Wireless Networking [ET4394]

Edition 2018: LoRa & LoRaWAN

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LoRa & LoRaWAN

Learning objectives:

- **LO1**: Introduction to LPWANs and LoRa
- **LO2**: Wireless compromise: Range-Power-Bitrate
- **LO3**: LoRaWAN MAC layer overview
- **LO4**: LoRa PHY layer (de)modulation

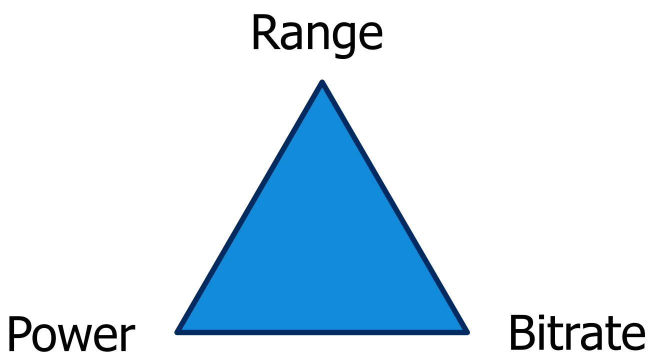
LoRa & LoRaWAN

What is it?

Communication standard for LPWAN

- Low Power Wide Area Network, optimized for IoT

Main compromise in wireless:



Choose two

LoRa approach:

Battery life ↑

Range ↑

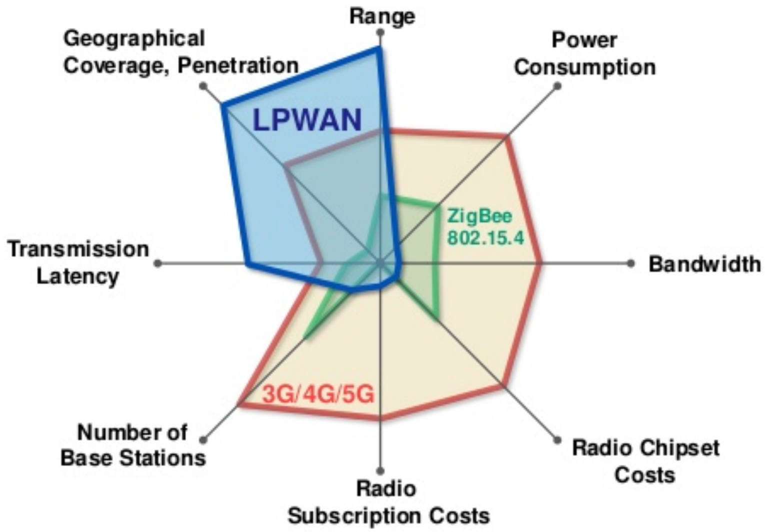
Duty cycle ↓

Bitrate ↓

LoRa & LoRaWAN

LPWANs

- High path loss budget → High sensitivity, Long range
- Low data rate & duty cycle → High latency, Low power



LPWAN – Peter R. Egli
www.slideshare.net/PeterREgli/lpwan

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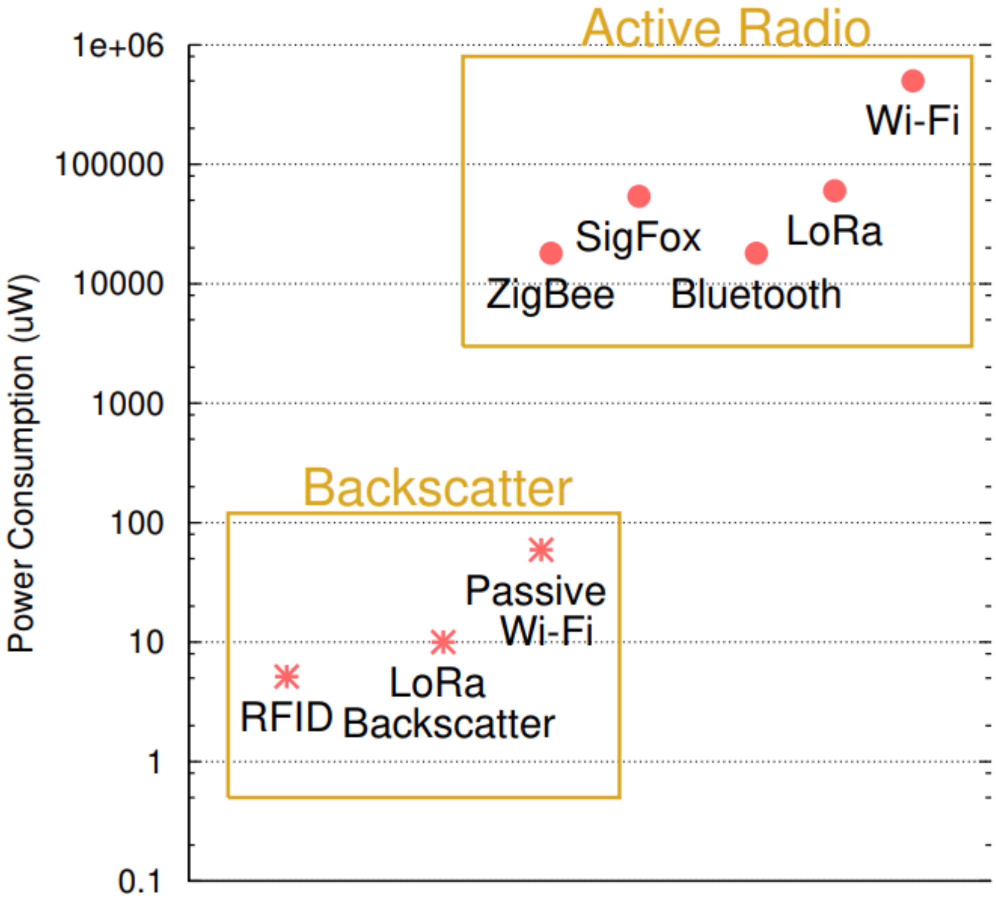
Power comparison



LoRa Backscatter: Enabling The Vision of Ubiquitous Connectivity
https://longrange.cs.washington.edu/files/loRaBackscatter.pdf

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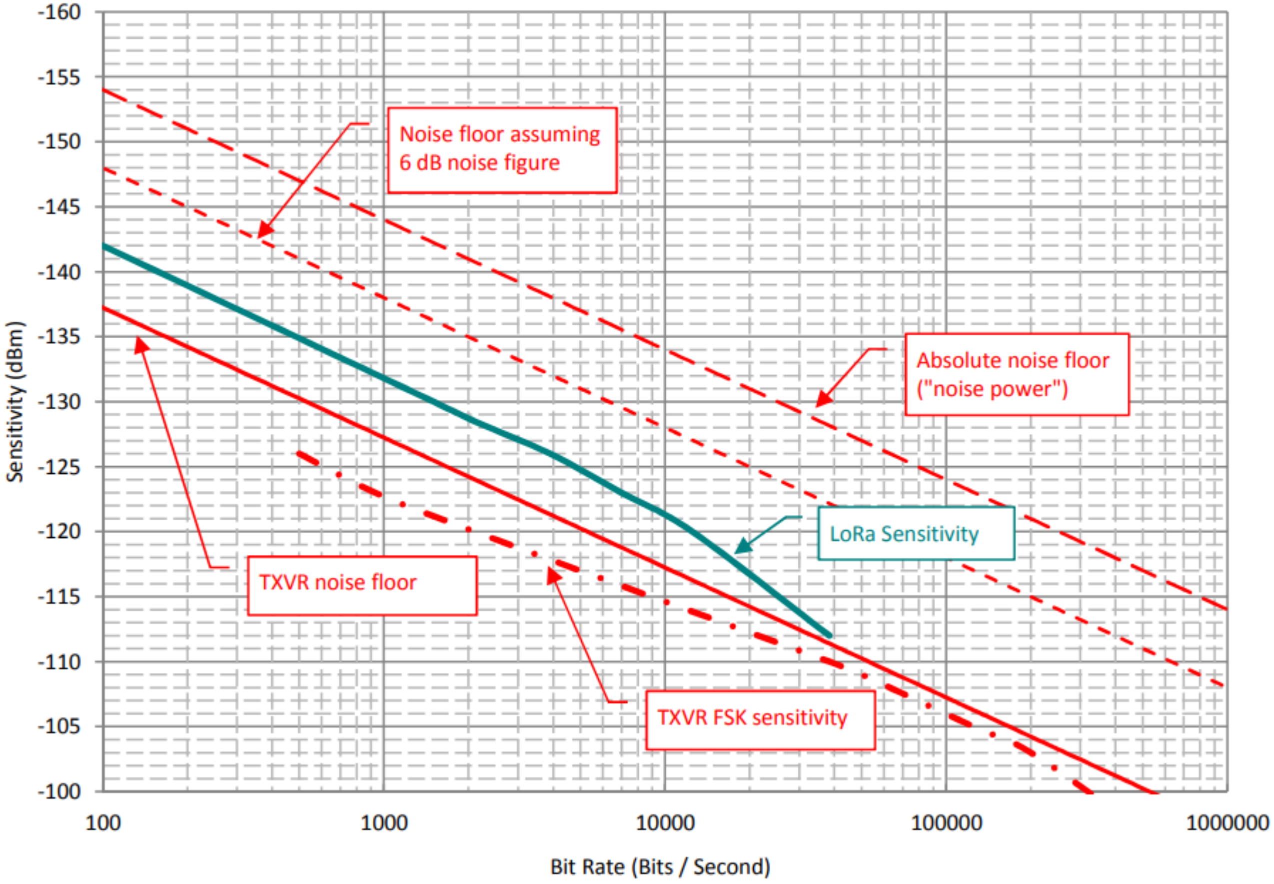
Sensitivity: LoRa vs FSK



Semtech AN1200.22: https://www.semtech.com/uploads/documents/an1200.22.pdf

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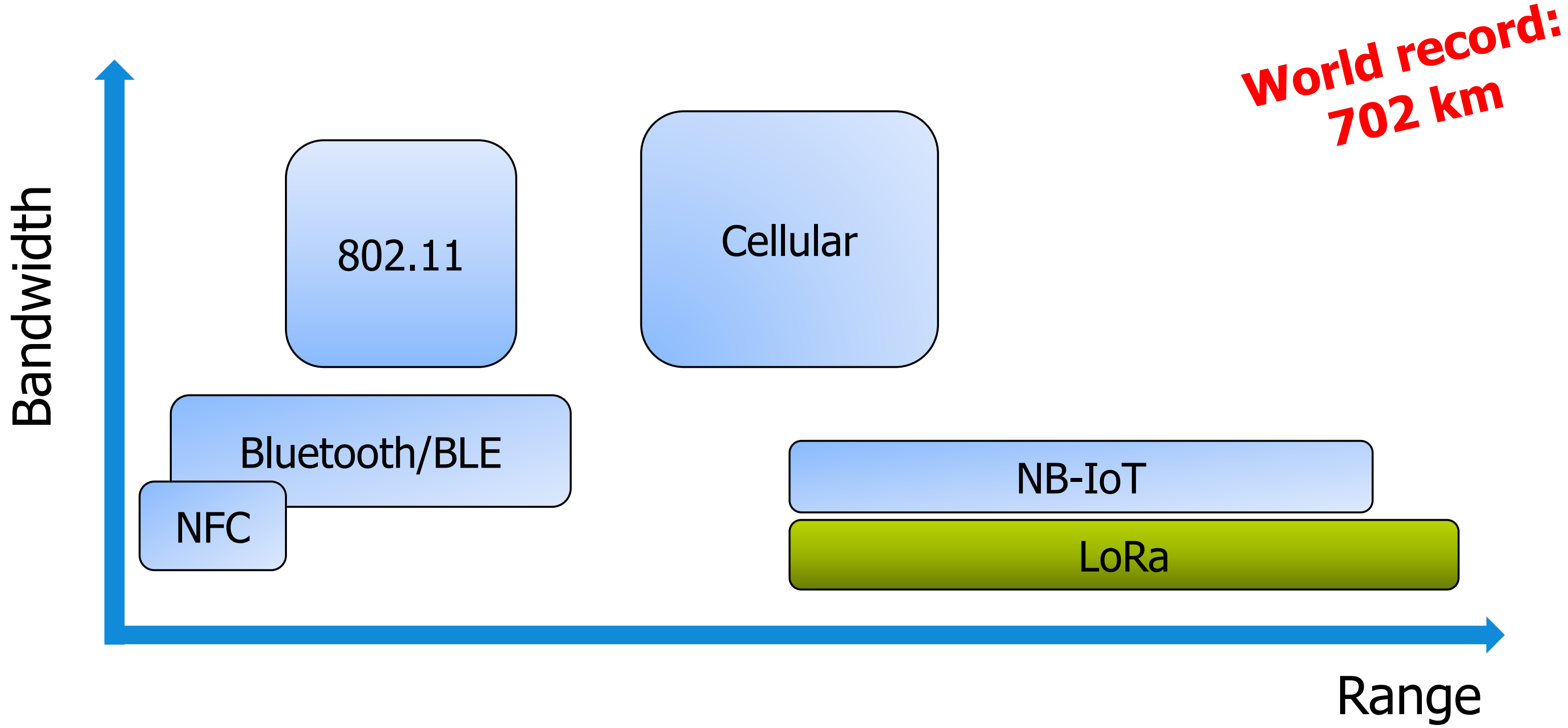
Where does it fit?



Up to years of battery life and a few km of range!

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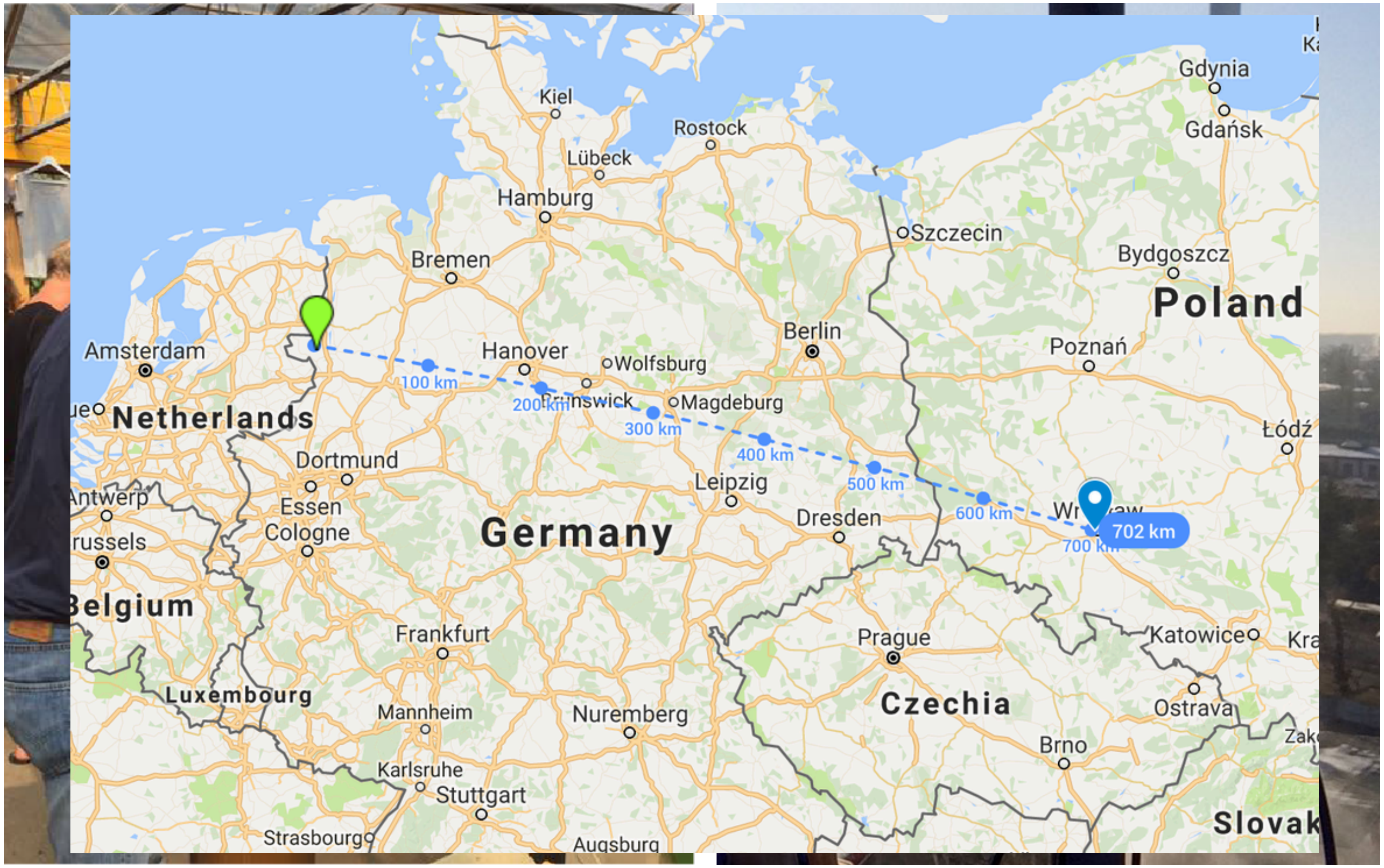
Distance world record



Helium balloon

38.7 km high
702 km away
14 dBm power

https://www.thethingsnetwork.org/article/ground-breaking-world-record-lorawan-packet-received-at-702-km-436-miles-distance

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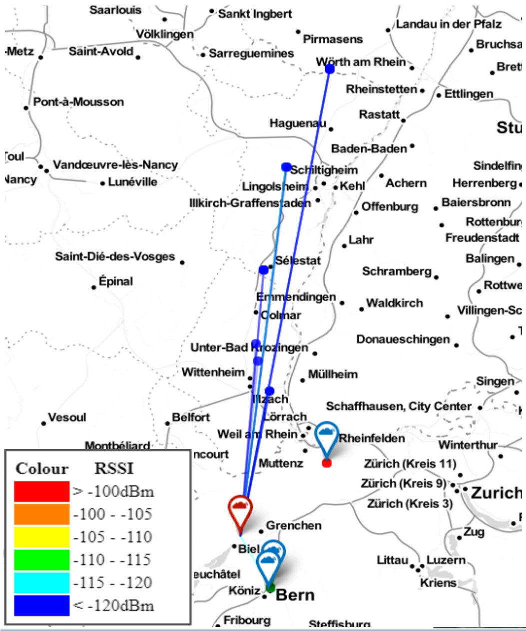
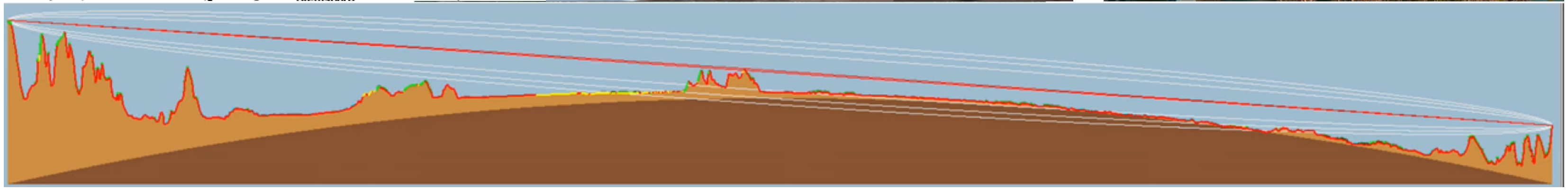
Distance world record: ground to ground

LOS: 212 km





https://youtu.be/adhWIo-7gr4

LoRa & LoRaWAN

How does it compare?

	WPAN		Cellular		LPWAN	
	BLE	Wi-Fi	3G	4G	NB-IoT	LoRa
Spectrum	Unlicensed	Unlicensed	Licensed	Licensed	Licensed	Unlicensed
Modulation	SS GFSK	OFDM Adaptive	SS Adaptive	OFDM Adaptive	QPSK	CSS Adaptive
Bandwidth	2 MHz	20/40 MHz	5 MHz	1,4-20MHz	180 kHz	125-500 kHz
Bitrate	1 Mbps	72 Mbps	27 Mbps	500 Mbps	250 kbps	27 kbps
Range	50 m	100 m	15 km	10 km	15 km	15 km

LoRa & LoRaWAN

Why so popular?

- Unlicensed spectrum (ISM band) & minimal infrastructure
- Relatively inexpensive hardware (~15-60€ end node)
- Semtech: analog & mixed signal company, owner of modulation patent and supplier of hardware
- The Things Network: crowdsourced community and infrastructure: www.thethingsnetwork.org/map
- Supported by LoRa Alliance: www.lora-alliance.org/member-list

RN2903 LoRa® Mote Board

http://www.microchip.com/DevelopmentTools/ProductDetails.aspx?PartNO=dm164139

LoRa Alliance™ SEMTECH THE THINGS NETWORK

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Spectrum regulations:

- Output power: up to 14 dBm
- Duty cycle: 1% transmit
- TTN establishes:
  - 10 downlink messages per day (ACK incl.)
  - 30 seconds air-time per device per day: 20 - 500 messages per day with 10 bytes of payload

https://www.thethingsnetwork.org/forum/t/limitations-data-rate-packet-size-30-seconds-uplink-and-10-messages-downlink-per-day-fair-access-policy/1300/6

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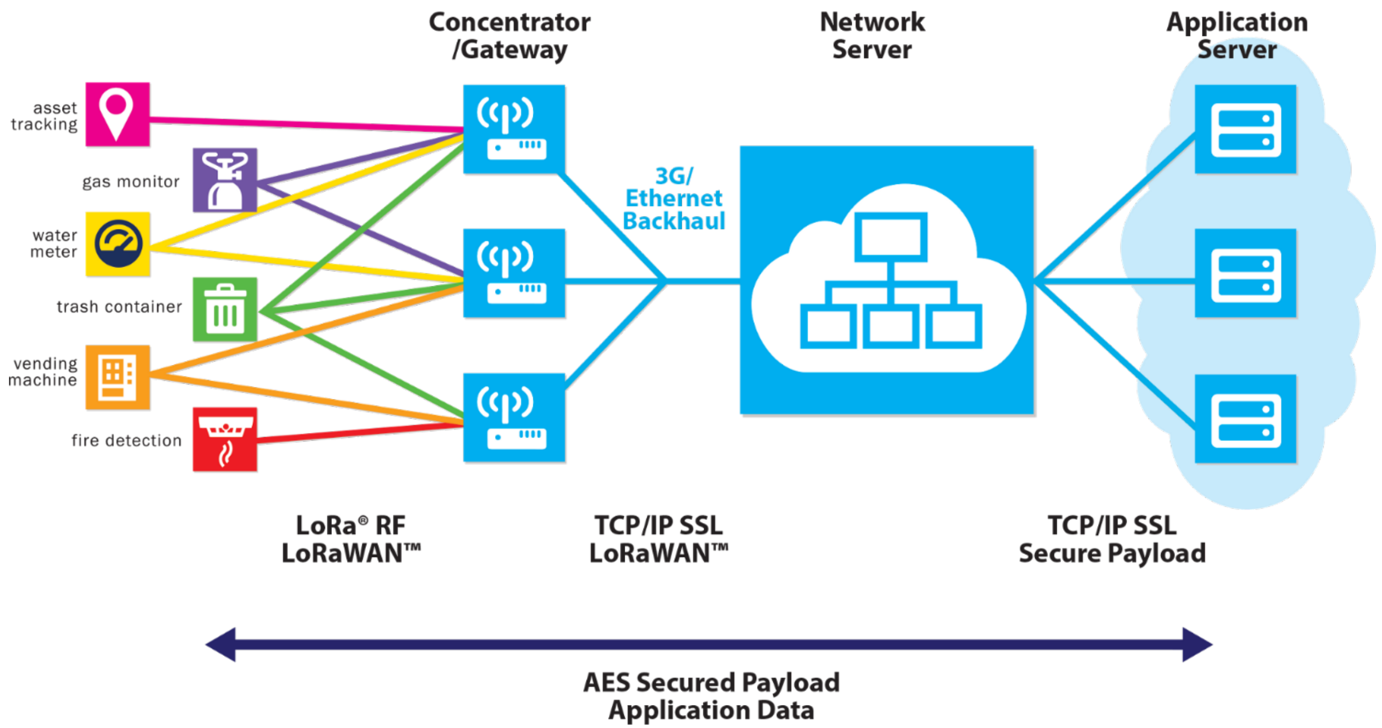
Network topology



Developed by Semtech in 2014-2015

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Applications

- Asset tracking: cattle, trucks, machinery, airport…
- Remote monitoring: pollution, agriculture, liquid detection…
- Home security: fall detector, sensor-alarm integration…
- Smart cities: parking management, lighting…

semtech.com

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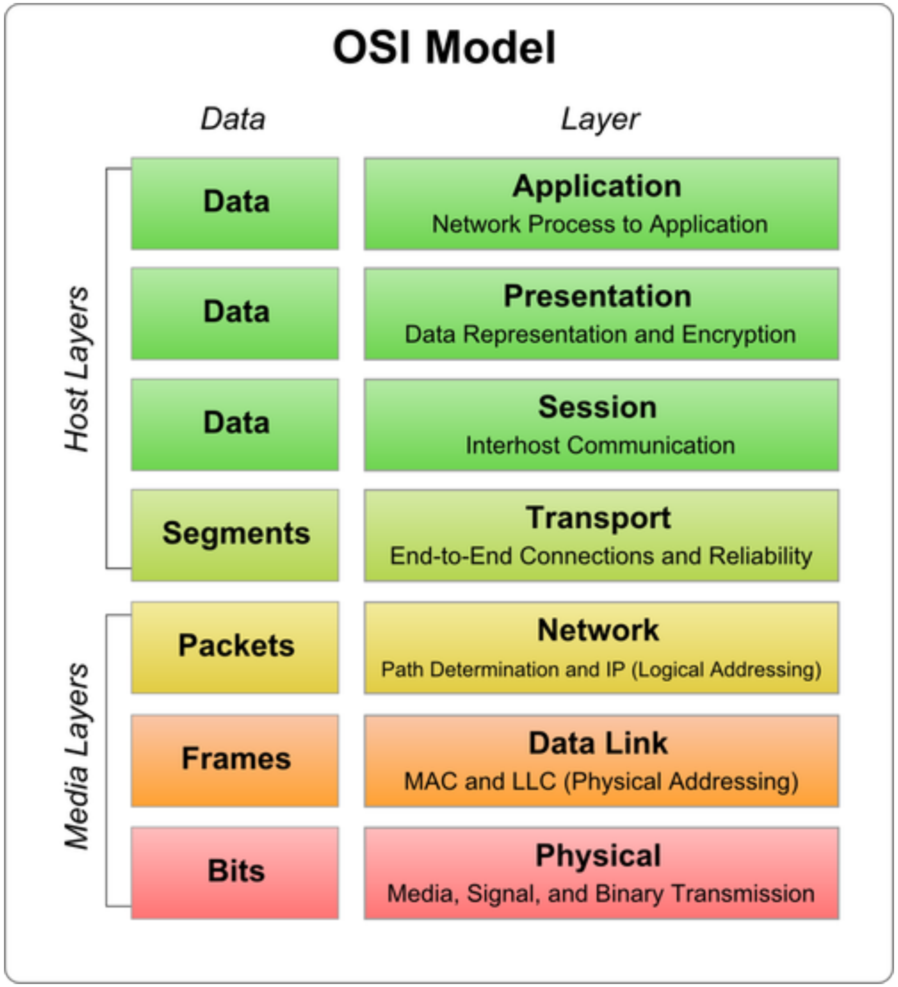
Example LoRa project

Vinduino: a wine grower's water saving project

Vinduino LoRa LAN Gateway
https://hackaday.io/project/6444-vinduino-a-wine-growers-water-saving-project/log/46095-vinduino-lora-lan-gateway

LoRa & LoRaWAN

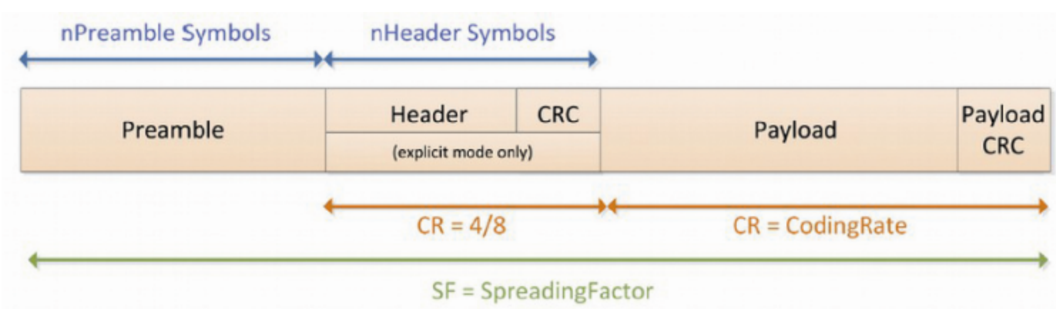
- **LoRa:**
  - **Physical**
- **LoRaWAN:**
  - **MAC**
  - **Network**
  - **Application**



LoRa

MAC layer

- Bidirectional communications
- Unicast messages
- Small payloads, long intervals

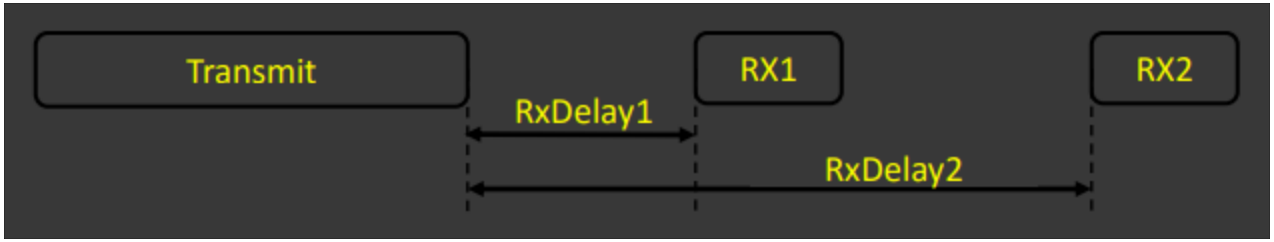


LoRa-Alliance.org

LoRa

MAC layer

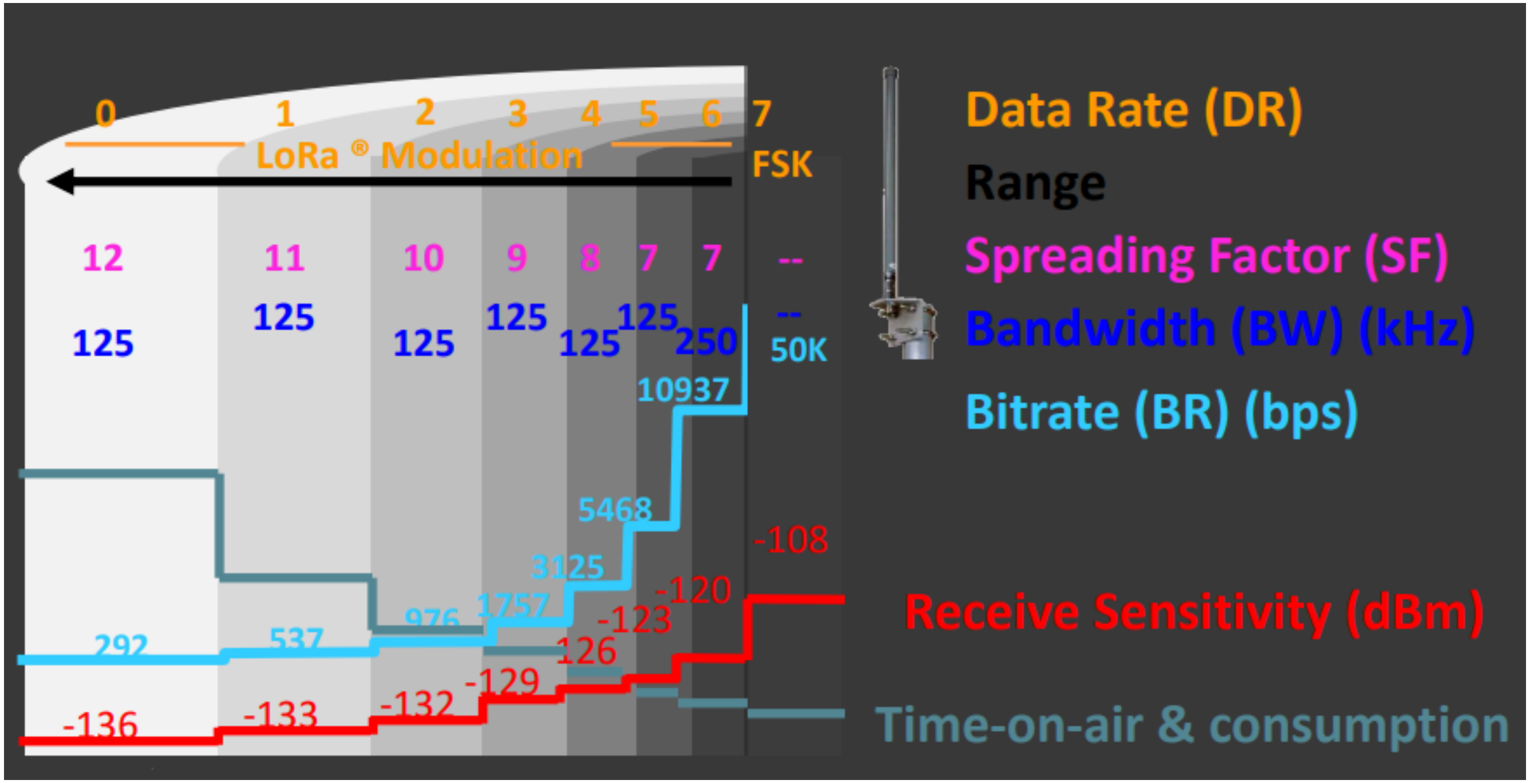
- End-device initiates communication (uplink)
- Server communicates with end-device (downlink) during predetermined response windows
- SF and data rate negotiation happens



LoRa-Alliance.org

LoRa

MAC layer



LoRa-Alliance.org

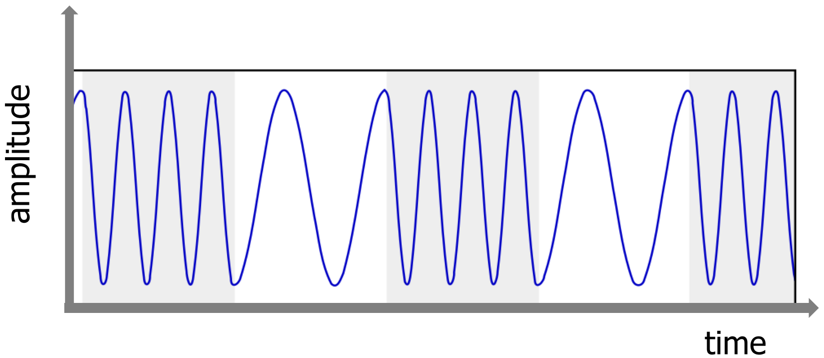
LoRa

Physical layer

- Modulation
  - Chirp Spread Spectrum (CSS)
- Encoding
  - Gray indexing
  - Whitening
  - Interleaving
  - Forward Error Correction

LoRa

- **Chirp Spread Spectrum (CSS)**
  - M-FSK modulation on top of a chirp signal.



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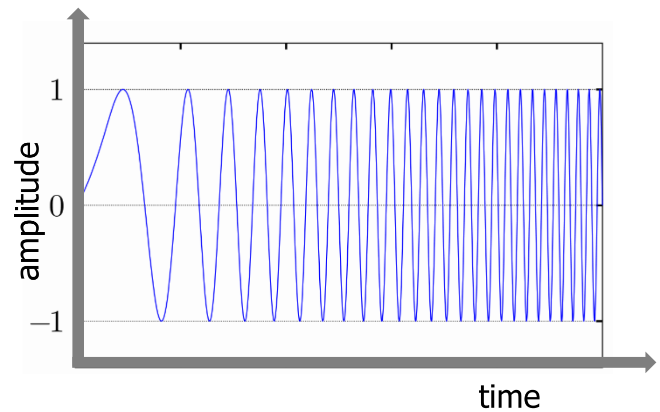

LoRa

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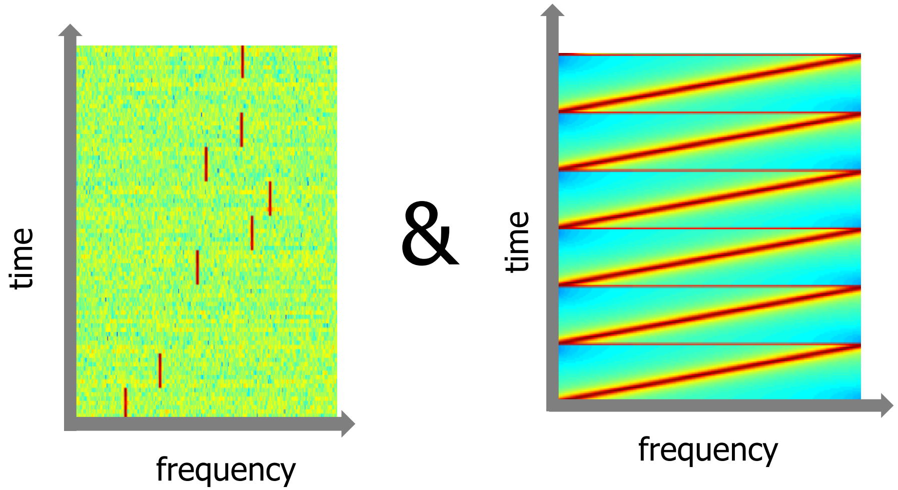

LoRa

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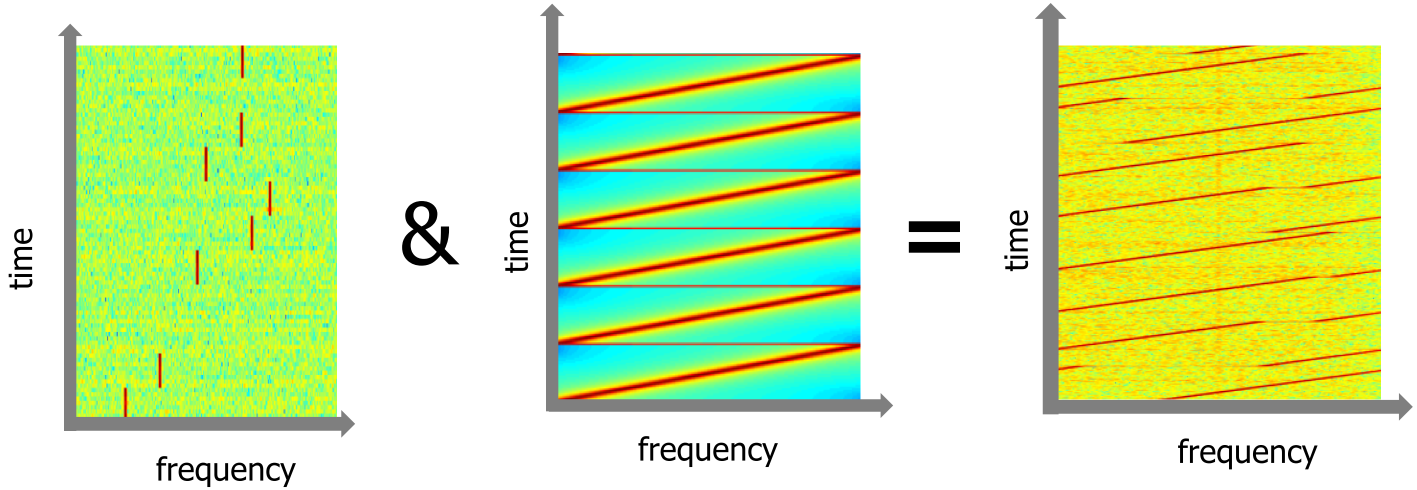
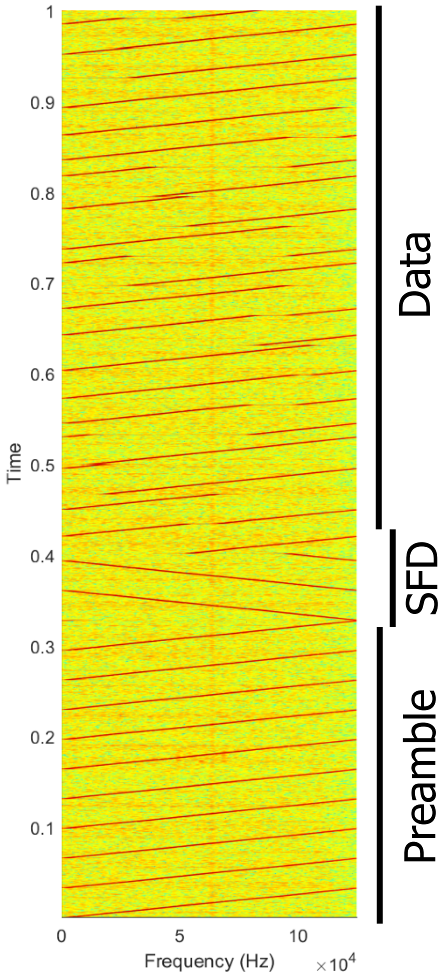


LoRa

- **Modulation details**
  - Bandwidth: 125 / 250 / 500 kHz
  - Spreading factor: 7-12 bits/symbol
  - Chirp rate: $\frac{BW}{2^{SF}}$, inverse of the symbol time
  - Preamble/training sequence: 10 up-chirps
  - Start of Frame Delimiter (SFD): 2,25 down-chirps

Link budget: 154 dB

Data rate: 0,25 to 27 kbps



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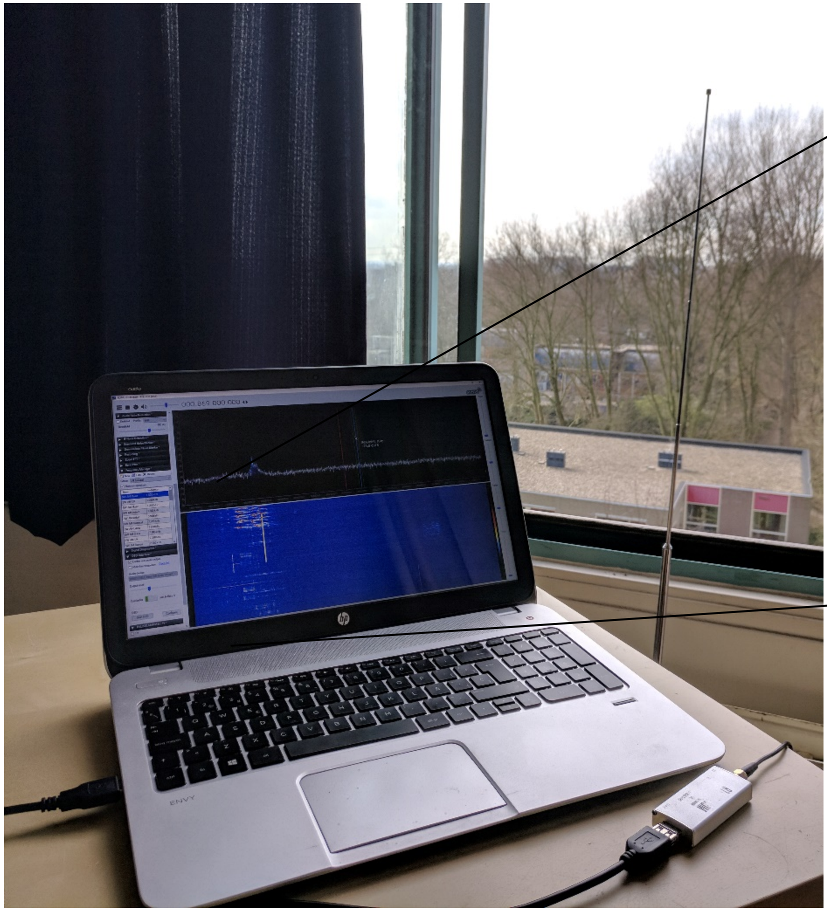
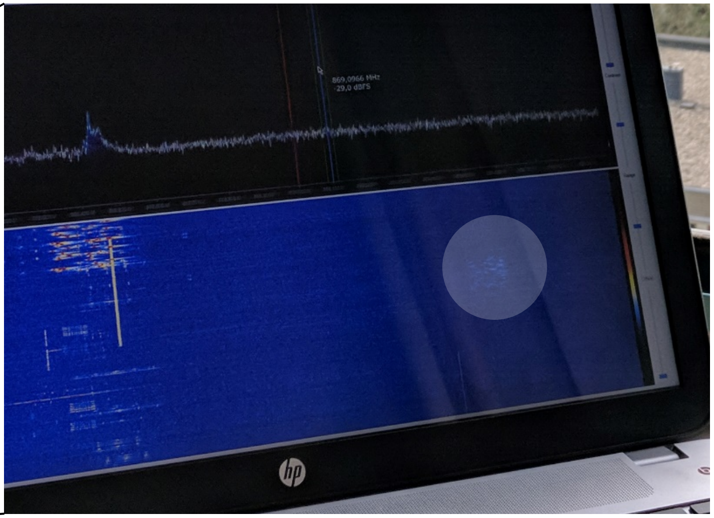
Capturing station



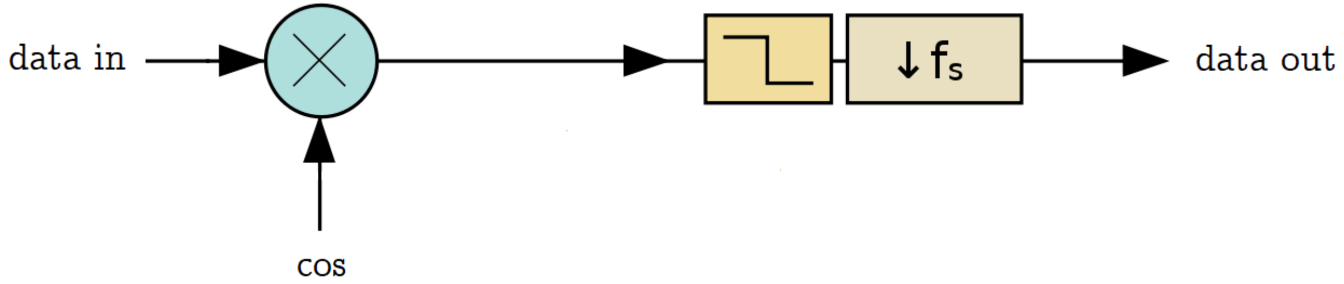


SDR# Software Defined Radio

LoRa

Demodulation

- Digital Down-Conversion (DDC) to channelize and resample:
    - Baseband conversion
    - Low-pass filtering
    - Decimation



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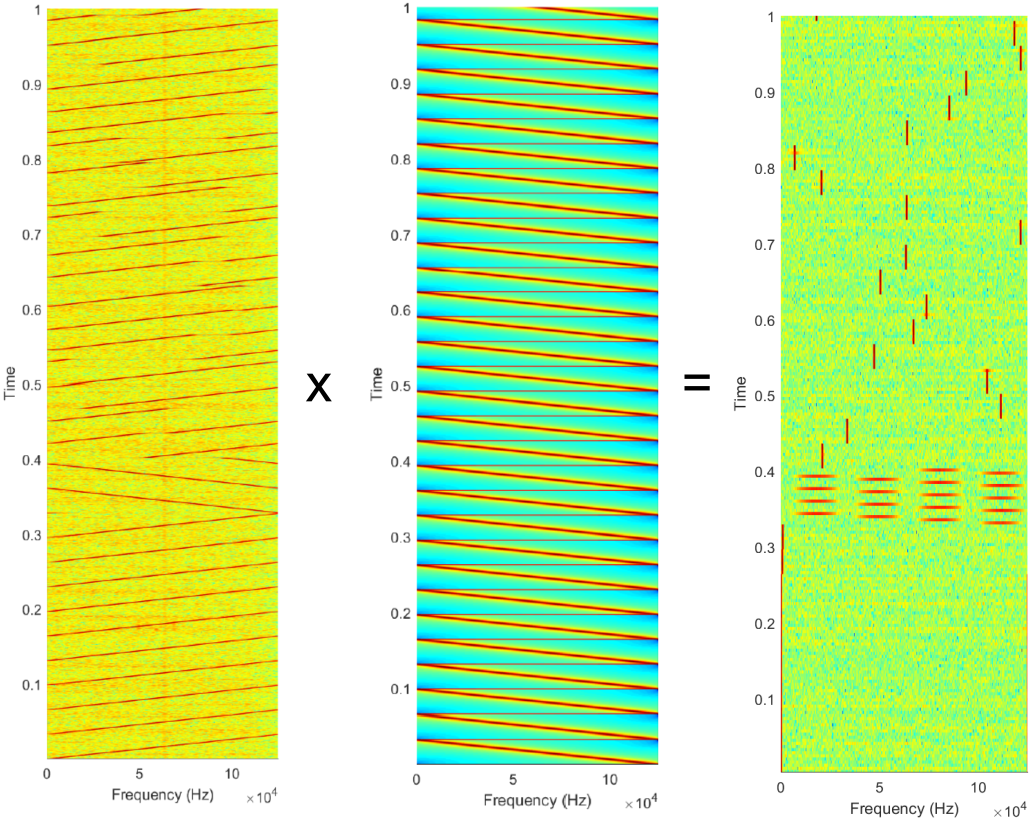
Demodulation

- De-chirping:
  - Generate local chirp of same rate.
  - Multiply incoming signal with local down-chirp.

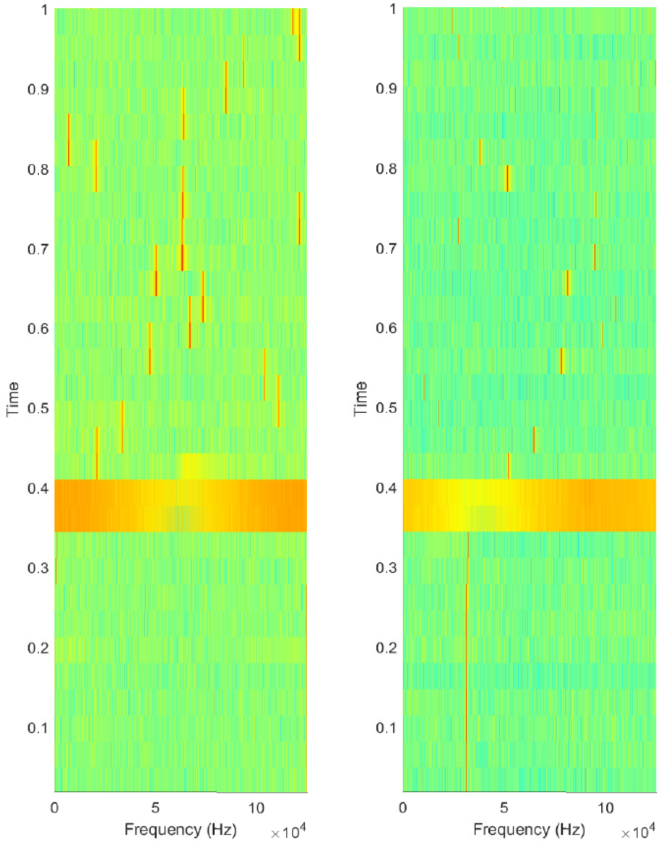
Result: M-FSK with $M=2^{SF}$



LoRa

Demodulation

- Synchronization and alignment
  - Start of the signal is identified with a correlation function (good correlation properties of chirp signals). Add more info about the correlation process.
  - Align data segment: power was spread over adjacent symbols due to 2,25 extra symbol times in the SFD. More explanation on this point.



LoRa

Demodulation

- Extraction of symbols and bits
  - Spectrogram set up to return one sample per symbol per frequency bin (as in last slide). Add extra explanation and supporting image.
  - A symbol corresponds to the frequency index of the strongest spectral component for each symbol time.
  - Symbols are translated into bits, decoding awaits.

0	'000000000000'
0	'000000000000'
0	'000000000000'
0	'000000000000'
0	'000000000000'
0	'000000000000'
0	'000000000000'
0	'000000000000'
24	'000000011000'
32	'000000100000'
3105	'110000100001'
2504	'100111001000'
696	'001010111000'
73	'000001001001'
3360	'110100100000'
3372	'110100101100'
1704	'011010101000'
2517	'100111010101'
1692	'011010011100'
468	'000111010100'

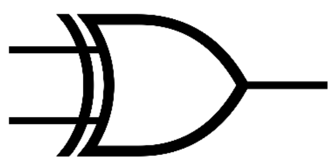
LoRa

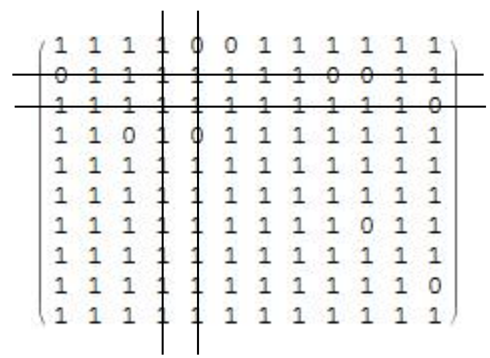
Decoding

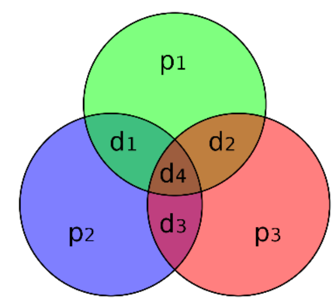
- Grey indexing: eases error correction, adjacent symbols differ by one bit
- Whitening: introduces randomness, data is XOR'd with random number
- Interleaving: scrambles bits, matrix read by columns/rows
- Forward Error Correction: adds parity bits to detect and correct flipped bits

	4	3	2	1
0	0	0	0	0
1	0	0	0	1
2	0	0	1	1
3	0	0	1	0
4	0	1	1	0
5	0	1	1	1
6	0	1	0	1
7	0	1	0	0

https://en.wikipedia.org/wiki/Gray_code







https://en.wikipedia.org/wiki/Hamming_code

LoRa

Known implementations:

- Reverse engineering LoRa by Matt Knight:

https://static1.squarespace.com/static/54cecce7e4b054df1848b5f9/t/57489e6e07eaa0105215dc6c/1464376943218/Reversing-Lora-Knight.pdf

References:

- LoRa modulation basics by Semtech:

https://www.semtech.com/uploads/documents/an1200.22.pdf

- Video explanation on LoRa’s CSS:

https://youtu.be/dxYY097QNs0