Connectivity

March, 2018

Agenda

Intro to communications

Information theory

Channel characteristics & media types

Encoding and error control

Internet refresher …

TCP/IP & HTTP

CoAP & MQTT

IoT specific protocols

Wireless: Wifi/HaLow, BT 4.0, LoRa, LTE, Zigbee, Z-wave, 6LowPAN

Wired: UART/RS485, SPI, I2C, OneWire, Ethernet, Modbus?, 4-20 mA

Intro to communications

What is information?

Data

Datum = something given, a thing

Knowledge

Subject + data = experience

Learning = increasing knowledge

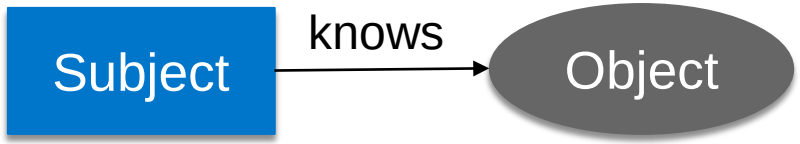
- Reduces uncertainty
- Improves outcome

Information

Conveys knowledge increments

Measured in bits

Entropy (data vs information)



Reducing uncertainty

$$P(A \mid E) > P(A)$$

Improving outcome

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

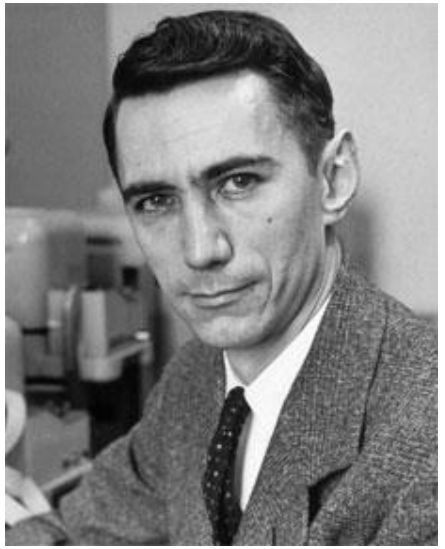
Quantity of information

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

Entropy

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

Shannon, Nyquist, Hartley, Mitchell



What is communication?

Communication

Conveying information (knowledge)

Encoding & decoding

Knowledge <-> Data

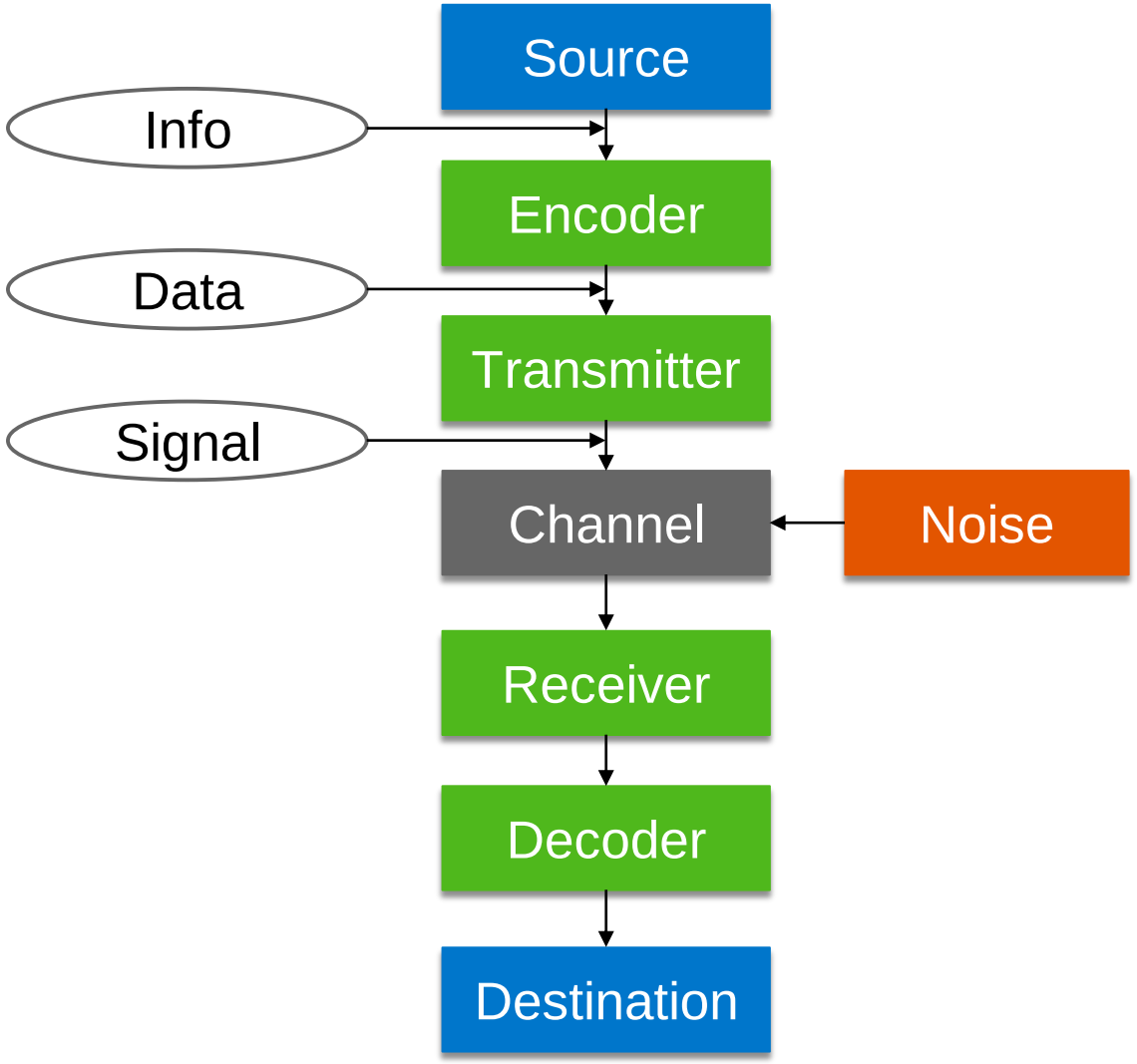
Transmission & reception

Data <-> Signal (energy wave)

Channel

Carries and modifies the signal / data

Information may be affected



Signal & channel characteristics

Signal

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]**

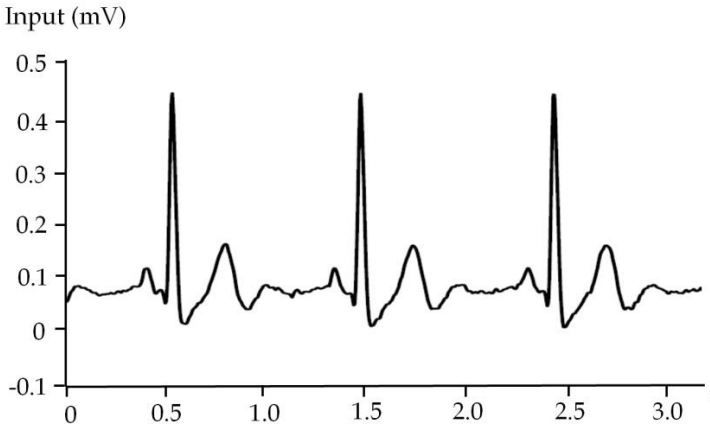
Digital signal

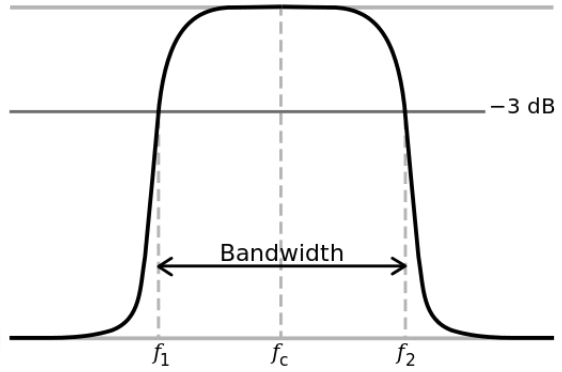
Time discretization (Nyquist): $F_S > 2B$

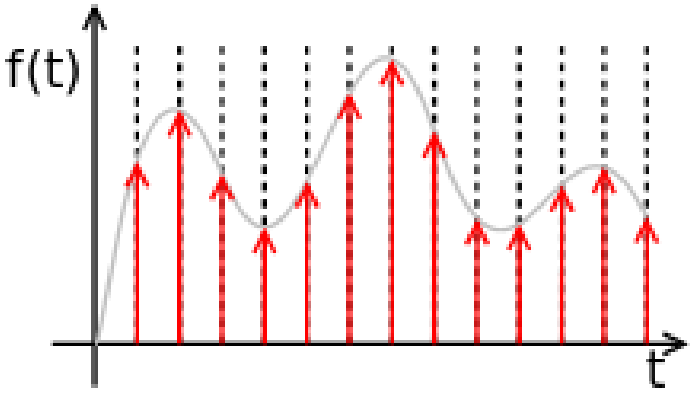
Amplitude quantization:

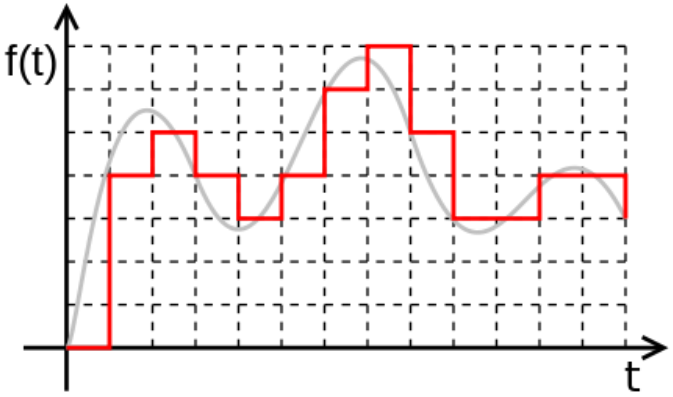
$SQNR = 20\log_{10}(2^Q) = 6.02\ Q$ **[dB]**

* Signal to quantization noise ratio: Q bits







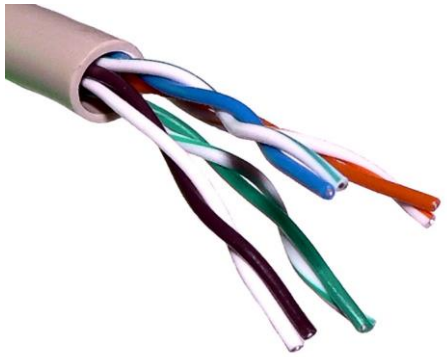


Common media types

Electrical wires

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

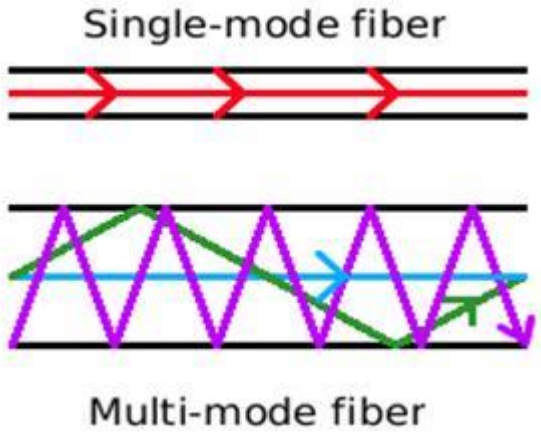
Coaxial: 10 MB/s, 450m, 0.5 EUR/m



Optical fibers

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

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



Radio (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 / directional

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

Encoding & Error control

Encoding

Text: Morse, ASCII, UTF8, CP1251 …

Images: BMP, GIF, JPEG, PNG …

Sound: Flac, Vorbis, MPEG, Speex, SILK, Opus …

Video: H264, Theora …

Error control

Detection: Parity bit, Checksum, CRC, 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

Internet refresher & more …

TCP/IP

IP

Private & public addresses

Routing, NAT and Firewalls

Host names (DNS)

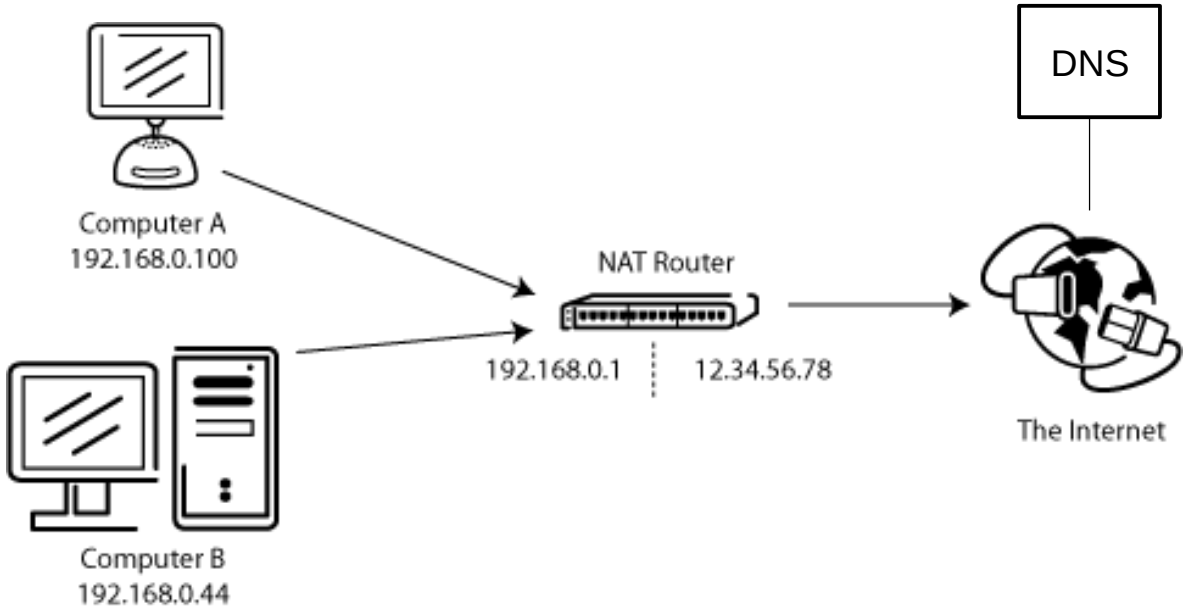
Load balancing

- DNS round robin
- Virtual IP

TCP & UDP

Ports (services)

Error control & ordering



HTTP Request

Method

GET, POST, PUT, DELETE …

Headers

Accept (content type, encoding ….)

Authorization

Cache-Control

Cookies

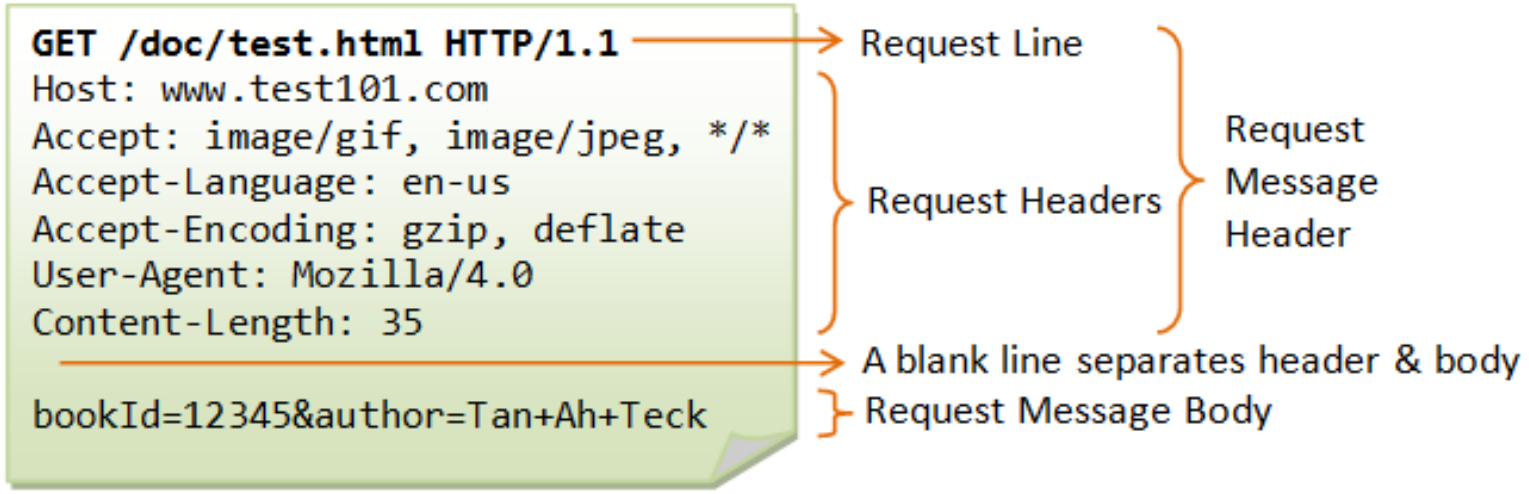
Content-Type

Host

Body

Application specific (e.g. JSON, XML …)

Usually POST and PUT methods only



HTTP Response

Status line

Protocol version

Status

Headers

Access-Control-Allow-Origin

Cache-Control

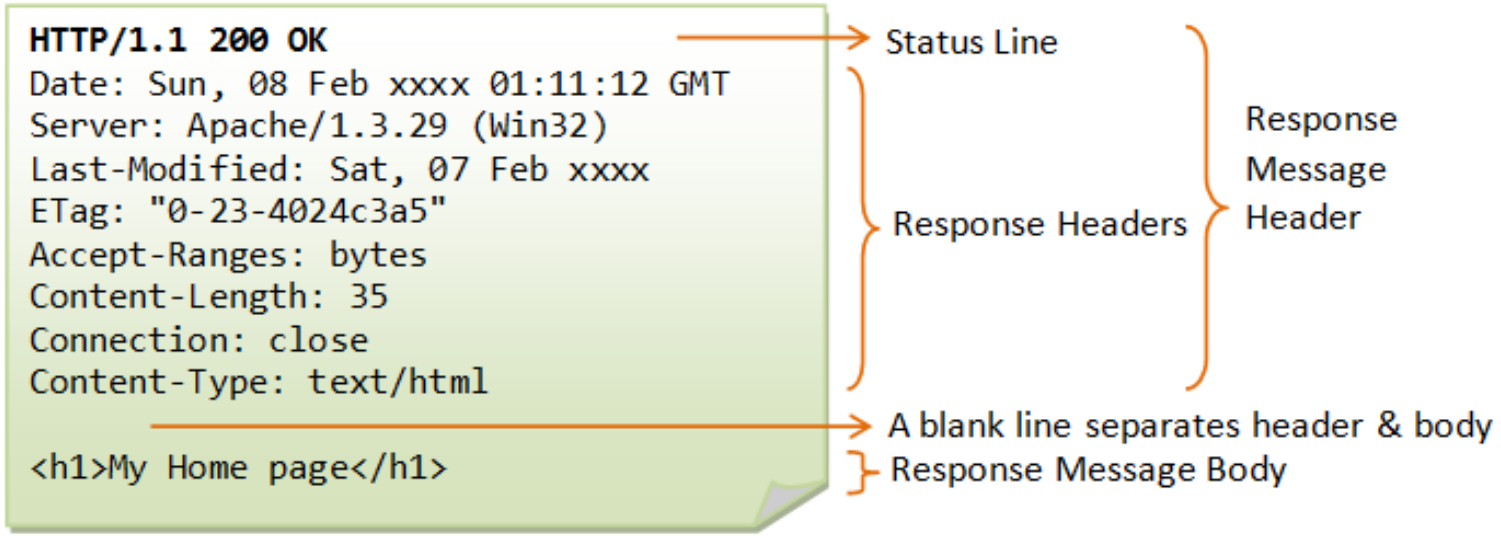
Content-Type

Set-Cookie

…

Body

Application specific (e.g. JSON …)



HTTP Proxies

Types of proxies

Forward proxy

- Transparent proxy (with DNS)

Reverse proxy

Proxy functions

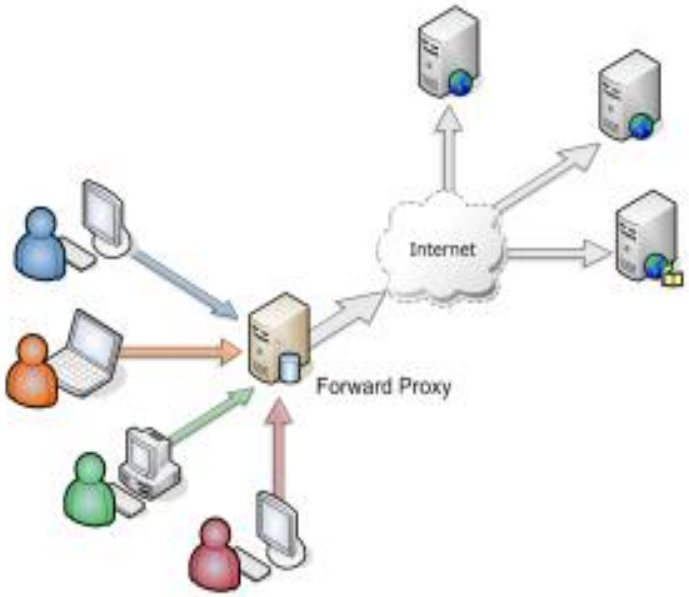
Virtual hosting

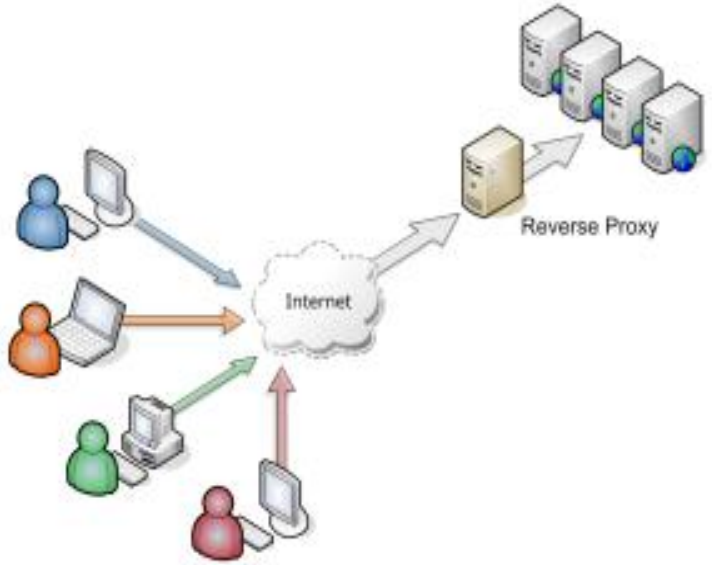
Load balancer (HTTP)

Cache

SSL terminator

DDoS protection





MQTT (ISO/IEC PRF 20922)

Overview

TCP/IP based

Small footprint / low bandwidth

Pub/sub (broker)

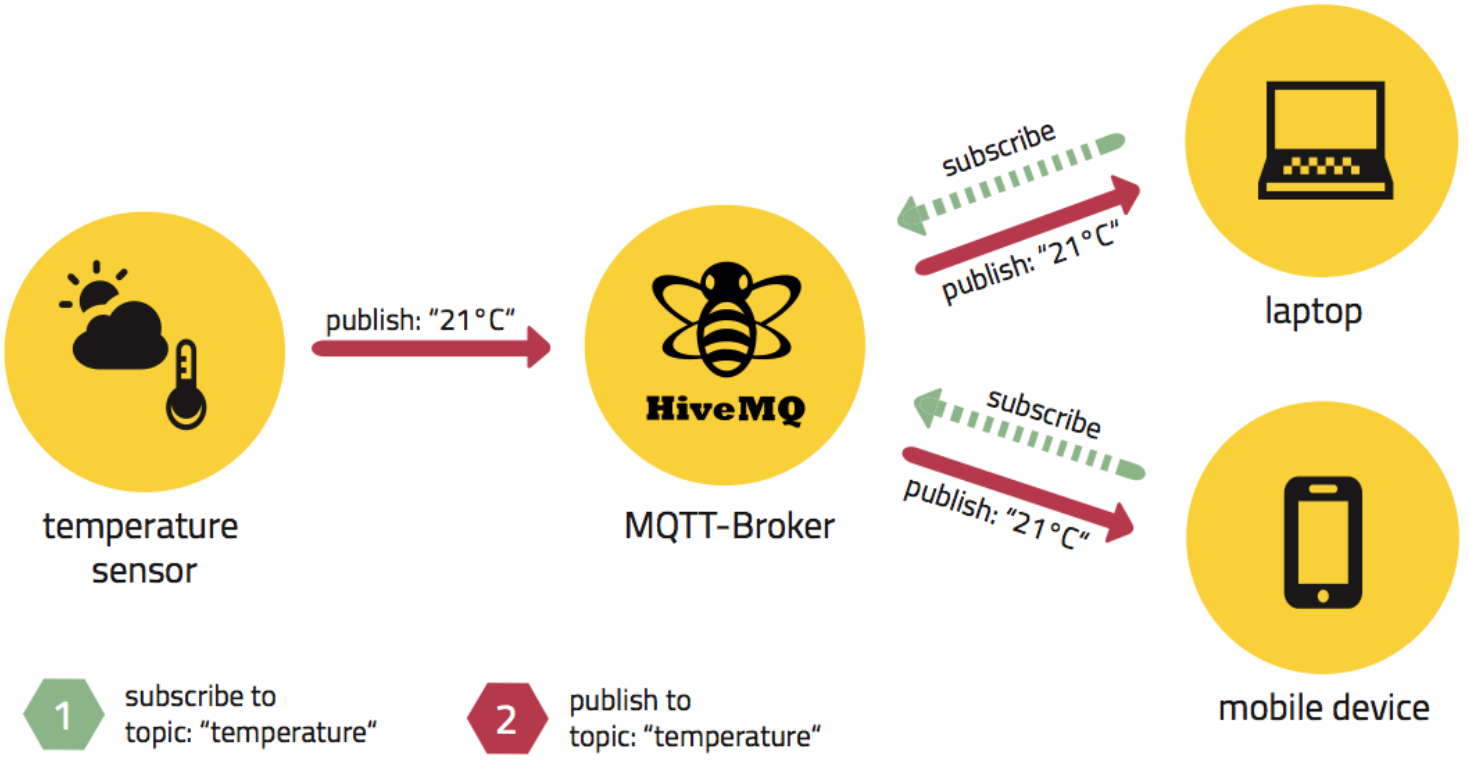
MQTT-SN: non TCP (e.g. Zigbee)

Methods

Connect / Disconnect

Subscribe / Unsubscribe

Publish



IoT wireless protocols

Common network topologies

P2P

Simplest

Star (Star of stars)

Common in public deployments

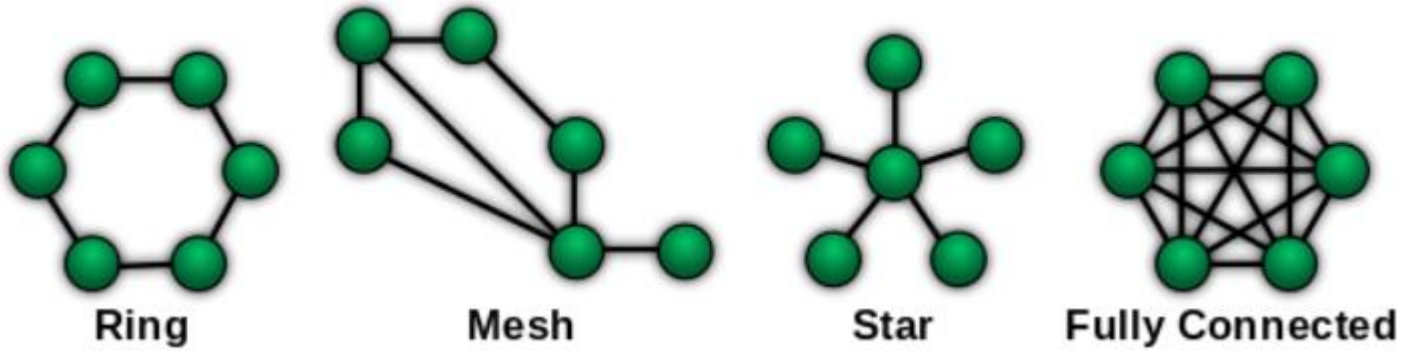
Mesh

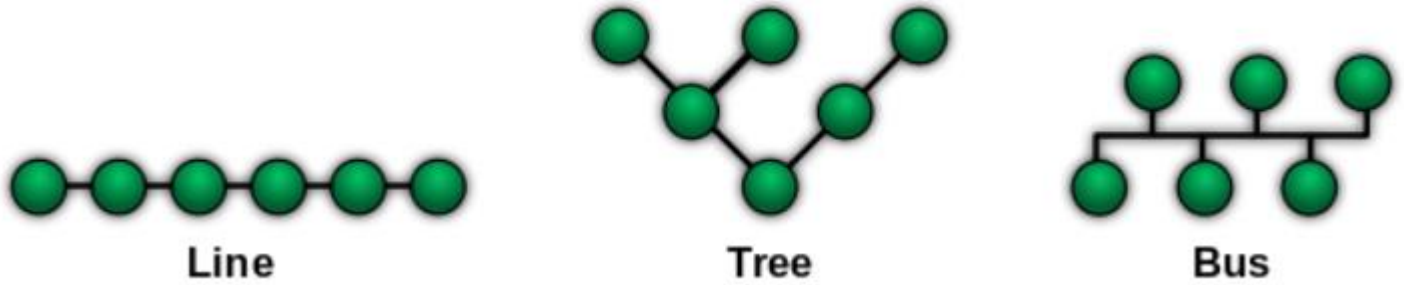
Complex

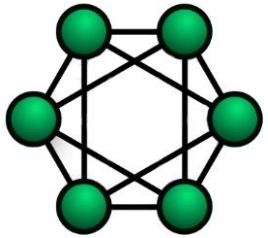
Potentially more reliable

Partially connected with XOR distance

(Petar Maymounkov – DHT)







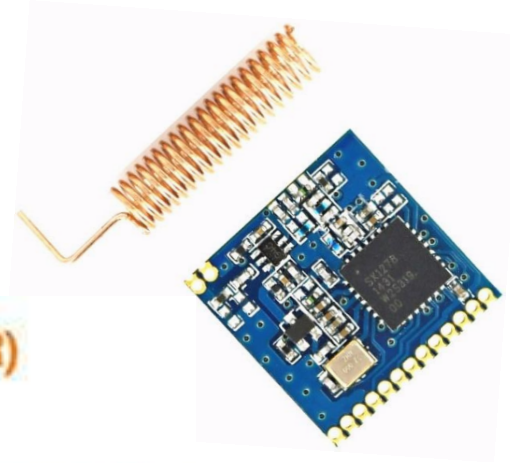
Partially connected XOR

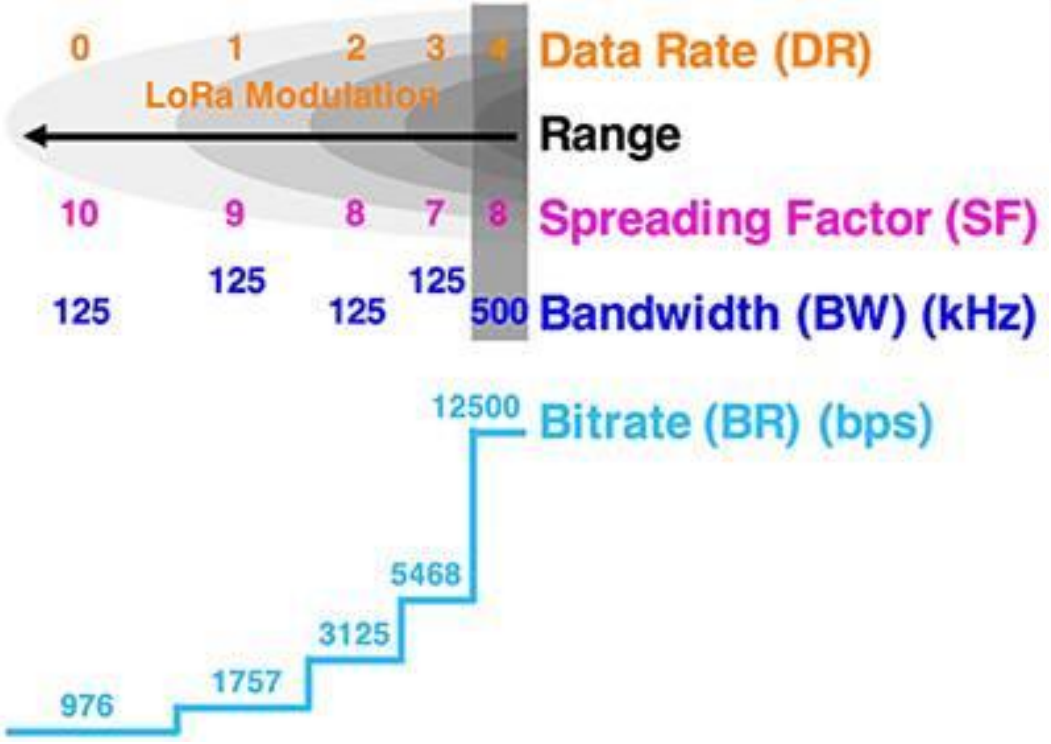
LoRa

FM Chirp Spread Spectrum & FEC

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

- 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)





Interesting properties

Star, P2P and Mesh topologies

Private & Public deployments (LoRaWAN)

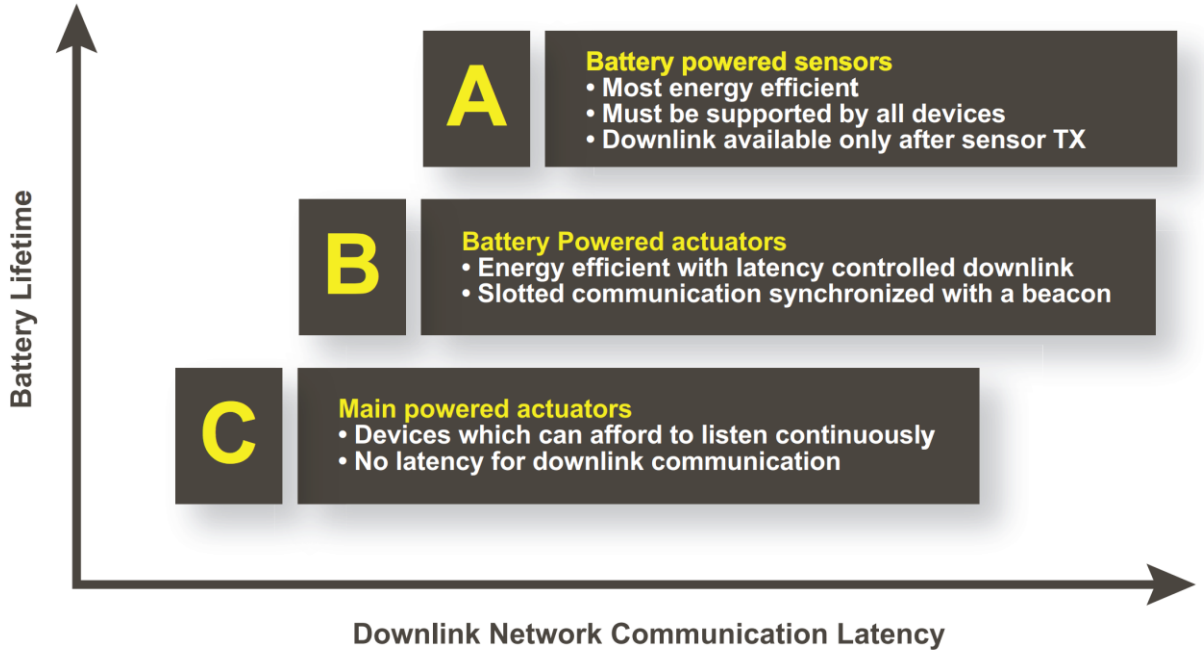
Military origin (anti-jamming & LPI)

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)



Bluetooth 4 (BLE)

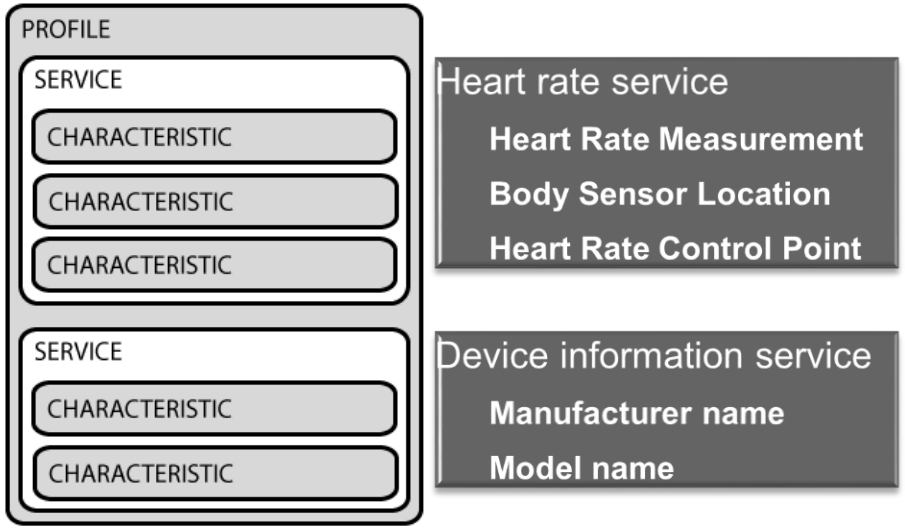
GATT (generic attribute profile)

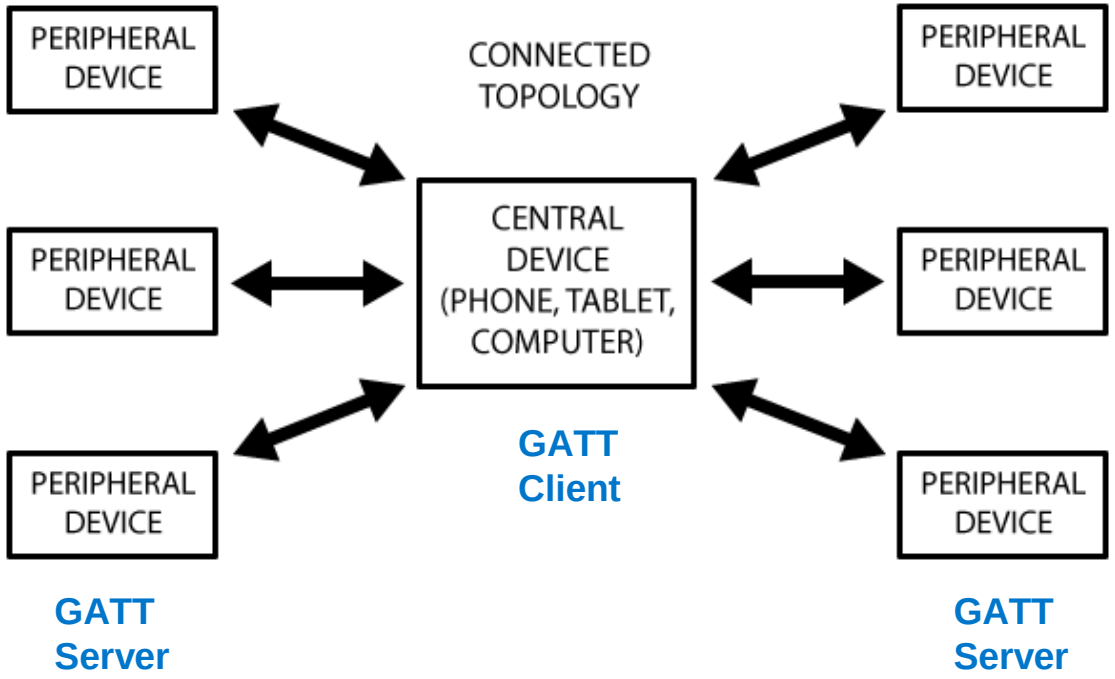
Designed for low power

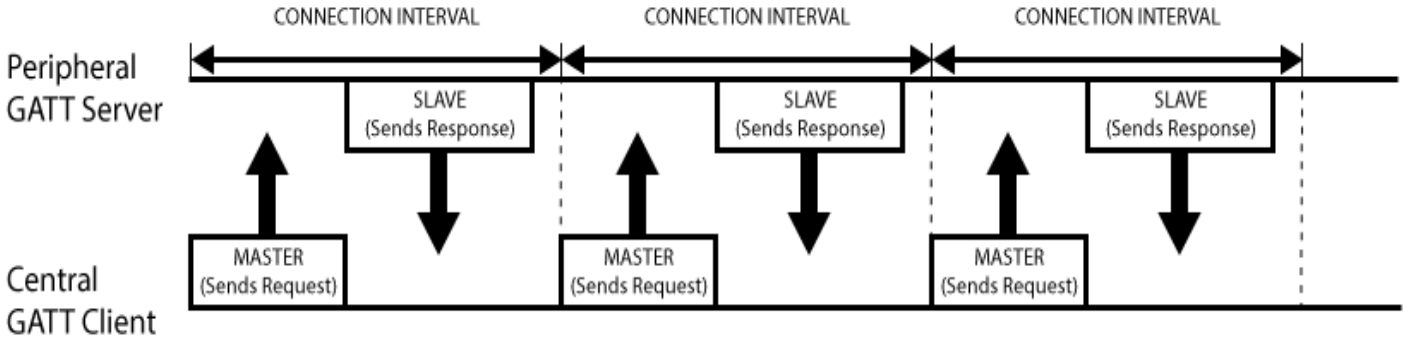
Peripherals advertise themselves

Central device initiates two way connection

Profiles, Services & Characteristics







Bluetooth 5

Already here and compatible with Bluetooth 4

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

Longer range (~ 4x)

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

Higher data throughput (~5x)

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

Data Length Extensions (DLE)

Increased broadcasting capacity (Advertising Extensions)

Less congestion, extended advertising payloads

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

Improved coexistence by CSA#2 - improved randomness of channel hop sequencing

Faster over-the-air (OTA) downloads and firmware updates.

Bluetooth Mesh

Compatible with both Bluetooth LE 4 and Bluetooth 5

Implements mesh topology for establishing many-to-many (m:m) device communications.

Optimized for creating large-scale device networks

Building automation, sensor network, and asset tracking solutions …

Design principles &technologies

Publish/subscribe model

Two-layer security – network layer key and application key.

Flooding with restricted relaying – prevents messages being relayed through too many hops

Power saving with "friendship“

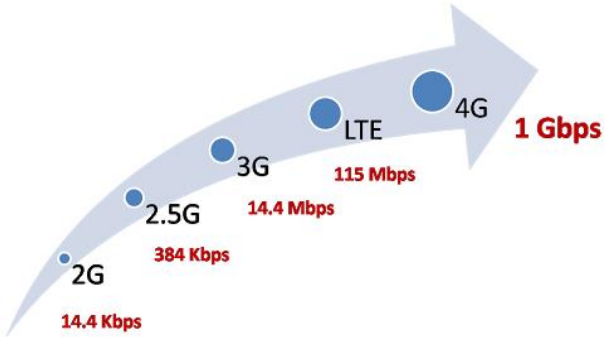
- Low-power devices can “friend” themselves with an always-on device
- Hi-power device stores, caches, and relays messages on their behalf, delivers security updates, etc.

BLE Proxy – proxy protocol for devices not supporting the advertising bearer defined by Bluetooth mesh natively (e.g smart phones).

Some other protocols

Cellular

3G, LTE, 4G, Sigfox et al (UNB)



IEEE 802.15.4

Zigbee

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

Z-wave

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

MiWi, SNAP, Thread, 6LoWPAN …

WiFi HaLow

IoT wired protocols

UART (Universal Async Receive Transmit – aka Serial)

Applications

Serial monitor

Legacy devices

Some sensors

Varieties

UART (3.3 / 5 V, few meters)

RS232 (9600 bps/ 15m)

RS485 (100kbps / 1200m)

I2C

Overview

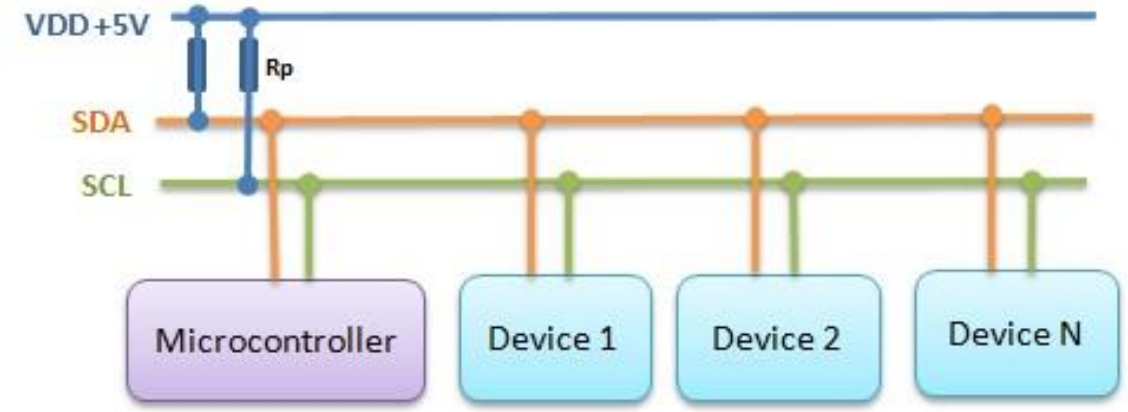
Distance: 1 – 10 m

Data and Clock lines

Synchronous bus (master clock)

Multi-master / up to 1008 slaves

Half-duplex, 100 kbit – 3.2mbit/s



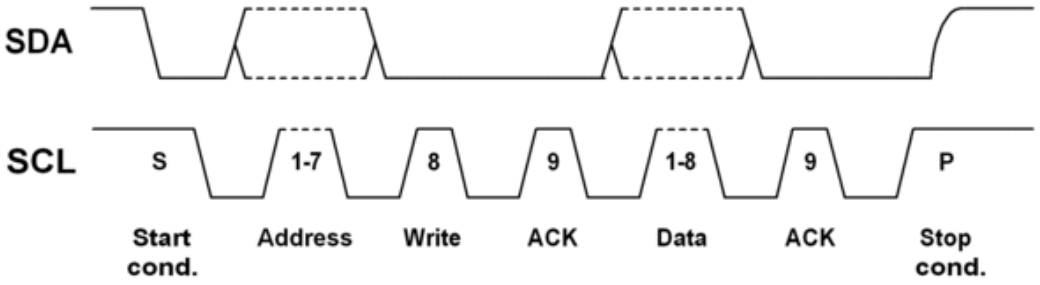
Programming

Slave address: 7/10 bit

Open address

Write data

Read data



SPI (Serial peripheral interface)

Overview

Distance: 1 – 10 m

Data, Clock and Select lines

Synchronous bus (master clock)

Single master / multi slave

Full duplex, high data rate

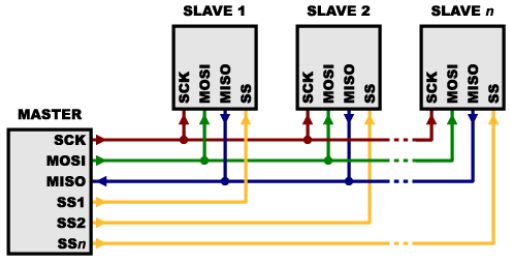
Programming

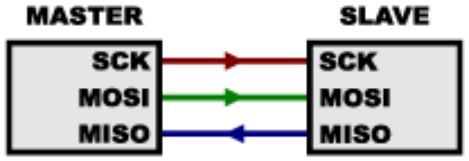
Software vs Hardware SPI

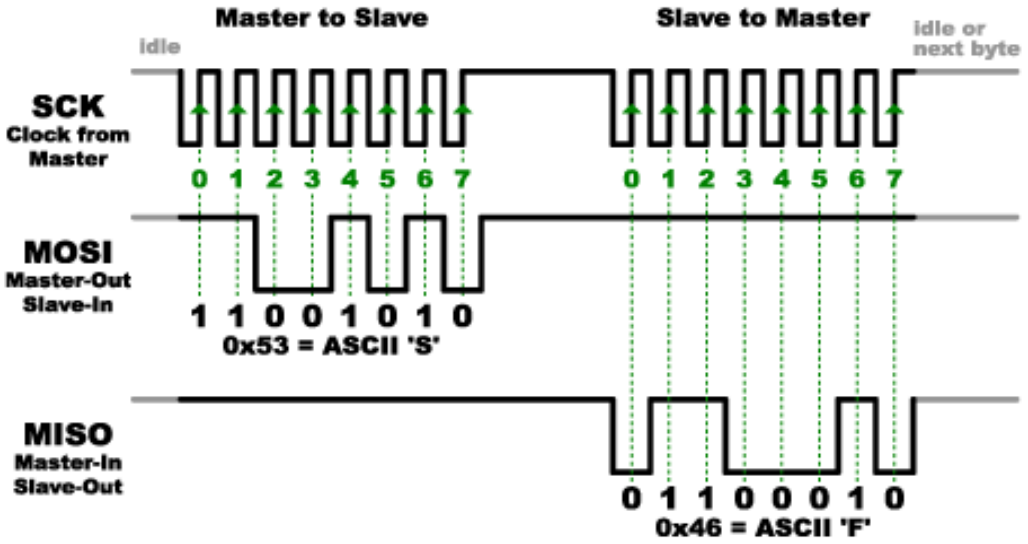
Bit order (LSB/MSB)

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

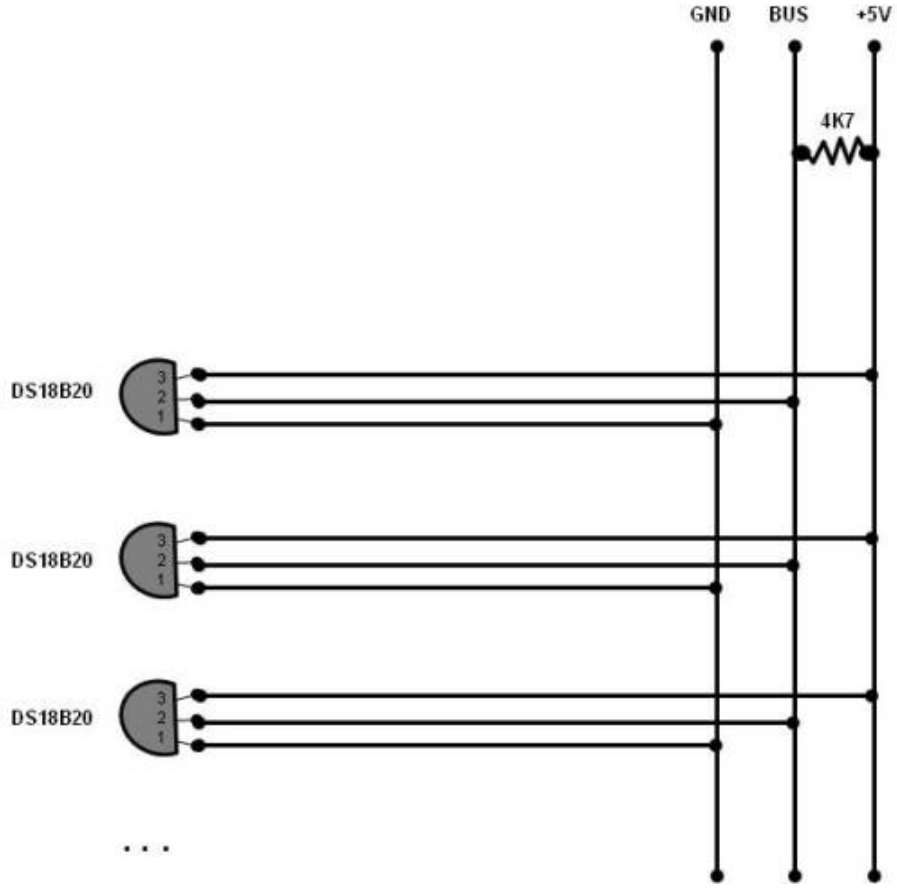
Programming

64bit slave IDs

Parasitic power (charge up)

Find devices

Communicate



Some other protocols

Industrial

CAN

CIP (common industrial protocol) - TODO

Ethernet (PROFINET)

Modbus (PLCs), Profibus, 4-20 mA

I2S

HiFi sound

Exercise

Exercises

WiFi modes

Station + HTTP client – optional, shall be ccovered in previous exercise

ESP Access point + HTTP server -> fire an LED upon HTTP request

SoftAP

HC-12

Connect two devices and send data

MQTT

ESP client to Java server