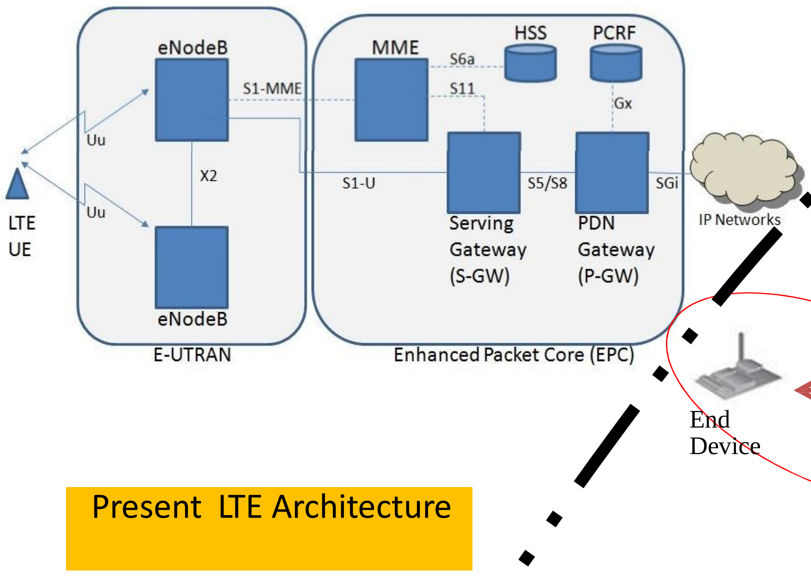
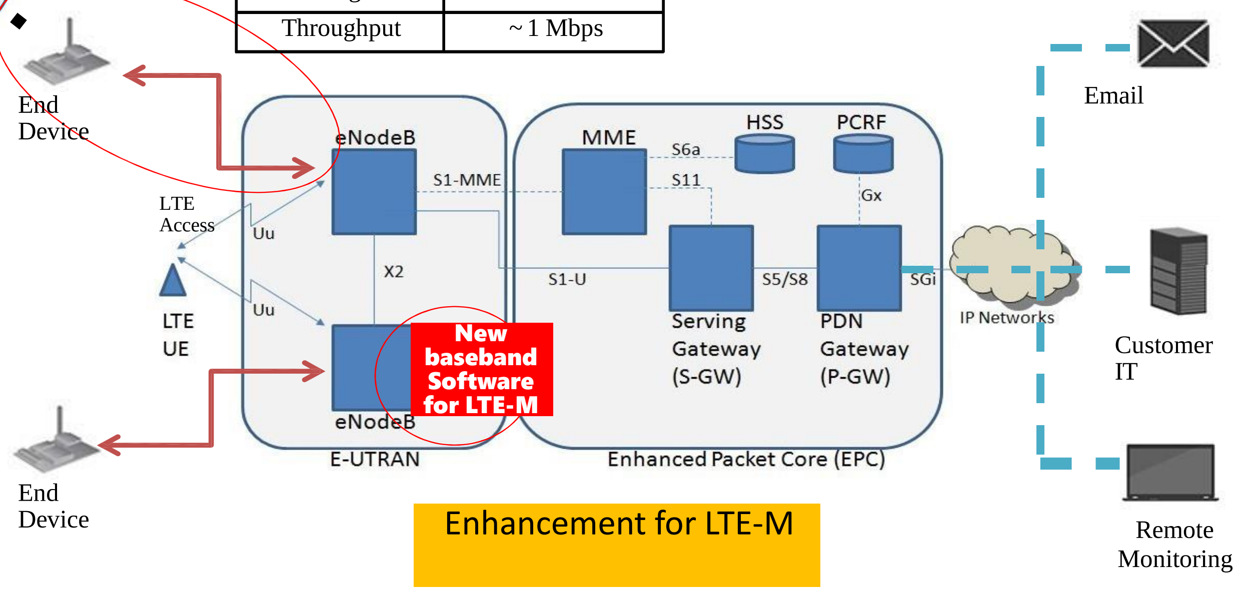
LTE to LTE-M - Architecture

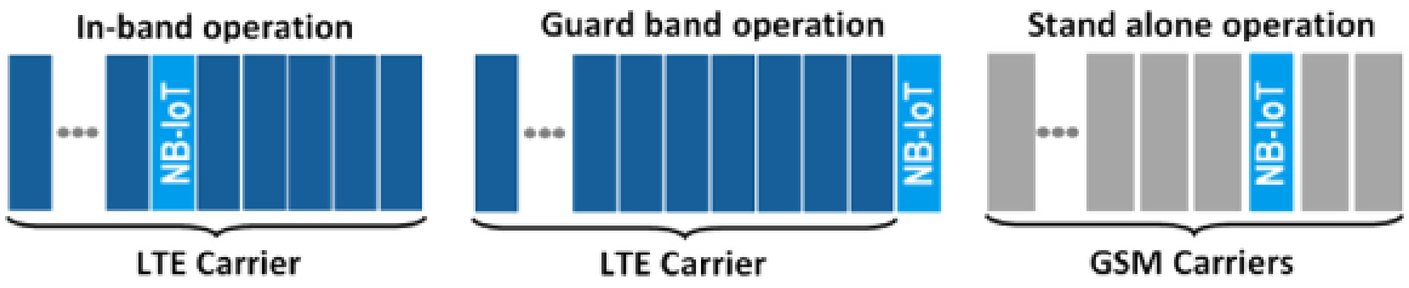


Frequency Band	Narrow Band
Access	LTE-M
Range	~ 11 Km
Throughput	~ 1 Mbps



NB-IoT

- Defined in R13, another mode instead of LTE-M
- Bandwidth – 200KHz
  - One resource block in GSM/LTE
- Based in LTE protocol, stripped down
  - OFDMA(down)/FDMA(up), QPSK
  - 200kbps (down)/20kbps(up)
- Three modes of operation



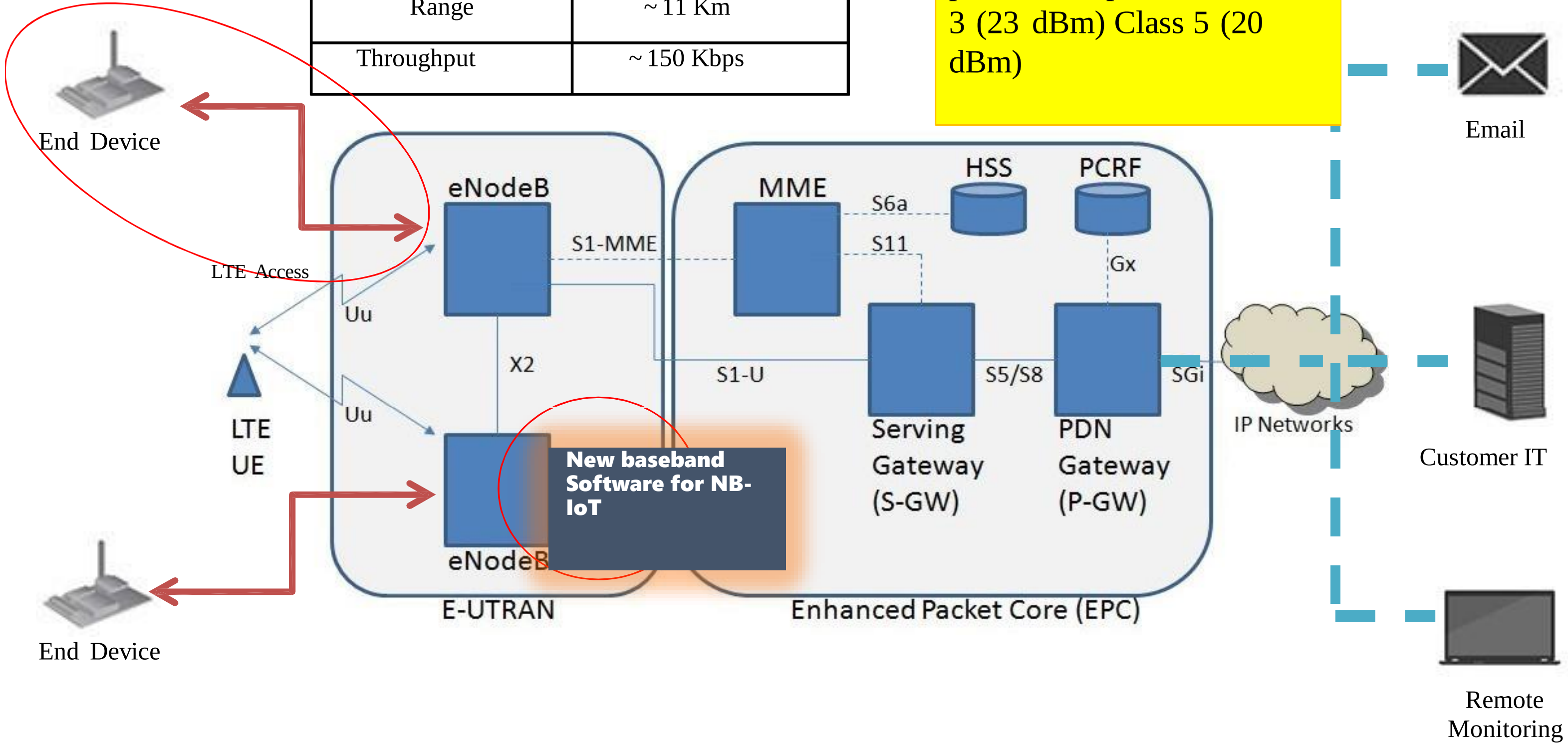
NB-IoT

- Uses LTE design extensively
- Lower cost in terms of channel utilization
- Extended coverage
- Low Receiver sensitivity = -141 dBm
- Long battery life: 10 years with 5 Watt Hour battery (depending on traffic and coverage needs)
- Support for massive number of devices: at least 50.000 per cell
- 3 modes of operation:
  - Stand-alone: *stand-alone carrier, e.g. spectrum currently used by GERAN (GSM Edge Radio Access Network) systems as a replacement of one or more GSM carriers*
  - Guard band: *unused resource blocks within a LTE carrier's guard-band*
  - In-band: *resource blocks within a normal LTE carrier*

NB-IoT - Architecture

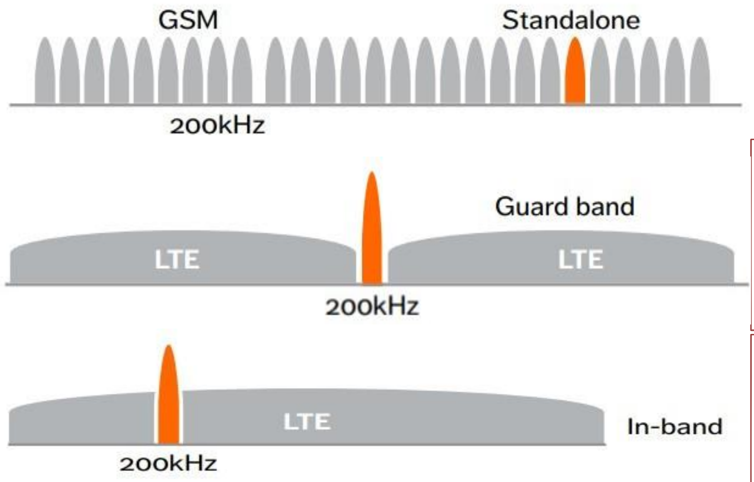
Frequency Band	Ultra Narrow Band
Range	~ 11 Km
Throughput	~ 150 Kbps

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



NB-IoT – Spectrum & Access

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

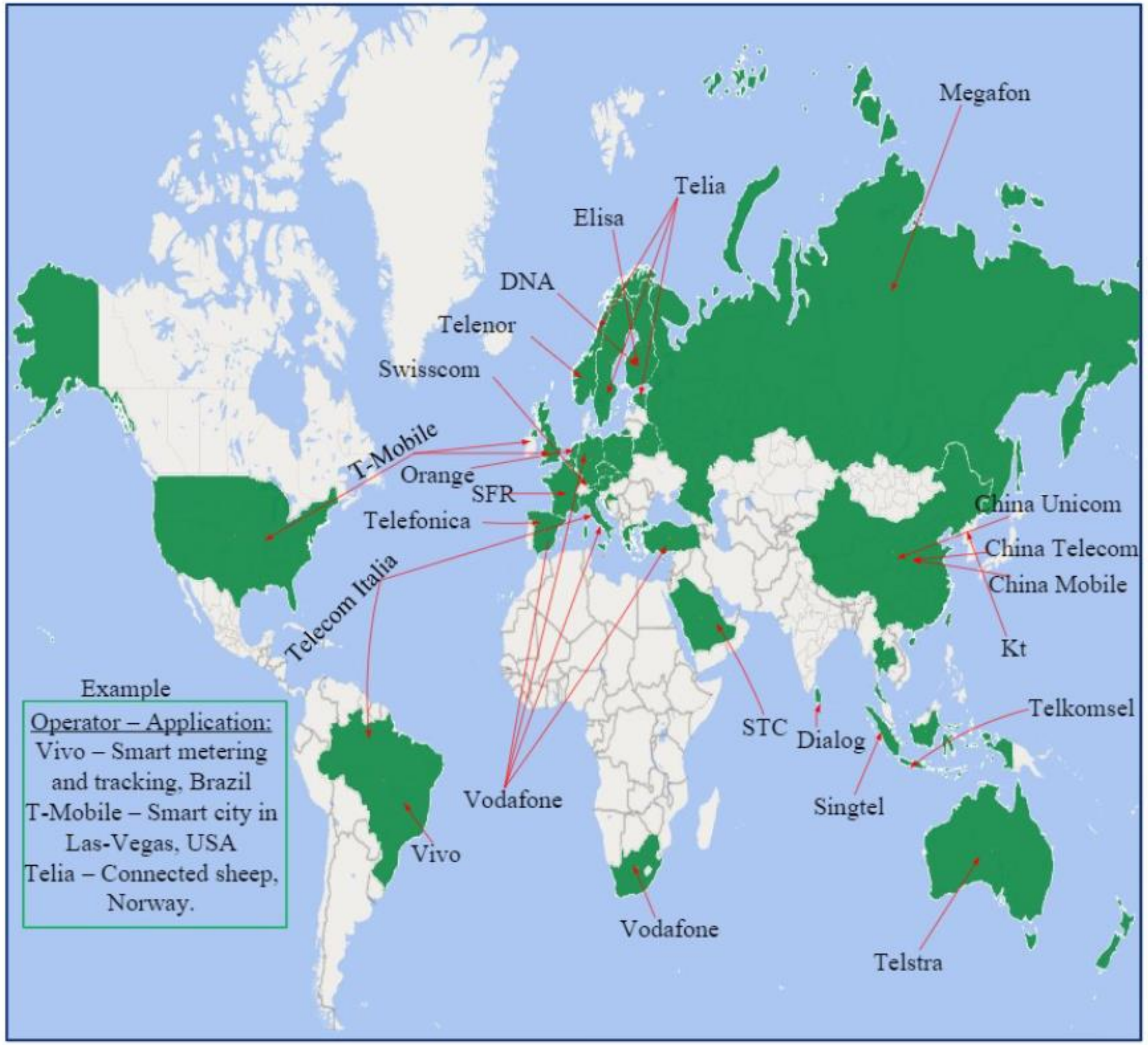


Stand-alone operation
Dedicated spectrum.
Ex.: By re-farming GSM channels

Guard band Operation:
Based on the unused RB within a LTE carrier's guard-band

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

NB-IoT (@2019)



Megafon
Telia
Elisa
DNA
Telenor
Swisscom
T-Mobile
Orange
SFR
Telefonica
Telecom Italia
China Unicom
China Telecom
China Mobile
Kt
Telkomsel
STC
Dialog
Singtel
Vodafone
Vivo
Vodafone
Telstra
Example
Operator – Application:
Vivo – Smart metering and tracking, Brazil
T-Mobile – Smart city in Las-Vegas, USA
Telia – Connected sheep, Norway.

Cellular technologies

- Two strategies, for different scenarios
  - No MIMO for lower end device energy.

	LTE-M	NB-IoT
Peak data rate	384 kbps	<100 kbps
Latency	50-100 ms	1.5-10 seconds
Power consumption	Best at medium data rates	Best at very low data rates
Mobility	Yes	No, stationary only
Voice	Yes	No
Antennas	1	1

SigFox

- Provide and maintain a PAID connectivity platform
  - Ultra Narrow Band: 100Hz per message
  - Ultra Low Bit rate: 12 byte messages, 140 messages per day (max!)
  - Long Range: ~50KM
  - Sensors lasting 10 years
  - Only provides connectivity, access control and a broker
- Business Model: connectivity service for alarms, smart meters, etc..

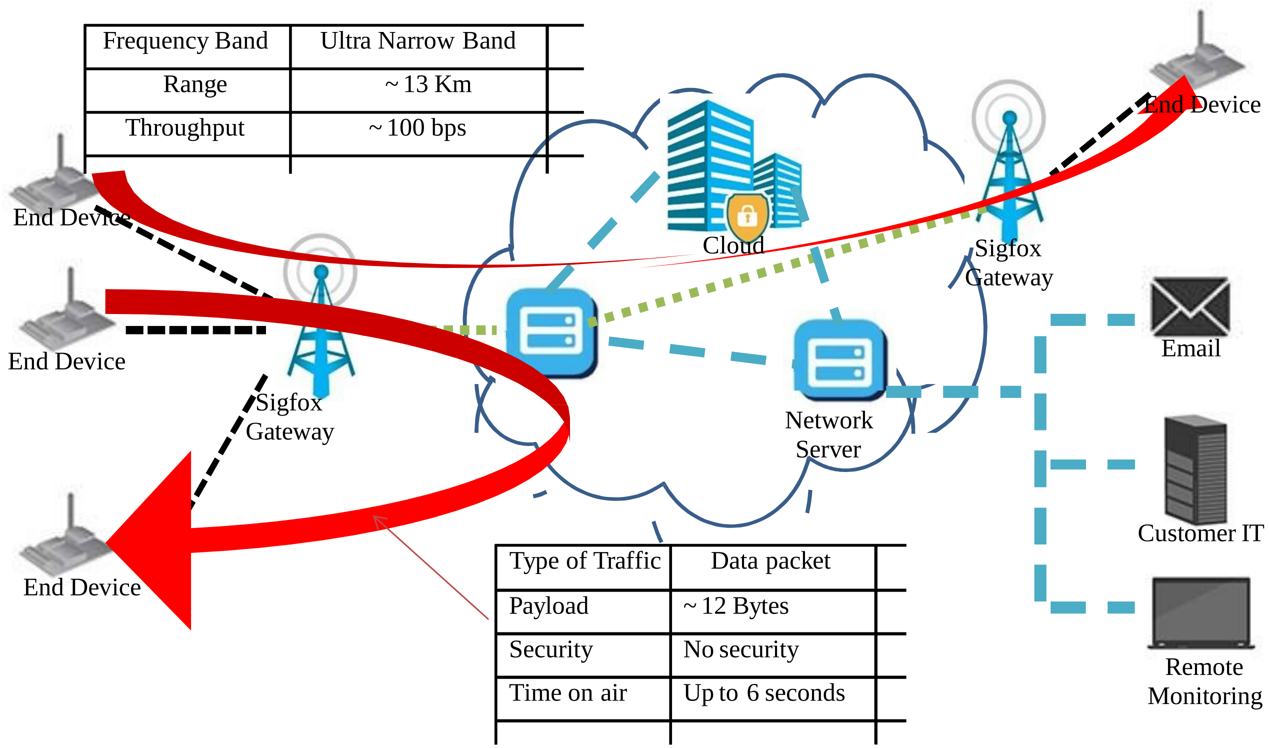
SigFox

- Low Power Wide Area Sensor Network (LPWASN)
- Thousands of millions ☺
  - A million per access point ;)
- Proprietary ☹ comercial
  - You have to use its access infrastructure (built with operators) and software
  - Open market for the endpoints
- 30-50km range in rural areas, and 3-10km range in urban
- Ultra narrow band, 868 (EU) or 902 (US) frequency (MHz)
- Low energy consumption
- Dedicated network

SigFox

- Each device can send up to 140 messages per day
  - Payload: 12 octets (~96 bytes)
  - Datarate: up to 100bps
- (**Duty cycle:** the time occupied by the operation of a device, which operates intermittently)
  - Common in the IoT
- Sigfox exploits this:
  - When a device has a message to be sent, the Sigfox interface wakes up, and the message is transmitted uplink
  - Then, the device listens for a short duration, if there is data to be sent to it
  - This is good for data acquisition scenarios
  - But not so good for command-and-control situations
- Use cases:
  - Smart meters, smoke detectors

Sigfox - Architecture



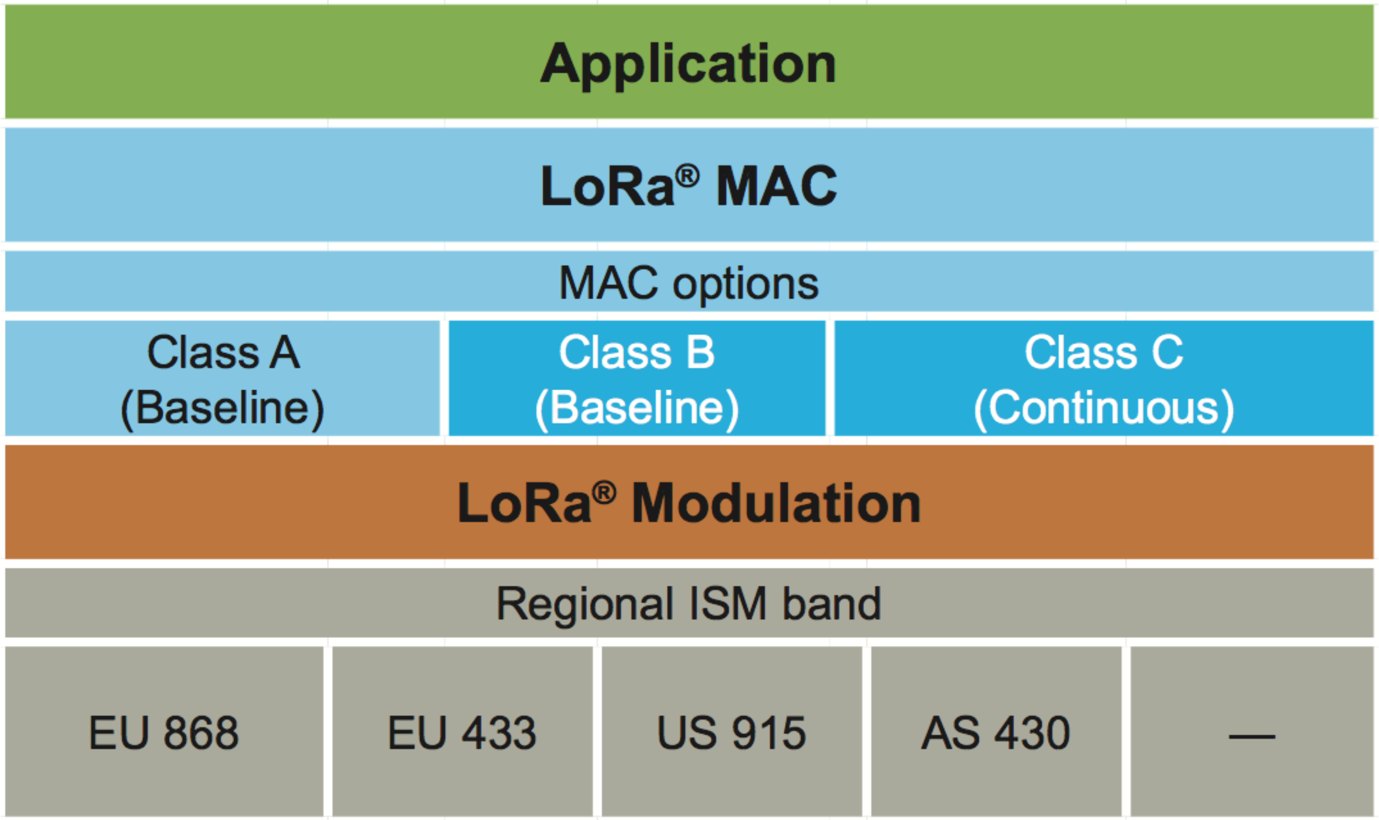
Frequency Band	Ultra Narrow Band
Range	~ 13 Km
Throughput	~ 100 bps

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

LoRa

- Stands for “Long Range”
- To be used in long-lived battery-powered devices scenarios
- Semi-proprietary
  - Parts of the protocol are well documented, others not
  - They own the radio part (but sub-licensing is on the way)
  - You can install your own gateways
- LoRa usually means two different things:
  - LoRa: a physical layer that uses Chirp Spread Spectrum (CSS) modulation
  - LoRaWAN: a MAC layer protocol

LoRa Stack



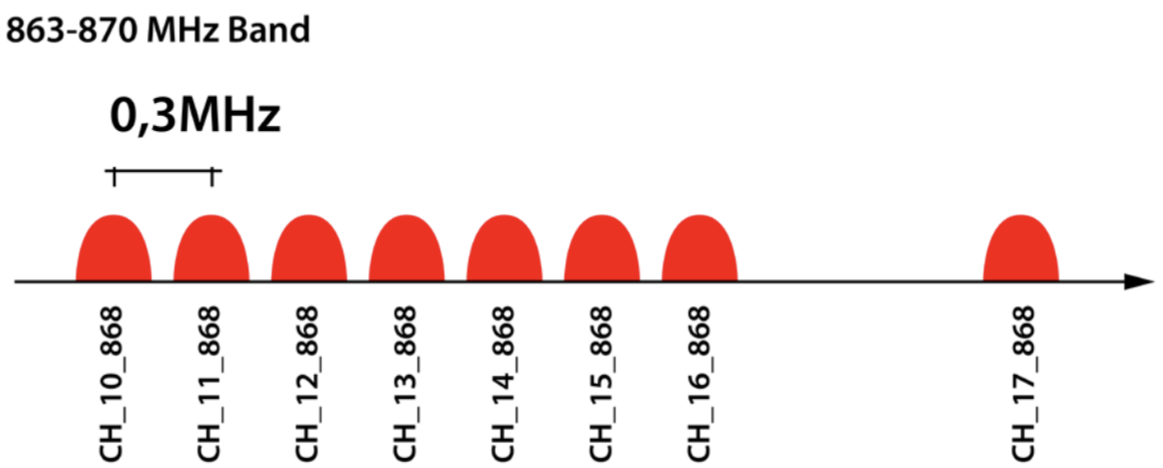
Application
LoRa® MAC
MAC options
Class A (Baseline)
Class B (Baseline)
Class C (Continuous)
LoRa® Modulation
Regional ISM band
EU 868
EU 433
US 915
AS 430
—

LoRa (the physical layer ☺)

- Developed by Semtech
- Low-range, low-power and low-throughput
- Operates on 433-, 868- (EU) or 915 (US) MHz bands
- Payload from 2 to 255 octets (2Kb)
  - Depends on configuration parameters
- Datarate: up to 50Kbps

LoRa (the physical layer ☺)

- In Europe, 8 channels with a bandwidth of 0.3MHz are used



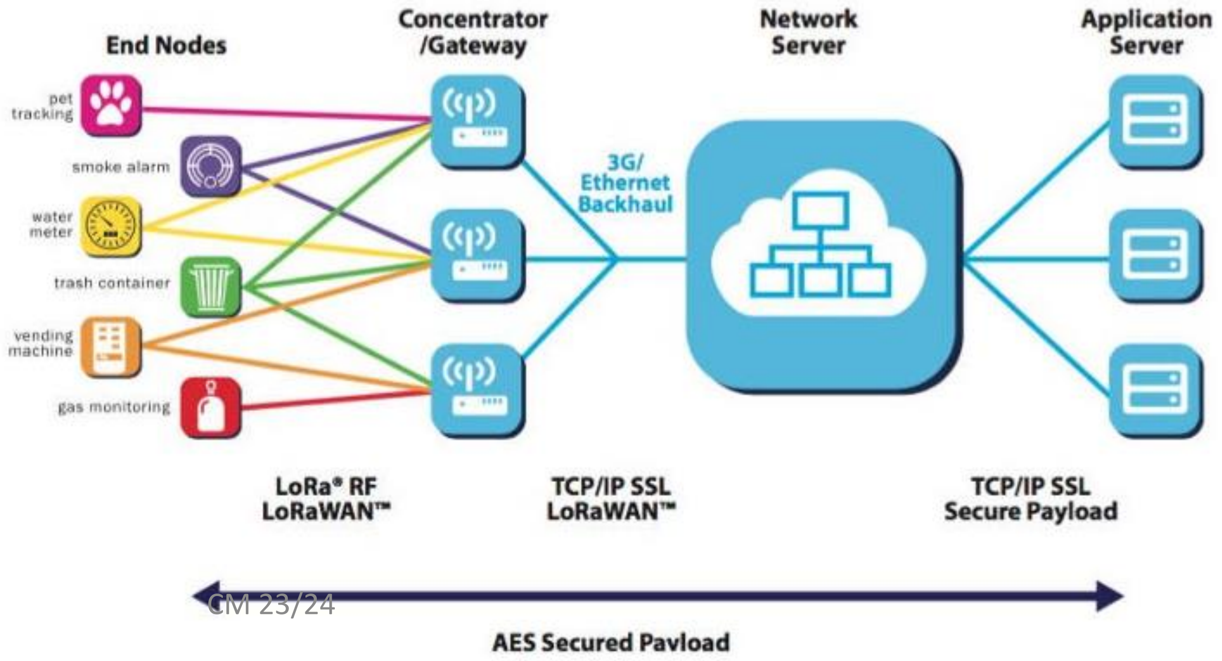
Source: Libelium

LoRaWAN

- MAC mechanism for controlling communications between end devices and LoRaWAN gateways. For all devices, it manages:
  - Communication frequencies
  - Data rate
  - Power
- Open Standard developed by the LoRa Alliance

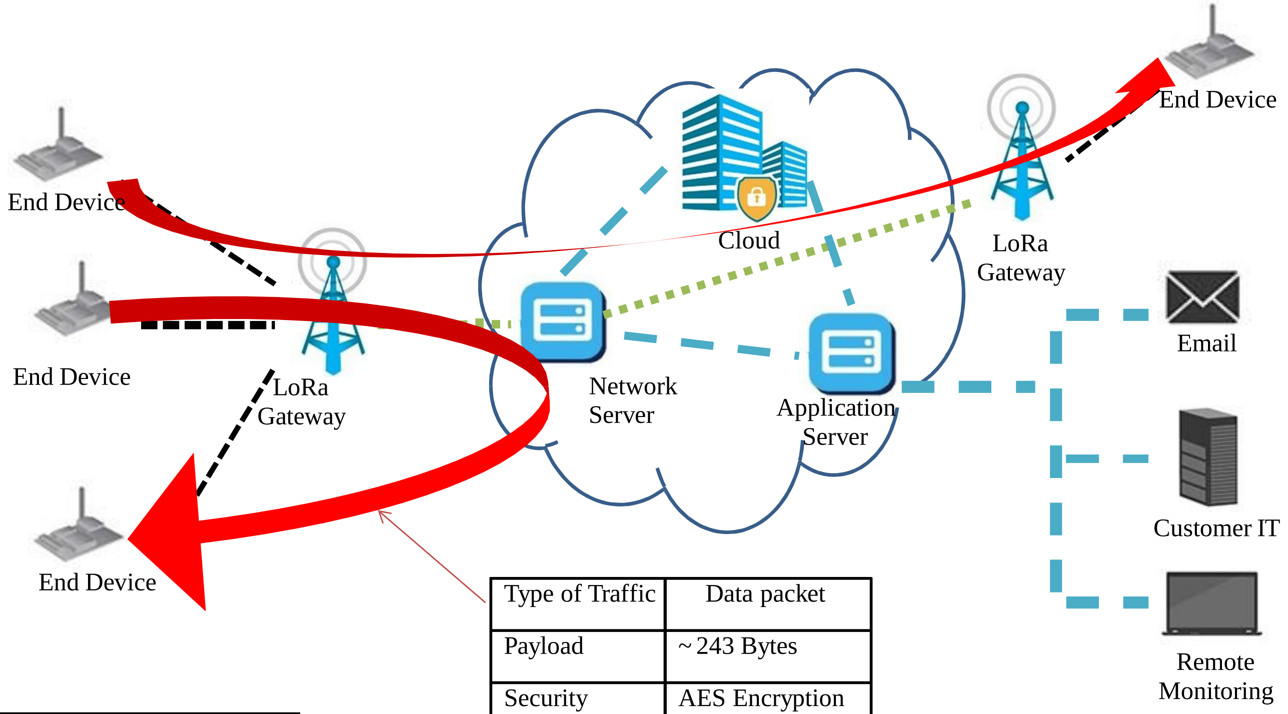
LoRA Network

- Star of stars topology
- Devices transmit data asynchronously
  - Data is received by multiple gateways
  - Each gateway forwards received data to a centralized network server, using a backhaul link (Ethernet or cellular)
  - The network server:
    - Filters duplicate packets
      - Packet with the strongest signal gets decoded
    - Realizes security checks
    - Manages the network



Source: semtech.com

LORA - Architecture



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

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

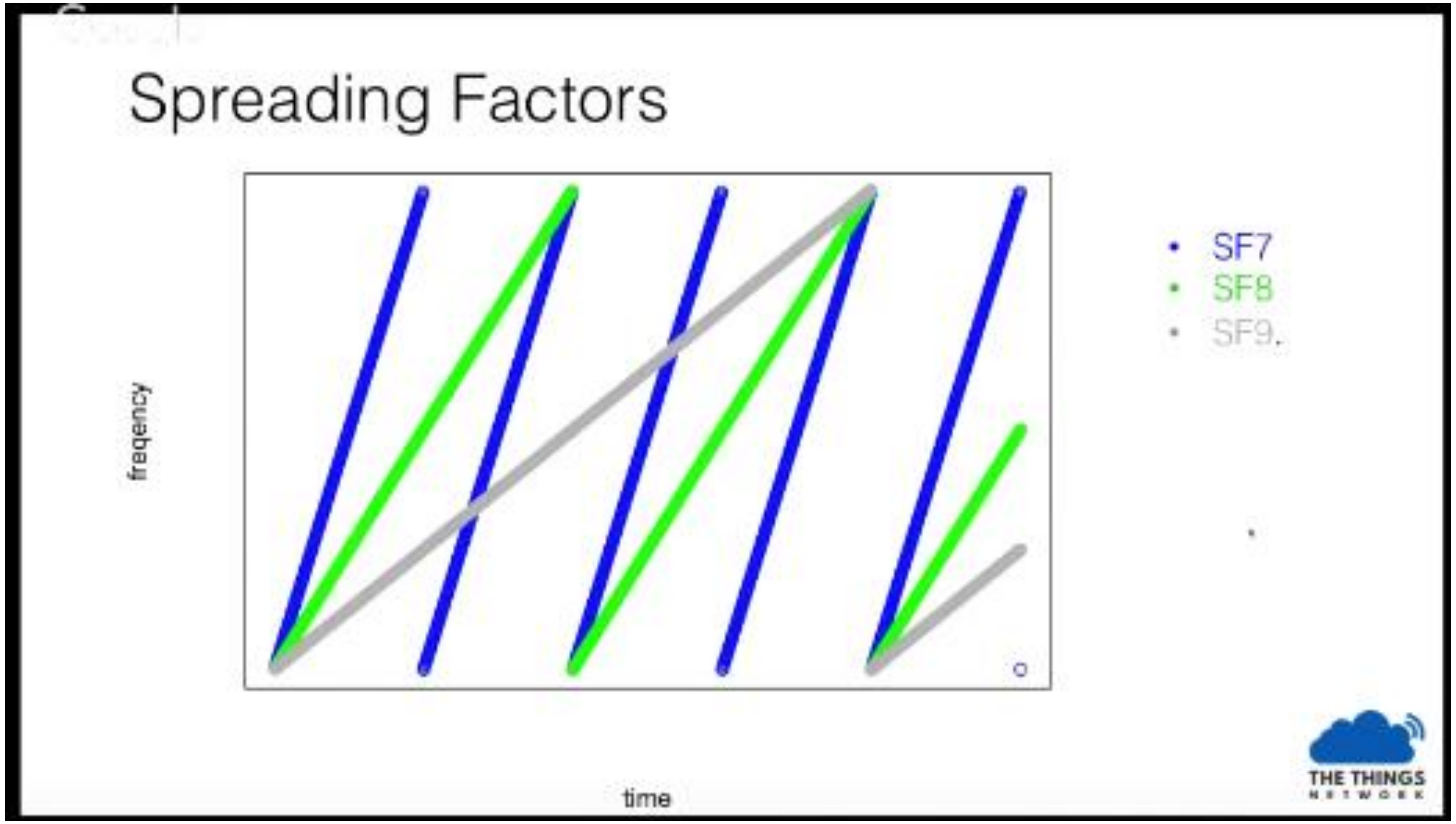
LoRa Physical Layer

- Modulation
  - (changing a signal, the carrier, in a way that allows it to contain information to be transmitted)
- LoRa uses a proprietary Spread-Spectrum modulation technique: Chirp Spread Spectrum (CSS)
    - (A chirp is a signal in which frequency raises or lowers with time)
  - Tries to increase range by:
    - Sending information with more power (within regulated values - <14dBm or 25mW)
    - Or by lowering the data rate
  - Increases link budget
  - Increases immunity to in-band interference
- This, along with Forward Error Correction techniques, contribute to extend the range and robustness of radio communication links
  - Compared to FSK

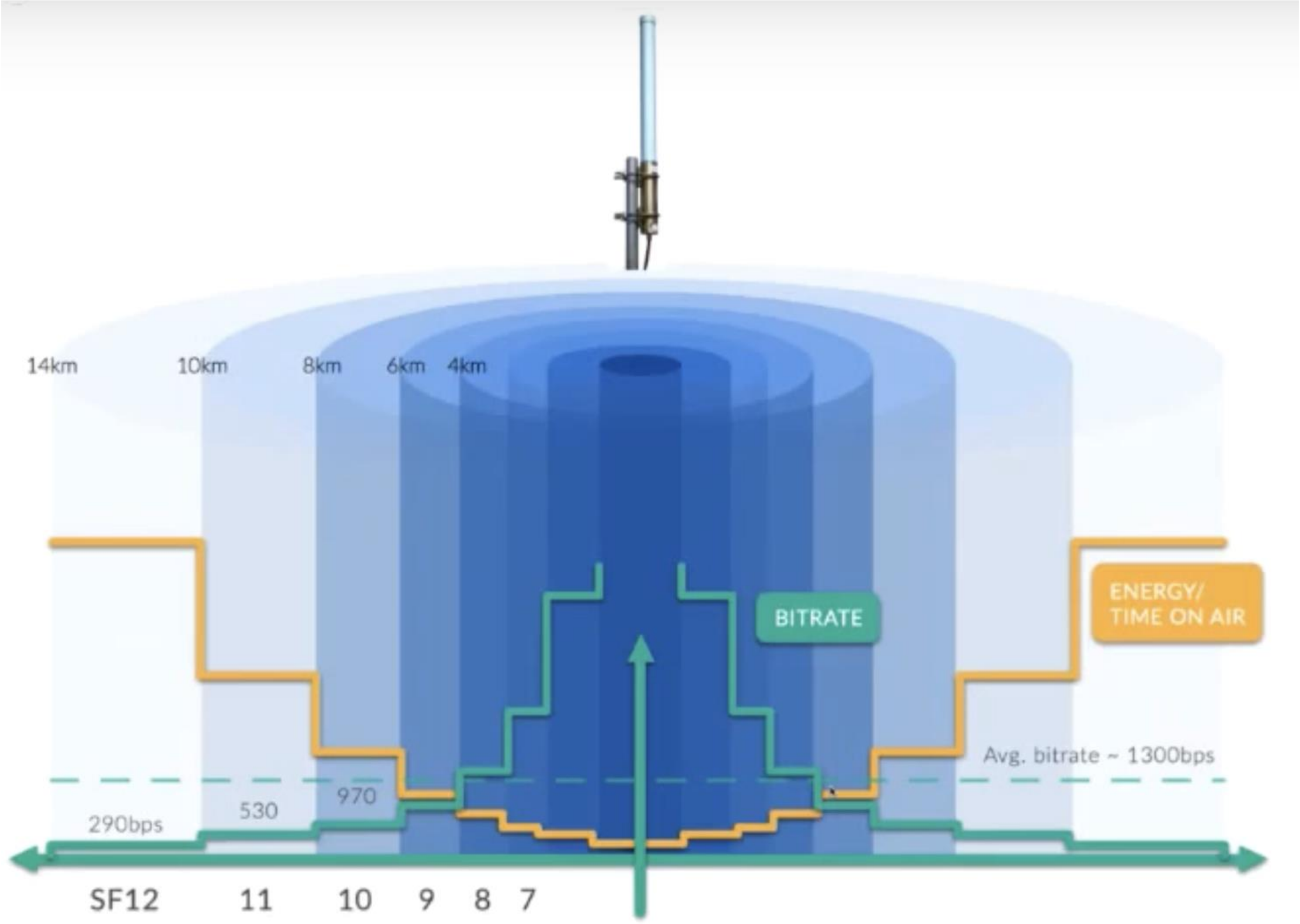
LoRa Physical Layer

- Has different Spread Factors (SF7 to SF12)
  - Spread factors can set the modulation rate and tune the distance
  - They indicate how fast or slow is the chirp (how many chirps you get per second) → **how much data you can encode per second**
    - The higher the SF, the lower the datarate
    - Each SF is 2x slower than the one before
    - The slower you send your data, the farther you can send it
    - The higher the SF, the more energy is required (time on air)
      - The interface has more time to decode and sensititviy is increased
- This helps on scaling the network
  - Closer nodes receive data much faster
  - Air is ”cleared” for other nodes to transmit
  - By adding more gateways, devices get nearer to them, applying the above

LoRa Physical Layer



Source: Thomas Telkamp


14km
10km
8km
6km
4km
BITRATE
ENERGY/
TIME ON AIR
Avg. bitrate ~ 1300bps
970
530
290bps
SF12
11
10
9
8
7

LoRa Physical Layer

- For a 125kHz bw (configurable by design)

Spreading Factor	Symbols/second	SNR limit	Time-on-air (10 byte packet) - ms	Bitrate - bps
7	976	-7.5	56	5469
8	488	-10	103	3125
9	244	-12.5	205	1758
10	122	-15	371	977
11	61	-17.5	741	537
12	30	-20	1483	293

LoRa Physical Layer

- The Bandwidth (kHz), Spreading Factor and Coding Rate are design variables that allow a system to optimize the trade-off between
  - Occupied bandwidth
  - Data rate
  - Link budget
  - Interference immunity
- By using software, it is possible to combine these values to define a transmission mode

LoRa Physical Layer

- Bandwidth
  - Show how wide is going to be the transmission signal
  - 3 options: 125 kHz, 250 kHz or 500 kHz
  - Greater reach: 125 kHz
  - Greater transmission speed: 500 kHz
  - Less bandwidth = more airtime = more sensitivity = more battery consumed

LoRa Physical Layer

- Coding Rate
  - 4 options: 4/5, 4/6, 4/7 and 4/8
  - Meaning:
    - Every 4 useful bytes are going to be encoded by 5, 6, 7 or 8 transmission bits
  - Smaller coding rate: 4/8
  - Lower coding rate = more airtime

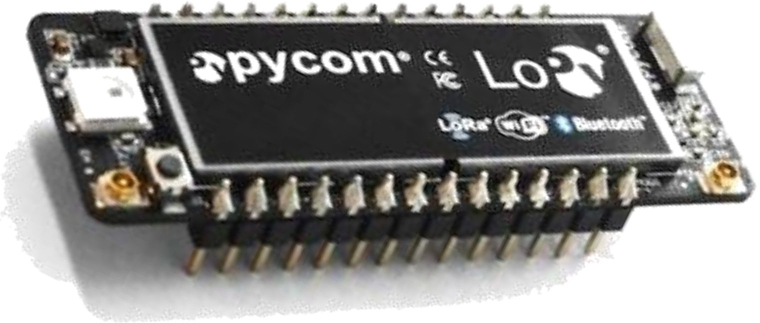
LoRa Physical Layer

- Spreading Factor
  - Number of chips per symbol used in data treatment before the transmission signal
  - 7 options: 6, 7, 8, 9, 10, 11 and 12
  - Greater Spreading Factor = Greater Range = more air time

LoRa Physical Layer

Mode	BW	CR	SF	Sensitivity (dB)	Transmission time (ms) for a 100-byte packet sent	Transmission time (ms) for a 100-byte packet sent and ACK received	Comments
1	125	4/5	12	-134	4245	5781	max range, slow data rate
2	250	4/5	12	-131	2193	3287	-
3	125	4/5	10	-129	1208	2120	-
4	500	4/5	12	-128	1167	2040	-
5	250	4/5	10	-126	674	1457	-
6	500	4/5	11	-125,5	715	1499	-
7	250	4/5	9	-123	428	1145	-
8	500	4/5	9	-120	284	970	-
9	500	4/5	8	-117	220	890	-
10	500	4/5	7	-114	186	848	min range, fast data rate, minimum battery impact

LoRa Physical Layer - Practical



- On the LoPy
  - Method
    - lora.init(mode, * , frequency=868000000, tx_power=14, **bandwidth=LoRa.BW_125KHZ**, **sf=7**, preamble=8, **coding_rate=LoRa.CODING_4_5**, power_mode=LoRa.ALWAYS_ON, tx_iq=False, rx_iq=False, adr=False, public=True, tx_retries=1, device_class=LoRa.CLASS_A)
- Bandwidth: **LoRa.BW_125KHZ / LoRa.BW_250KHZ / LoRa.BW_500KHZ**
- SF: **sf=6 / sf=7 / sf=8 / sf=9 / sf=10 / sf=11 / sf=12**
- Coding Rate: **LoRa.CODING_4_5 / LoRa.CODING_4_6 / LoRa.CODING_4_7 / LoRa.CODING_4_8**

LoRaWAN

- Components
  - End-Device
    - Devices (low-power) that communicate with the LoRa Gateway
    - They are not associated to a particular gateway.
    - They are, however, associated to a Network Server.
  - Gateway
    - Intermediate devices that relay packets between end-devices and a network server.
    - Linked to the Network server via a higher bandwidth backhaul network.
    - They add information about the quality of reception, when forwarding a packet from an end-device to a network server.
    - They are transparent to the end-devices.
    - There are multiple gateways in a network
    - Multiple gateways can receive the same packet transmitted from the same end-device
  - Network Server
    - Decodes and de-duplicates packets sent from devices.
    - Generates packets to be sent towards devices
    - Choses the appropriate gateway to send packets to a specific end-device

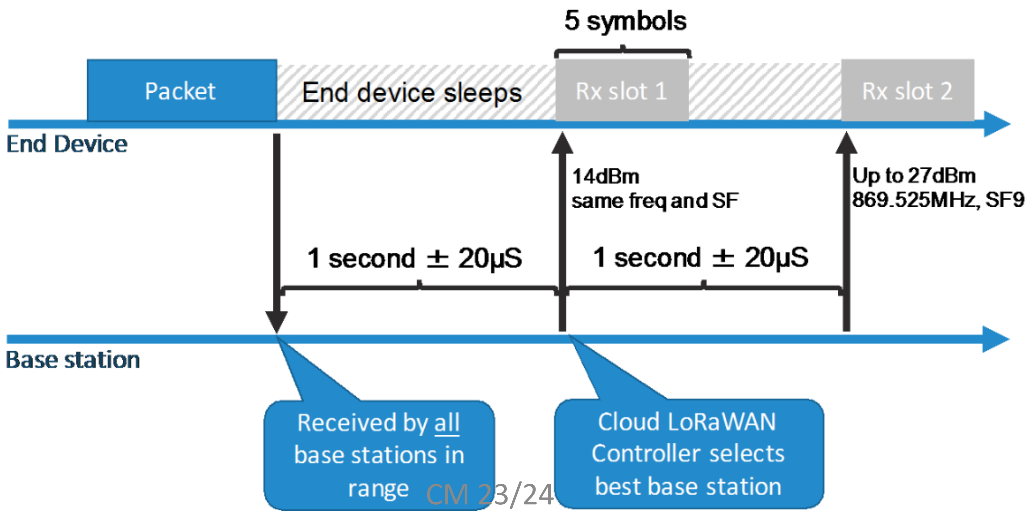
LORA – Device Classes

Classes	Description	Intended Use	Consumption	Examples of Services
A (« all »)	Listens only after end device transmission	Modules with no latency constraint	The most economic communication Class energetically.. Supported by all modules. Adapted to battery powered modules	• 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

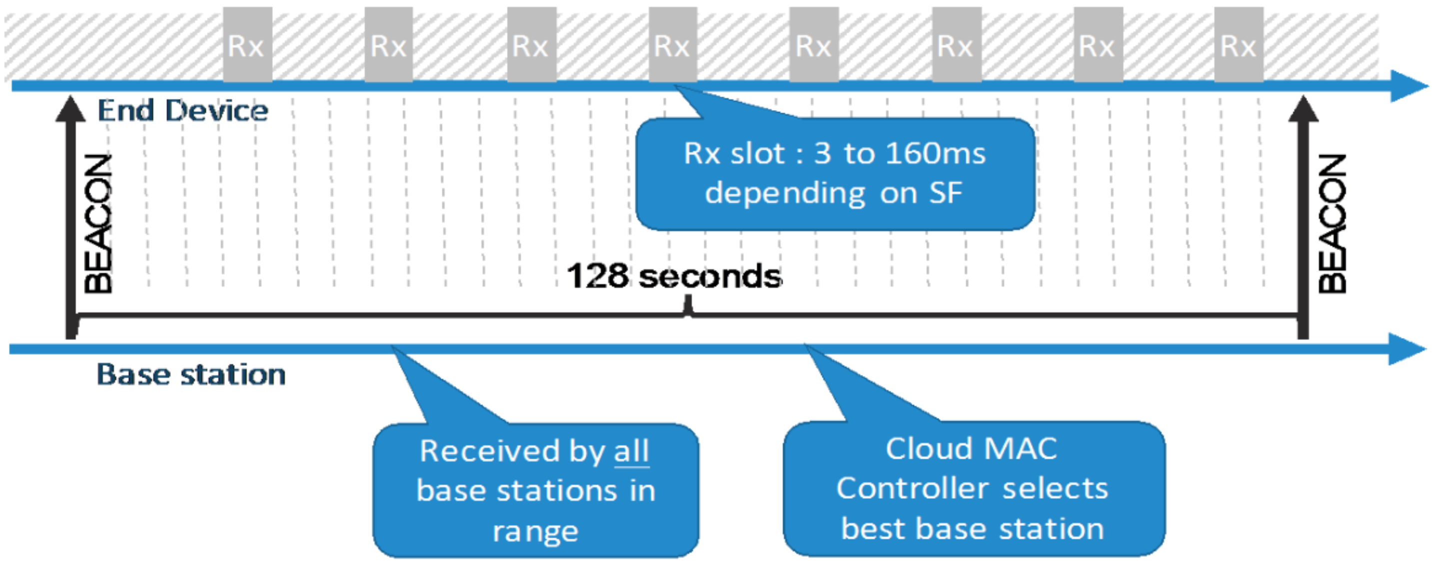
LoRaWAN

- End-devices classes
  - Class A – bi-directional
    - Lowest power consumption
    - Devices schedule uplink transmissions according to their requirements, with a small variation before transmission.
    - Each uplink transmission is followed by two short downlink receive windows
      - Downlink transmissions at any other time have to wait until the next uplink transmission
      - Less flexibility for downlink



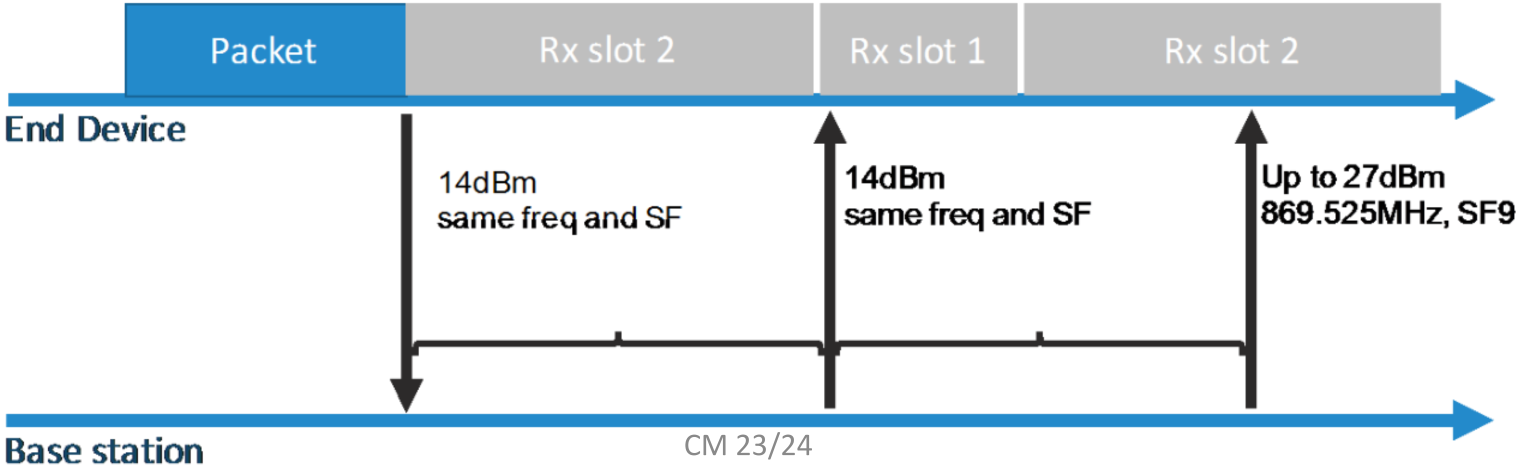
LoRaWAN

- End-devices classes
  - Class B – bi-directional with scheduled receive slots
    - Devices open more receive windows at scheduled times
    - There is a synchronized beacon from the gateway to the network server, indicating when the device is listening



LoRaWAN

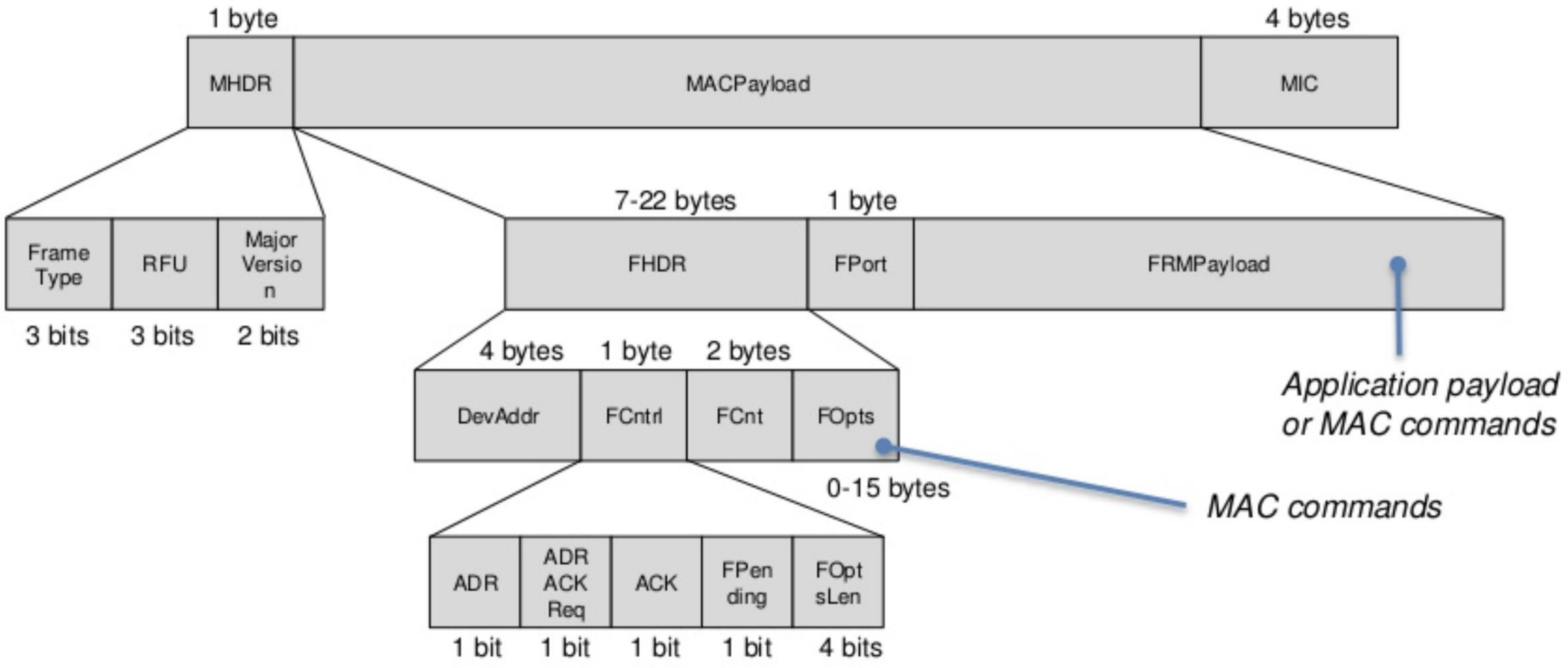
- End-devices classes
  - Class C – bi-directional with maximal receive slots
    - Greatest power consumption
    - Almost continuous receiving windows
      - Server can initiate transmission almost anytime



LoRaWAN

- End-Device Duty Cycle
  - Besides transmission frequency, duty cycle regulations apply
  - Delay between successive frames sent by a device
  - 1% limitation for end-devices
    - Device has to wait 100x the time it took for it to send the message, in order to be able to send again in the same channel
  - Gateways: 10%

LoRaWAN - Payload



Source: Stephen Pharrell

LoRaWAN

- *DevAddr* - short address of the device.
- *FPort* - multiplexing port field.
- *FCnt* - frame counter.
- *MIC* - cryptographic message integrity code
- *MType* - message type (uplink, downlink, confirmed (requires an ACK, …).
- *Major* - LoRaWAN version
- *ADR* and *ADRAckReq* - data rate control adaptation mechanism by the network server.
- *ACK* - acknowledges the last received frame.
- *Fpending* - indicates that there is still data to be sent by the network server (end-device is required to send another message to open a receive window).
- *FOptsLen* - length of the *FOpts* field in bytes.
- *FOpts* - contains MAC commands on a data message.
- *CID* - MAC command ID.
- *Args* -optional arguments of the command.
- *FRMPayload* - payload, encrypted using AES with a key length of 128 bits.

The minimal size of the MAC header is 13 bytes; its maximal size is 28 bytes.

There is no destination address on uplink packets, or source address on downlink packets.

LoRaWAN

- MAC Commands
  - Allows the network to customize end-device parameters
- Checks
  - Link status (this can be send by the end-device itself)
  - Device battery
  - Device margin (SNR)
- Settings
  - Datarate
  - TX power
  - TX and RX channels
  - RX timing
  - Repetition
  - Duty cycle
  - Dwell time

LoRaWAN

- End-Device Connection to a network
  - Also known as ***Activation***
- This process provides the end-device with:
  - End-device address (*DevAddr*): An identifier composed by the network identifier (7bit) and by the end-device's network address (25bit)
  - App identifier *(AppEUI):* Unique identification of the end-device owner
  - Network Session Key (*NwkSKey*): A key used by both the network server and end-device to verify and ensure message integrity
  - App Session Key (*AppSKey*): A key used by both the network server and end-device to encrypt the payload of received messages
- Note on security:
  - LoRaWAN protocol security is based on 802.15.4
    - AES-128

LoRaWAN

- To activate the device, there are two procedures:
  - Over-the-Air Activation (OTAA)
    - *Join-Request* and *Join-Response* messages are exchanged in each new session, allowing the end-devices to obtain the network and application session keys
  - Activation By Personalization (ABP)
    - The devices have both keys already stored internally

LoRaWAN

- Adaptive Data Rate
  - The network tells the node at which data rate it can send data
    - Manages the SF for each end-device
  - The aim is to:
    - Optimize for fastest data rate versus range
    - Maximize battery life
    - Maximize network capacity

LoRaWAN

- Typically, there is no node-to-node direct communication
  - LoRaWAN allows this by having 2 gateways and a network server in between the nodes
- However, most end-device vendors also include (for testing, mostly) a raw form of LoRa
  - Allows peer-to-peer communication between nodes
  - Contains only the link layer protocol
  - Only allows a very small number of nodes in a topology
    - There is no packet management

  (useful for a first try with LoRa)