Software Technology of Internet of Things

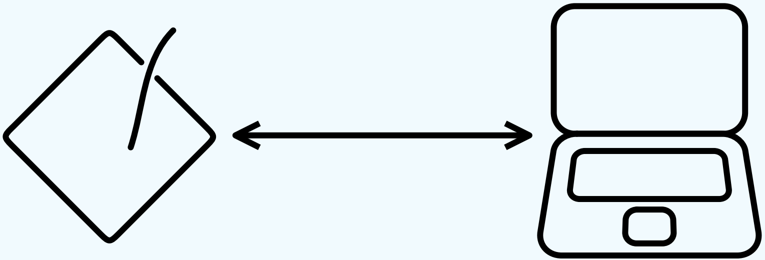
Radio Communication

Aslak Johansen asjo@mmmi.sdu.dk

Mar 18, 2025

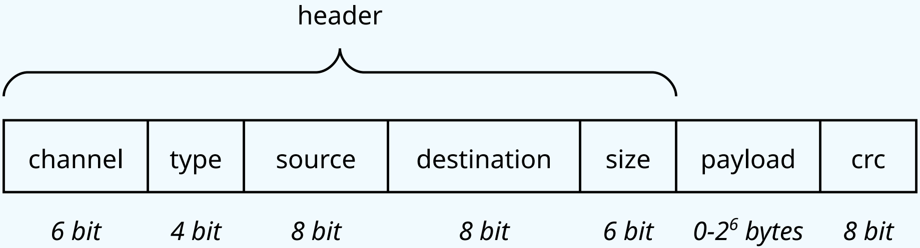
Part 1: Introduction

Going Wireless Wired communication



Going Wireless Wireless communication

Frame Formats



Frame Formats

```c
#include <stdio.h>

typedef struct frame_t {
    unsigned int channel     : 6;
    unsigned int type        : 4;
    unsigned int source      : 8;
    unsigned int destination : 8;
    unsigned int size        : 6;
    char*        payload;
    unsigned int src         : 8;
} __attribute__ ((__packed__)) frame_t;

int main (int argc, char* argv)
{
    frame_t f;
    f.type = 3;
    printf("Type of frame: %u\n", f.type);
    printf("Size of structure: %lu\n", sizeof(frame_t));
    printf("(6.0+4+8+8+6+64+8)/8=%f\n", (6.0+4+8+8+6+64+8)/8);
    return 0;
}
```

```
$ gcc example.c -o example
$ ./example
Type of frame: 3
Size of structure: 13
(6.0+4+8+8+6+64+8)/8=13.000000
```

Part 2:
Rules of the Game

Spectrums

Radio waves are classified by heir frequency.

These frequencies exist on a spectrum.

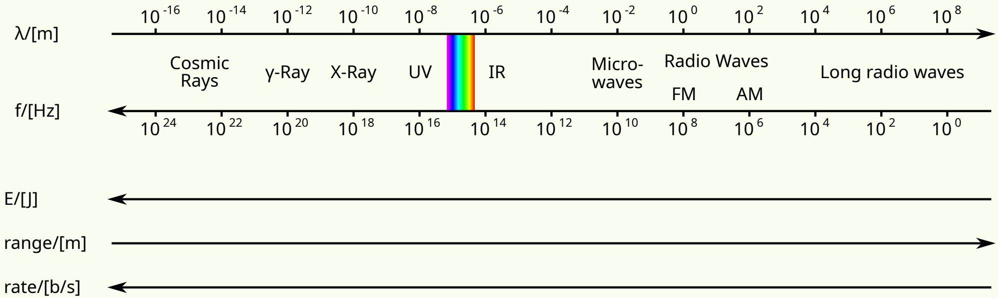
Parts of that spectrum are regulated and earmarked for specific uses.

Other parts are *open*.

We will be operating in open spectrums.

Tradeoff: Given the same encoding and power consumption a lower frequency will give a longer range while a higher frequency will give a higher throughput.

Spectrums



λ/[m]
10^{-16} 10^{-14} 10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8}
Cosmic Rays
γ-Ray
X-Ray
UV
IR
Micro-waves
Radio Waves
FM
AM
Long radio waves
f/[Hz]
10^{24} 10^{22} 10^{20} 10^{18} 10^{16} 10^{14} 10^{12} 10^{10} 10^{8} 10^{6} 10^{4} 10^{2} 10^{0}
E/[J]
range/[m]
rate/[b/s]

Signal Strength

An ombidirectional EM field extends according to the inverse square law.

The inverse square law states that:

$$i \propto \frac{1}{d^2}$$

(where i is the intensity at the distance d)

Consequence 1: The intensity of a signal drops polynomially with the distance.

Consequence 2: It is infeasible to send a signal over a long distance.

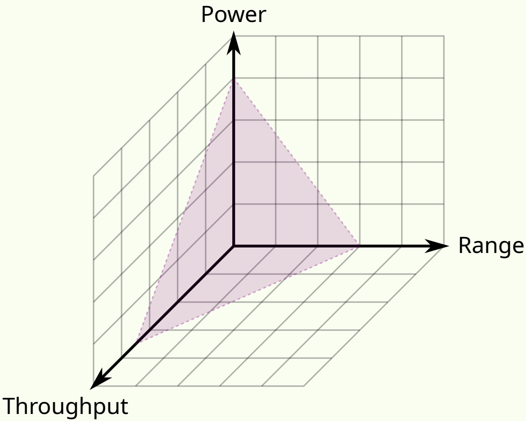
Performance Space

Three-way tradeoff.

An improvement along one dimension will result in a penalty along the others.

True technological breakthroughs rarely happen.

There are a few ways to get around this tradeoff.



Noise

The signal received from the antenna is noisy.

The noise received when no signal is being transmitted is referred to as the *noise floor*.

Every transmission is competing against that noise floor; if the produced signal is not strong enough to clearly differentiate itself from the noise floor then it likely won't be received . . . or it will be received incorrectly.

Bitflips

Radio setups can be more or less susceptible to noise.

All radios need some SNR to differentiate the signal from the noise floor.

When this ratio (plus a safety margin) is violated, bit errors start to occur.

Redundancy Checks

A practical method of dealing with bitflips is to include some form of redundancy check in each transmission.

In RS-232 serial communication we had one parity bit per character.

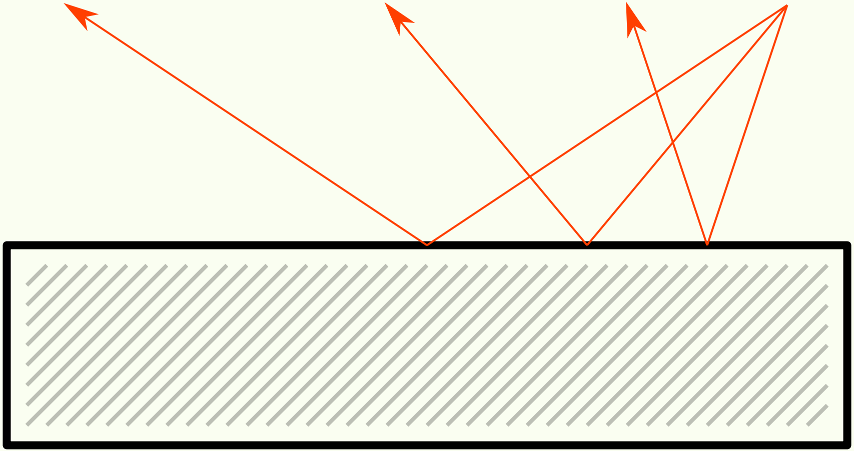
For larger amounts of data more bits are usually used.

These are often referred to as the cyclic redundancy check (CRC) code of the data.

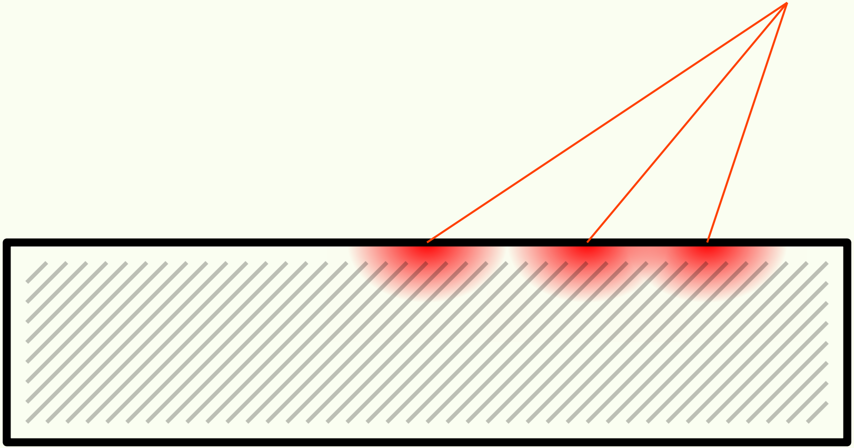
At reception, the CRC is checked to see if the received data has been corrupted.

Redundancy checks offers protection against various levels of unlikeliness, but never full protection.

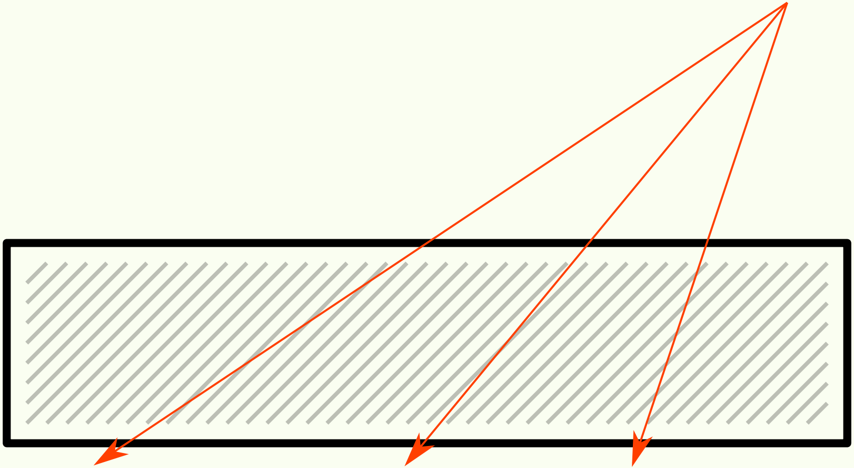
Reflection



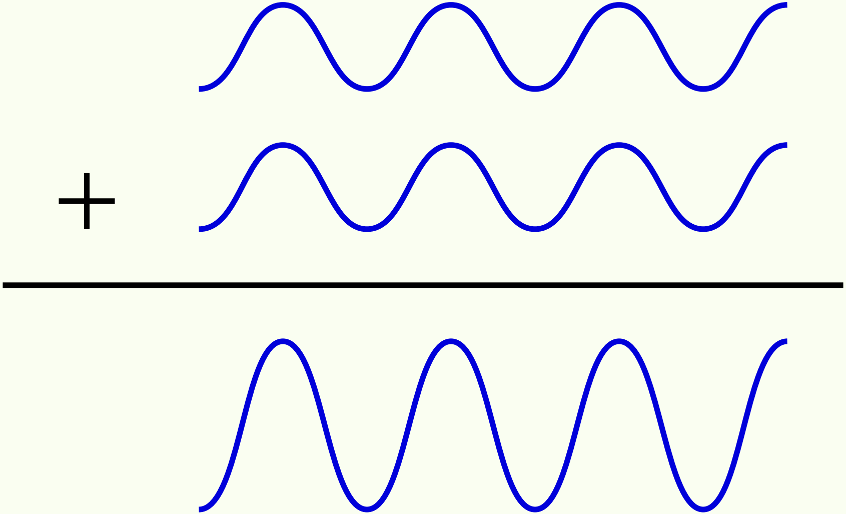
Absorption



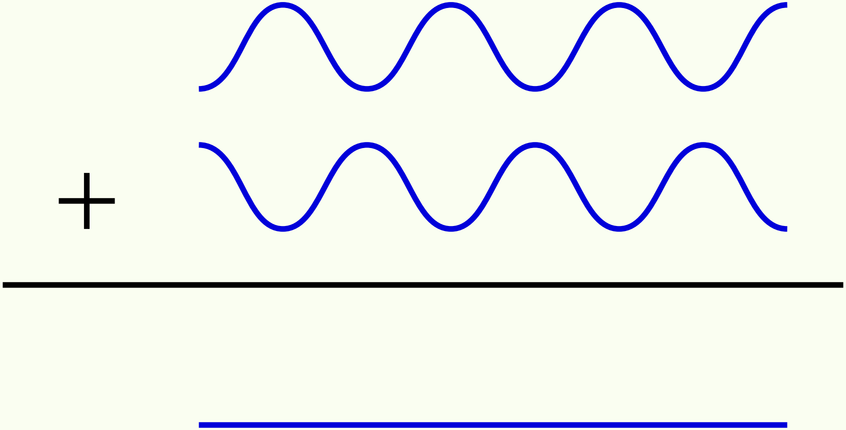
Transparancy



Constructive Interference



Destructive Interference



Shared Media and Collisions

On a wired network the recipients of a signal are restricted to those physically connected (snoopers excepted).

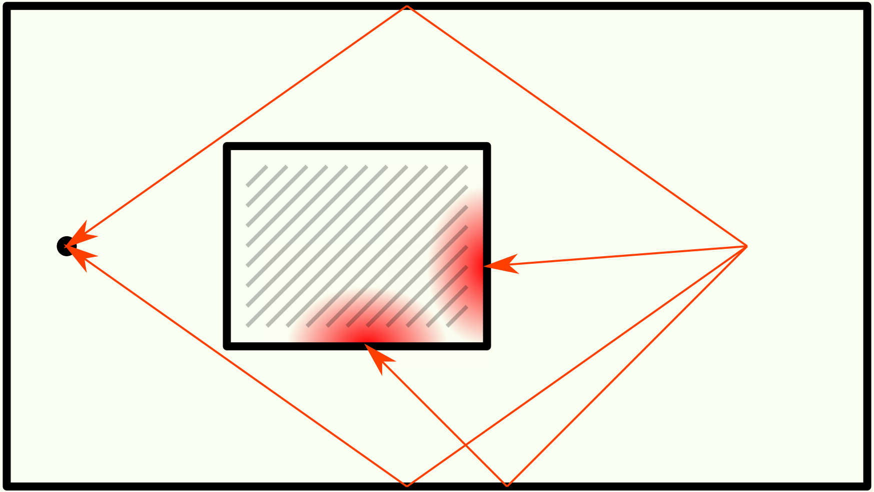
On a wireless network the recipients of a signal are restricted to those within range (snoopers included).

For this reason, we say that the media is *shared*.

. . . and because it is shared with strangers it is impossible for us to avoid collisions.

Definition: A collision happens when the signals of two (or more) packets overlap in both time and space.This results in a combination of constructive and destructive interference which is likely to cause at least one of the signals to be lost . . . at this position.

Multipath



Restrictions

Different networking technologies use different frequencies in more or less sophisticated ways.

As such, they map to a set of restrictions in terms of:

- End-to-end latency
- Bandwidth
- Frame rate
- Power envelope
- ...

Network Topologies

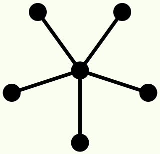
Network Topologies

Line

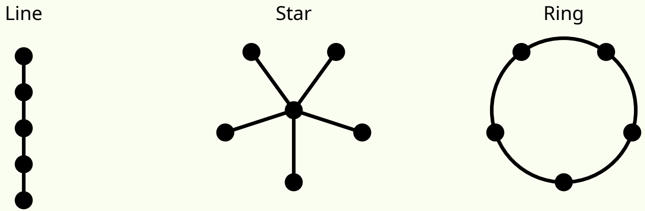
Network Topologies

Line

Star



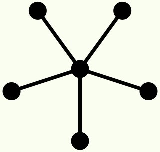
Network Topologies



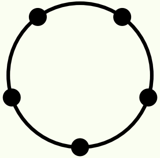
Network Topologies

Line

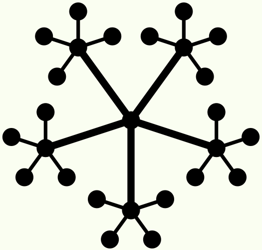
Star



Ring



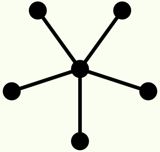
Tiered



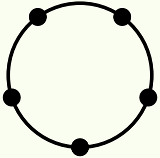
Network Topologies

Line

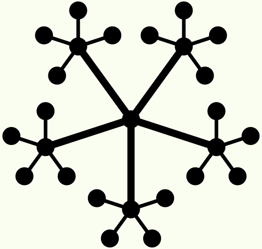
Star



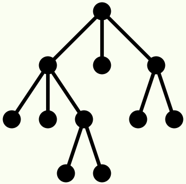
Ring



Tiered



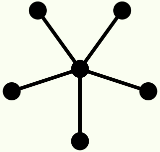
Tree



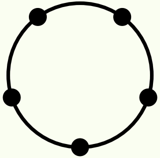
Network Topologies

Line

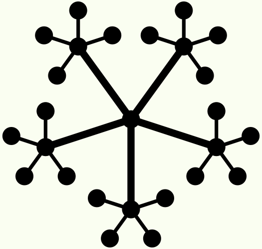
Star



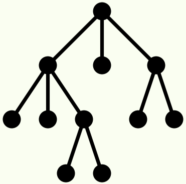
Ring



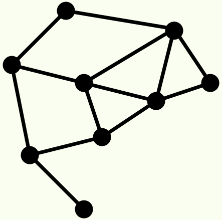
Tiered



Tree



Mesh



Part 3:
Solution Space

To Ack or Not to Ack, That Is the Question

Packets are usually made up of individual frames.

Frames are often dropped due to detected corruption or complete lack of reception.

To deal with this, many protocols use acknowledgements (ACKs), and retransmit on lack of acknowledgement.

When is the ACK being sent?

1. After each frame, or
2. After each packet, or
3. When data is going in the opposite direction anyways.

OSI Model

OSI Model

Level 1	**Physical**	*bit (or symbol)*	Electrical, audio or radio link

OSI Model

Level 2	**Data Link**	*frame*	Reliable* delivery of frame to local named receiver
Level 1	**Physical**	*bit (or symbol)*	Electrical, audio or radio link

OSI Model

Level 3	**Network**	*packet*	Multi-node and routing
Level 2	**Data Link**	*frame*	Reliable* delivery of frame to local named receiver
Level 1	**Physical**	*bit (or symbol)*	Electrical, audio or radio link

OSI Model

Level 4	**Transport**	*segment / datagram*	Connection-orientation, multiplexing and flow control
Level 3	**Network**	*packet*	Multi-node and routing
Level 2	**Data Link**	*frame*	Reliable* delivery of frame to local named receiver
Level 1	**Physical**	*bit (or symbol)*	Electrical, audio or radio link

OSI Model

Level 5	**Session**	*data*	Session management of connections
Level 4	**Transport**	*segment / datagram*	Connection-orientation, multiplexing and flow control
Level 3	**Network**	*packet*	Multi-node and routing
Level 2	**Data Link**	*frame*	Reliable* delivery of frame to local named receiver
Level 1	**Physical**	*bit (or symbol)*	Electrical, audio or radio link

OSI Model

Level 6	**Presentation**	*data*	Convenient translations (e.g., encryption and coding)
Level 5	**Session**	*data*	Session management of connections
Level 4	**Transport**	*segment / datagram*	Connection-orientation, multiplexing and flow control
Level 3	**Network**	*packet*	Multi-node and routing
Level 2	**Data Link**	*frame*	Reliable* delivery of frame to local named receiver
Level 1	**Physical**	*bit (or symbol)*	Electrical, audio or radio link

OSI Model

Level 7	**Application**	*data*	APIs
Level 6	**Presentation**	*data*	Convenient translations (e.g., encryption and coding)
Level 5	**Session**	*data*	Session management of connections
Level 4	**Transport**	*segment / datagram*	Connection-orientation, multiplexing and flow control
Level 3	**Network**	*packet*	Multi-node and routing
Level 2	**Data Link**	*frame*	Reliable* delivery of frame to local named receiver
Level 1	**Physical**	*bit (or symbol)*	Electrical, audio or radio link

OSI Model

Level 8	**Individual**	*"correspondance"*	Application user
Level 7	**Application**	*data*	APIs
Level 6	**Presentation**	*data*	Convenient translations (e.g., encryption and coding)
Level 5	**Session**	*data*	Session management of connections
Level 4	**Transport**	*segment / datagram*	Connection-orientation, multiplexing and flow control
Level 3	**Network**	*packet*	Multi-node and routing
Level 2	**Data Link**	*frame*	Reliable* delivery of frame to local named receiver
Level 1	**Physical**	*bit (or symbol)*	Electrical, audio or radio link

OSI Model

Level 9	**Organization**	*"guideline"*	Organizational framework
Level 8	**Individual**	*"correspondance"*	Application user
Level 7	**Application**	*data*	APIs
Level 6	**Presentation**	*data*	Convenient translations (e.g., encryption and coding)
Level 5	**Session**	*data*	Session management of connections
Level 4	**Transport**	*segment / datagram*	Connection-orientation, multiplexing and flow control
Level 3	**Network**	*packet*	Multi-node and routing
Level 2	**Data Link**	*frame*	Reliable* delivery of frame to local named receiver
Level 1	**Physical**	*bit (or symbol)*	Electrical, audio or radio link

OSI Model

Level 10	**Government**	*"legislation"*	Rules for organizations and compliance
Level 9	**Organization**	*"guideline"*	Organizational framework
Level 8	**Individual**	*"correspondance"*	Application user
Level 7	**Application**	*data*	APIs
Level 6	**Presentation**	*data*	Convenient translations (e.g., encryption and coding)
Level 5	**Session**	*data*	Session management of connections
Level 4	**Transport**	*segment / datagram*	Connection-orientation, multiplexing and flow control
Level 3	**Network**	*packet*	Multi-node and routing
Level 2	**Data Link**	*frame*	Reliable* delivery of frame to local named receiver
Level 1	**Physical**	*bit (or symbol)*	Electrical, audio or radio link

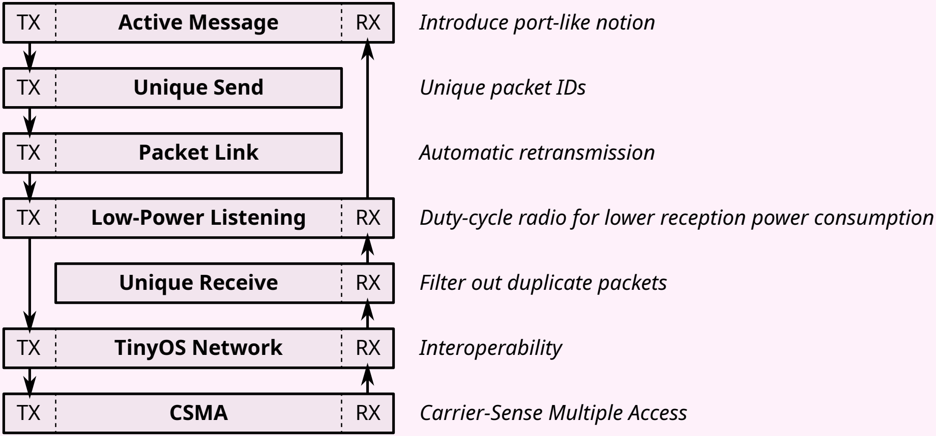
Message Brokering

Message Brokering

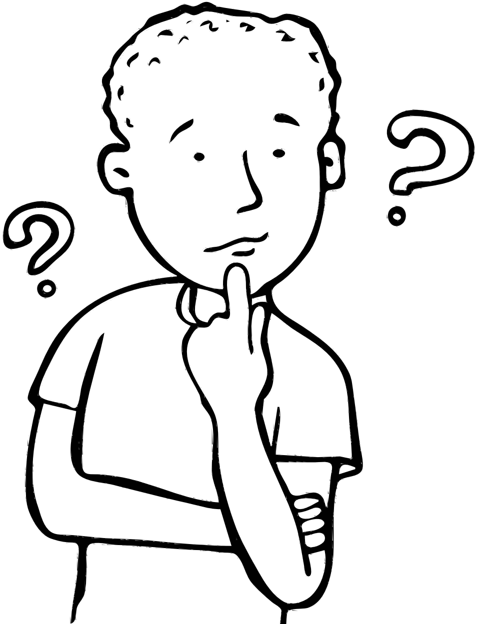
Message Brokering

Message Brokering

TinyOS CC2420 Radio Stack (TEP 126)



Questions?



https://openclipart.org/detail/238687/boy-thinking-of-question