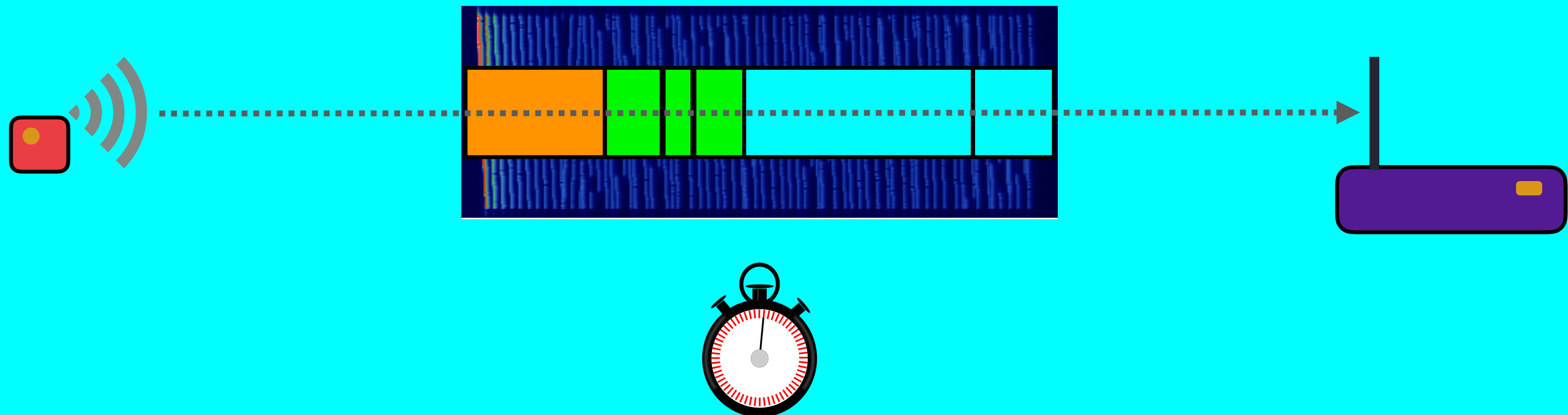


LORA / LORAWAN TUTORIAL 17

LoRa Packet Format, Time on Air and Adaptive Data Rate



INTRO

- In this tutorial I will explain what the LoRa packet format is, how the Time on Air is calculated and what Adaptive Data Rate is.

LORA PACKET FORMAT

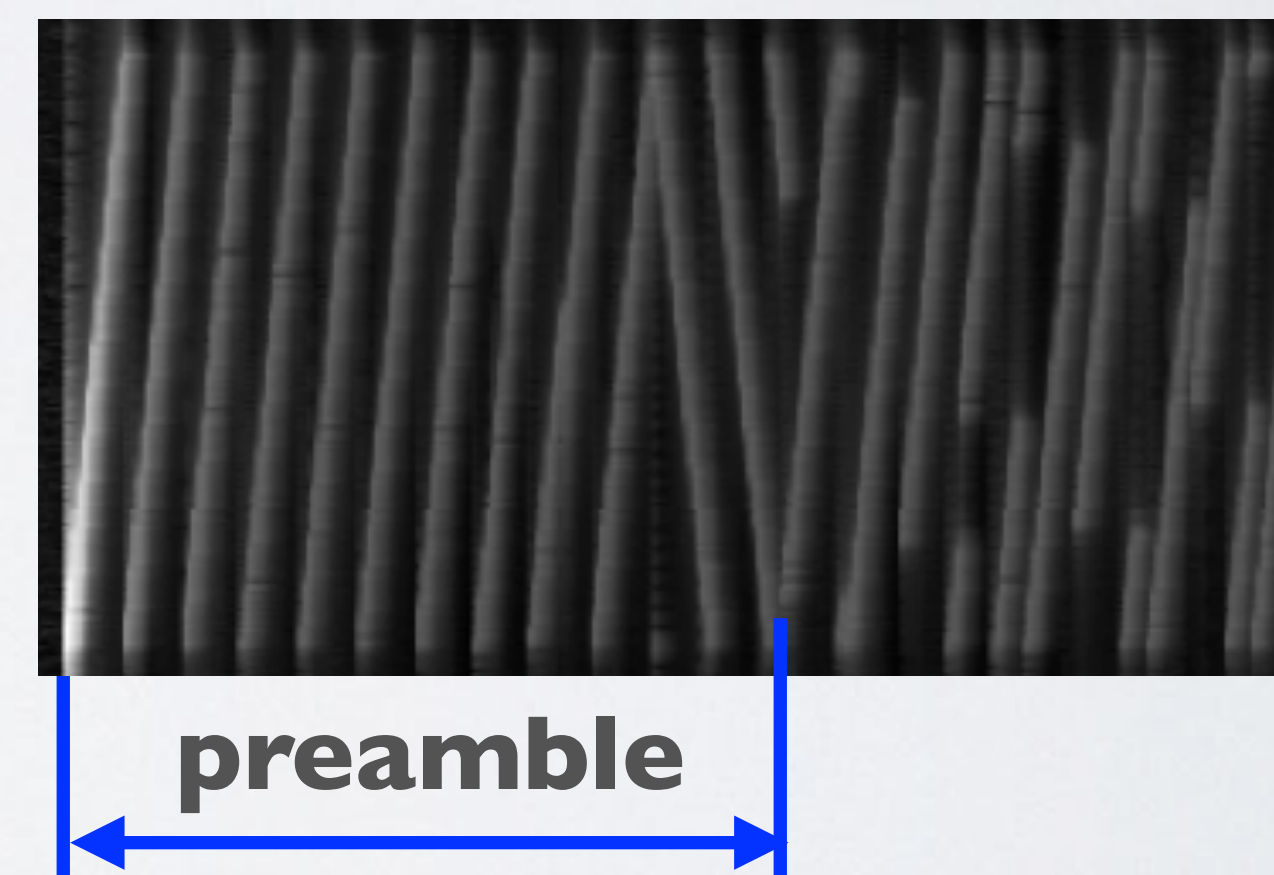
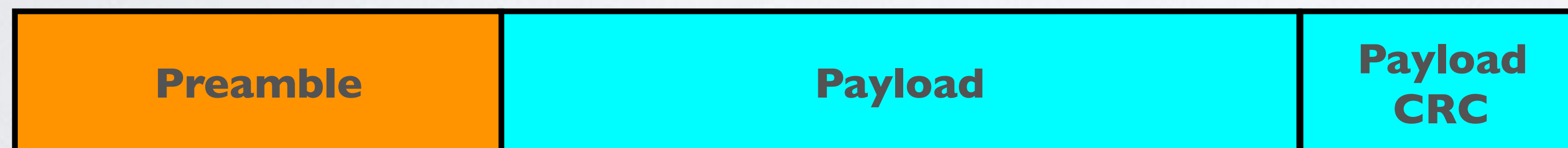
- The LoRa packet comprises of three elements: Preamble, header (optional) and payload.

Explicit header mode

Header



Implicit header mode



LORA PACKET FORMAT

- There are two types of LoRa packet format modes:
 - The explicit header mode includes a short header that contains information about the payload length, coding rate and whether a CRC is used in the packet. CRC stands for Cyclic Redundancy Check and is used to detect errors in digital data.
 - The implicit header mode where the payload, coding rate and CRC presence are fixed. In this mode the header is removed from the packet thus reducing transmission time. In this case the payload length, error coding rate and presence of the payload CRC must be manually configured on both sides of the radio link.

LORA PACKET FORMAT

- **The preamble** is used to detect the start of the packet by the receiver.
- **The header** (only in explicit header mode) is the default mode of operation. It provides information on the payload:
 - The payload length in bytes.
 - The forward error correction code rate.
 - The presence of an optional 16 bits CRC for the payload.
- **The payload** is a variable-length field that contains the actual data coded at the forward error correction code rate either as specified in the header in explicit mode or fixed in implicit mode. An optional payload CRC may be appended.

TIME ON AIR

- Time on Air (ToA) is the amount of time that the transmitter antenna is energised and transmitting data.

Note: ToA is **not** the time from Tx to Rx.



TIME ON AIR

- The Time on Air (ToA), aka LoRa packet duration (T_{packet}) is calculated as follow:

$$\mathbf{ToA} = \mathbf{T_{\text{packet}}} = \mathbf{T_{\text{preamble}}} + \mathbf{T_{\text{payload}}} \quad [2]$$

Preamble duration (T_{preamble}) in sec

Payload duration (T_{payload}) in sec

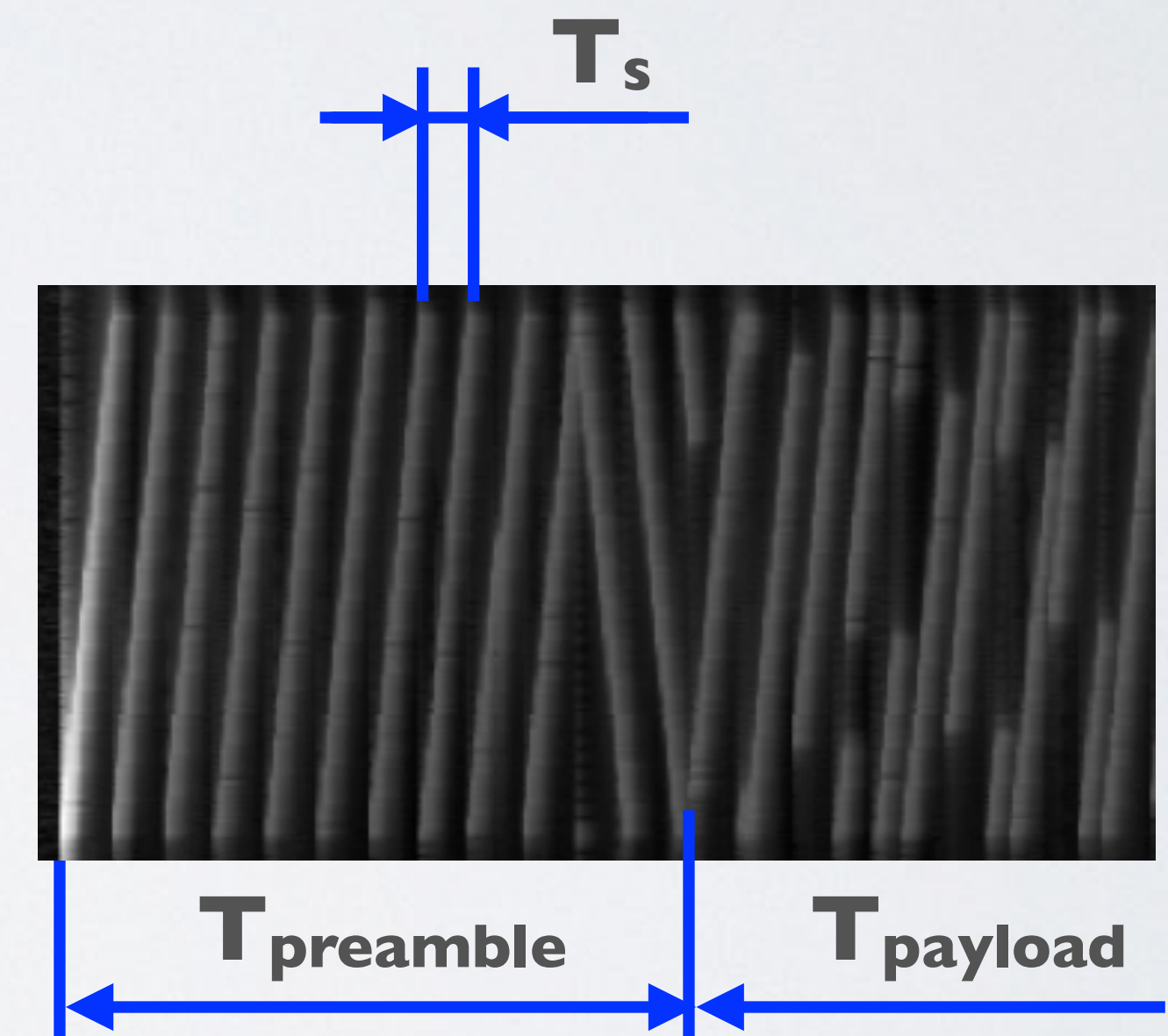
- The preamble duration is calculated as follow:

$$\mathbf{T_{\text{preamble}}} = (\mathbf{n_{\text{preamble}}} + \mathbf{4.25}) \mathbf{T_s} \quad [2]$$

Number of preambles

For EU868: $n_{\text{preamble}} = 8$ symbols

Symbol duration (T_s) in sec



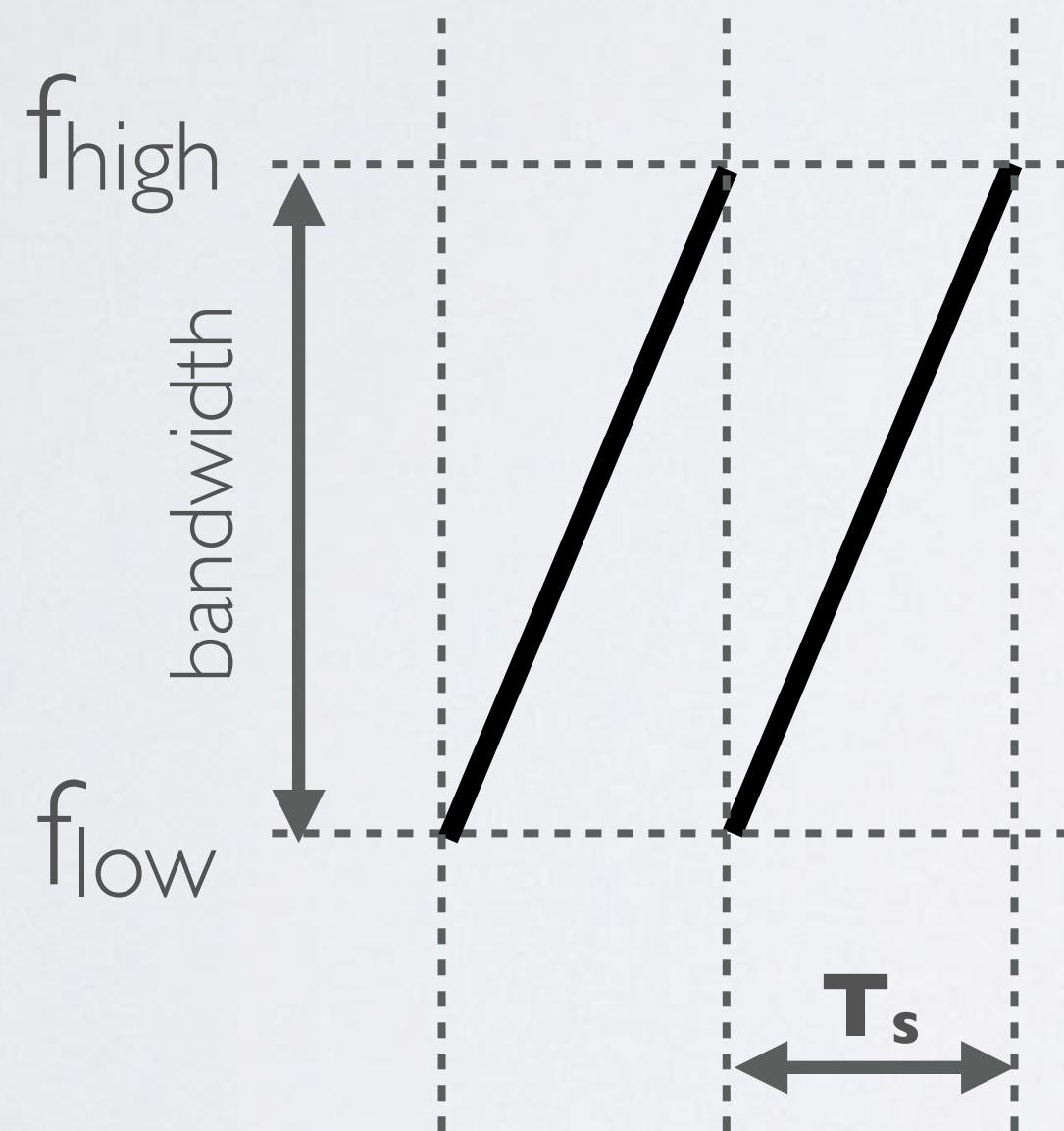
TIME ON AIR

- The symbol duration was already explained in Tutorial 15.
The symbol duration or sweep time is calculated as follow:

$$\mathbf{T_s (sec) = 2^{SF} / BW [1]}$$

Bandwidth (BW) in Hz (For EU868: 125 kHz or 250 kHz)

Spreading Factor (SF): 7-12



TIME ON AIR

- The payload duration (T_{payload}) is calculated as follow:

$$T_{\text{payload}} = T_s (8 + \max(\text{ceil}((8\text{PL} - 4\text{SF} + 28 + 16\text{CRC} - 20\text{H}) / 4 (\text{SF} - 2\text{DE})), (\text{CR} + 4), 0)) \quad [3]$$

Symbol duration (T_s) in sec

Payload (PL) in bytes

Spreading Factor (SF=7-12)

CRC (enabled=1, disabled=0. For LoRaWAN default CRC=1)

Header (disabled H=1 [implicit], enabled H=0 [explicit])

For LoRaWAN header is enabled: H=0

LowDataRateOptimize (enabled DE=1, disabled DE=0)

Coding rate (CR=1,2,3 or 4. For LoRaWAN default CR=1)

LOW DATA RATE OPTIMIZATION

- Given the potentially long duration of the packet at high spreading factors the Low Data Rate Optimization (LowDataRateOptimize) option can be set to improve the robustness of the transmission to variations in frequency over the duration of the packet transmission and reception.
- When the Low Data Rate Optimization is enabled it increases the robustness of the LoRa link at these low effective data rates. Its use is mandated when the symbol duration exceeds 16ms. Note that both the transmitter and the receiver must have the same setting for LowDataRateOptimize.
- The LowDataRateOptimize is enabled for bandwidth 125 kHz and Spreading Factor ≥ 11

TIME ON AIR

- An online tool to calculate the Time on Air see:

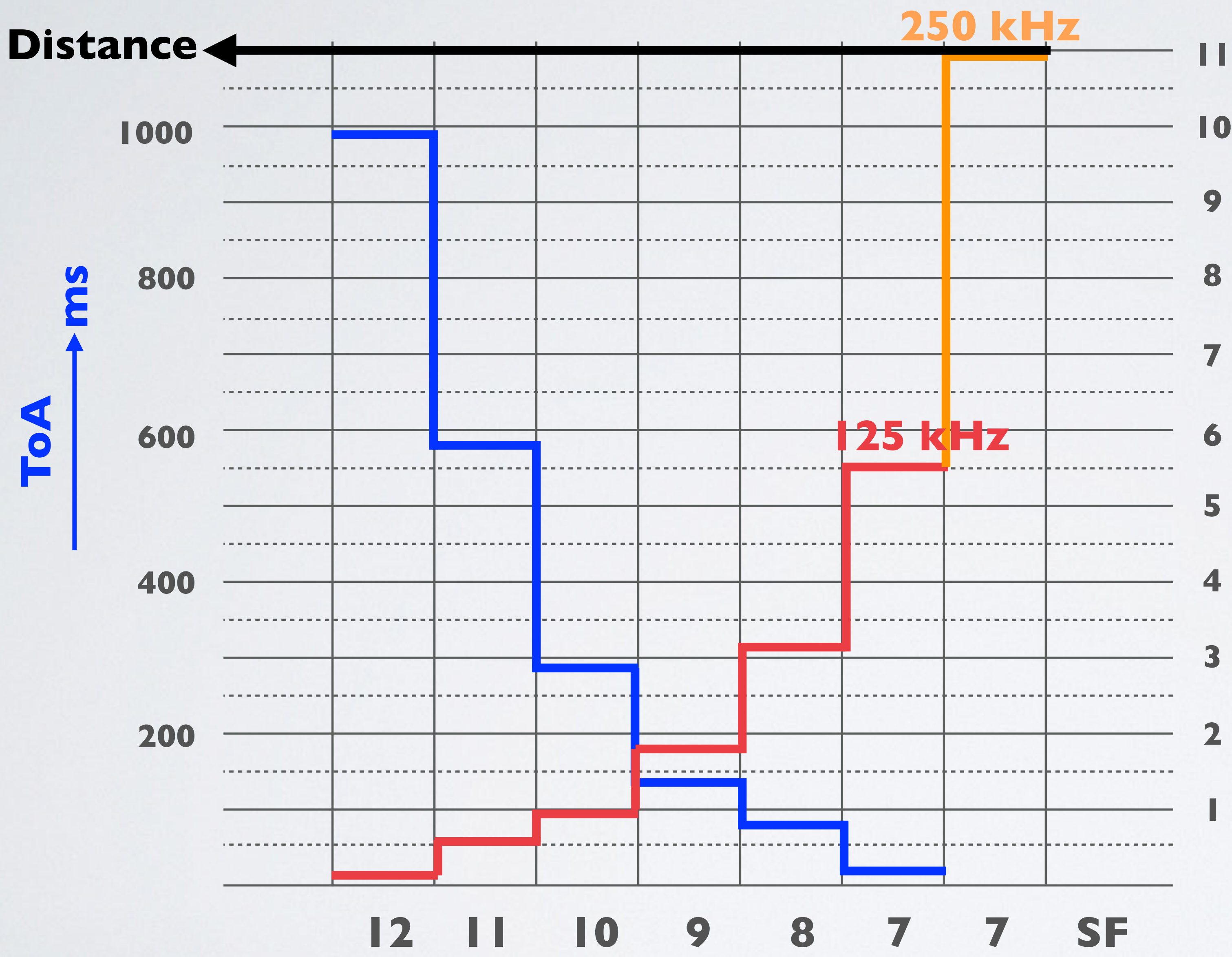
<https://www.loratools.nl/#/airtime>

- For example:

$n_{\text{preamble}} = 8$, explicit header=enabled, CRC=enabled, payload length=10 bytes, CR=1 and BW=125 kHz

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

TIME ON AIR & DATA RATE



BW = 125 kHz
CR = 1
Payload = 10 bytes

ToA data see
Tutorial 17

Data rate data see
Tutorial 15, slide 7

kbits/s
data rate

TIME ON AIR & DATA RATE

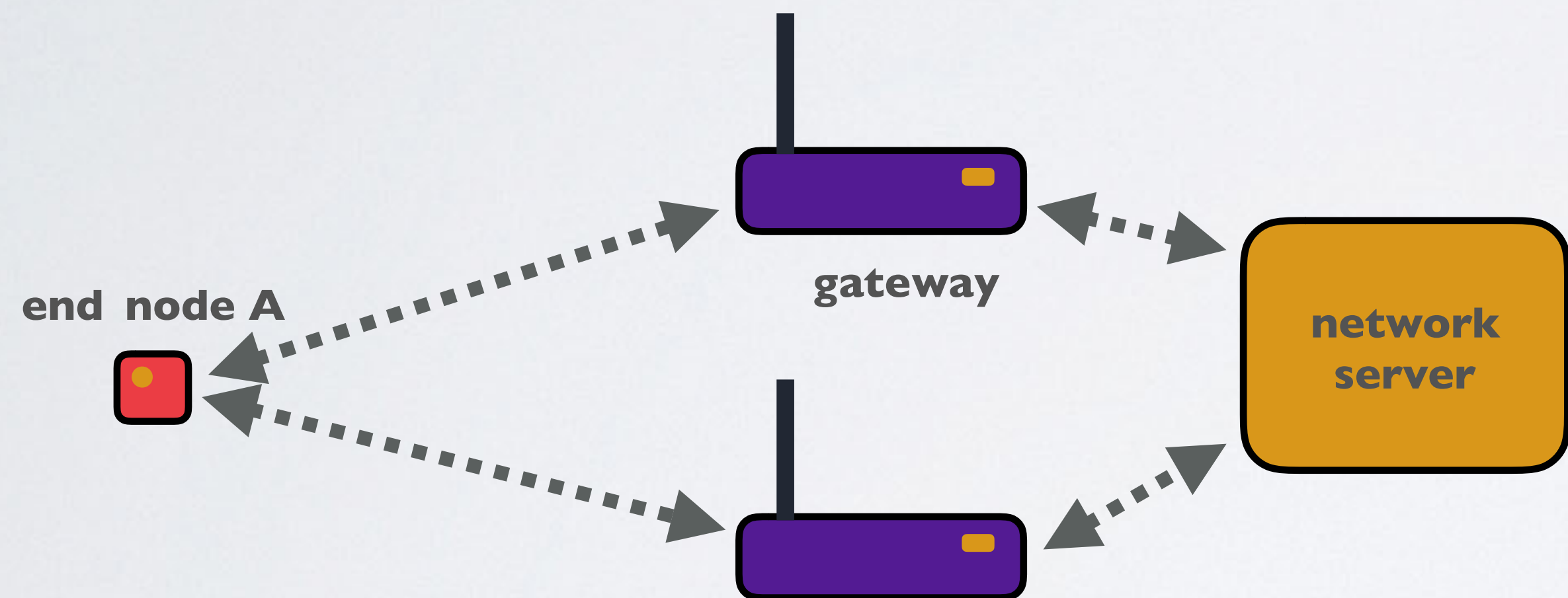
- A higher spreading factor means a longer Time on Air and a lower data rate as can be seen in the previous graph.
- A higher spreading factor also means the sender-receiver range gets larger but it requires more energy (battery power).

ADAPTIVE DATA RATE

- The LoRaWAN protocol defines the Adaptive Data Rate (ADR) scheme to control the uplink transmission parameters of LoRa devices:
 - Spreading Factor (SF)
 - Bandwidth (BW)
 - Transmission powerTransmission parameters
- Whether the ADR functionality will be used is requested by the end nodes by setting the ADR flag in the uplink message. If the ADR flag is set, the network server can control the end node's transmission parameters.
- ADR should only be used in stable Radio Frequency (RF) situations where end nodes do not move. Mobile end nodes which are stationary for longer times can enable ADR during those times.

ADAPTIVE DATA RATE

- What now follows is a *simplified* explanation how the Adaptive Data Rate works.
- The network server collects the 20 most recent uplink transmissions data (such as data rate and Signal-to-Noise Ratio (SNR)) from an end node.



20 most recent uplink transmissions data from end node A

#01: data rate = SF12BW125, SNR=5

#02: data rate = SF12BW125, SNR=1

#03: data rate = SF12BW125, SNR=5

:

#20: data rate = SF12BW125, SNR=1

ADAPTIVE DATA RATE

- Of the 20 received uplink messages the network server takes the maximum SNR value which is now called the $SNR_{measured}$ and the corresponding data rate. The network server calculates the margin as follow:

$$\mathbf{margin} = \mathbf{SNR}_{measured} - \mathbf{SNR}_{limit} - \mathbf{margin}_{default}$$

For example:

$$\text{Data rate} = SF \cdot BW / 2^5 \quad (\text{data rate equation: } R_b = SF \times (BW / 2^{SF}))$$

$$SNR_{measured} = 5 \text{ dB}$$

$$SNR_{limit} = -20 \text{ dB (See Tutorial 16)}$$

$$margin_{default} = 10 \text{ dB}$$

$$margin = SNR_{measured} - SNR_{limit} - margin_{default} = 5 - (-20) - 10 = 15 \text{ dB}$$

- The margin is large which means the end node uses unnecessary too much battery power to transmit uplink messages.

ADAPTIVE DATA RATE

- The network server does the following calculation with an optimised data rate:
- For example:
 - Data rate = **SF7**BW125 (was previously **SF12**BW125)
 - $\text{SNR}_{\text{measured}} = 5 \text{ dB}$
 - $\text{SNR}_{\text{limit}} = -7.5 \text{ dB}$ (See Tutorial 16)
 - $\text{margin} = \text{SNR}_{\text{measured}} - \text{SNR}_{\text{limit}} - \text{margin}_{\text{default}} = 5 - (-7.5) - 10 = 2.5 \text{ dB}$
- The margin is changed from 15 dB to 2.5 dB, but it can further be optimised by lowering the transmission power.
- This optimised data rate and/or transmission power are the transmission parameters calculated by the network server and send to the end node.

ADAPTIVE DATA RATE

- The end node will use these new transmission parameters to transmit its data and thus using less power.
- How the ADR actually works is explained in detail in the LoRaWAN specification [4].