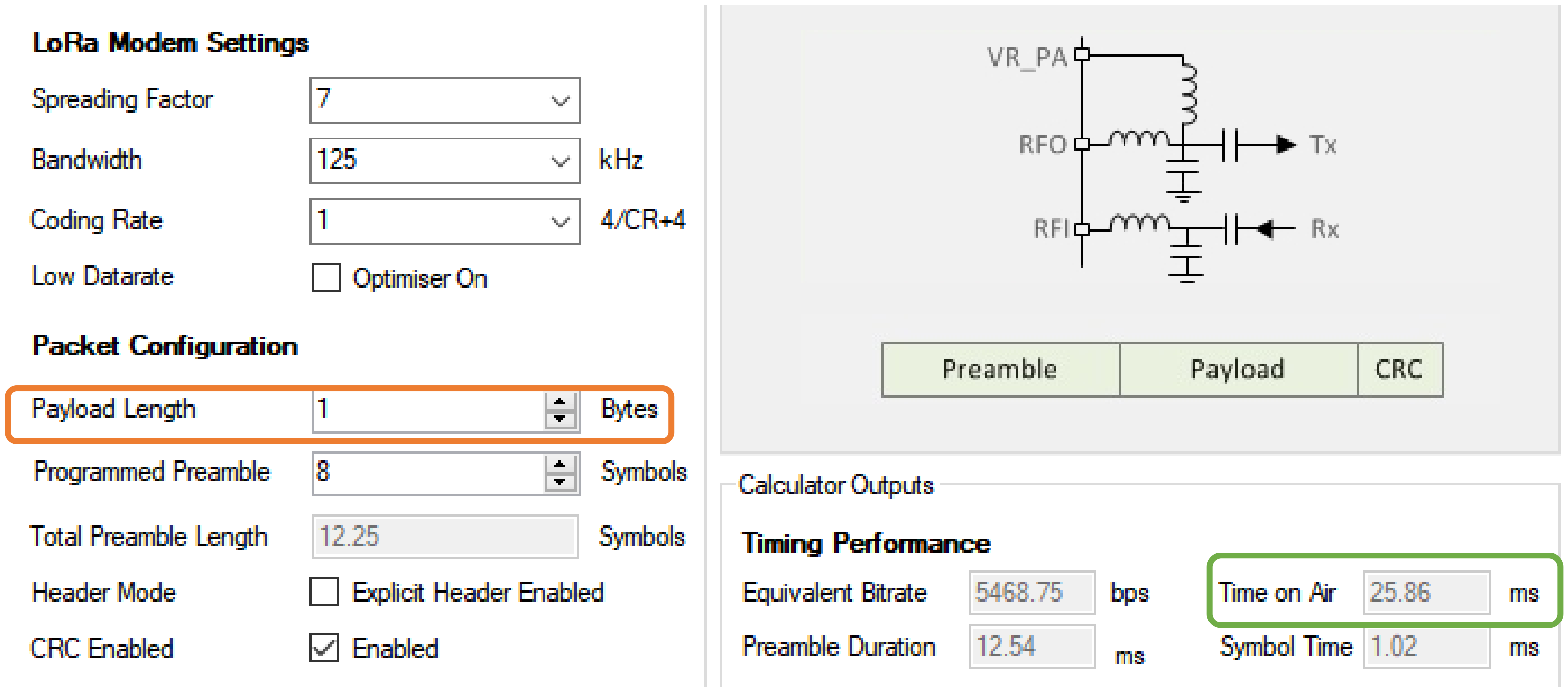
We are sending 1 byte of data.

  - *SF7 , 125 kHz, CR of 4/5, bitrate 5469 bps*
  - *SF12, 125 kHz, CR of 4/5, bitrate 293 bps*

LoRa data frame and bitrate

- SF7 , 125 kHz, CR of 4/5, bitrate 5469 bps:

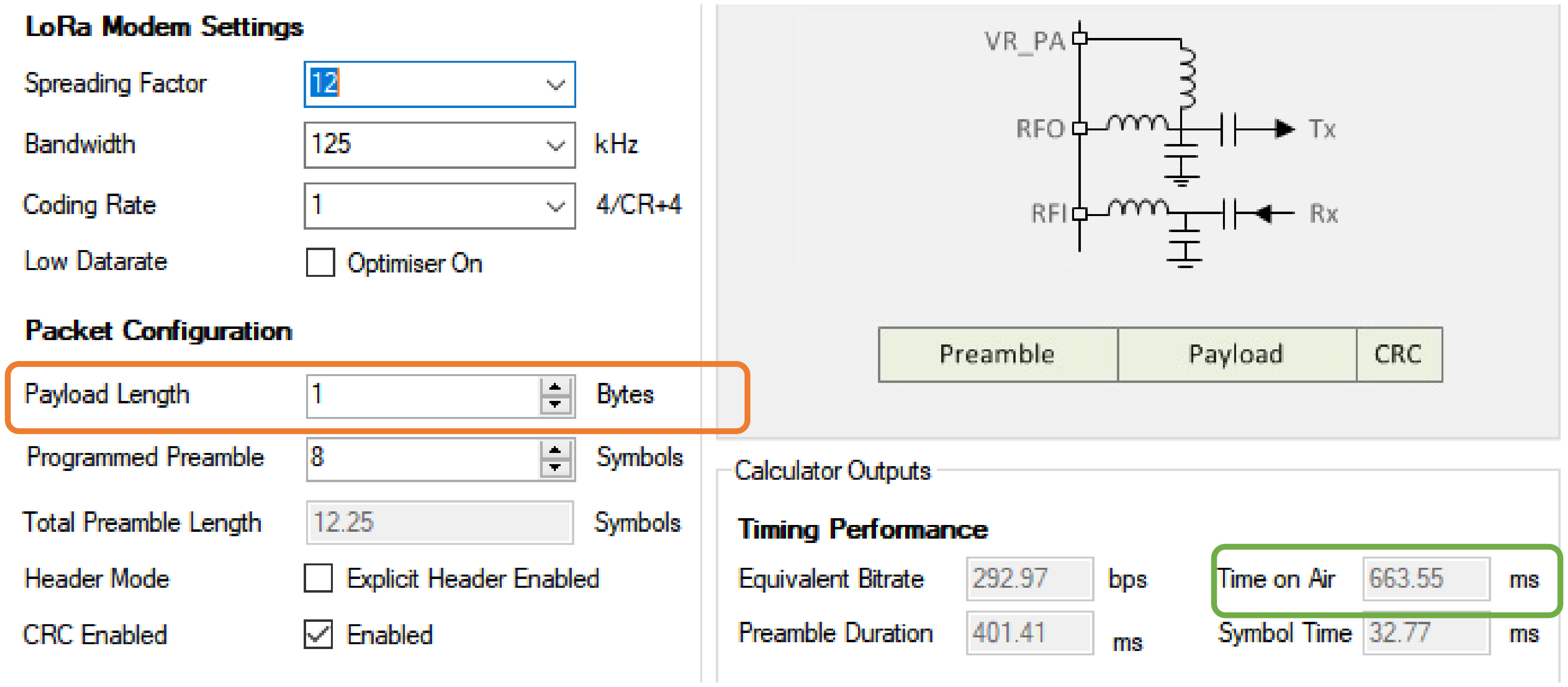
bit rate$_{\text{LoRa payload}}$ = 8 / 25.86 ms = **309.4 bps**



LoRa data frame and bitrate

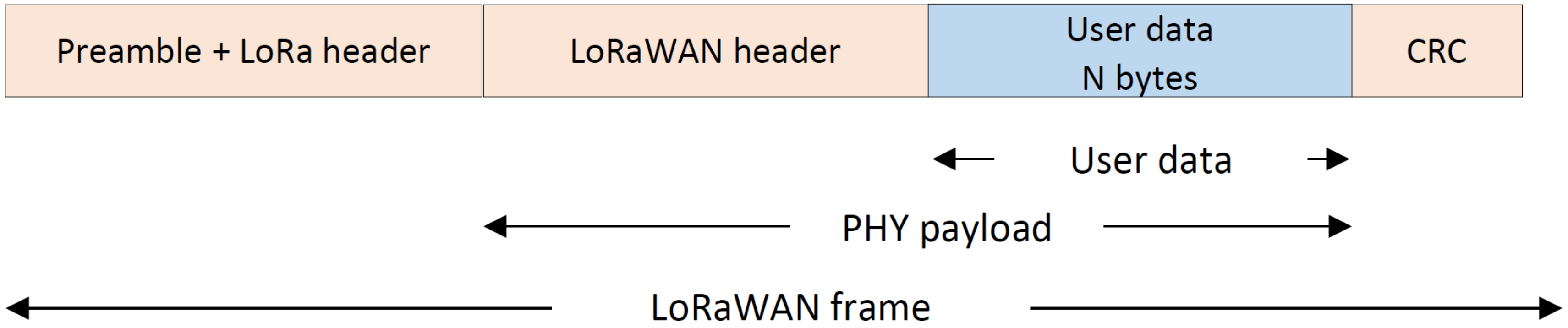
- SF12, 125 kHz, CR of 4/5, bitrate 293 bps :

bit rate$_{\text{LoRa payload}}$ = 8 / 663.55 ms = **12.06 bps**



LoRaWAN data frame and bitrate

- LoRaWAN adds also information to our payload.
  - PHY payload = LoRaWAN header + user payload (useful data)
  - PHY payload length = The LoRaWAN Header (usually 13 bytes) + user data



- This overhead should be taken into account when calculating the actual bitrate (real user data rate).

LoRaWAN data frame and bitrate

- ❑ Exercise: find the real user data rate (bitrate) using data from the last exercise.

Use the Lora modem calculator to get the Time on Air for each case.

We are sending 1 byte of data + the LoRaWAN Header (usually 13 bytes)

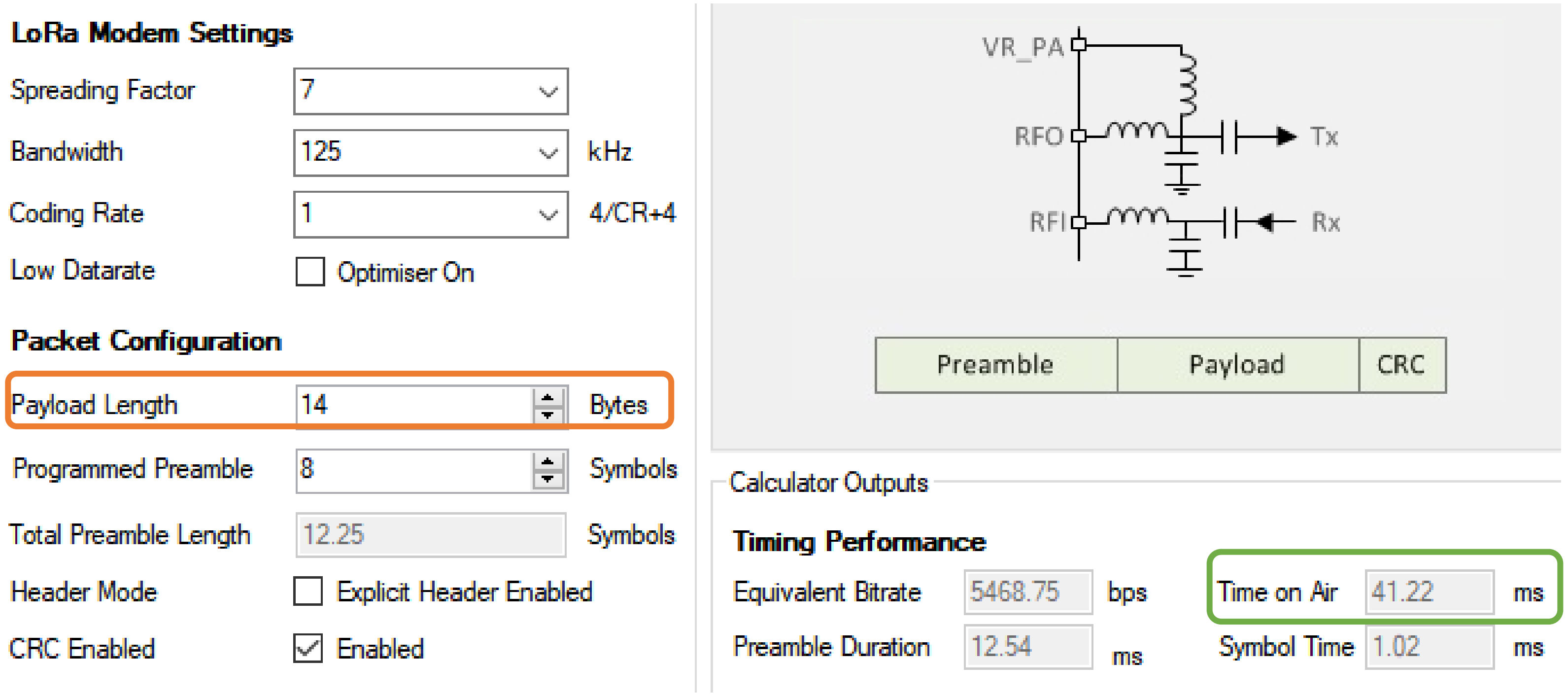
  - ❑ SF7 , 125 kHz, CR of 4/5, bitrate 5469 bps:

  - ❑ SF12, 125 kHz, CR of 4/5, bitrate 293 bps:

LoRaWAN data frame and bitrate

- SF7 , 125 kHz, CR of 4/5, PHY payload bitrate 309.4 bps:

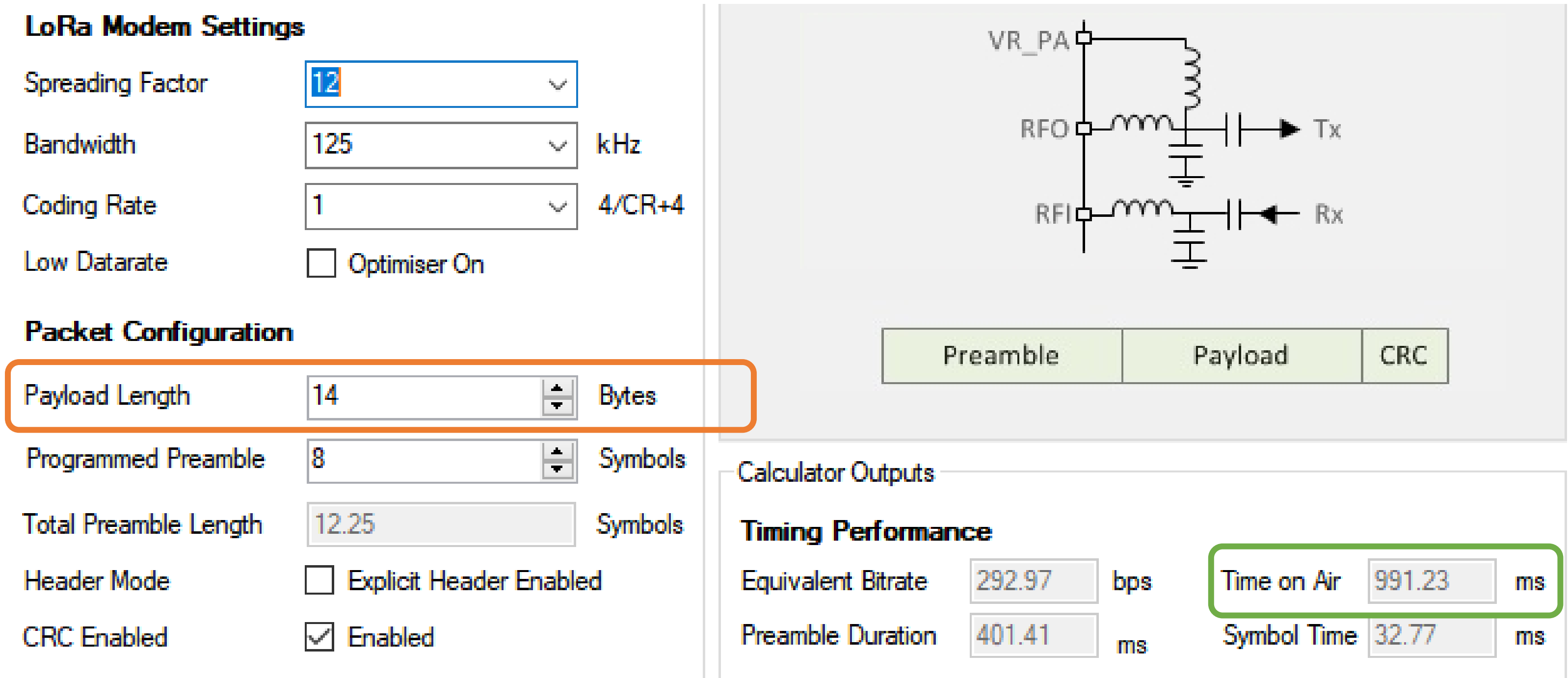
bit rate$_{\text{Real Payload}}$ = 8 / 41.22 ms = **194.08 bps**



LoRaWAN data frame and bitrate

❑ SF12, 125 kHz, CR of 4/5, , PHY payload bitrate 12.06 bps :

bit rate$_{\text{Real Payload}}$ = 8 / 991.23 ms = **8.07 bps**



Duty cycle and bitrate

- European regulation → transmit no more than 1% of time in the 868 MHz band.

- Example: from last exercise with SP7, the Time on Air was 41.22. The device should not transmit for 99 * 41.22 = 4080.78 ms = 4.08 s.

- Exercise: find the real user data rate (bitrate) using data from the last exercise.

Take into account the 1% duty cycle for each case.

  - SF7 , 125 kHz, CR of 4/5, $\text{bitrate}_{\text{Real Payload}}$ = 194.08 bps: $\text{bitrate}_{\text{Real Payload 1\%}}$ = 194.08 / 100 = **1.94 bps**

  - SF12, 125 kHz, CR of 4/5, $\text{bitrate}_{\text{Real Payload}}$ = 8.07 bps: $\text{bitrate}_{\text{Real Payload 1\%}}$ = 8.07 / 100 = **0.08 bps**

Energy consumption

- The real consumption of a LoRa system depends on several parameters.

- The amount of data to transmit (payload)
- The Spreading Factor
- The possible collisions at the emission (and thus retransmission)
- The request for acknowledgement of the transmitted frames
- The duty-cycle
- The transmission power of the transceiver
- The power consumed in standby between two transmissions

This online simulator gives a first approximation of the consumption and therefore the autonomy of a LoRaWAN end-device.

The LoRaWAN protocol

LoRa Alliance

- https://lora-alliance.org/
- Non-profit organization founded in 2015

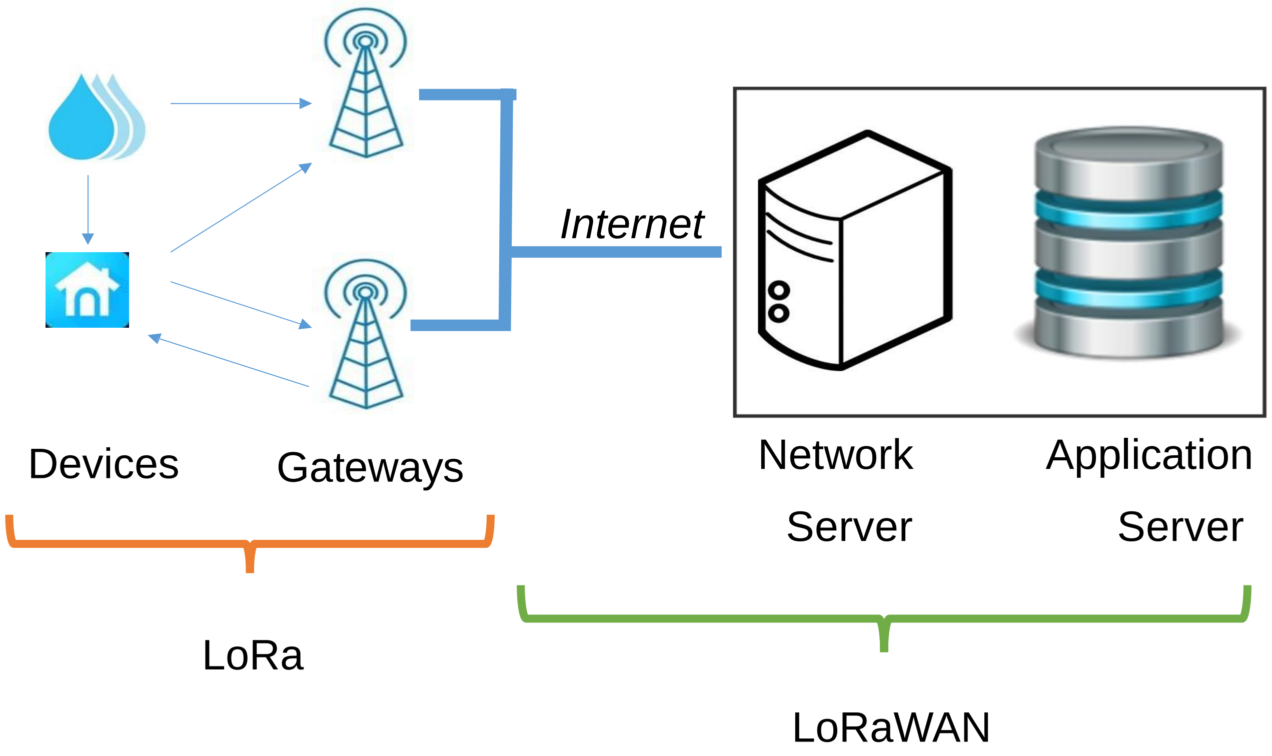
- Aims to develop LoRaWAN technology and the LoRaWAN ecosysteme.
- Maintains the specification and evolution of the LoRaWAN standard
  - Protocol versions 1.0.0 → 1.0.4*, 1.1 (being deployed, few devices and networks support currently).
  - LoRaWAN Regional Parameters.

  *For this course we consider the LoRaWAN standard version 1.0.x.

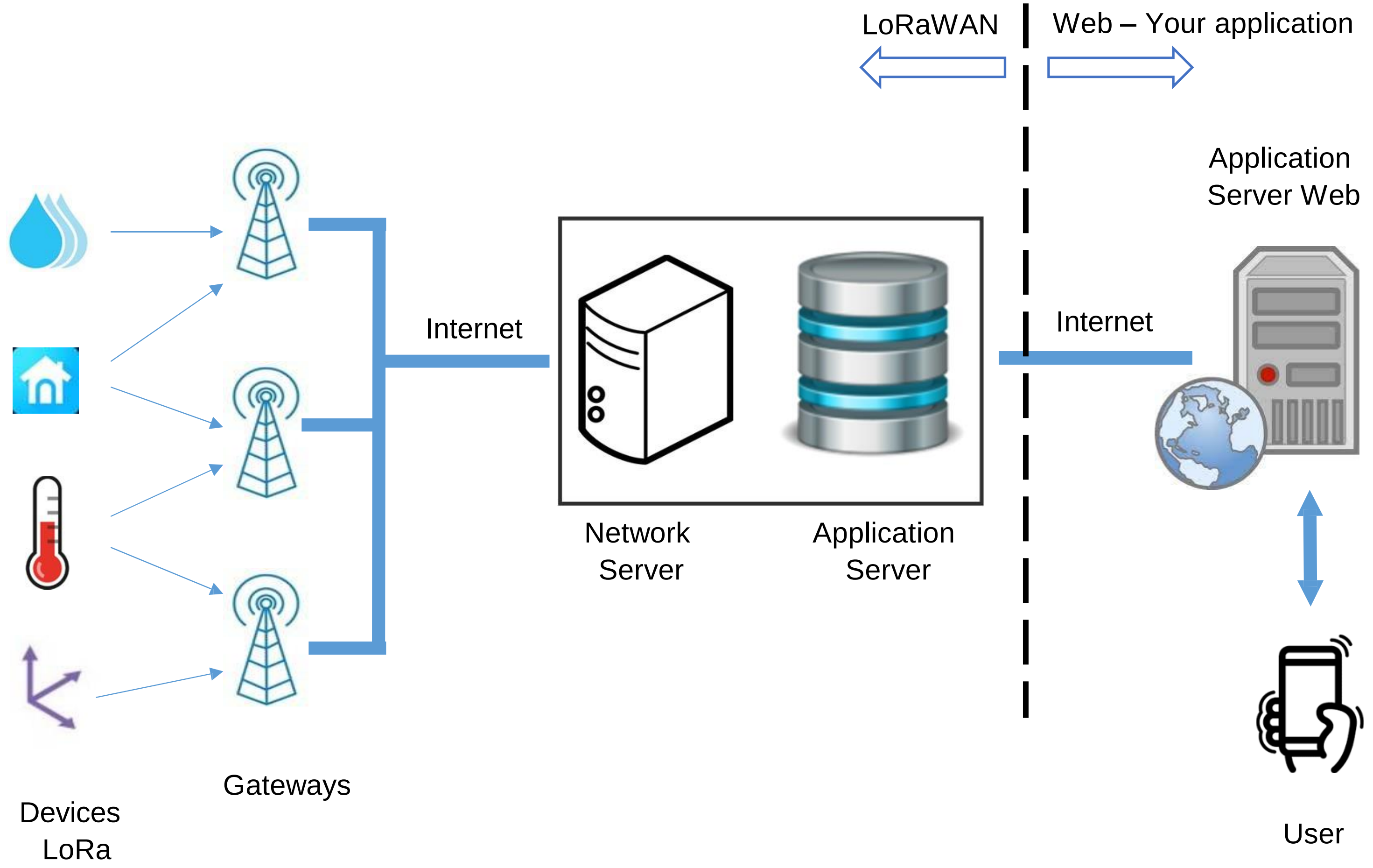
- Certified products.

Differences between LoRa and LoRaWAN

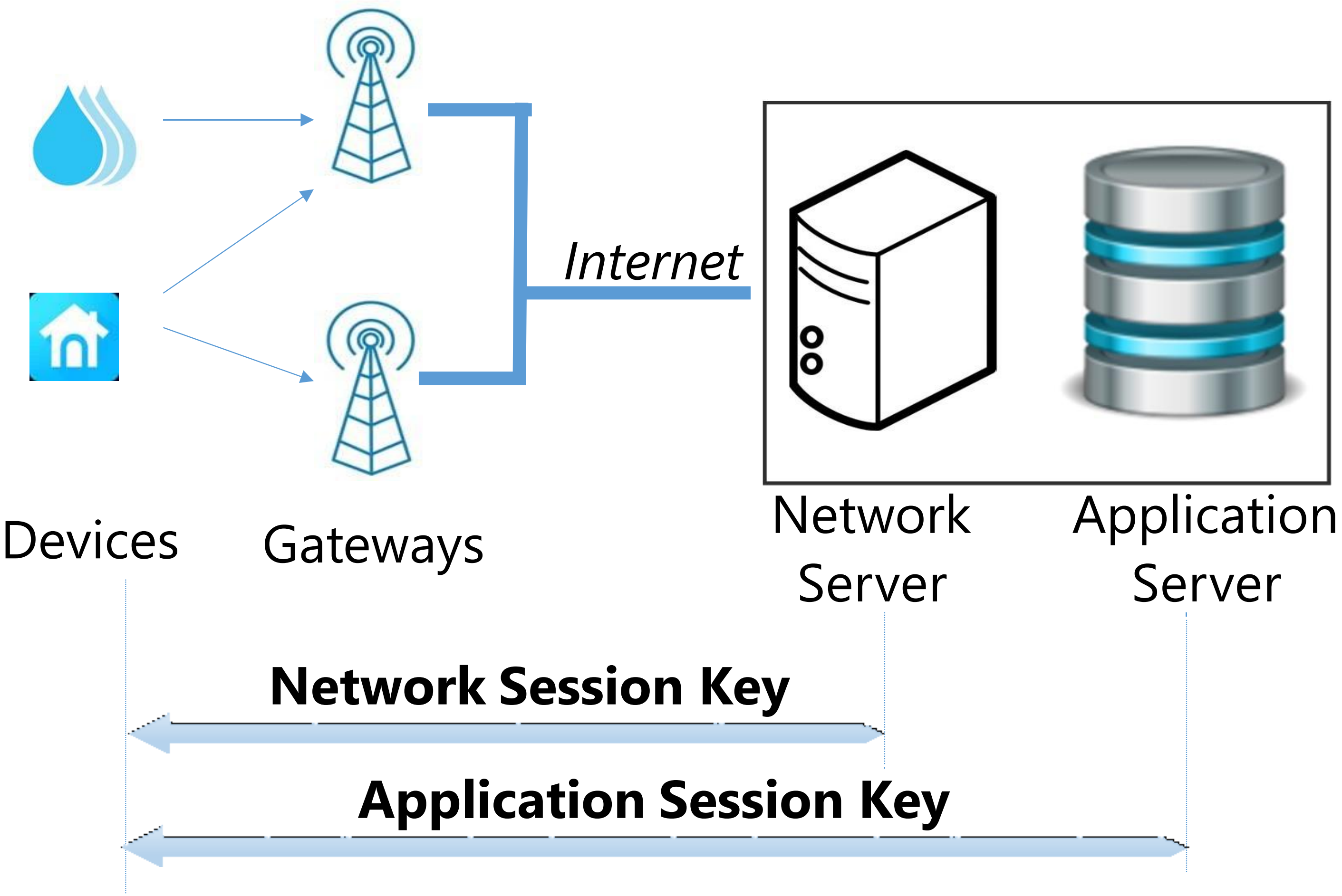
- LoRa is at the physical layer and represents the modulation of signal between two devices
  - Chirp Spread Spectrum and
  - Physical frame format
  - Communication device to device or device to gateway
- LoRaWAN is a protocol stack (standard) that builds on top of the LoRa modulation.
  - Network architecture (end-device, gateways, servers)
  - Security and Logical addressing (MAC layer)
  - Communication ~~device to device or~~ device to gateway.



Overall architecture of a LoRaWAN network



Network Server and Application Server



NwSKey

AppSkey

128-bit AES key

NwSKey

AppSkey

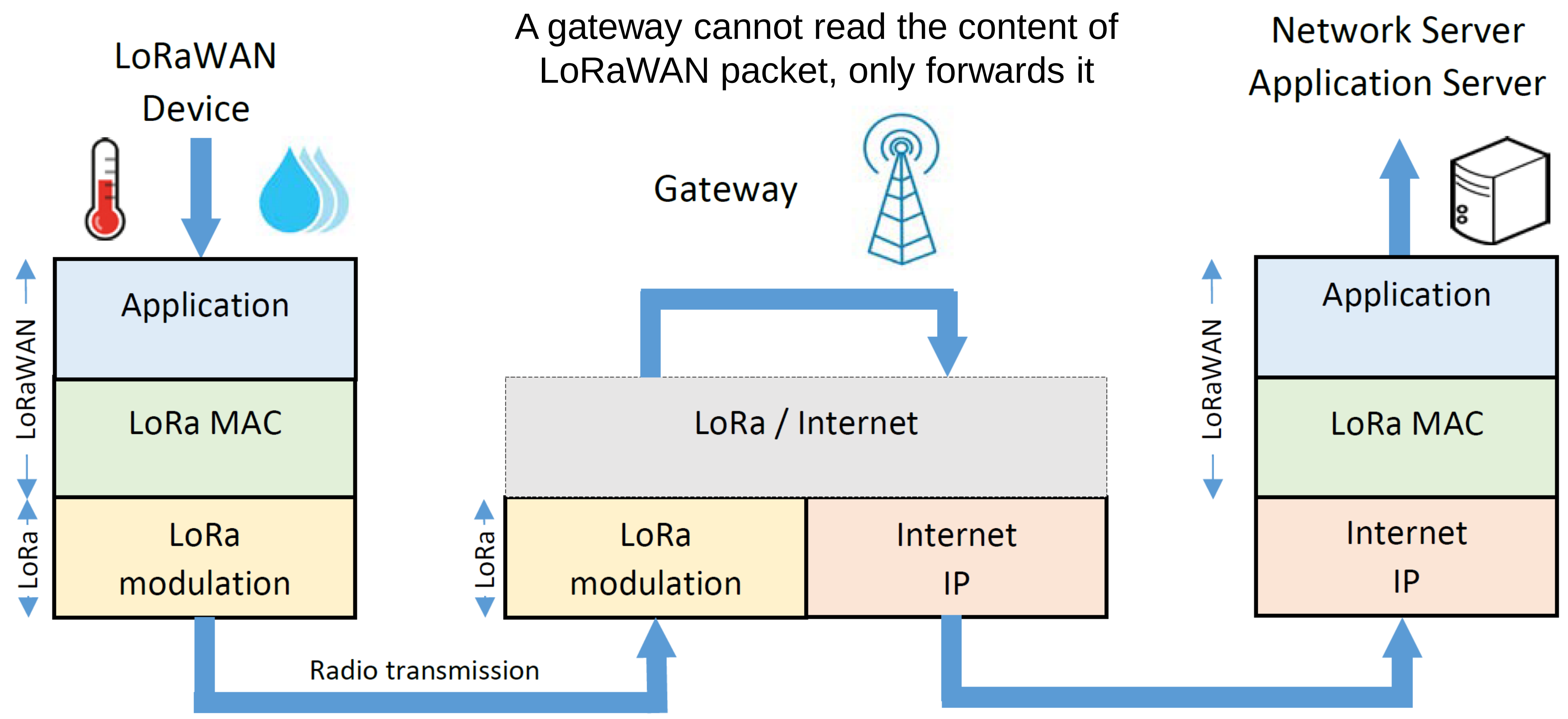
128-bit AES key

Network Server and Application Server

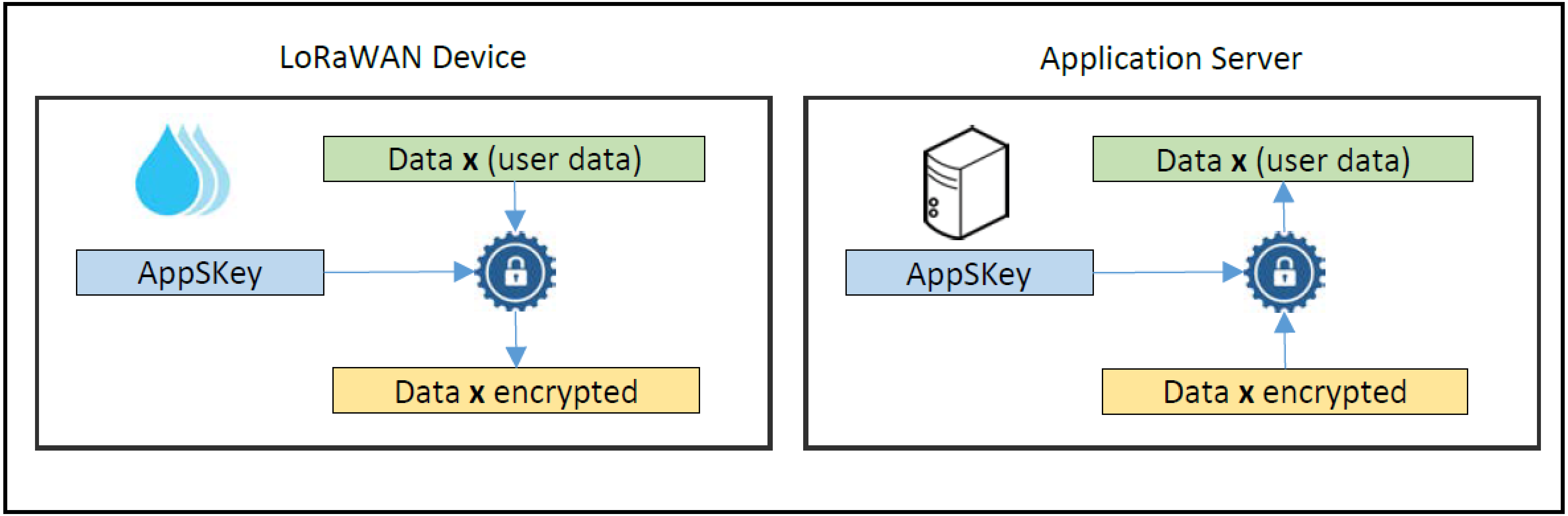
- LoRaWAN Network Server:
  - Manages the entire network
  - Ensures the authenticity of every sensor on the network
  - Ensures the integrity of every message, deletes duplicates
  - Acknowledgements of received messages
  - Forwarding uplink messages to the application server
  - Queuing of downlink messages from application server to devices
  - The network server cannot see nor access the application data

- LoRaWAN Application Server:
  - Securely handling, managing and interpreting sensor application data
  - Generate all the application-layer downlink payloads to devices

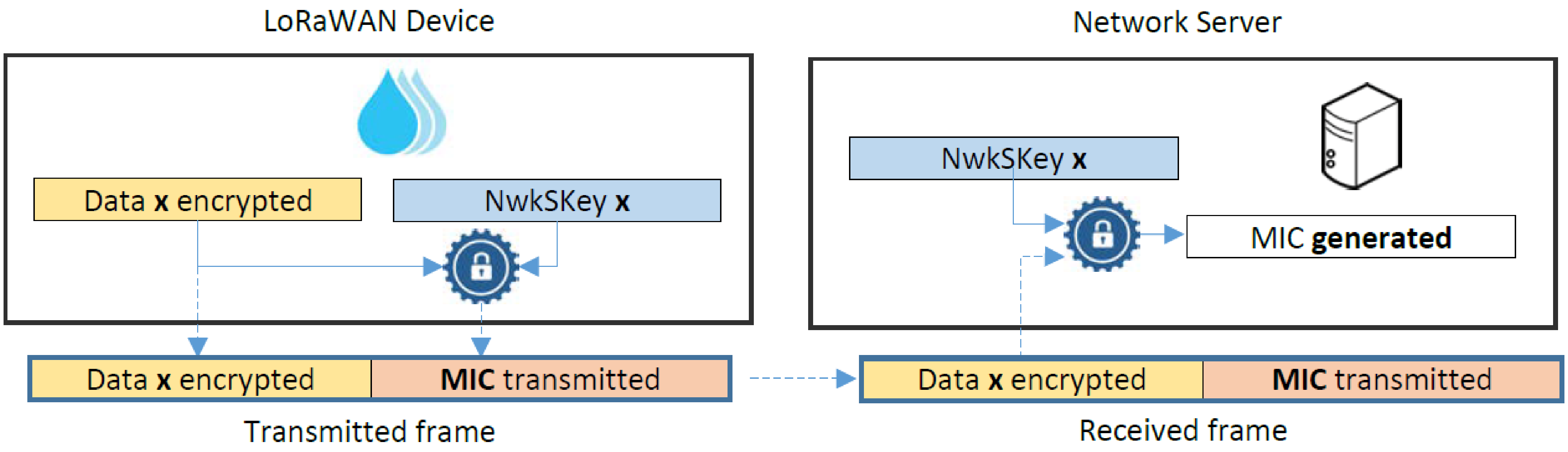
LoRaWAN gateways



LoRaWAN data encryption



LoRaWAN authentication

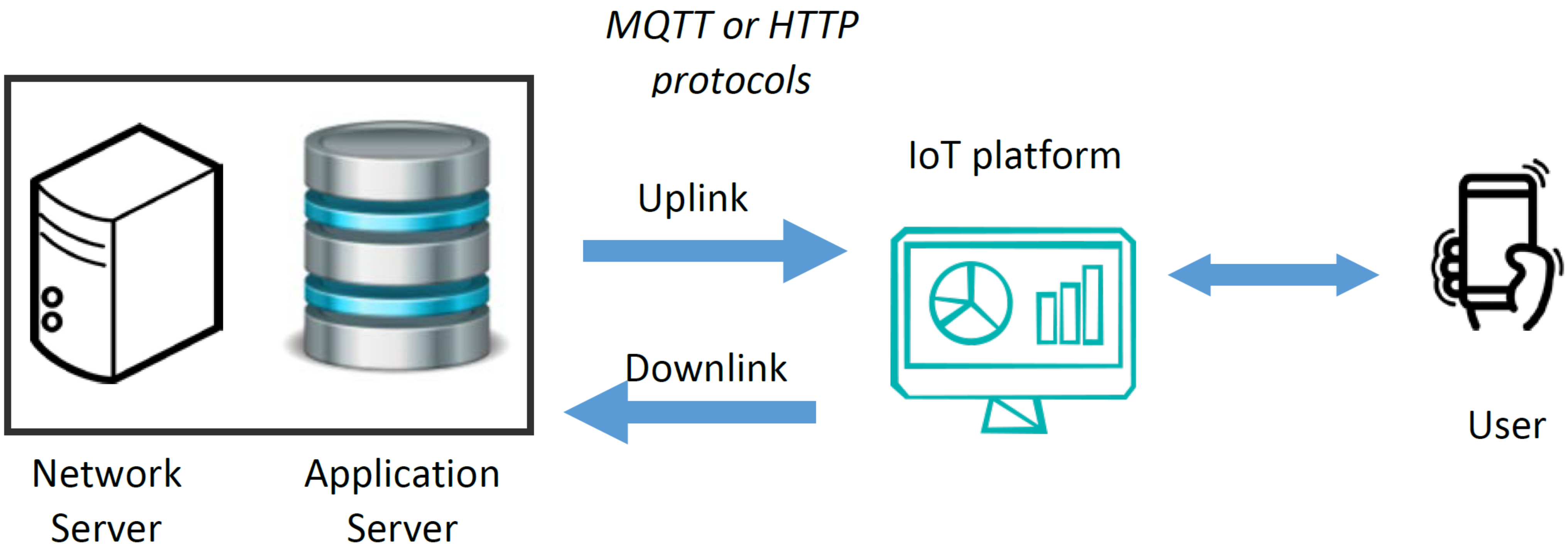


If MIC **transmitted** = MIC **generated**

Then the frame is authenticated

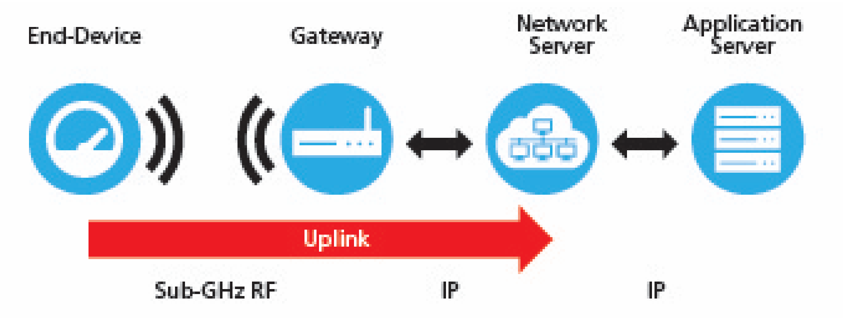
* MIC: message integrity check

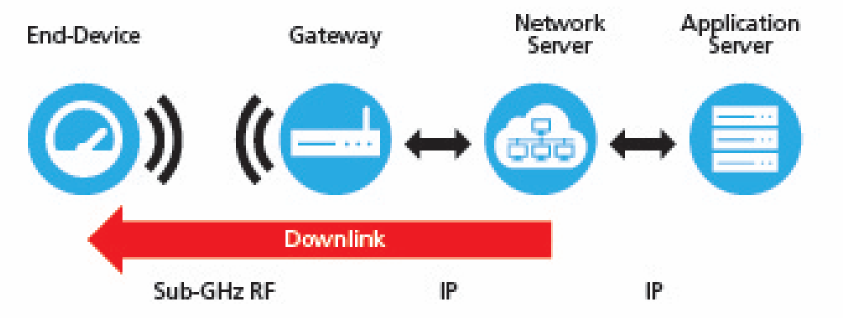
From the Application Server to Your Platform



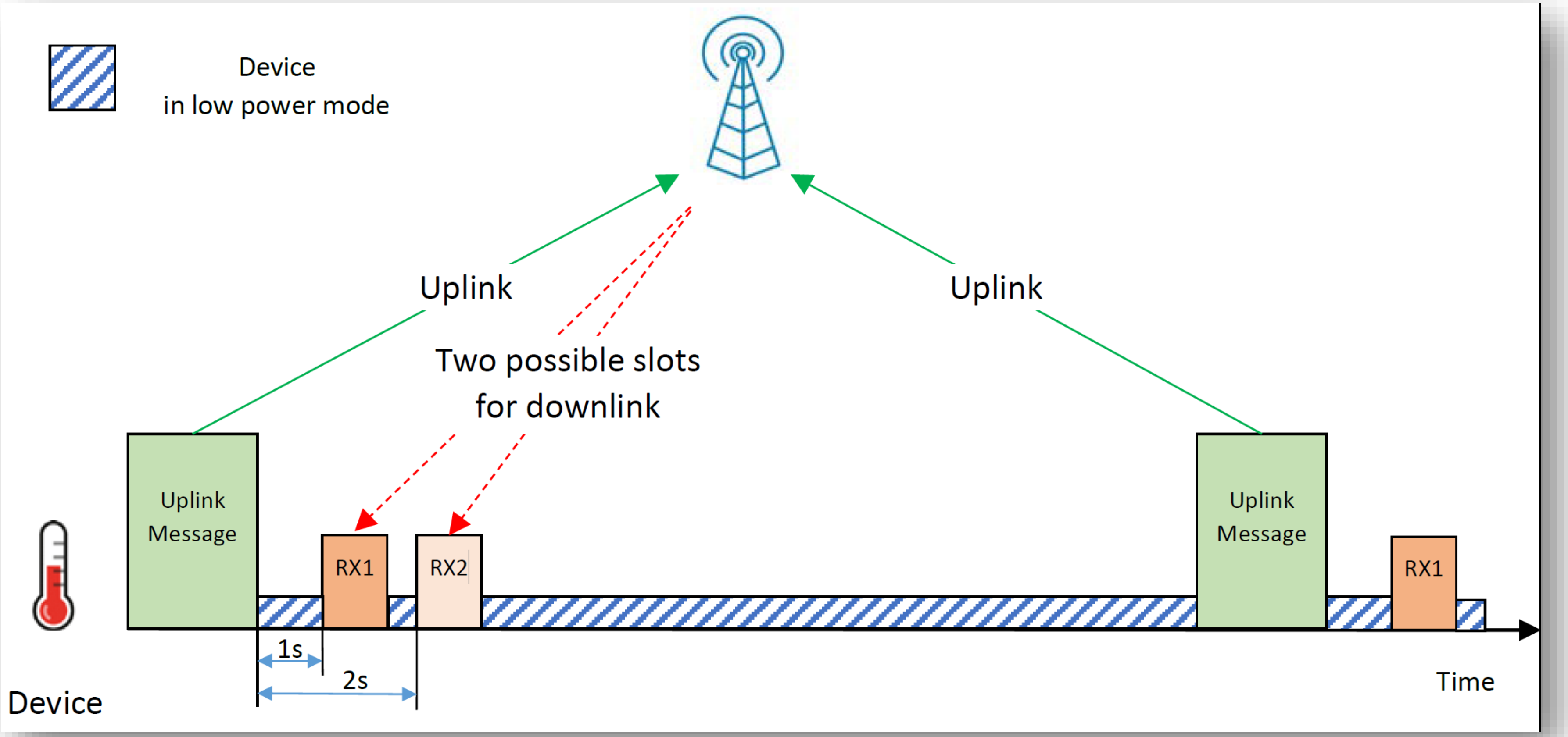
LoRaWAN end device classes

- Uplink: end device to server.
- Downlink: server to end device.
- 3 classes for LoRaWAN end devices:
  - Class A (must be implemented)
  - Class B (optional, extension of class A)
  - Class C (optional, extension of class A)
- End device's class determines:
  - When a device can receive downlink messages.
  - Device's energy efficiency (time in sleep mode).



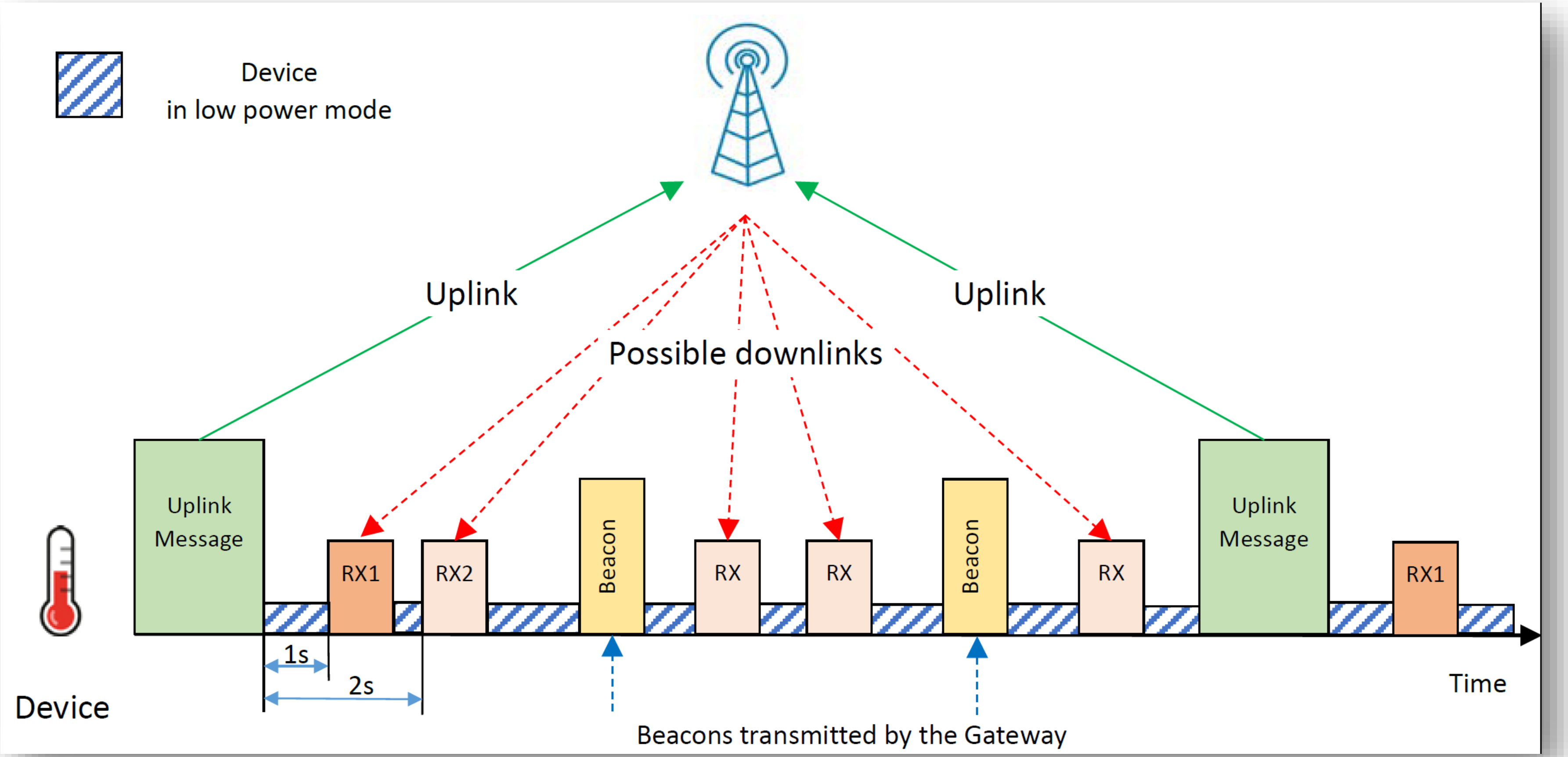


LoRaWAN end device class A



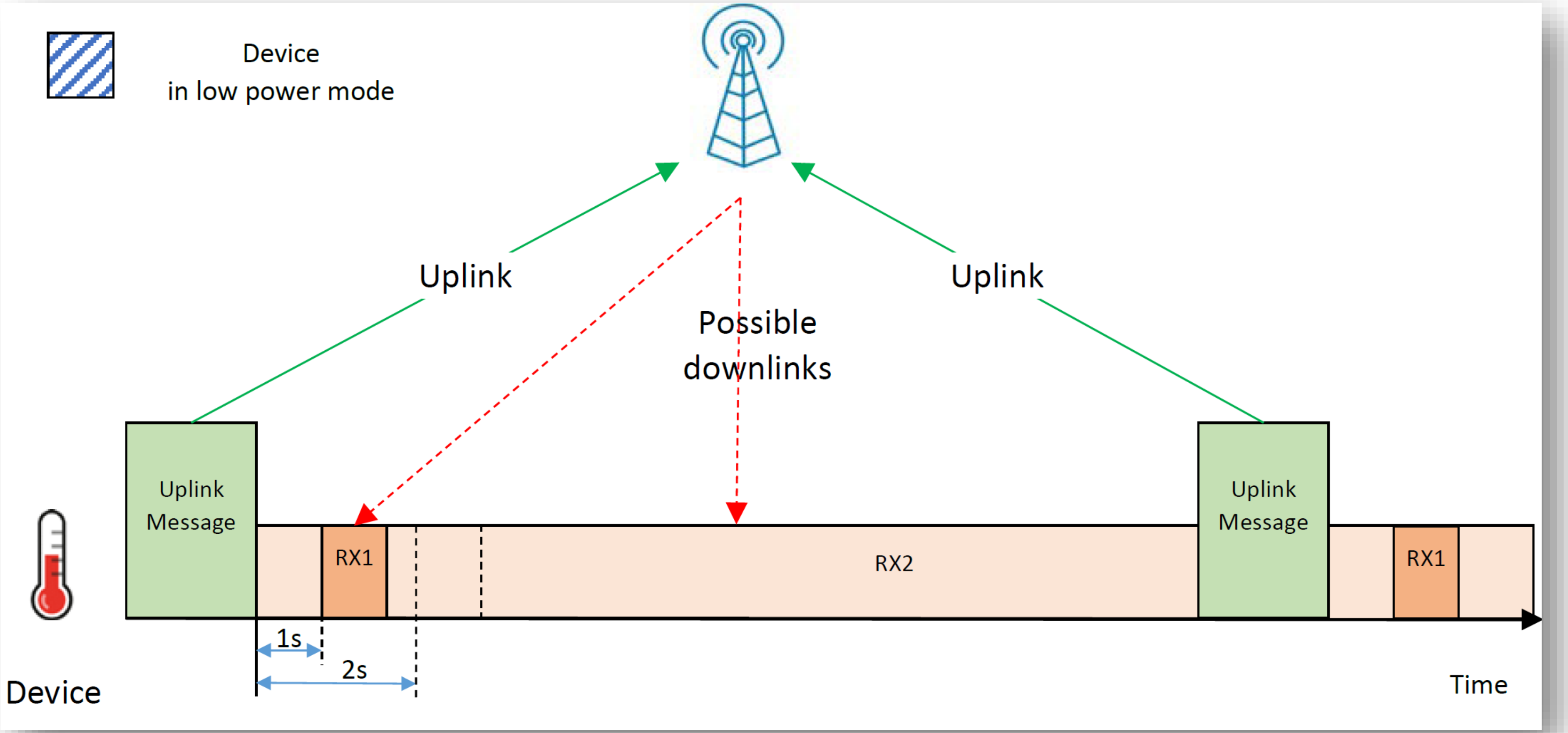
- ❑ A class A end-device can't receive if it has not transmitted uplink data. Therefore, we can’t easily reach a class A end-device.
- ❑ Minimal power consumption

LoRaWAN end device class B



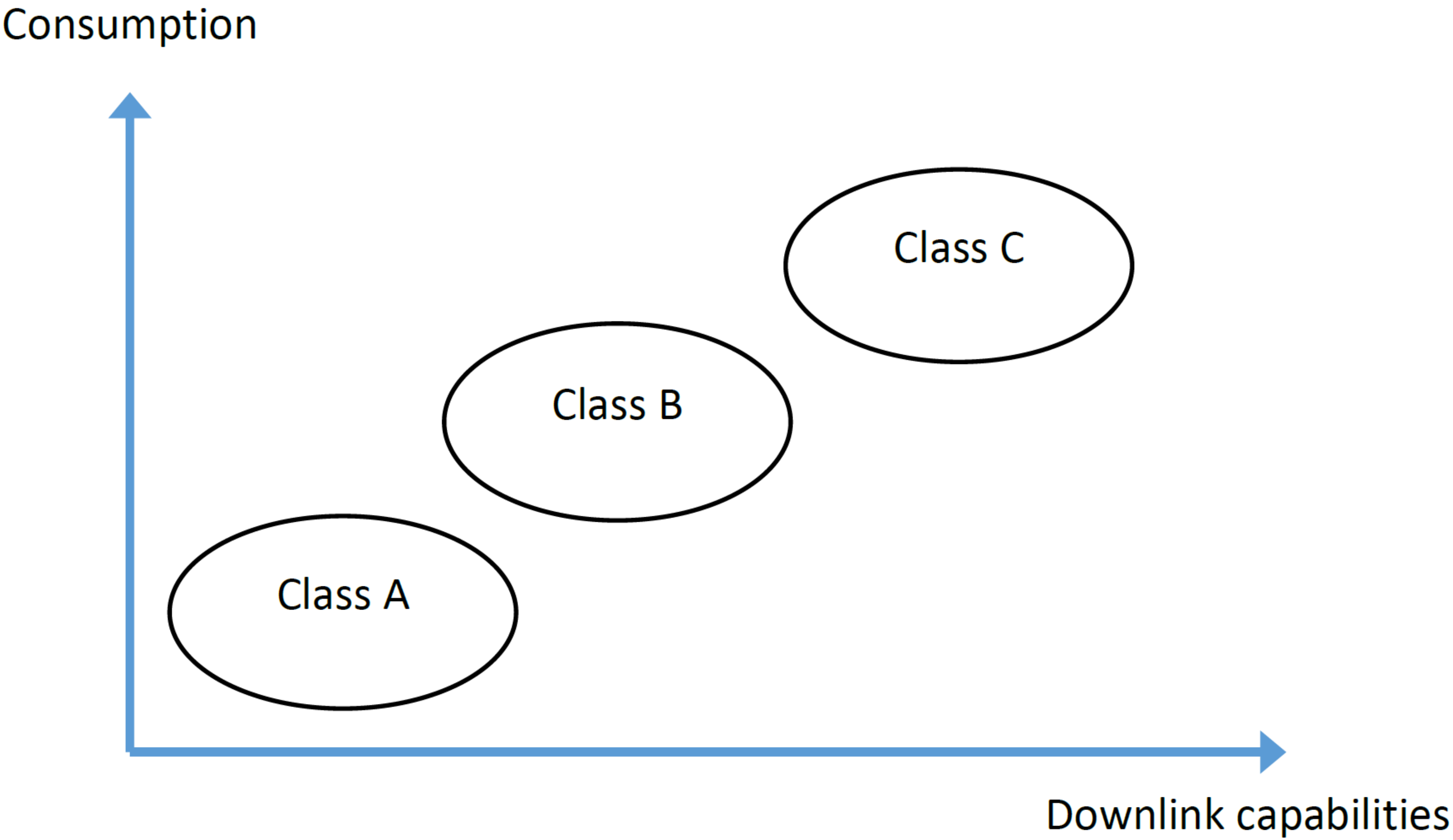
- ❑ A class B end-device can be reached regularly without necessarily having to transmit. On the other hand, it consumes more power than a class A device

LoRaWAN end device class C

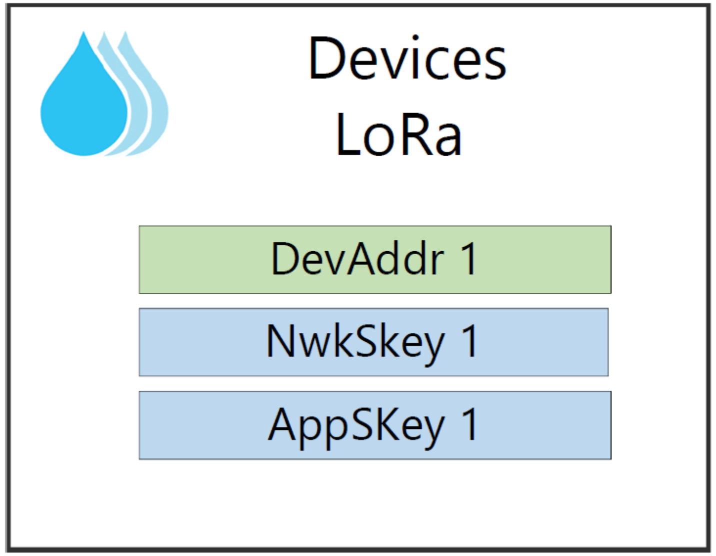


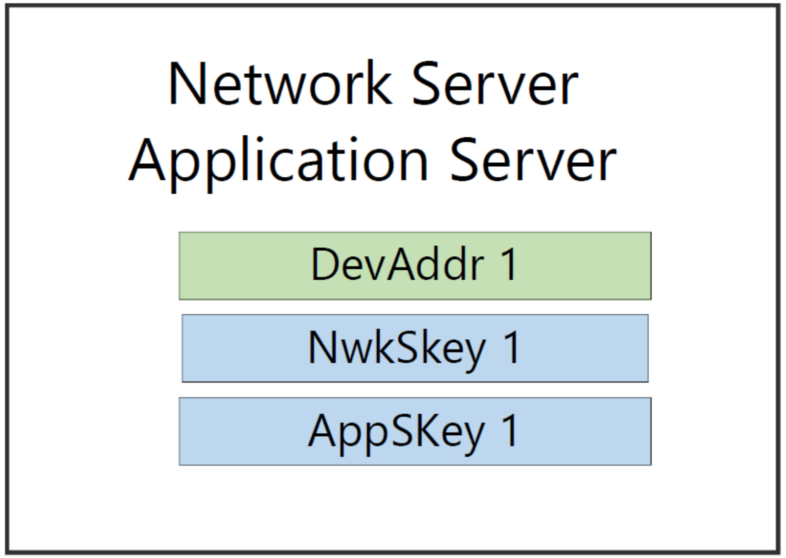
- ❑ A class C end-device is always reachable. However, this class is the most energy consuming of the three

LoRaWAN end device classes



Activation of LoRaWAN end devices

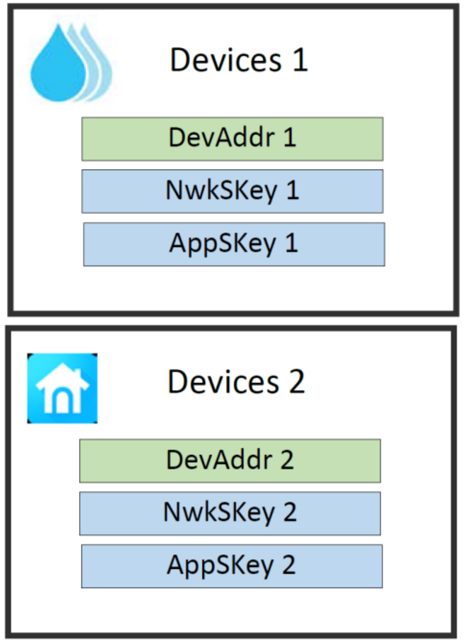




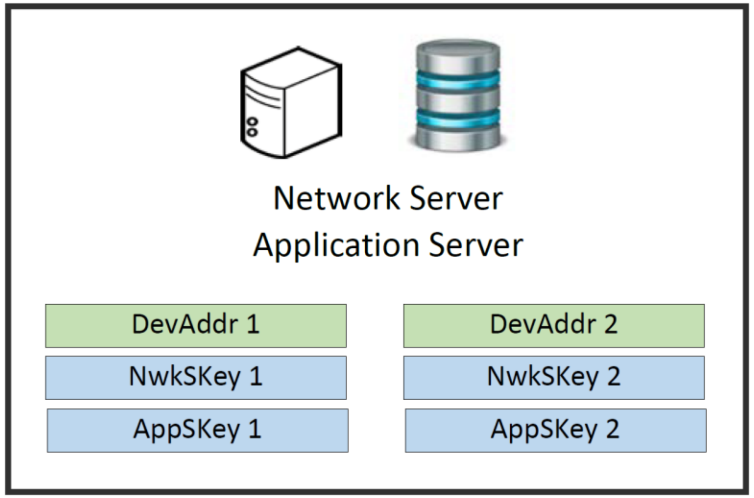
- ❑ Activation By Personalization (ABP)
- ❑ Over The Air Activation (OTAA)

Activation By Personalization (ABP)

- ❑ Simplest method
- ❑ Suitable for testing a prototyping
- ❑ Static DevAddr, NwkSKey and AppSKey are stored in the end-device
- ❑ The same DevAddr, NwkSKey and AppSKey are stored in the LoRaWAN server



Parameters stored in the Device



Parameters stored on the server

Over The Air Activation (OTAA)

- DevAddr, AppSKey and NwkSKey are generated during a join procedure
- We need
  - DevEUI

    64-bit Global Unique Identifier for the end-device
  - AppKey : AES 128 key

    authenticate Join-Request,

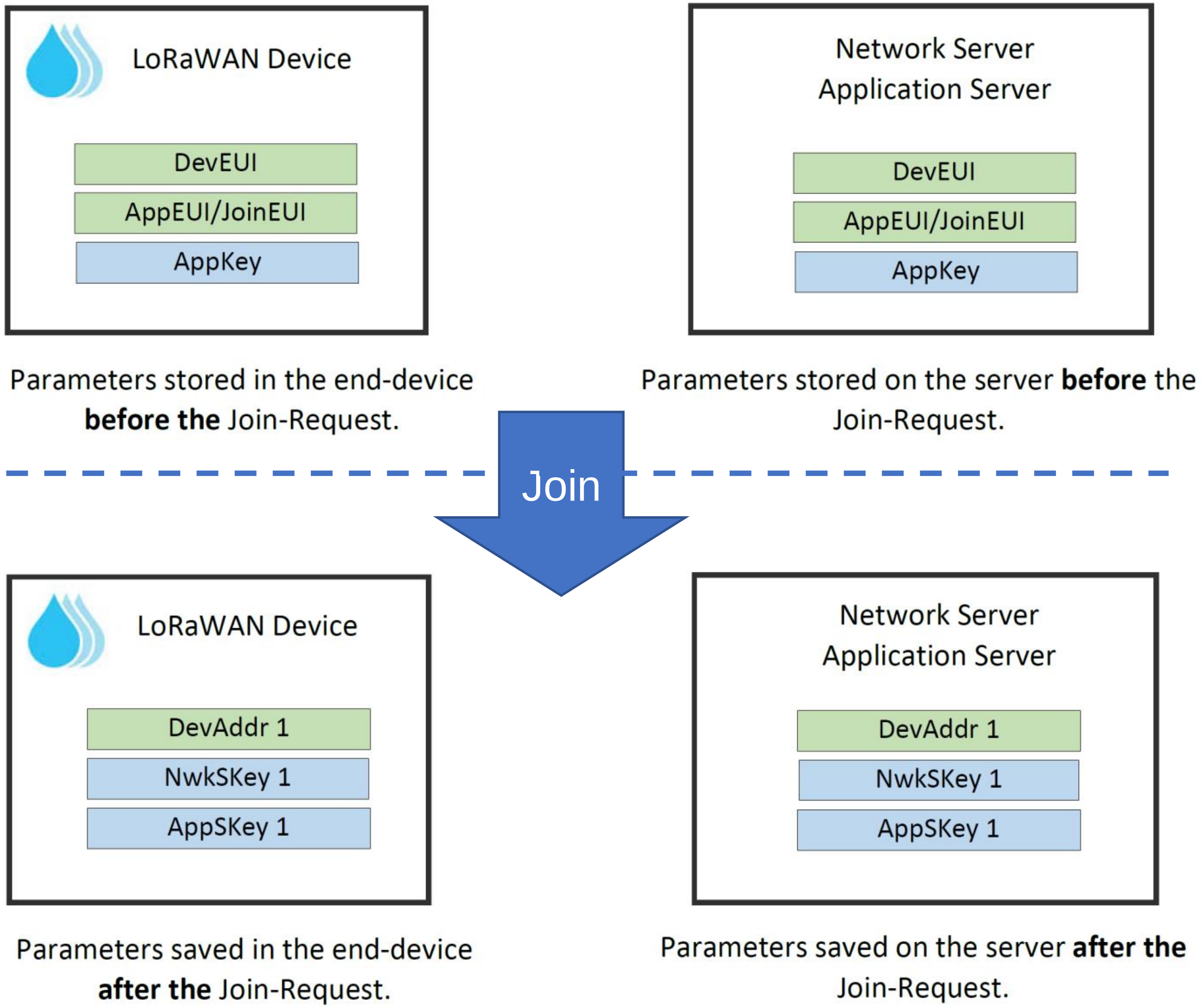
    encrypt the Join-Accept

    generate the session keys
  - AppEUI/JoinEUI

    application identifier

    LoRaWAN 1.0.4 + → Join Server identifier.

*EUI (Extended Unique Identifier) are always unique and are 8 bytes large



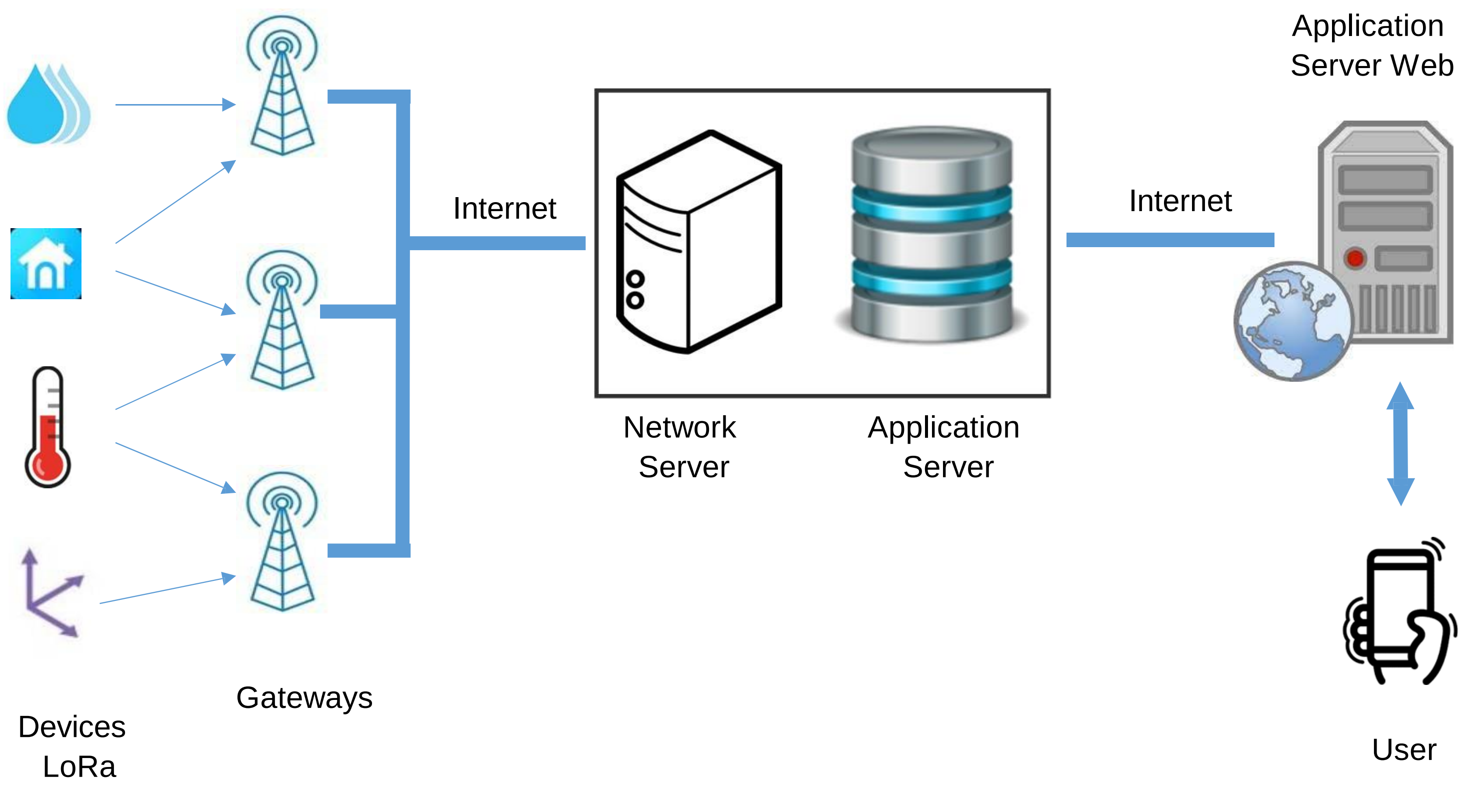
Activation of LoRaWAN end devices

- ❑ Activation By Personalization (ABP)
- ❑ Over The Air Activation (OTAA)

- ❑ Which one you recommend ? Why ?

LoRaWAN networks and servers

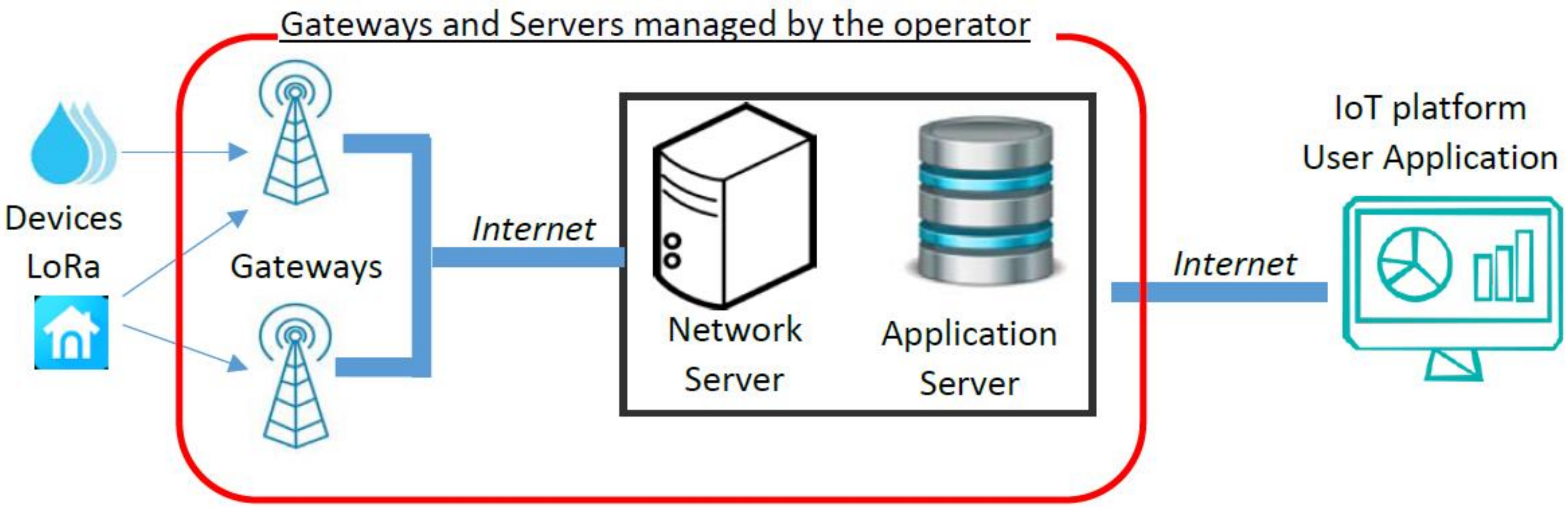
LoRaWAN: three network types



- ❑ Public operator LoRaWAN networks
- ❑ Private LoRaWAN networks
- ❑ Hybrid LoRaWAN networks

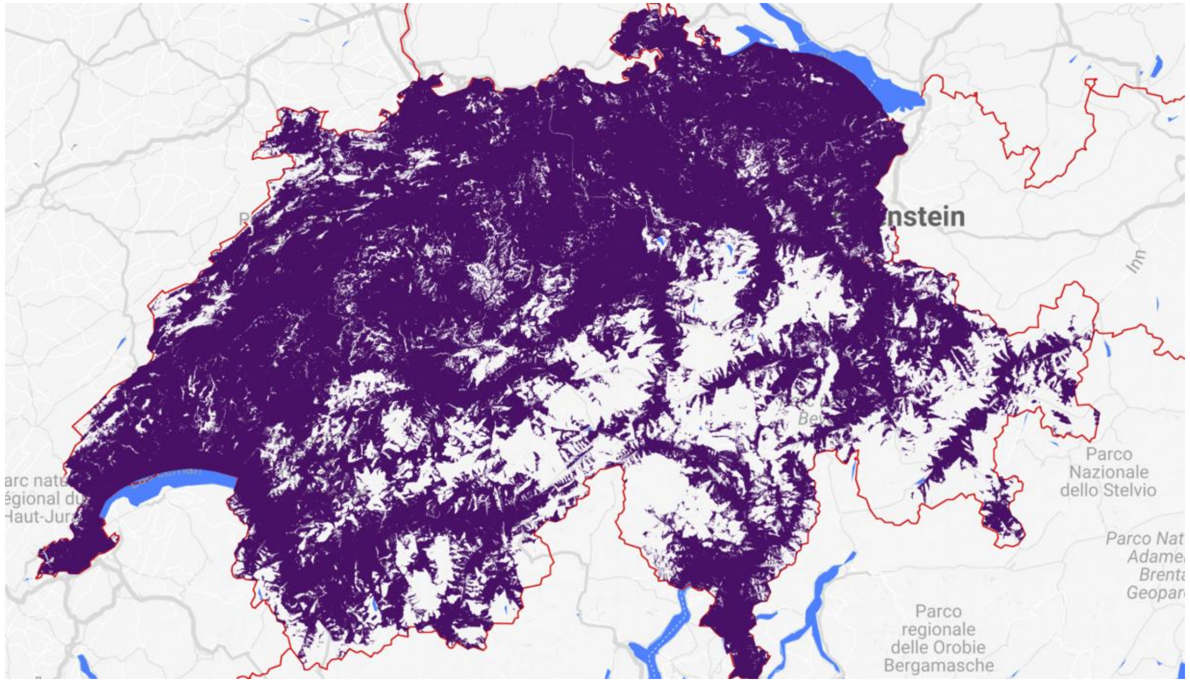
Public operator LoRaWAN networks

- ❑ Nation wide coverage
- ❑ User manages end-devices and user application.
- ❑ Public operator manages Gateways and servers.
- ❑ Subscription / plans: cost, limits on uplink and downlink …
- ❑ As of 2022, there are 165 LoRaWAN network operators in 171 countries.



Public operator LoRaWAN networks

- Exemple Suisscom.



IoT Low Basic

CHF 0.60 / actif / mois

Pour 1 Actif et plus

Frais de mise en service
CHF 49.00

Acheter maintenant

Idéal pour

Clients professionnels: des capteurs qui envoient rarement des données.

Inclus

Utilisateurs : illimité

Prix par uplink: CHF 0.00045

Prix par downlink: CHF 0.0020

Frais d'installation CHF 49.00

Les coûts mensuels récurrents sont

IoT High Basic

CHF 1.00 / actif / mois

Pour 1 Actif et plus

Frais de mise en service
CHF 49.00

Acheter maintenant

Idéal pour

Clients professionnels: capteurs qui envoient des données toutes les heures ou plus.

Inclus

Utilisateurs : illimité

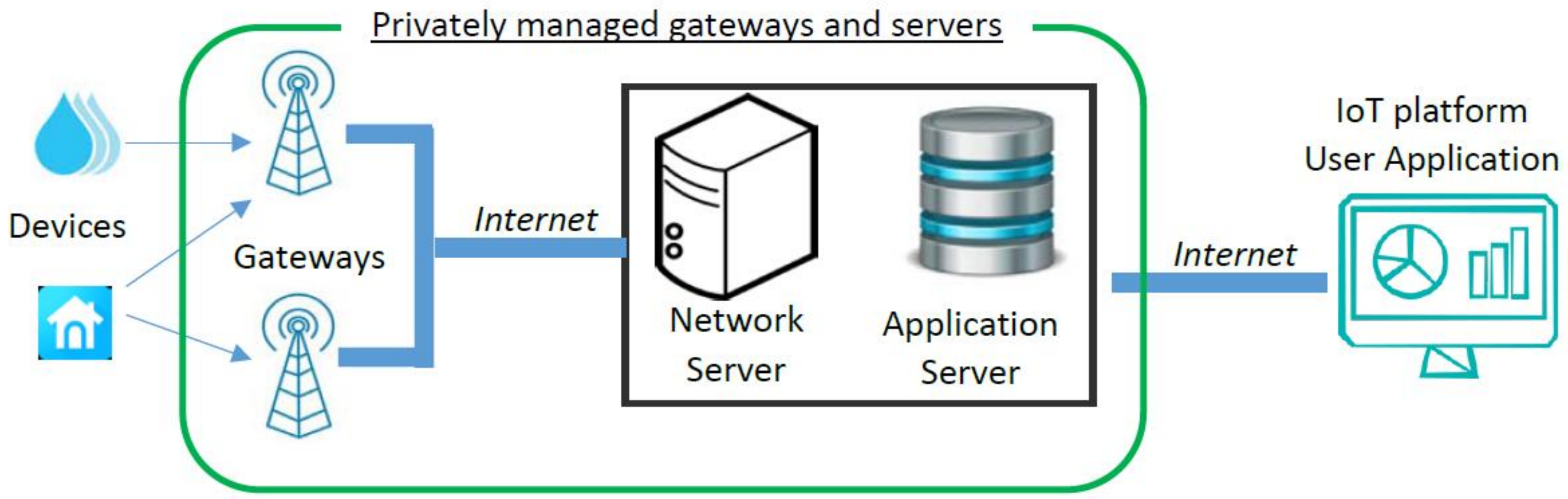
Prix par uplink: CHF 0.000025

Prix par downlink: CHF 0.0005

Frais d'installation CHF 49.00

Private LoRaWAN networks

- ❑ Create your own private network
- ❑ User manages end-devices, Gateways, servers and user application.
- ❑ NO Subscription, NO limits (in respect of duty cycle)
- ❑ In some gateways, an instance of a LoRaWAN server is proposed
- ❑ Server stack: on premises licence (payed) or open-source stacks



THE THINGS STACK

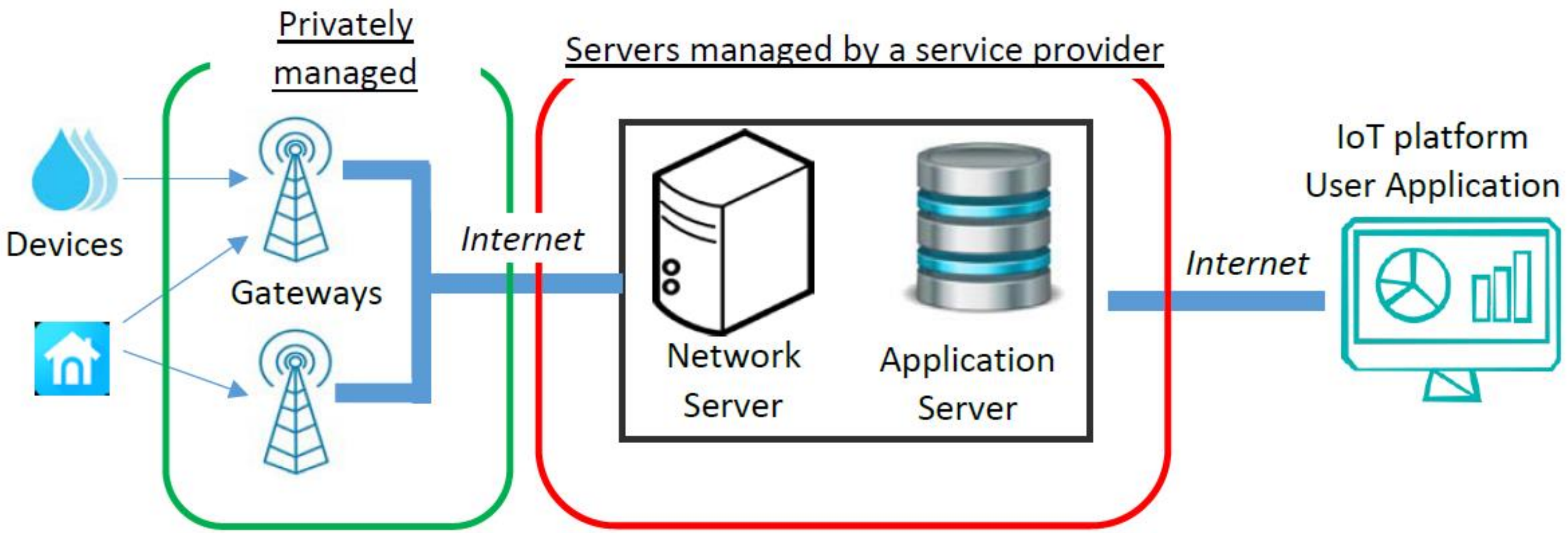
ChirpStack

Private or Public LoRaWAN networks

	Private network	Operated network
Subscription costs	No subscription	Monthly subscription cost per uplink / downlink per LoRaWAN end-device
Infrastructure costs	Important investment at the beginning (gateways and servers)	Included in the subscription
Skills required	Requires skills for installation, administration and maintenance	Everything is managed by the operator
Coverage	Optimized according to needs	Depends on the chosen operator Possibility of roaming between operators
Uplink	Unlimited within the duty-cycle	Limited according to the subscription
Downlink	Unlimited within the duty-cycle	Limited in number or pay-as-you-go

The hybrid LoRaWAN network

- ❑ User manages end-devices, Gateways and user application.
- ❑ Cloud-hosted solution manages servers.
- ❑ There are payed and community (free) solutions.
- ❑ Advantage: limit investments and maintenance for the server part



THE THINGS STACK
Community Edition

Actility
Connecting with intelligence

Actility: ThingPark Community

LoRaWAN network configuration

- Infrastructure (gateways + servers) must be operational:
  - public operated network: no action needs to be taken
  - hybrid network: gateways connected to the internet + subscribed to a cloud-hosted LoRaWAN server
  - private network: gateways connected to the internet + set up the LoRaWAN server yourself

- The configuration is always the same:
  - Gateway configuration (private + hybrid)
  - Gateway registration on the LoRaWAN server (private + hybrid)
  - Device registration on the LoRaWAN server (public + private + hybrid)
  - Device configuration (public + private + hybrid)

References

- LoRa – LoRaWAN and Internet of Things, Savoie Mont-Blanc University, Sylvain Montagny.

- https://www.thethingsnetwork.org/

- LoRa and LoRaWAN: A Technical Overview, Technical Paper, February 11, 2020 Semtech

Prof. Fouad HANNA, PhD.

fouad.hanna@heig-vd.ch