Wireless standards for IoT: WiFi, BLE, SigFox, NB-IoT and LoRa

Ermanno Pietrosemoli

The Abdus Salam International Centre for Theoretical Physics

Specific issues pertaining IoT Nodes

- Limited processing power
- Battery operated, so must be power miser, sleeping capabilities highly desireable
- Robust, deployable in harsh environment
- Weatherproof
- Easy to configure
- Inexpensive, deployable in great numbers

Capacity of a communications channel

$$\boxed{C = B * \log_2\{1 + [S/(N_o * B)]\}}$$

Noise power density, W/Hz

Received signal power, W

Bandwidth, Hz

Capacity (maximum throughput), bit-per-second

Capacity depends on the width of the channel in Hz, the received power and noise

The maximum range is determined by the energy per bit received, and depends on the effective transmitted power, receiver sensitivity, interference and data rate

LoRa and Sigfox represent different strategies to achieve long range

Technology	Sensitivity	Data rate	Spectrum Strategy
WiFi (802.11 b,g)	-95 dBm	1-54 Mb/s	Wide Band
Bluetooth	-97 dBm	1-2 Mb/s	Wide Band
BLE	-95 dBm	1 Mb/s	Wide Band
ZigBee	-100 dBm	250 kb/s	100 m
SigFox	-126 dBm	100 b/s	Ultra Narrow Band
LoRa	-149 dBm	18 b/s - 37.5 kb/s	Wide Band
Cellular data (2G,3G)	-104 dBm	Up to 1.4 Mb/s	Narrow Band

Some existing solutions

- WiFi
- Bluetooth and BLE (Bluetooth Low Energy)
- Personal Area Networks (PAN)
  - 802.15.4 based
    - ZigBee, 6LoWPAN, Thread
- Cellular

  extended coverage GSM (EC-GSM)

  enhanced machine type communication (eMTC) also called LTE-M

  EC NB-IoT (still in development)

802.11ah (Sub 1 GHz) WiFi HaLow at 900 MHz

WiFi consumes too much power, so an IoT customised version was developed

Low power, long range Wi-Fi

Up to 1 km range, lower power consumption thanks to a sleep mode

1, 2, 4, 8 and 16 MHz channels

Competes with Bluetooth, 100 kb/s to 40 Mb/s

Bluetooth

Based on IEEE 802.15.1

Smart Mesh

79 channels 1 MHz wide and frequency hopping to combat interference at 2.4 GHz

Used mainly for speakers, health monitors and other short range applications

Bluetooth Low Energy (BLE) or Smart Bluetooth

Based on IEEE 802.15.1

Subset of Bluetooth 4.0, but stemming from an independent Nokia solution

Smart Mesh

Support for IOS, Android, Windows and GNU/Linux

40 channels 2 MHz wide and frequency hopping to combat interference

Used in smartphones, tablets, smart watches, health and fitness monitoring dev.

Zigbee

Based on IEEE 802.15.4, provides the higher layers up to application

Latest standard Zigbee 3.0 issued Dec 2015

Mesh topology

Short range, 20 to 250 kbps

2.4 GHz, 915 MHz or 868 MHz

Channels 2 MHz with Direct Sequence Spread Spectrum media access

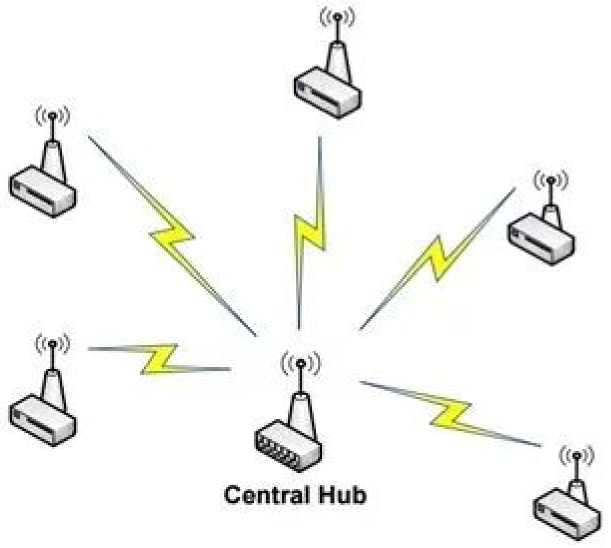
Cheaper than Bluetooth

Low Power Wide Area Network (LPWAN)

Optimized for IoT and Machine to Machine (M2) applications

Trade throughput for coverage (up to several kilometers)

Star topology



Can accept:

Low throughput, application specific

Very sparse datagrams

Delays (DTN)

Sleeping times

Emerging Standards

SIGFOX
One network A billion dreams

nwave

LoRa™

LTE-M

NB-LTE

ingenu

WEIGHTLESS

IEEE 802.11ah

DASH7™ ALLIANCE

EC-GSM

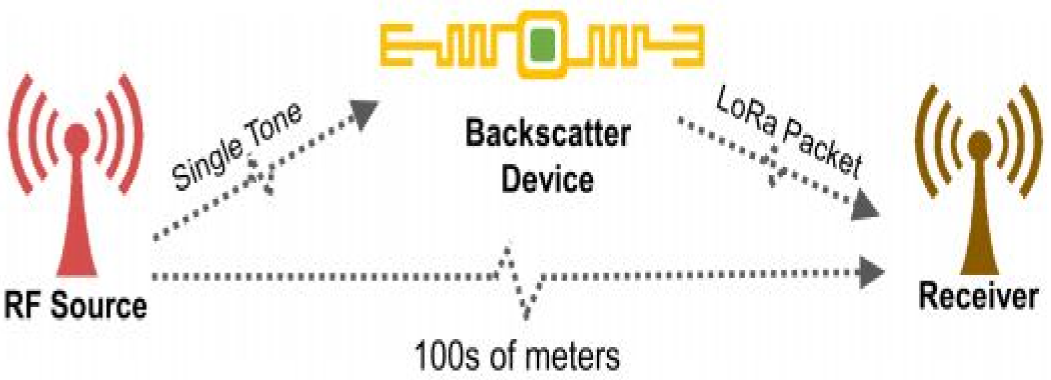
ZigBee 3.0

Battery duration

- LoRa: up to years How?
- 2G, a few days
- 802.15.4 months
- WiFi, a few days
- Energy scavenging schemes are being investigated
- Inductive powering
- Photovoltaic

➤ Devices sleep most of the time, low rate and limited messages

LoRa Backscatter Implementation



- Piggybacking data on an existing RF signal with very low power backscattering device
- Self interference handled by frequency shifting and harmonic cancellation

https://arxiv.org/pdf/1705.05953.pdf 16 May 2017

Spectrum Usage

- Frequencies allocation country dependent
- Cellular uses costly exclusive licensed spectrum
- Alternatives use ISM bands, without fee payment, but subject to interference

Interference can be addressed by:

  - Listen Before Talk (LBT)
  - Duty Cycle limitations
  - Effective Transmitted power limitations
  - Spatial confinement
    - Use high directivity antennas
    - Frequencies subjected to high attenuation (60Ghz)
    - Light communication blocked by walls

Weightless

Weightless-P

Sub 1 GHz spectrum, 12.5 kHz channels, frequency hopping

From 200 bps to 100 kbps

Weightless-N is for uplink only

Sub 1 GHz spectrum, 200 Hz channel, 100 b/s

Weightless-W TV White Spaces

TV spectrum, 5 MHz channel, 1 kb/s to 0 M b/s

RPMA

Random Phase Multiple Access, backed by Ingenu

Spread Spectrum technology based on CDMA

172 dB link budget offers long range

2.4 GHz band, 1 MHz channel bandwidth

Up to 624 kbps UP and 156 kbps DL, slower in mobile applications

NB-IoT

3GPP backed, based in LTE

Licensed spectrum, 180 kHz bidirectional channels, in band or in guard bands

Improved coverage thanks to 10 dB advantage compared with LTE

Reduced consumption by intermittent operation

Dl up to 250 kb/s, 164 dB link budget

Optimized for low end of IoT

On-going trials, expected commercial availability in 2018

Sigfox

868 MHz in Europe, 915 MHz in US

Maximum of 140 messages/day, 12 bytes long on a 100 Hz channel, 100 b/s UL

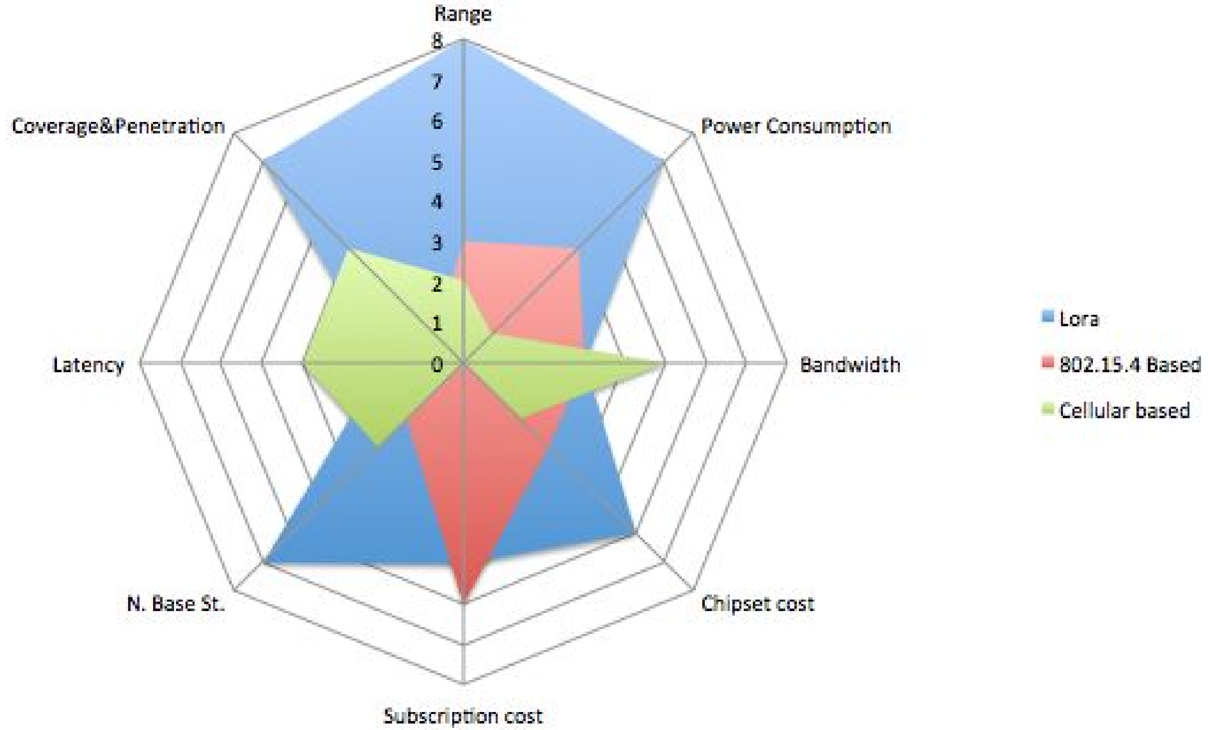
146- 162 dB link budget, potential of huge range

Ultra narrow band, BPSK UP, GFSK DL, 600 b/s

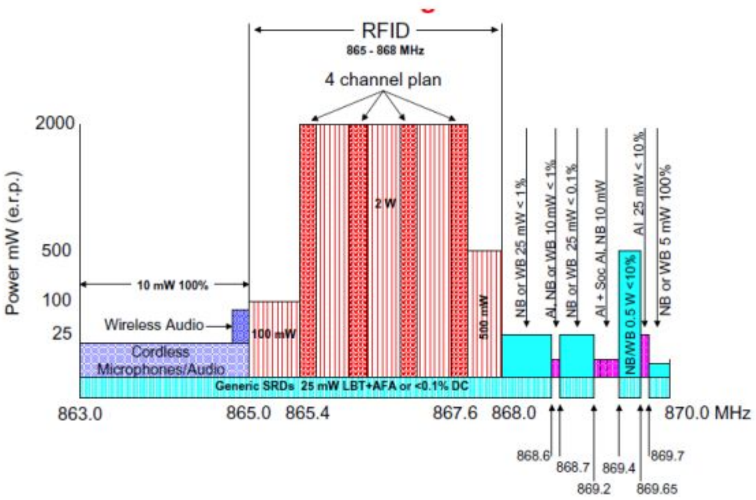
Mobility restricted to 6 km/h

Many network operators worldwide offer service

Comparison of LPWAN solutions



Short Range Devices and LoRa spectrum access



G1: 868,000 MHz to 868,600 MHz with 25 mW EIRP (14 dBm) and 1 % duty cycle.
G2: 868,700 MHz to 869,200 MHz with 25 mW EIRP (14 dBm) and 0,1 % duty cycle.
G3: 869,400 MHz to 869,650 MHz with 500 mW EIRP (27 dBm) and 10 % duty cycle.

http://www.etsi.org/deliver/etsi_tr/103000_103099/103055/01.01.01_60/tr_103055v010101p.pdf

LoRa spectrum usage

Europe: 863 to 868 MHz and 434 MHz

Duty cycle limitations: 0.1%, 1% and 10%

Max EIRP: 14 dBm, 27 dBM in G3 sub-band

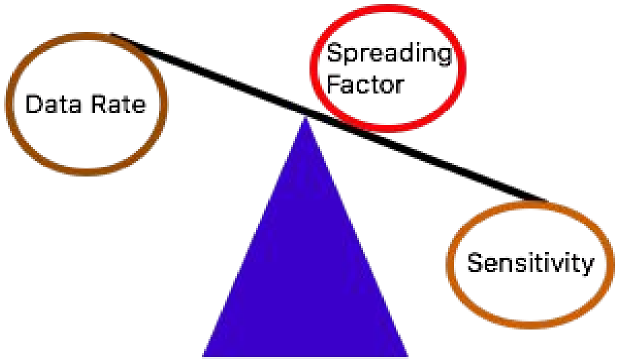
US: 902 to 928 MHz

400 ms max dwell time per channel (SF 7 to SF 10 at 125 kHz)

Max EIRP: 21 dBm on 125 kHz, 26 dBm on 500 kHz channel

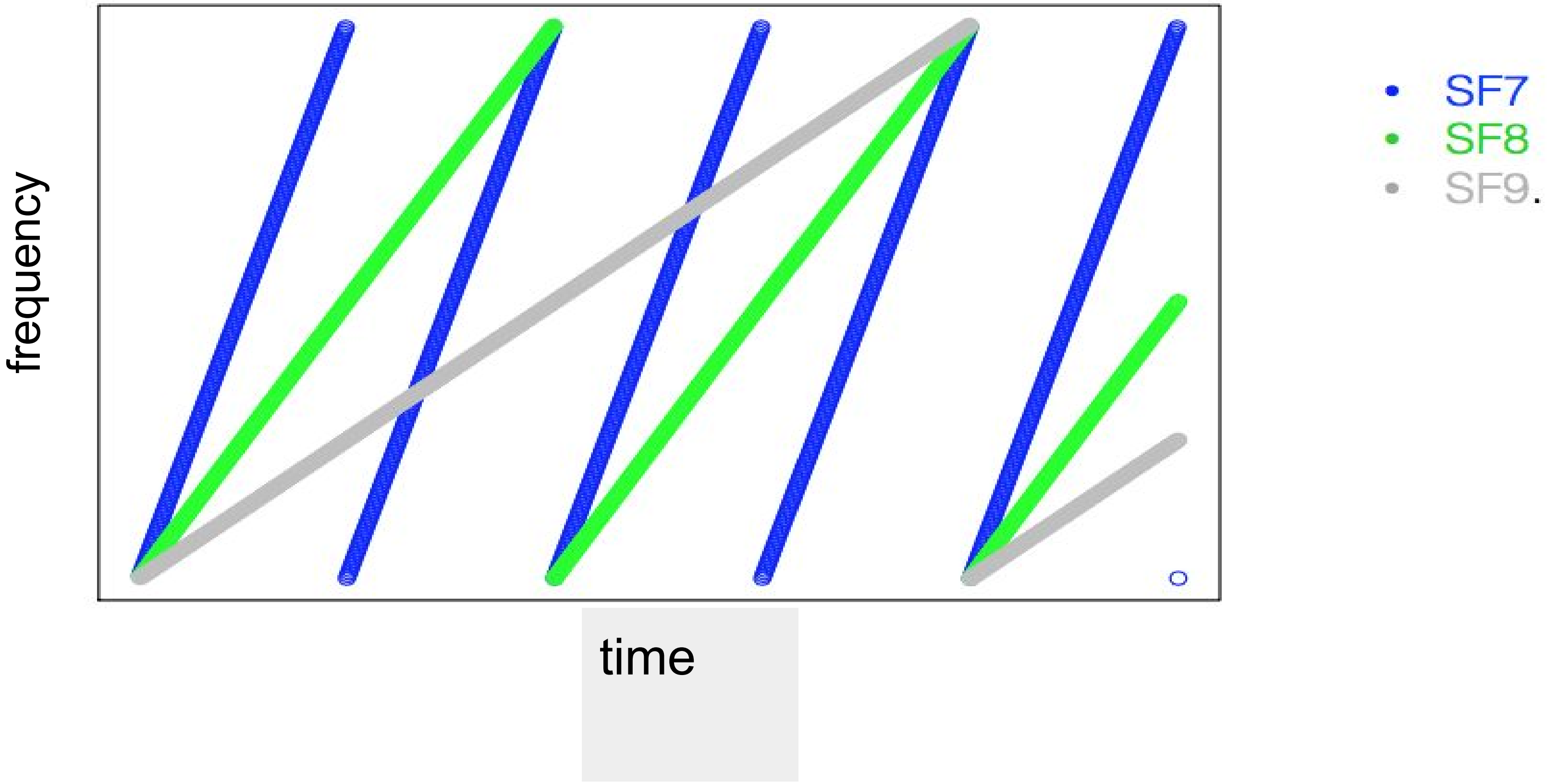
Adaptive Data Rate (ADR) at 125 kHz BW

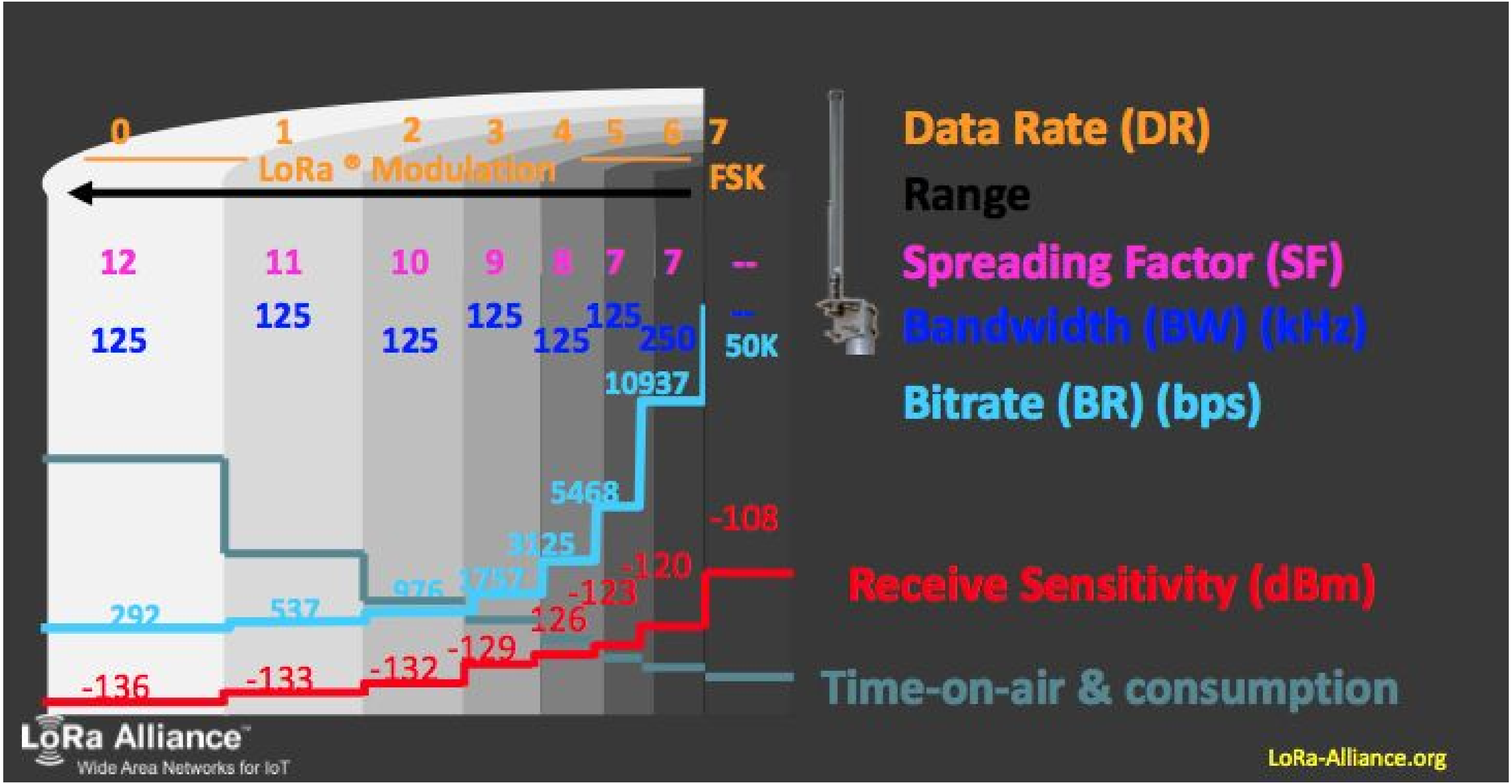
Spreading Factor	Signal/Noise	bit rate	ms per 10 byte packet
7	-7.5	5469	56
8	-10	3125	103
9	-12.5	1758	205
10	-15	977	371
11	-17.5	537	741
12	-20	292	1483



Sensitivity is proportional to S/N

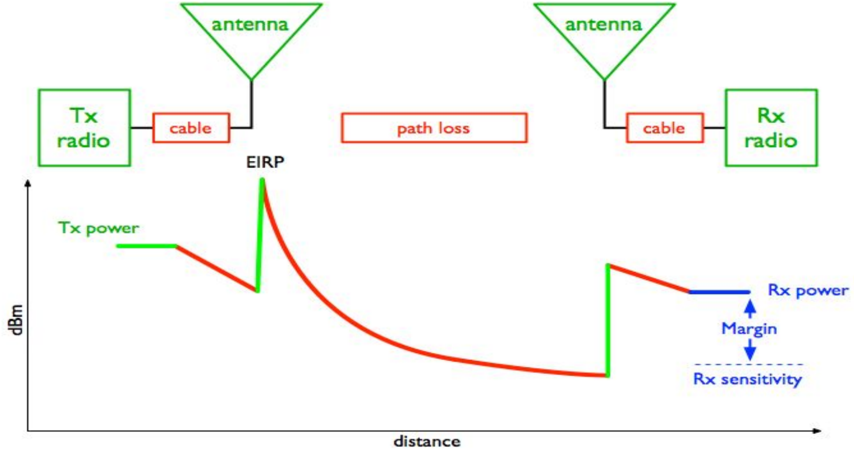
Spreading Factors





0 1 2 3 4 5 6 7
LoRa ® Modulation
FSK
Data Rate (DR)
Range
12 11 10 9 8 7 7 --
Spreading Factor (SF)
125 125 125 125 125 125 250 --
50K
Bandwidth (BW) (kHz)
10937
Bitrate (BR) (bps)
5468
3125
1757
976
537
292
-108
-120
-123
-126
-129
-132
-133
-136
Receive Sensitivity (dBm)
Time-on-air & consumption
LoRa Alliance
Wide Area Networks for IoT
LoRa-Alliance.org

LoRa link budget



Tx=14 dBm

BW = 125 kHz, S/N = -20 (for SF 12)

Assume Noise Figure = 6 dB

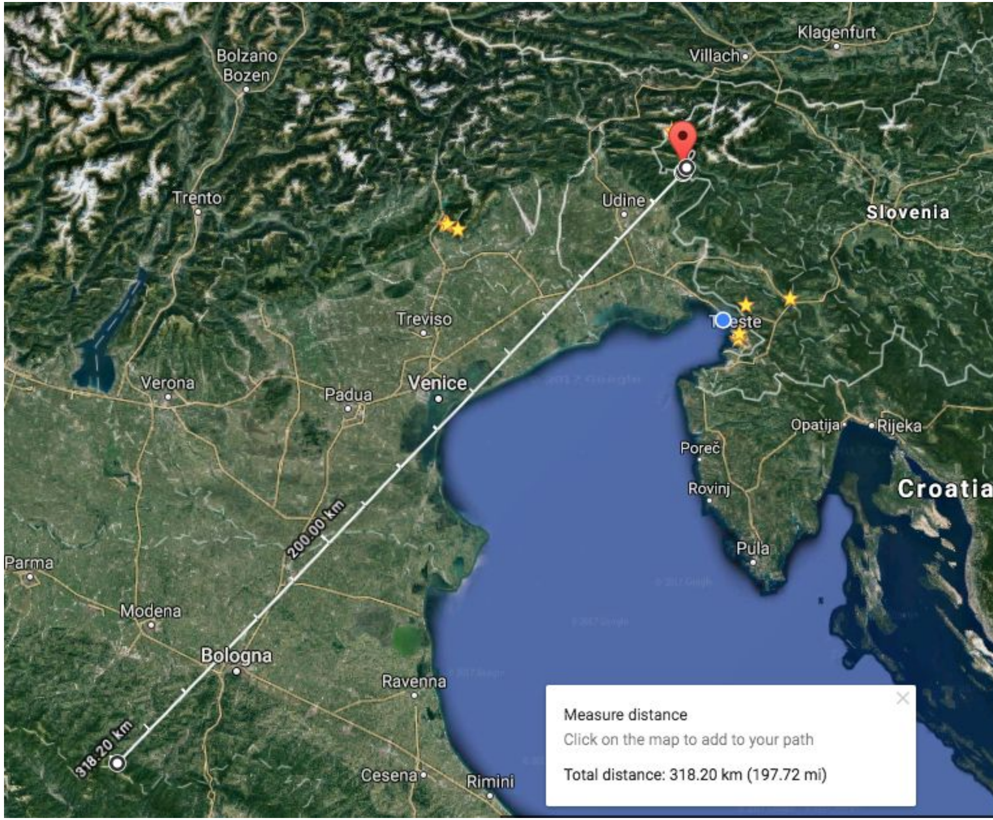
Sensitivity = $-174 + 10 \log_{10}(BW) + NF + S/N = -174+51+6-20 = -137$ dBm

Link budget for Europe: 14+137 = 151 dB

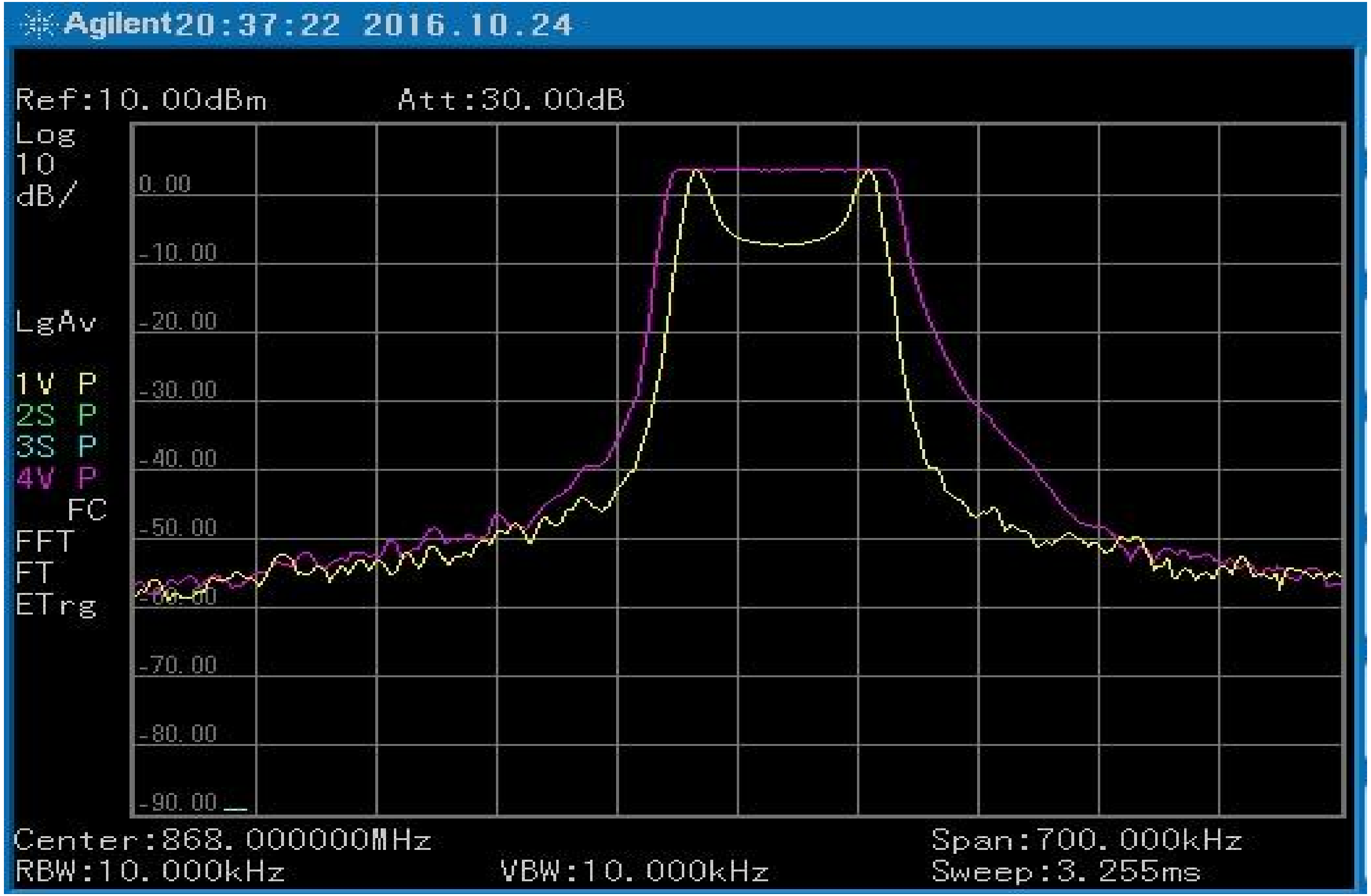
In US, up to -157 dB in the 900 MHz band

Range

- LoRa and SigFox: many kilometers
- 2G, typically 3 km, maximum 30 km
- 802.15.4 less than 100 m
- WiFi, typically 100 m, much higher values attainable with high gain antennas



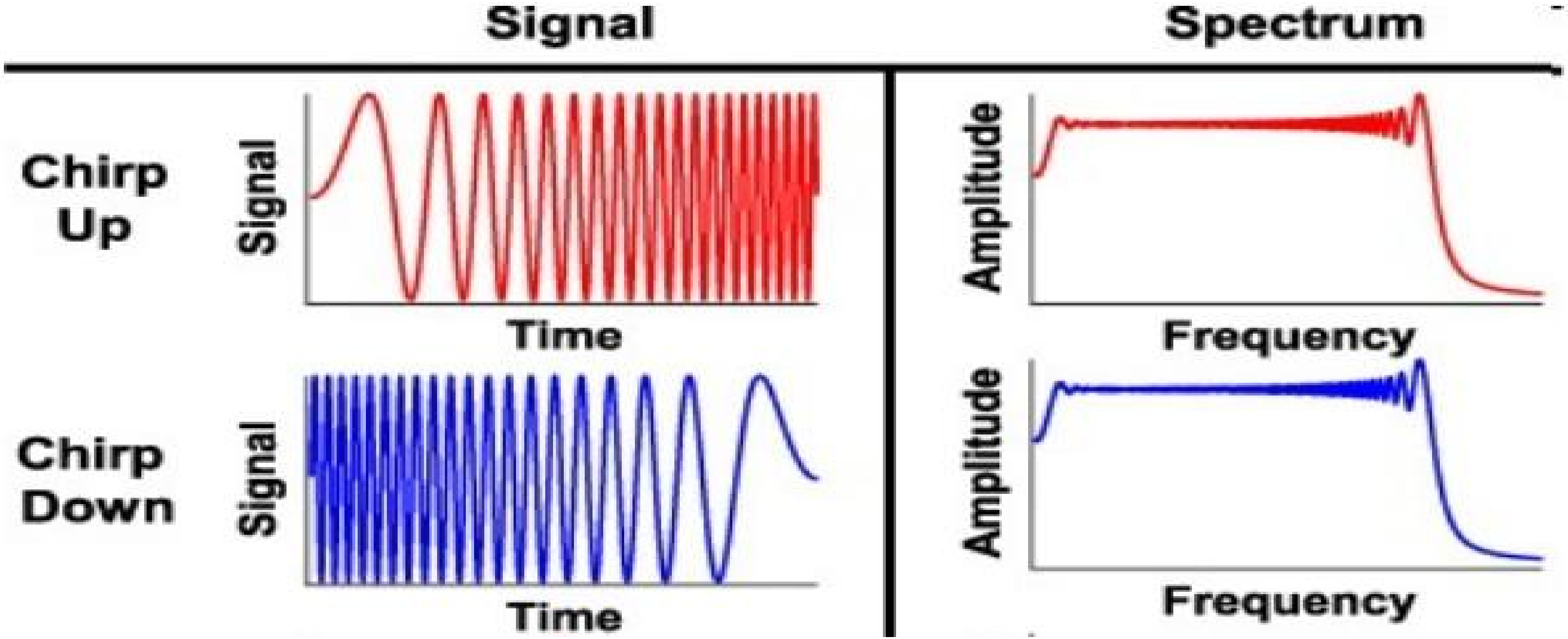
LoRa and FSK spectra



TCP/IP Networking layers

Layer number	Name
5	Application
4	Transport
3	Internet
2	Data Link
1	Physical

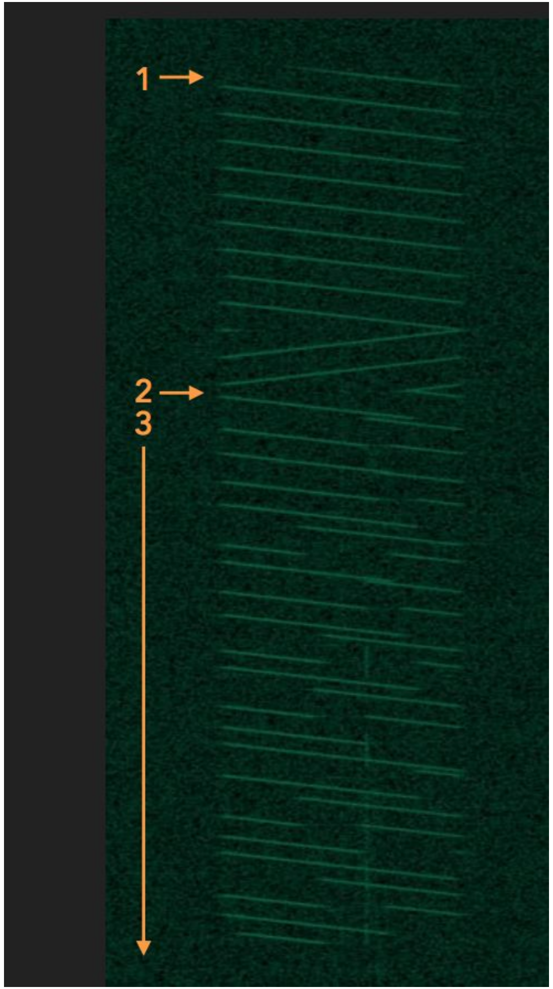
LoRa physical layer



Upper layers defined in LoRaWAN

LoRa physical layer

1. Preamble: 5 up-chirps followed by 2 down-chirps
2. Beginning of data
3. Information transmitted by the Instantaneous frequency transitions



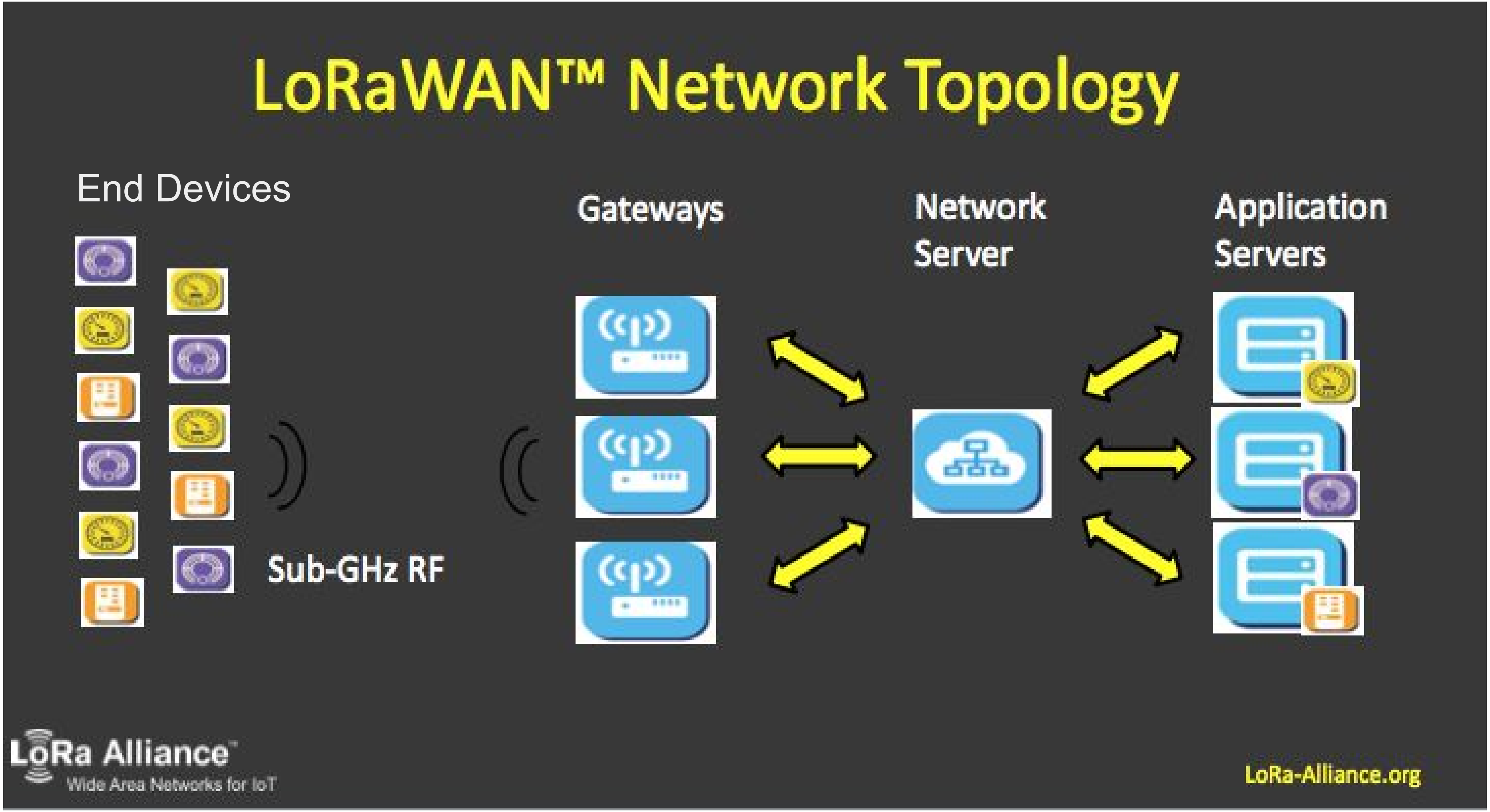
Chirp Spread Spectrum advantages

- Great link budget, low power transmission
- Resistant to multipath and other interference
- Orthogonality of spreading factors
- Simplified electronic for receiver synchronisation
- Robust against Doppler shift (mobile applications)

LoRaWAN

Communication protocol that uses LoRa physical layer

- Supports
  - Secure bidirectional traffic
  - Mobility
  - Localization


LoRaWAN™ Network Topology
End Devices
Gateways
Network
Server
Application
Servers
Sub-GHz RF
LoRa Alliance™
Wide Area Networks for IoT
LoRa-Alliance.org

LoRaWAN

LoRaWAN networks typically are laid out in a star-of-stars topology in which gateways relay messages between end-devices and a central network server at the backend.

Gateways are connected to the network server via standard IP connections while end devices use single-hop LoRa or FSK communication to one or many gateways.All communication is generally bi-directional, although uplink communication from an end- device to the network server is expected to be the predominant traffic.

To maximize both battery life of the end-devices and overall network capacity, the LoRa network infrastructure can manage the data rate and RF output for each end-device individually by means of an adaptive data rate (ADR) scheme.

LoRaWAN Messages

Uplink messages are sent by end-devices to the network server relayed by one or more gateways.

Each downlink message is sent by the network server to only one end-device and is relayed by a single gateway.

Following each uplink transmission the end-device opens two short receive windows. The receive window start times is a configured periods are the end of the transmission of the last uplink bit

A confirmed-data message has to be acknowledged by the receiver, whereas an unconfirmed-data message does not require an acknowledgment.

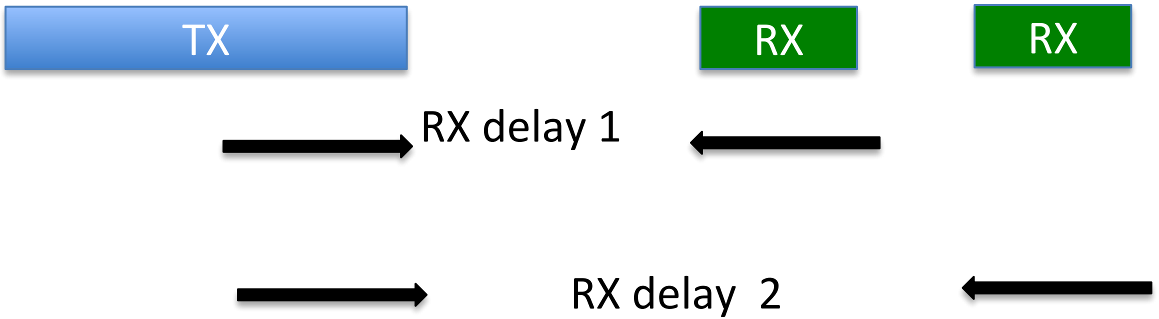
LoRaWAN Duty cycle example

A device just transmitted a 0.5 s long frame on one default channel.

This channel is in a sub-band allowing 1% duty-cycle.

This whole sub-band (868 – 868.6) will be unavailable for 49.5 seconds, but the same device can hop to another sub band meanwhile.

Down-stream transmission modes



Class A optimized for battery power
For low latency, use class B
For no latency, class C

Conclusions

IoT requires specific standards.

Current cellular not efficient.

WiFi and BLE have limited range.

LoRa and SigFox are widely used worldwide for long distance but with limited data rate.