

Computer Networks

Data Link Layer - Medium Access Control

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Coordinated Medium Access

- If multiple **Network Interface Cards (NICs)** are connected to a medium the access needs to be coordinated
- Otherwise **collisions** (simultaneous transmissions) may occur
- We distinguish between
 - **Contention-based Protocols**
 - Participants **compete** for medium access
 - Multiple NICs may transmit simultaneously \Rightarrow collisions must be handled
 - Perform well for **low to medium utilization** and **bursty** traffic
 - **Contention-free Protocols**
 - Access to the medium is **allocated in advance**
 - Collisions can be completely avoided
 - Perform well for **high utilization** and can guarantee **fair use** of the capacity

Agenda

■ Contention-based

- ALOHA
- CSMA
- CSMA/CD
- CSMA/CA and MACA

■ Contention-free

- Token Passing
- TDMA
- FDMA
- CDMA

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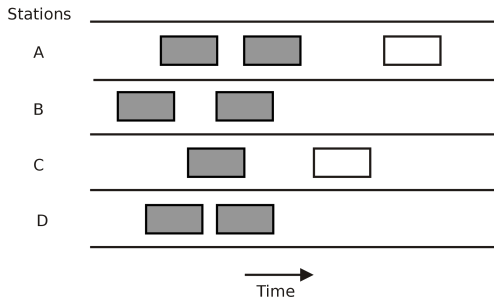
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ALOHA¹

- No central control, **no coordination** between stations
- Stations start sending whenever they want to



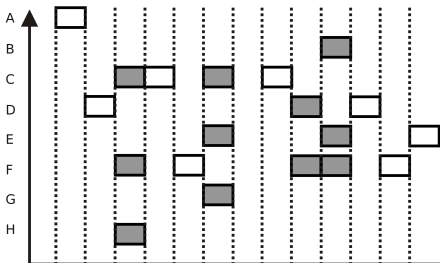
- Collision may occur
- No fairness

Source: Wikipedia, CC 3.0

→ Very simple solution without any requirements

Slotted ALOHA

- Send packets of fixed length within **fixed time-slots**
⇒ Requires common time-base for **synchronization**
- Stations start sending whenever they want to



Slotted ALOHA protocol (shaded slots indicate collision)

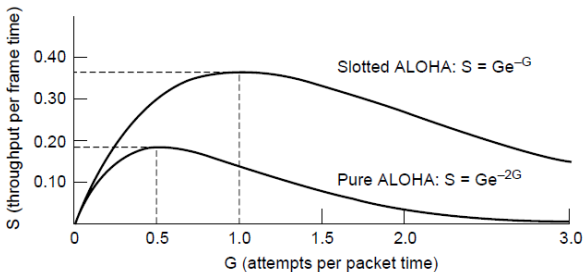
Source: Wikipedia, CC 3.0

- Only complete collision may occur
- No fairness
- Improved throughput
- Increased delay

- Used for first **GSM** networks

Performance of ALOHA

- According to an analysis from the **queuing theory** the **throughput S** of a network using **ALOHA** MAC looks as follows:



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- For 1 attempted transmission per packet time the achieved throughput peaks at $\approx 18\%$ resp. 37% of the channel's capacity
- ⇒ Performance is rather low

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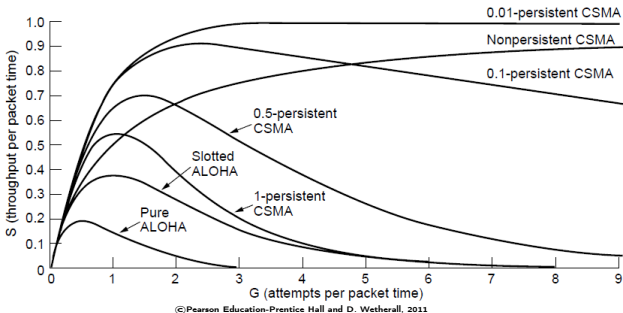
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CSMA

- Carrier Sense → Listen before talk
- Multiple Access → Multiple stations compete for the medium
- p-persistent CSMA:
 - Medium is busy: keep listening until it becomes idle
 - Medium is idle: With probability p , transmit the frame
⇒ with probability $1-p$, wait until next time slot and then sense the medium again
- non-persistent CSMA:
 - Medium is busy: wait a random amount of time, before sensing the medium again
 - Medium is idle: transmit the frame immediately

Performance of CSMA

- Comparing the performance for the different variants of CSMA to ALOHA:



- The lower the probability p the better the performance (particular for higher load)
- Latency may suffer for lower values of p

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CSMA/CD

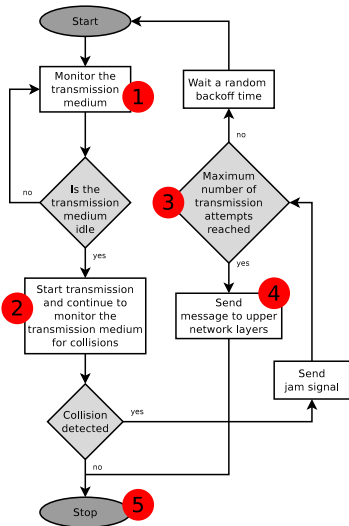
- Collision Detection
- During transmission, keep sensing the medium to detect collisions
- If collision detected, stop frame transmission and send a JAM signal to guarantee that everyone detects the collision
 - ⇒ Time wasted on collisions is reduced
- Wait a random amount of time before transmitting again
- Waiting time is determined by how many collisions have occurred before (exponential backoff algorithm)

Example: Ethernet

- For Ethernet networks with Hubs or using a Bus (e.g., 10Base5)
- When using switches, there is no need to use CSMA/CD
- Only applicable if nodes are able to detect collisions

Functioning of CSMA/CD (1/2)

Image Source: Wikipedia



If a network device **wants to transmit** frames via Ethernet, it ...

1 Monitors the transmission medium

- Transmission medium is idle \Rightarrow step 2
- Transmission medium is busy \Rightarrow step 3

2 Start transmission and continue to monitor the transmission medium

■ Successful transmission

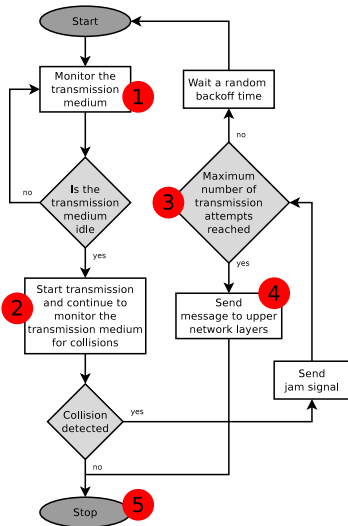
- Signal success to upper network layers \Rightarrow step 5

■ Collision is detected

- Stop frame transmission and send the 48 bits long (**jam signal**) to announce the collision \Rightarrow step 3

Functioning of CSMA/CD (2/2)

Image Source: Wikipedia



- 3 Transmission medium is **busy**. Check the number of **transmission attempts**:
 - Maximum number not yet reached
 - Wait a **random time** \implies step 1
 - The random time is calculated using the backoff method
 - Maximum number is reached \implies step 4
- 4 Error
 - Maximum number of transmission attempts reached
 - Signal error to upper network layers \implies step 5

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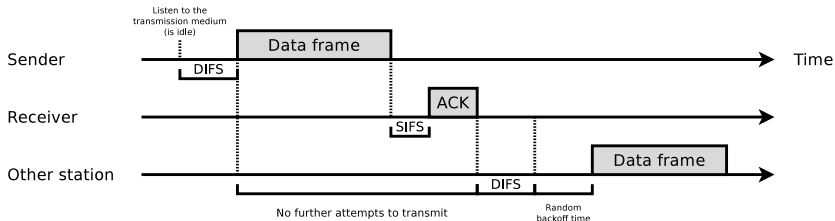
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CSMA/CA

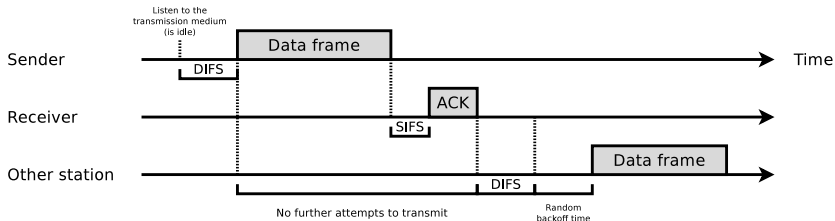
- In wireless networks collisions cannot be detected reliably
 - Sending and receiving (i.e., sensing collisions) at the same time is difficult
 - Hidden terminal problem
- ⇒ Goal: **Collision Avoidance**
- **Sender:**
 - If medium is idle for a certain amount of time slots (DIFS), transmit frame
 - If no ACK received, retransmit frame
- **Receiver**
 - Check if received frame OK (using CRC), send ACK with a short time delay (SIFS)

Functioning of CSMA/CA – 1/3



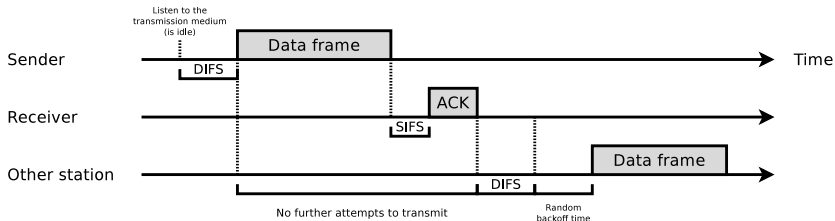
- First, the sender **listens** to the transmission medium (\implies carrier sense)
- The transmission medium needs to be **idle** for a short period
 - This period is called **Distributed Interframe Spacing (DIFS)** $\approx 50\mu s$
- If the transmission medium is idle for the duration of 1 DIFS, the station can start sending a frame

Functioning of CSMA/CA – 2/3



- If a station receives a frame, which passes the **CRC check**, it waits for a short period
 - This period is called **Short Interframe Spacing (SIFS)** $\approx 10\mu s$
 - Next, the receiver sends an **acknowledgement frame (ACK)**
- **DIFS** and **SIFS** guarantee for CSMA/CA a minimum spacing, when a sequence of frames shall be transmitted

Functioning of CSMA/CA – 3/3



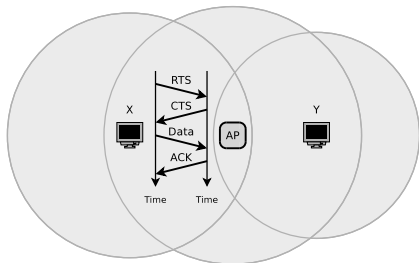
- If another DIFS with an idle transmission medium has expired, a **backoff time** is calculated
 - The backoff time is calculated by using a random value between the minimum and maximum **contention window** and multiplying this random value with the **slot time**
 - After the backoff time has expired, the frame is transmitted

Source: Grundkurs Computernetzwerke, Jürgen Scherff, Vieweg + Teubner (2010)

If during the backoff time period, another station occupies the transmission medium, the counter variable is stopped until the transmission medium is idle again for the duration of at least one DIFS.

MACA (Multiple Access with Collision Avoidance)

- CSMA/CA reduces the number of collisions, but cannot fully avoid them
- A **better collision avoidance** implements **MACA/MACAW**
 - Concept: Sender and receiver exchange **control frames** first
 - This way, all stations in the network learn that a transmission will start soon
 - Control frames: **Request To Send (RTS)** and **Clear To Send (CTS)**
 - They contain information about the occupation time of the channel

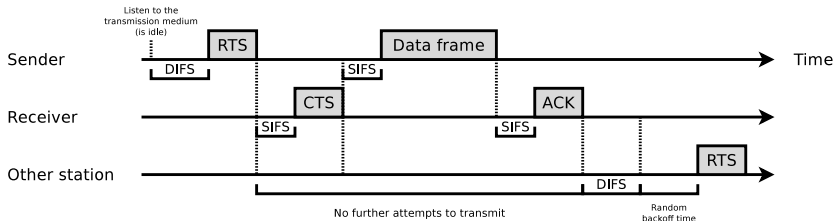


- Collisions can only occur during the transmission of RTS and CTS frames
 - Because of the hidden terminal problem

Figure on left side. . .

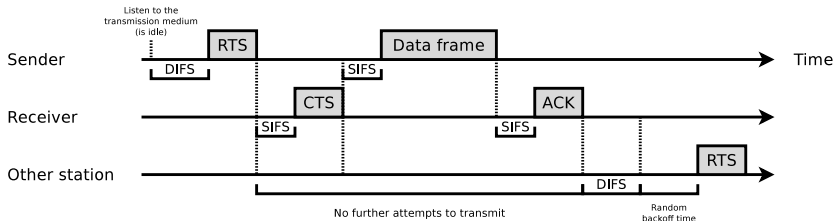
Station Y cannot receive the RTS frame from X, but the CTS frame from the Access Point

Functioning of MACA – 1/3



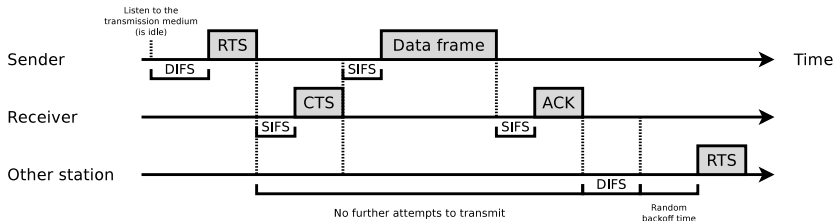
- After the DIFS, the sender transmits a **RTS** frame to the receiver
- The receiver acknowledges the reservation request by waiting the SIFS and then transmitting a **CTS** frame, which also contains the period of time, the sender wants to reserve the transmission medium

Functioning of MACA – 2/3



- After the receiver successfully received the data frame, it waits for the period of a SIFS and transmits an ACK frame to the sender
- If the transmission medium is occupied, no further station tries to transmit a frame, until the end of the **Network Allocation Vector (NAV)**
 - The NAV is a counter variable that each station manages by itself
 - Reduces the number of collisions
 - Contains the expected occupation time of the transmission medium
 - Is decremented over time, until it reaches value 0

Functioning of MACA – 3/3



Advantages

- Fewer collisions, because it solves the problem of hidden terminals
- Less energy consumption, because no transmission attempts during NAV

Drawbacks:

- The reservation of the transmission medium causes delays
- The RTS and CTS frames are overhead

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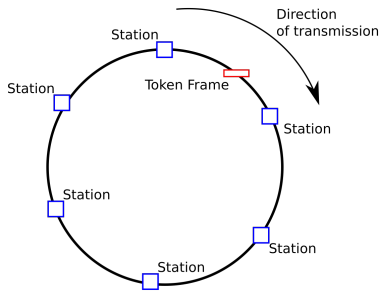
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Token Passing

- A **Token** frame is sent around the ring → defining the sending order
- Only the station that currently has the token may send
- Idea can be used without ring too, e.g., token bus



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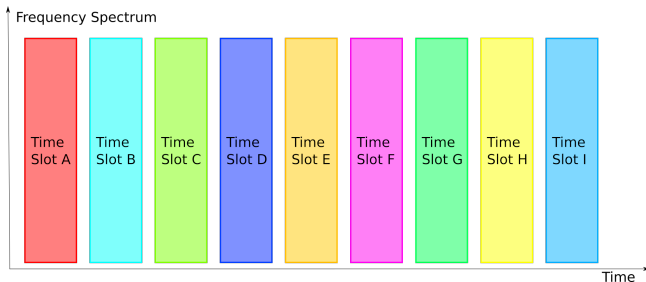
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Time Division Multiple Access (TDMA)

- Time is divided into **time slots**
- Each time slot is **assigned** to one particular host → **scheduling**
- During the time slot this host can use the full channel capacity
- The schedule can be **static** or **dynamic**
- Some time slots may be assigned for **broadcast traffic**
- Combination with contention-based MAC is possible



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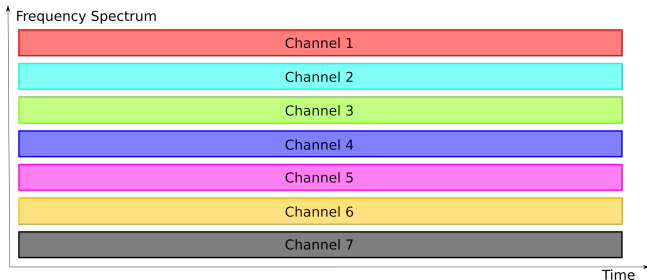
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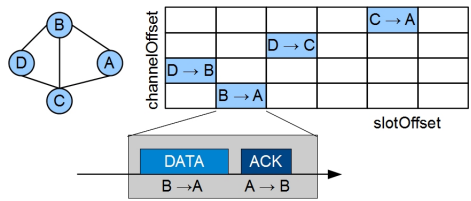
Frequency Division Multiple Access (FDMA)

- Subdivide spectrum into **sub-channels**
- **Assign** sub-channel to host or link
- **Control traffic** and **beacons** are typically sent on fixed channels
- Static vs. dynamic assignment
- → Graph coloring problem



Example: IEEE 802.15.4e

- IEEE 802.15.4 is a specification for PANs, cf. *Zigbee*
 - IEEE 802.15.4e is an amendment to the MAC layer for Time-Slotted Channel-Hopping (TiSCH)
- ⇒ Combining TDMA and FDMA



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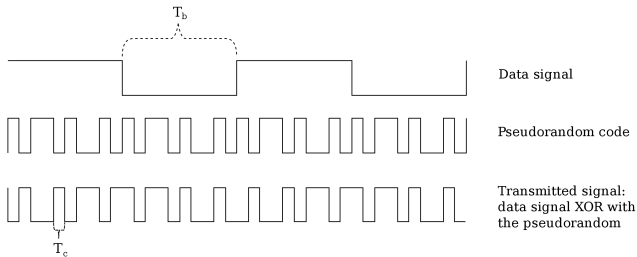
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Code Division Multiple Access (CDMA)

- Hosts can access the medium at the same time on the same frequency using different **coding schemes**
- These codes have to be **orthogonal**
- **Forward Error Correction (FEC)** can be used to restore erroneous frames



You should now be able to answer the following questions:

- Why a media access control mechanism is important?
- What is the difference between contention-based and contention-free media access?
- Which performance can ALOHA, different CSMA variants, and contention-free MAC protocols achieve?
- How can collisions be detected or avoided?

