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Wide Area Wireless Sensor Networks

WWSN

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What is this?

- WWSN – wide area wireless sensor networks
- LPWSN – low power wireless sensor networks
- Technologies for sensor networks in wide areas
  - either for low power, or for geography
  - Typically: Sigfox, LoRa, cellular (LTE-M, NB-IoT)

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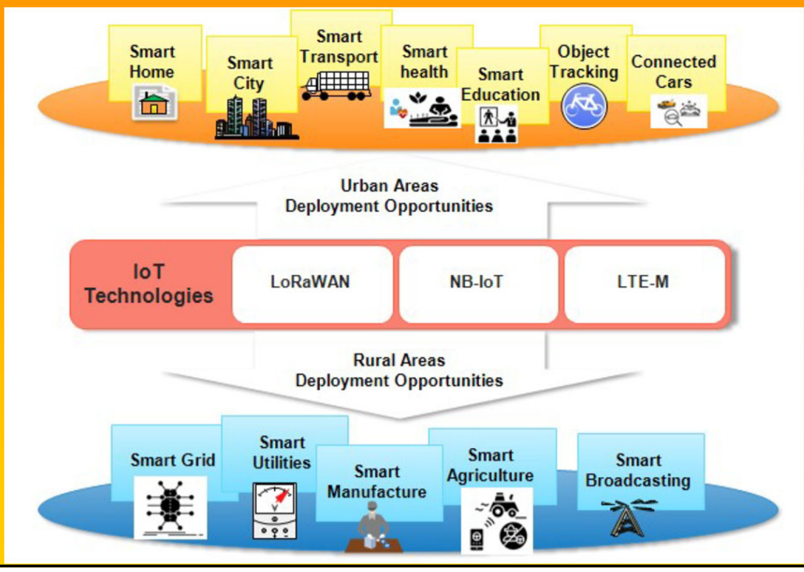
LPWSN



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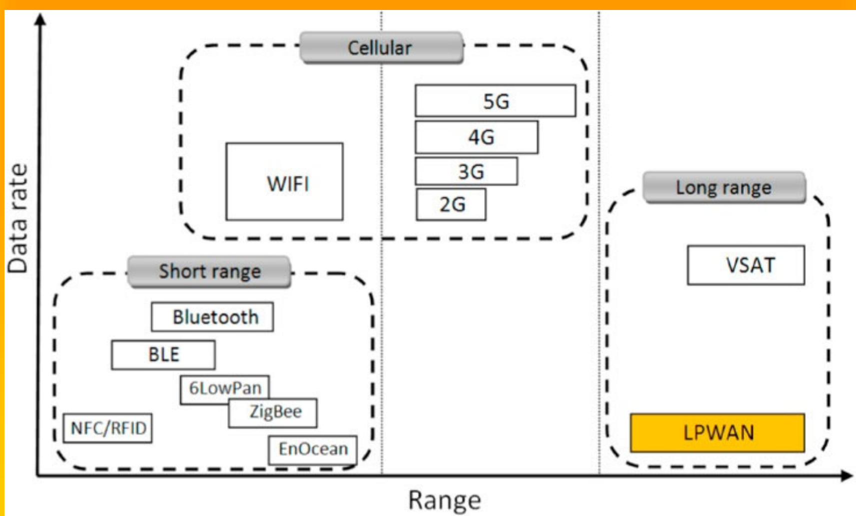
Technology review



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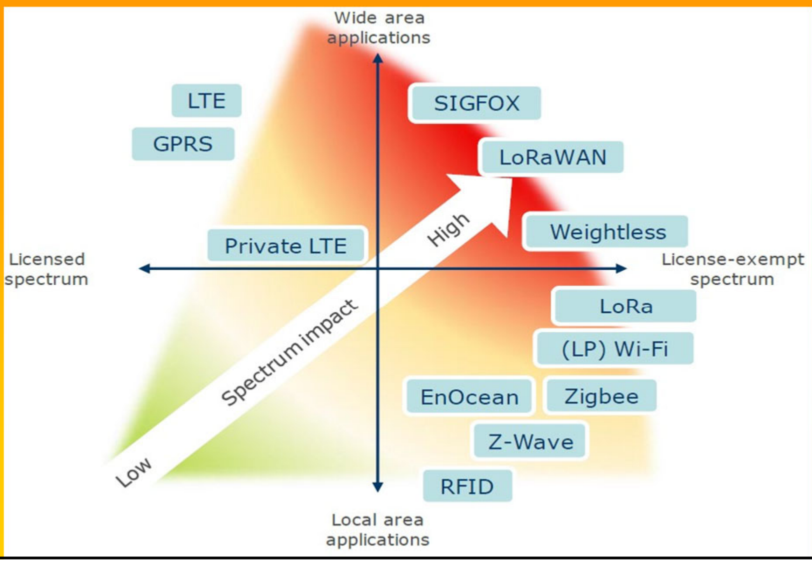
Licensed vs licensed-exempt



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Overview of LPWAN

Overview of LPWAN technologies: Sigfox, LoRa, and NB-IoT.

	Sigfox	LoRaWAN	NB-IoT
Modulation	BPSK	CSS	QPSK
Frequency	Unlicensed ISM bands (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia)	Unlicensed ISM bands (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia)	Licensed LTE frequency bands
Bandwidth	100 Hz	250 kHz and 125 kHz	200 kHz
Maximum data rate	100 bps	50 kbps	200 kbps
Bidirectional	Limited / Half-duplex	Yes / Half-duplex	Yes / Half-duplex
Maximum messages/day	140 (UL), 4 (DL)	Unlimited	Unlimited
Maximum payload length	12 bytes (UL), 8 bytes (DL)	243 bytes	1600 bytes
Range	10 km (urban), 40 km (rural)	5 km (urban), 20 km (rural)	1 km (urban), 10 km (rural)
Interference immunity	Very high	Very high	Low
Authentication & encryption	Not supported	Yes (AES 128b)	Yes (LTE encryption)
Adaptive data rate	No	Yes	No
Handover	End-devices do not join a single base station	End-devices do not join a single base station	End-devices join a single base station
Localization	Yes (RSSI)	Yes (TDOA)	No (under specification)
Allow private network	No	Yes	No
Standardization	Sigfox company is collaborating with ETSI on the standardization of Sigfox-based network	LoRa-Alliance	3GPP

	Spectrum cost	Deployment cost	End-device cost
Sigfox	Free	>4000€/base station	<2€
LoRa	Free	>100€/gateway >1000€/base station	3–5€
NB-IoT	>500 M€ /MHz	>15 000€/base station	>20€

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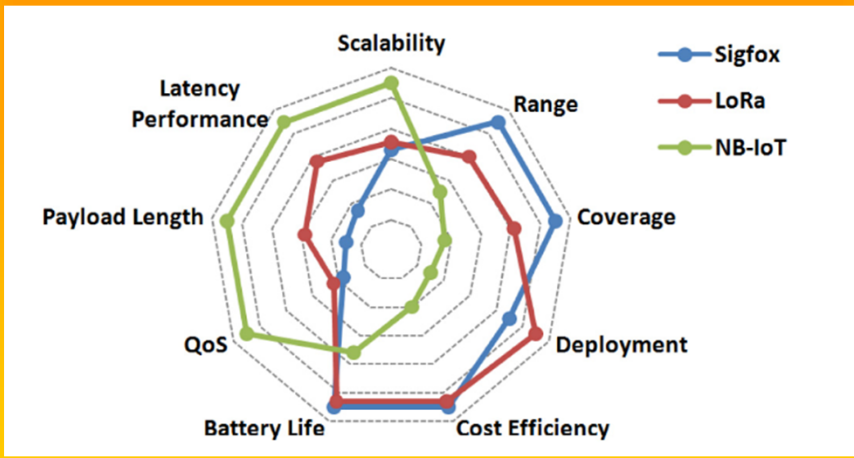
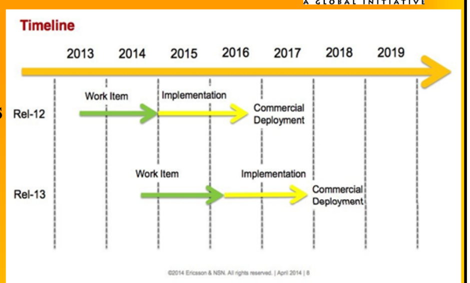
Comparison Radar



LTE-M - Overview

- Evolution of LTE optimized for IoT
- Low power consumption and autonomous
- Easy Deployment
- Interoperability with existing LTE networks
- Coverage up to 11 Km
- Max Throughput ≤ 1 Mbps



- ✓ First released in Rel.12 in 2 Q4 2014
- ✓ Optimization in Rel.13
- ✓ Specifications completed in Q1 2016
- ✓ Available since 2017

Evolution from LTE to LTE-M

3GPP Releases	8 (Cat.4)	8 (Cat. 1)	12 (Cat.0) LTE-M	13 (Cat. 1,4 MHz) LTE-M
Downlink peak rate (Mbps)	150	10	1	1
Uplink peak rate (Mbps)	50	5	1	1
Number of antennas (MIMO)	2	2	1	1
Duplex Mode	Full	Full	Half	Half
UE receive bandwidth (MHz)	20	20	20	1.4
UE Transmit power (dBm)	23	23	23	20

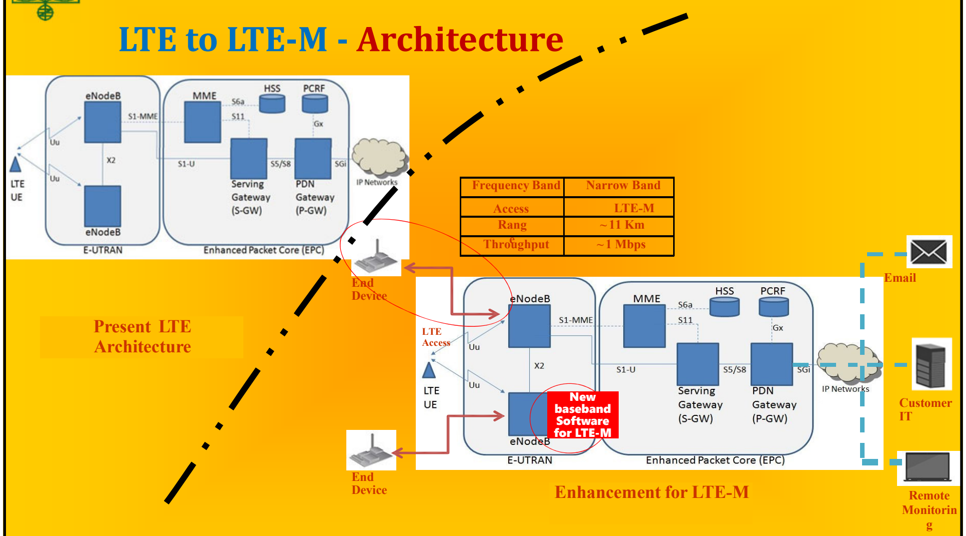
Release 12

- New category of UE ("Cat-0"): lower complexity and low cost devices
- Half duplex FDD operation allowed
- Single receiver
- Lower data rate requirement (Max: 1 Mbps)

Release 13

- Reduced receive bandwidth to 1.4 MHz
- Lower device power class of 20 dBm
- 15dB additional link budget: better coverage
- More energy efficient because of its extended discontinuous repetition cycle (eDRX)

LTE to LTE-M - Architecture



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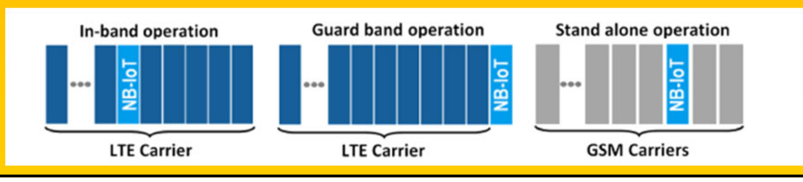
NB-IoT

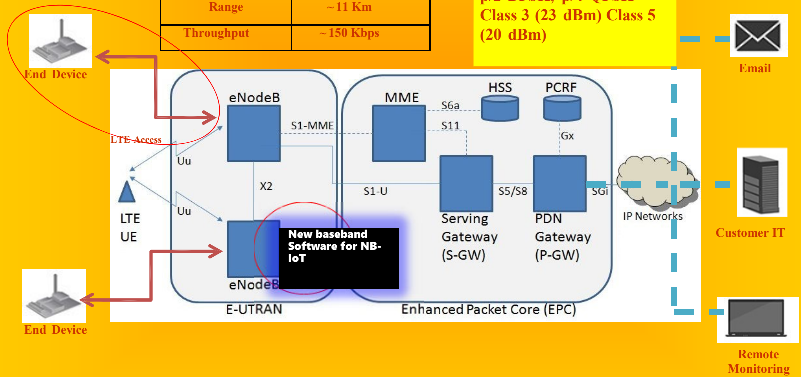
- Defined in R13, another mode instead of LTE-M
- Bandwidth – 200KHz
  - One resource block in GSM/LTE
- Based in LTE protocol, stripped down
  - OFDMA(down)/FDMA(up), QPSK
  - 200kbps (down)/20kbps(up)
- Three modes of operation



NB-IoT - Architecture

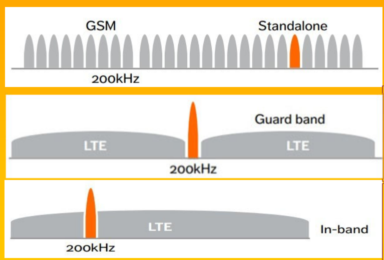
Frequency Band	Ultra Narrow Band
Range	~11 Km
Throughput	~150 Kbps

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

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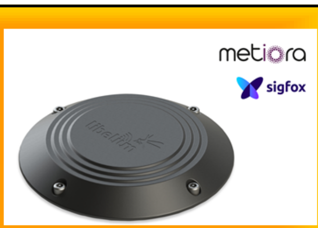
NB-IoT (@2019)

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..**

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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

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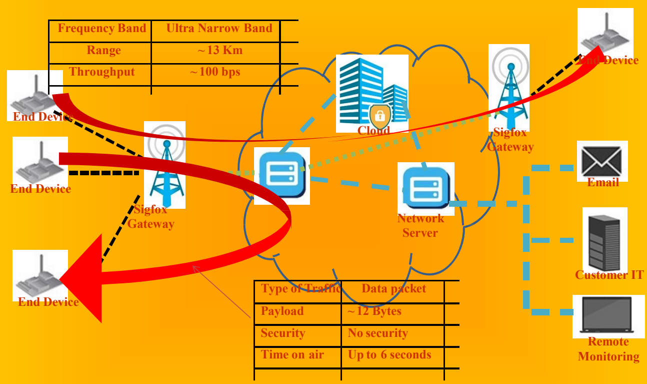
SigFox

- 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

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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

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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	—

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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**

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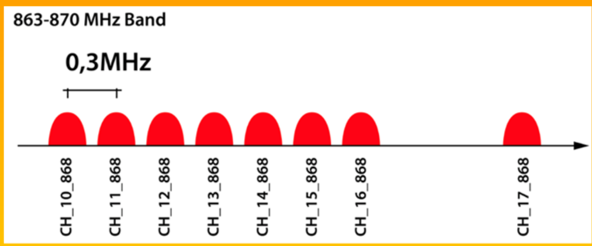
LoRa (the physical layer ☺)

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



Source: Libelium

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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

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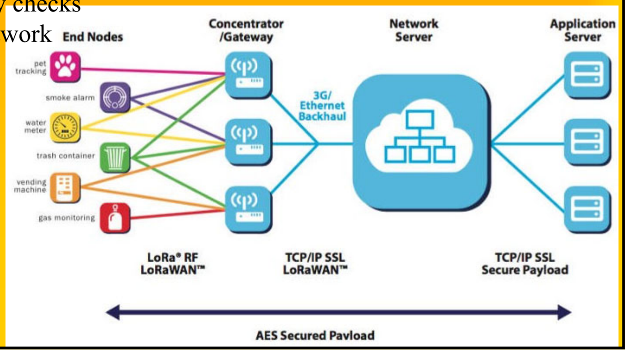
LoRA Network

- 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

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LoRA Network

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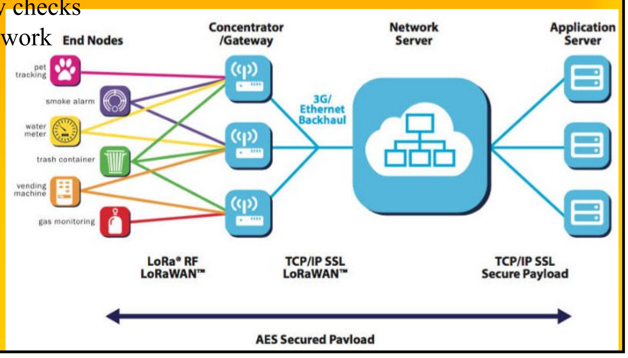
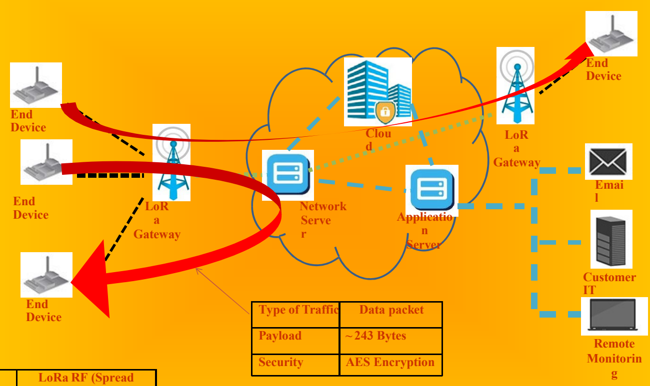


Source: semtech.com

LORA - Architecture



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

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

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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**

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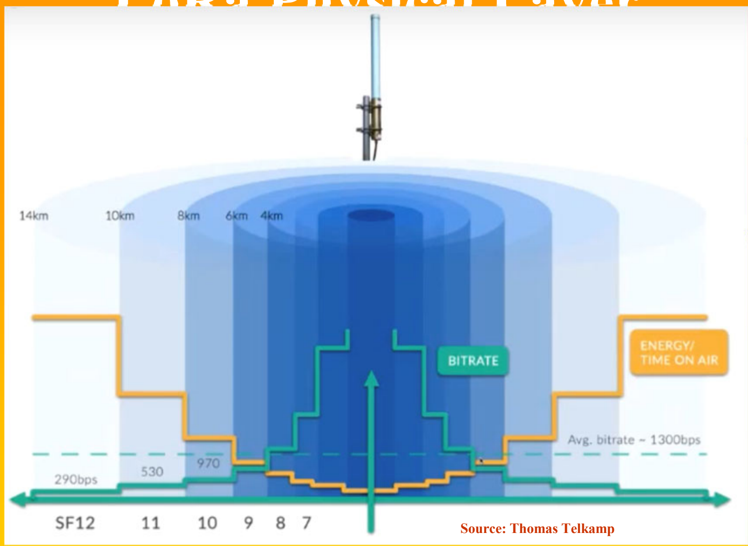
LoRa Physical Layer



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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

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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

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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

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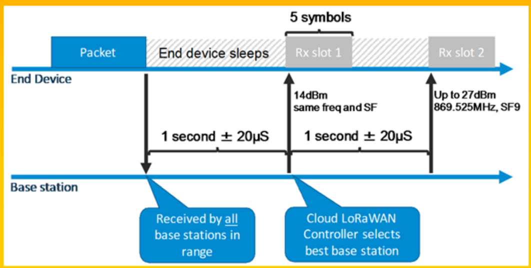
LoRaWAN

- **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



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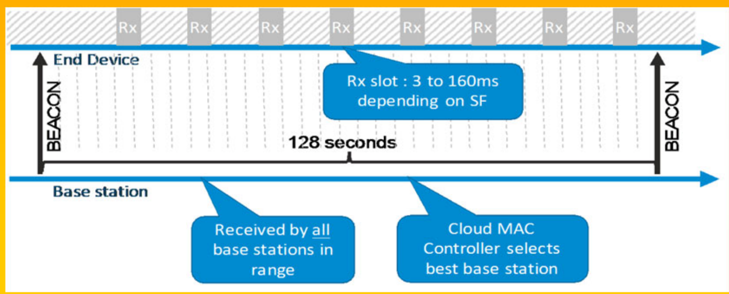
LoRaWAN

- **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



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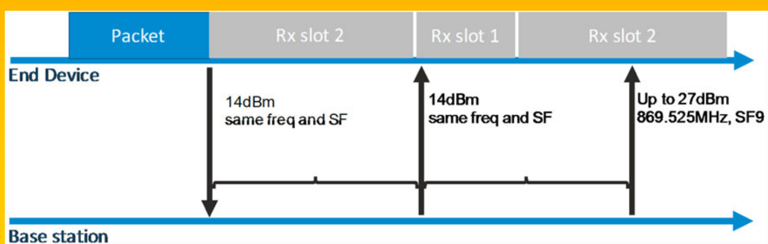
LoRaWAN

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



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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%**

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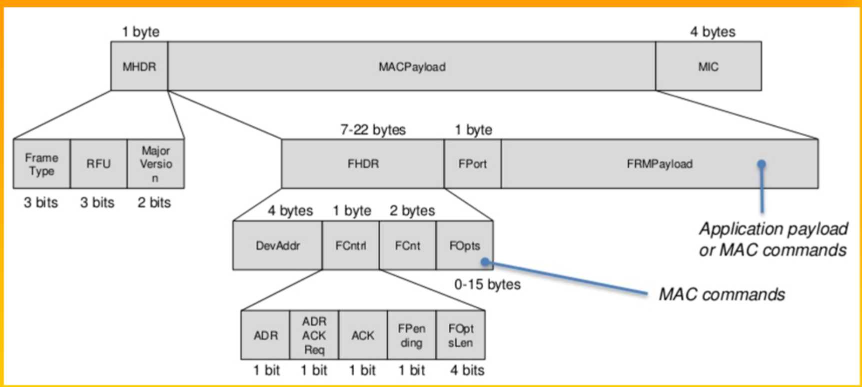
LoRaWAN - Payload



Source: Stephen Pharrell

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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.

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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

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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

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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

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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

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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)

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LoRaWAN vs NB-IoT

Table 5. NB-IoT vs. LoRaWAN average power consumption, latency, and throughput.

Features	NB-IoT	LoRaWAN
Joining network	3 mAh	1 mAh
Uplink message (44 bytes)	1.8 mAh	100 µAh
UE class	Cat NB1	A
Data rate (20 bytes)	0.6–4 bps	
Frequency	28 Mhz	EU868 MHz

The Things Network

- **Built in a crowdsourced manner by companies and enthusiasts**
  - Low density coverage, mostly in larger cities (3 GW in Aveiro)
  - 1-2Km range in cities, 10km in open space
- **Provides a Free connectivity service, and broker with APIs**
- **Composed by:**
  - Nodes: owned by companies and citizens, send data to Gateways
  - Gateways: owned by companies and citizens, interface with TTN
  - TTN Servers: Hosted by TTN, routing data to/from user apps