

Introduction to LoRaWAN and LPWAN

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ICTP

IoT specific case

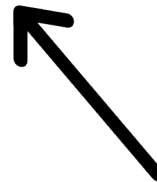
IoT nodes can accept:

Low throughput, for many applications

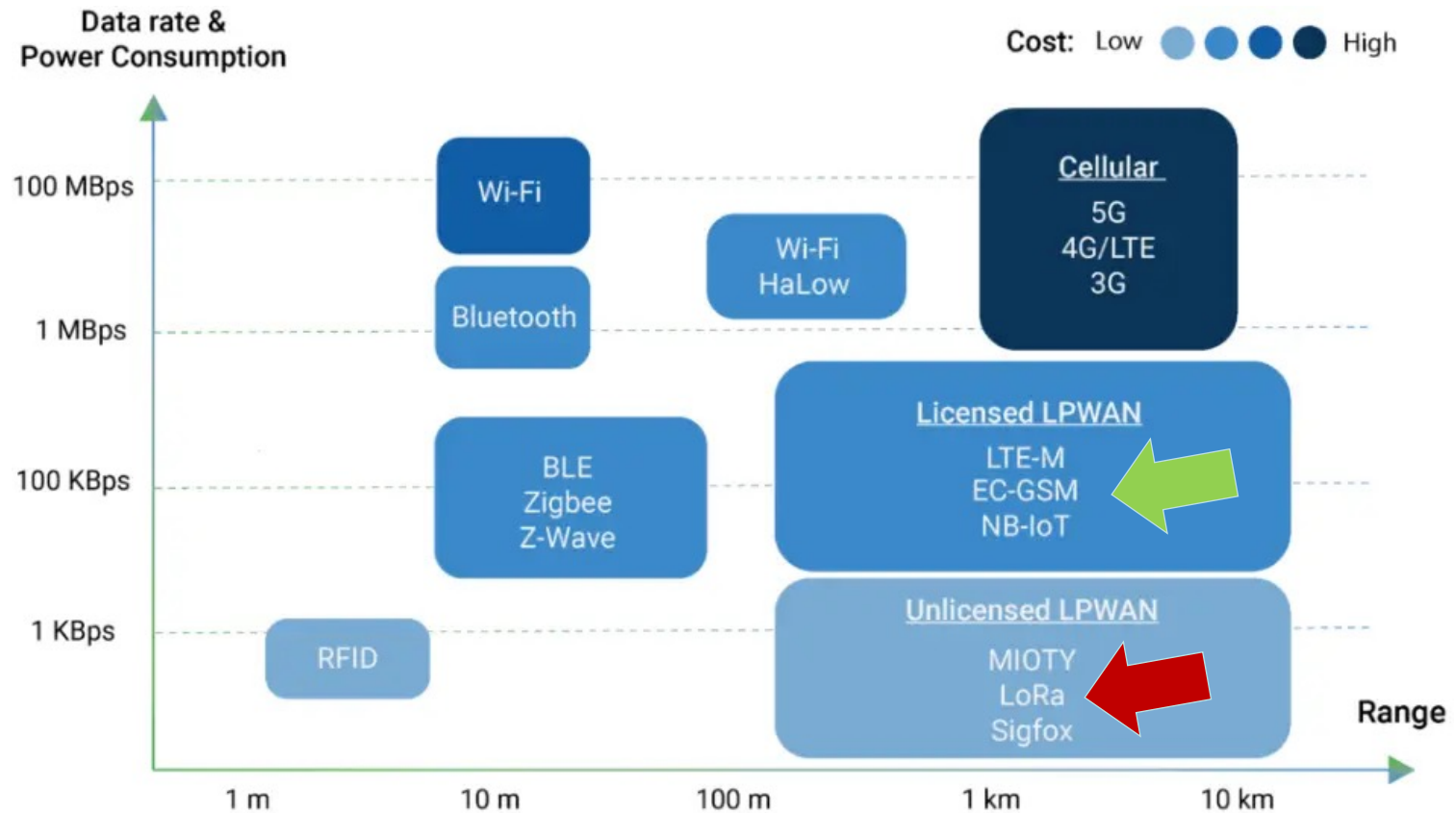
Delays

Long Sleeping times

Which ones don't?



LPWAN: range vs power



<https://www.mokolara.com/lora-and-wireless-technologies/>

Something about wireless...



[illegible]

ISM bands

Industrial, Scientific and Medical Radio Bands

ISM Band Frequencies	
	6.765 - 6.795 MHz
	13.553 - 13.567 MHz
	26.957 - 27.283 MHz
	40.66 - 40.70 MHz
	83.996 - 84.004 MHz
	167.992 - 168.008 MHz
→	433.05 - 434.79 MHz
→	886 - 906 MHz
→	2.400 - 2.500 MHz
	5.725 - 5.875 MHz
	24.0 - 24.25 GHz
	61.0 - 61.5 GHz
	122 - 123 GHz
	244 - 246 GHz

$f(\text{space, time})$



Line of sight (LOS) and free space loss

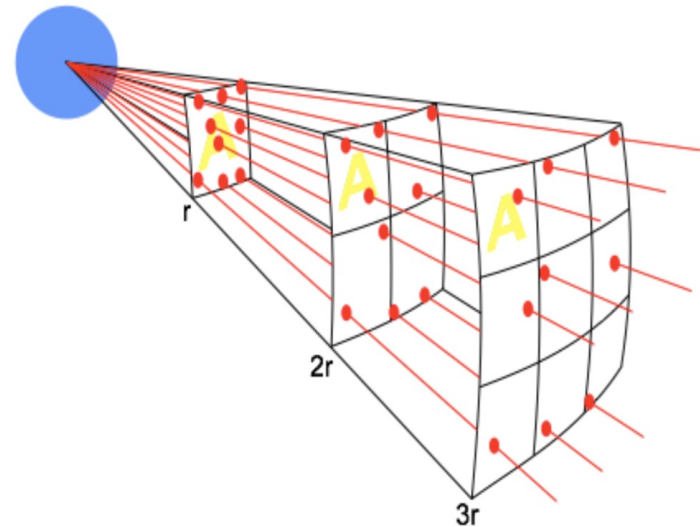
- Signal power is diminished by geometric spreading of the wavefront, commonly known as **Free Space Loss**.
- The power of the signal is spread over a wave front, the area of which increases as the distance from the transmitter increases. Therefore, the power density diminishes.
- **Friis free space equation:**

$$\begin{aligned} \text{FSPL} &= \left(\frac{4\pi d}{\lambda} \right)^2 \\ &= \left(\frac{4\pi d f}{c} \right)^2 \end{aligned}$$



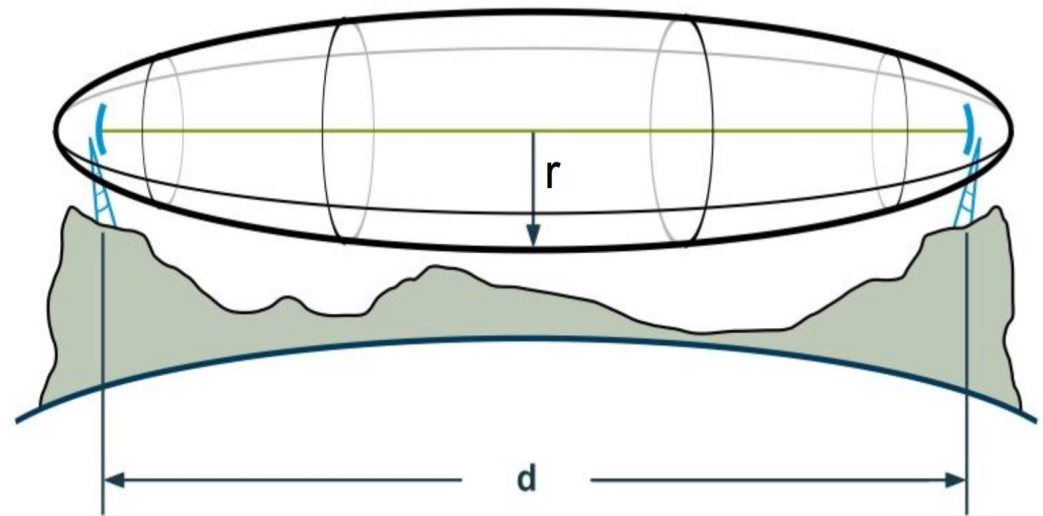
$$L_{fs} = 32,45 + 20 \cdot \log(D) + 20 \cdot \log(f)$$

where L_{fs} is expressed in dB, D is in km and f is in MHz.



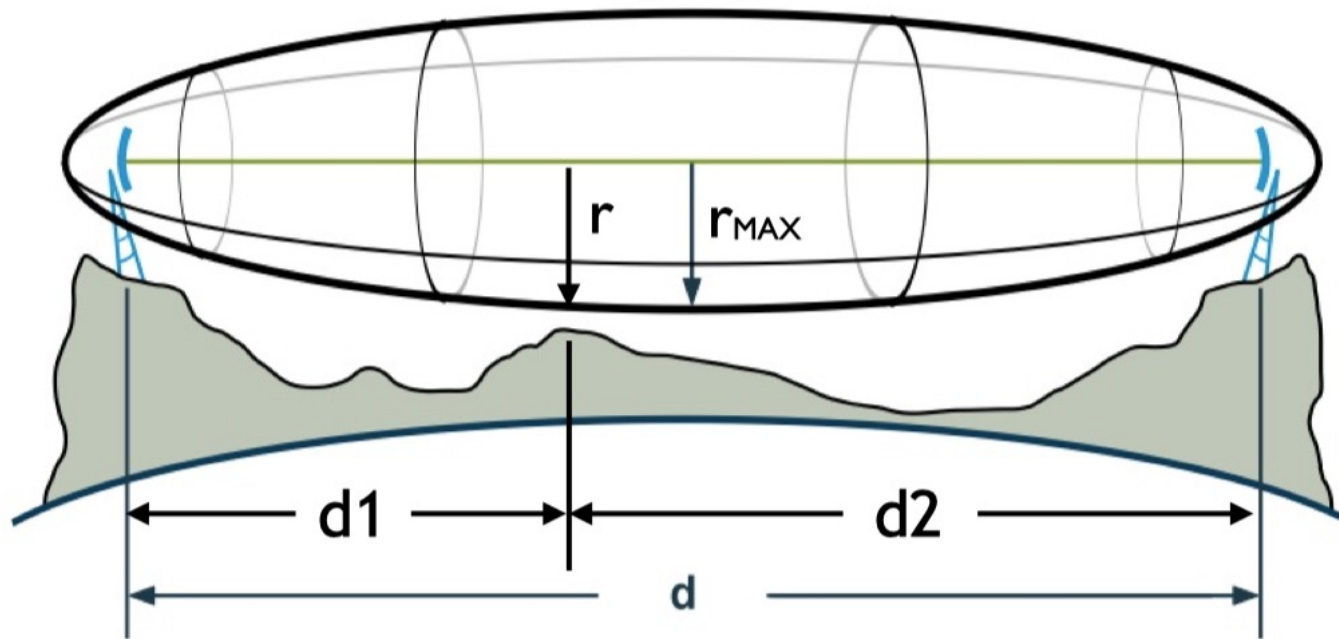
Earth is not flat...and Fresnel Zones

- The First Fresnel Zone is an ellipsoid-shaped volume around the Line-of-Sight path between transmitter and receiver.
- The Fresnel Zone is important to the integrity of the RF link because it defines a volume around the LOS that must be clear of any obstacle for the the maximum power to reach the receiving antenna.
- Objects in the Fresnel Zone as trees, hilltops and buildings can considerably attenuate the received signal, even when there is an unobstructed line between the TX and RX.



<http://www.heywhatsthat.com/profiler.html>

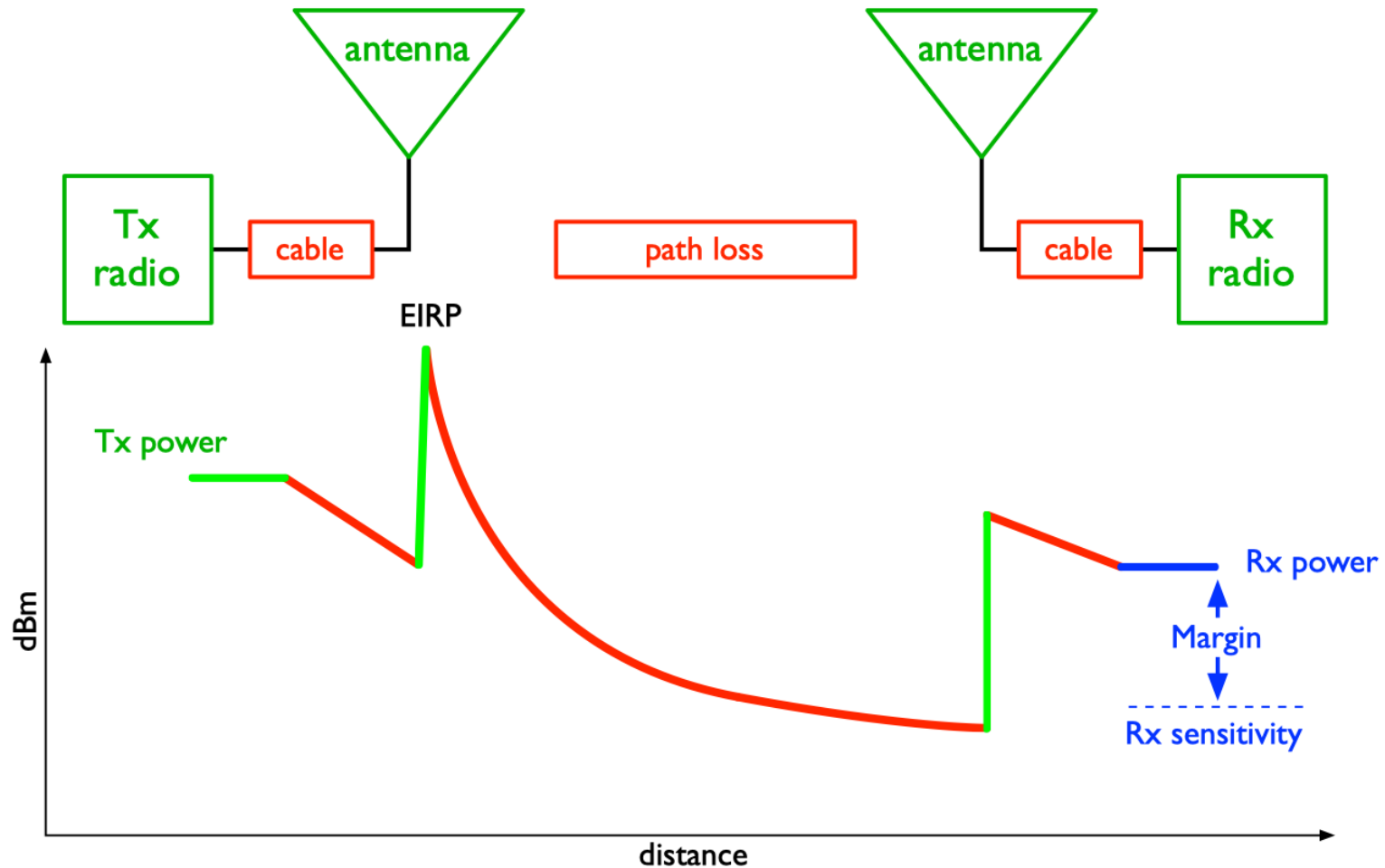
Line of Sight and Fresnel Zones



$$r = \sqrt{d_1 * d_2 * \lambda / d}$$

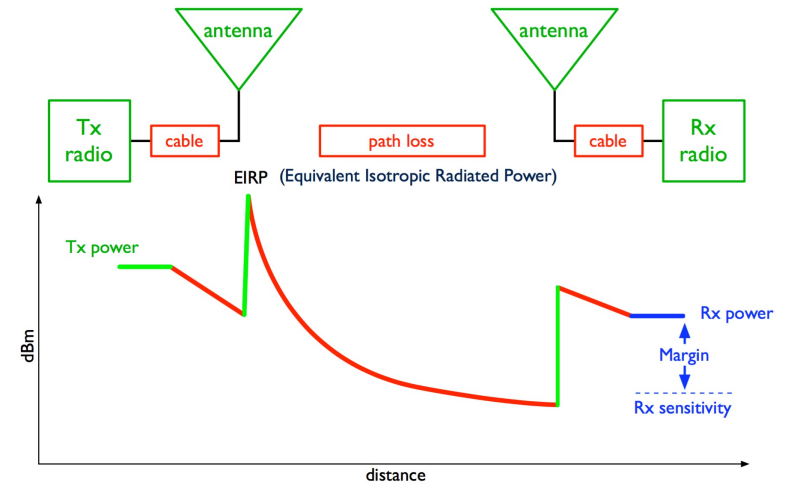
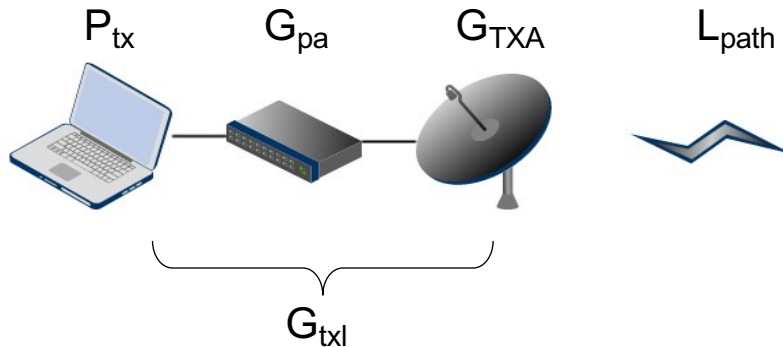
- The performance of any communication link depends on the quality of the equipment being used.
- **Link budget is a way of quantifying the link performance.**
- The received power is determined by three factors:
 - transmit power,
 - transmitting antenna gain, and
 - receiving antenna gain.
- **If that power, minus the free space loss of the link path, is greater than the minimum received signal level of the receiving radio, then a link is possible.**
- The difference between the minimum received signal level and the actual received power is called the link margin.
- The link margin must be positive and should be maximized

Power in a wireless system

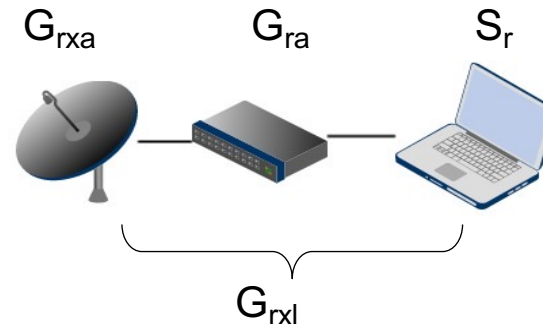


Power/Link Budget

- $P_{rx} = P_{tx} + G_{pa} - G_{txl} + G_{txa} - L_{path} + G_{rx a} + G_{ra} - G_{rxl}$
 - $P_{rx}[\text{dBm}]$ = Power received
 - $P_{tx}[\text{dBm}]$ = Power generated by TX
 - $G_{pa}[\text{dB}]$ = Gain of the Power Amplifier (PA)
 - $G_{txa}[\text{dBi}]$ = Gain of TX antenna
 - $G_{txl}[\text{dB}]$ = Gain (loss) of transmission line
 - $L_{path}[\text{dB}]$ = Loss of the transmission medium
 - $G_{rx a}[\text{dBi}]$ = Gain of RX antenna
 - $G_{ra}[\text{dB}]$ = Gain of the Receive Amplifier (RA)
 - $G_{rxl}[\text{dB}]$ = Gain (loss) of receiving line
 - $S_r[\text{dBm}]$ = Sensivity of receiver
- Must hold the condition $P_{rx} > S_r$



$$\text{EIRP (Effective Isotropically Radiated Power)} = P_{tx} + G_{pa} + G_{txa} - G_{txl}$$





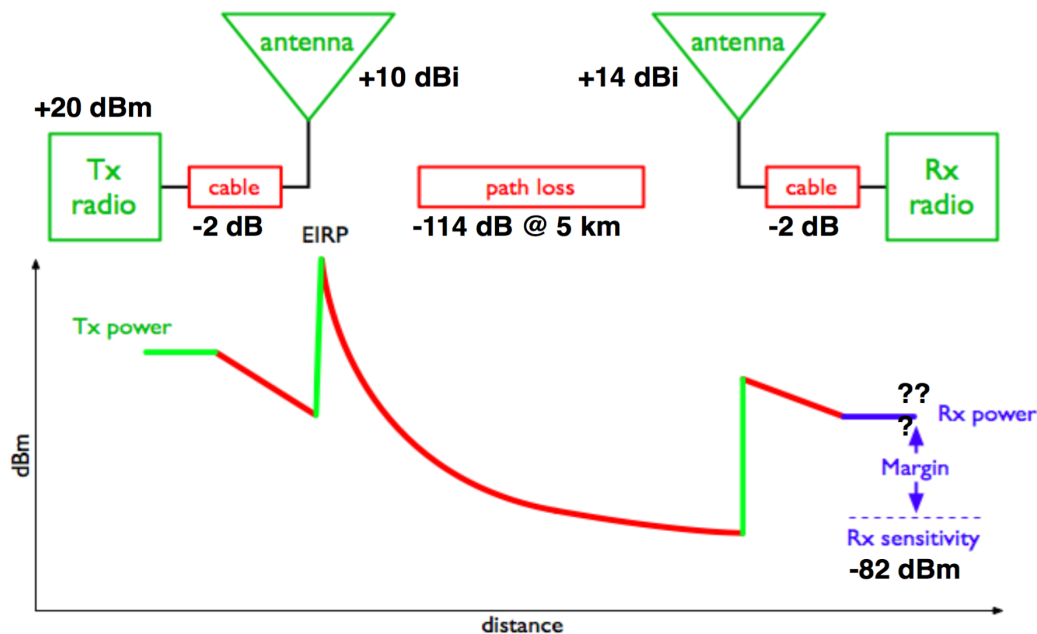
BULLET2 DATASHEET



SYSTEM INFORMATION			
Processor Specs		Atheros MIPS 4KC, 180MHz	
Memory Information		16MB SDRAM, 4MB Flash	
Networking Interface		1 X 10/100 BASE-TX (Cat. 5, RJ-45) Ethernet Interface	
REGULATORY / COMPLIANCE INFORMATION			
Wireless Approvals		FCC Part 15.247, IC RS210, CE	
RoHS Compliance		YES	
RADIO OPERATING FREQUENCY 2412-2462 MHz			
TX SPECIFICATIONS			
	DataRate	TX Power	Tolerance
802.11b	1Mbps	20 dBm	+/-1dB
	2Mbps	20 dBm	+/-1dB
	5.5Mbps	20 dBm	+/-1dB
	11Mbps	20 dBm	+/-1dB
802.11g OFDM	6Mbps	20 dBm	+/-1dB
	9Mbps	20 dBm	+/-1dB
	12Mbps	20 dBm	+/-1dB
	18Mbps	20 dBm	+/-1dB
	24Mbps	20 dBm	+/-1dB
	36Mbps	18 dBm	+/-1dB
	48Mbps	16 dBm	+/-1dB
	54Mbps	15 dBm	+/-1dB
RX SPECIFICATIONS			
	DataRate	Sensitivity	Tolerance
802.11b	1Mbps	-95 dBm	+/-1dB
	2Mbps	-94 dBm	+/-1dB
	5.5Mbps	-93 dBm	+/-1dB
	11Mbps	-90 dBm	+/-1dB
802.11g OFDM	6Mbps	-92 dBm	+/-1dB
	9Mbps	-91 dBm	+/-1dB
	12Mbps	-89 dBm	+/-1dB
	18Mbps	-88 dBm	+/-1dB
	24Mbps	-84 dBm	+/-1dB
	36Mbps	-81 dBm	+/-1dB
	48Mbps	-75 dBm	+/-1dB
	54Mbps	-72 dBm	+/-1dB

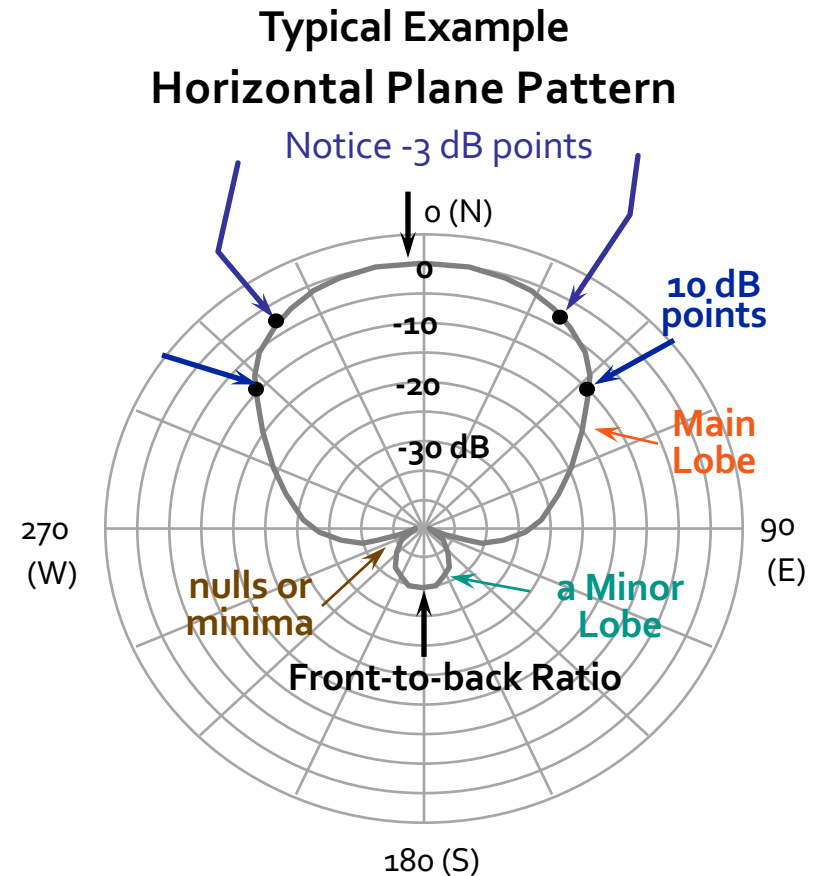
Example link budget calculation

- Let's estimate the feasibility of a 5 km link, with one access point and one client radio.
- The access point is connected to an antenna with 10 dBi gain, with a transmitting power of 20 dBm and a receive sensitivity of -89 dBm.
- The client is connected to an antenna with 14 dBi gain, with a transmitting power of 15 dBm and a receive sensitivity of -82 dBm.
- The cables in both systems are short, with a loss of 2dB at each side at the 2.4 GHz frequency of operation.



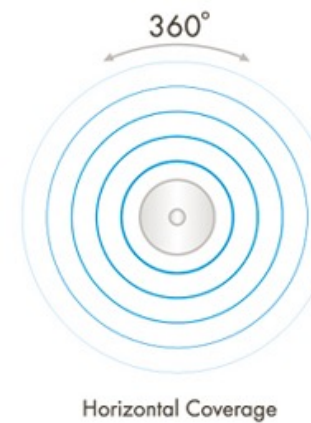
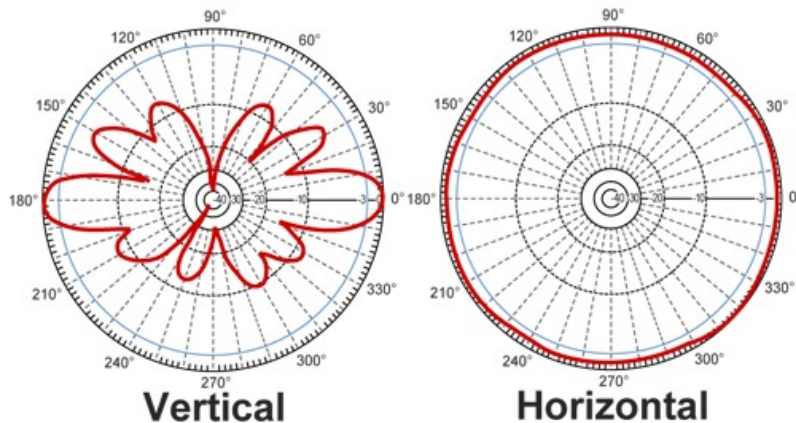
20 dBm	(TX Power AP)
+ 10 dBi	(Antenna Gain AP)
- 2 dB	(Cable Losses AP)
+ 14 dBi	(Antenna Gain client)
- 2 dB	(Cable Losses client)
40 dB	Total Gain
- 114 dB	(free space loss @5 km)
- 74 dBm	(expected received signal level)
- (- 82 dBm)	(sensitivity of Client)
8 dB	(link margin)

- An antenna's directivity is expressed as a series of patterns
- The **Horizontal Plane Pattern** graphs the radiation as a function of azimuth (i.e., direction N-E-S-W)
- The **Vertical Plane Pattern** graphs the radiation as a function of elevation (i.e., up, down, ...)



Omnidirectional Antenna

- The smallest, simplest, most practical type of antenna that can be made
 - But that also exhibits the least amount of gain
- Non-directional



Long reach antennas

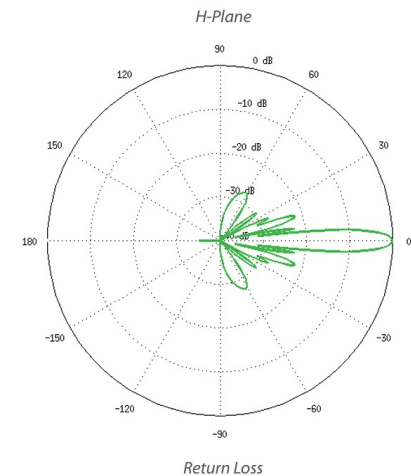
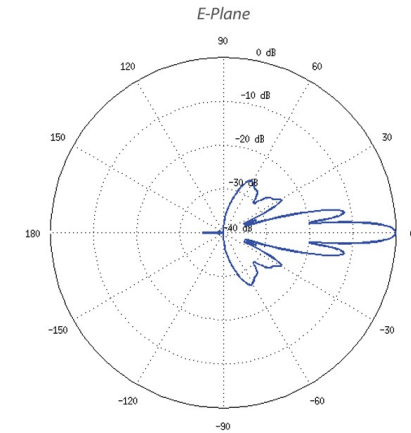
	PBE-M5-620	PBE-M5-400	PBE-M5-300	PBE-M2-400
Frequency Band	5 GHz	5 GHz	5 GHz	2.4 GHz
Antenna Gain	29 dBi	25 dBi	22 dBi	18 dBi
Dish Reflector	620 mm	400 mm	300 mm	400 mm
Throughput	150+ Mbps	150+ Mbps	150+ Mbps	150+ Mbps
Network Interface	10/100/1000	10/100/1000	10/100	10/100



PowerBeam^M 400 mm Radome

Model	PBE-M2-400	PBE-M5-400	PBE-M5-300
PBE-RAD-400	✓	✓	N/A

A protective radome is available as an optional accessory for the PBE-M2-400 and PBE-M5-400.



LPWAN

What is LoRa

Wireless modulation technology, based on Semtech's proprietary Chirp Spread Spectrum (CSS)

Physical (PHY) layer for long range wireless communications
Operates in the license-free Industrial Scientific Medical (ISM) bands all around the world

Based on spread spectrum, trading bandwidth for S/N.



What is LoRa

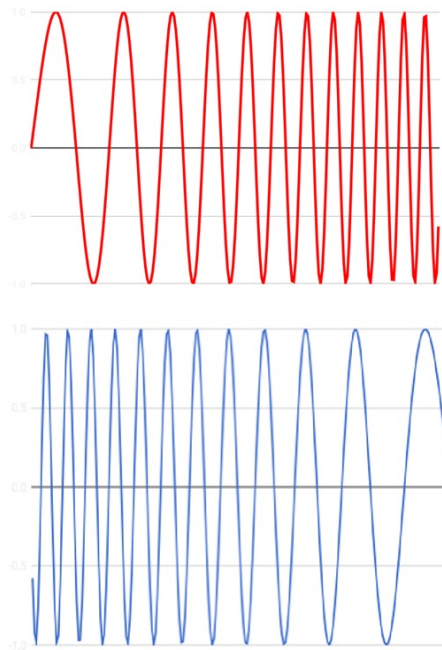
Sub-GHz frequency, e.g: 433, 868, 915 MHz, depends on the country's regulation

Regulated power, duty-cycle, and bandwidth.

E.g: in EU, **1%** per sub-band duty-cycle limitation (per hour, meaning transmission is allowed for 36 sec in each 1 hour)

LoRa modulation

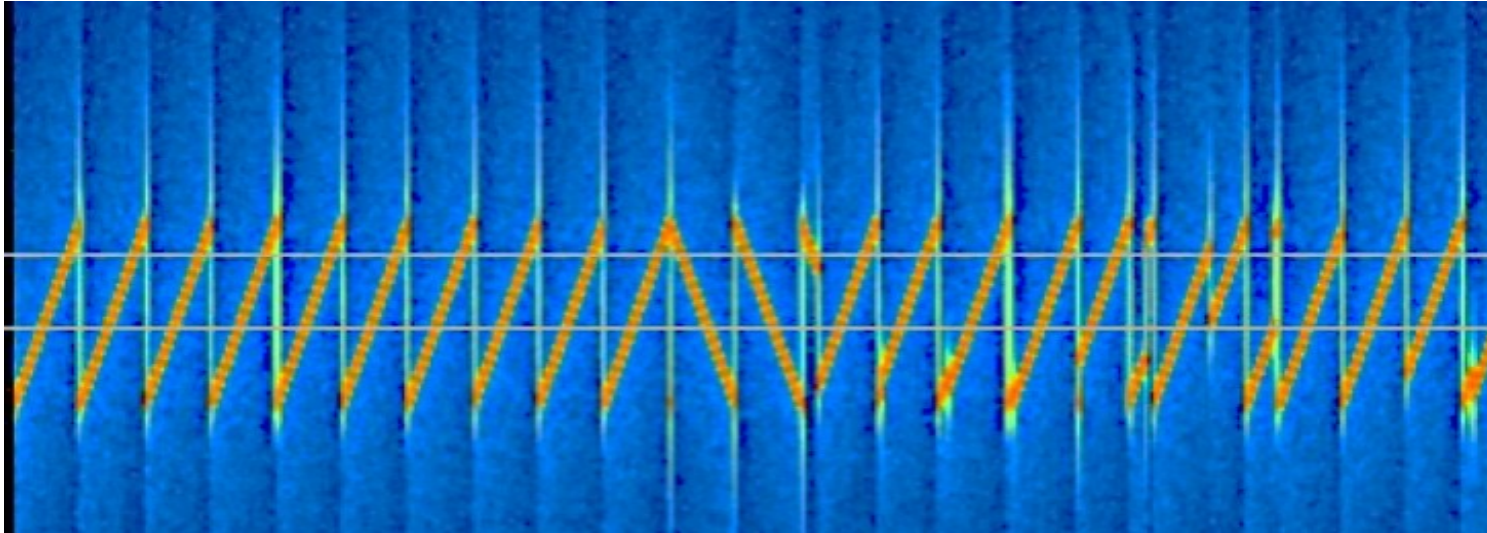
Uses linearly varying frequency pulses called “**chirps**” inspired in radar signals.



Up-chirp:
sinusoidal signal of
linearly
increasing frequency

Down-chirp:
sinusoidal of linearly
decreasing frequency

LoRa Physical Layer



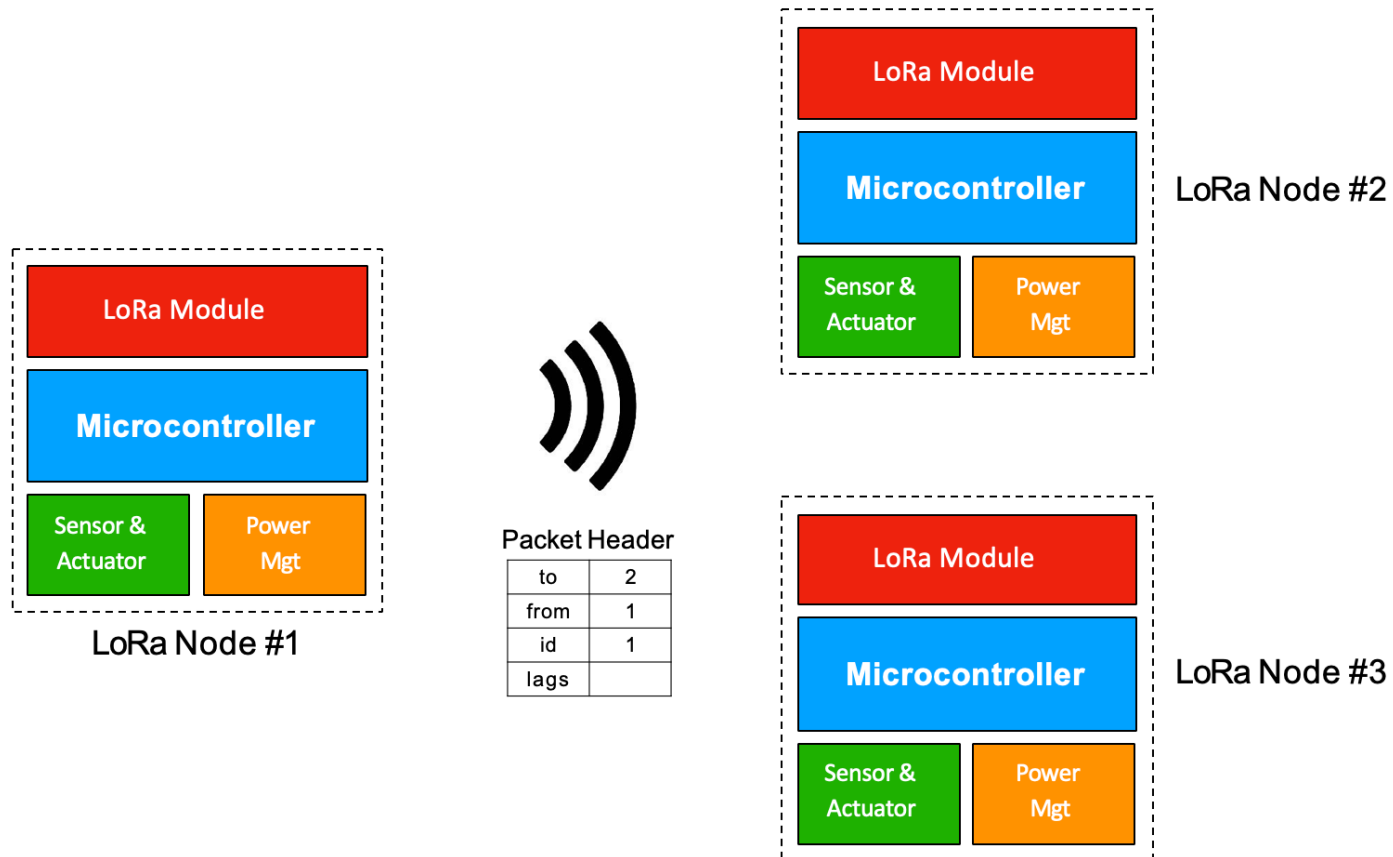
Preamble: at least 10 up-chirps followed by 2.25 down-chirps

Data: information transmitted by the instantaneous frequency transitions

LoRa physical layer consists of many parameters which can be configured into 6720 different settings!

Parameter	Values	Definition	Effects
Bandwidth	125, ..., 500 kHz	Width of spectrum occupied by chirp	A higher bandwidth is required for transmitting data at high rates (1 kHz = 1kcsps). However, increasing this parameter decreases the communication range and sensitivity.
Spreading Factor	$2^6, \dots, 2^{12}$ chips/symbol	Number of bits encoded per symbol. Symbol is RF state representing some quantity of information. SF12 means 2^{12} chips/symbol, 12 bits of data	A higher spreading factor (SF) increases the communication range, radio sensitivity, and the signal-to-noise ratio (SNR). However, energy consumption consequently increases.
Coding Rate	1, ..., 4 or 4/5, ..., 4/8	Proportion of transmitted bits that carries actual data, as opposed to error correction bits. $CR = 4/(4+1) = 4/5$	Bigger coding rates increase the protection against decoding errors and interference bursts at the expense of longer packets, longer air time, and higher power consumption.
Transmission Power	-4, ..., 20 dBm	Transmission power can be adjusted from -4 to 20 dBm, in 1dB steps. Because of hardware implementation limits, the range is often limited to 2 to 20 dBm.	The signal-to-noise ratio is increased by increasing the transmission power at the cost of energy expenditure.
Carrier Frequency	137, ..., 1020 MHz	CF represents the central transmission frequency used in a band, can be programmed between 137 MHz to 1020 MHz, in steps of 61 Hz.	Lower frequency enables to achieve higher communication ranges for the same transmission power. However, selected CF needs to comply with country's regulation.

LoRa nodes



What is LoRaWAN

Communications protocol and architecture utilizing the LoRa physical layer

Open Source and freely available, specified by LoRa Alliance

Star of Starts Topology.

Nodes connect to multiple gateways

What is LoRaWAN

Adaptive Data Rate (ADR) to improve performance

Built-in multiple levels of security: network or application level encryption, frame counter, etc



LoRaWAN end device/mote

Communicates with LoRaWAN gateways, never directly with other motes.

Has 64 bit globally unique identifier: **DevEUI**.

When joining a network, it receives a 32 bit unique identifier: DevAddr.

Defined 3 device classes: A, B, and C

LoRaWAN device classes

Class A

Device-initiated communication; lowest power

Devices are typically in deep sleep and send messages on intervals and/or events

After uplink transmission, device opens two receive windows at specified times for downlink messages

Best fit for most battery-powered sensor applications

Class B

Time-synchronized communication, deterministic downlink

Extend Class A by adding scheduled receive windows for downlink messages from backend

Using time-synchronized beacons transmitted by the gateway, the devices periodically open receive windows

Best for most downlink intensive applications

Class C

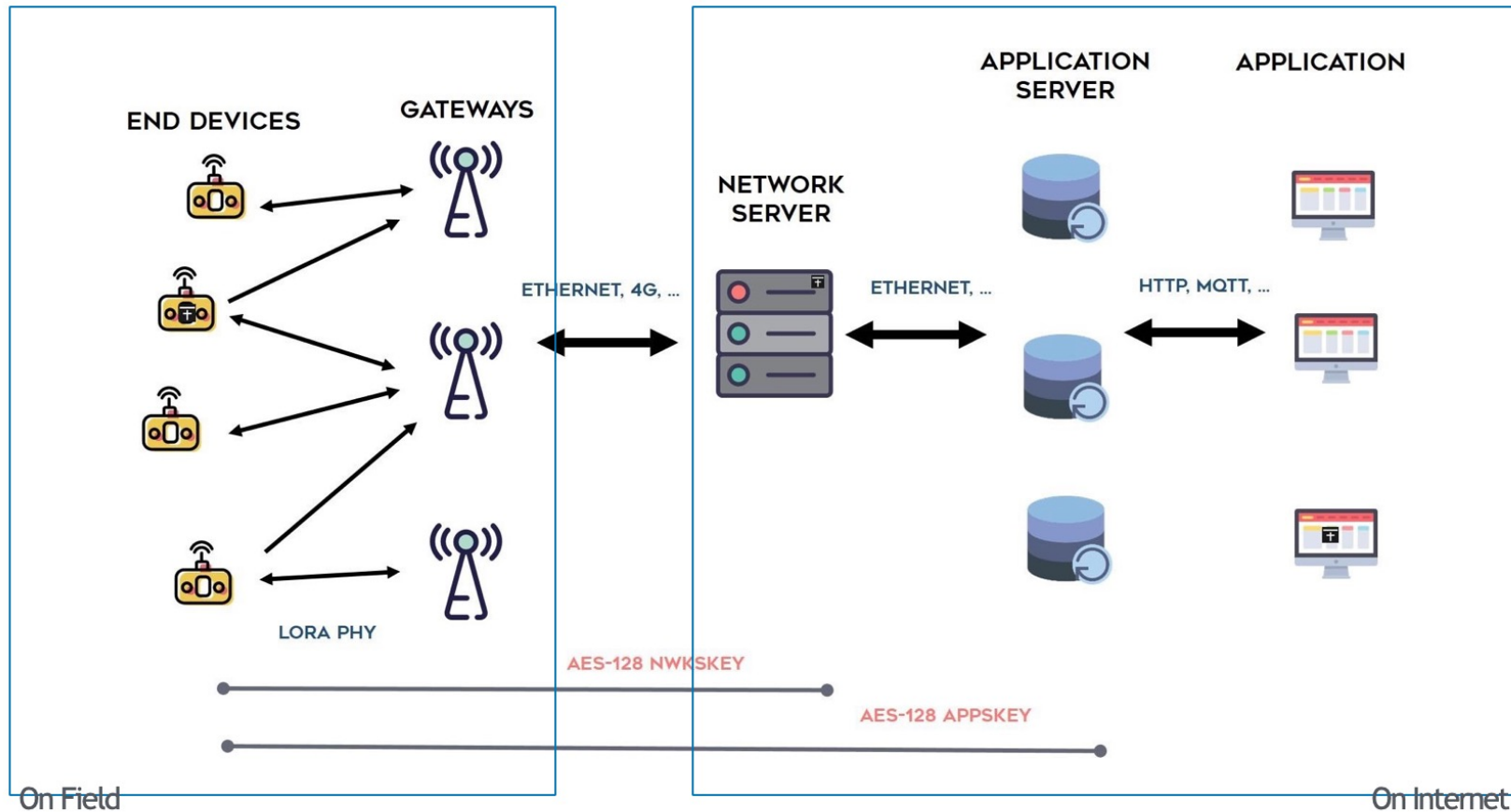
Network-initiated communication; lowest latency

Extend Class A by keeping the receive windows open unless uplink-transmitting

The backend can send downlink message at any given time

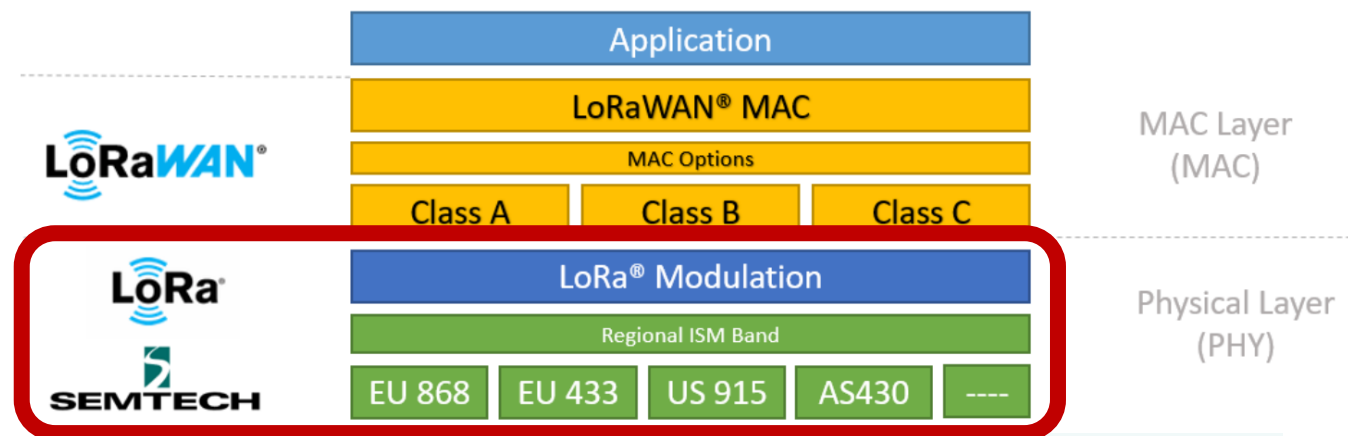
Best for downlink intensive applications that require low latencies, non battery-powered

LoRaWAN architecture



Source: <http://www.frugalprototype.com/technologie-lora-reseau-lorawan/>

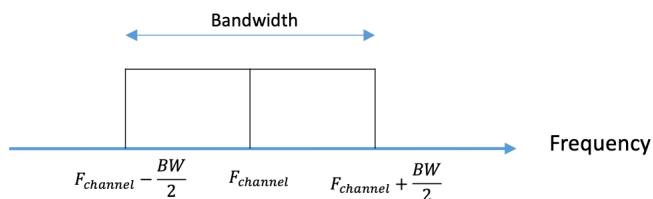
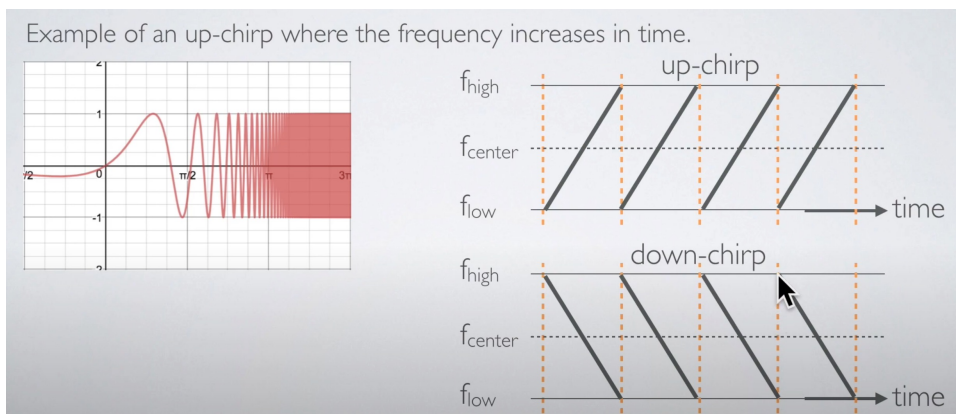
- LoRa is the physical layer, or the wireless modulation used to create the long-range communication link.
- LoRa modulation uses Spread Spectrum to transmit its data. Instead of using "codes", it uses "Chirps" and that is why it is called Chirp Spread Spectrum (CSS) modulation.
- Chirp spread spectrum has been used in military and space communication for decades due to the long communication distances that can be achieved and robustness to interference, but LoRa is the first low-cost implementation for commercial usage.
 - Chirp: Compressed High Intensity Radar Pulse*



<https://lora-developers.semtech.com/library/tech-papers-and-guides/lora-and-lorawan/> ©

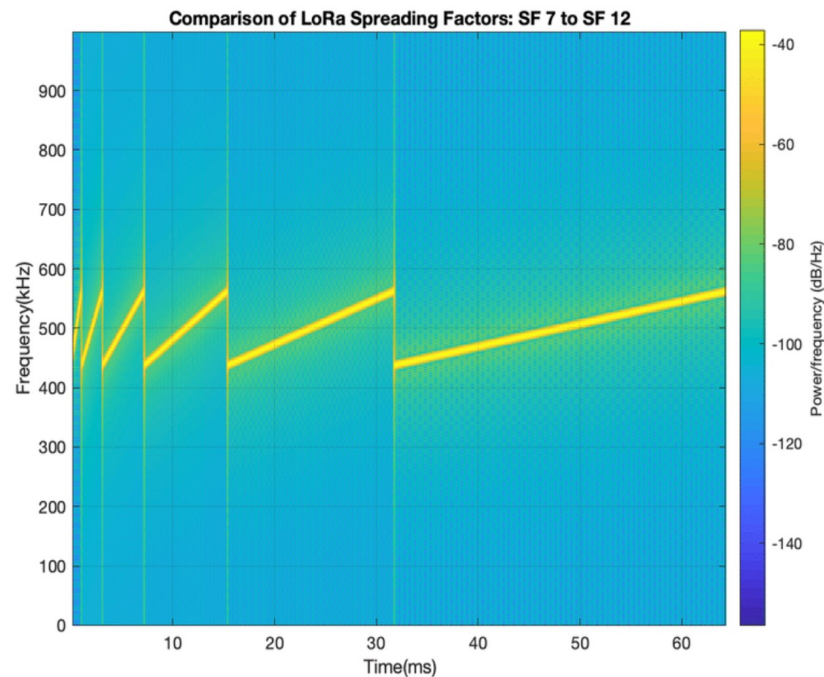
Chirp Modulation

A chirp is a signal in which the frequencies increases (up-chirp) or decreases (down-chirp) with time



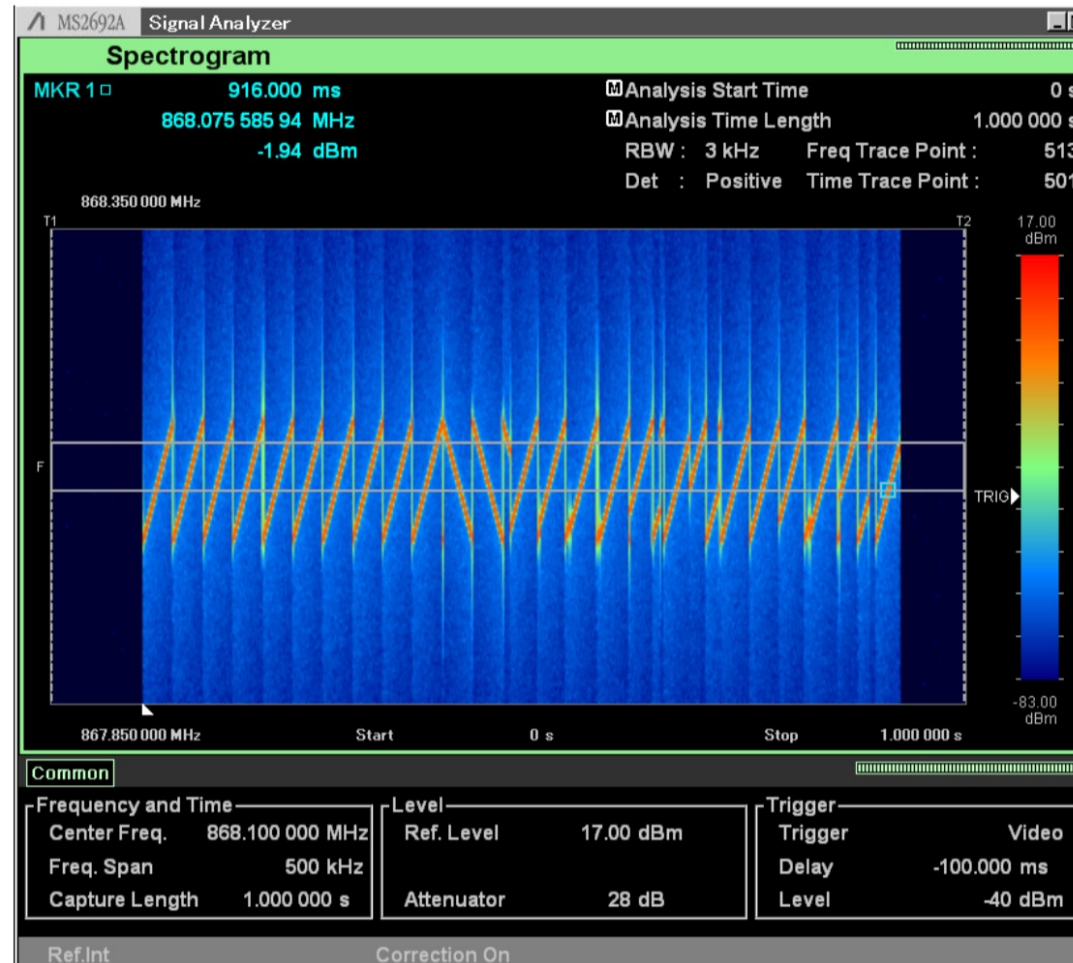
There are **2** critical factors

- **Bandwidth (BW)**: 3 possible values 125, 250, and 500 kHz.
- **Spreading factor (SF)**: 6 values from SF7 to SF12



Kim, Dong-Hoon & Lee, Eun-Kyu & Kim, Jibum. (2019). Experiencing LoRa Network Establishment on a Smart Energy Campus Testbed. Sustainability. 11. 1917. 10.3390/su11071917.

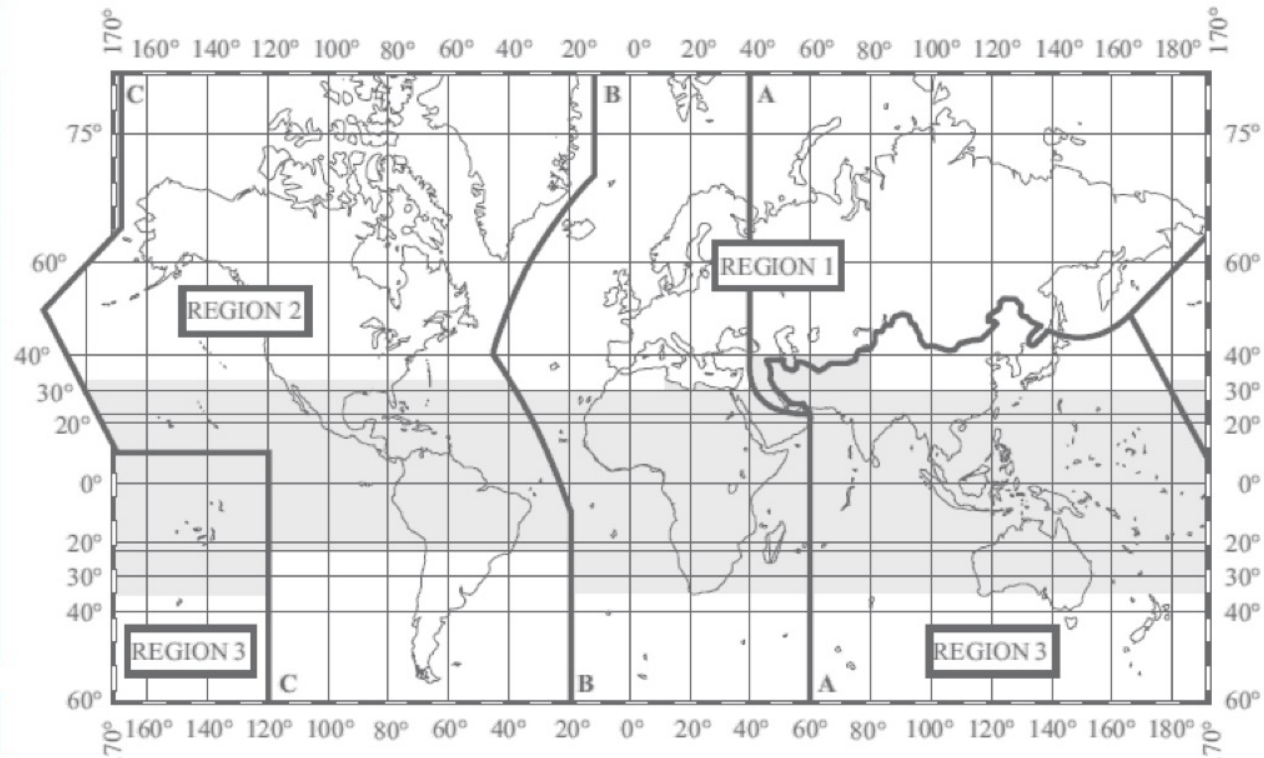
Spectrogram of a LoRa packet



Gaelens, Johnny & Van Torre, Patrick & Verhaevert, Jo & Rogier, Hendrik. (2017). LoRa Mobile-To-Base-Station Channel Characterization in the Antarctic. Sensors (Switzerland). 17. 10.3390/s17081903.

LoRa frequency bands

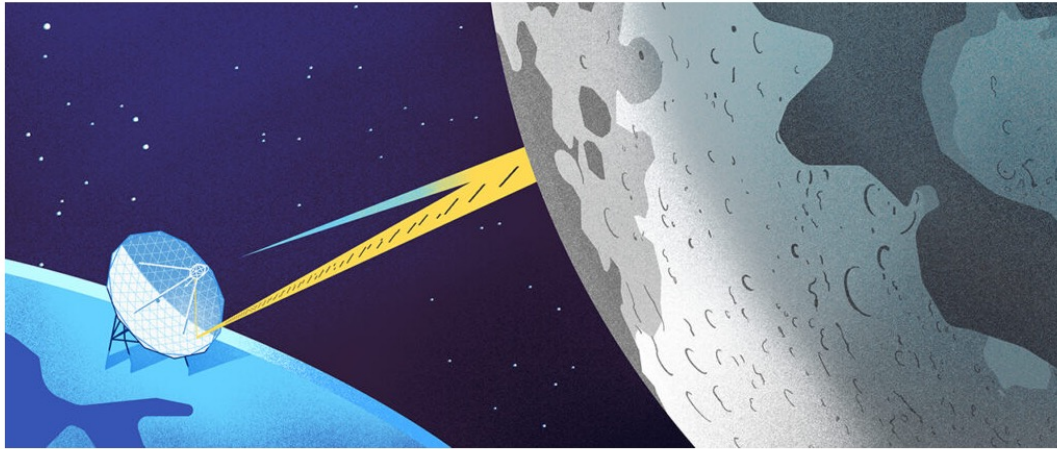
Countries	Frequency band review	Max. output power
EU	868 MHz	14 dBm
USA	915 MHz	20 dBm
Korea	900 MHz	14 dBm
Japan	920 MHz	
Malaysia	862 to 875 MHz	20 dBm
Philippines	868 MHz	
Vietnam	920 to 925 MHz	
India	865 to 867 MHz	
Singapore	922 MHz	
Thailand	920 to 925 MHz	
Indonesia		
ANZ	915 to 928 MHz	
Taiwan	920 to 925 MHz	
China	470 to 510 MHz	17 dBm



LoRa capabilities

First LoRa® message bounced off the moon

24 November 2021



For the first time ever we bounced a LoRa® message off the moon on October 5th 2021, using the Dwingeloo radio telescope. This first was achieved by a team consisting of Jan van Muijlwijk (CAMRAS, PA3FXB), Tammo Jan Dijkema (CAMRAS), Frank Zeppenfeldt (ESA, PD0AP) and Thomas Telkamp (Lacuna Space, PA8Z). The signal traveled an amazing distance of 730,360 km, which to our knowledge is the furthest distance a LoRa® modulated message has ever traveled.

For a short moment the entire message was in space, in between the Earth and the Moon. We transmitted the signal with a Semtech LR1110 RF transceiver chip (in the 430-440 Mhz amateur band), amplified to 350 Watt, using the 25 meter dish of the telescope. Then, 2.44 seconds later, it was received by the same chip. One of the messages even contained a full LoRaWAN® frame.

■ Data rate

- A lower spreading factor provides a higher bit rate for a fixed bandwidth and coding rate.

Case 1: For SF7, 125 kHz

>

bit rate = **6,836 bps**

Case 2: For SF12, 125 kHz

>

bit rate = **366 bps**

$$\text{Bit Rate} = SF \cdot \frac{\text{Bandwidth}}{2^{SF}}$$

■ Time-On-Air

- Compared to a lower spreading factor, sending a fixed amount of data (payload) with a higher Spreading Factor and a fixed bandwidth needs longer time-on-air.

■ Receiver Sensitivity

- Higher spreading factors provide higher receiver sensitivity.

■ Battery Life

- The battery life of an end device is highly dependent on the spreading factor used. Higher spreading factors result in longer active times for the radio transceivers and shorter battery life.

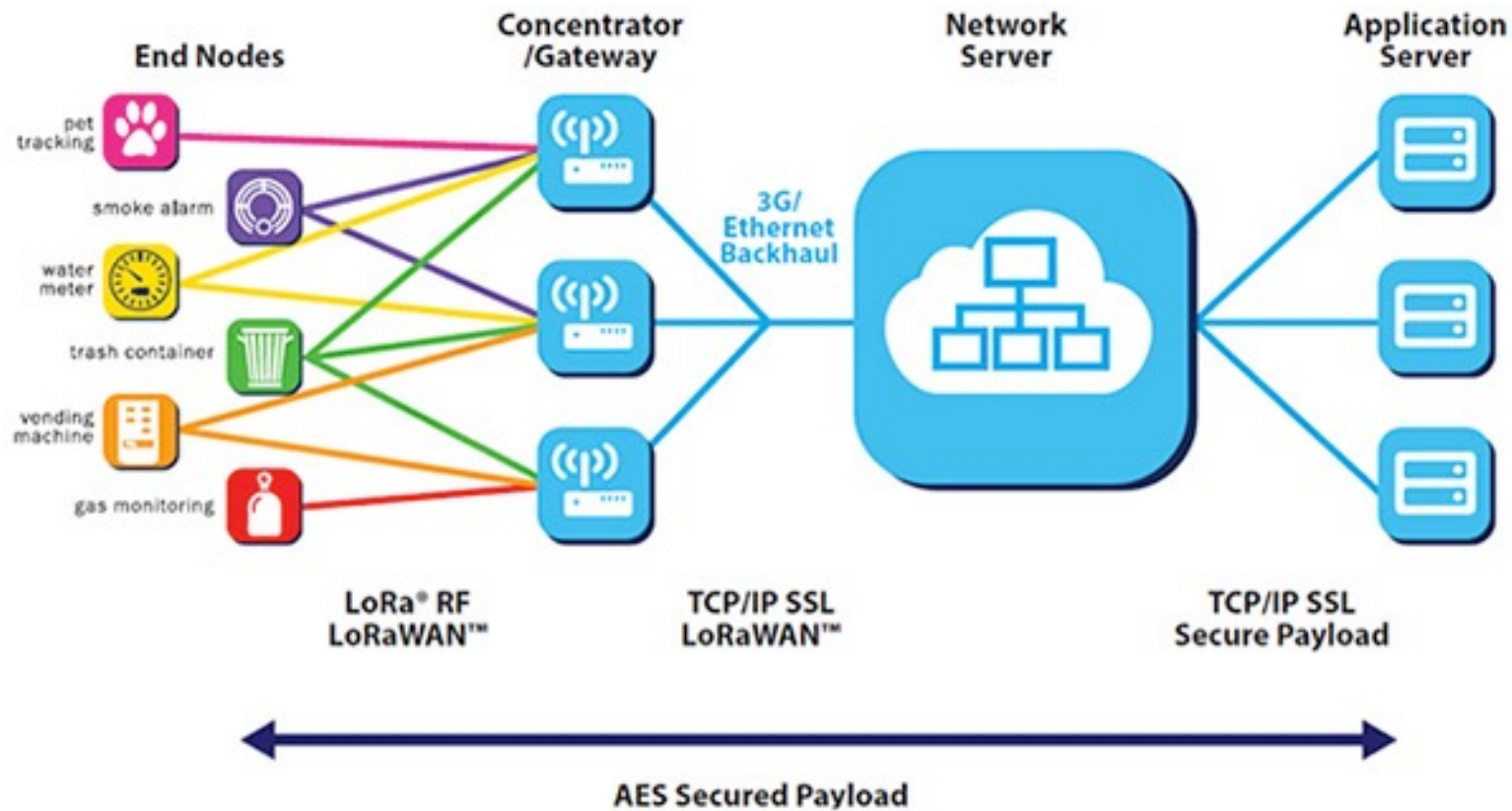
- The Coding Rate is a ratio that increases the number of bits transmitted in order to carry out error detection and correction. In the case of a $CR = 4/8$, there is 8 bits truly transmitted each time we want to transmit 4 bits.

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

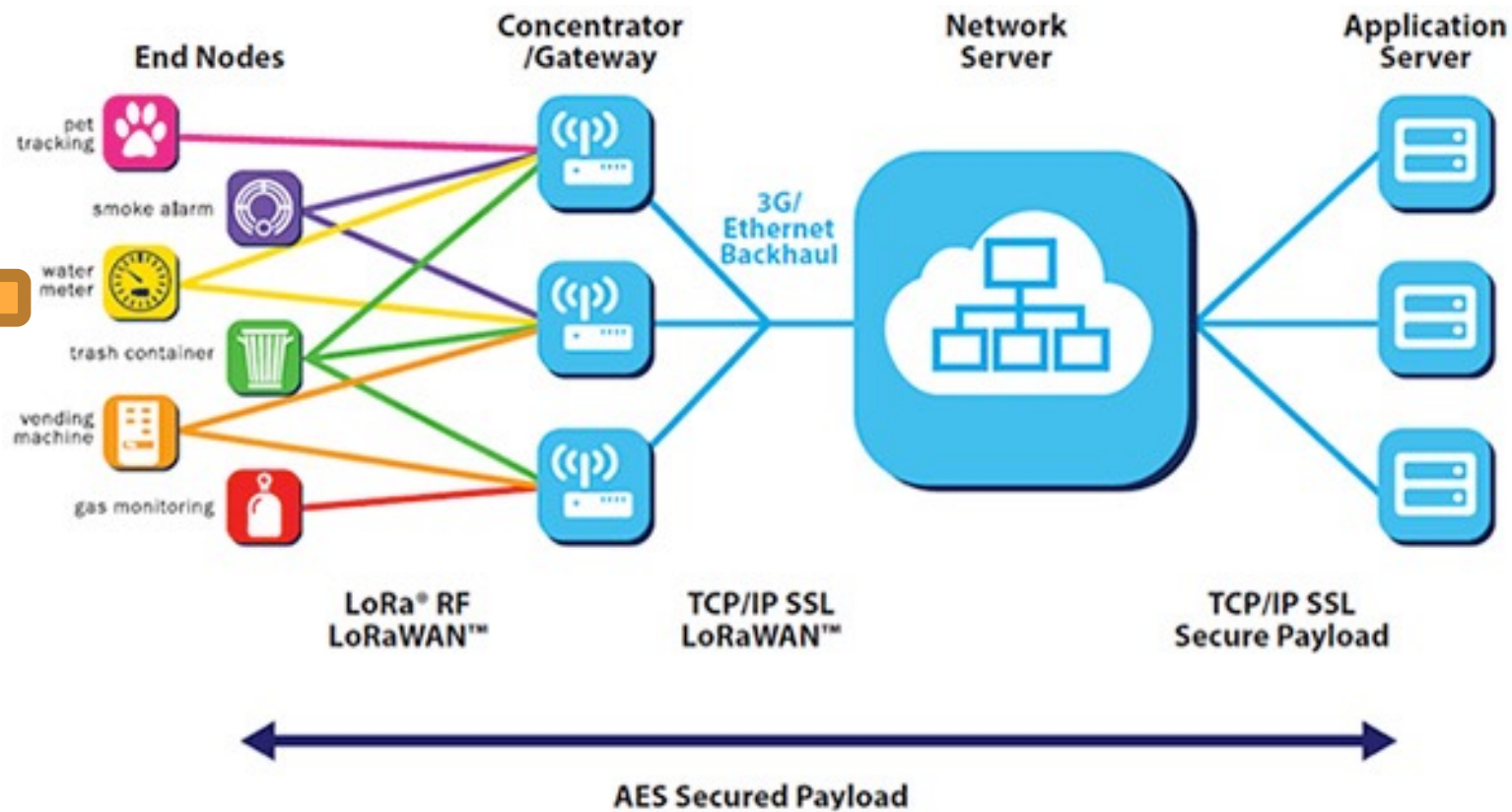
- For example
 - For SF7, 125 kHz and CR_{4/5} → bit rate = 6.836 kbps / 1.25 = 5469 bps
 - For SF12, 125 kHz and CR_{4/5} → bit rate = 366 bps/1.25=293bps
- **The documentation of a LoRa transceiver gives the data rates according to the Spreading Factor, the Bandwidth and the Coding Rate.**
- An online LoRa simulator is also available at <https://loratools.nl/#/airtime>

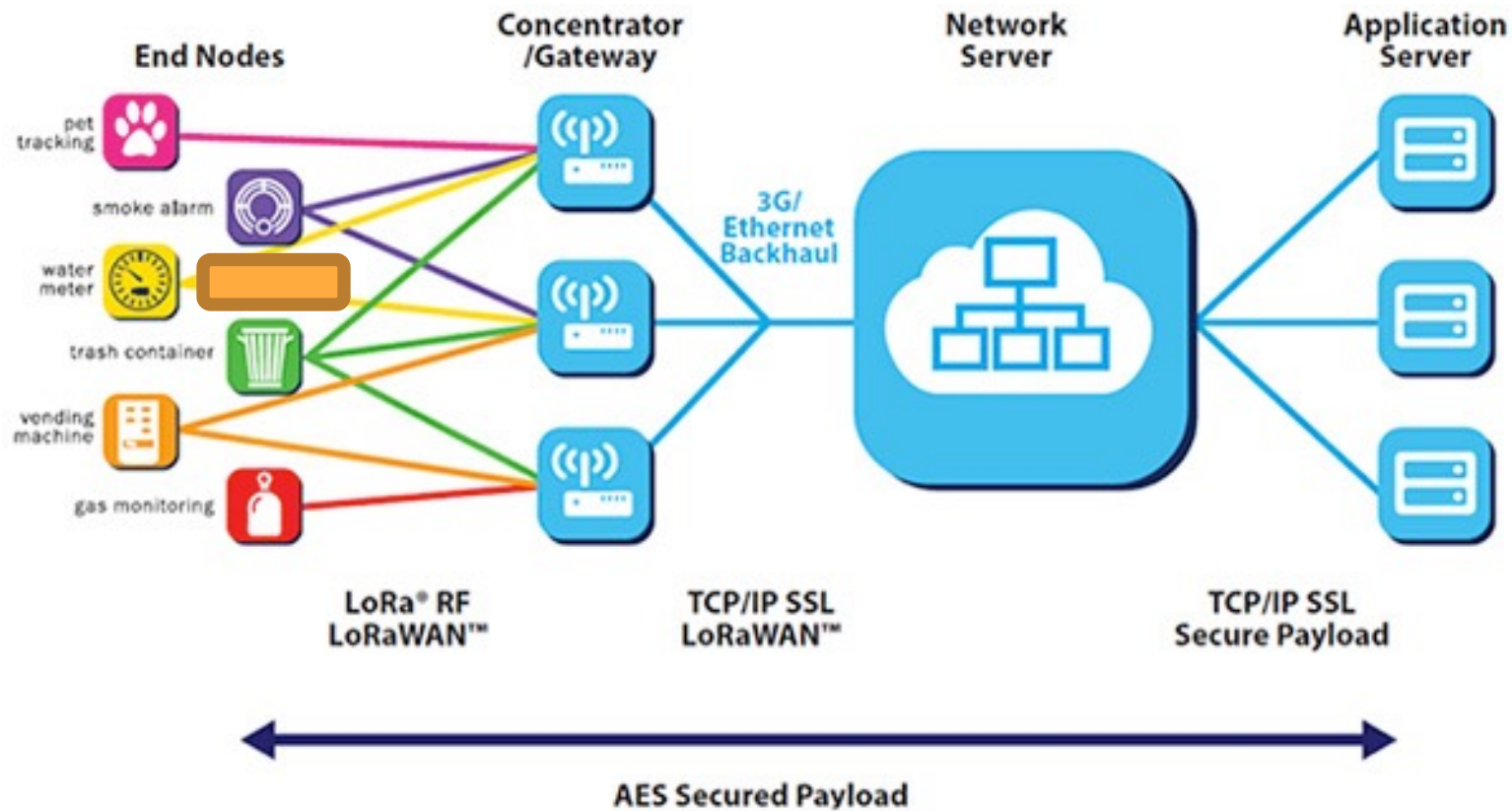
Data Rate	Configuration (SF + BW)	Bit rate (bit/s)
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF7 / 250 kHz	11000

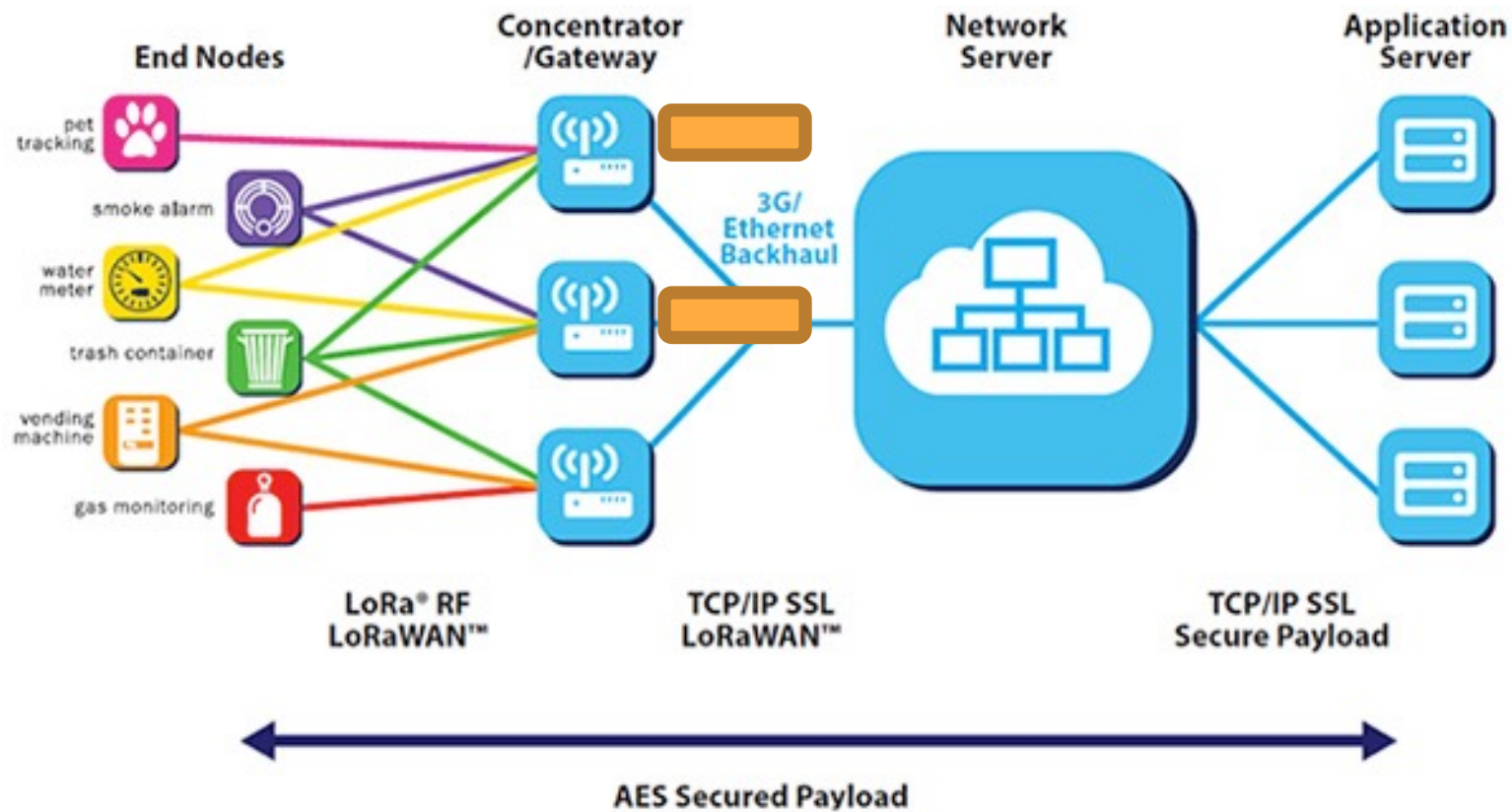
Data Rate	Spreading Factor	Bandwidth	Max Frame payload (Number N)
DR 0	SF12	125 kHz	51 bytes
DR 1	SF11	125 kHz	51 bytes
DR 2	SF10	125 kHz	51 bytes
DR 3	SF9	125 kHz	115 bytes
DR 4	SF8	125 kHz	242 bytes
DR 5	SF7	125 kHz	242 bytes
DR 6	SF7	250 kHz	242 bytes

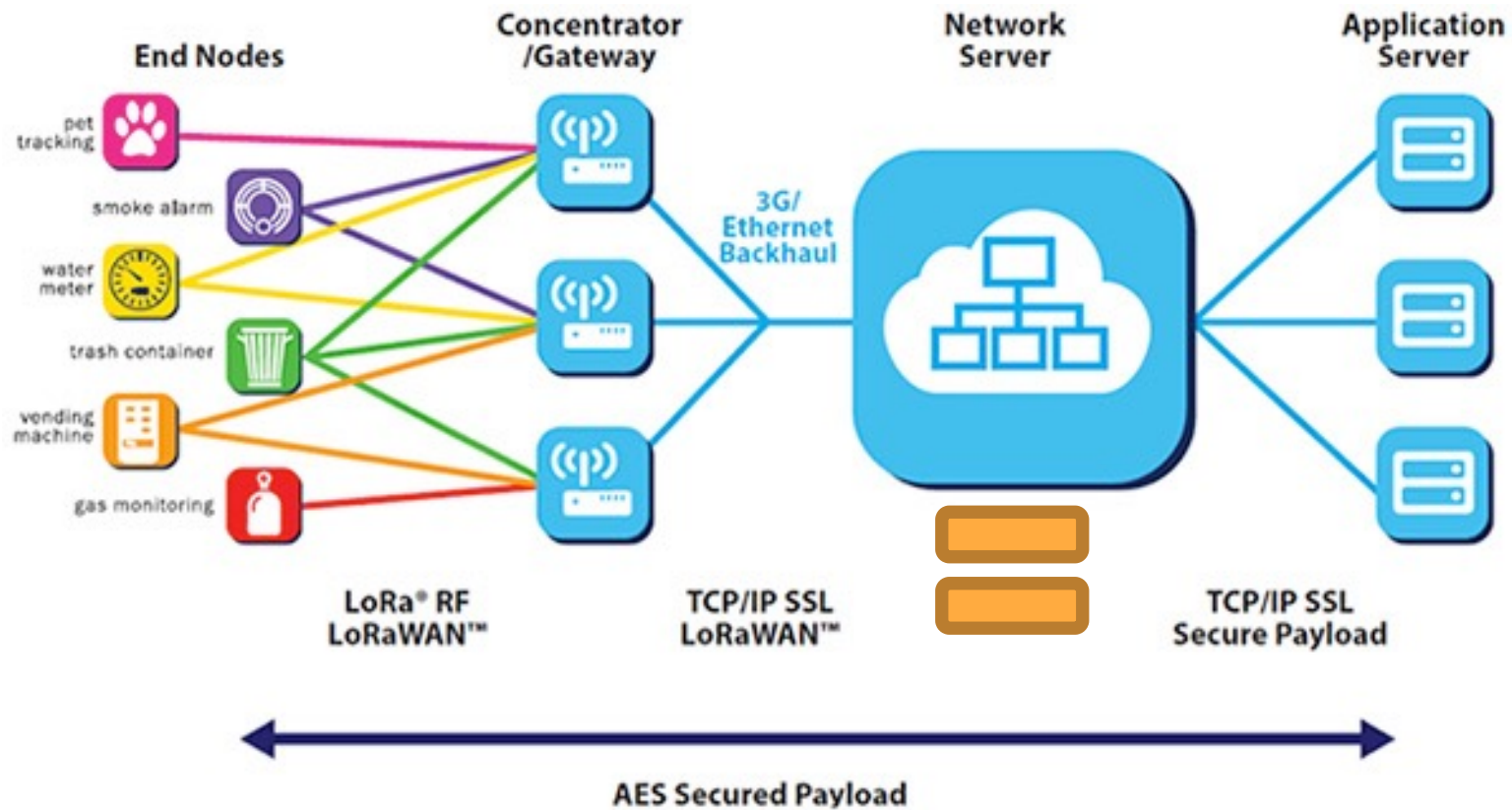


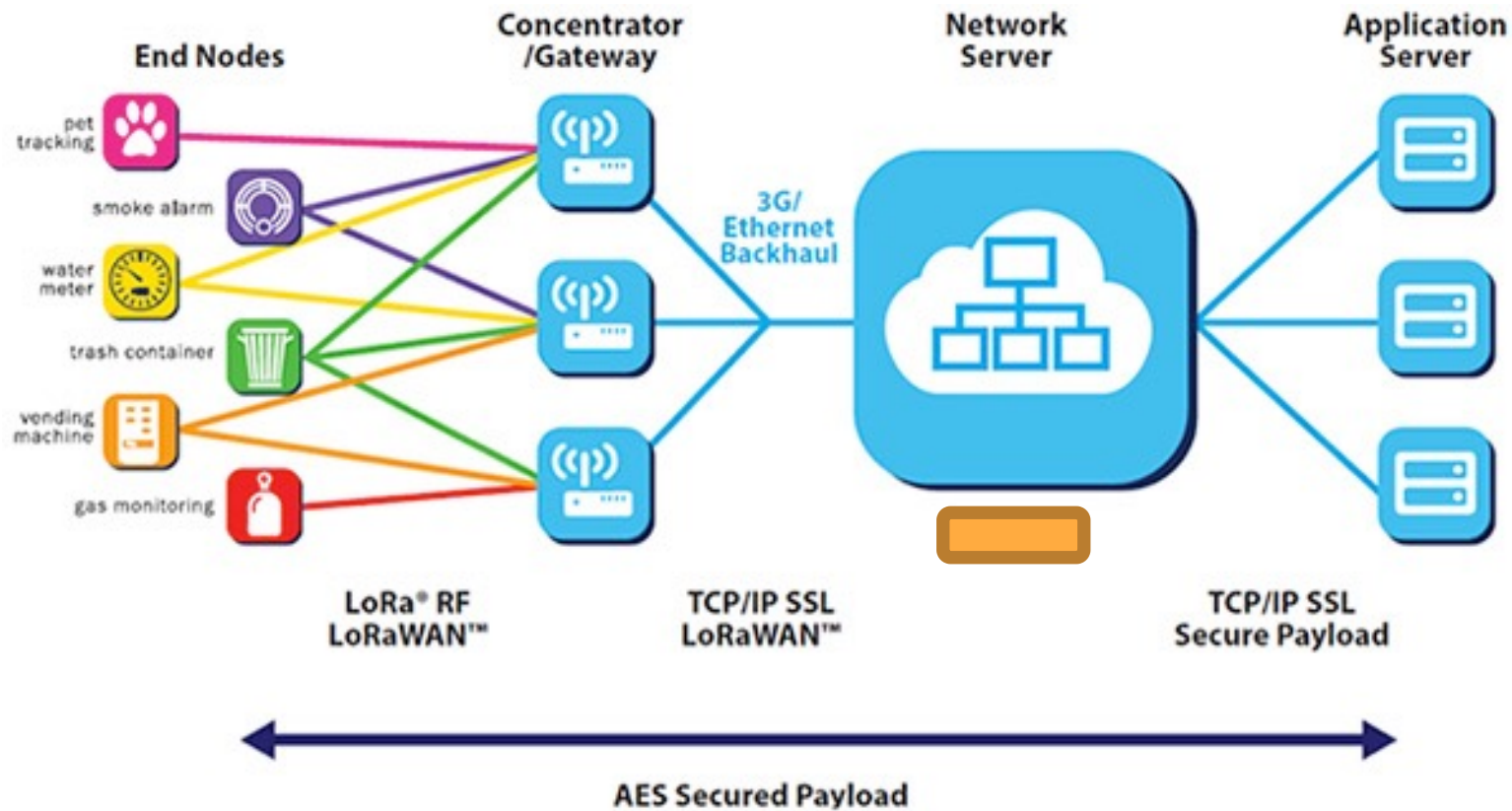
123

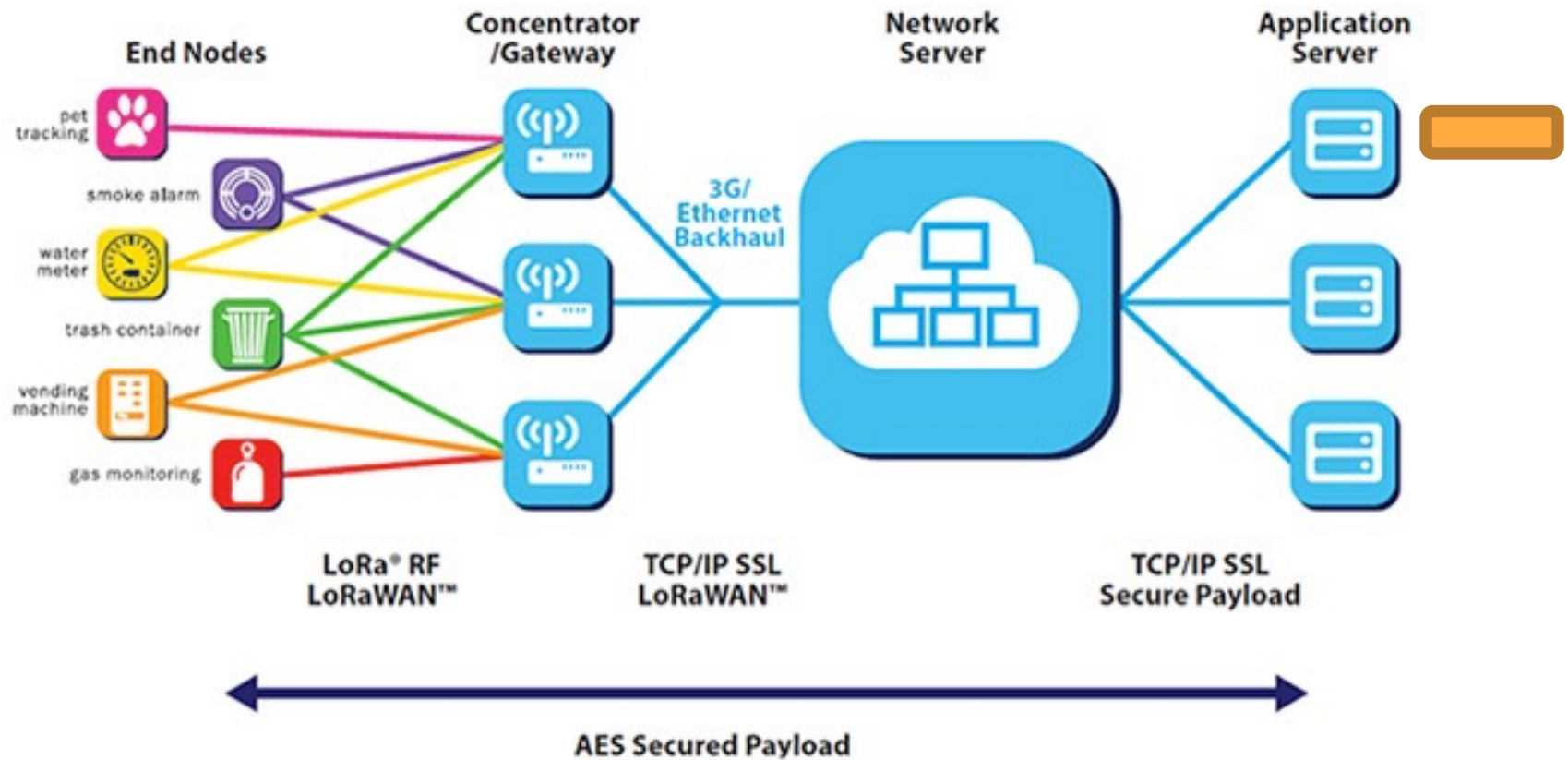


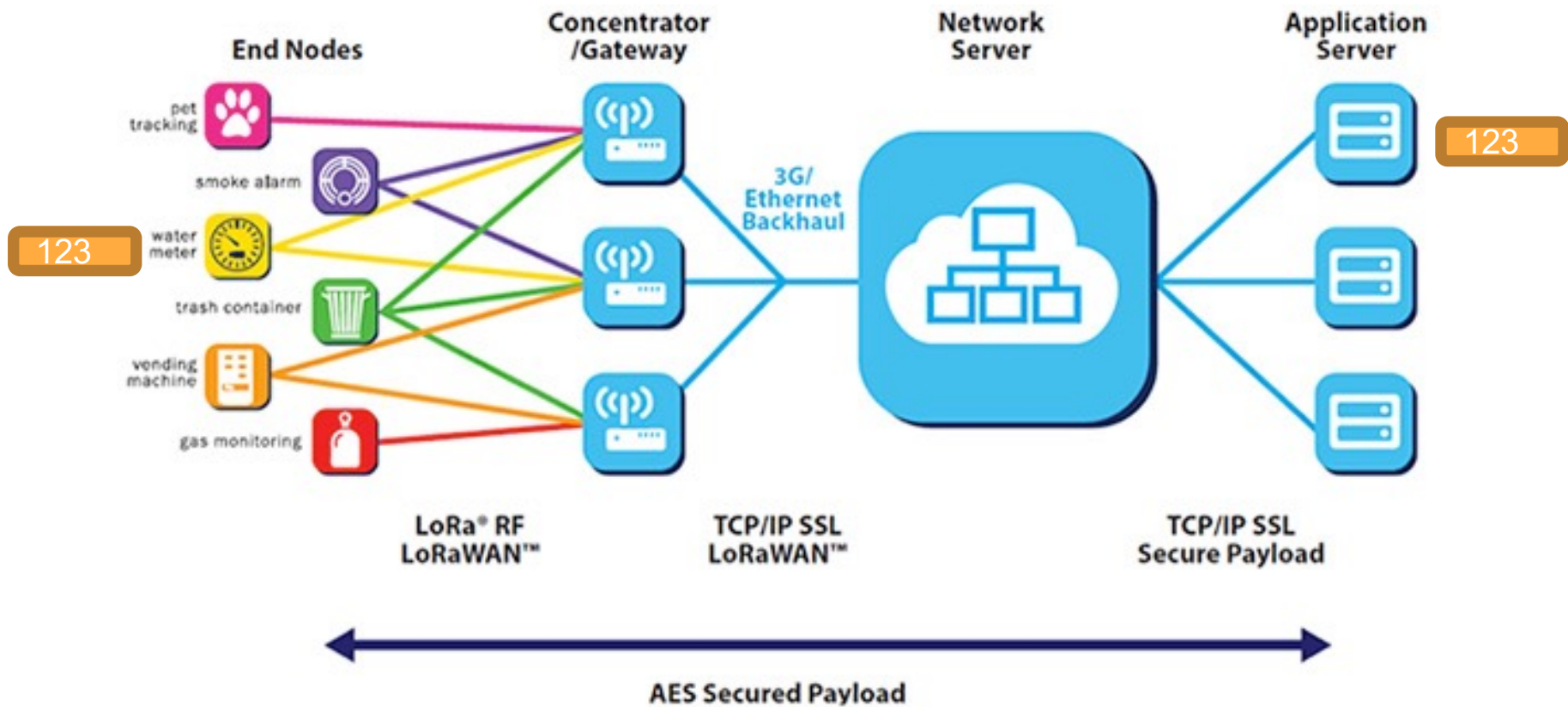




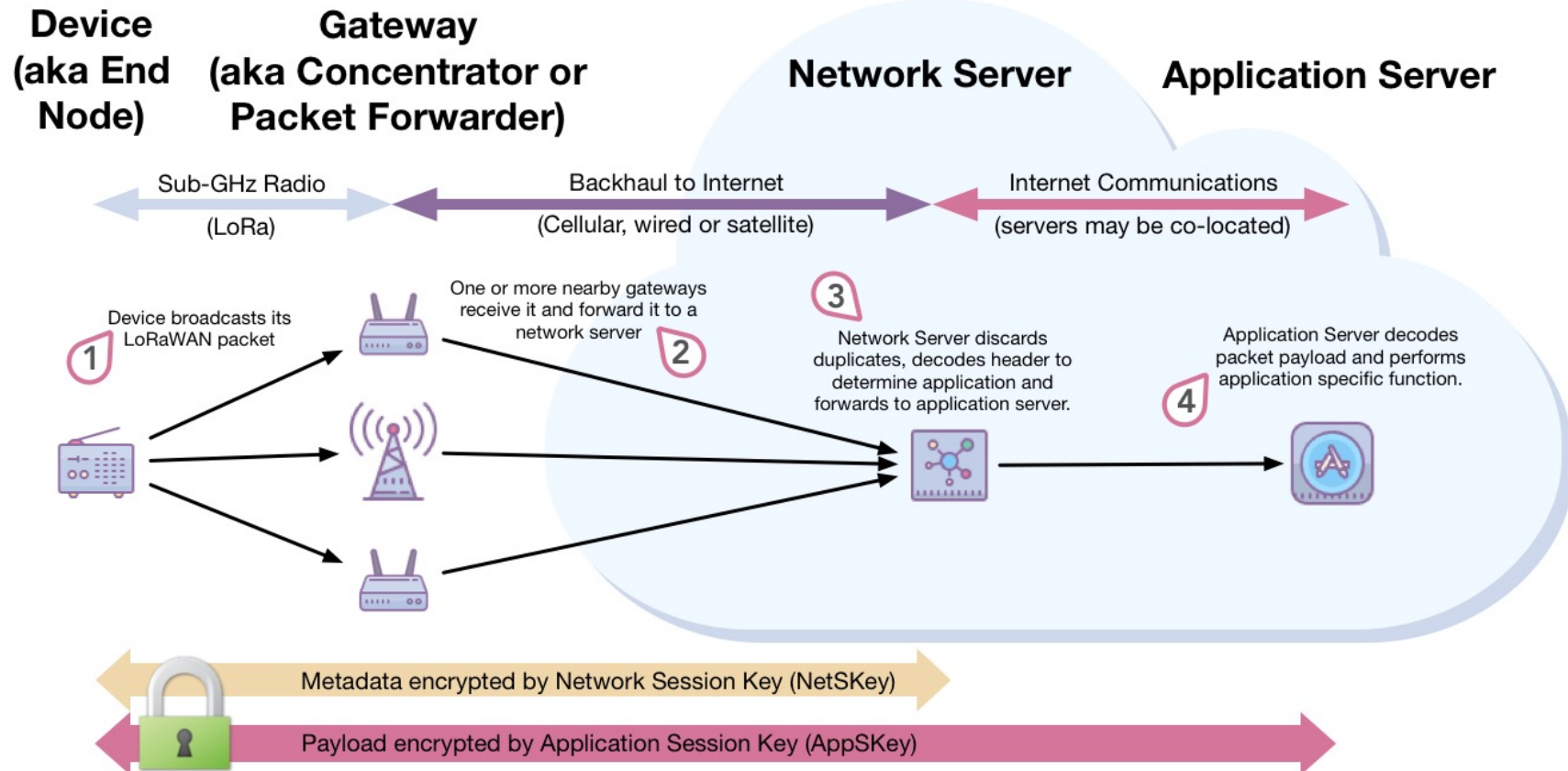






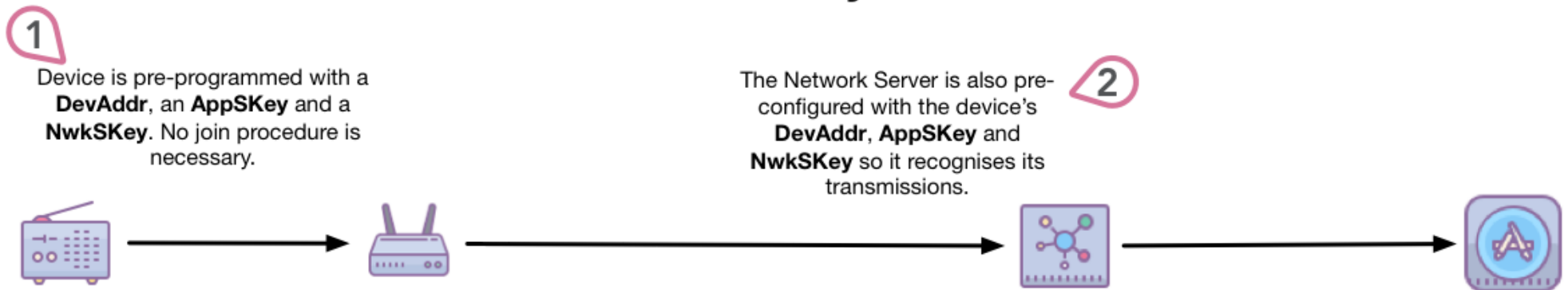


LoRaWAN architecture



LoRaWAN architecture

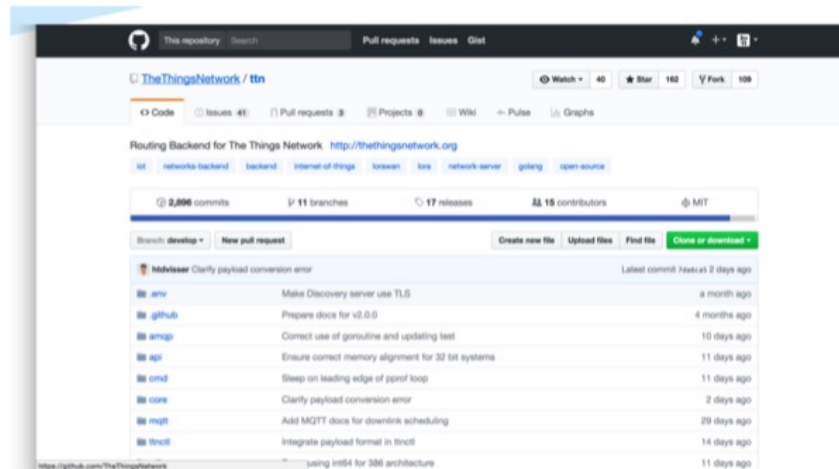
ABP: Activation By Personalisation



The Things Network Manifesto

Everything that carries power will be connected to Internet eventually.

Controlling the network that makes this possible means controlling the world. ***We believe that this power should not be restricted to a few people, companies or nations. Instead this should be distributed over as many people as possible without the possibility to be taken away by anyone.*** We therefore founded "The Things Network".



OPEN SOURCE BACKEND

**We are a global collaborative
Internet of Things ecosystem
that creates networks, devices
and solutions using LoRaWAN®.**

[Start building](#)
[Learn more](#)


50M

Messages today

151

Countries

1.1K

Certified developers

172.3K

Members

20.3K

Gateways

1.6M

YouTube views

15K

YouTube subscribers

711

GitHub stars

13.

GitHub c

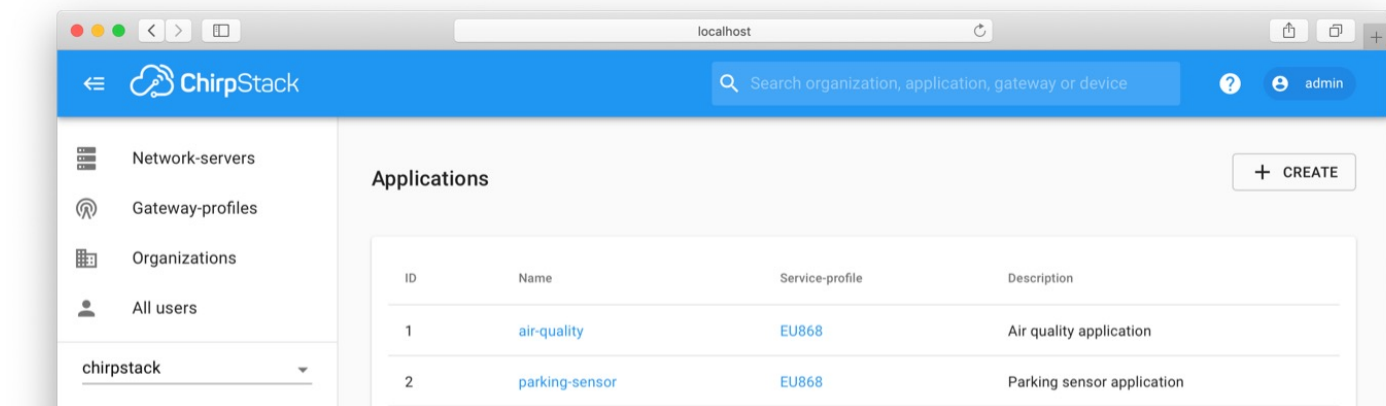


Chirpstack

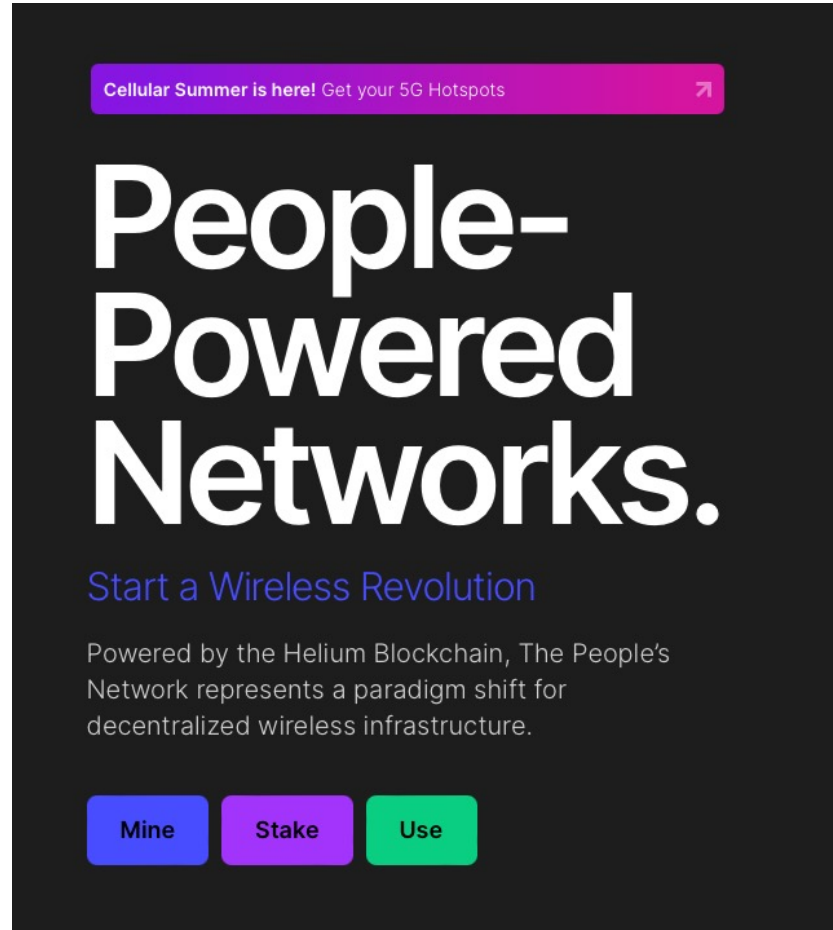
ChirpStack, open-source LoRaWAN[®] Network Server stack

The ChirpStack open-source LoRaWAN Network Server stack provides open-source components for LoRaWAN networks. Together they form a ready-to-use solution including an user-friendly web-interface for device management and APIs for integration. The modular architecture makes it possible to integrate within existing infrastructures. All components are licensed under the MIT license and can be used for commercial purposes.

[Get started](#)



Helium

A screenshot of the Helium mobile application interface. At the top, a pink banner reads "Cellular Summer is here! Get your 5G Hotspots" with a right-pointing arrow. Below this, the text "People-Powered Networks." is displayed in large white font. Underneath, "Start a Wireless Revolution" is written in blue. A paragraph follows: "Powered by the Helium Blockchain, The People's Network represents a paradigm shift for decentralized wireless infrastructure." At the bottom, there are three colored buttons: "Mine" (blue), "Stake" (pink), and "Use" (green).

Cellular Summer is here! Get your 5G Hotspots

People-Powered Networks.

Start a Wireless Revolution

Powered by the Helium Blockchain, The People's Network represents a paradigm shift for decentralized wireless infrastructure.

Mine Stake Use

LoRaWAN products

LoRaWAN Certified^{CM} Products

A huge array of certified products available now to fulfill the wide-ranging spectrum of IoT use cases served by LoRaWANTM.

Soon this will be extended to include LoRa AllianceTM member services, software and full solutions in addition to these certified devices. This will be a comprehensive directory of all our Members' products and services with tools to find the right solution for every LPWAN requirement.



ED1608

1M2M

1M2M's ED1608 is an out of the box, ready to use universal Low Power WAN Smart Sensor/GPS Tracker. It has on board 3D accelerometer,



ED1608 Rail Temperature Sensor

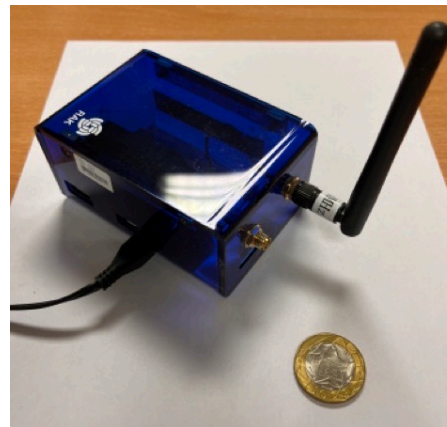
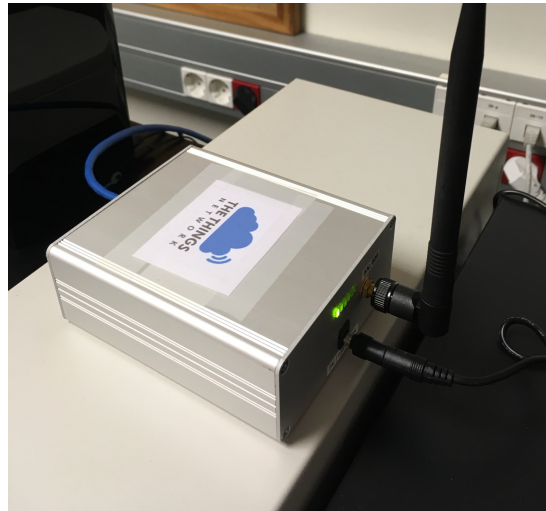
1M2M

The ED1608RTS is a rail temperature sensor that can be used to measure the temperature

LoRaWAN tracking devices



Gateways: examples



Gateways: examples

