Medium Access Control (MAC) protocols

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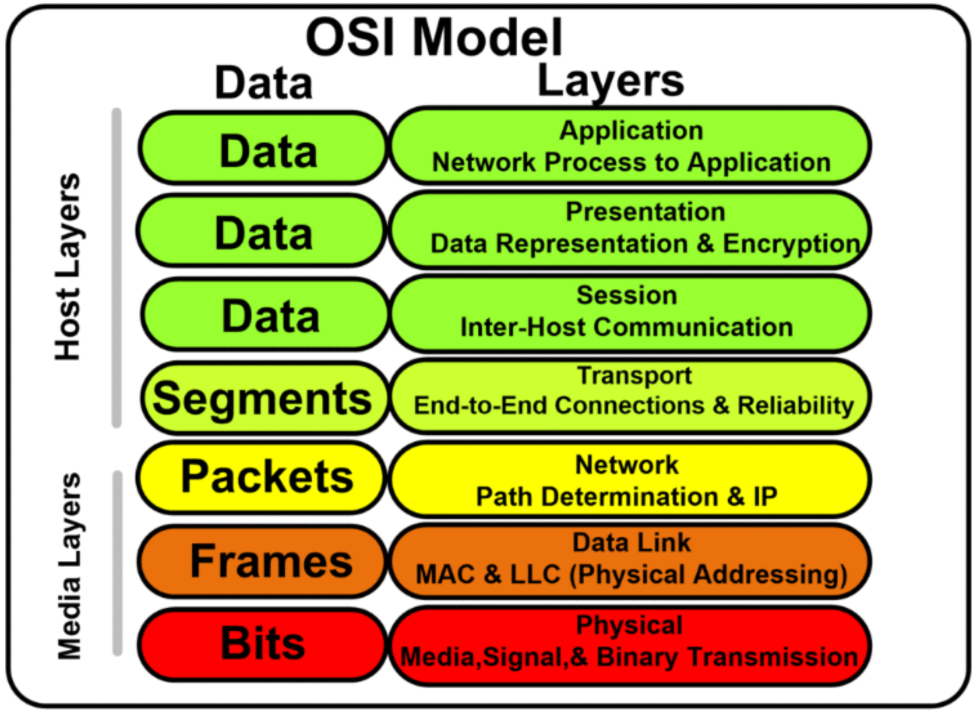
Cnam

MAC layer

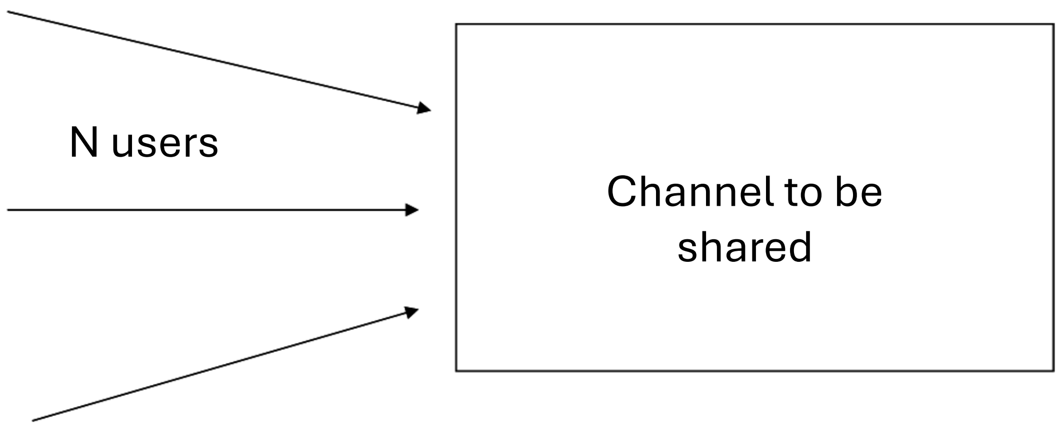
- **Medium Access Control**
- Part of Data Link layer:
  - Layer 2 of OSI model
  - Together with Logical Link Control

- Provides flow control and **multiplexing** for the transmission medium



What is multiplexing?

- Users' data are multiplexed on a channel (wired or wireless) so that **the number of collisions is minimized**
- A collision occurs if several users transmit on the same channel set

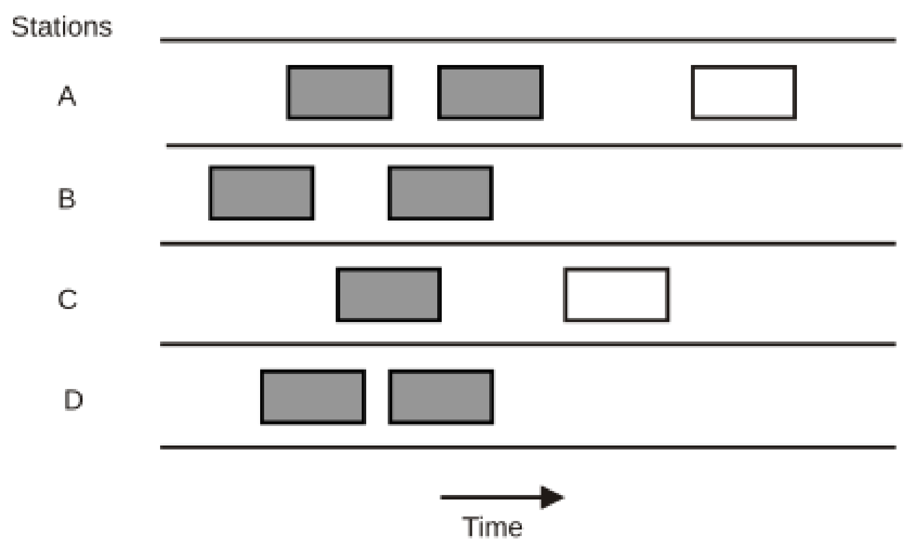


Multiplexing techniques

- Multiplexing can be performed:
  - Either by relying to **random access**: ALOHA, CSMA-CD, CSMA-CA,…
    - Simple, does not require a centralizer
    - Collisions may occur
    - No delay guarantee: not efficient for time-constrained applications
  - Or by using **strictly orthogonal fixed channel resources** : TDMA, FDMA, CDMA,…
    - More complex
    - No collision
    - But requires a centralizer

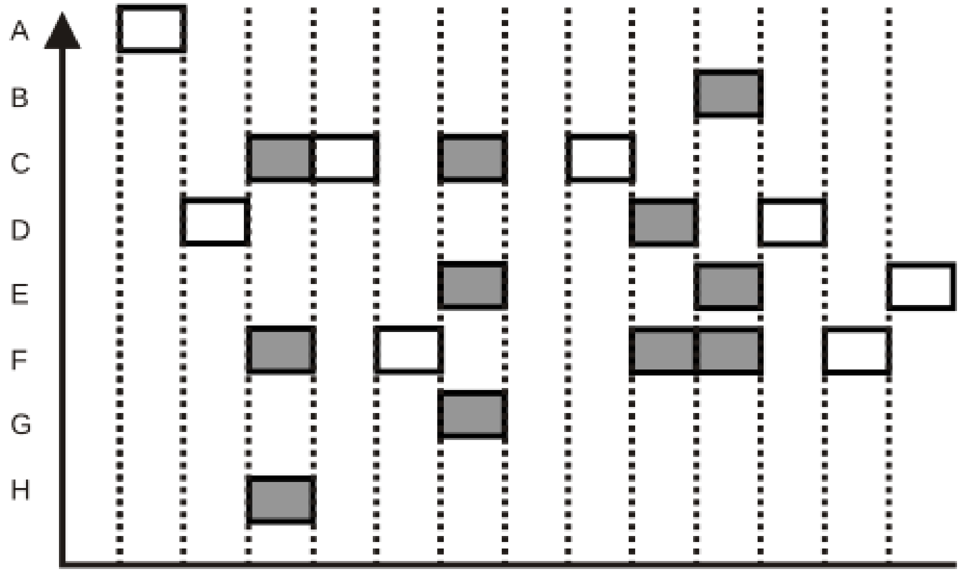
ALOHA protocol: pure ALOHA

- Easy **random** multiple access protocol :
  - If you have data to send, send the data
  - If, while you are transmitting data, you receive any data from another station, there has been a message collision. All transmitting stations will need to try resending later.
- **Drawback: many collisions occur !**
- 18.4% of the time is used for successful transmission



Slotted ALOHA

- Same as pure ALOHA but a station can **start a transmission only at the beginning of a time slot**
- **Reduced collisions rate** compared to pure ALOHA
- Improved performance: 36 % of the time is used for successful transmission



Slotted ALOHA protocol (shaded slots indicate collision)

CSMA/CD

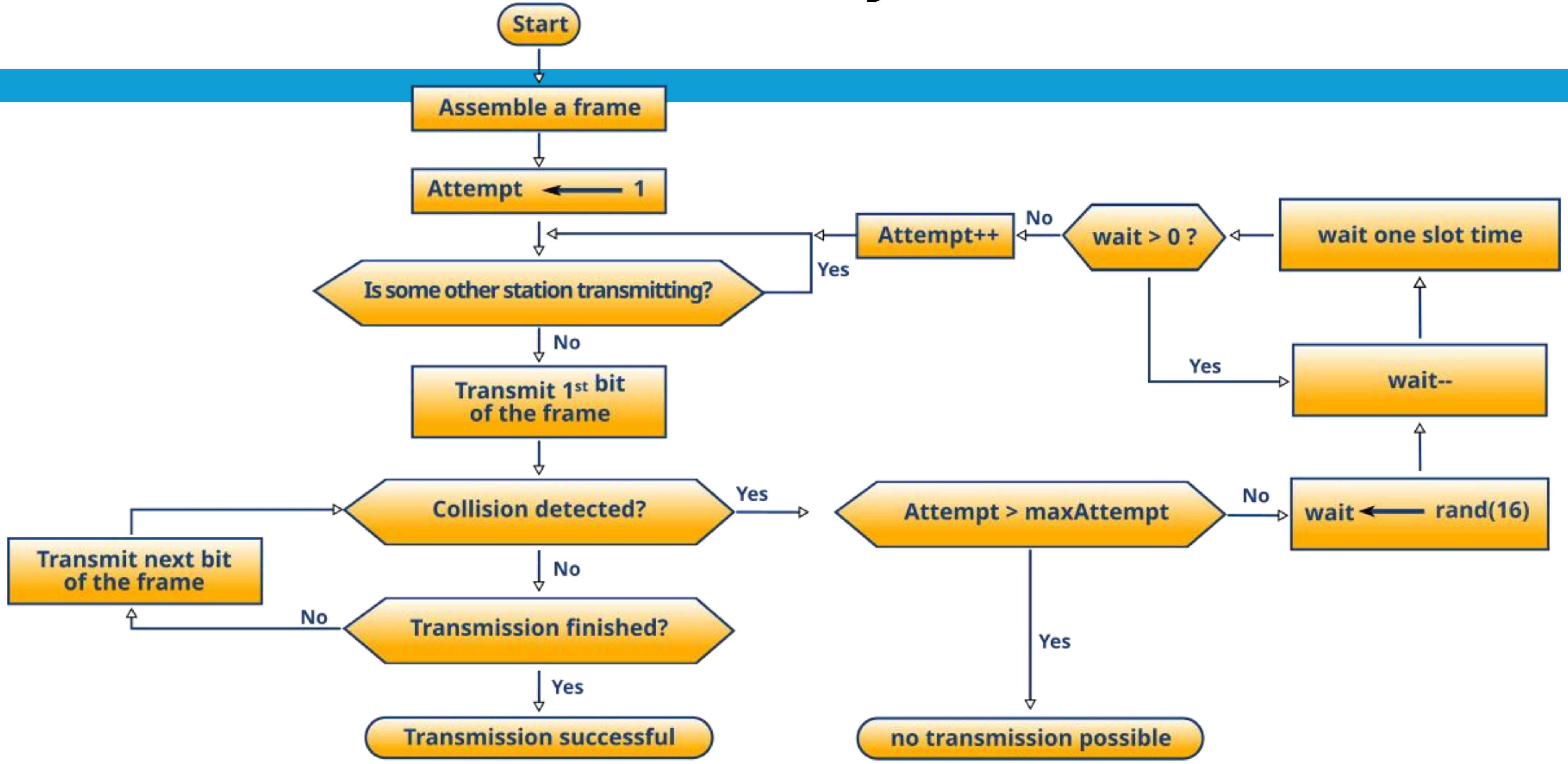
- **Carrier-sense multiple access with collision detection** (CSMA/CD)
- Used in early Ethernet (coaxial cables, twisted pairs cables)
- Stations first **sense the channel** to check if it is being used by another station for data transmission or if it is free:
  - If the channel is free, the station sends data and listens to the channel to check any collision
  - If the channel is being used, the station waits

CSMA/CD : collision

- A **collision occurs if two stations sensed that the channel is free and sent data at the same time:**
  - Then both stations send a jam signal instead of data to inform the other stations of the collision
  - Therefore, the receiving stations will discard the packets that were corrupted by the collision.

- When a collision is detected, both stations **wait for a random amount of time** until they retransmit again

CSMA/CD : summary



CSMA/CD : Binary exponential back-off

- The random waiting time is given by:

$$\text{Backoff} \sim \text{Uniform}(0, 2^k - 1) \times \text{slot time}$$

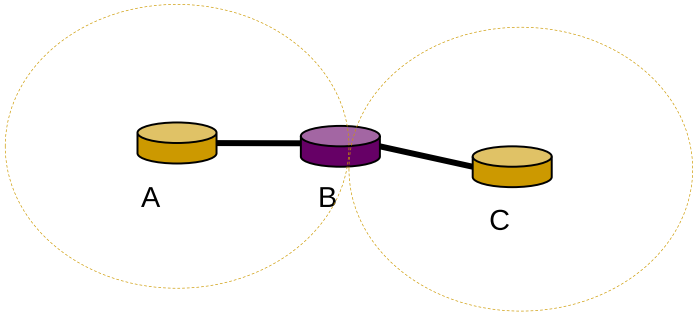
- Where k is the number of transmission attempts (max: 10)
- Example:
  - 1st collision: backoff ∈ [0, 1]
  - 2nd collision : backoff ∈ [0, 3]
  - 3rd collision : backoff ∈ [0, 7]

802.11 MAC layer: CSMA/CA

- In wireless networks, users cannot all listen to the medium
- Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol
  - Similar principle as in CSMA/CD, but with **additional messages/probes to detect if the medium is available, and avoid collisions**
  - Slower than CSMA/CD.

CSMA/CA: Hidden terminal problem

- Collision Detection impossible in wireless (# Ethernet) because 2 nodes who want to transmit to the same node may not detect each other.



A does not detect C,

C does not detect A.

a collision may occur at B

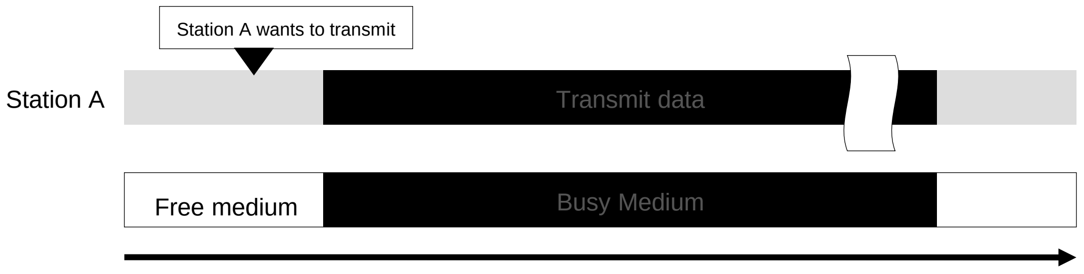
if both A and C simultaneously

transmit to B:

Hidden terminal problem

CSMA/CA: DCF

- Simplest version: Distributed Coordination Function (DCF).
- Without any certainty that the medium is actually free because of hidden terminal problem, stations transmit when they think the medium is free.
- Cannot guarantee QoS constraints fulfillment (such as delay)



CSMA/CA: CW

- If a collision occurs, stations wait for a random delay before they can retransmit.
  - It is called Contention window
  - It is a random number number between CWmin and CW size.
- Whenever a transmission fails :
  - Double CW size
  - Until CW size reaches Cwmax.
- This technique adapts to the number of nodes
  - Increase CW size so that the collision probability is decreased.
  - Drawback: medium access delay may be very long.

CSMA/CA: CW

- Example: CWMin = 15 and CWMax = 1023
  - 1st transmission (even without collision) : backoff ∈ [0, 15]
  - 1st collision: backoff ∈ [0, 31]
  - 2nd collision : backoff ∈ [0, 63]
  - 3rd collision : backoff ∈ [0, 127]
  - …
  - Until backoff ∈ [0, 1023]

CSMA/CA with CW

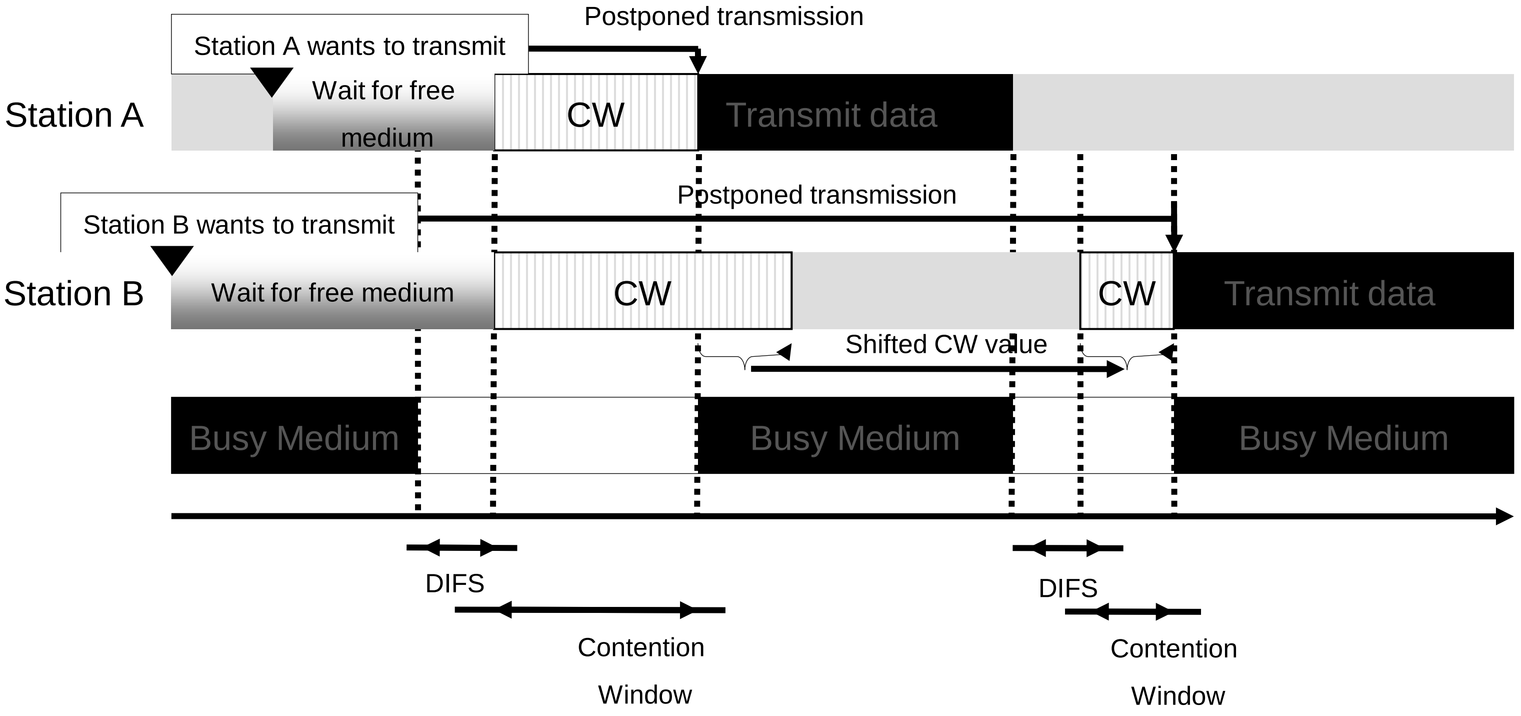
If the medium is free:

- Directly transmit data.

Else:

- Wait until the medium becomes free.
- And wait for DIFS (fixed) and Contention Window (random).
- Then:
  - If the medium is free, transmit.
  - Else, wait until next free medium period. Store the remaining CW and only wait for this time at next access request.

CSMA/CA with CW



CSMA/CA with RTS/CTS

- Ready To Send/ Clear To Send.
- To avoid hidden terminal problem.
- Before sending data, a node sends a RTS with:
  - Destination node’s address.
  - Approximate transmission time (NAV, Network Allocation Vector).
- The destination node replies: CTS (including NAV).
- The other nodes cannot transmit until NAV.

This way, nodes near to the transmit node or to the destination node become aware of the transmission

-> To avoid hidden terminal problem

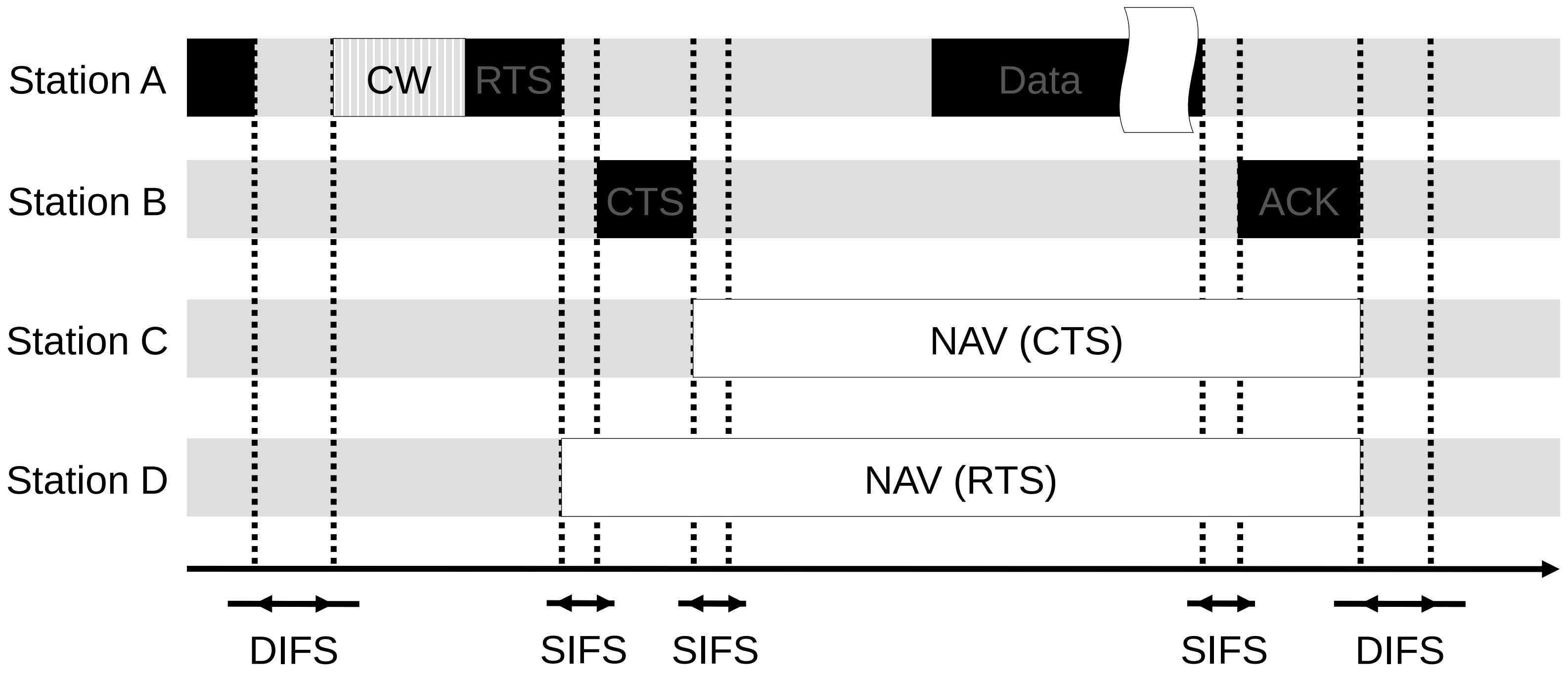
The NAV (approximate transmission time) is sent both by the transmit and destination node so that the other nodes can wait during transmission

CSMA/CA with RTS/CTS

B can detect A and C.

A cannot detect C.

D can only detect A.



CSMA/CA with RTS/CTS

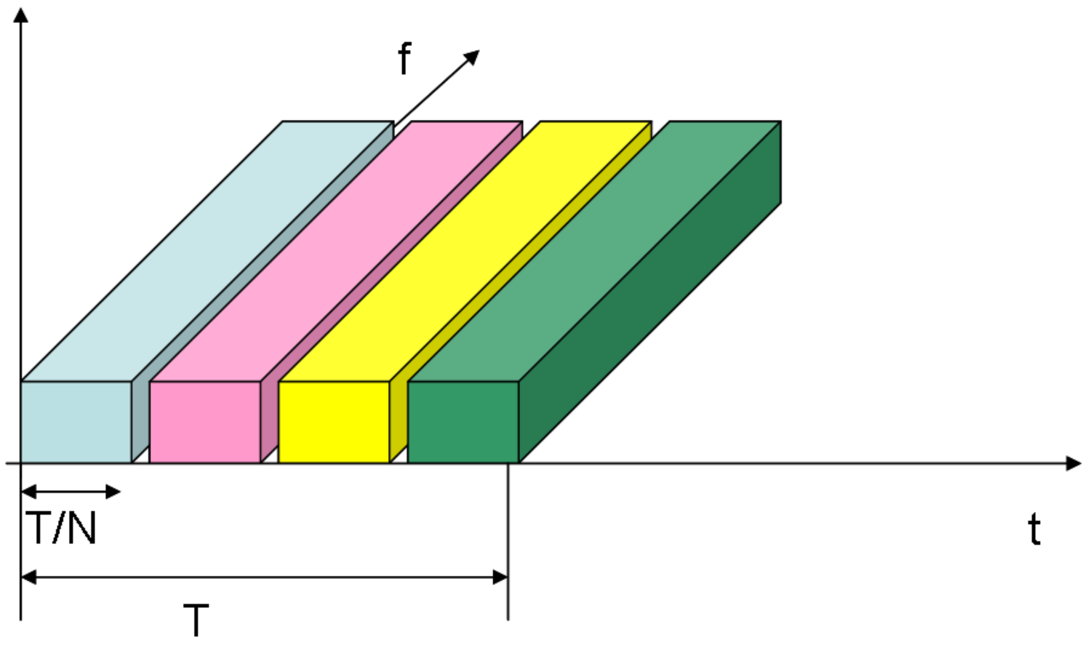
Inter-frame spacing (802.11 DCF):

- **SIFS** (Short Inter-Frame Spacing):
  - Before each frame in the same exchange.
  - Between RTS and CTS, CTS and data, data and ACK.
- **DIFS** (Distributed Inter-Frame Spacing):
  - Before each new frame in different exchanges.

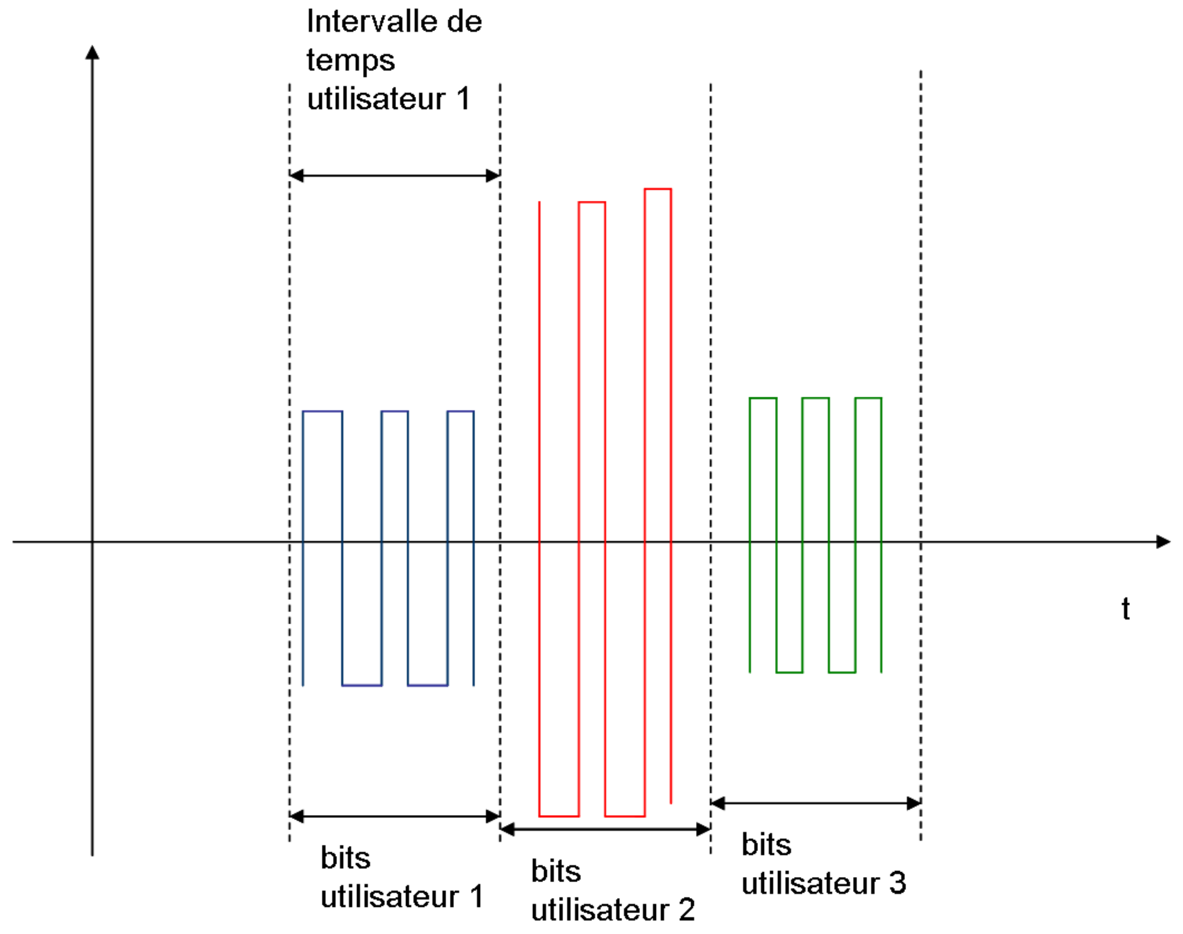
ACK sent by the destination after each received data.

TDMA

- **Time Division Multiple Access**
- Used in cellular networks
- No collisions are accepted
- **The channel is time-separated**
- One frame is separated into several time slots
- Each user is allocated a different time slot
- Example: 2G

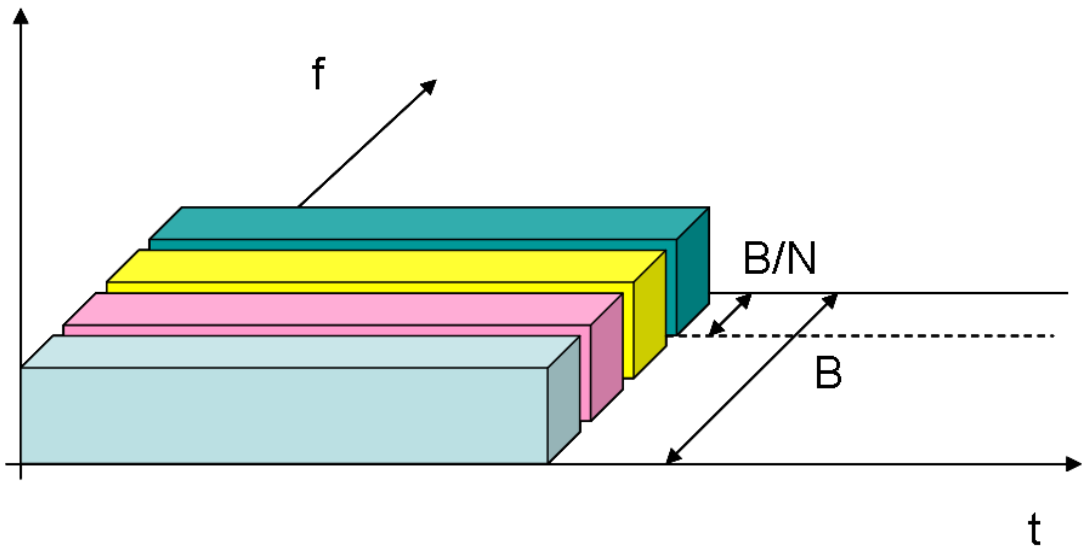


TDMA

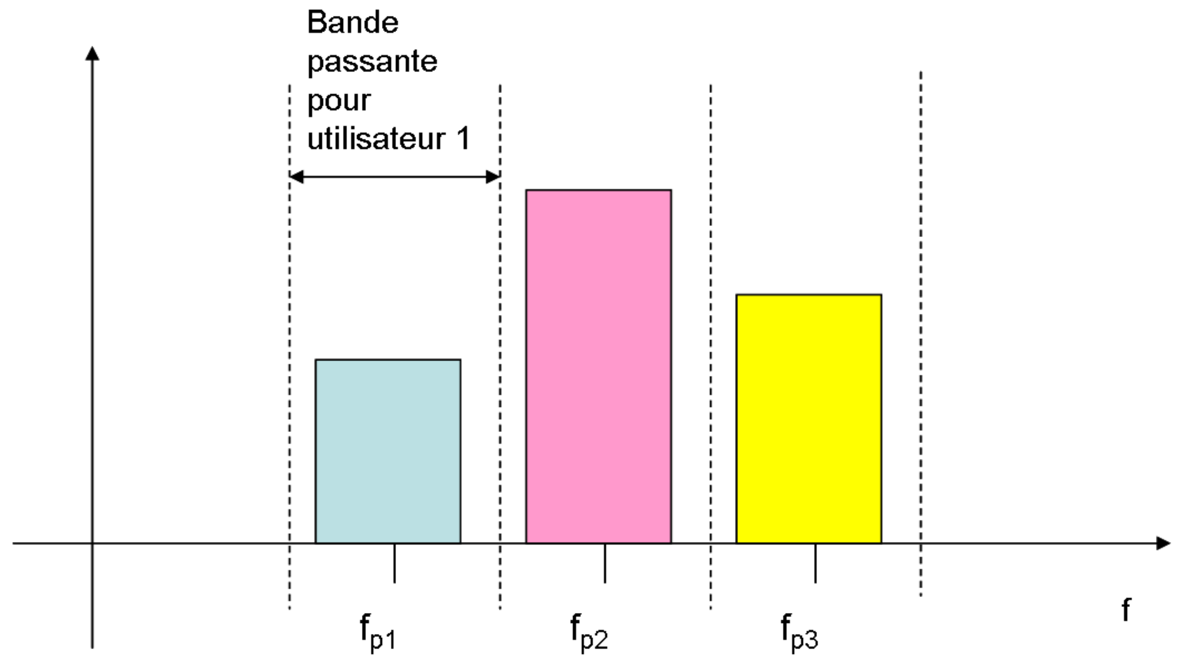

Intervalle de temps utilisateur 1
t
bits utilisateur 1
bits utilisateur 2
bits utilisateur 3

FDMA

- **Frequency Division Multiple Access**
- **The channel is frequency-separated**
- One frame is separated into several frequency sub-bands
- Each user is allocated a different sub-band
- Each user transmits during the whole frame
- Example: 4G, 5G

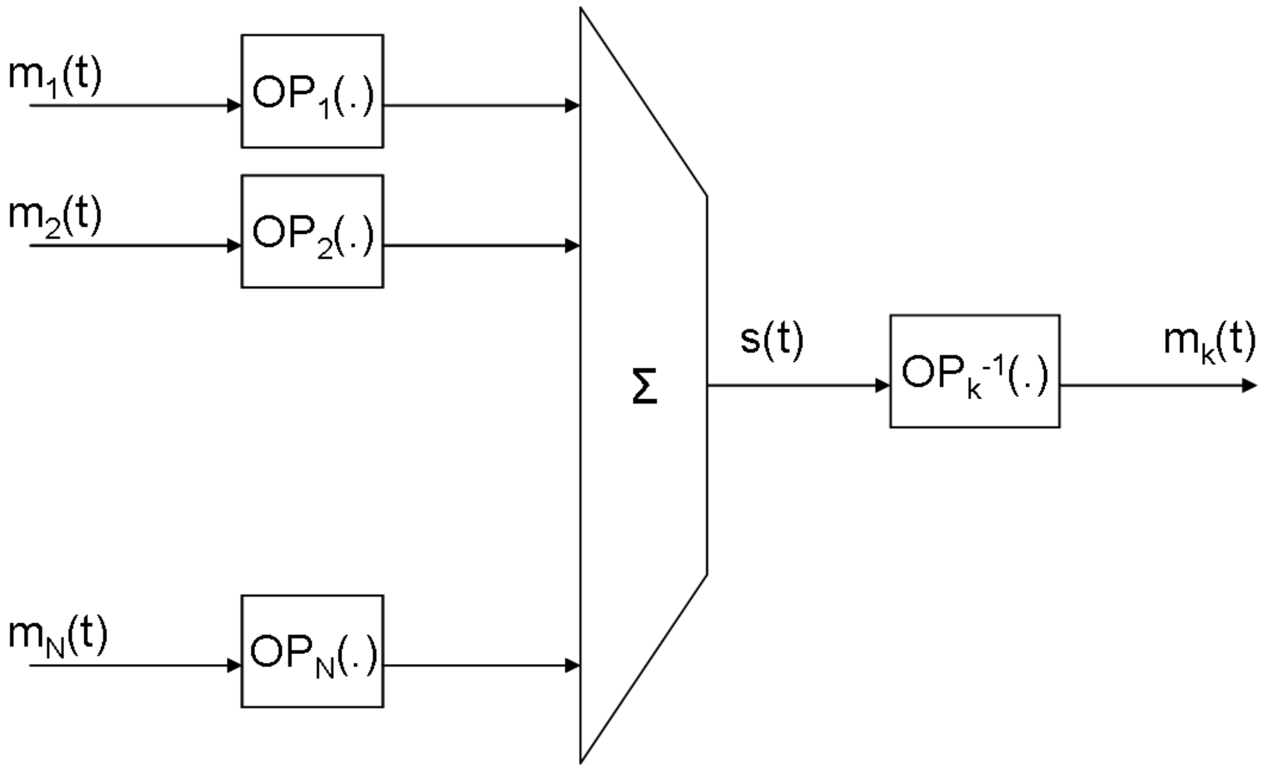


FDMA



CDMA

- **Code Division Multiple Access**
- All users transmit on the same time interval and on the whole frequency
- **But their signals are made orthogonal through coding**
- Example: 3G



CDMA

- Transmit signal: $s(t) = \sum_{i=1}^{N} \mathrm{OP}_i\,[m_i(t)]$

- Apply the inverse code on s(t):

$$
\begin{aligned}
r(t) &= \mathrm{OP}_k^{-1}\,[s(t)] \\
&= m_k(t) + \sum_{i=1, i\neq k}^{N} \mathrm{OP}_k^{-1}\,[\mathrm{OP}_i\,[m_i(t)]]
\end{aligned}
$$

- m_k can be recovered without interference if codes are orthogonal:

$$
\sum_{i=1, i\neq k}^{N} \mathrm{OP}_k^{-1}\,[\mathrm{OP}_i\,[m_i(t)]] = 0
$$

CDMA

- Examples of orthogonal codes: Walsh-Hadamard sequence

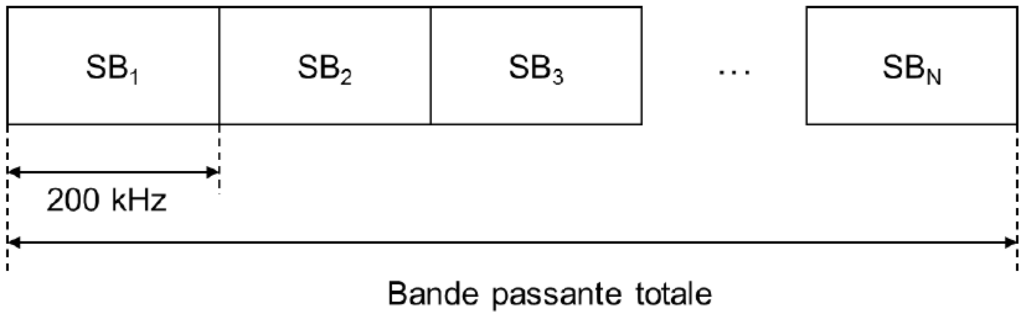
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	
1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	
1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	
1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	
1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	
1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	
1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	1	-1	…
1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	
1	-1	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	
1	1	-1	-1	1	1	-1	-1	-1	-1	1	1	-1	-1	1	1	
1	-1	-1	1	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	
1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	
1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	1	-1	1	-1	
1	1	-1	-1	-1	-1	1	1	-1	-1	1	1	1	1	-1	-1	
1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	1	-1	-1	1	
								…								…

Example GSM (2G European network)

- GSM multiplexes users both in FDMA and TDMA.
- The reserved GSM 900 frequency bands are :
  - Mobile to BTS (uplink) : 880-915 MHz
  - BTS to Mobile (downlink) : 925-960 MHz
- The reserved GSM 1800 frequency bands are :
  - Mobile to BTS (uplink) : 1710-1785 MHz
  - BTS to Mobile (downlink) : 1805-1880 MHz

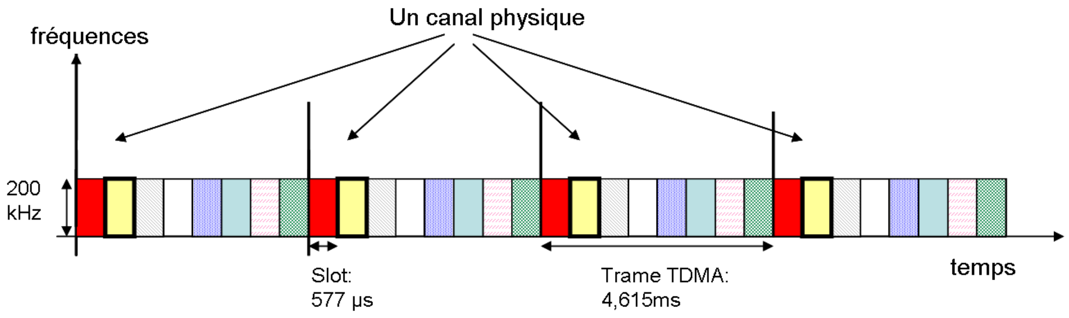
GSM Multiplexing

- In uplink and downlink, the bandwidth is separated in sub-bands of de 200 KHz.
- TRX : a pair of sub-bands (downlink and uplinkf) of 200 KHz each.



TDMA multiplexing per cell

- Each sub-band of 200 KHz corresponds to a frame separated in 8 time slots.
- A different user per time slot : up to 8 users per TRX.
- The same time slot is allocated to the same user during its whole conversation.



FDMA multiplexing between cells

- Cells are separated by their TRX.
- The same TRX can only be reused if two cells are far enough not to generate high interference.
- A frequency reuse factor is used (here : with 7 bands).