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

$$P(A \mid E) \;!=\; P(A)$$

Improving outcome

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

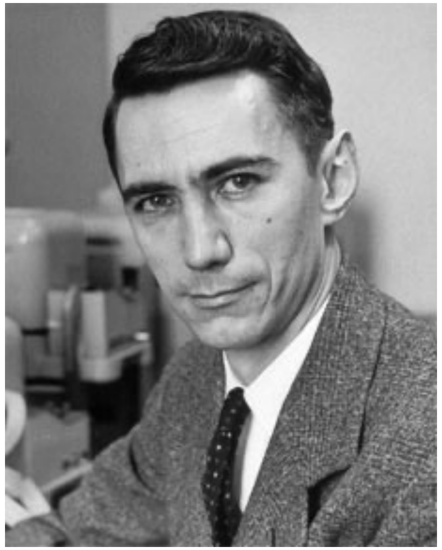
Quantity of information

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

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

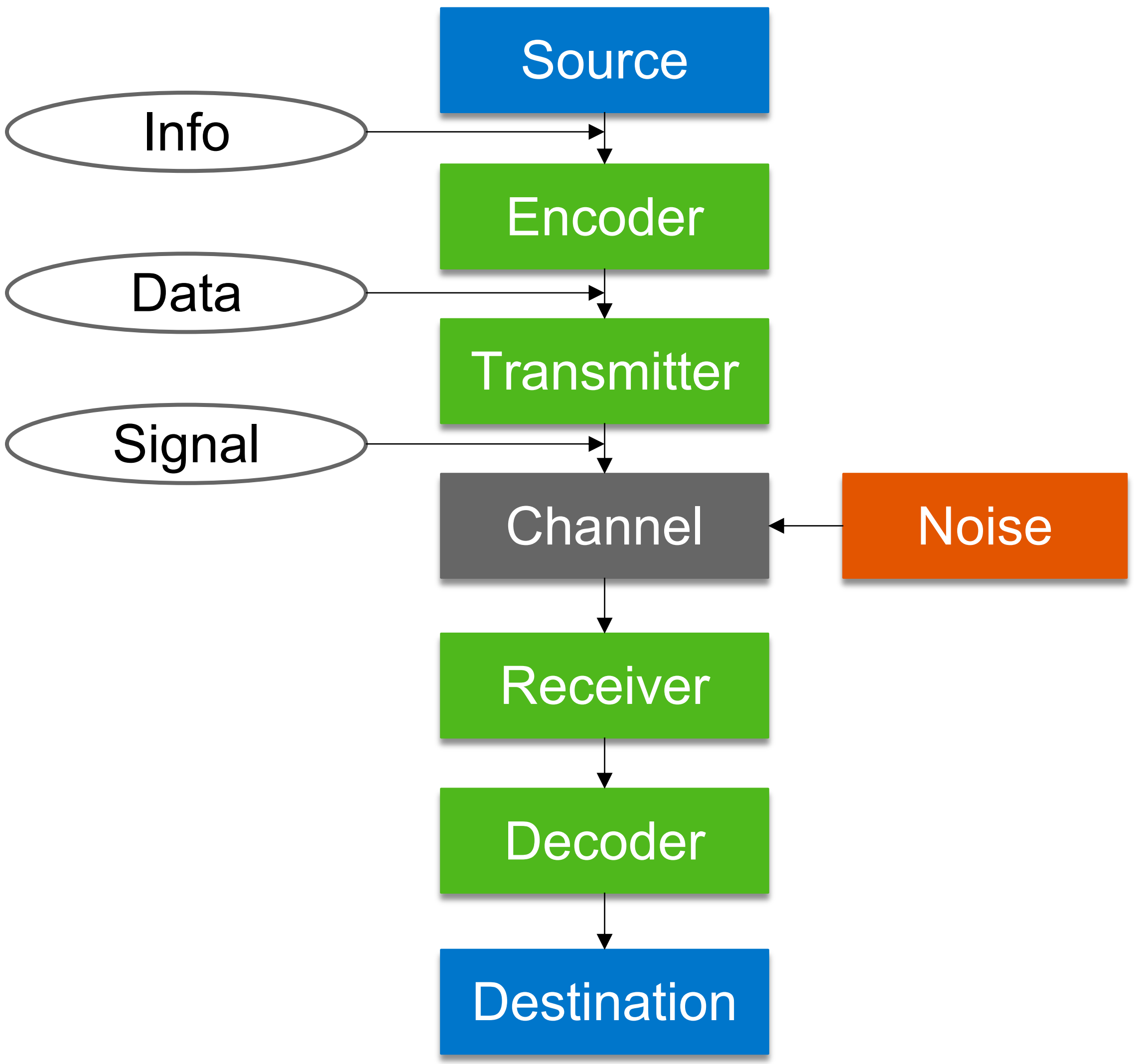
Transmission & reception

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)

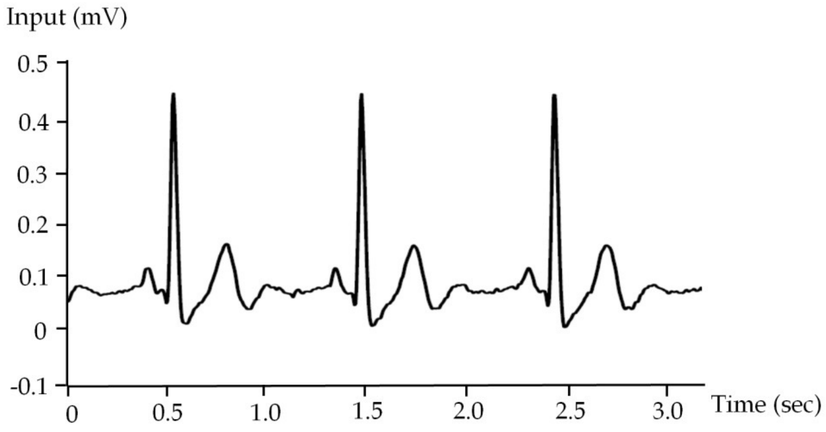
Channel

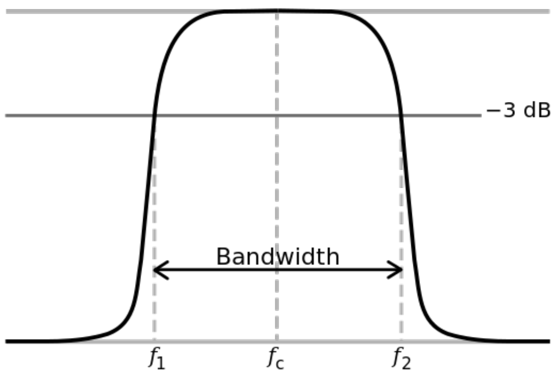
Bandwidth, power, noise, attenuation

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: $F_S > 2B$

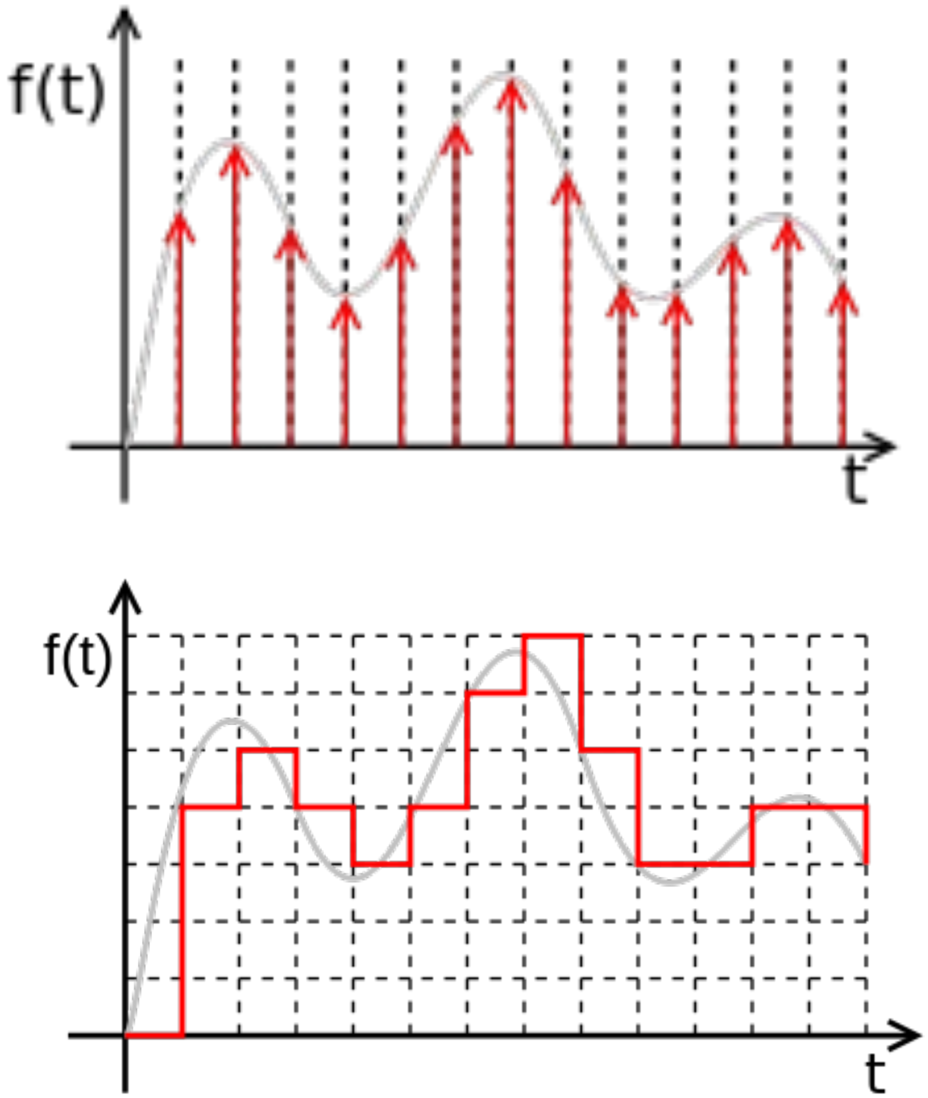
Amplitude quantization

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

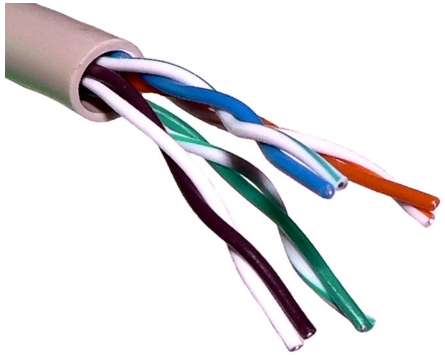
Single mode: 100TB/s, ~150 km, 0.06 EUR/m

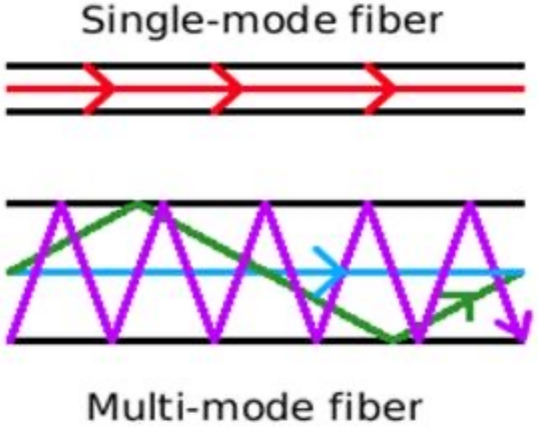
Multi-mode: 1GB/km, ~2 km, 0.3 EUR/m

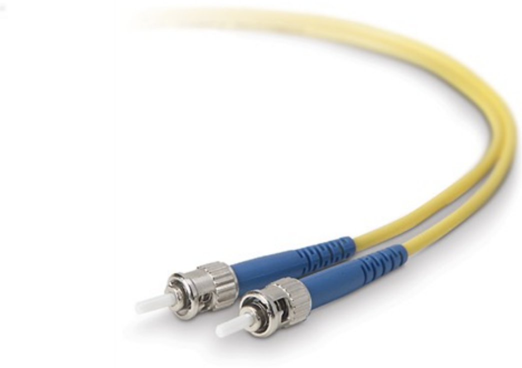
Radio (e.g. ISM bands)

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

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)

Encoding & decoding

Information <-> Data

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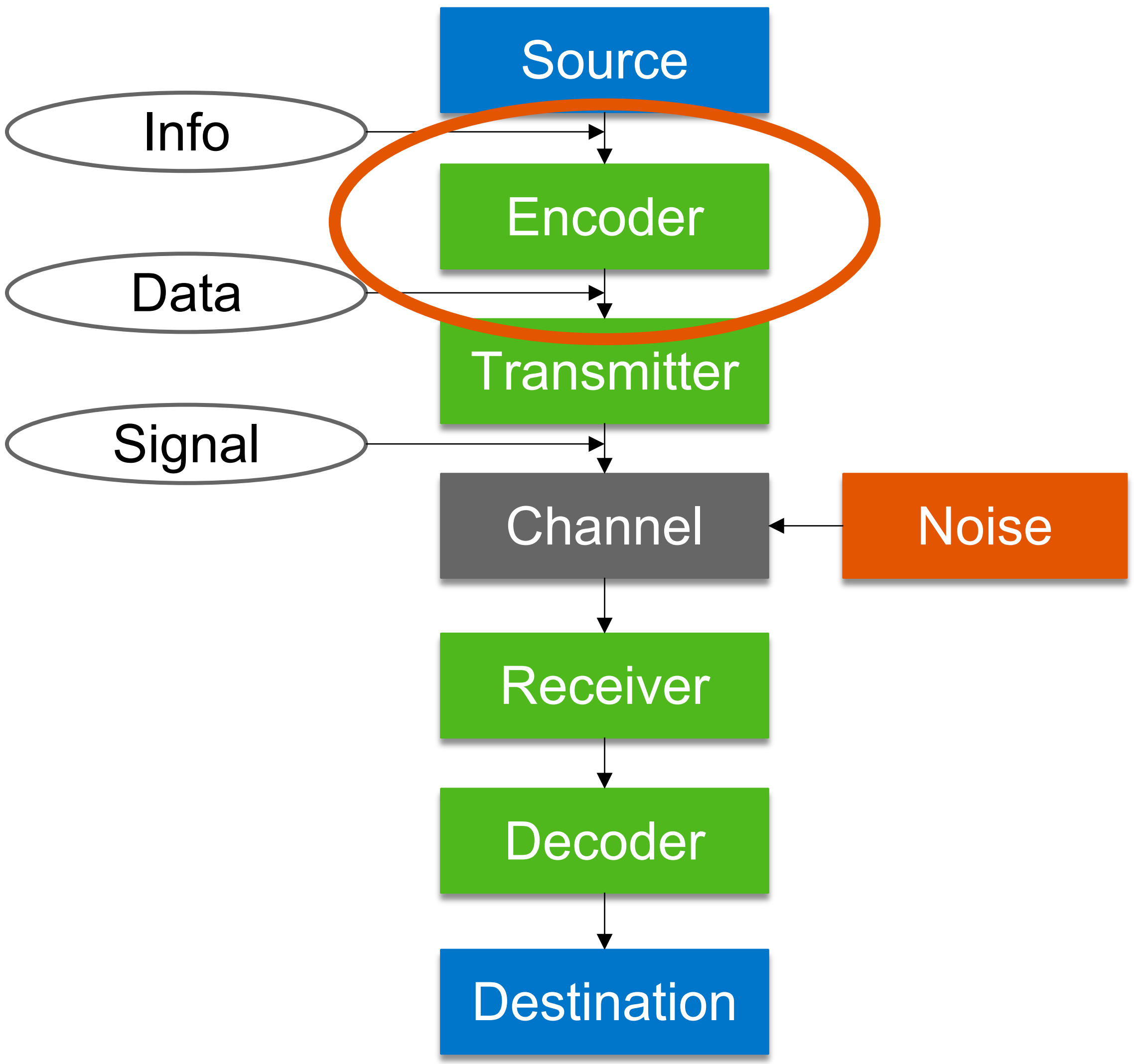
Channel

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)

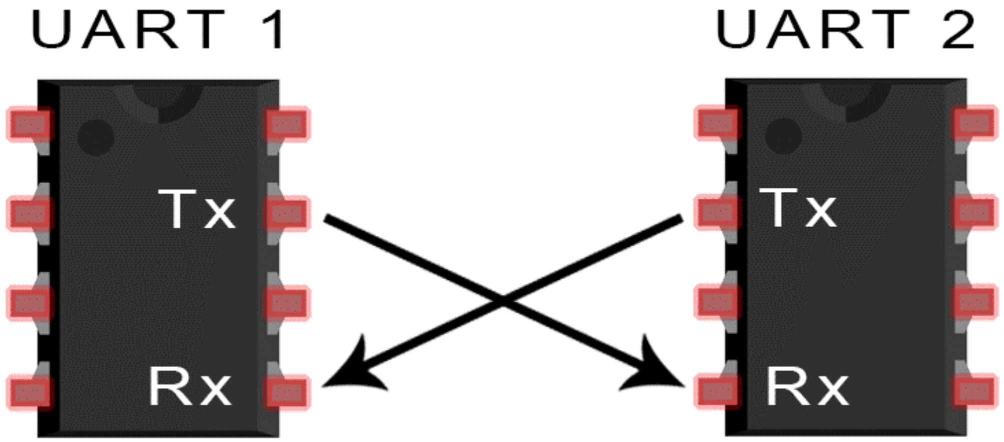
Overview

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

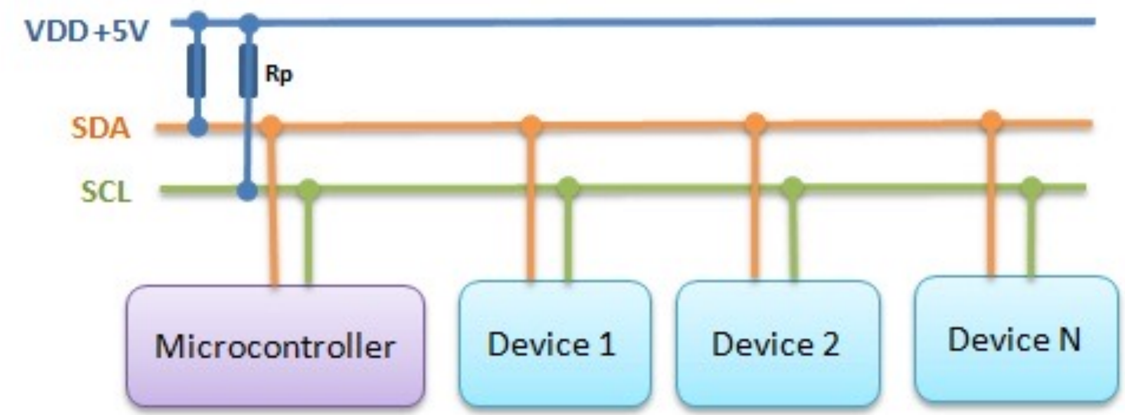
Distance: 1 – 10 m

Data and Clock lines

Synchronous bus (master clock)

Multi-master & up to 1008 slaves

Half-duplex, 100 kbit – 3.2mbit/s



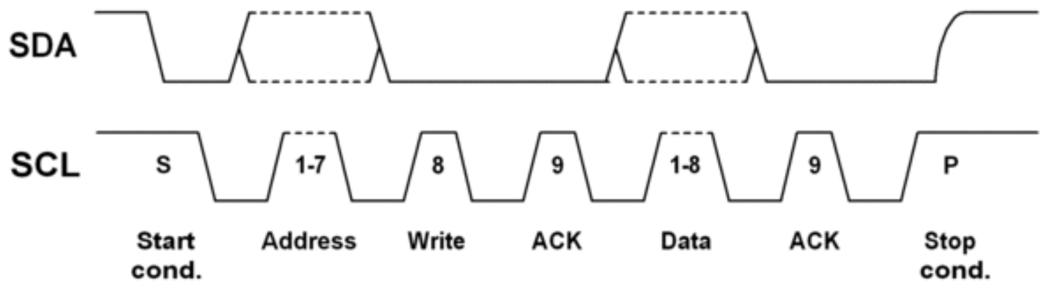
Programming

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

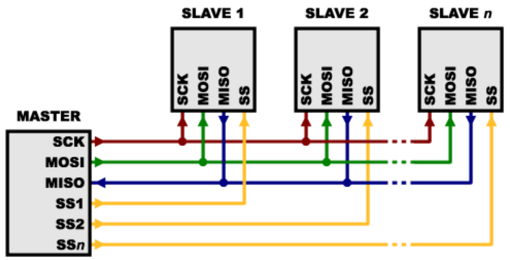
Implementation

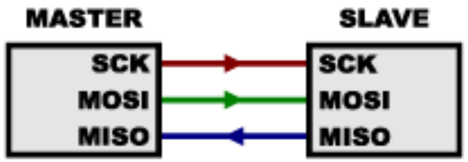
ESP32: Hardware SPI

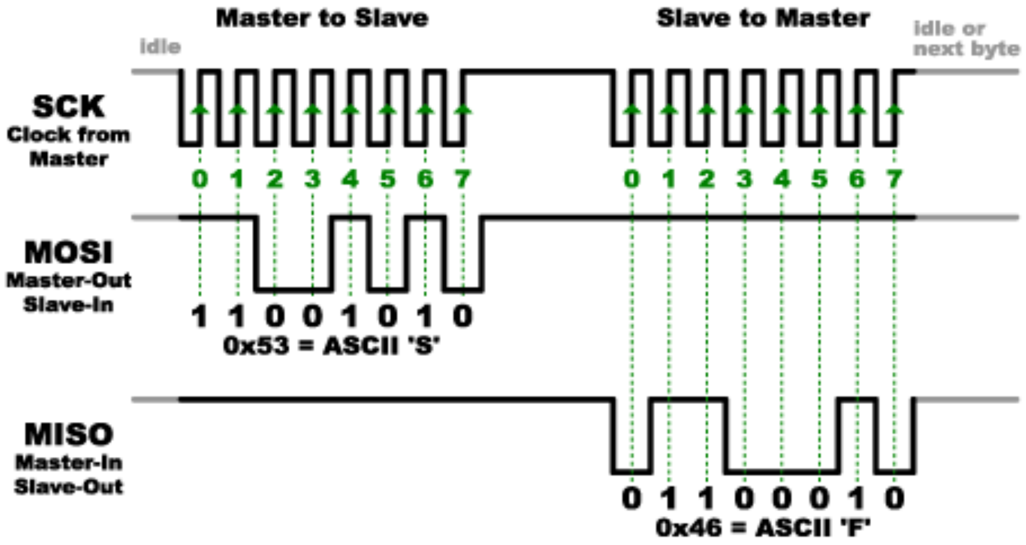
Bit order (MSB/LSB)

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

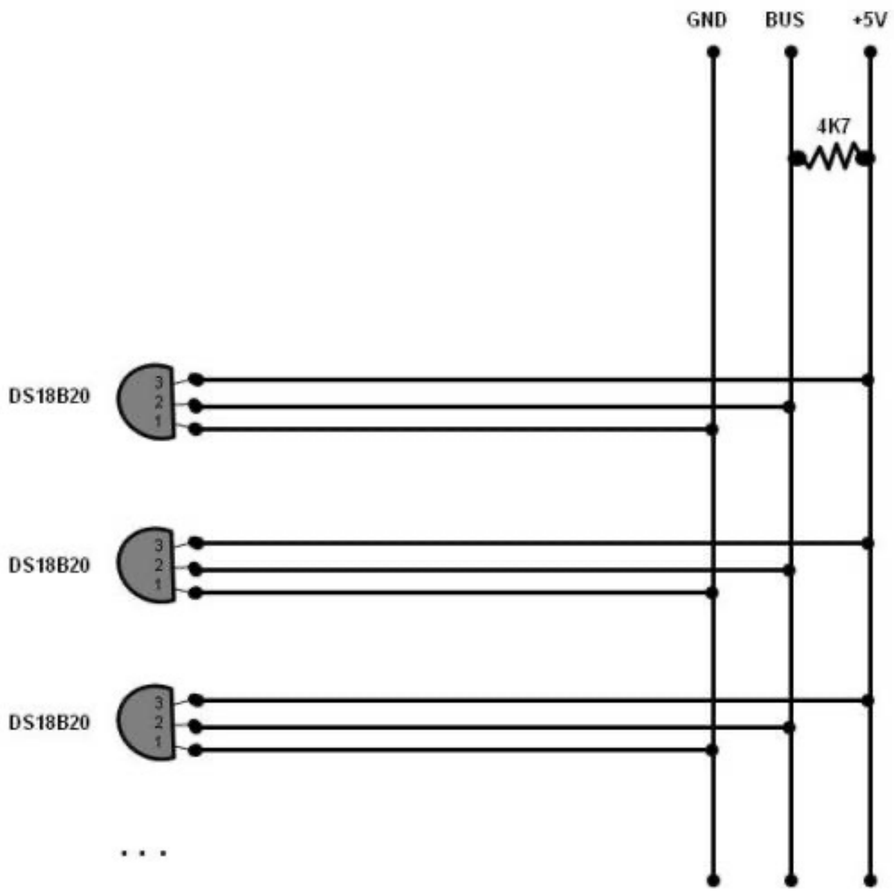
Programming

64bit slave IDs

Parasitic power (charge up)

Find devices

Communicate



Some other protocols

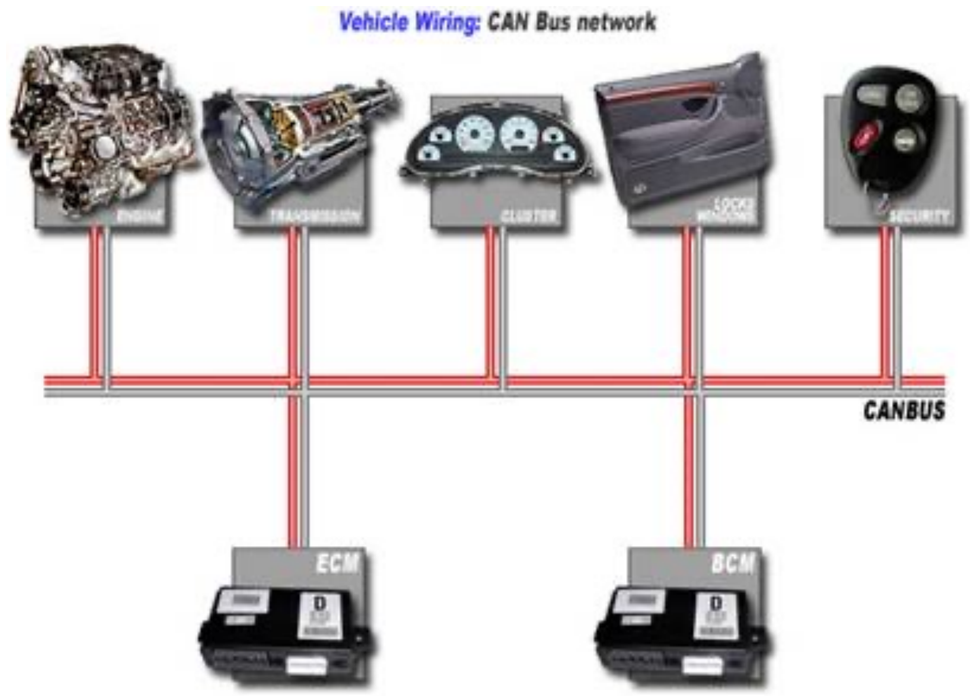
Industrial

CAN bus (hw support in ESP32)

LIN bus

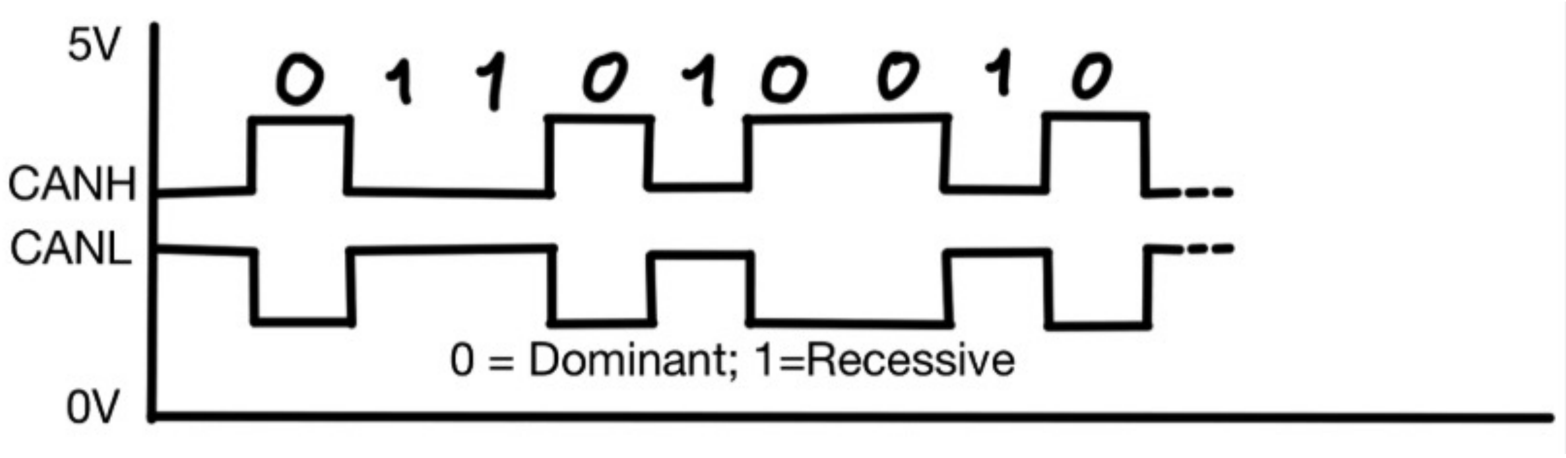
Industrial Ethernet (PROFINET, Modbus TCP …)

4-20 mA



HiFi sound

I2S



IoT wireless protocols

Common network topologies

P2P

Simplest

Star (Star of stars)

Common in public deployments

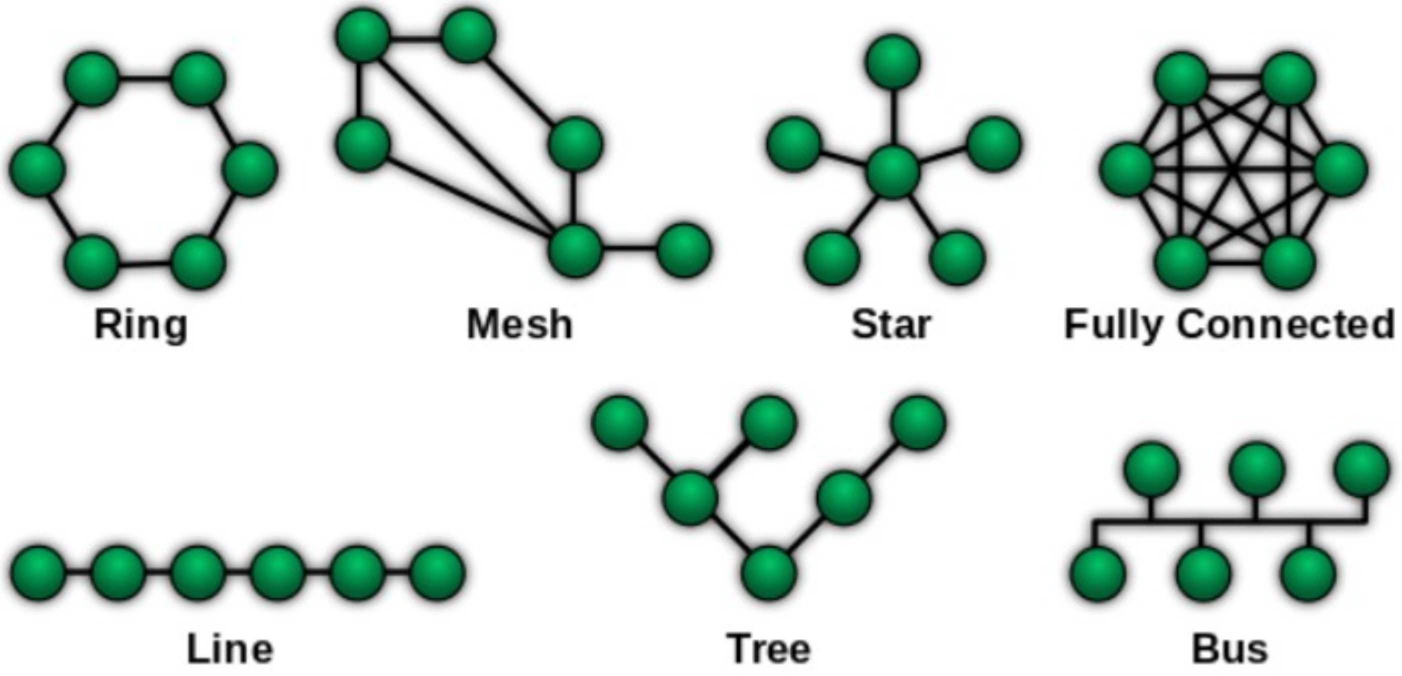
Mesh

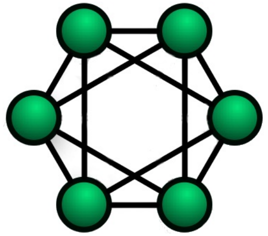
Complex

Potentially more reliable

Partially connected with XOR distance

(Petar Maymounkov – DHT)





Partially connected XOR

Bluetooth 4&5 (BLE)

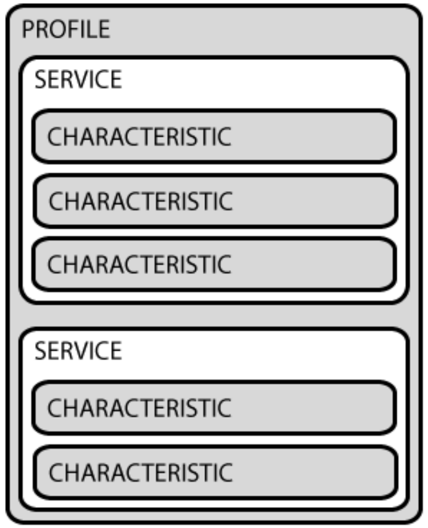
GATT (generic attribute profile)

Designed for low power

Peripherals advertise themselves

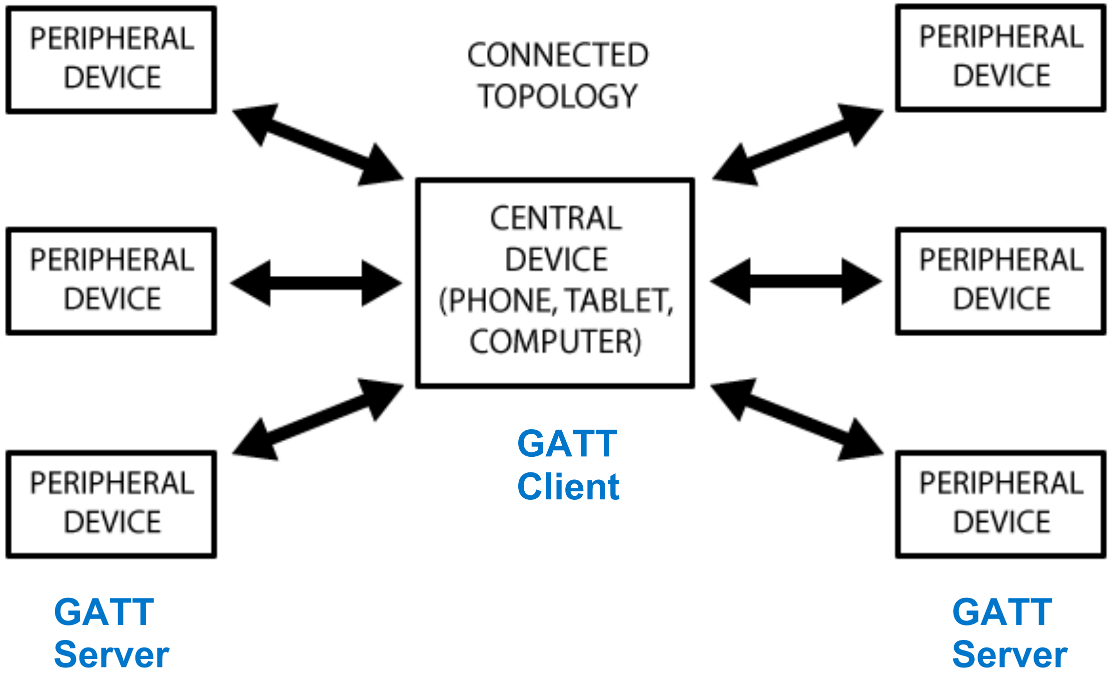
Central device initiates two way connection

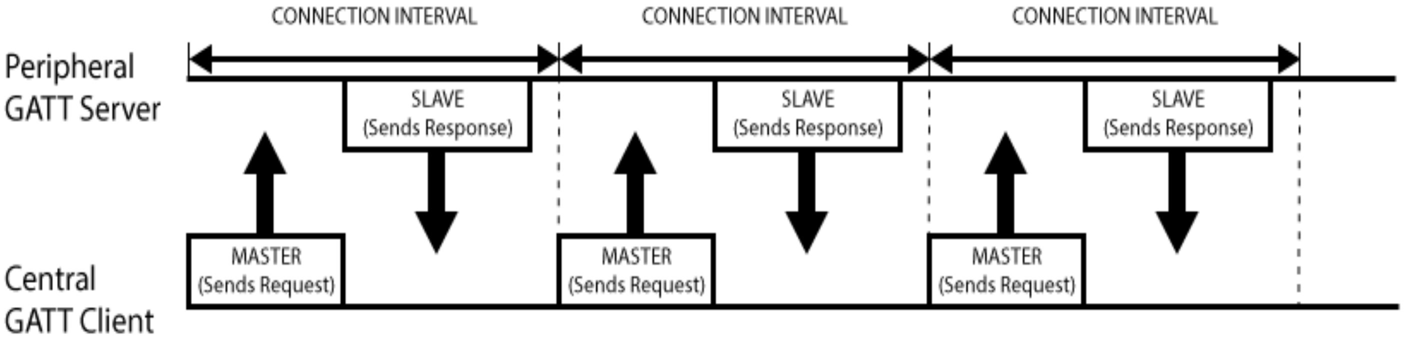
Profiles, Services & Characteristics



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

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



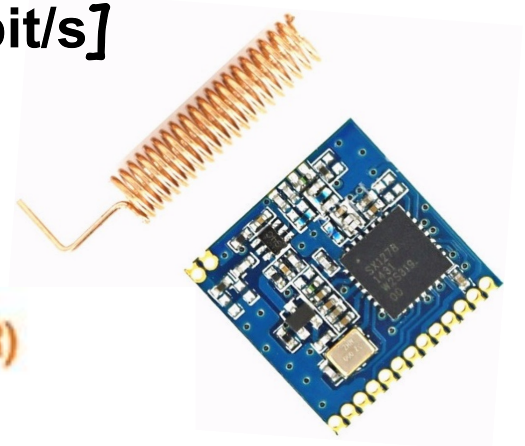


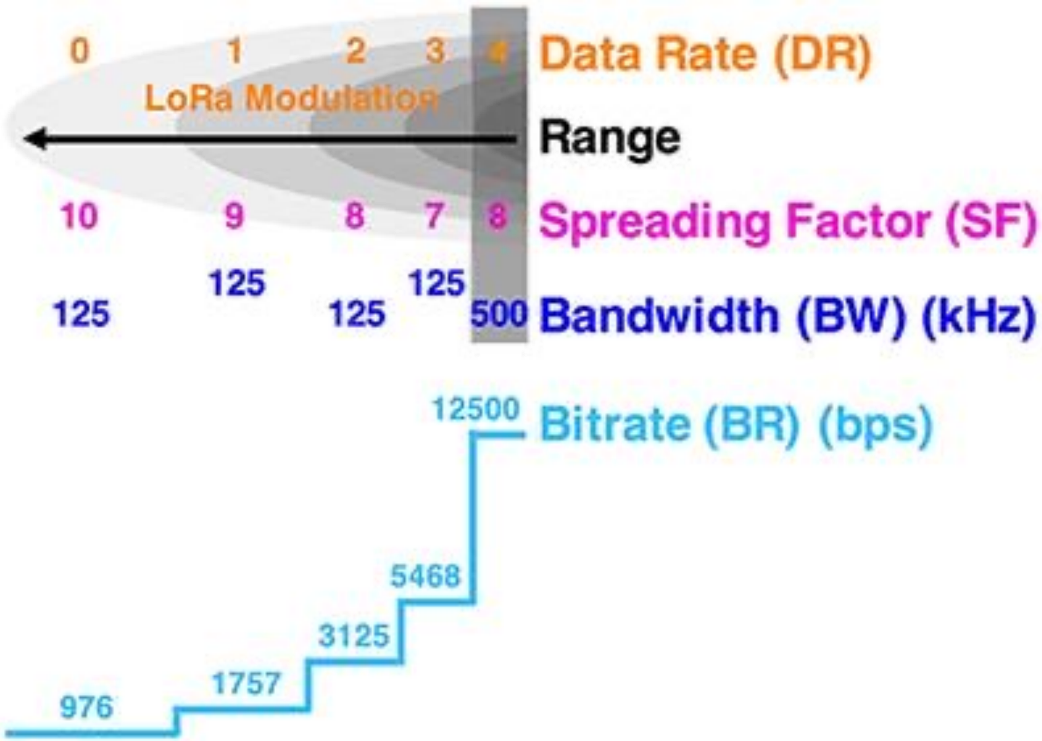
LoRa

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

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

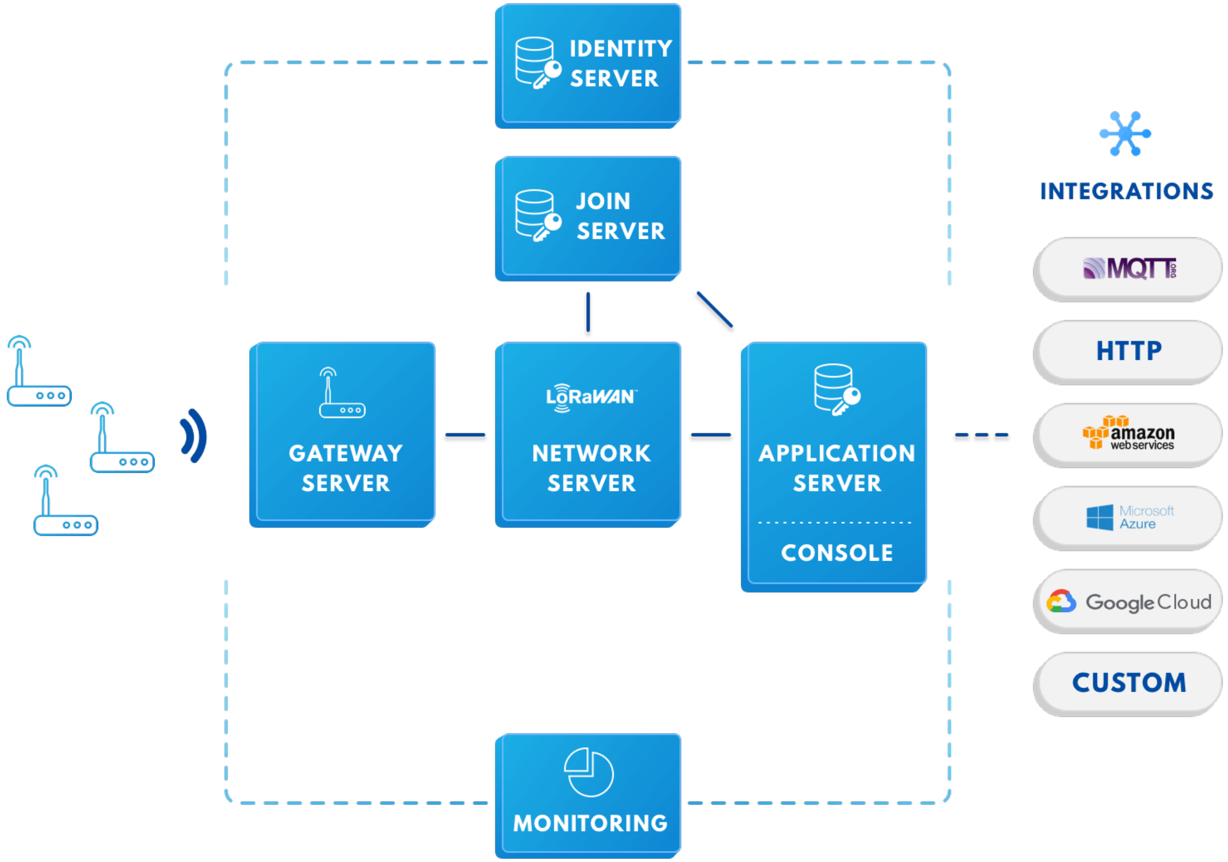
Centralized backbone

But you can deploy one yourself

Open source

End devices

Kind of expensive (compared to ESP)



Helium IoT network

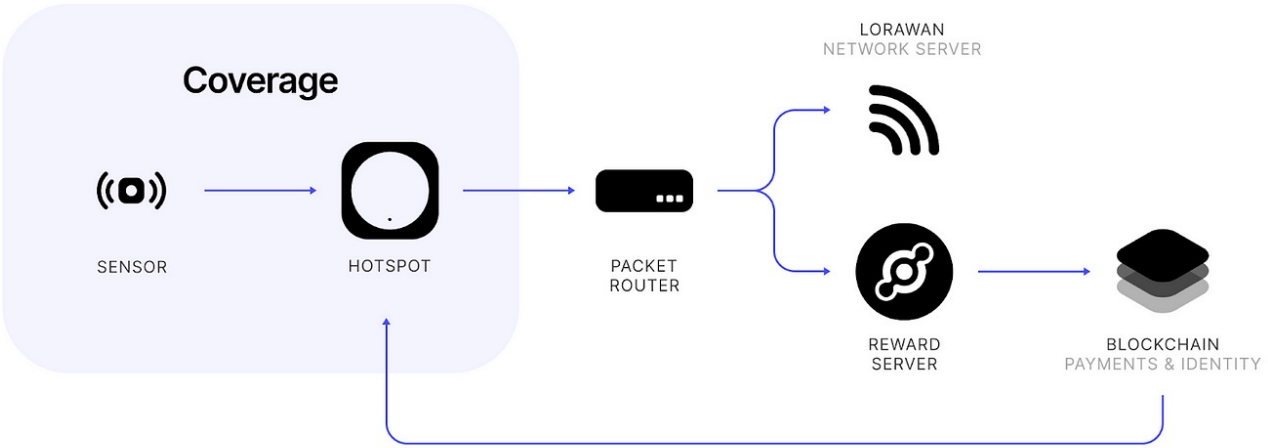
LoRaWAN based decentralized network

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

Rewards with Helium tokens (PoC, and data)

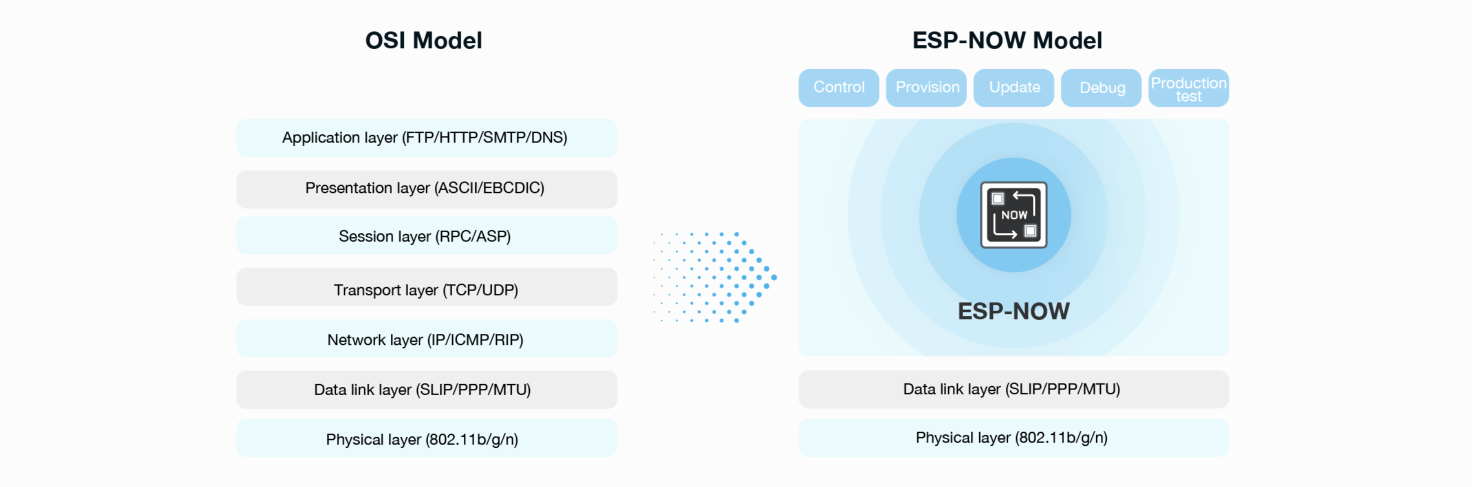
1 packet transfer costs 0.0001$

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

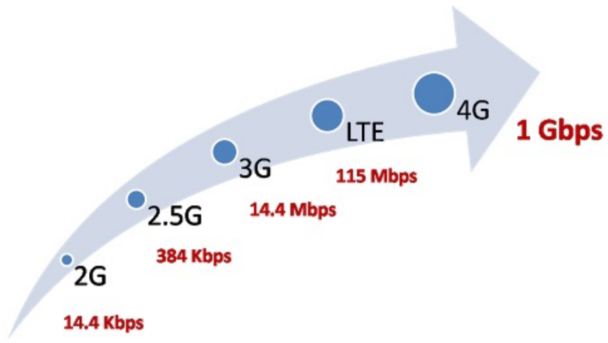


https://docs.arduino.cc/tutorials/nano-esp32/esp-now/

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