A Brief Introduction to LoRa™

Simon Pirkelmann

imaginärraum

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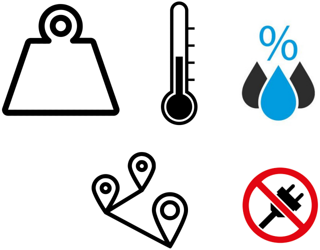
Outline

Motivation

- Example: monitor well-being of honey bees



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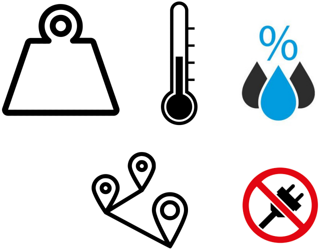

- Requirements:
  - Low data rate (a few bytes per day)
  - Low power consumption
  - Low cost
  - Long range

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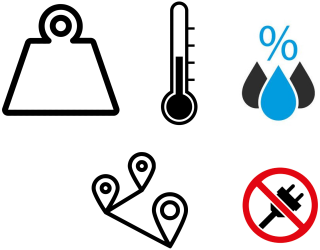

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Options:

- Data line (e.g. ethernet)
- Wifi, Bluetooth
- Cellular

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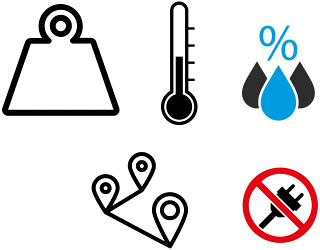
- Example: monitor well-being of honey bees



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- Solution: LPWAN (**L**ow-**P**ower **W**ide-**A**rea **N**etwork)
  - **LoRa**, **LoRaWAN**, **TheThingsNetwork**
  - SigFox, NB-IoT, Weightless, ...

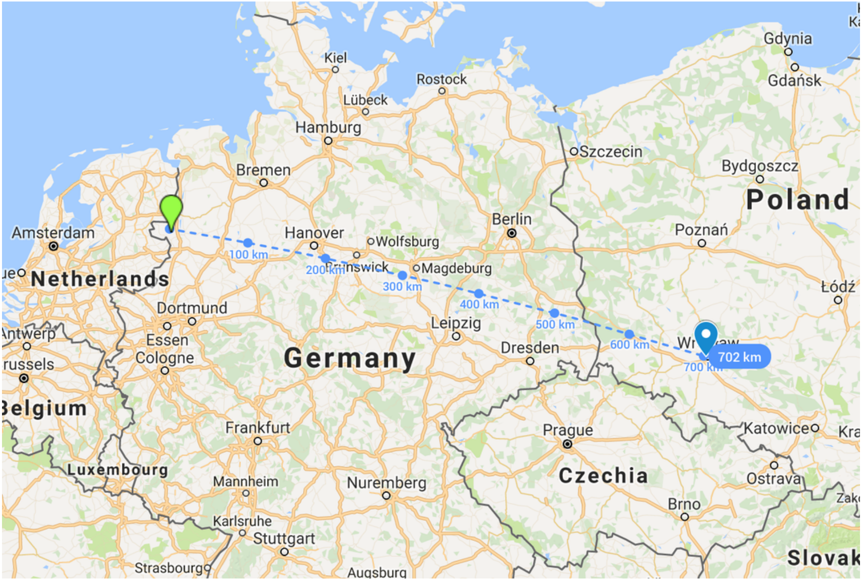
LoRa Facts

- Developed by **Semtech** (originally by Cycleo)
  Note: parts of the PHY layer are **proprietary**!
- Frequency: **868 MHz SRD** band (in the EU)
- **25 mW** transmission power
- Bandwidth: **125** to **500 kHz**
- Data rate between **250 Bit/sec** and 21 **kBit/sec**
  BUT: not made for a lot of data
- Low cost: $\sim$**10 EUR** CAPEX (for nodes), almost no OPEX
- Low power: devices can last **years on battery**
- Long distance: up to **10 km** range

https://www.thethingsnetwork.org/docs/lorawan/

LoRa Facts

LoRa distance record



LoRa facts

LoRa is **NOT** for:

- Realtime data - only small packets, every couple of minutes
- Phone calls - you can do that with GPRS/3G/LTE
- Controlling lights in your house - check out ZigBee or BlueTooth
- Sending photos, watching Netflix - check out WiFi

Important: LoRa™ $\leftrightarrow$ LoRaWAN™ $\leftrightarrow$ THE THINGS NETWORK

- **LoRa**: PHY layer $\Rightarrow$ modulation technique
- **LoRaWAN**: Network protocol
- **TheThingsNetwork (TTN)**: Network server, handles routing of data to the *cloud*

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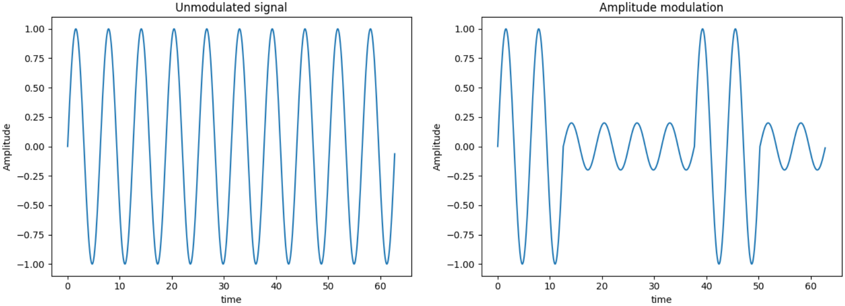
https://www.thethingsnetwork.org/docs/lorawan/

Digital modulation

- **A**mplitude **S**hift **K**eying (ASK)



Digital modulation

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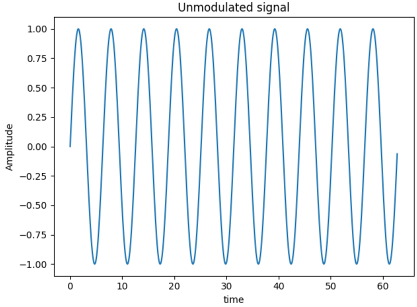
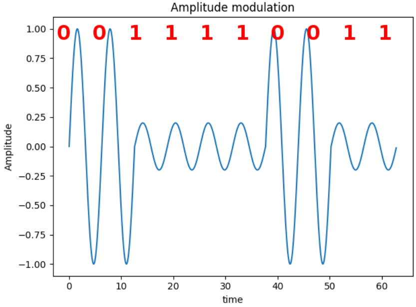
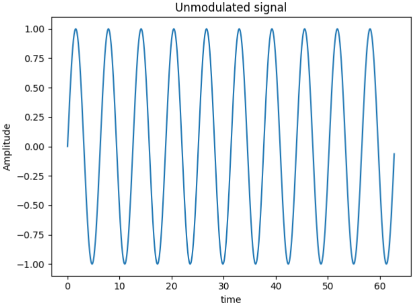
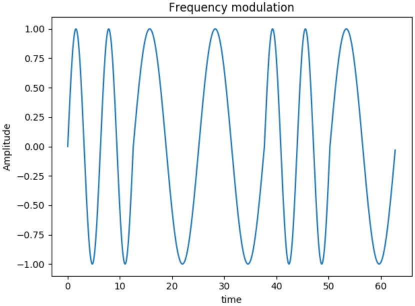




Digital modulation

- **F**requency **S**hift **K**eying (FSK)





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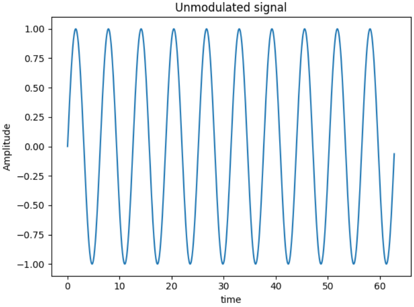
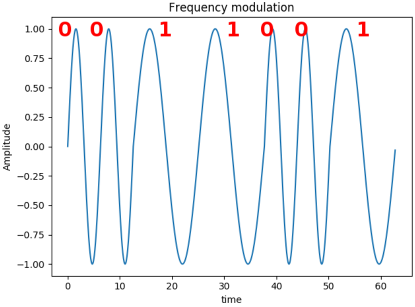
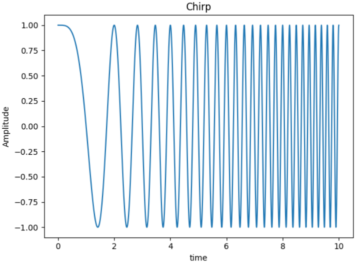
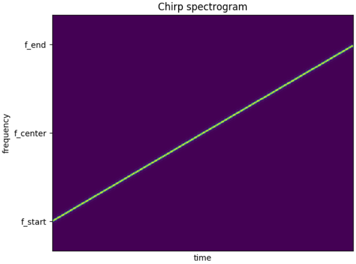




Digital modulation

- Used by LoRa: **C**hirp **S**pread **S**pectrum (CSS) modulation

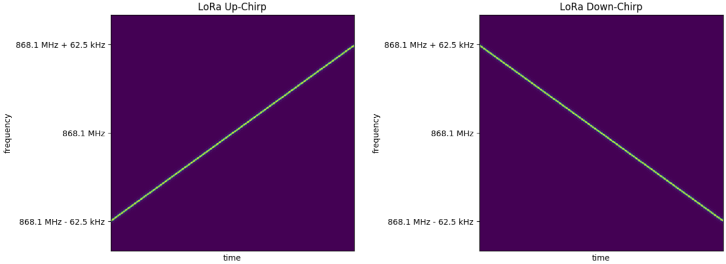




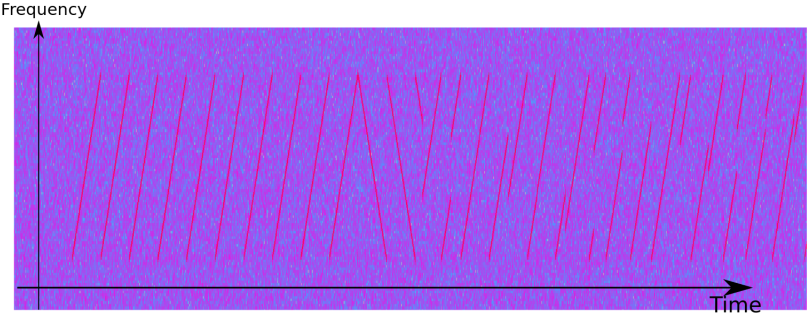
- Chirp = frequency change over time

LoRa modulation

- LoRa uses **Up-Chirps** (frequency increases) and **Down-Chirps** (frequency decreases)

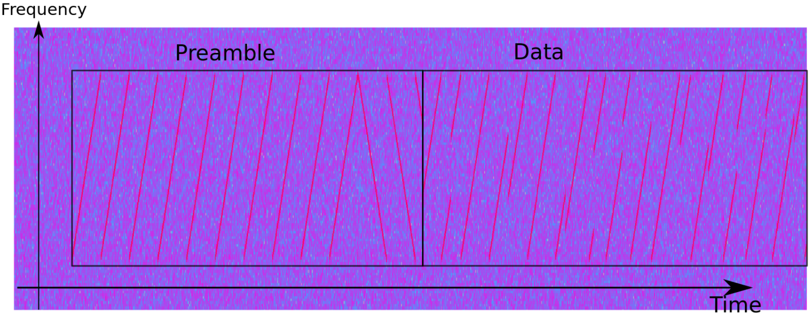


Example LoRa packet



Thanks Valentin and Stefan (DM4SG) for providing this data

Example LoRa packet



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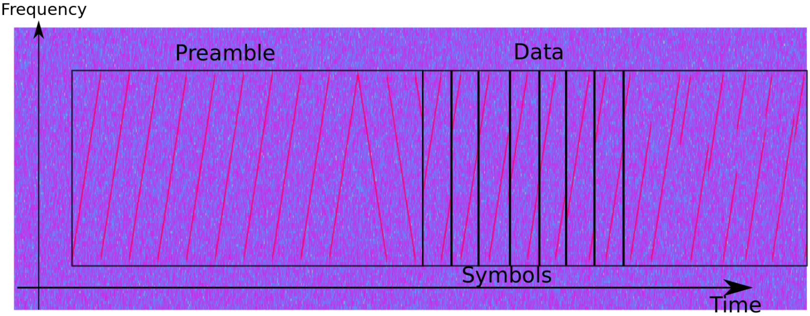

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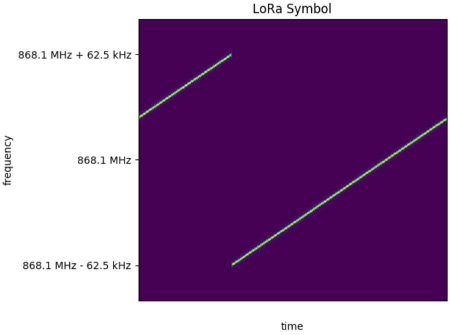
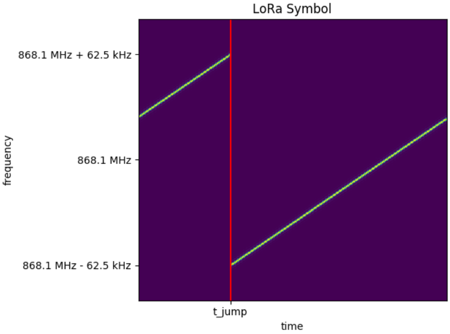
Chirps and Symbols

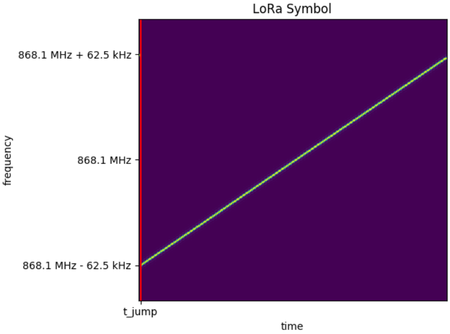


Chirps and Symbols



Time of frequency jump determines which data is encoded

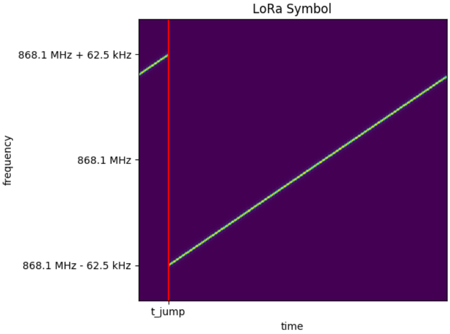
Chirps and Symbols



Time of frequency jump determines which data is encoded

Example: `data = 00000`

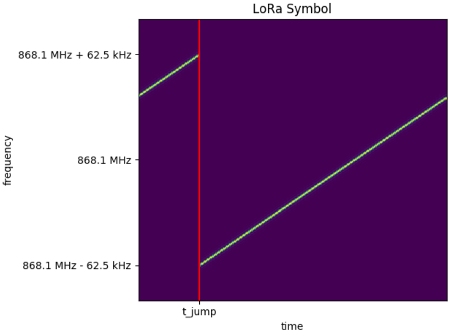
Chirps and Symbols



Time of frequency jump determines which data is encoded

Example: `data = 00010`

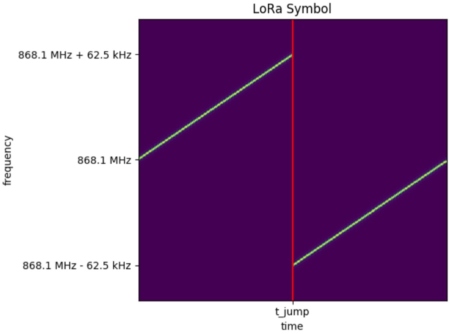
Chirps and Symbols



Time of frequency jump determines which data is encoded

Example: `data = 00011`

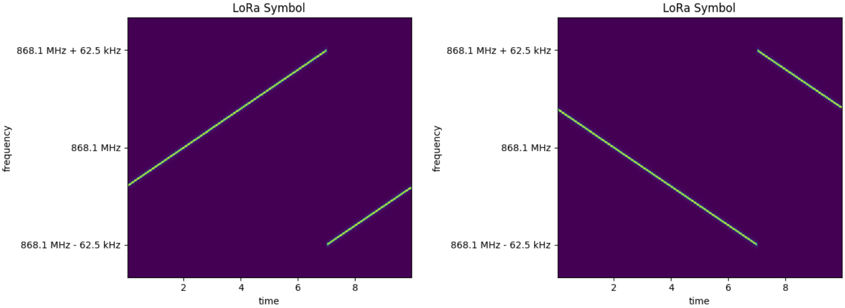
Chirps and Symbols



Time of frequency jump determines which data is encoded

Example: `data = 10110`

Chirps and Symbols

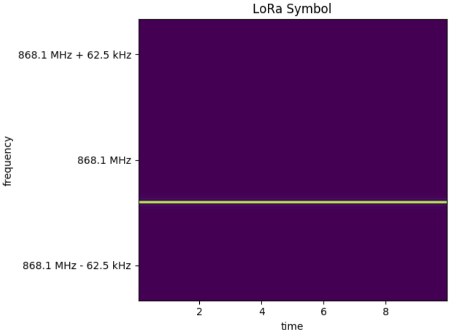


Time of frequency jump determines which data is encoded

Demodulation:

- De-chirp signal by multiplying (mixing) with conjugate chirp
- Fourier Transform
- Alignment using detect sequence at start of transmission

Chirps and Symbols



Time of frequency jump determines which data is encoded

Demodulation:

- De-chirp signal by multiplying (mixing) with conjugate chirp
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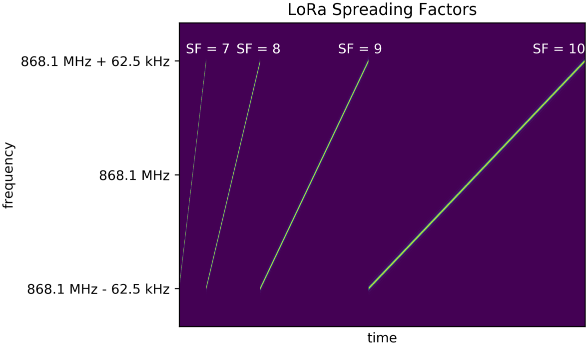
Spreading factor

- Number of bits per symbol is determined by **spreading factor** (SF)



- Possible values: SF7 - SF12
  - SF7: 7 bits per symbol
  - SF12: 12 bits per symbol
- Spreading factor influences max. range

Demodulation

- De-chirp signal by multiplying (mixing) with conjugate chirp
- Fourier Transform

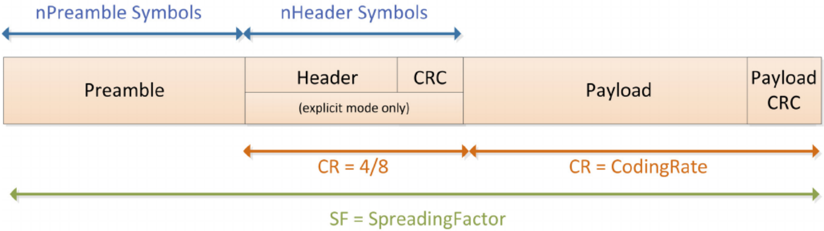
Forward error coding

- For each symbol several **parity bits** are added (= redundant information)
  Reason: allows to detect and fix errors that occur during transmission (due to interference, etc.)
- **Coding rate** determines number of parity bits:

$$\begin{aligned} \text{CR } 4/5 &: \text{ of 5 bits transmitted, 4 bits are actual data} \\ &\vdots \\ \text{CR } 4/8 &: \text{ of 8 bits transmitted, 4 bits are actual data} \end{aligned}$$

- Additionally: **C**yclical **R**edundancy **C**heck (CRC)

LoRa package format



- Header: contains information about
  - payload length
  - coding rate
  - CRC present?
- Implicit header mode: no header sent

Source: SX1276/77/78/79 datasheet

Data rate and air time

- Data rate depends on bandwidth (BW), spreading factor (SF) and coding rate (CR)

Symbol duration:

$$T_{sym} = \frac{2^{SF}}{BW}$$

Symbol rate:

$$R_{sym} = \frac{1}{T_{sym}}$$

- **Data rate**:

$$R_{data} = \underbrace{SF}_{\#\text{bits per symbol}} \cdot \underbrace{R_{symb}}_{\text{symbol rate}} \cdot \underbrace{\frac{4}{4+CR}}_{\text{coding rate}}$$

- Example data rates:

SF7	BW250	CR4/5	≈ 10.9	$\frac{kbit}{s}$
SF7	BW125	CR4/5	≈ 5.5	$\frac{kbit}{s}$
SF12	BW125	CR4/5	≈ 0.29	$\frac{kbit}{s}$

Time-On-Air

- Comply with **duty cycles** of the SRD band:

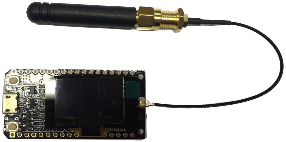
Frequency	Duty Cycle	ERP
868,0 - 868,6 MHz	1 %	25 mW

- This amounts to $\approx$ 30 seconds of transmission time per hour (maximum!). Try to keep it way below.
- Airtime calculator: `https://www.loratools.nl/#/airtime`
- Example: `20 bytes` payload
  $\rightarrow$ max. 25 messages per hour on SF12
  $\rightarrow$ max. 600 messages per hour on SF7

According to *Allgemeinzuteilung von Frequenzen zur Nutzung durch Funkanwendungen mit geringer Reichweite für nicht näher spezifizierte Anwendungen; Non-specific Short Range Devices (SRD)*, Bundesnetzagentur, 2018

Playground Part I

- Module used: **Wemos® TTGO LORA32 868Mhz ESP32**
  - ESP32
  - LoRa Chip SX1276
  - OLED display
  - Antenna (needs to be connected!)



- Programmable in MicroPython thanks to uPyLora library by lemariva (https://github.com/lemariva/uPyLora)

```
from lora_transceiver import LoRaTransceiver
from uPySensors.ssd1306_i2c import Display

disp = Display()

# create transceiver
lora = LoRaTransceiver(display=disp)

# send a string
lora.send_string("Hello World!")

# send some raw binary data
lora.send([0x01, 0x02, 0x03])
```

- Alternative: HopeRF **RFM95W** chip
- For "documentation" see: https://imaginaerraum.de/git/Telos4/LoRa-Workshop

Playground Part I

- Receiving data:

```
from lora_transceiver import LoRaTransceiver
from uPySensors.ssd1306_i2c import Display

disp = Display()

# create transceiver
lora = LoRaTransceiver(display=disp)

# start receiving data (and output on the screen)
lora.recv()
```

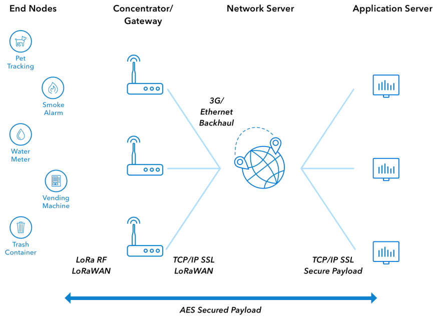
- Change LoRa parameters

```
# change the spreading factor
lora.setSpreadingFactor(10)

# change the frequency
lora.setFrequency(868.1e6)

# change signal bandwidth
lora.setSignalBandwidth(250e3)

# change sync word
lora.setSyncWord(0x34)
```

- Task: *Turn off your neighbors LED!*

LoRaWAN

- LoRaWAN is for getting your sensor data online
- Media access control (MAC) protocol
- Network topology:

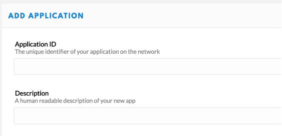


- **Gateways** forward data from nodes to the *cloud*
- Transmission is secured by AES-128 encryption

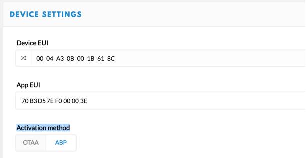
https://www.thethingsnetwork.org/docs/lorawan/

Device registration

- **TheThingsNetwork** aims to build a global LoRaWAN network
- Devices need to be registered and assigned to an application before they can communicate with the network
  1. Create an account on `https://www.thethingsnetwork.org/`
  2. Log in and open the *Console*
  3. Create an application



  4. Create a device and register it. Go to *Settings* and change activation method to Activation by Personalisation (ABP)



Keys

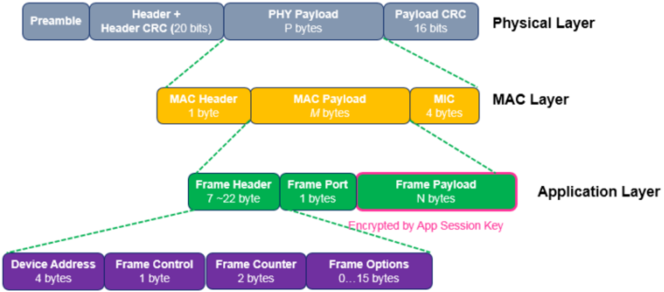
- Three important keys (when using ABP):

Device Address (**DevAddr**)	identification of the device in TTN
Network Session Key (**NwkSKey**)	secure communication between device and TTN
Application Session Key (**AppSKey**)	secure communication between device and application

  - DevAddr tells TTN where to route the data
  - NwkSKey used for message validity check (MIC) (prevents tampering with messages)
  - AppSKey are used for payload encryption/decryption (prevents reading the data)
  - Need to be **hardcoded** into the device
- Alternatively: use Over-the-Air Activation (OTAA) (more secure)
- Frame counters: Each message is equipped with a counter that prevents re-transmit attacks

https://nootropicdesign.com/projectlab/2018/10/28/lorawan-end-devices/

LoRaWAN payload format



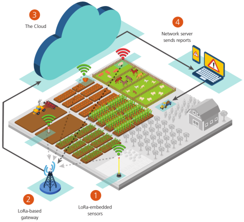
Useful link:

- LoRaWAN packet decoder
  `https://lorawan-packet-decoder-0ta6puiniaut.runkit.sh/`

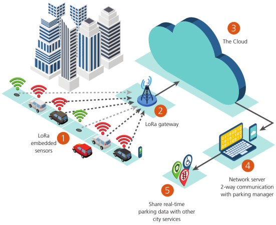
http://www.techplayon.com/lora-long-range-network-architecture-protocol-architecture-and-frame-formats/

Use cases

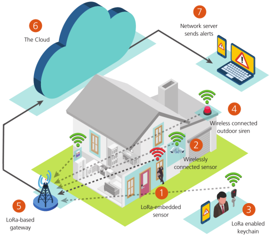
Smart farming



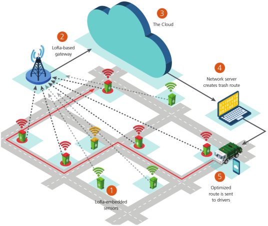
Smart parking



Smart home



Smart waste management



https://www.semtech.com/lora/resources/lora-white-papers

Playground Part II

Example code for sending data to **TheThingsNetwork**:

```
from lora_transceiver import LoRaTransceiver
from uPySensors.ssd1306_i2c import Display
import uLoRaWAN
from uLoRaWAN.MHDR import MHDR

disp = Display()

# create transceiver for LoRaWAN frequency (channel 0 = 868.1 Mhz)
lora = LoRaTransceiver(frequency=868.1E6, syncword=0x34, display=disp)

# set address and keys for LoRaWAN (with ABP)
devAddr = [0x26, 0x01, 0x16, 0x5C] # ir_test_device_01
nwkSKey = [0x9D, 0x95, 0x0F, 0xAB, 0xCB, 0x63, 0xD3, 0x04, 0xBC, 0x09,
             0xC4, 0x9E, 0xC5, 0xDF, 0x3C, 0x37]
appSKey = [0xC9, 0x6C, 0x00, 0xD1, 0xB0, 0x1C, 0x2E, 0x42, 0x11, 0xBA,
             0x32, 0x6F, 0x2F, 0xC2, 0x75, 0x6A]

# lorawan object for conversion of data in LoRaWAN message format
lorawan = uLoRaWAN.new(nwkSKey, appSKey)

message =  list(map(ord, 'Hello World!'))       # convert to bytes
lorawan.create(MHDR.UNCONF_DATA_UP, { 'devaddr': devAddr, 'fcnt': 0,
                 'data': message })
payload = lorawan.to_raw()

lora.send(payload)
```

(the code is based on the `uLoRaWAN` library by mallagant, see: `https://github.com/mallagant/uLoRaWAN`)

Playground Part II

For testing you can use the following device addresses and keys:

- **nwkSKey**

```
9D 95 0F AB CB 63 D3 04 BC 09 C4 9E C5 DF 3C 37
```

- **appSKey**

```
C9 6C 00 D1 B0 1C 2E 42 11 BA 32 6F 2F C2 75 6A
```

- **devAddr** (choose one):

```
 1:  26 01 16 5C          10:  26 01 1A CE
 2:  26 01 18 52          11:  26 01 12 F1
 3:  26 01 1E 4F          12:  26 01 1B 18
 4:  26 01 17 83          13:  26 01 19 40
 5:  26 01 1B 5C          14:  26 01 19 96
 6:  26 01 1E B5          15:  26 01 18 FF
 7:  26 01 13 DA          16:  26 01 12 5B
 8:  26 01 1E 8F          17:  26 01 13 63
 9:  26 01 18 F1          18:  26 01 12 09
```

- Watch incoming data (forwarded as HTTP POST request) at

  `https://t1p.de/ocp6`

  and check the gateway log at (connected to @BayernWLAN wifi)

  `http://192.168.1.1:1337`

References and more information

References:

- Decoding LoRa https://revspace.nl/DecodingLora
- *LoRa und The Things Network* - talk by Hubert Högl (FH Augsburg)
- Stackexchange thread about LoRa symbols
- LoRa talk
- Mobilefish.com LoRa youtube tutorials

Further reading:

- TTN Applications: APIs, Python SDK, Integrations https://www.thethingsnetwork.org/docs/applications/
- Best practices to reduce payload size: https://www.thethingsnetwork.org/forum/t/best-practices-to-limit-application-payloads/1302
- Forum about all things LoRa: https://www.thethingsnetwork.org/forum/
  - Gateway guides
  - Radio module/antenna recommendations
  - ...
- Cayenne Low Power Payload (LPP)

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Thanks for your attention!