

6th Slide Set

Computer Networks

Prof. Dr. Christian Baun

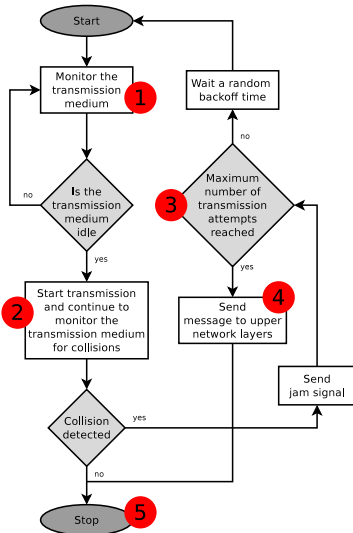
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Learning Objectives of this Slide Set

- Data Link Layer (part 3)
 - Media access control methods
 - Media access control method of Ethernet
 - Media access control method of WLAN
 - Address resolution with ARP

Functioning of CSMA/CD (1/2)

Image Source: Wikipedia

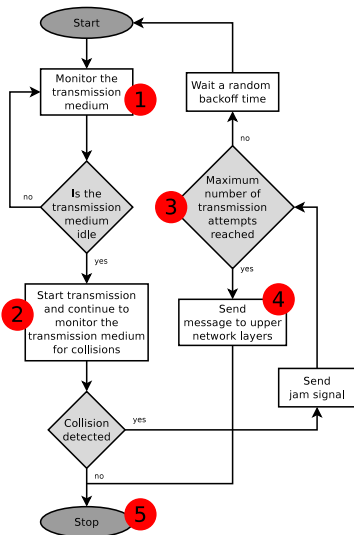


- If a network device wants to transmit frames via Ethernet, it operates according to the following sequence

- 1 Monitor the transmission medium
 - Transmission medium is idle \implies step 2
 - Transmission medium is busy \implies step 3
- 2 Start transmission and continue to monitor the transmission medium
 - Successful transmission
 - Send success message to upper network layers \implies step 5
 - Collision is detected
 - Stop frame transmission and send the 48 bits long (*jam signal*) to announce the collision \implies step 3

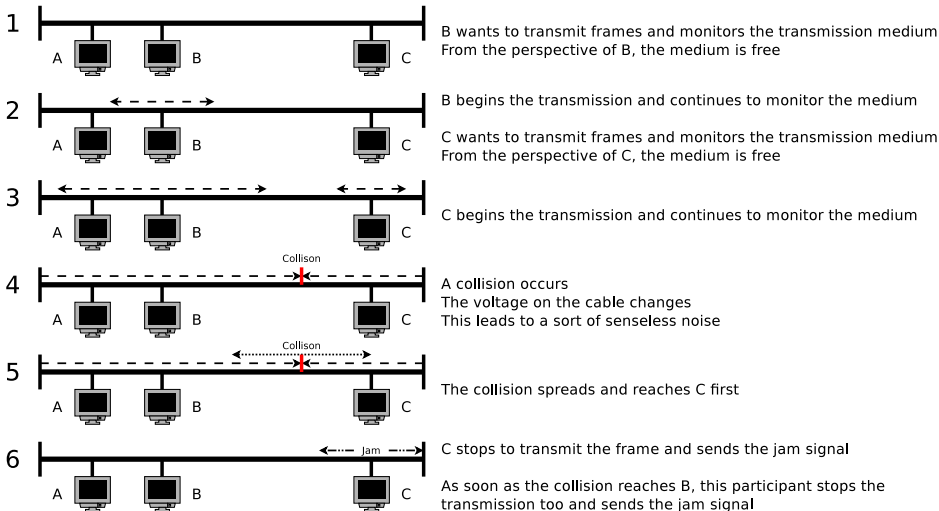
Functioning of CSMA/CD (2/2)

Image Source: Wikipedia



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

Example of CSMA/CD



Network Size and Collision Detection

- A collision must be detected by the sender
 - It is important that the transmission of a frame is **not completed** when a collision occurs
 - Otherwise, the network device might already be finished with sending the frame and assumes the transmission was successful
- Each frame must have a certain **minimum length**
 - It must be dimensioned in a way, that the transmission duration for a frame with minimum length does not fall below the maximum RTT (round trip time)
 - The RTT is the time it takes for a frame to travel from one end of the network to the most distant end and return back
 - **This ensures that a collision reaches the sender before its transmission is finished**
 - If a sender detects a collision, it knows that its frame has not arrived correctly at the receiver, and can try the transmission again later

Ethernet specifies a maximum network size and a minimum frame length

Minimum frame length for Ethernet: 64 Bytes

Maximum length of the physical network depends on the Ethernet standard used

Minimum Frame Length and Collision Detection (Example)

- Ethernet specifies a maximum network size and a minimum frame length
- The **minimum frame length**, where collision detection is still possible, is calculated as follows:

$$P = 2 * U * \frac{D}{V}$$

P = Minimum frame length in bits
 U = Data rate of the transmission medium in bits per second (bps)
 D = Network length in meters
 V = Signal speed on the transmission medium in meters per second

- Calculation example for 10BASE5 with 10 Mbps and coaxial cables:

- $U = 10 \text{ Mbps} = 10,000,000 \text{ bps}$
- $D = 2,500 \text{ meters}$ (this is the maximum length for 10BASE5)
- $V = \text{speed of light} * \text{velocity factor}$
 - Speed of light = 299,792,458 m/s
 - Velocity factor = 0.77 for coaxial cables
 - $V = 299,792,458 \text{ m/s} * 0.77 \approx 231,000,000 \text{ m/s}$

$$P = 2 * 10 * 10^6 \text{ bps} * \frac{2,500 \text{ m}}{231 * 10^6 \text{ m/s}} \approx 217 \text{ bits} \approx 28 \text{ bytes}$$

- Outcome: The minimum frame length of 64 bytes for Ethernet is more than enough

Velocity Factor (Wave Propagation Speed)

- The **velocity factor**, also called wave propagation speed, depends on transmission medium and is:
 - 1 for vacuum
 - 0.64 for twisted pair cables Cat-5e
 - 0.65 – 0.66 for coaxial cables RG-58 (\implies Ethernet 10BASE2)
 - 0.67 for optical fiber
 - 0.77 – 0.78 for coaxial cables RG-8 (\implies Ethernet 10BASE5)
- Describes the speed of a signal on a transmission medium relative to the speed of light

Sources

- Kaiser, Kenneth L. (2005). *Transmission Lines, Matching, and Crosstalk*. CRC Press. P. 2–24.
- Renesas (2020). *How to Determine the Length and Characteristic Impedance of a Data Transmission Cable*
<https://www.renesas.com/us/en/document/apn/r15an0004-how-determine-length-and-characteristic-impedance-data-transmission-cable-rev100>

Network Size and Collision Detection (Example)

- The **maximum network size**, where collision detection is still possible, is calculated as follows:

$$2 * S_{max} = V * t_{frame}$$

S_{max} = Maximum network size with collision detection
 V = Signal speed of the transmission medium in meters per second (mps)
 t_{frame} = transmission duration of a frame in seconds

- Calculation example for 10BASE5 with 10 Mbps and coaxial cables:
 - $V = 231,000,000 \text{ m/s} = 231 * 10^6 \text{ m/s}$
 - Transmission duration t_{frame} = Transmission duration for a single bit, multiplied with the number of bits in a frame ($\implies 512 \text{ Bits} = 64 \text{ Bytes}$)
 - The transmission duration for a single bit at 10 Mbps is 0.1 microseconds
 - A frame with the minimum frame length of 64 Bytes requires $51.2 \mu\text{s}$ for its complete transmission
 - A $51.2 \mu\text{s}$ long frame travels in the coaxial cable the following distance:

$$231 * 10^6 \frac{\text{m}}{\text{s}} * 51.2 * 10^{-6} \text{ s} = 11,827.20 \text{ m} = 11.83 \text{ km}$$
 - Outcome: With a maximum network size of 2.5 km collision detection is possible

CSMA/CD nowadays

- The media access method **CSMA/CD** is **absolutely necessary** only for Ethernet networks, which implement the **bus network topology**
 - Reason: In a bus network topology, all network devices are directly connected to a shared transmission medium
- Almost all Ethernet-based networks nowadays are **fully switched networks** and therefore **collision-free**

Media Access Control Method CSMA/CA of WLAN

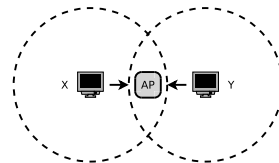
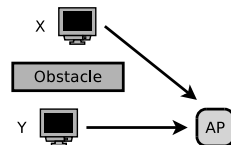
- CSMA/CD cannot be used with wireless networks
- With CSMA/CD, the sender detects occurring collisions
 - In wired networks with a shared transmission medium, each participant receives the transmissions of all other nodes
 - Therefore, each node detects any collision
 - For wireless networks like WLAN, this is not always the case
 - Therefore, the media access method *Carrier Sense Multiple Access / Collision Avoidance* (CSMA/CA) is used, which tries to **minimize** the occurrence of collisions
- Special challenges of the transmission medium in wireless networks cause undetected collisions at the receiver
 - **Hidden terminal problem**
 - **Fading**

PowerLAN / Powerline also uses CSMA/CA as media access method

Source: Analysis of CSMA/CA used in Power Line Communication. *Martin Koutny, Petr Mlynek, Jiri Misurec*. IEEE (2013)

Special Characteristics of the Transmission Medium

- **Hidden terminal problem** (caused by invisible/hidden terminal device)
 - X and Y both send frames to the Access Point
 - Because of obstacles, the stations X and Y can not detect each other's transmissions, although they interfere at the Access Point
- **Fading** (decreasing signal strength)
 - X and Y both send frames to the Access Point
 - The electromagnetic waves are weakened by obstacles and in free space
 - Caused by the positions of X and Y to each other, their signals are so weak, that the stations cannot detect each others transmissions



Source: Computernetzwerke, *James F. Kurose, Keith W. Ross*, Pearson (2008)

WLAN (802.11) implements 3 different Media Access Control Methods

① CSMA/CA

- Strategy: *Listen before talk*
- Collision avoidance via random backoff time
- Minimum spacing between frames, when a sequence of frames shall be transmitted
- Acknowledgements – ACK (not for broadcast)
- Default method which is implemented in all WLAN devices

② CSMA/CA RTS/CTS (Request To Send/Clear To Send)

- Solves the problem of hidden terminals
- Optional method and implemented in most WLAN devices

③ CSMA/CA PCF (Point Coordination Function)

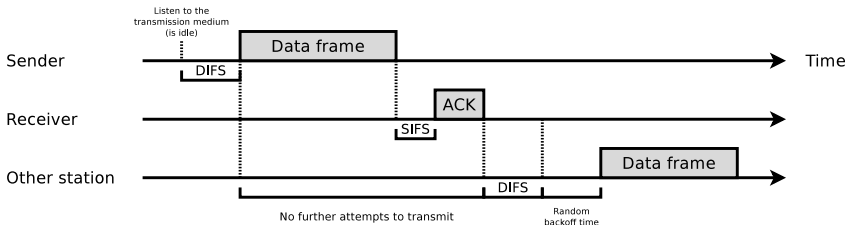
- Access Point controls the access to the transmission medium
- Optional method and seldom implemented

Source: Lecture slides of Prof. Dr. Michael Massoth and Wikipedia

Transmission of Frames

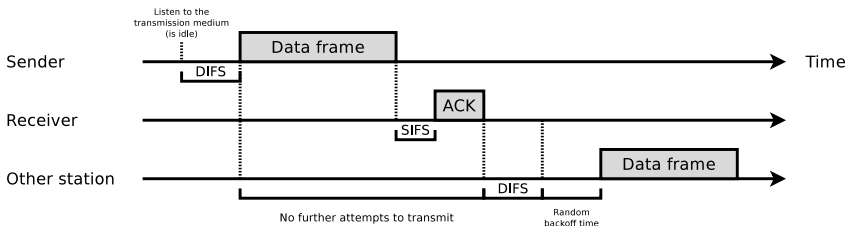
- If a node, which transmits frames, detects a collision via CSMA/CD (Ethernet), it aborts the transmission of the frame
- WLAN does not use collision detection, but with CSMA/CA it implements **collision avoidance** (actually it is just a **collision minimization**)
 - If a station starts transmitting a frame, it will send the entire frame in any case
 - Once a station has started transmitting, there is no turning back
 - The sender must therefore be able to detect if a frame has not arrived correctly at the receiver
 - Solution: The receiver confirms by **ACK** that the frame was received correctly

Functioning of CSMA/CA – 1/5



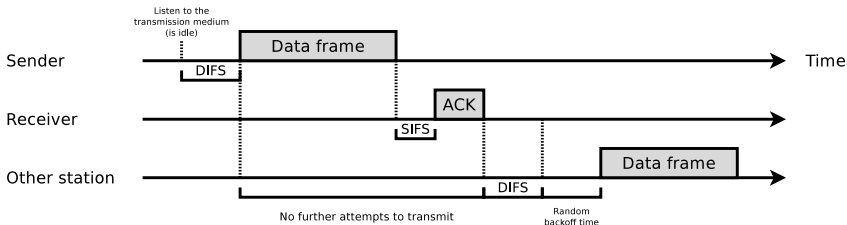
- First, the sender *listens* to the transmission medium (\implies carrier sense)
- The transmission medium needs to be idle for a short period
 - This period is called **Distributed Interframe Spacing (DIFS)** $\approx 50\mu s$
- If the transmission medium is idle for the duration of 1 DIFS, the station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

Functioning of CSMA/CA – 2/5



- 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 – 3/5



- 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.

Functioning of CSMA/CA – 4/5

Modulation method	SIFS	DIFS ¹	Slot Time	Minimal CW	Maximum CW
FHSS (802.11)	28 μ s	128 μ s	50 μ s	15	1023
DSSS (802.11b)	10 μ s	50 μ s	20 μ s	31	1023
OFDM (802.11a/h/n/ac)	16 μ s	34 μ s	9 μ s	15	1023
OFDM (802.11g) ²	16 μ s	34 μ s	9 μ s	15	1023
OFDM (802.11g) ³	10 μ s	50 μ s	20 μ s	15	1023

¹ DIFS = SIFS + 2 * Slot Time

² Supports data rates 1-54 Mbps

³ Supports only data rates > 11 Mbps

- Minimum CW, maximum CW and slot time depend on the modulation method used and are fixed
- The minimum and maximum CW values are always a power of 2, and from the result, value 1 is subtracted
 - If a WLAN uses e.g. the modulation method OFDM...
 - at the 1st attempt to transmit, the CW is ≥ 15 and ≤ 31
 - at the 2nd attempt to transmit, the CW is ≥ 31 and ≤ 63
 - at the 3rd attempt to transmit, the CW is ≥ 63 and ≤ 127

Functioning of CSMA/CA – 5/5

Modulation method	SIFS	DIFS ¹	Slot Time	Minimal CW	Maximum CW
FHSS (802.11)	28 μ s	128 μ s	50 μ s	15	1023
DSSS (802.11b)	10 μ s	50 μ s	20 μ s	31	1023
OFDM (802.11a/h/n/ac)	16 μ s	34 μ s	9 μ s	15	1023
OFDM (802.11g) ²	16 μ s	34 μ s	9 μ s	15	1023
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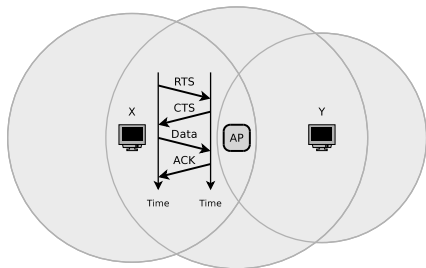
³ Supports only data rates > 11 Mbps

- Further transmission attempts cause the CW to rise exponentially until the maximum value is reached
- As soon as a transmission of a frame was successful and the frame has been acknowledged via ACK, the lower bound of the CW is set to the minimum CW value in the table

Source: Wireless LANs, Jörg Rech, Heise (2012)

CSMA/CA RTS/CTS

- CSMA/CA reduces the number of collisions
 - But it cannot avoid all collisions
- A **better collision avoidance** implements CSMA/CA RTS/CTS
 - 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)**
 - Both control frames contain a field, which indicates how long the transmission medium (the channel) will be occupied (see slides 28 + 29)

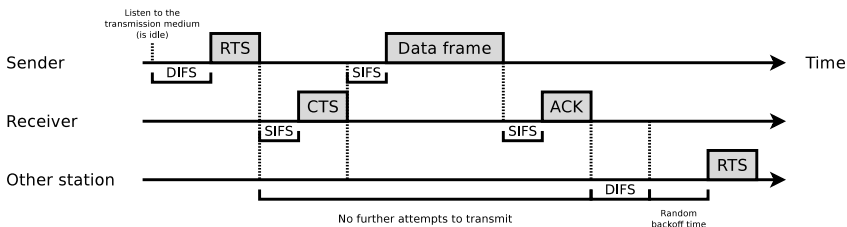


- Collisions can only occur during the transmission of RTS and CTS frames
 - Because of the hidden terminal problem

Figure on left side. . .

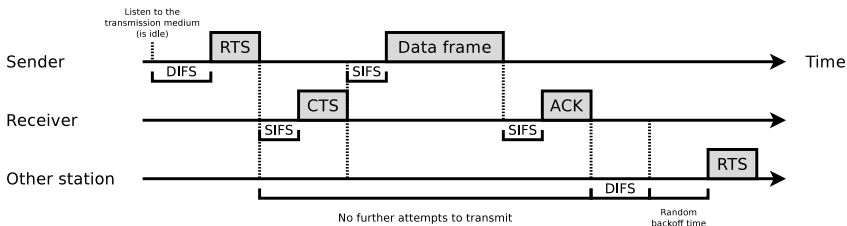
Station Y cannot receive the RTS frame from X, but the CTS frame from the Access Point

Functioning of CSMA/CA RTS/CTS – 1/3



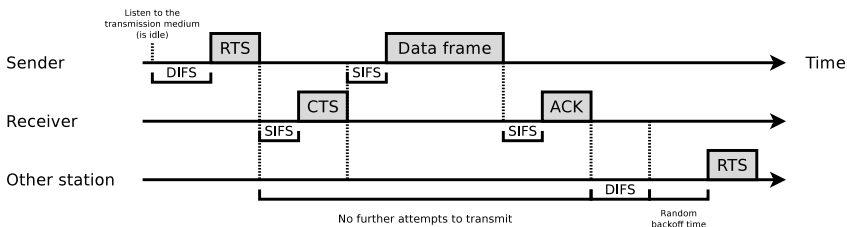
- After the DIFS, the sender transmits a **RTS** frame to the receiver
 - The RTS frame contains a field, which specifies the period, the sender wants to reserve (use) the transmission medium (the channel) to transmit the frame
- The receiver acknowledges the reservation request by waiting for the SIFS and then transmitting a **CTS** frame, which also contains the period of time, the sender wants to reserve the transmission medium
 - The receiver confirms this way the period which is required to transmit the data frame

Functioning of CSMA/CA RTS/CTS – 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 (the channel) 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 CSMA/CA RTS/CTS – 3/3



• Advantages

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

• Drawbacks:

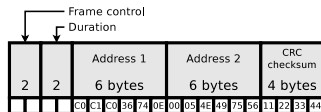
- The reservation of the transmission medium causes **delays**
- The RTS and CTS frames are **overhead**

WLAN Control Frames (Special Frames) – RTS Frame

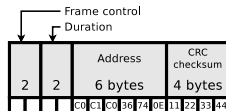
The control frames RTS, CTS and ACK have a different structure compared with data frames

- Length of **RTS frames**: 20 bytes
- With the RTS frame, a station, which wants to transmit frames, **sends a reservation request** for the transmission medium to the Access Point
- 1st address field = MAC address of the Access Point
- 2nd address field = MAC address of the station, which sends the request

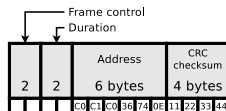
RTS frame



CTS frame



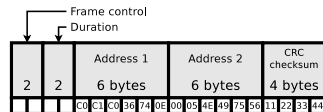
ACK frame



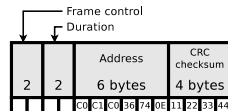
WLAN Control Frames (Special Frames) – CTS Frame

- Length of **CTS frames**: 14 bytes
- With a CTS frame, an Access Point **confirms the reservation request** for the transmission medium
- address = MAC address of the station, which sent the reservation request

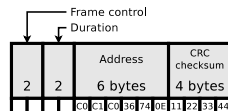
RTS frame



CTS frame



ACK frame



CSMA/CA PCF

- **PCF = Point Coordination Function**
- The Access Point controls the media access
 - It requests the registered stations to transmit payload frames
 - The approach is called **polling**
- CSMA/CA PCF is an optional method and seldom implemented
 - For this reason, it is not discussed here in detail

