

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

Intro to communications

What is information?

Data

Datum = something given, a thing

Knowledge

Subject + data = experience

Learning = increasing knowledge

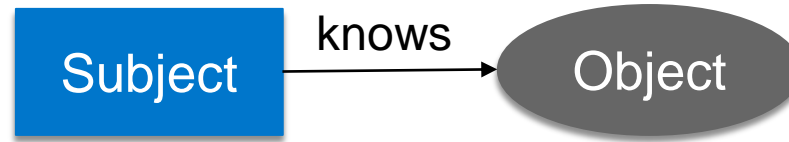
- Reduces uncertainty
- Improves outcome

Information

Conveys knowledge increments

Measured in bits

Entropy (data vs information)



Reducing uncertainty

$$P(A | E) \neq P(A)$$

Improving outcome

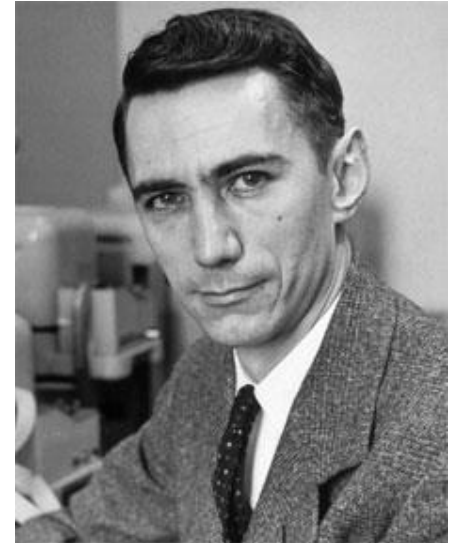
$$O'_T | E > O_T$$

Quantity of information

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

Entropy

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



Shannon, Nyquist, Hartley, Mitchell

What is communication?

Communication

Conveying information (knowledge)

Encoding & decoding

Information \leftrightarrow Data

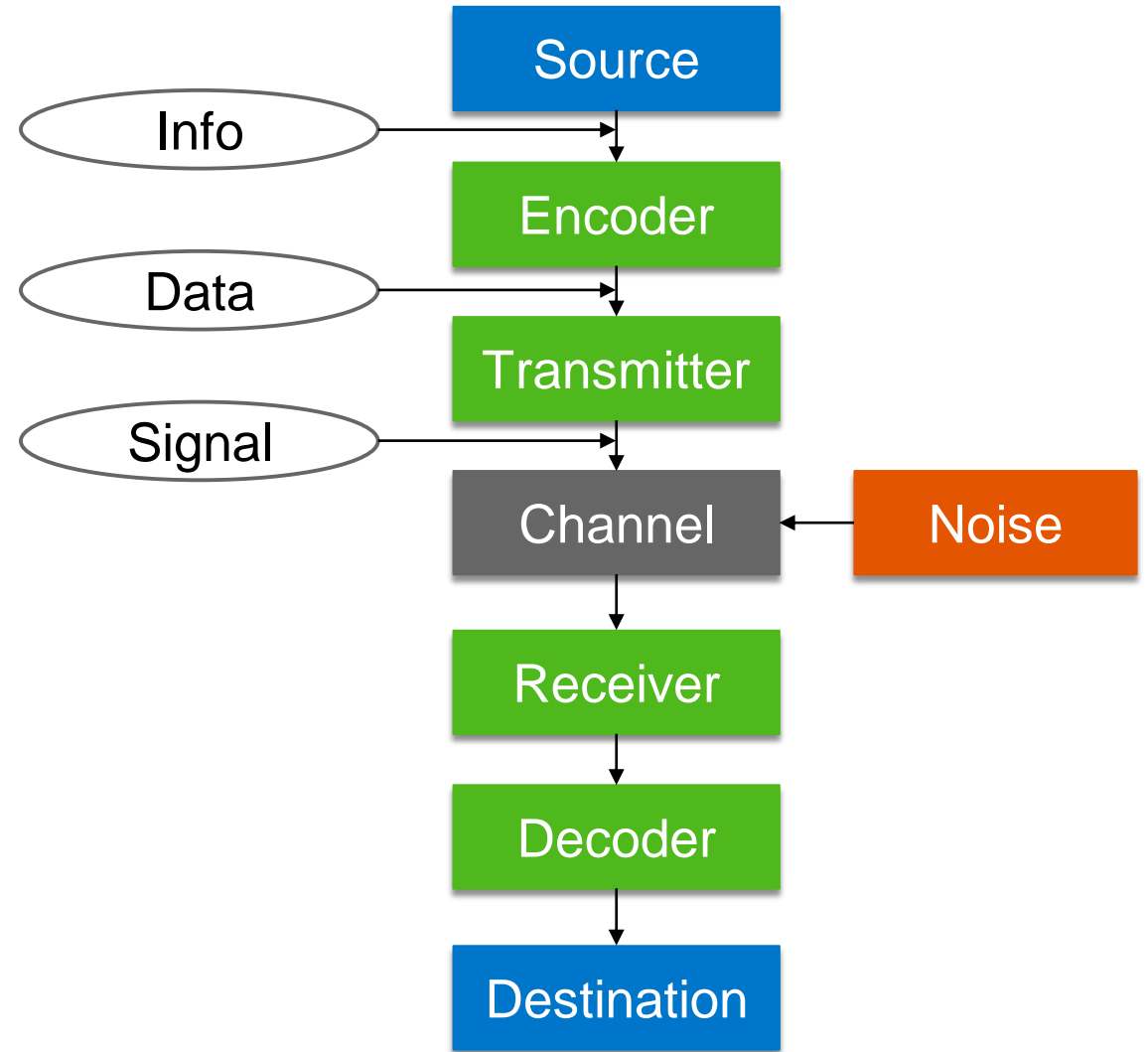
Transmission & reception

Data \leftrightarrow Signal (energy wave)

Channel

Carries and modifies the signal / data

Information may be affected



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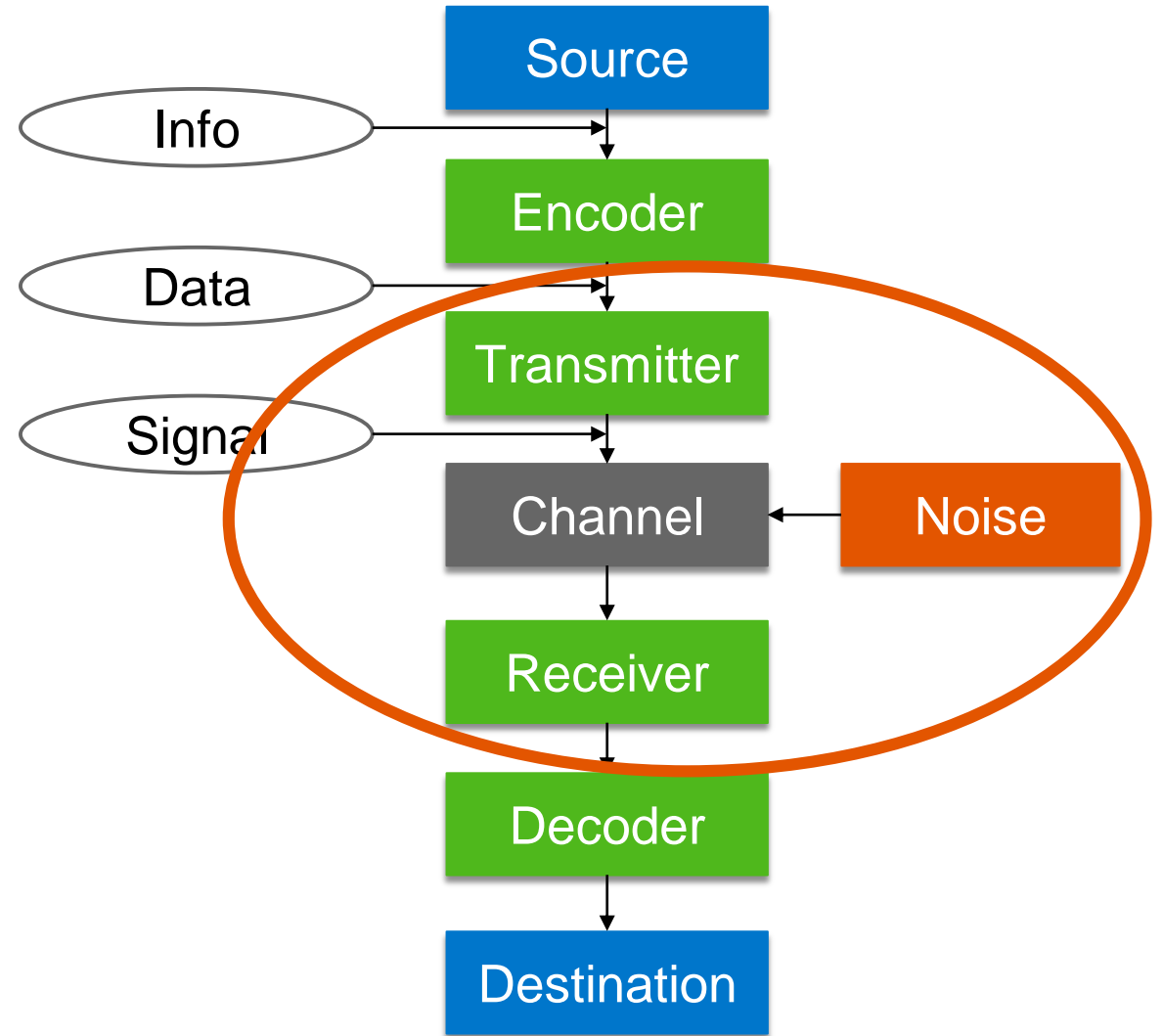
Transmission & reception

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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

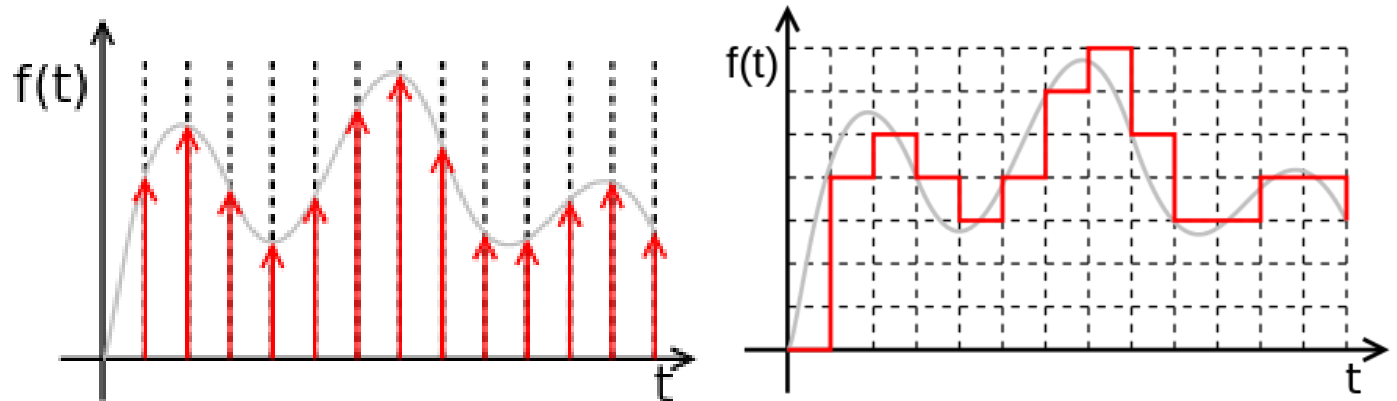
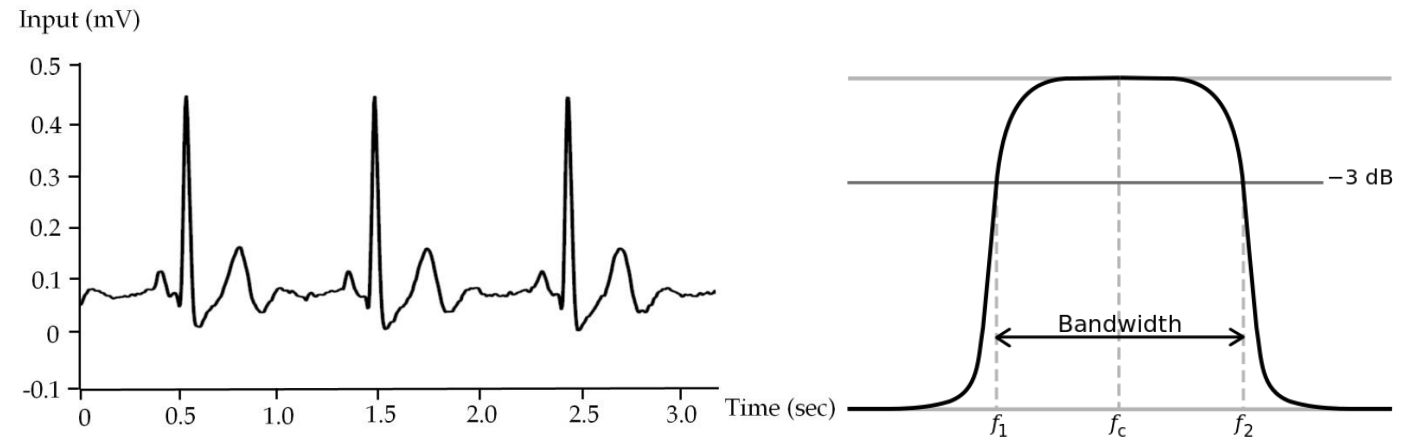
Digital signal

Time discretization (Nyquist): $F_S > 2B$

Amplitude quantization:

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

* Signal to quantization noise ratio: Q bits



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

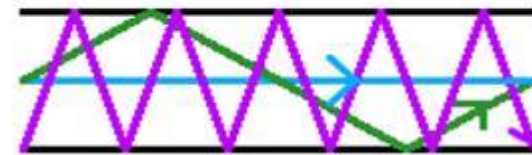
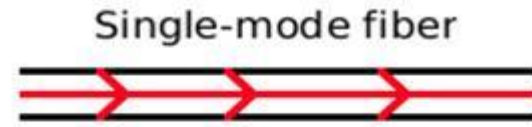
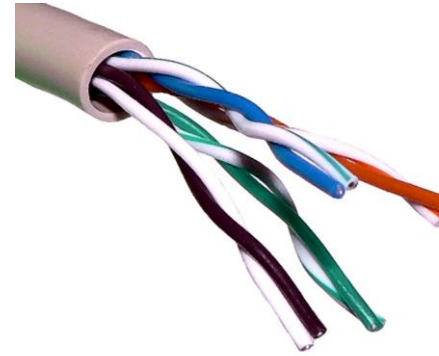
Single mode: 100TB/s, ~150 km, 0.06 EUR/m

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



Multi-mode fiber



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

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Encoding & decoding

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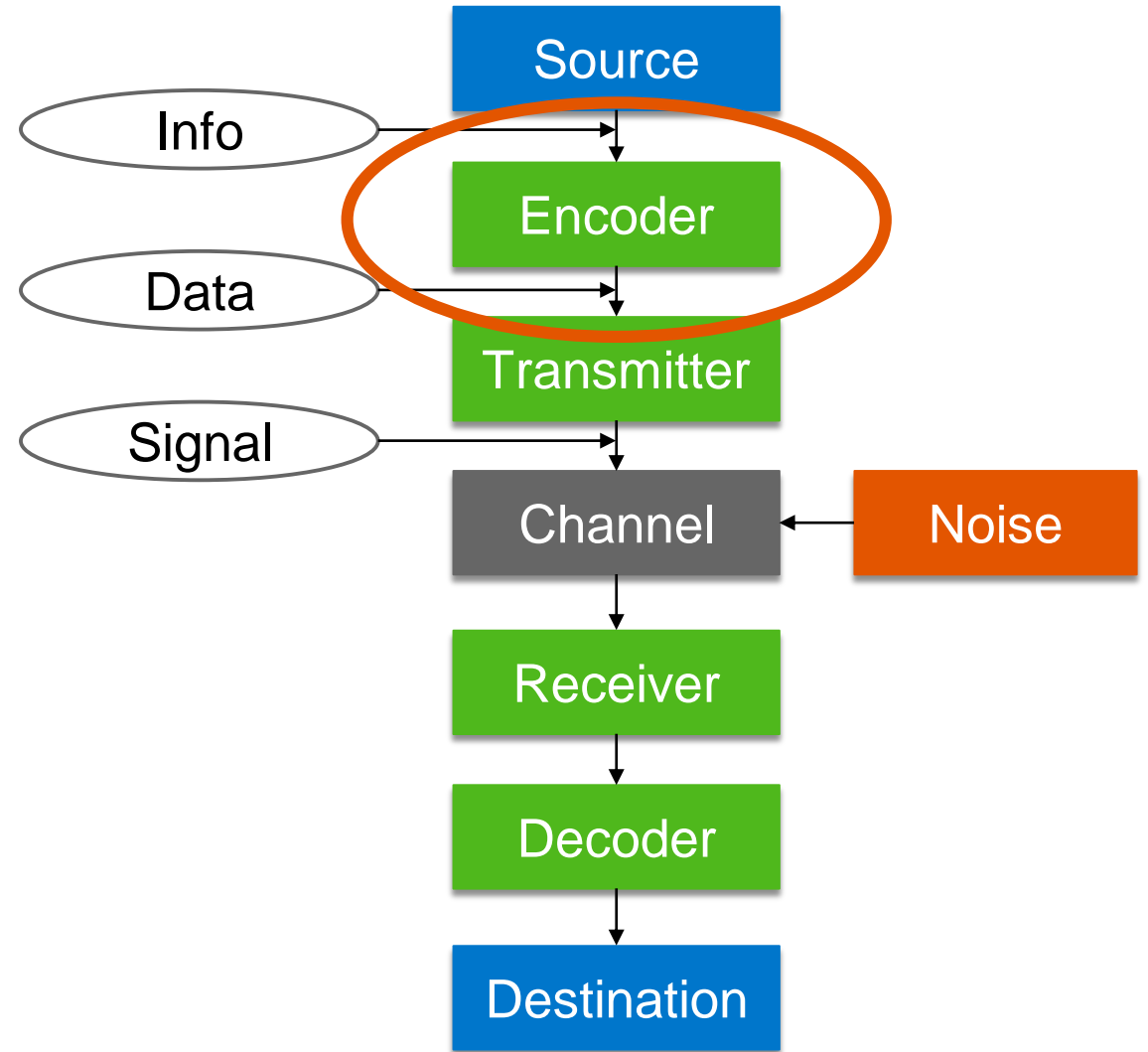
Transmission & reception

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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

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

Applications

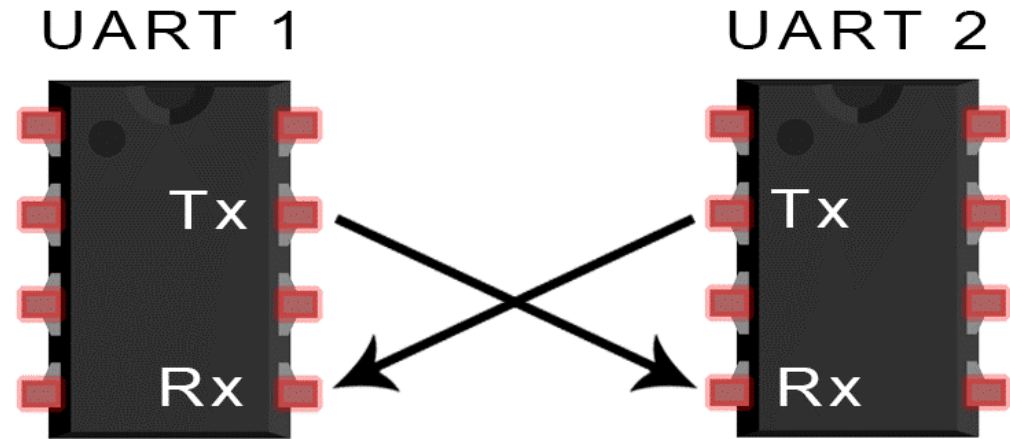
Industrial devices (RS485)

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

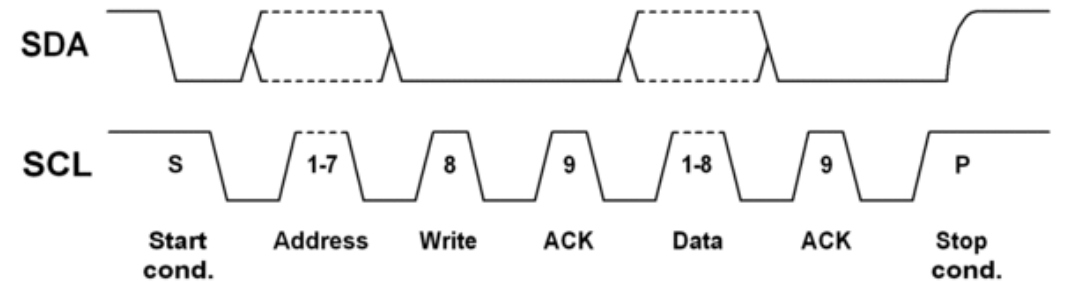
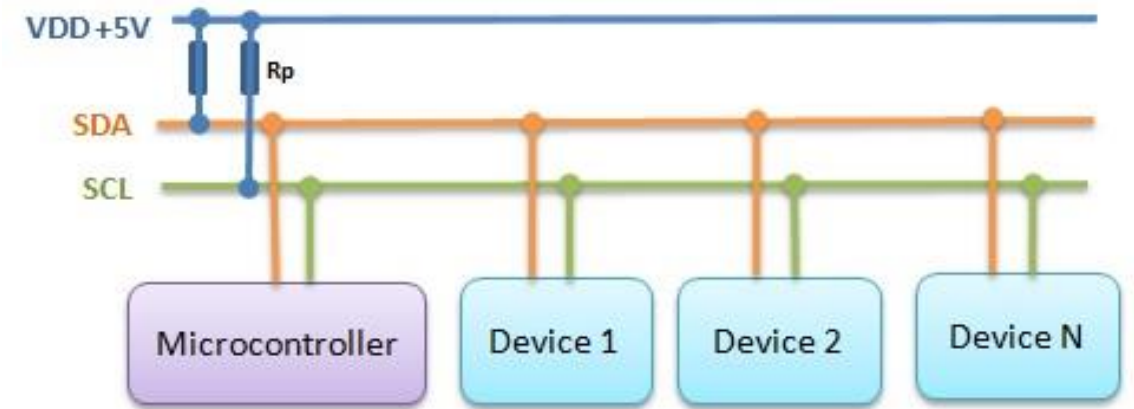
Programming

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

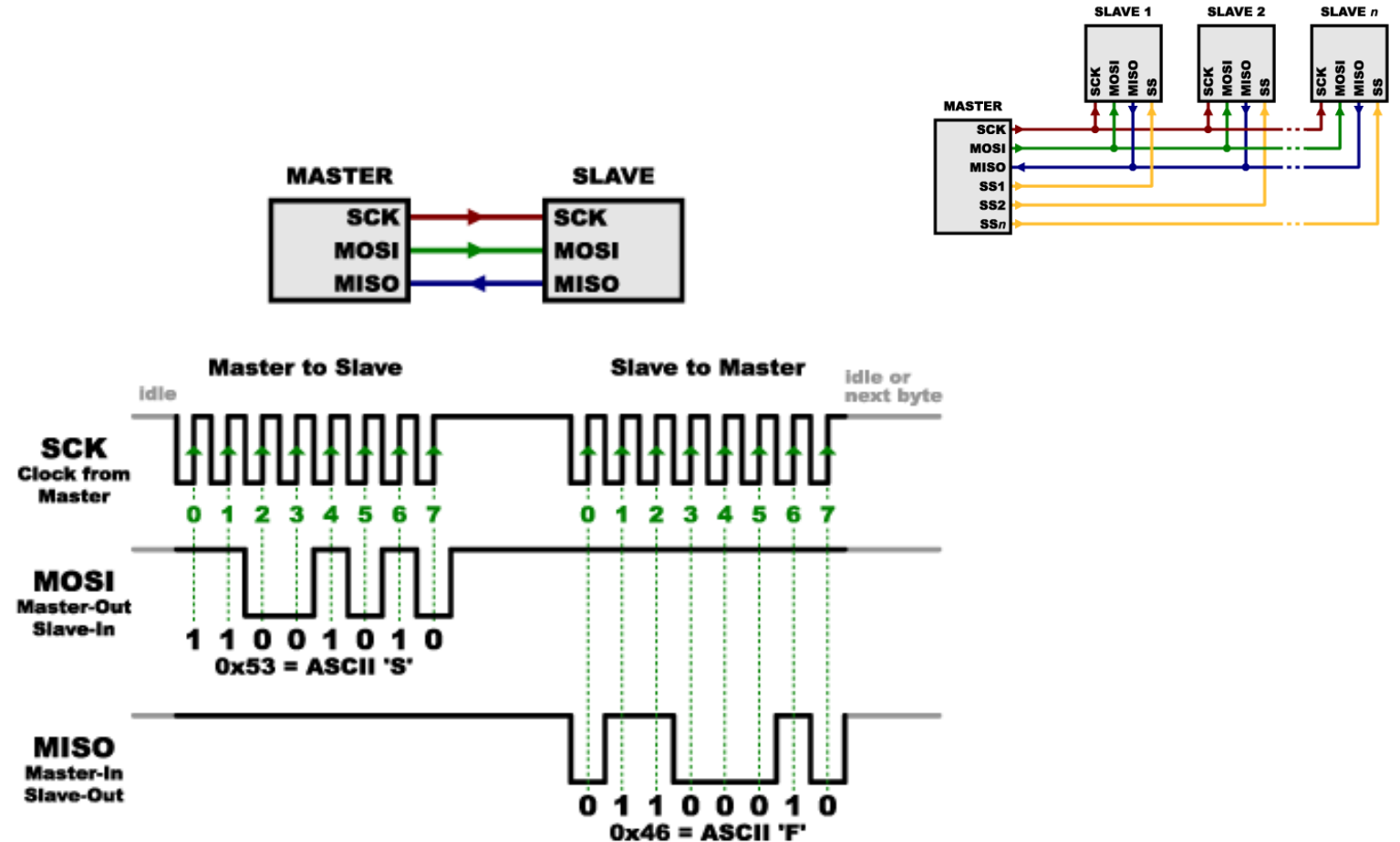
Implementation

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 / 125 kbit (overdrive)

Data line only (2/3 wire interface)

Single master / up to 100s of slaves

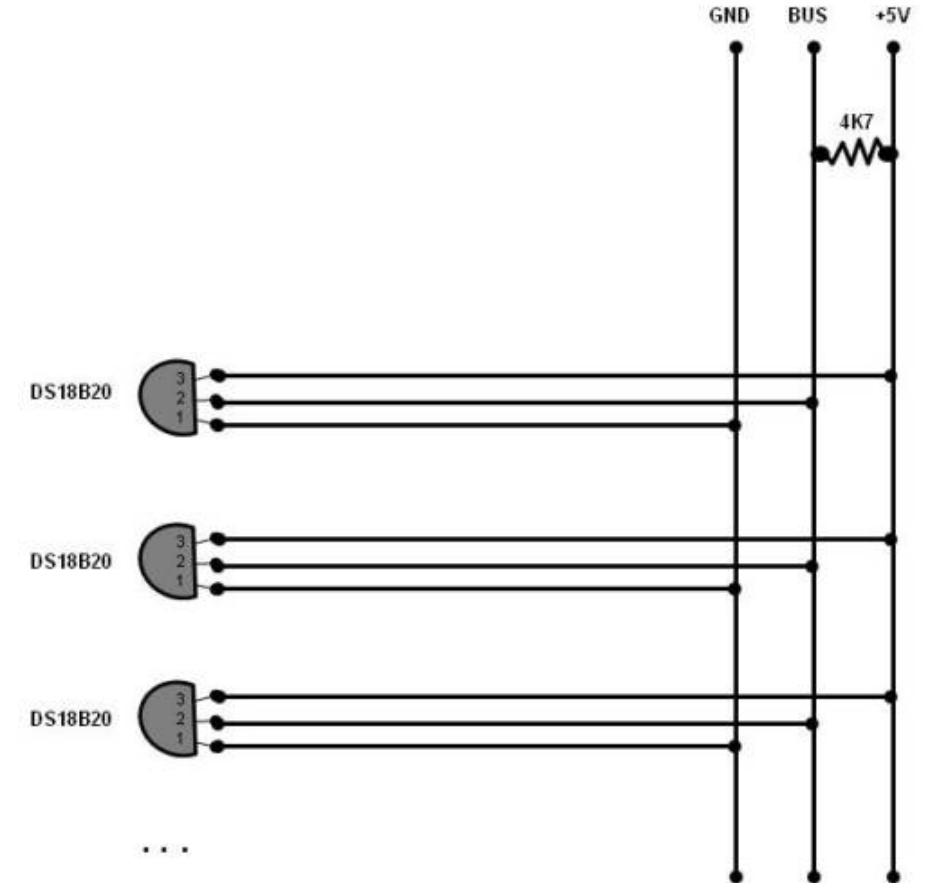
Programming

64bit slave IDs

Parasitic power (charge up)

Find devices

Communicate



Some other protocols

Industrial

CAN

Ethernet (PROFINET)

Modbus (PLCs), Profibus, 4-20 mA

I2S

HiFi sound

IoT wireless protocols

Common network topologies

P2P

Simplest

Star (Star of stars)

Common in public deployments

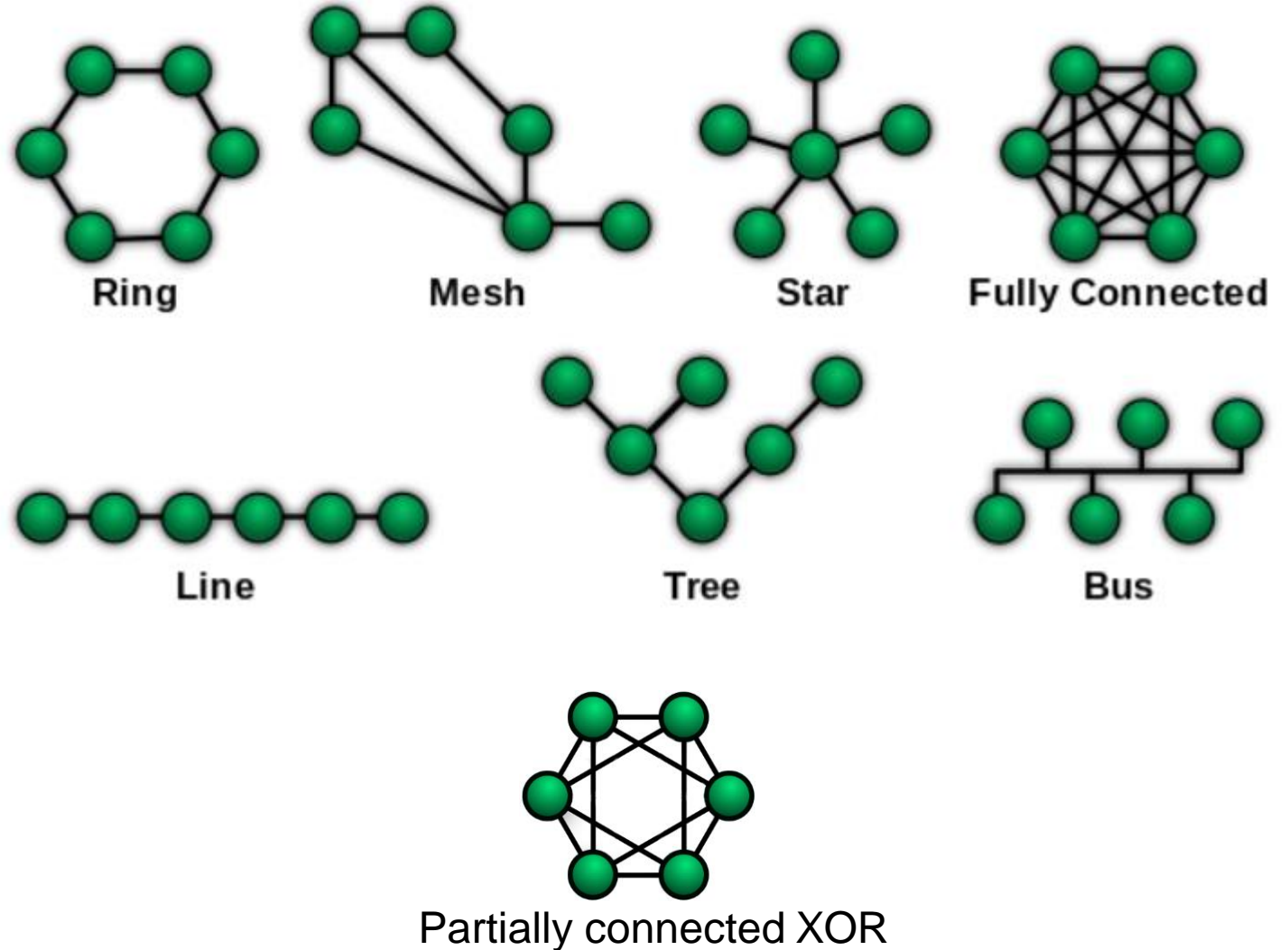
Mesh

Complex

Potentially more reliable

Partially connected with XOR distance

(Petar Maymounkov – DHT)



Bluetooth 4 (BLE)



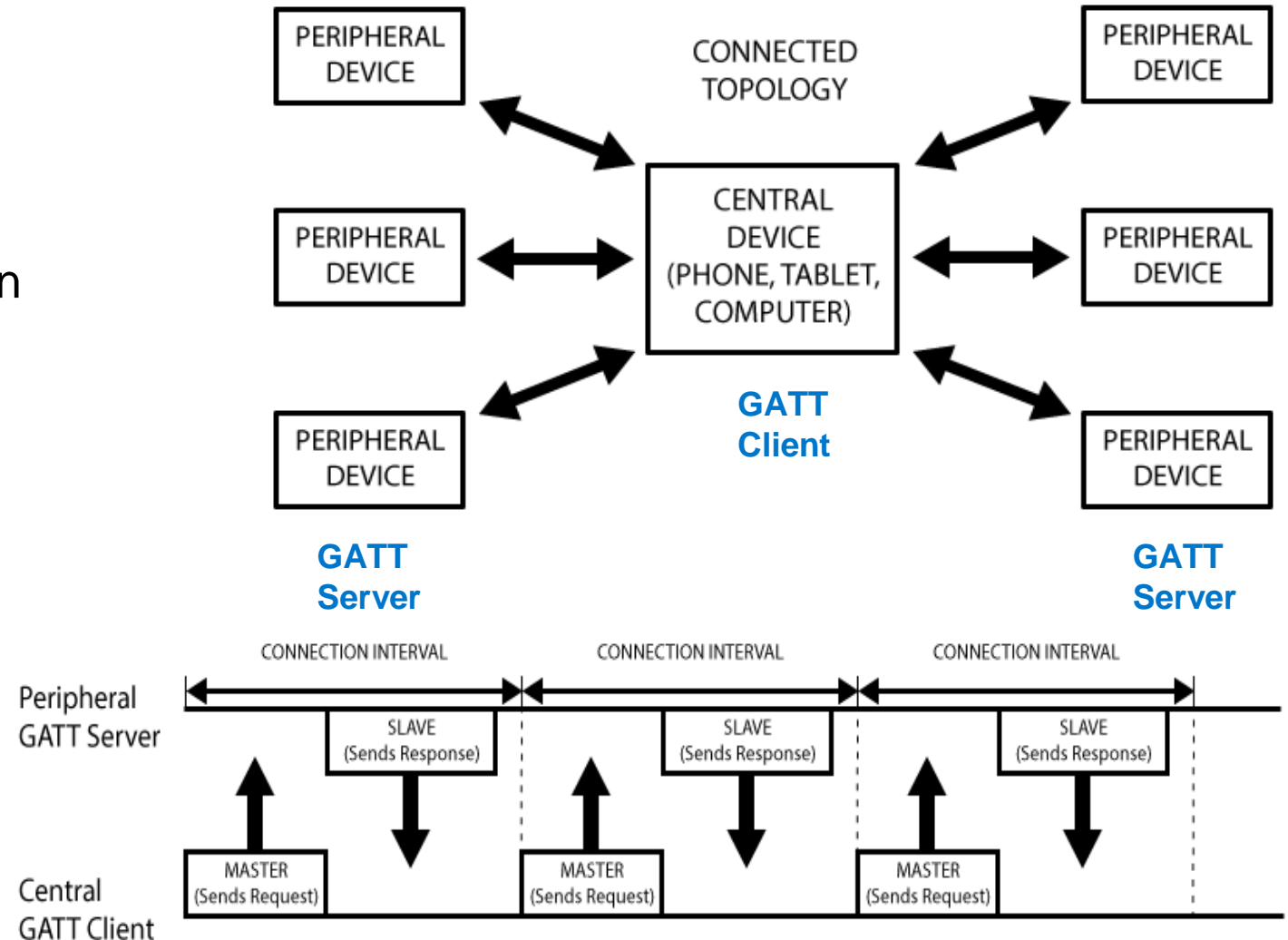
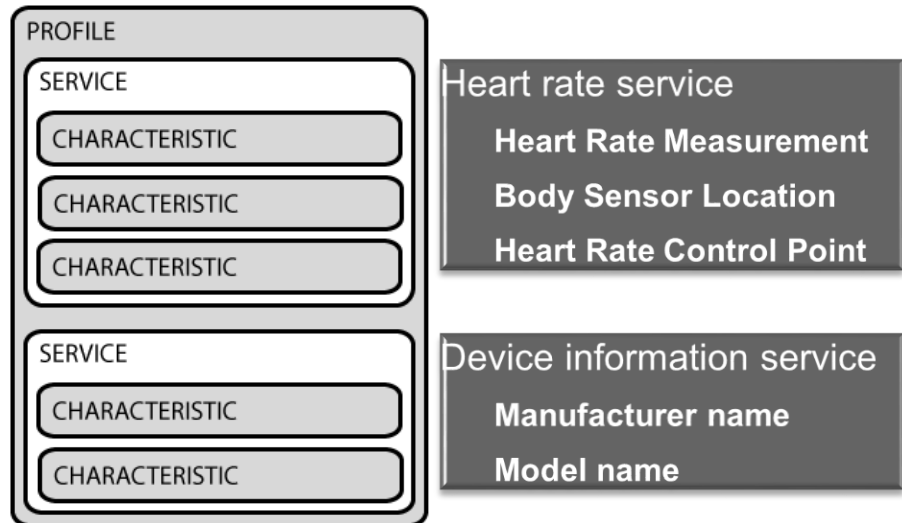
GATT (generic attribute profile)

Designed for low power

Peripherals advertise themselves

Central device initiates two way connection

Profiles, Services & Characteristics



Bluetooth 5

Already here (BT4 compatible)

Samsung Galaxy S8, S8+, Note, S9, S9+, iPhone 8, some boards

... and ESP32 😊

Longer range (~ 4x)

12dB improved sensitivity, 500kbps or 125kbps modes with Coded PHY

Higher data throughput (~5x)

2x LE (up to 2Mbps) by changes in physical / radio layer

Data Length Extensions (DLE)

Better broadcasting (Advertising Extensions)

Less congestion, extended advertising payloads

Periodic advertising & long range connections (e.g. for way-finding, indoor navigation, asset tracking)



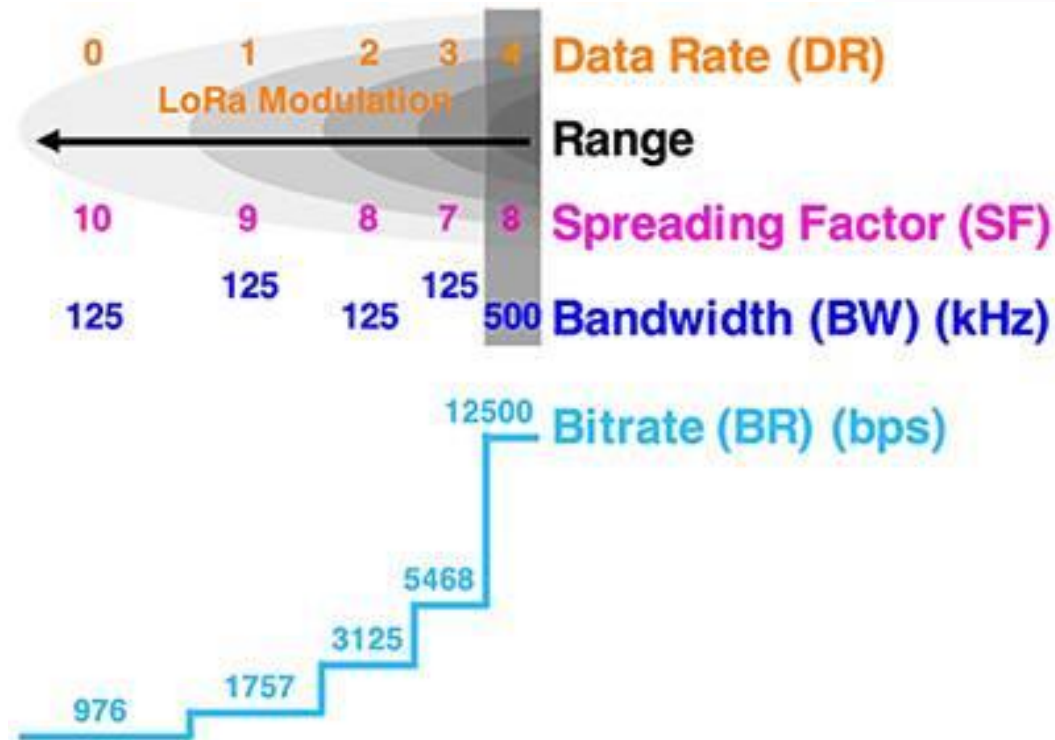
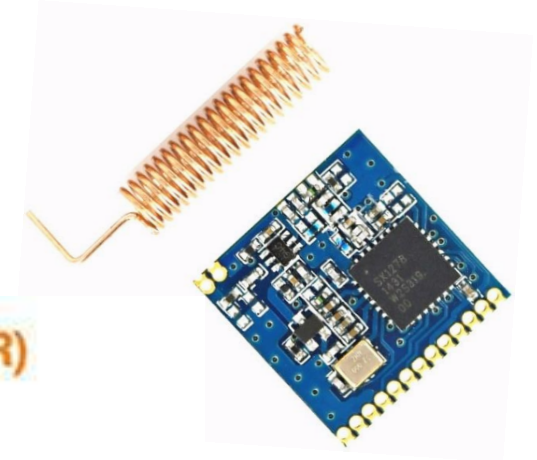
LoRa



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
- Resistance to fading (e.g. from multipath)

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



Interesting properties

Star, P2P and Mesh topologies

Private & Public deployments (LoRaWAN)

Military origin (anti-jamming & LPI)

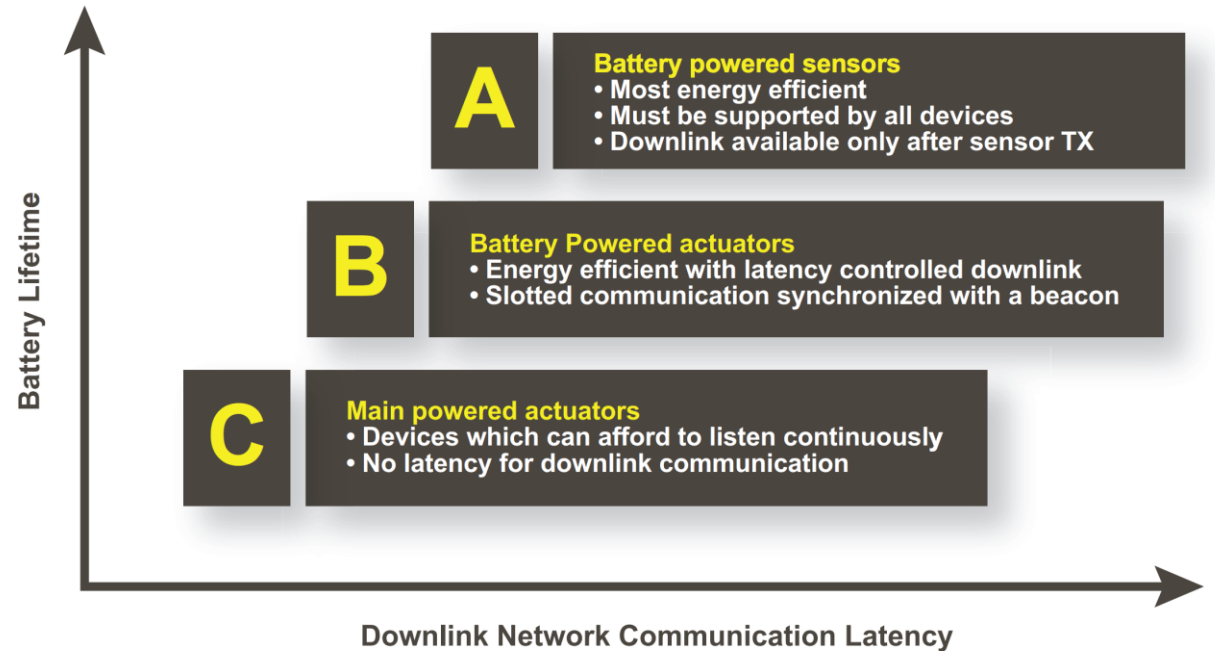
LoRaWAN



Wide area network on top of LoRa

Security:

- **Network** - authenticity of the nodes in the network
- **Application** - the network operator does not have access to the end user's application data (AES encryption)



Some other protocols

Cellular

3G, LTE, 4G, Sigfox ...

IEEE 802.15.4

ZigBee (popular in EU)

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

Z-wave (popular in US)

- 868MHz, Mesh, single vendor
- Use cases: Home automation, Smart buildings

Custom

e.g. HC-12

