Network Physical Layer

Fundamentos de Redes

Mestrado Integrado em
Engenharia de Computadores e Telemática
DETI-UA

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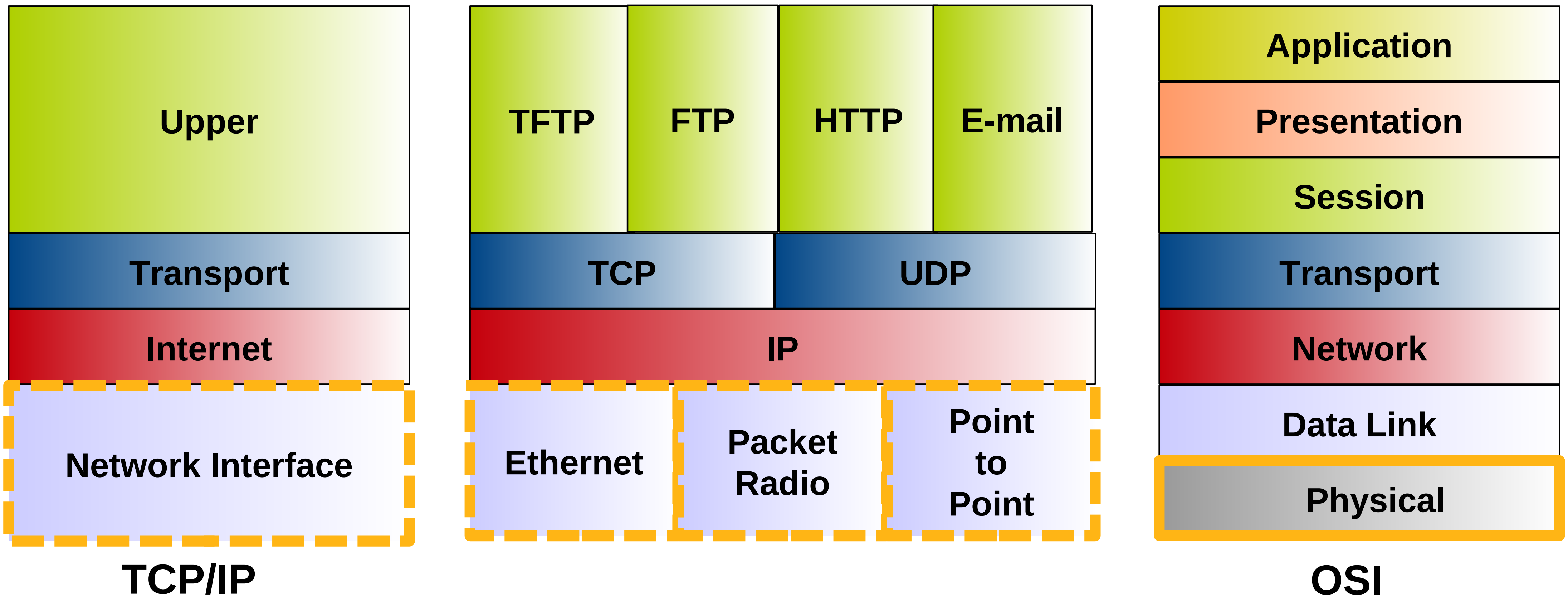
TCP/IP Reference Model



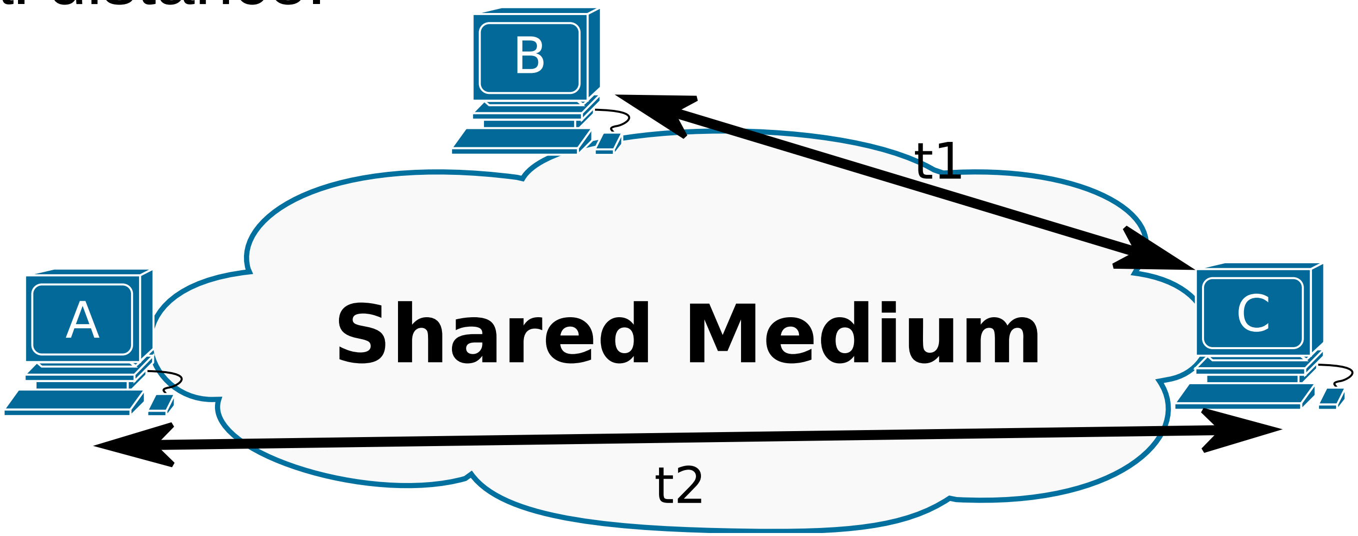
Shared Medium Access

ALOHA

- The first version of the protocol (called "Pure ALOHA"):
  - If a station has data to send, sends it.
  - If, while transmitting data, the station receives any data from another station, there has been a message collision.
  - After a collision, all transmitting stations will need to try resend data later.
- A more efficient version (called “Slotted ALOHA”):
  - Introduced discrete timeslots.
    - A station can start a data transmission only at the beginning of a timeslot, and thus collisions are reduced.
  - Increased the maximum throughput.
  - Still used in very-low-data-rate satellite communications networks.
- Both are very inefficient.

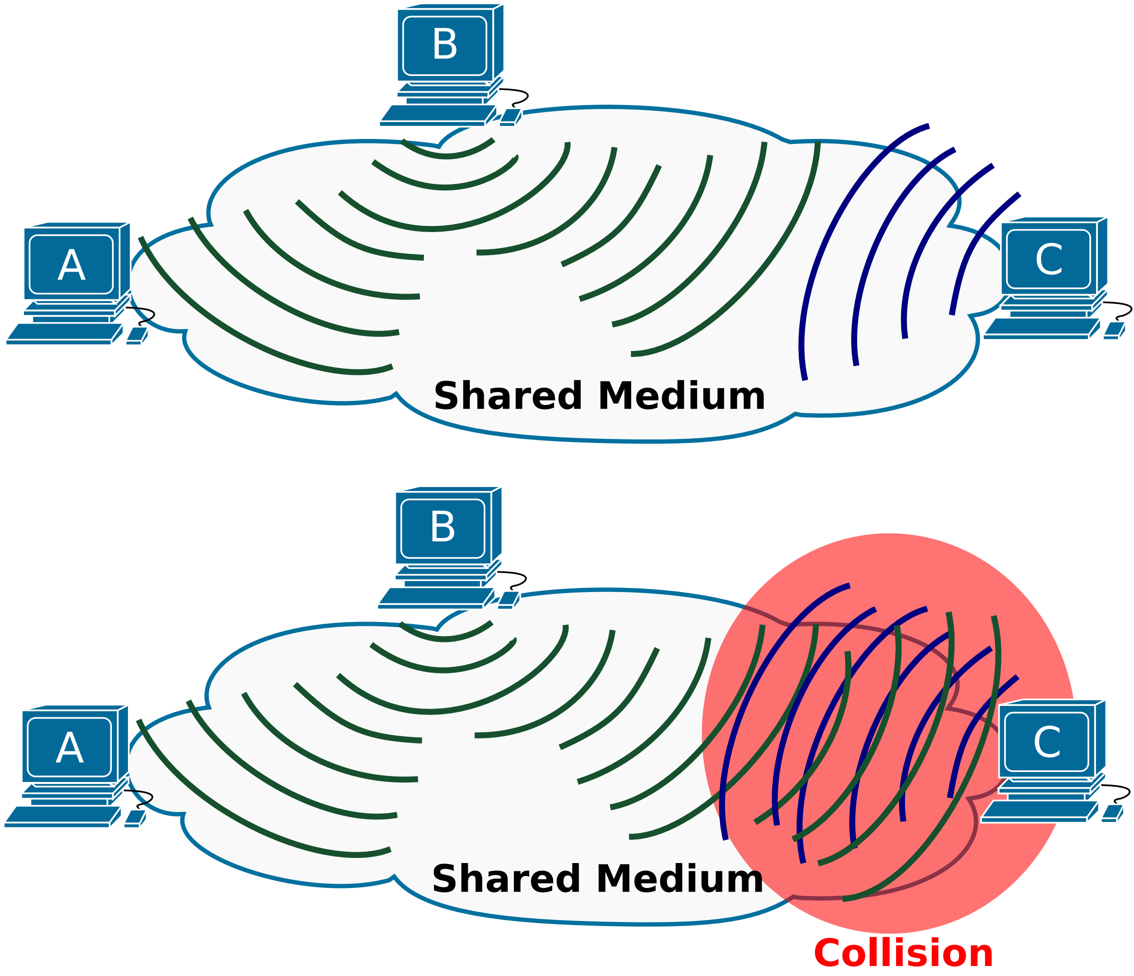
Carrier Sense Multiple Access (CSMA)

- Stations transmit and receive on the same channel.
- The stations listen to the medium before transmitting (carrier sense - CS).
- Only transmit if the medium is detected free.
- The number of collisions is minimized.
- Collisions may occur due to transmission times over some physical distance.



CSMA with Collision Detection (CSMA/CD)

- When stations detect a collision:
  - Stop transmitting,
  - May send a jam signal to reinforce collision detection,
  - Wait a random time before trying to resend message.
- To ensure that all stations detect a collision, all messages have a minimum size.
  - The time that takes all bots from a message to be transmitted must be larger that the time it takes (the first bit) to reach the farthest station on the shared medium, and return (round-trip time).



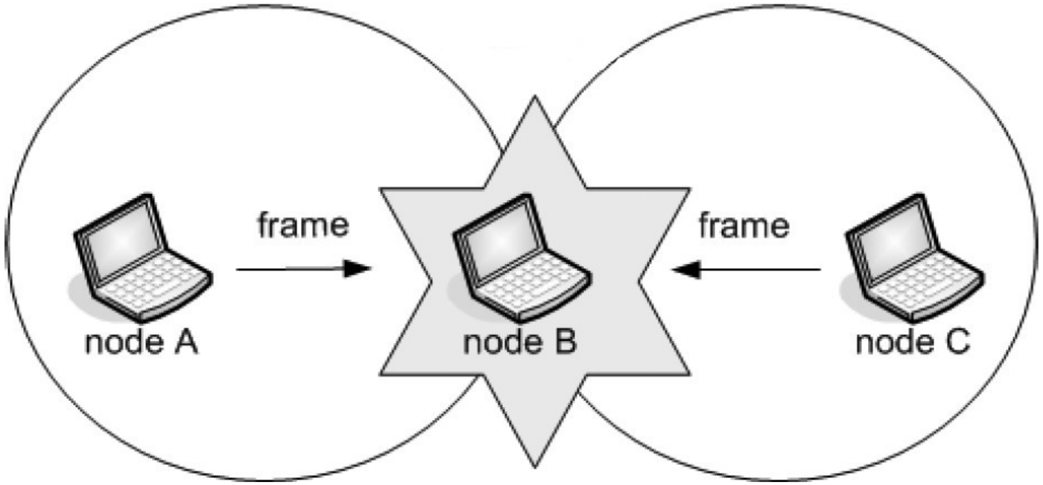
Ethernet vs.WiFi Medium Access

- Ethernet
  - Uses CSMA/CD,
  - In modern Ethernet networks (with no hubs) there is no collisions.
    - Switches avoid collisions.
    - Medium is not really shared.
- WiFi
  - Used CSMA/CD, however:
    - Medium is shared,
    - Signal power reduces with the square distance,
    - Sender can apply CS and CD, but collisions occur in the receiver!
    - Sender may not listen the collision (CD does not work),
    - CS may not work either with hidden nodes.

Hidden Nodes

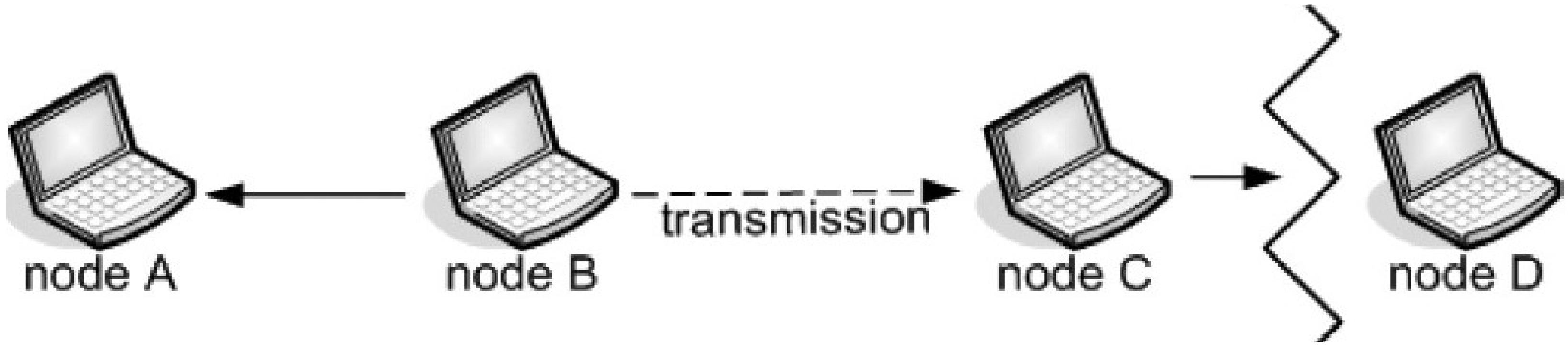
- Hidden terminals
  - A and C do not ear each other.
  - Collision in B, if A and C send at the same time.
  - Neither A or C understand that a collision occurred.

Solution
  - Detect collisions in the receiver.
  - “Virtual carrier sensing”: sender asks the receiver if he is receiving traffic; in the case of absence of answer, he assumes that the channel is busy.



Exposed Nodes/Terminals

- Exposed terminals
  - B transmits to A;
  - Node C wants to transmit to node D but mistakenly thinks that this will interfere with B's transmission to A, so C refrains from transmitting.
    - D is not in the range of B and A is not in the range of C, so traffic could have been transmitted.
  - B and C are exposed terminals.
  - The "exposed node" problem leads to loss of efficiency.

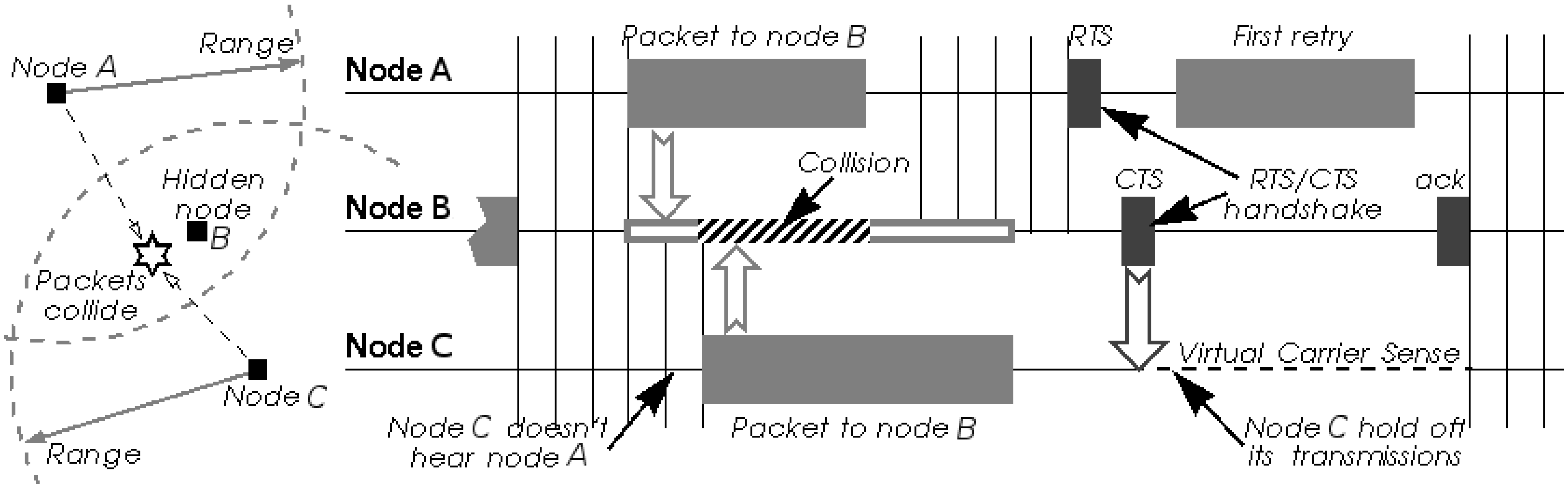


MACA: Multiple Access with Collision Avoidance

- MACA: avoids collisions using signalling packets
  - RTS (request to send)
    - A small packet is sent before transmitting
  - CTS (clear to send)
    - Receiver provides the right to transmit, when it is able to receive
- Signalling packets (RTS/CTS) contain
  - Sender address
  - Receiver address
  - Packet length (to be transmitted)
- Used in networks scenarios with a large amount of traffic/collisions.

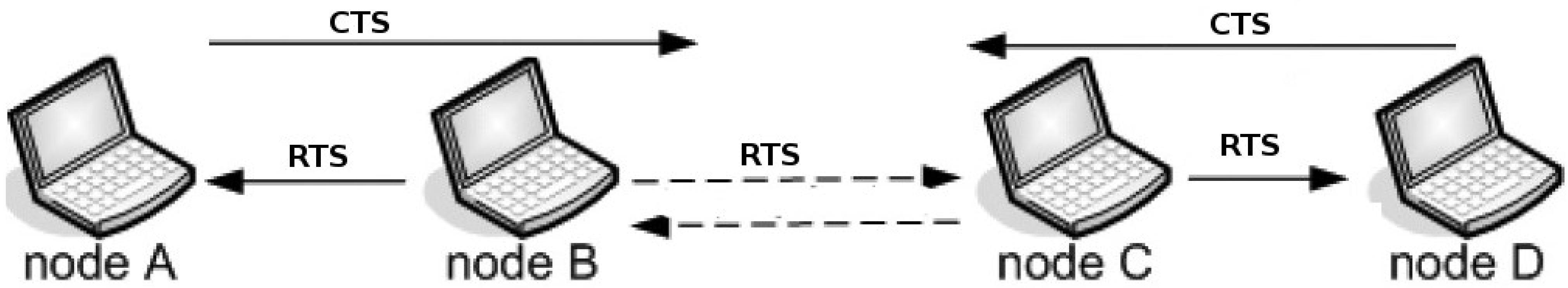
MACA Advantages (1)

- MACA and hidden nodes
  - A, C → B (Collision!)
  - A RTS → B
  - B CTS → A
  - C ears CTS of B.
  - C waits for the period announced in A transmission.



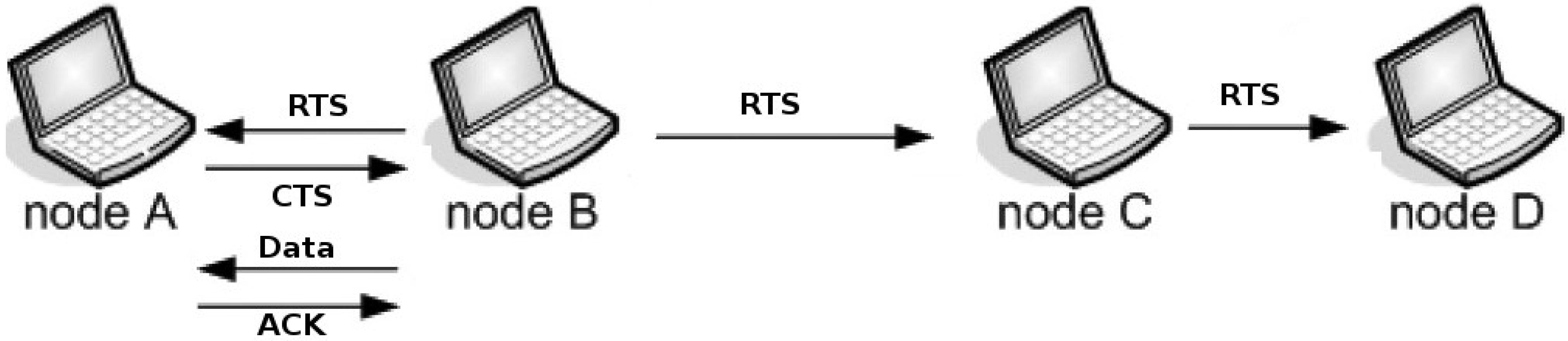
MACA Advantages (2)

- MACA and exposed nodes
  - B → A, C → D(?)
  - B RTS → A
  - A CTS → B
  - C ears RTS of B.
  - C does not ear CTS of A.
  - C RTS → D



MAC Reliability

- Wireless connections are very prone to errors.
  - Transport is not reliable!
- Solution: use **Acknowledgements**
  - When A receives DATA from B, answers with ACK.
  - If B does not receive ACK, B retransmits.
  - C and D will not transmit until the ACK (to avoid collisions).
  - Total expected duration (including ACK) is included in the RTS/CTS packets.



RST/CTS Frames

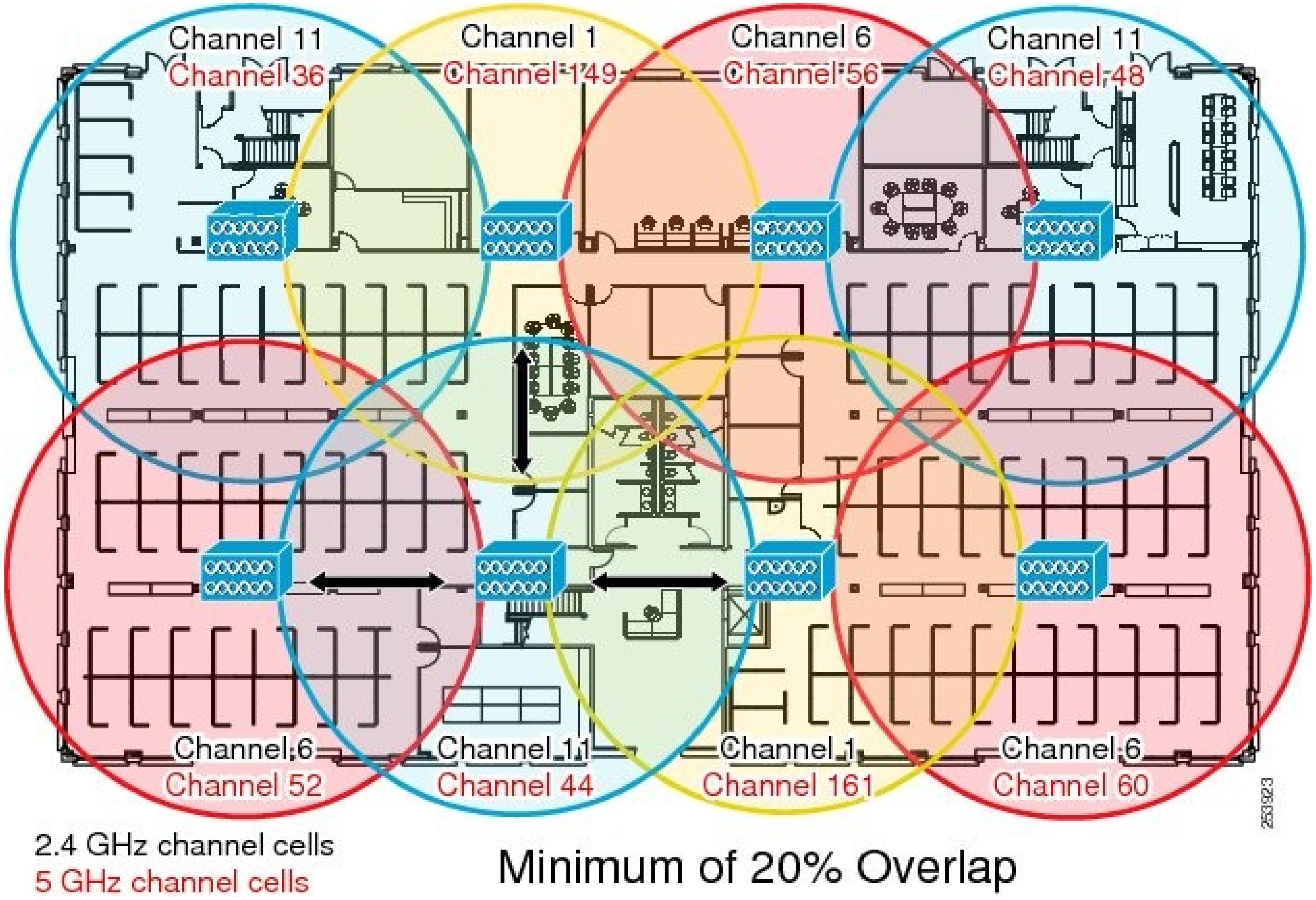
```
IEEE 802.11 Request-to-send, Flags: ........C
  Type/Subtype: Request-to-send (0x001b)
  Frame Control Field: 0xb400
  .000 0111 0000 0100 = Duration: 1796 microseconds
  Receiver address: Cisco_2b:d3:70 (f4:cf:e2:2b:d3:70)
  Transmitter address: Microsof_0a:43:e3 (c0:33:5e:0a:43:e3)
  Frame check sequence: 0xe058c51c [unverified]
  [FCS Status: Unverified]
```

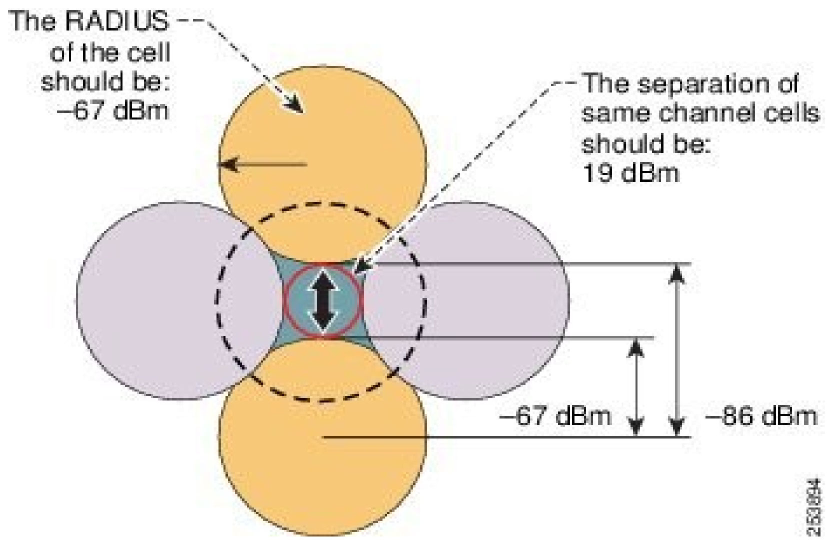
← From Data Transmitter

From Data Receiver →

```
IEEE 802.11 Clear-to-send, Flags: ........C
  Type/Subtype: Clear-to-send (0x001c)
  Frame Control Field: 0xc400
  .000 0110 0010 1010 = Duration: 1578 microseconds
  Receiver address: Microsof_0a:43:e3 (c0:33:5e:0a:43:e3)
  Frame check sequence: 0xaac303a8 [unverified]
  [FCS Status: Unverified]
```

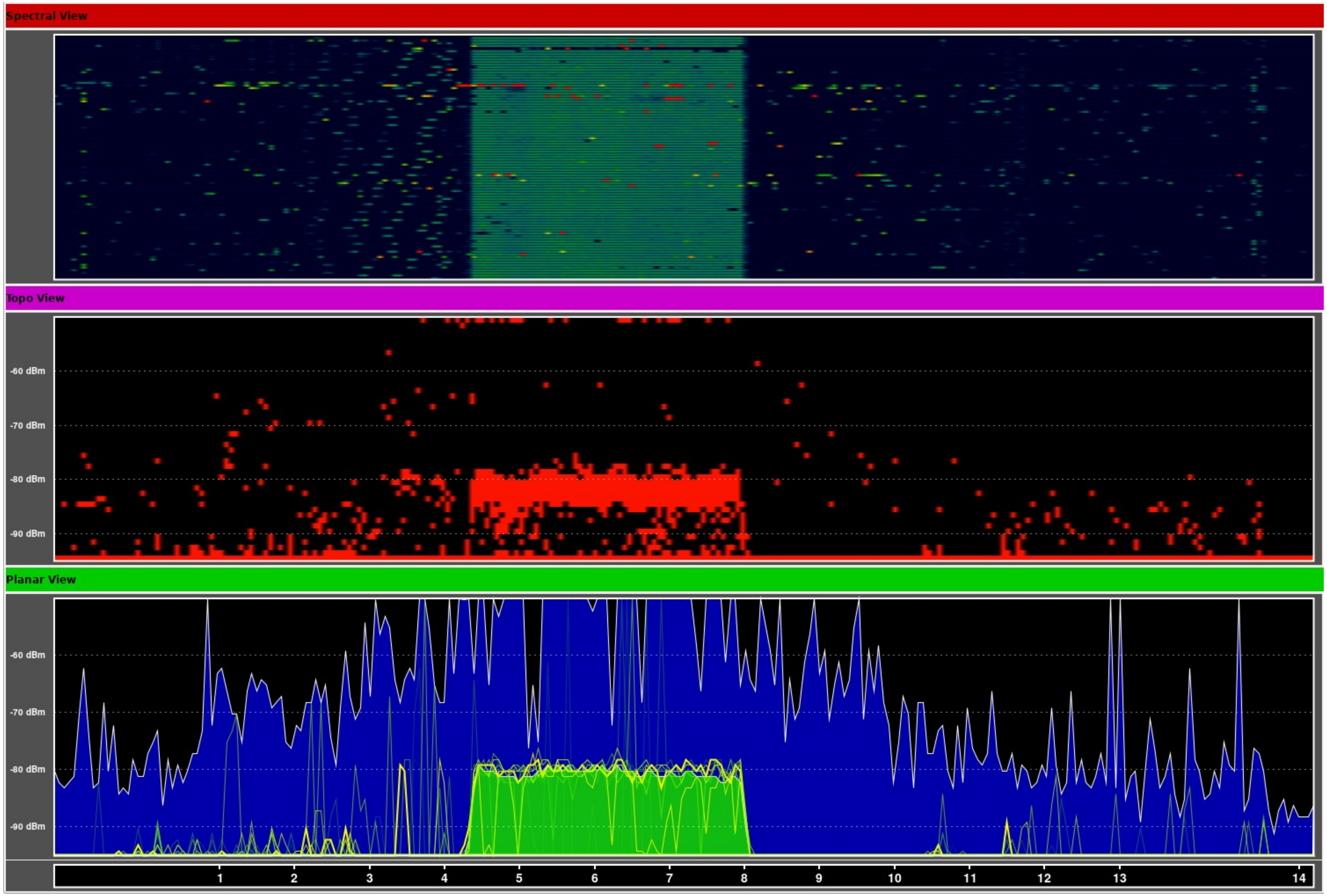
AP Placement and Channel Allocation





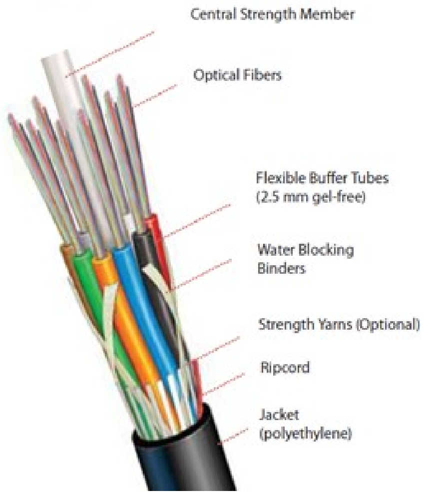
- 802.11n or 802.11ac 5GHz deployment does not have the overlap or collision domain issues of 2.4GHz.

Usage of Spectrum Analysis



Transmission Systems and Technologies

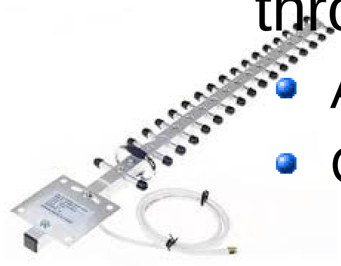
Guided/Unguided Transmission Systems



- A transmission system can be classified as **Guided** or **Unguided**.
- In **Guided** systems, a signal travels through a bounding physical medium.
  - Copper cable, Optical fibre, …
- In **Unguided** media, a signal travels through a boundless medium
  - Air, Water, Vacuum, …
  - Can be directional or omni-directional.
    - In directional configuration, the source emits a focused beam in a particular direction.
      - The receiver should be aligned for receiving the signals.
    - In omni-directional configuration, the source emits equally in all directions.

Microwave link

Free Space Optics (FSO)

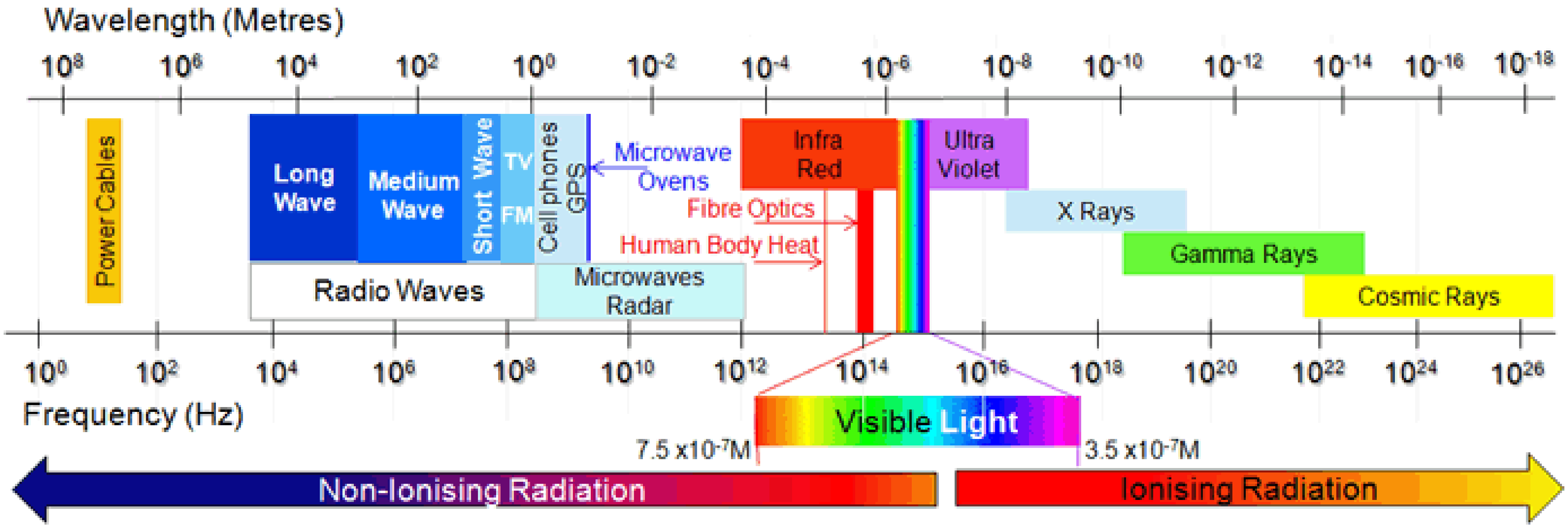


Directional LTE

Omnidirectional LTE

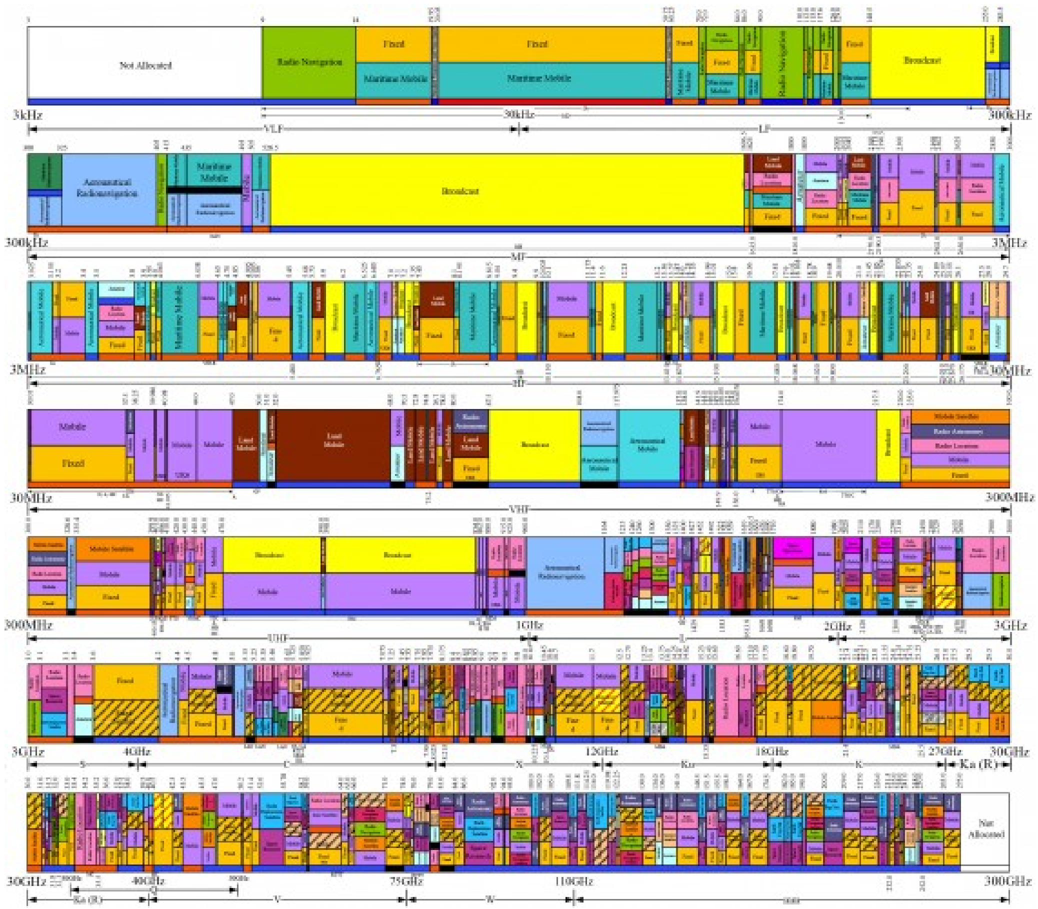
802.11 Omnidirectional

Electromagnetic Spectrum



- For radio signals the antenna transmits a sinusoidal signal (“carrier”) that radiates in air/space.

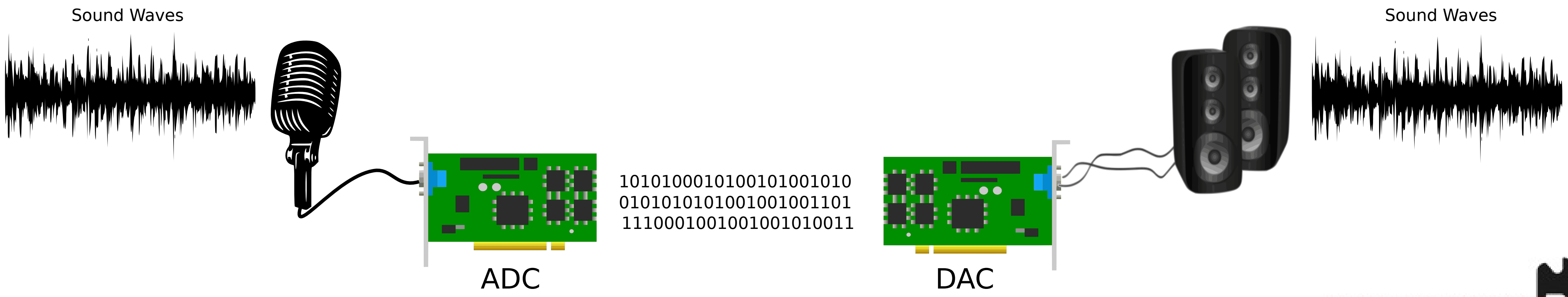
Radio/Microwave Spectrum (3KHz-300GHZ)



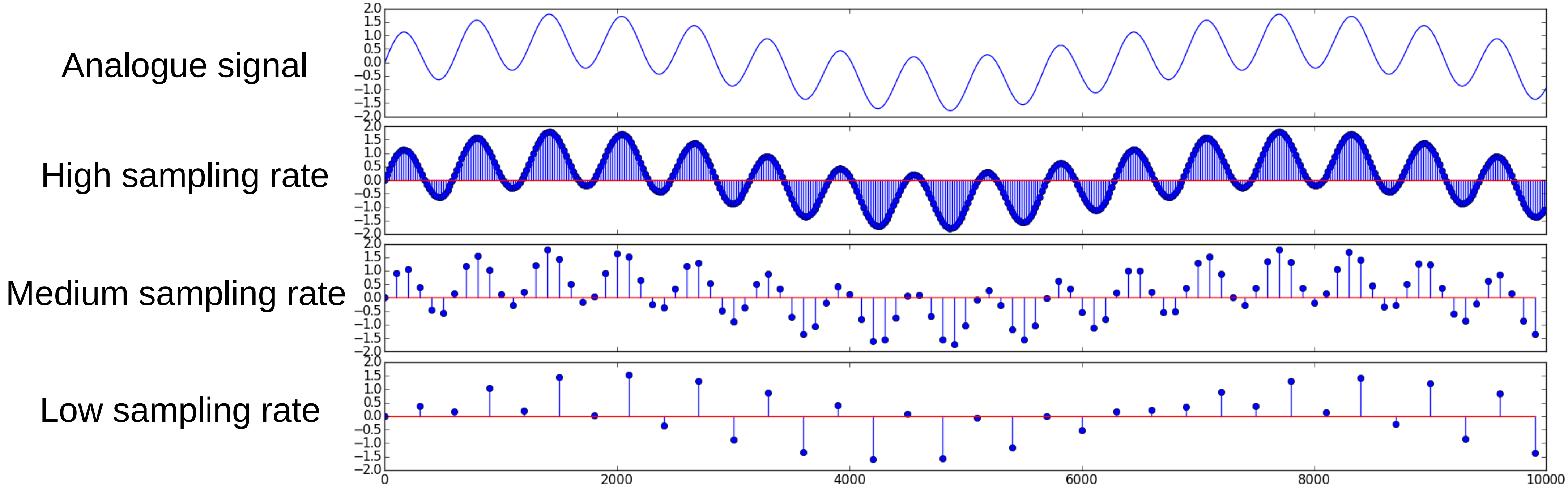
- Portugal (ANACOM)
  - https://www.anacom.pt/render.jsp?categoryId=150422
- UK (OFCOM)
  - https://www.ofcom.org.uk/spectrum/information/uk-fat
- USA (FCC)
  - https://www.fcc.gov/engineering-technology/policy-and-rules-division/general/radio-spectrum-allocation
- ...

Analogue-Digital Conversion

- The digital transmission of analogue signals requires:
  - An ADC in the source, and
  - A DAC in the destination.
- ADC (Analogue to Digital Conversion)
  - Sampling
  - Quantization and Encoding
- DAC (Digital to Analogue Conversion)
  - Signal reconstruction



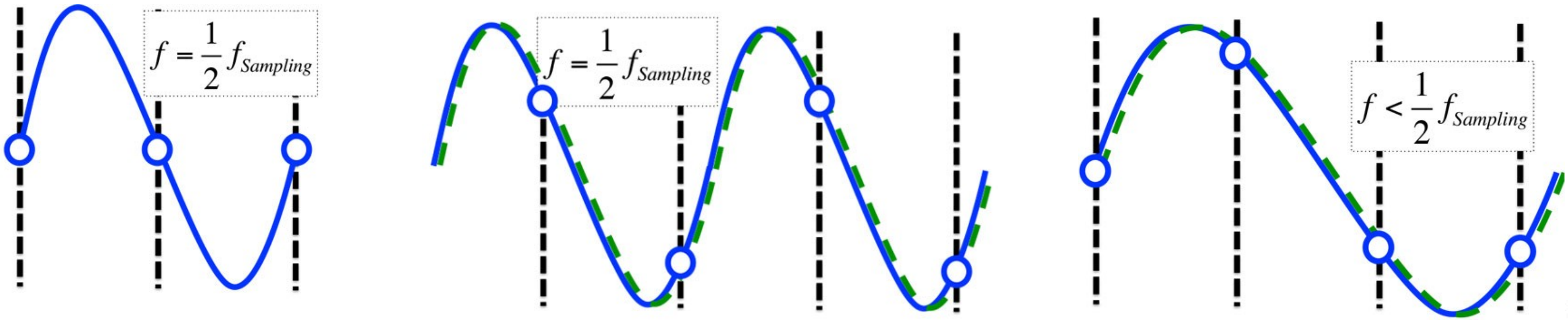
Sampling



- The sampling process, measures and quantifies the analogue signal at equally space time intervals.
- The sampling process must be able to capture the main characteristics of the original analogue signal.
- The sampling rate determines the amount of information that its transferred to the digital signal.

Sampling Theorem

- To reconstruct a signal from the samples, the sampling frequency must be high enough to capture the relevant signal information (frequency components).
  - Sampling frequency is the number of samples per second (f_s).
- For a signal where the highest (relevant) frequency is f_m, the sampling frequency (f_s) must be higher than two times f_m
  - $f_s > 2 * f_m \Leftrightarrow f_m < f_s / 2$
  - $f_s / 2$ is called the **Nyquist frequency**.
  - $2 * f_m$ is called the **Nyquist rate**.



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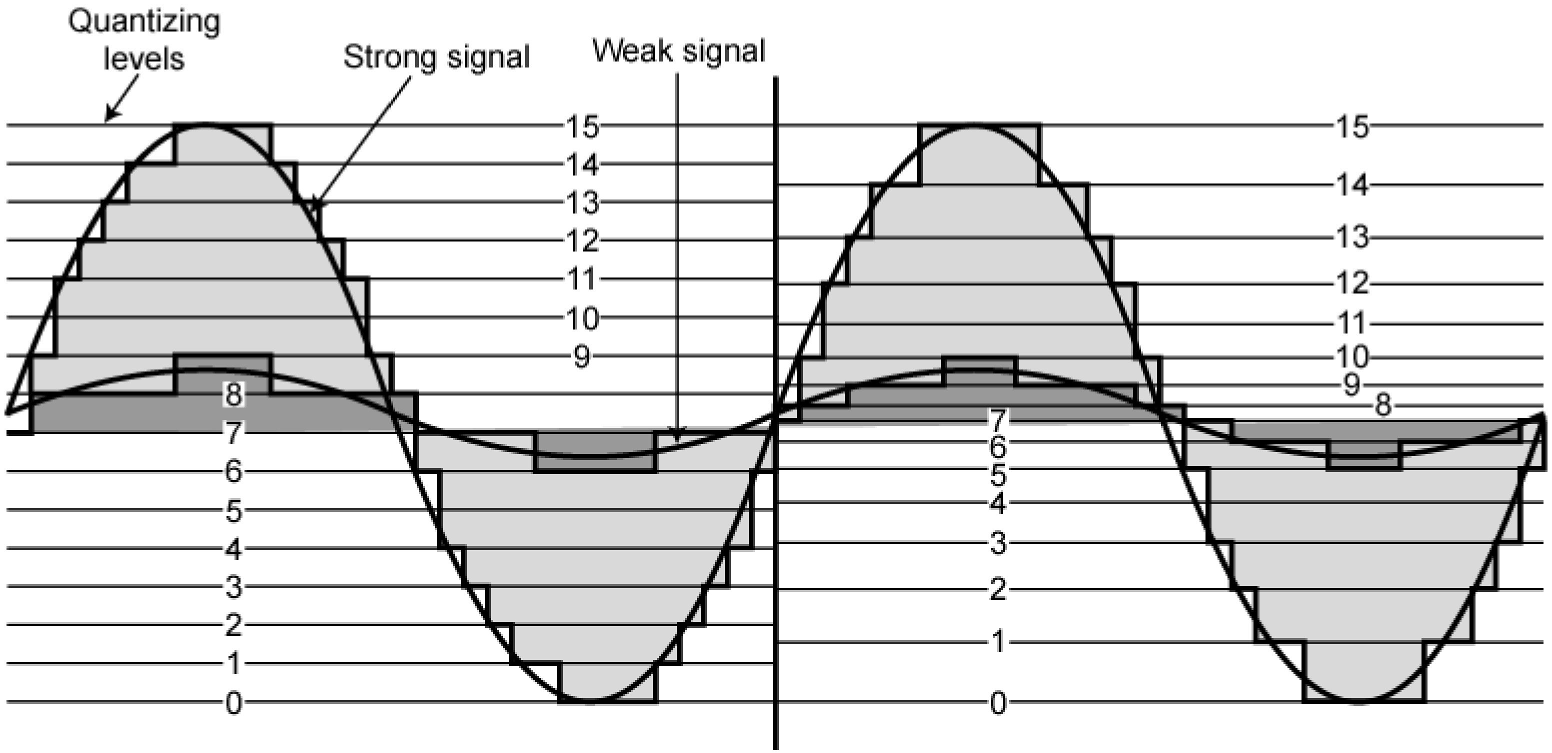
Signal Quantization and Encoding

- Each sampled value must be “rounded” to the nearest member of a set of discrete values.
- The resulting value is then encoded into a binary format.

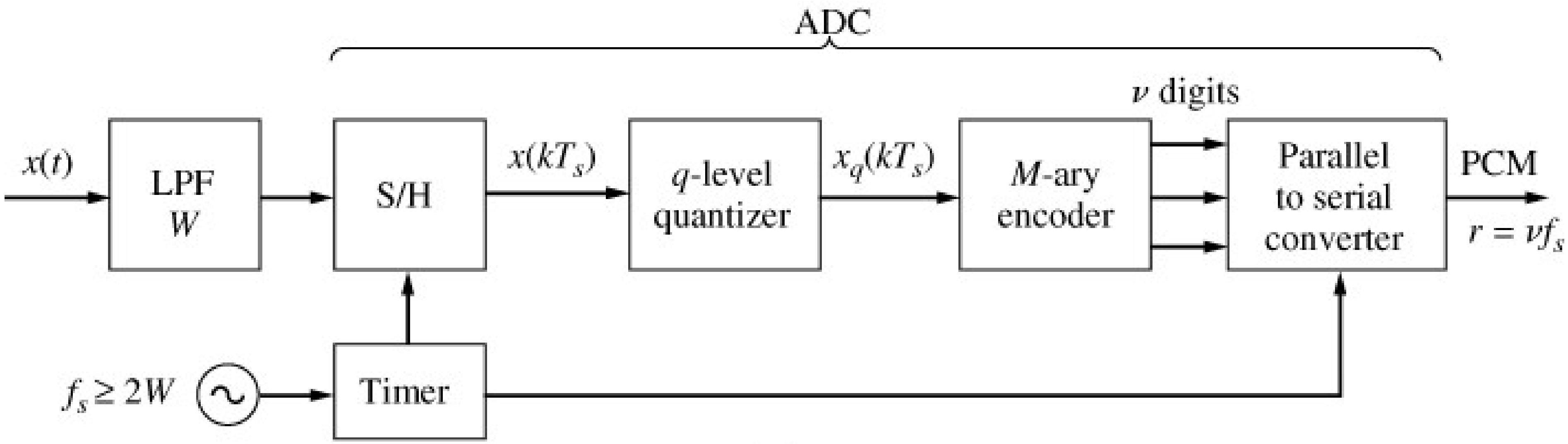


(a) Without nonlinear encoding

(b) With nonlinear encoding

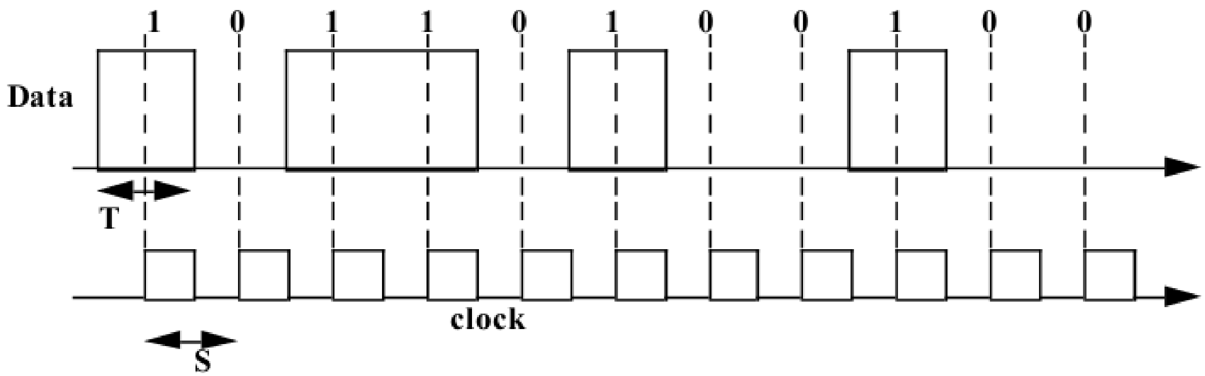
Pulse Code Modulation (PCM)

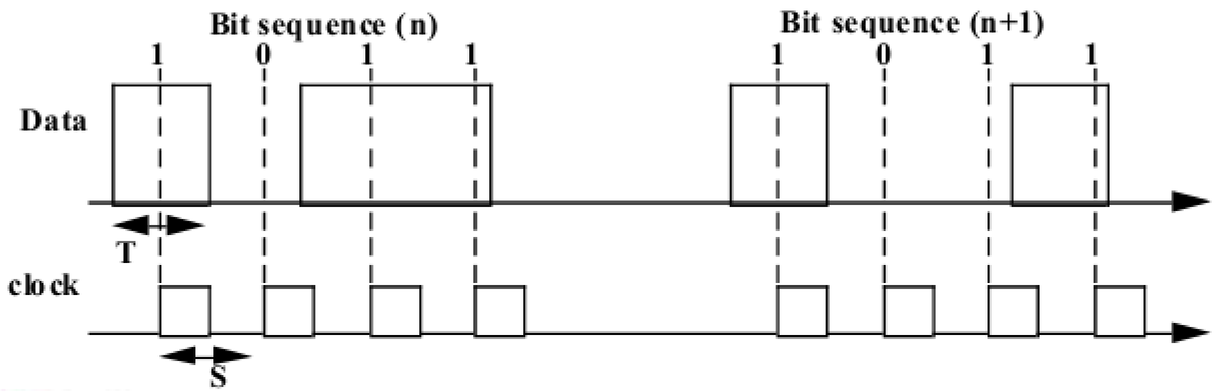
- All mechanisms of an ADC can be implemented using a PCM encoder.



Digital Transmission

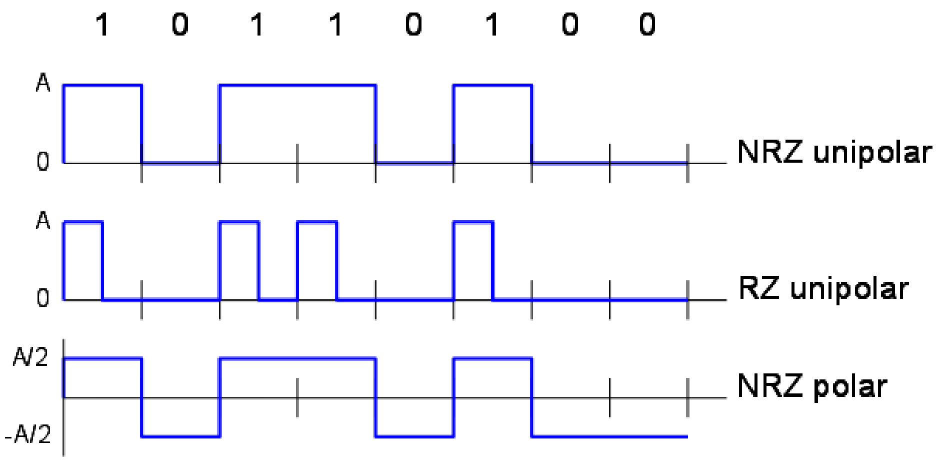
- Can be synchronous or asynchronous.
  - Synchronous Transmission data is transferred in the form of frames.
  - Asynchronous Transmission data is transmitted 1 bit or byte at a time.
- Synchronous Transmission requires a clock signal between the sender and receiver.
- Asynchronous Transmission sender and receiver does not require a clock signal, but data blocks must have a parity bit attached to it which indicates the start (start bit) of the new byte.
  - And, an optional stop bit.

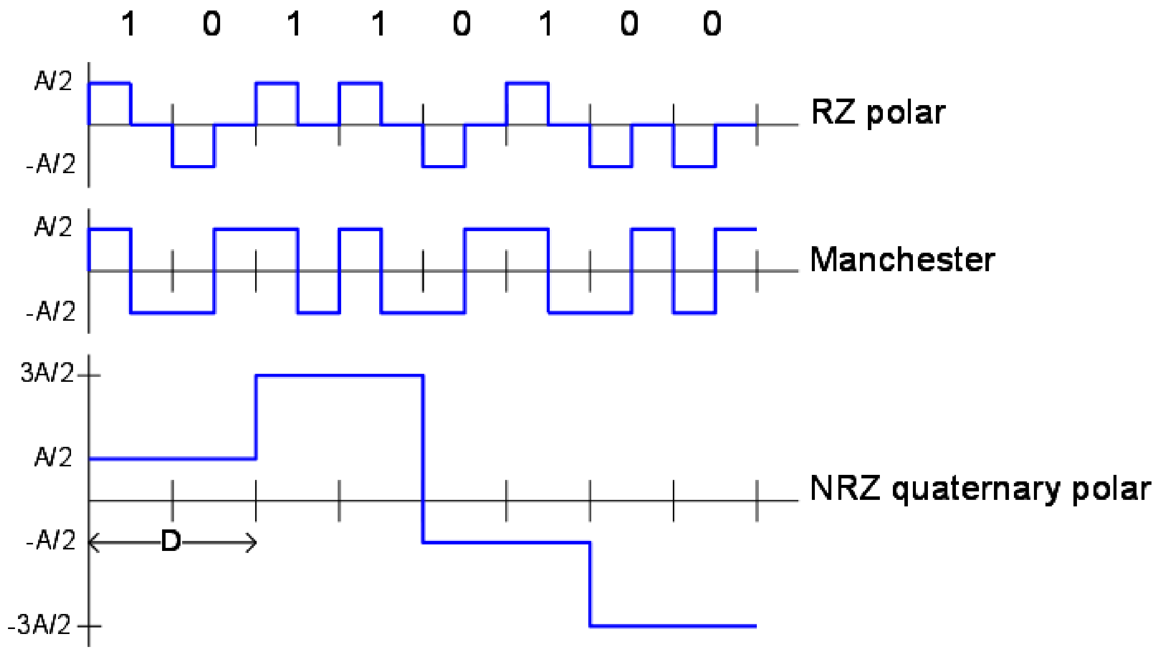




Line Coding (1)

- Line Coding converts a binary sequence into a digital signal
- Sender then uses the digital signal to modulate transmitting signal in a way that the receiver can recognize.
- Line Coding can be done bit a bit, or in block of several bits (symbol).
- There are several (bit a bit) Line Codes:





Line Coding (2)

- mB/nB Encoding
  - Symbols of m bits are coded as line symbols of n bits.
  - Each valid line symbols has at least two 1s.

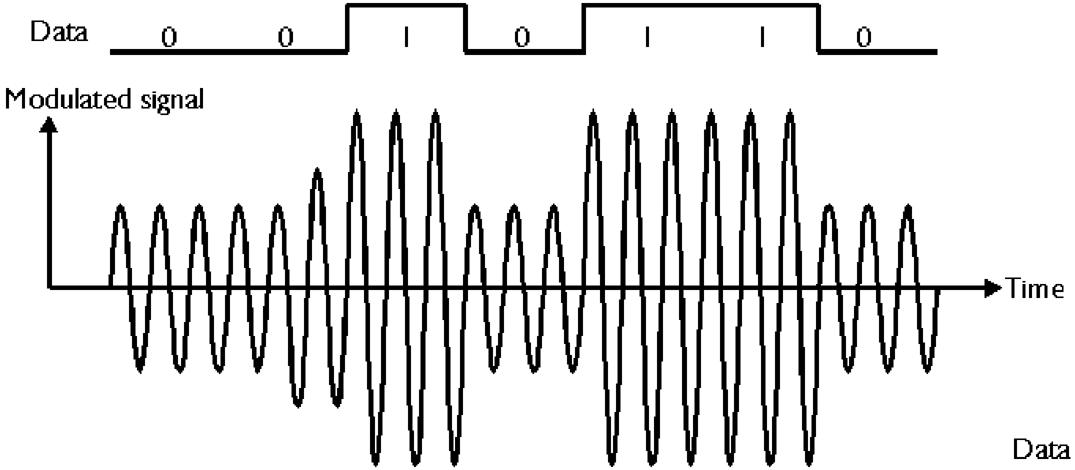
4B/5B Code

Bits	Symbol
0000	11110
0001	01001
0010	10100
0011	10101
0100	01010
0101	01011
0110	01110
0111	01111
1000	10010
1001	10011
1010	10110
1011	10111
1100	11010
1101	11011
1110	11100
1111	11101

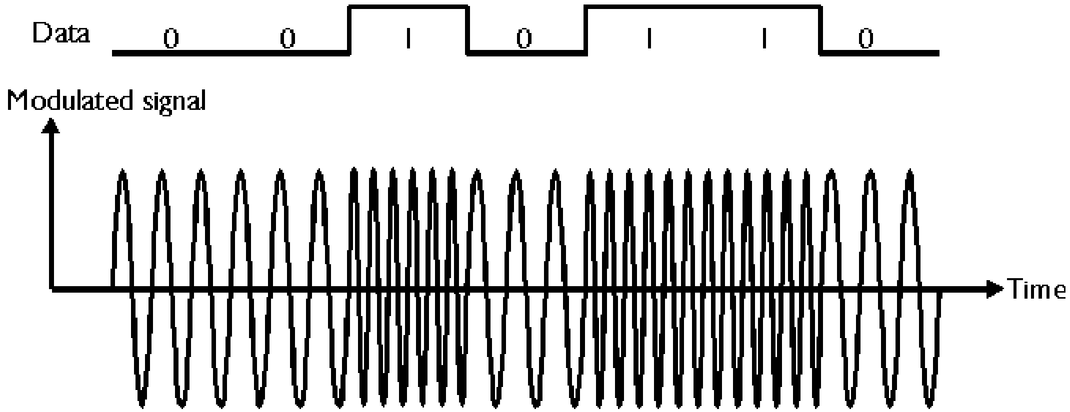
Bits	Symbol
IDLE	11111
J	11000
K	10001
T	01101
R	00111
S	11001
QUIET	00000
HALT	00100

Modulation (1)

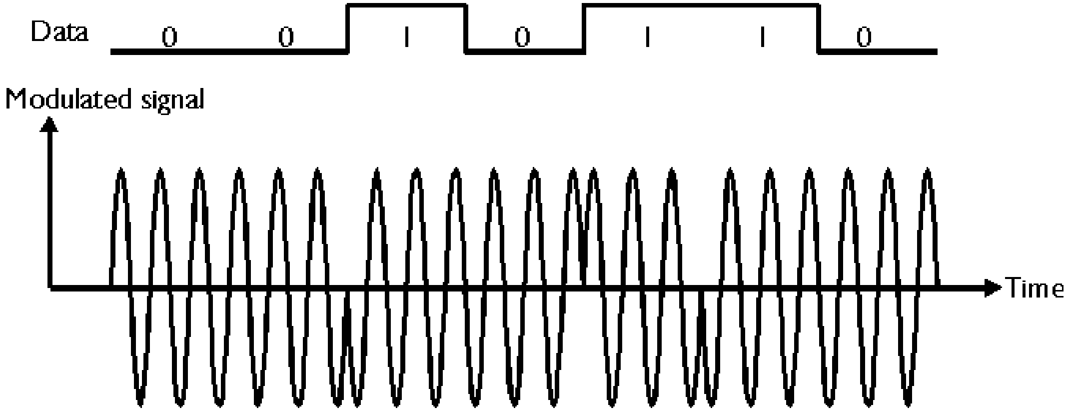
- Amplitude



- Frequency

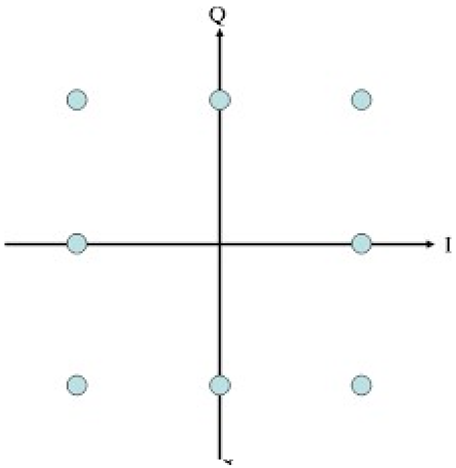


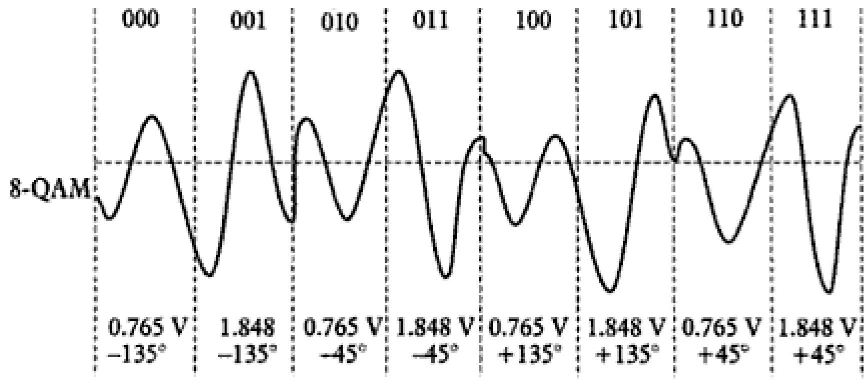
- Phase



Modulation (2)

- Quadrature Amplitude Modulation (QAM)
  - Uses 2-Dimensional signalling
    - Quadrature ← Sine wave + Cosine wave
  - $$s(t) = I(t)cos(2\pi f_0 t) - Q(t)sin(2\pi f_0 t)$$
- 8-QAM





- 16-QAM