# Connectivity 1

# Agenda

**Intro to communications**

**IoT/HW specific protocols**

Wired: UART/RS485, SPI, I2C, OneWire

Wireless: WiFi, BT 4.0/BLE, LoRa, LTE, Zigbee, Z-wave, NFC, IrDA

**Exercises**
ESP-NOW
Bluetooth Hearth Rate

# Intro to communications

# What is information?

**Data**

Datum = something given, a thing

**Knowledge**

Reduces uncertainty

Improves outcome

**Information**

Measurable (abstract) knowledge [bit]

Entropy (data vs information)

“*If the base 2 is used the resulting units may be called binary digits, or more briefly* ***bits****, a word suggested by J. W. Tukey*”

**Reducing uncertainty**

$$P(A \mid E) \mathrel{!=} P(A)$$

**Improving outcome**

$$O'_T \mid E > O_T$$

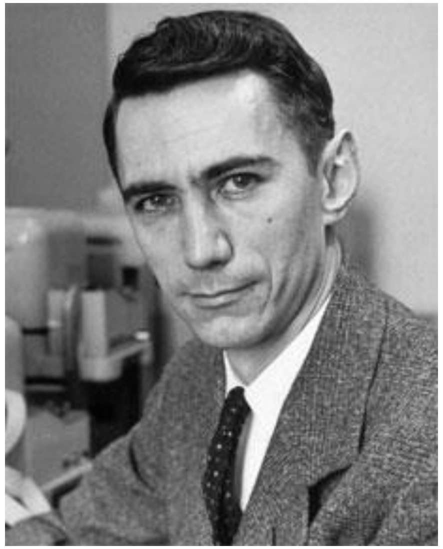
**Quantity of information**

$$I(m) = \log_2(M) \text{ [bit]}$$

**Entropy**

$$H = -\mathrm{sum}(\, P_i \log_2(P_i) \,) \text{ [bit]}$$

Shannon, Nyquist, Hartley, Mitchell



1916 - 2001

https://github.com/pgenevski/notebooks/blob/master/math/Entropy.ipynb

# What is communication?

**Communication**

Conveying information (knowledge)

**Encoding & decoding**

Information <-> Data

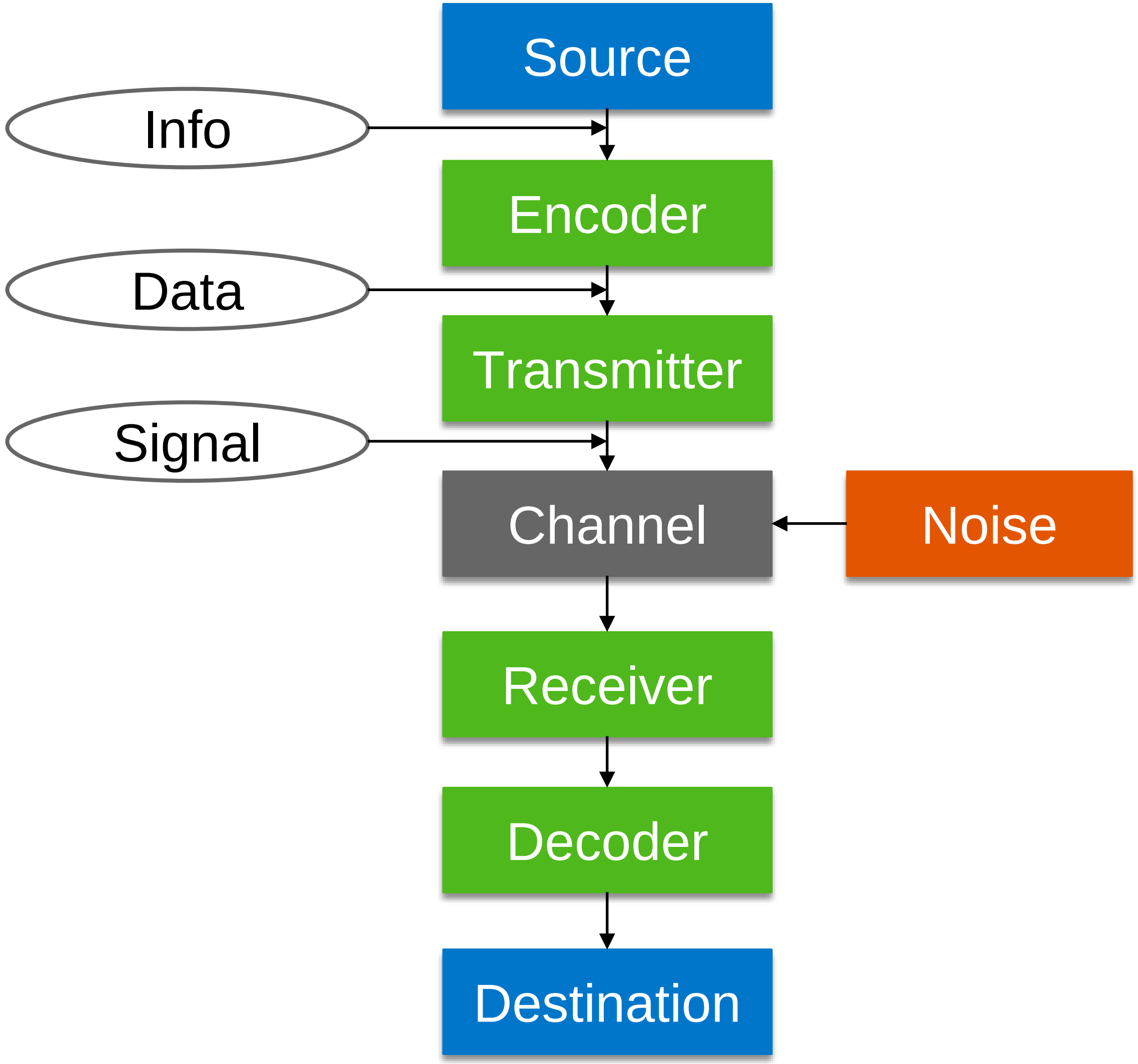
**Transmission & reception**

Data <-> Signal (energy wave)

**Channel**

Carries the signal / data

May add noise/disturbance



# Signal & channel characteristics

**Signal**

Energy: An energy wave

Spectrum (Fourier sum of sine waves)

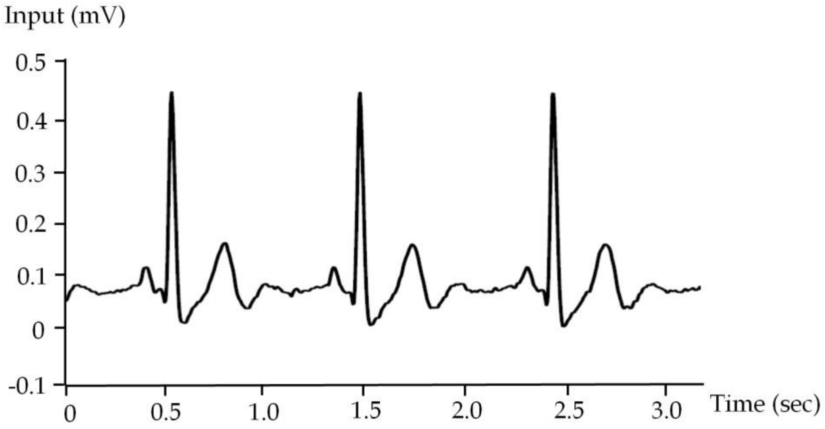
**Channel**

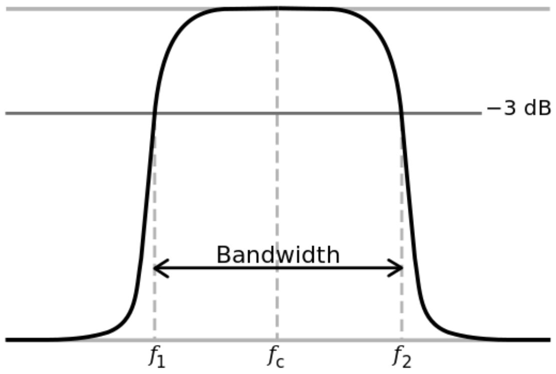
Bandwidth, power, noise, attenuation

Latency

Capacity: $C = B \log_2(1+P_S/P_N)$ **[bit/s]**

*P is power in Watts





https://www.compadre.org/osp/pwa/soundanalyzer/

https://teropa.info/harmonics-explorer/

# Signal digitalization

### Time discretization

Lossless

Nyquist frequency: $F_S > 2B$

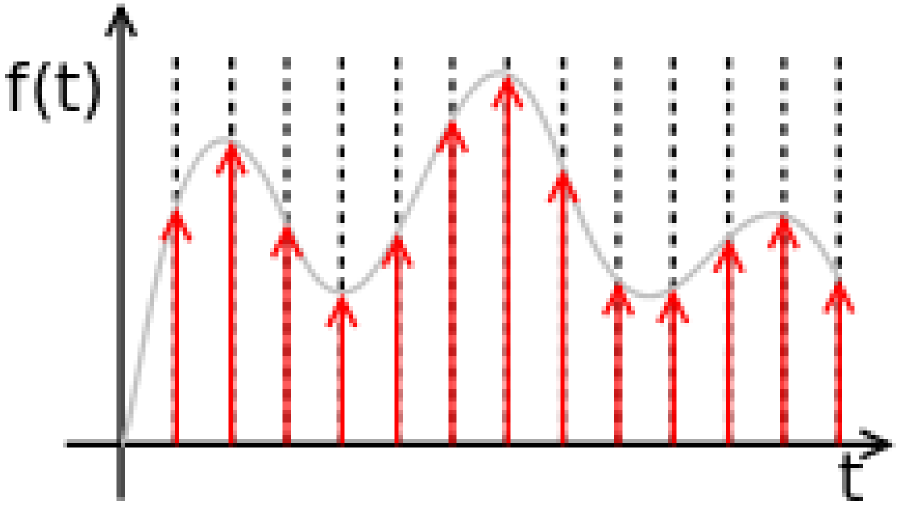
### Amplitude quantization

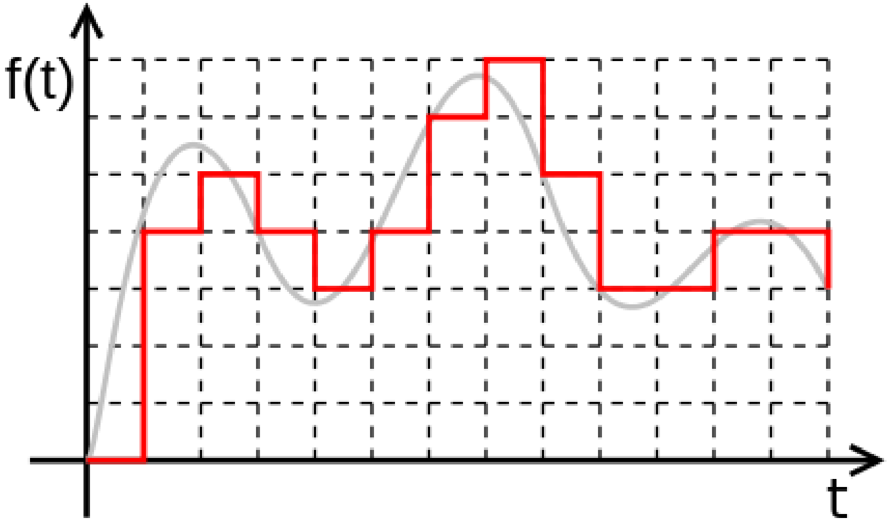
Always lossy

$SQNR = 20\log_{10}(2^Q) = 6.02\ Q$ [dB]

* Signal to quantization noise ratio: Q bits

Trick: companding compression





# Common media types

**Electrical wires**

Twisted pair: 10 GB/s, 100 m, 0.5 EUR/m

Coaxial: 10 MB/s, 450m, 0.5 EUR/m

**Optical fibers**

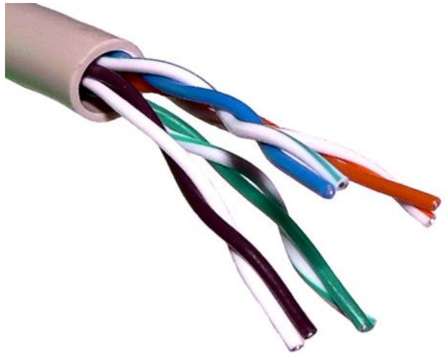
Single mode: 100TB/s, ~150 km, 0.06 EUR/m

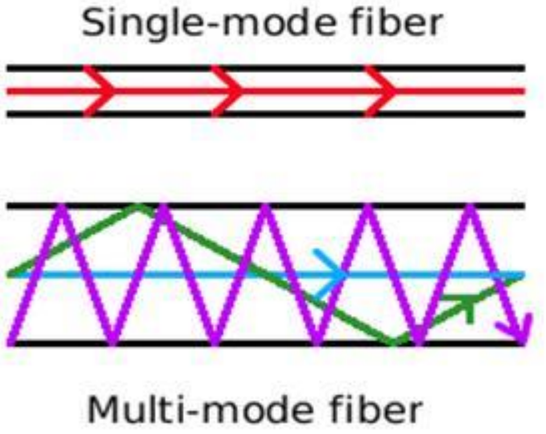
Multi-mode: 1GB/km, ~2 km, 0.3 EUR/m

**Radio (e.g. ISM bands)**

2.4 / 5GHz: 300MB/s, 50 m

433 / 868 MHz: 64KB/s, 20 km





# More about radio

**Propagation**

Direction & Multi path

Penetration

Polarization

**Antennas**

Omni and directed

Connectors: SMA, UF.L, BNC, F …

**Regulations**

Standard bodies: FCC(US), ETSI (EU) …

Restrictions: Frequency, power, duty cycle

UF.L

SMA

BNC

F

| Connector | Frequency | Impedance |
|---|---|---|
| SMA | < 17 GHz | 50Ω |
| UF.L | < 6 GHz | 50Ω |
| BNC / F | < 3 GHz | 50Ω, 75Ω |

# What is communication?

**Communication**

Conveying information (knowledge)

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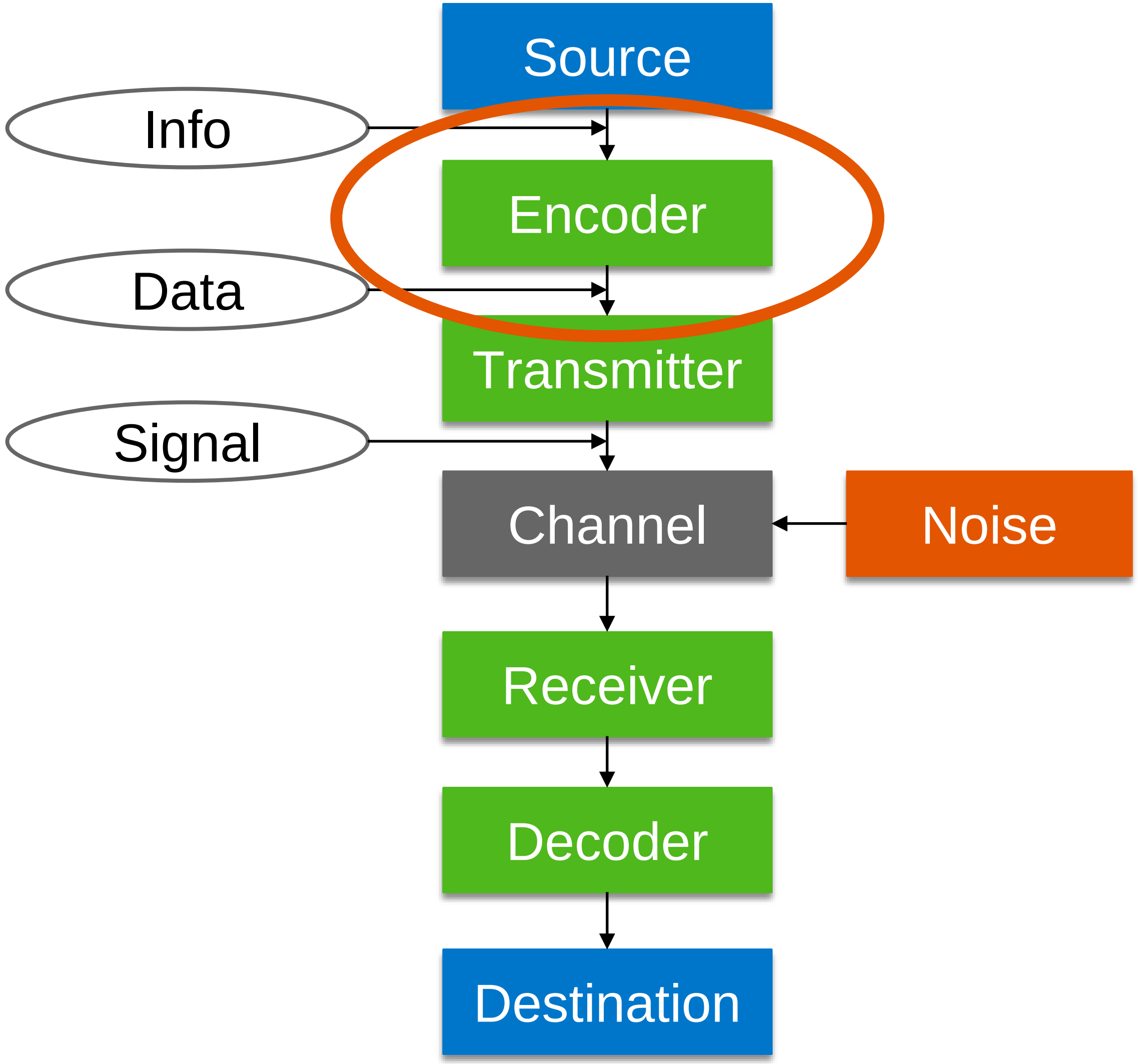
**Channel**

Carries and modifies the signal / data

Information may be affected



# Encoding & Error control

**Encoding**

Text: Morse, ASCII, UTF8, CP1251 …

Images: BMP, GIF, JPEG …

Sound: MPEG/MP3, Flac, Vorbis, Speex …

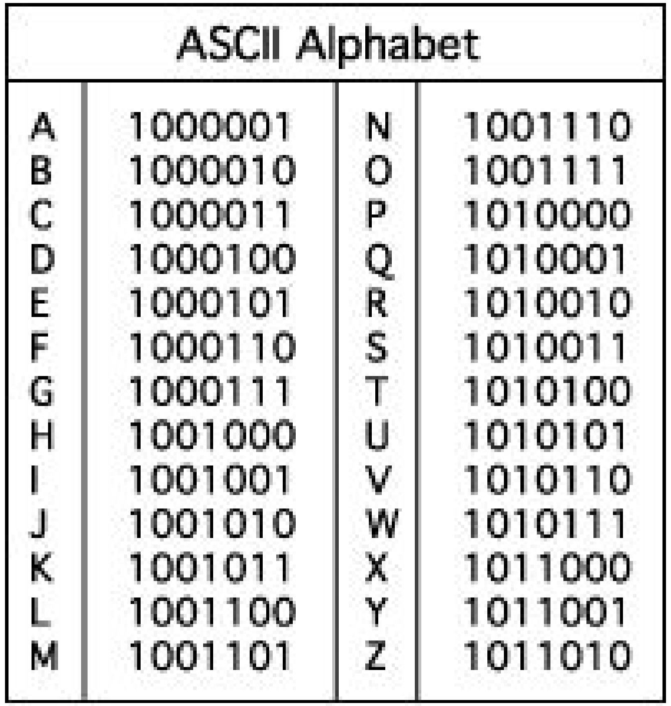
Video: VP9, H265 …

**Error control**

Detection: Parity bit, Checksum, Hash…

Correction:

- ACK/ARQ
- FEC: Hamming, Reed-Solomon, Turbo code, LDPC



| ASCII Alphabet | | | |
|---|---|---|---|
| A | 1000001 | N | 1001110 |
| B | 1000010 | O | 1001111 |
| C | 1000011 | P | 1010000 |
| D | 1000100 | Q | 1010001 |
| E | 1000101 | R | 1010010 |
| F | 1000110 | S | 1010011 |
| G | 1000111 | T | 1010100 |
| H | 1001000 | U | 1010101 |
| I | 1001001 | V | 1010110 |
| J | 1001010 | W | 1010111 |
| K | 1001011 | X | 1011000 |
| L | 1001100 | Y | 1011001 |
| M | 1001101 | Z | 1011010 |

# IoT wired protocols

# UART (Universal Async Receive Transmit – aka Serial)

**Overview**

UART (3.3 / 5 V, few meters)

RS232 (9600 bps/ 15m)

RS485 / Modbus

- 35Mbs / 12 m … 100kbps / 1200m
- Multi node (master slave or ethernet like)

**Applications**

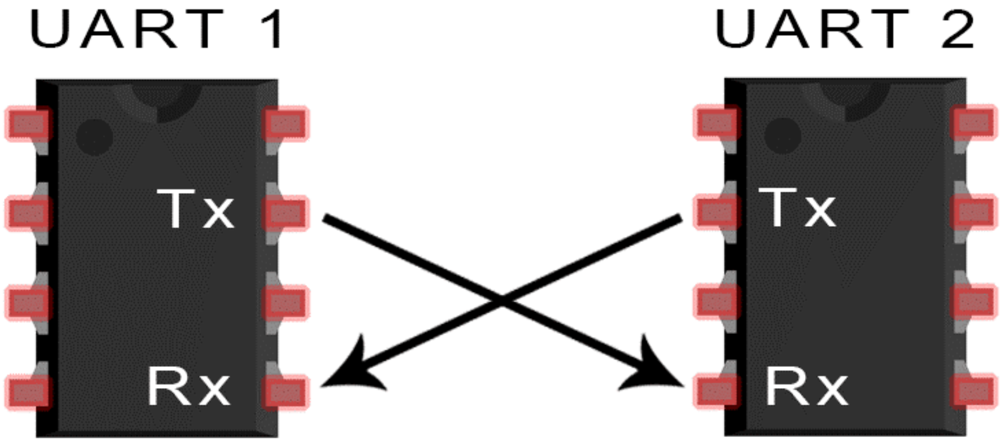
Industrial devices / solar (RS485)

Some (old) sensors

**Implementation**

ESP8266: SoftwareSerial

ESP32: HardwareSerial



RS485 anemometer example

# I2C

**Overview**

Distance: 1 – 10 m

Data and Clock lines

Synchronous bus (master clock)

Multi-master & up to 1008 slaves

Half-duplex, 100 kbit – 3.2mbit/s

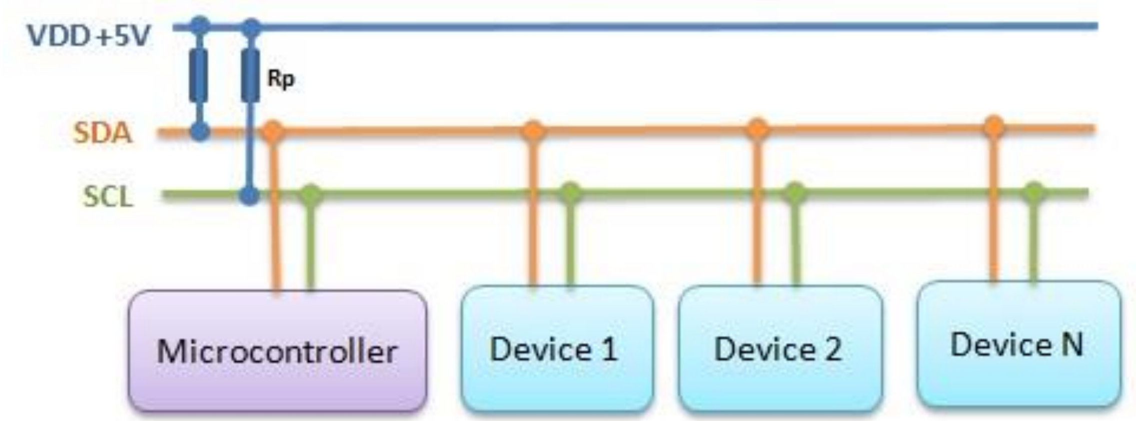
**Programming**

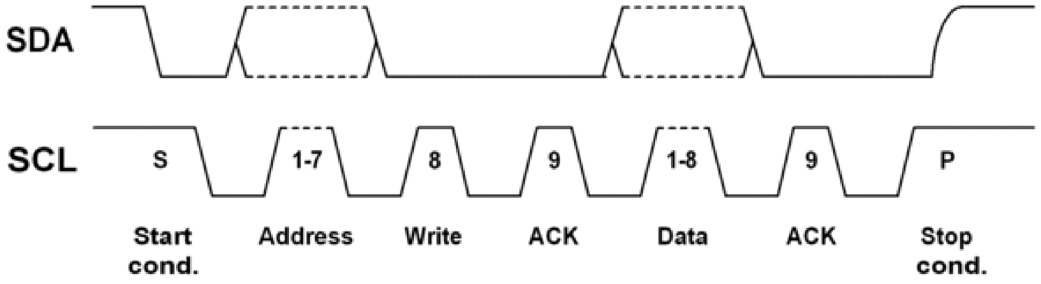
Slave address: 7/10 bit

Open address

Write data

Read data





# SPI (Serial peripheral interface)

## Overview

Distance: 1 – 10 m

Synchronous bus (master clock)

- Data, Clock and Chip select lines
- Single master / multi slave (SS)

Full duplex, up to 50Mbit/s

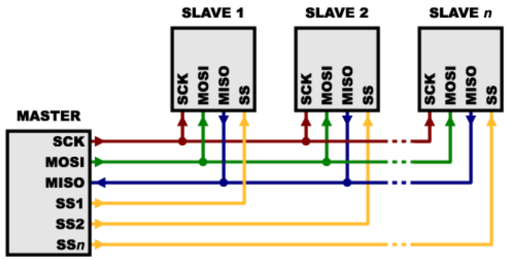
## Implementation

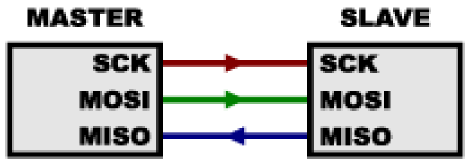
ESP32: Hardware SPI

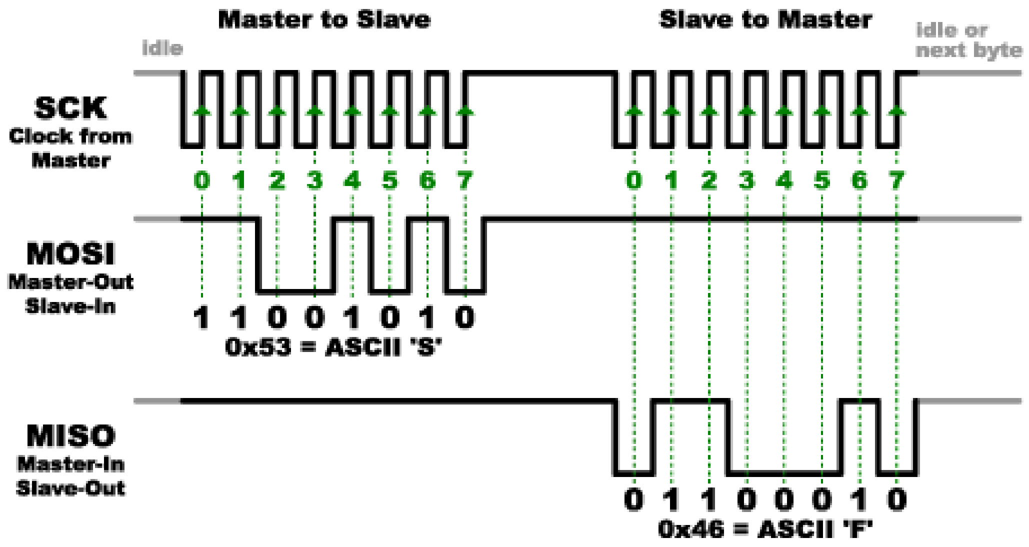
Bit order (MSB/LSB)

Data mode (rising/falling edge)

Clock speed (divider)







# OneWire et al

**Overview**

Distance: 10 to 100s of meters

- Radius & weight

Half-duplex, 16 kbit to 125 kbit (overdrive)

Data line only (2 or 3 wire interface)

Single master / up to 100s of slaves

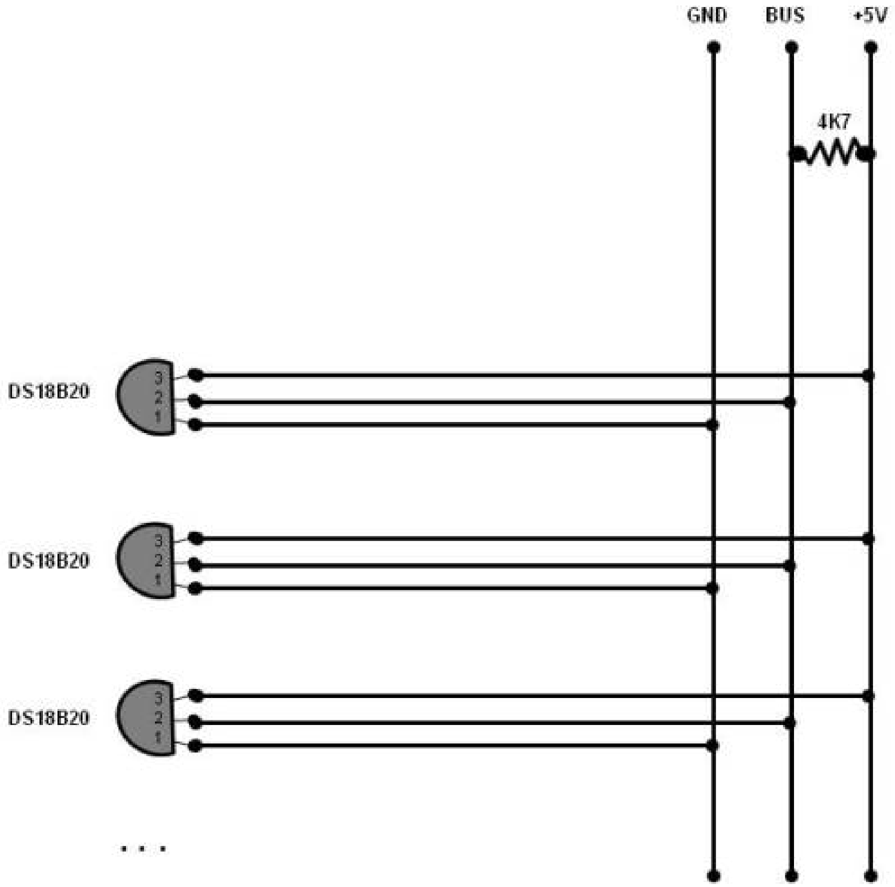
**Programming**

64bit slave IDs

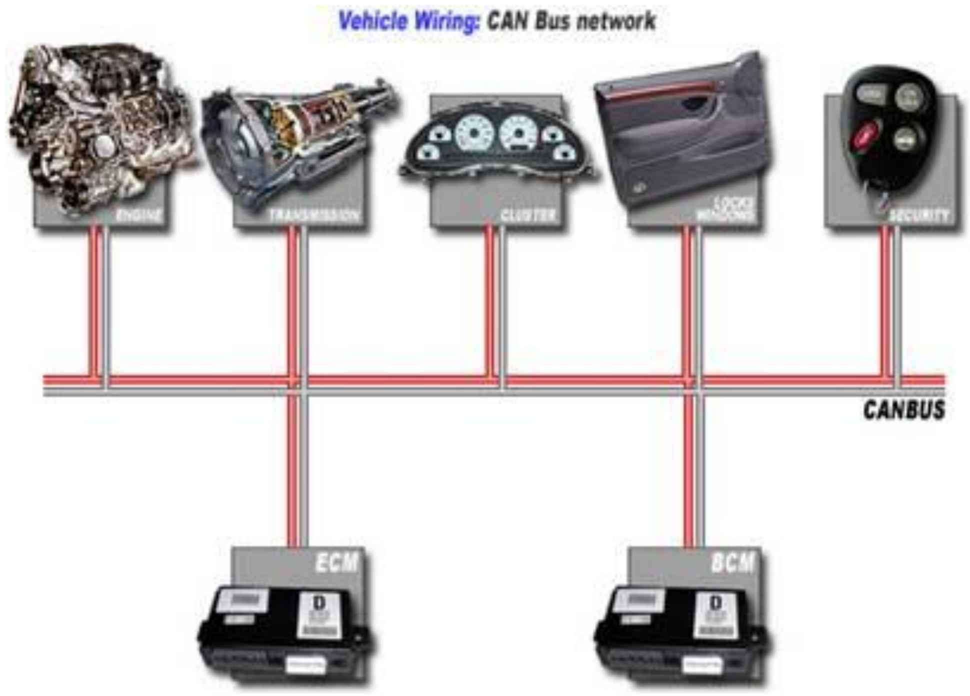
Parasitic power (charge up)

Find devices

Communicate



# Some other protocols



**Industrial**

CAN bus (hw support in ESP32)

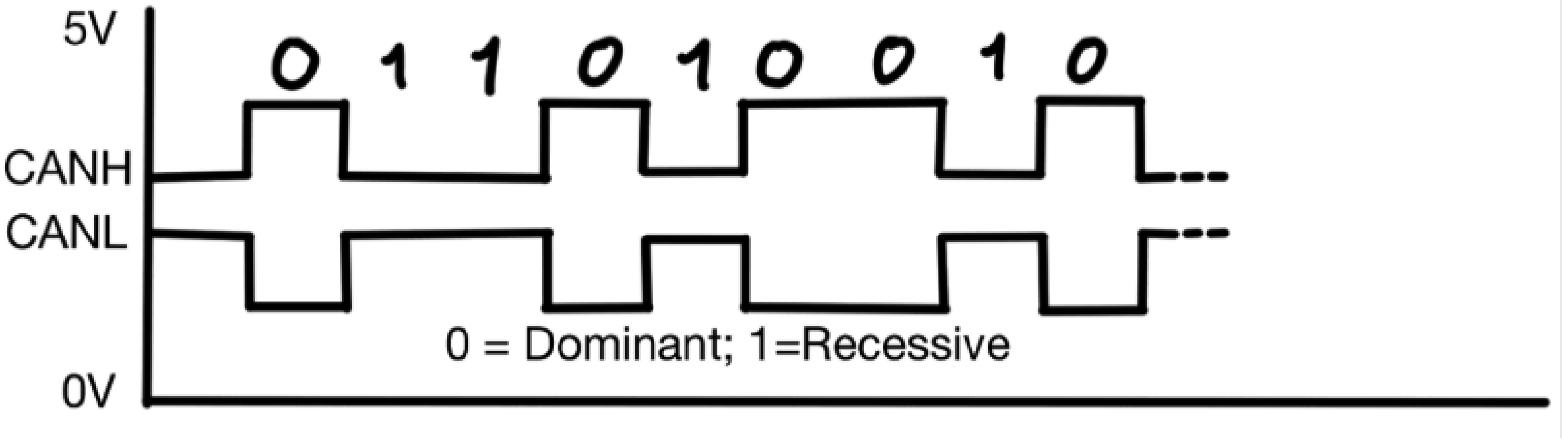
LIN bus

Industrial Ethernet (PROFINET, Modbus TCP …)

4-20 mA

**HiFi sound**

I2S



# IoT wireless protocols

# Common network topologies

**P2P**

Simplest

**Star (Star of stars)**

Common in public deployments

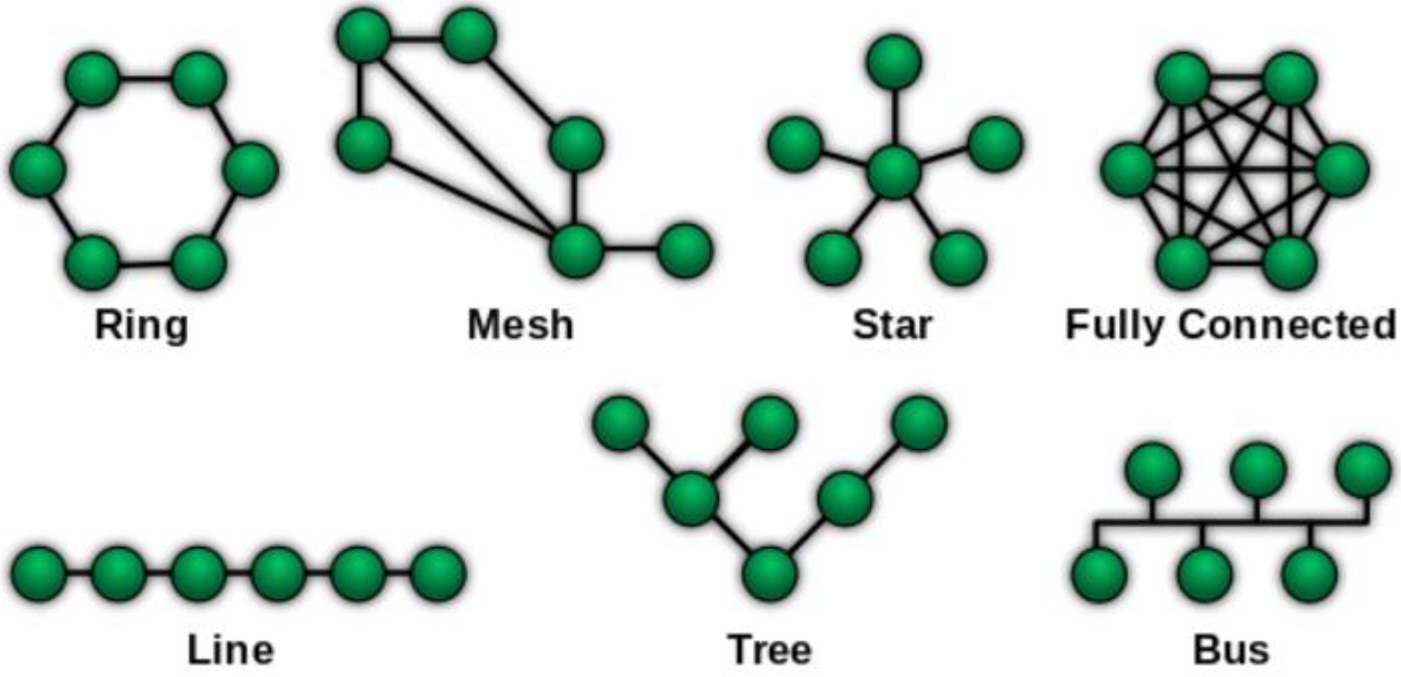
**Mesh**

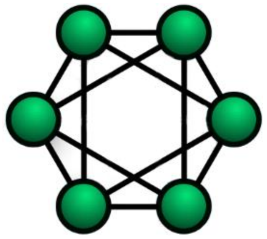
Complex

Potentially more reliable

Partially connected with XOR distance

(Petar Maymounkov – DHT)





Partially connected XOR

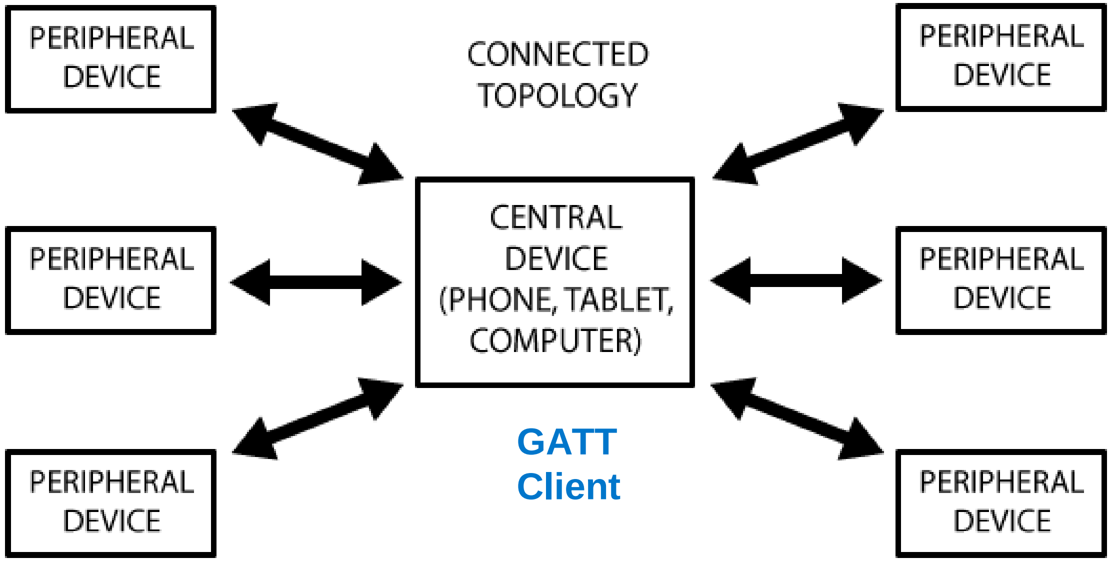
# Bluetooth 4&5 (BLE)

**GATT (generic attribute profile)**

Designed for low power

Peripherals advertise themselves

Central device initiates two way connection

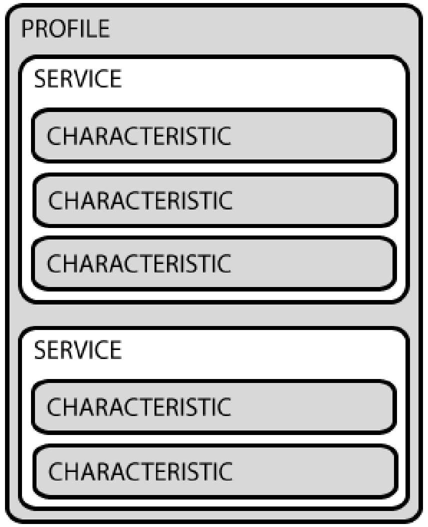


GATT Client

GATT Server

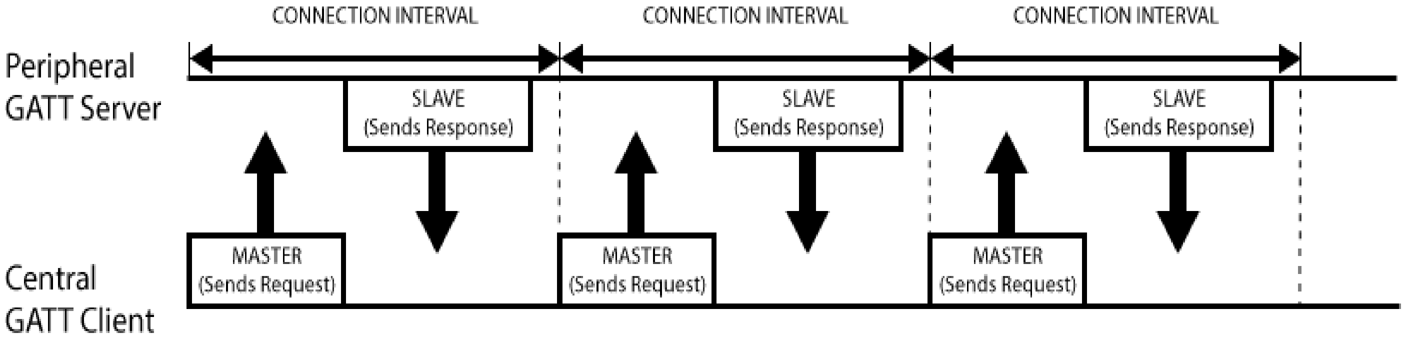
GATT Server

## Profiles, Services & Characteristics



Heart rate service
- **Heart Rate Measurement**
- **Body Sensor Location**
- **Heart Rate Control Point**

Device information service
- **Manufacturer name**
- **Model name**

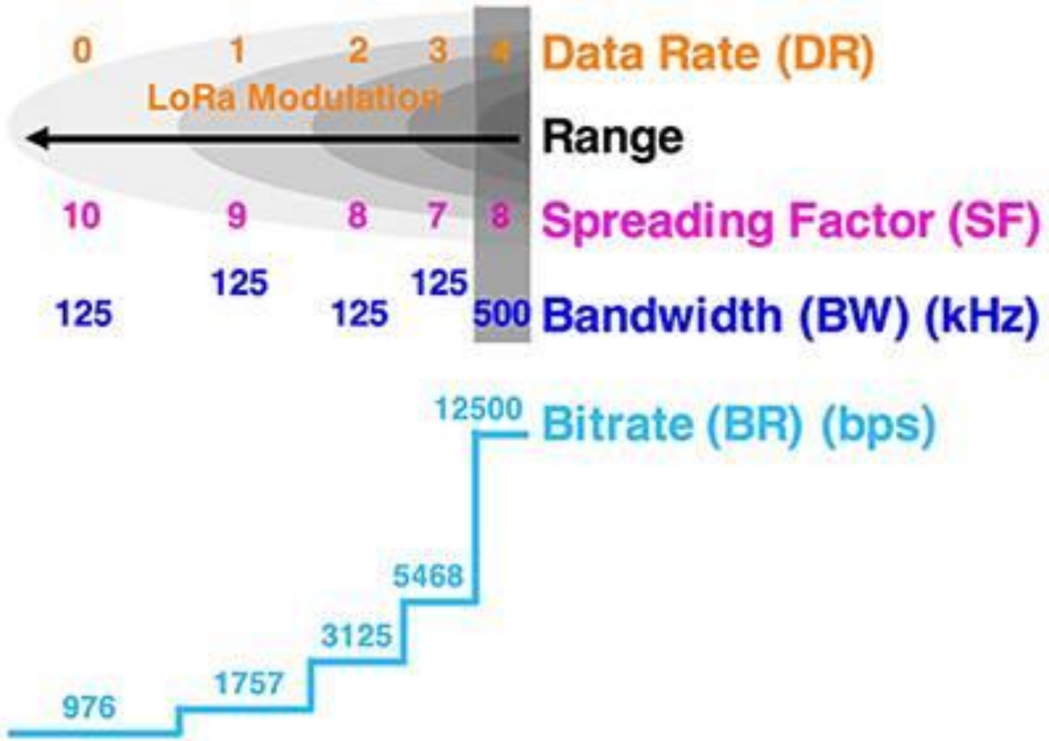


# LoRa

$$C = B \log_2(1+P_S/P_N) \text{ [bit/s]}$$

## FM Chirp Spread Spectrum & FEC

- Noise like signal: SNR = -5 to -20dB
- Bandwidth (7.8 – 500KHz) @ 868/915 MHz carrier
- Spreading factor (64 - 4096)
- Coding rate (for FEC)
- Range: LoS ~20km, non LoS ~2km
- Throughput = 18bps – 78Kbps



## Interesting properties

Star, P2P and Mesh topologies

Private & Public deployments (LoRaWAN)

Military origin (anti-jamming & LPI)

LoRa Broadcast Video

# LoRaWAN

**TTN - The things network**

**Crowd sourced gateways**

You can build one too

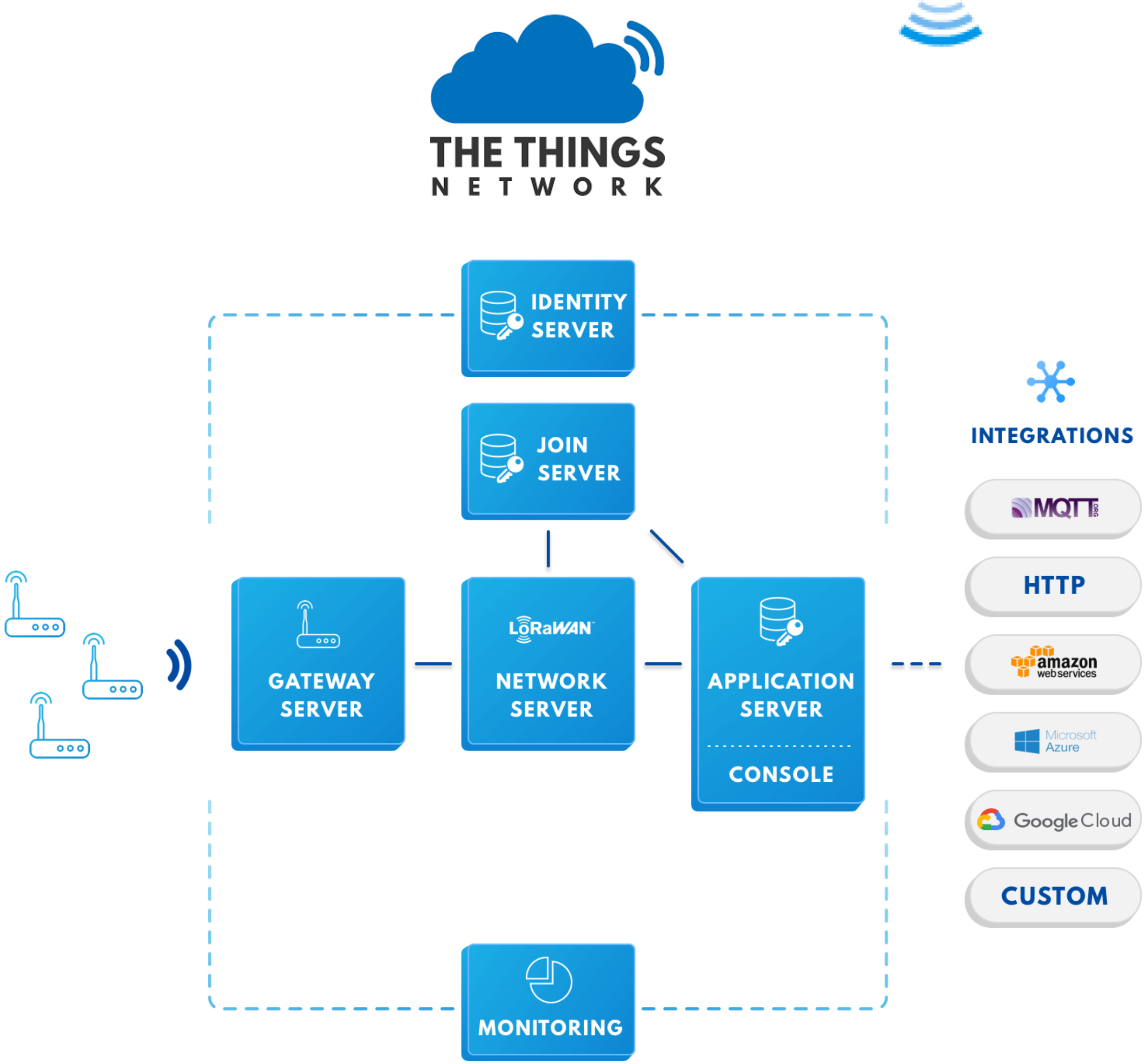
**Centralized backbone**

But you can deploy one yourself

Open source

**End devices**

Kind of expensive (compared to ESP)



# Helium IoT network

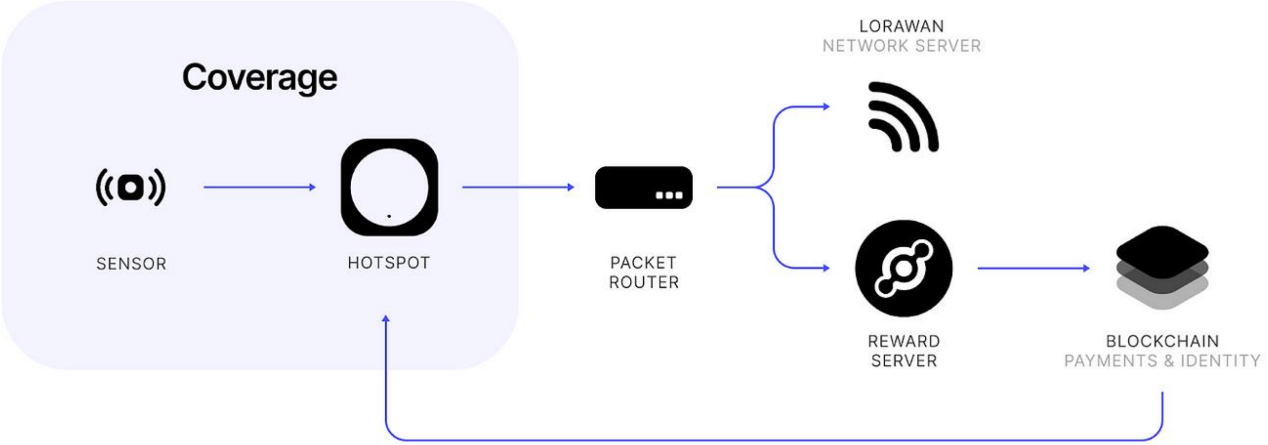
**LoRaWAN based decentralized network**

**Uses Proof-of-coverage consensus (challenger-transmitter-witness)**

**Rewards with Helium tokens (PoC, and data)**

**1 packet transfer costs 0.0001$**

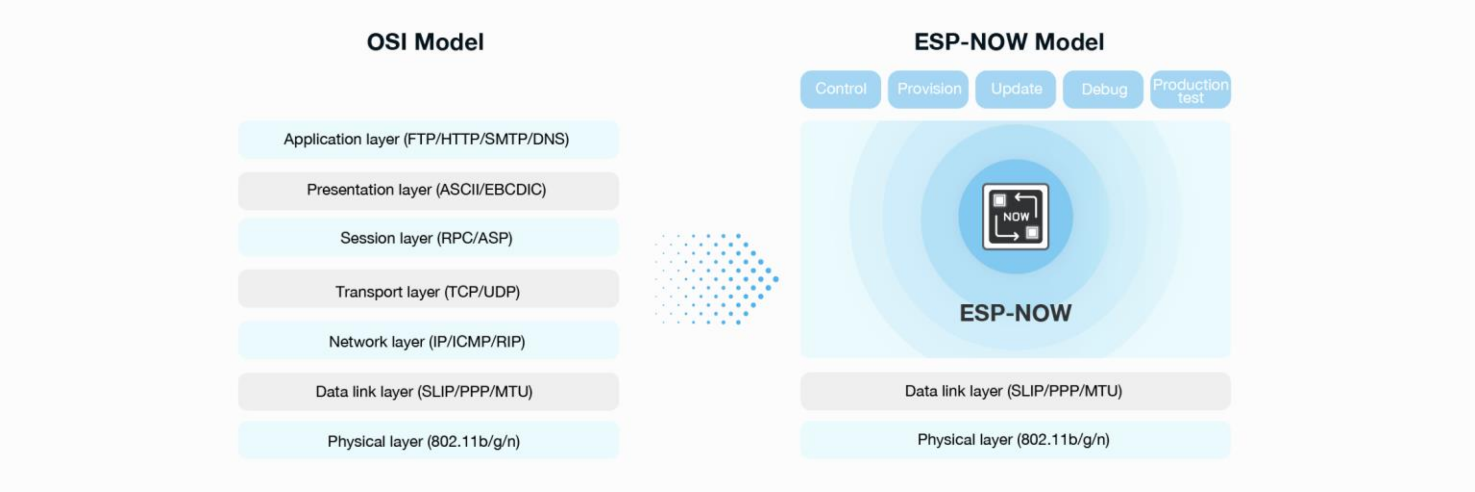
https://docs.helium.com/iot/transaction-fees/



# ESP-NOW

- Expresiff wireless protocol (ESP32, ESP8266)
- P2P one- or 2-way
- Lightweight, messages up to 250 bytes
- No need for network infrastructure
- Low latency
- Low power consumption
- Limited encryption

https://docs.arduino.cc/tutorials/nano-esp32/esp-now/


OSI Model

Application layer (FTP/HTTP/SMTP/DNS)

Presentation layer (ASCII/EBCDIC)

Session layer (RPC/ASP)

Transport layer (TCP/UDP)

Network layer (IP/ICMP/RIP)

Data link layer (SLIP/PPP/MTU)

Physical layer (802.11b/g/n)

ESP-NOW Model

Control | Provision | Update | Debug | Production test

NOW

ESP-NOW

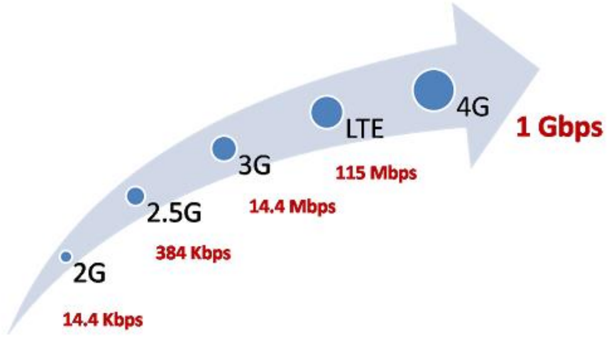
Data link layer (SLIP/PPP/MTU)

Physical layer (802.11b/g/n)

# Some other protocols

**Cellular**

3G, LTE, 4G, 5G, Sigfox, NBIoT …



**IEEE 802.15.4**

ZigBee (popular in EU)

- 2.4 GHz, Mesh, many vendors = Interop. problems
- Use cases: Home automation, Smart buildings, meters …

Thread (evolved Zigbee, uses IPv6)

Z-wave (popular in US)

- 868MHz, Mesh, single vendor
- Use cases: Home automation, Smart buildings
- Matter (connectivity standard by Amazon, Apple, Google, Samsung SmartThings and the Zigbee Alliance)

**Custom**

e.g. HC-12