Internet of Things
MAC protocols

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http://robot.unipv.it/toolleeo

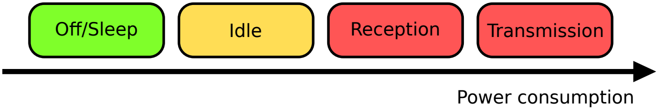
States of a radio transceiver

Sensor node can be in one of the following three modes:

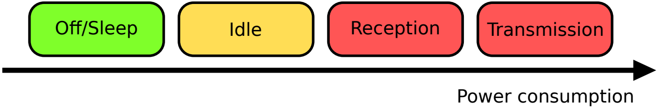
- Active.
- Standby.
- Battery exhausted.

The common wireless radio transceivers can be in one of the following four modes:

- **Transmitting** - Maximum power consumption
- **Receiving** - Maximum power consumption
- **Idle** - Reduced power consumption
- **Turned off** - Least power consumption



Focus on radio transceiver usage



Turnaround time = Time to change from one mode to another (especially important is time from sleep to wakeup and vice-versa)

> Protocol designs focus on placing a node in these different modes depending upon several factors

Constraints on MAC protocols for IoT

Traditional MAC protocols provide:

- High throughput
- Low latency
- Fairness
- Mobility

However they have little consideration for energy!!

Constraints on MAC protocols for IoT

MAC protocols for IoT must provide best performance using the smallest amount of energy

As for traditional protocols:

- Fairness
- Latency
- Throughput

Additional requirements for sensor networks:

- Power efficiency
- Scalability

CSMA types

- The wireless communication is broadcast in nature.
- The transmission from a node can interfere with another, if in the same transmission range.

Carrier-sense multiple access (CSMA) is a Medium Access Control (MAC) protocol in which a node checks for other traffic before transmitting on a shared transmission medium

- A carrier-sense mechanism is used to determine whether another transmission is in progress before initiating a transmission.
- If a carrier is sensed, the node waits for the transmission in progress to end before initiating its own transmission.
- Multiple nodes may, in turn, send and receive on the same medium.

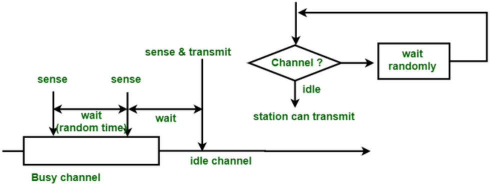
Variations of CSMA

Variations on basic CSMA include

- CSMA/CA, with collision-avoidance.
- CSMA/CD, with collision-detection.
- Collision-resolution techniques.

CSMA access modes

Non-persistent CSMA

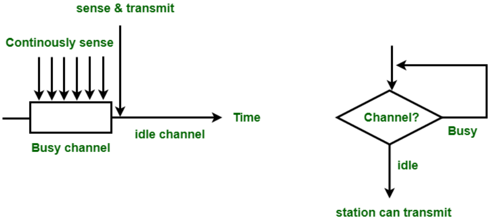


- If channel is idle, the frame is sent immediately.
- If the channel is busy, wait for the random time and again sense for the state of the channel whether idle or busy.

From `https://www.geeksforgeeks.org/difference-between-1-persistent-p-persistent-and-non-persistent-csma/`

CSMA access modes

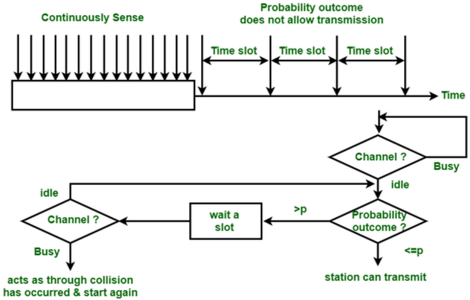
1-persistent CSMA



- The channel is sensed continuously.
- The message is sent as soon as the medium is detected as free.
- Aggressive method.

CSMA access modes

p-persistent CSMA



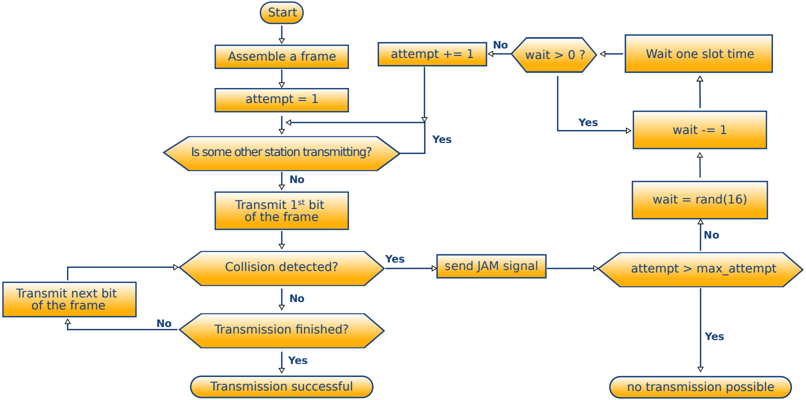
- Channel has time-slot with duration equal to or greater than the maximum propagation delay time.
- The station senses the channel when it needs to transmit.
- If the channel is busy, the station waits for the next slot.
- If the channel is idle, the frame is sent with probability p; further waiting happens with probability $1 - p$.

CSMA/CD

CD = Collision Detection

- Carrier Sensing + deferral as in CSMA.
- Colliding transmissions are aborted within short time.
- Used in Ethernet.
- Collision detection is easy in wired LANs: measure signal strengths, compare transmitted and received signals.
- Unsuitable for wireless LANs due to receiver shut off while transmitting and background noise.

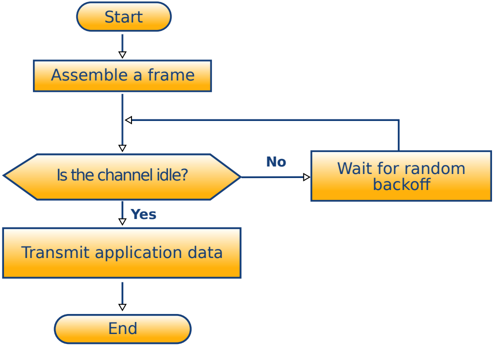
CSMA/CD simplified logic



Adapted from `https://en.wikipedia.org/wiki/Carrier-sense_multiple_access_with_collision_detection`

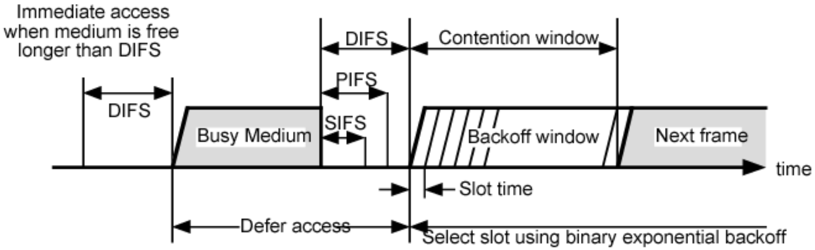
CSMA/CA

CA = Collision Avoidance



Adapted from `https://en.wikipedia.org/wiki/Carrier-sense_multiple_access_with_collision_avoidance`

CSMA/CA



Basic access method

IFS = Inter-Frame Space
SIFS = Short IFS (used for ACK, CTS, etc.)
PIFS = PCF IFS - used in Point Mode (PCF)
DIFS = DCF IFS - used in Distributed Mode (DCF)

CSMA/CA

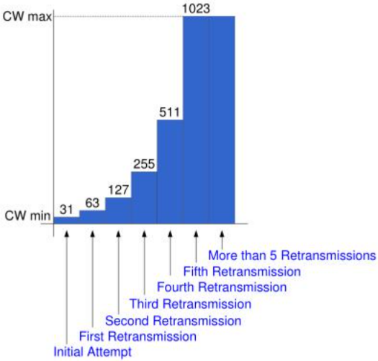
Calculation of the backoff time

$$Backoff = rand(0, CW) \cdot SlotTime$$

where

- *CW* is the **Contention Window**.
- *SlotTime* is the duration of a time slot (depends from the protocol).

CW is set equal to *CWmin* to begin, and it is doubled at every retransmission, up to a maximum value of *CWmax*



SIFS and DIFS durations

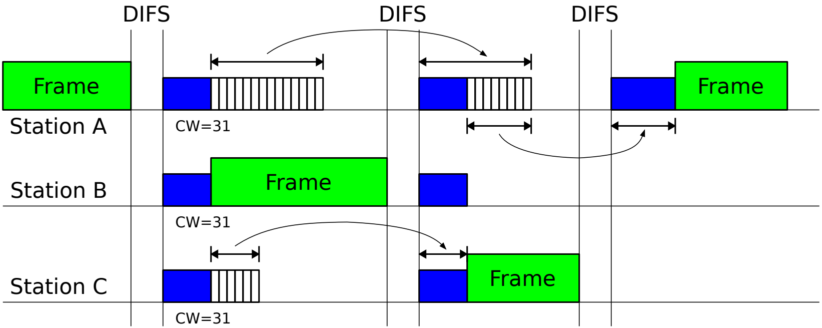
Duration of SIFS and DIFS depends from the protocol

Standard	SIFS (μs)
802.11-1997 (FHSS)	28
802.11-1997 (DSSS) 802.11b	10
802.11a	16
802.11g 802.11n (2.4 GHz)	10
802.11n 802.11ac (5 GHz) 802.11ax	16
802.11ah (900 MHz)	160
802.11ad (60 GHz)	3

Standard	Slot time (μs)	DIFS (μs)
802.11-1997 (FHSS)	50	128
802.11-1997 (DSSS)	20	50
802.11b	20	50
802.11a	9	34
802.11g	9 or 20	28 or 50
802.11n (2.4 GHz)	9 or 20	28 or 50
802.11n (5 GHz)	9	34
802.11ac (5 GHz)	9	34

$$\text{DIFS} = \text{SIFS} + (2 \cdot \text{Slot time})$$

CSMA/CA DCF mode



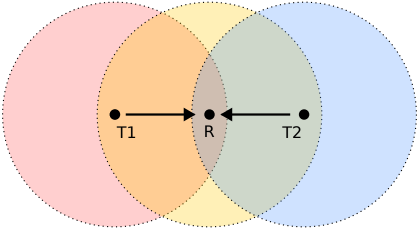
Interferences in wireless communications

Main problems:

- **Hidden node** problem.
- **Exposed node** problem.

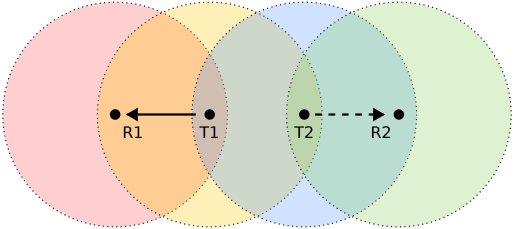
These problems are due to the physical positions of nodes that are involved in the communication, their transmission ranges, and which nodes are willing to transmit/receive.

Hidden node problem



- Node $T1$ starts the transmission towards the receiver node R.
- Node $T2$ is not in range with node $T1$, thus it does not sense its transmission.
- Therefore, node $T2$ starts its transmission too.
- The two transmissions interfere on node R,
- As a result, node R does not receive neither of the two transmission.

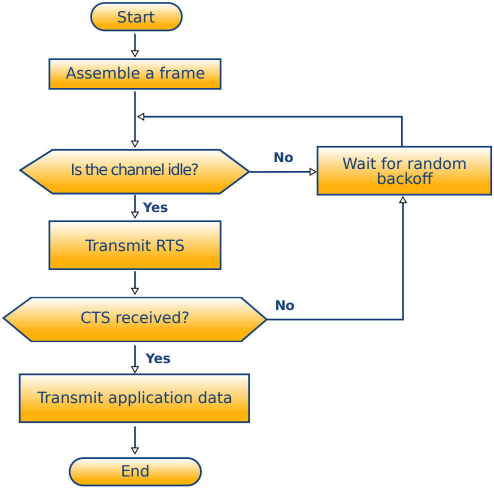
Exposed node problem



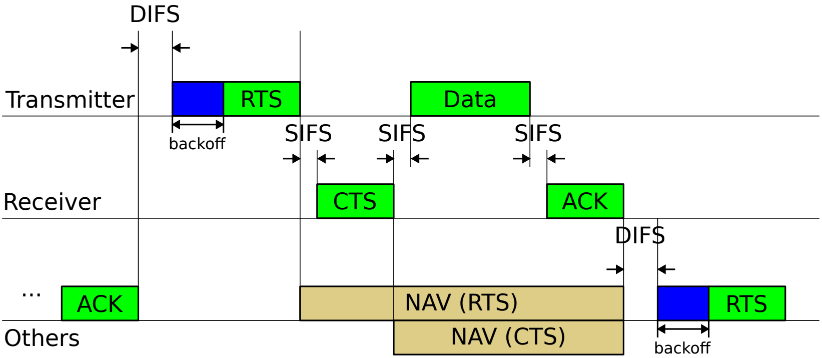
- Node $T1$ wants to trasmit data to receiver node $R1$, while node $T2$ wants to trasmit data to receiver node $R2$.
- Node $T1$ starts its tranmission successfully towards node $R1$.
- The transmission also reaches node $T2$.
- Node $T2$ senses the channel and detects it as busy.
- Node $T2$ does not start its transmission to avoid interference.
- The communication from $T2$ to $R2$ does not take place although it could happen successfully.

CSMA/CA with RTS+CTS

Request to Send (RTS) / Clear To Send (CTS) packets are used to mitigate the hidden/exposed node problems.



CSMA/CA with RTS+CTS



Network Allocation Vector (NAV) = Time set by other nodes after having received the duration of the transmission from the transmitter.

"Taking Turns" MAC protocols

Channel partitioning MAC protocols

- Share channel efficiently and fairly at high load.
- Inefficient at low load: delay in channel access, $1/N$ bandwidth allocated even if only 1 active node!

Random access MAC protocols

- Efficient at low load: single node can fully utilize channel.
- High load: collision overhead.

"Taking turns" protocols

- Look for best of both worlds!

Controlled access

In **controlled access**, the stations consult one another to find which station has the right to send

A station cannot send unless it has been authorized by other stations.

Three popular controlled-access methods will be discussed:

- Reservation
- Token passing
- Polling

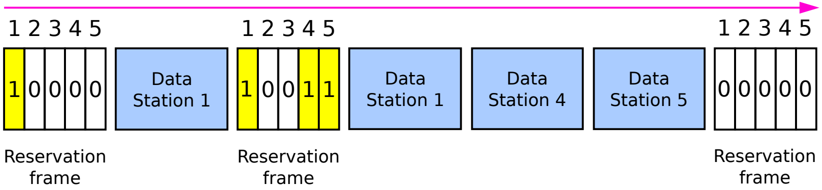
Reservation

Slave node sends request to reserve a slot

Issues:

- Reservation overhead.
- Contention based reservation.
- Single point of failure (master).

Reservation



Reservation-station needs to make a reservation before sending data.

Token passing

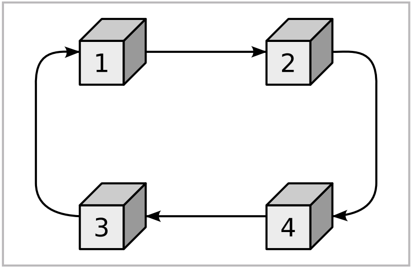
Works by passing a control token from one node to the next, sequentially

Issues:

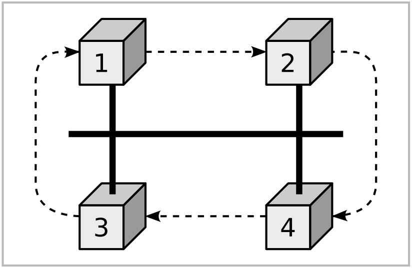
- Token overhead.
- Latency.
- Single point of failure (token).

Token passing

Token passing: stations in network organized in a logical ring with predecessors and successors.
Token: gives station right to access the channel; needs token management.



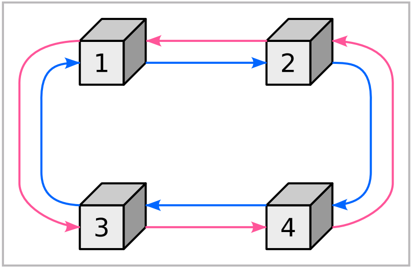
Physical ring - A station sends the token to its successor.



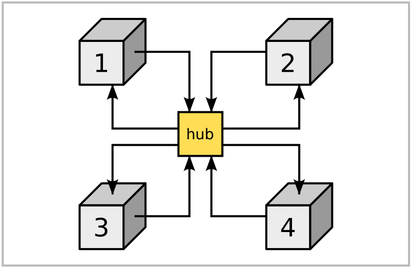
Bus ring (token bus) - Stations are connected to single cable called bus, but make logical ring.

Token passing

Token passing: stations in network organized in a logical ring with predecessors and successors.
Token: gives station right to access the channel; needs token management.



Dual ring - Uses second ring which operates in reverse direction.



Star ring - Physical topology is star, the wiring inside hub makes the ring.

Polling/selection

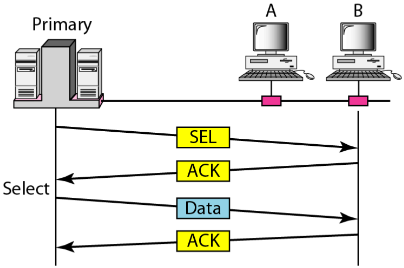
Master node "invites" slave nodes to transmit in turn

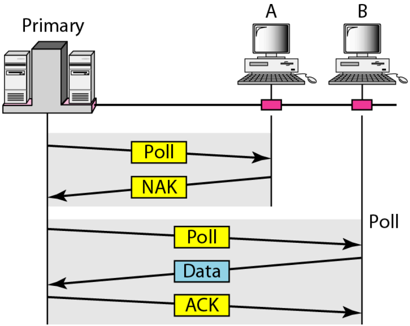
Issues:

- Polling overhead.
- Latency.
- Single point of failure (master).

Polling/selection

One device as primary station and the other device as secondary station





Select - The primary device wants to send data to secondary device, secondary device gets ready to receive.

Poll - The primary device solicits (ask) transmissions from secondary devices.