Wireless Mesh and Vehicular Networks

802.11MAC Fundamentals

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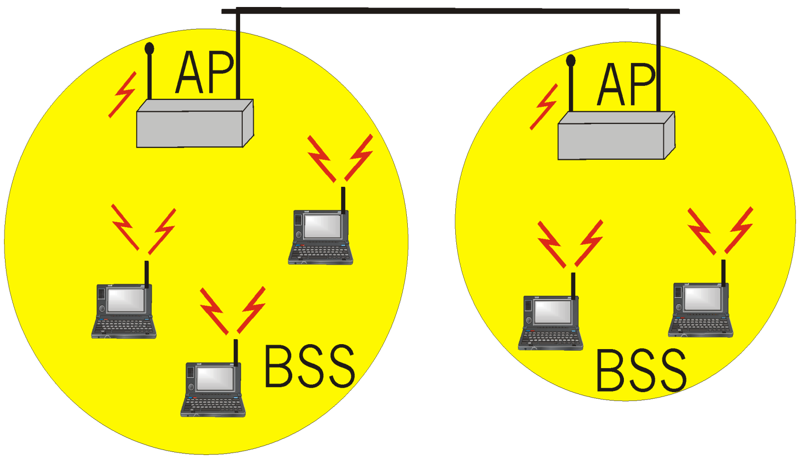
IEEE 802.11

- Wireless LAN standard specifying a wireless interface between a client and a base station (or access point), as well as between wireless clients
- Defines the PHY and MAC layer (LLC layer defined in 802.2)
- Physical Media: radio or diffused infrared (not used)
- Standardization process begun in 1990 and is still going on (1st release ’97, 2nd release ’99, then ’03, ’05, ... ‘12)

802.11 Architecture

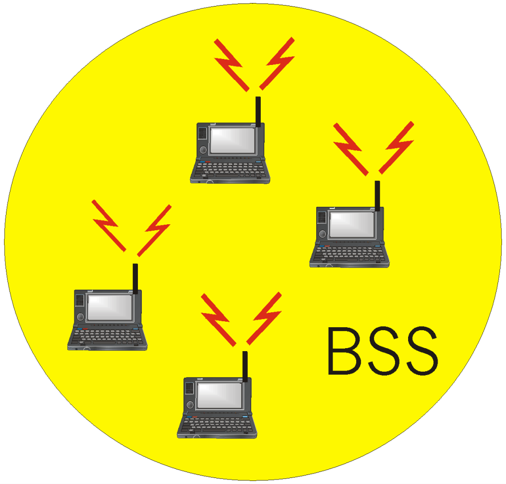
- BSS (Basic Service Set): set of nodes using the same coordination function to access the channel
- BSA (Basic Service Area): spatial area covered by a BSS (WLAN cell)
- BSS configuration mode
  - ad hoc mode
  - with infrastructure: the BSS is connected to a fixed infrastructure through a centralized controller, the so-called Access Point (AP)

- BSS contains:
  - wireless hosts
  - access point (AP): base station
- BSS's interconnected by distribution system (DS)



Ad Hoc WLANs

- Ad hoc network: IEEE 802.11 stations can dynamically form a network *without* AP and communicate directly with each other: IBSS Independent BSS
- Applications:
  - Vehicular Networks
  - Meeting in conference room
  - Interconnection of “personal” devices
  - Battlefield
  - ....
- IETF MANET (Mobile Ad hoc Networks) working group; VANET; V2V; V2X; ...

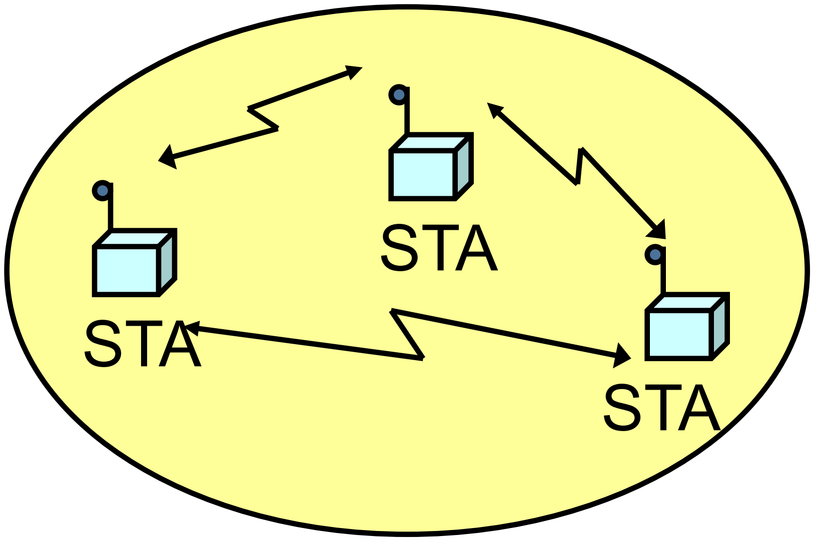


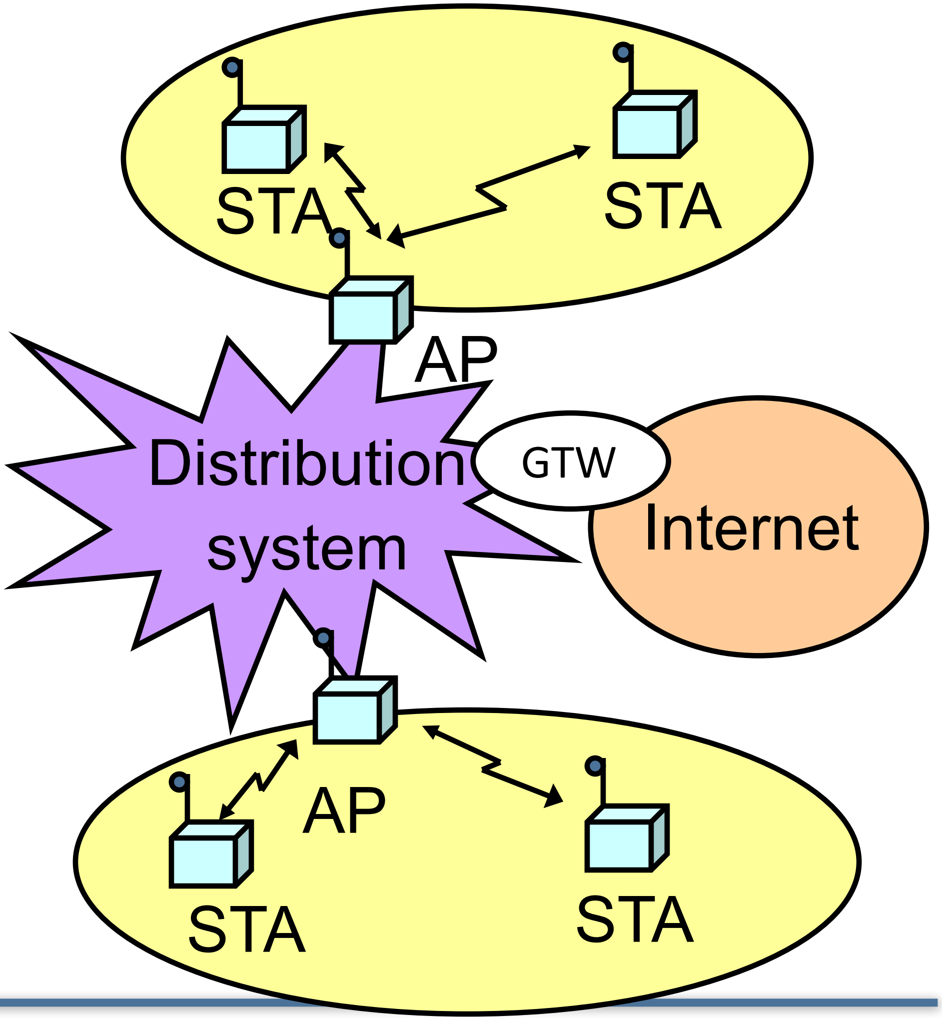
Extended Service Set (ESS)

- Several BSSs interconnected with each other at the MAC layer
- The backbone interconnecting the BSS APs (Distribution System) can be a:
  - LAN (802 family)
  - wired MAN
  - IEEE 802.11 WLAN, possibly meshed (a large part of our course)
- An ESS can give access to the fixed Internet network through a gateway node

Possible Scenarios (1)

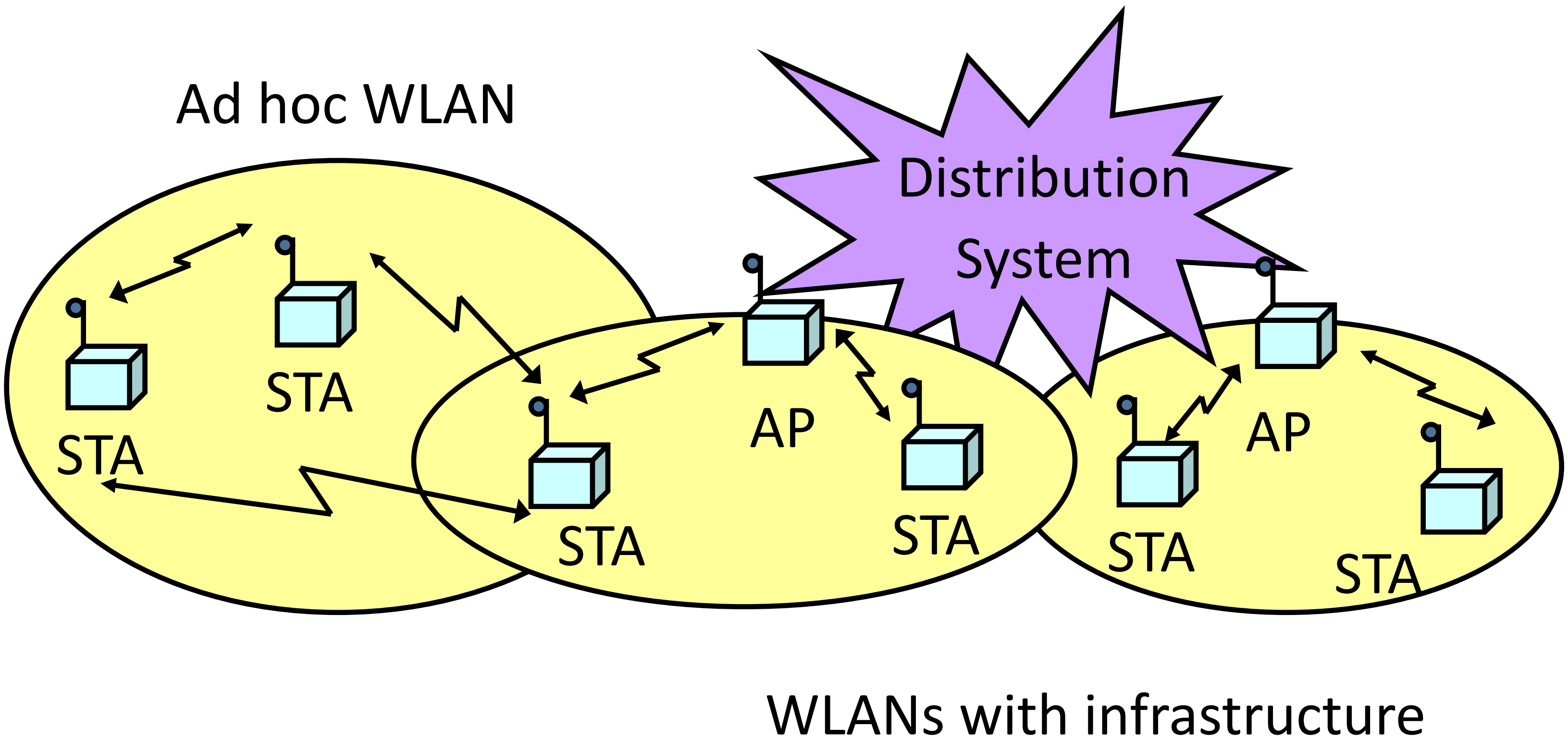
Ad hoc networking
Independent BSS (IBSS)





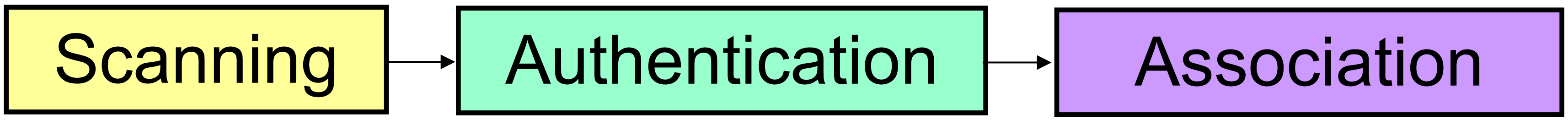
Network with infrastructure

Possible Scenarios (2)



Forming a BSS

- Between the PHY/MAC and the 802.2 LLC (or IP) there are additional functions for registering one interface to the others
  - With infrastructured systems we say to “join a BSS/AP”
- Without proper association a network is not formed and STA do not communicate
  - Exception: 802.11p → Vehicular Networks



- BSS with AP: Both authentication and association are necessary for joining a BSS

- Independent BSS: Neither authentication neither association procedures are mandatory or specified in the standard an IBSS → ad-hoc, proprietary, none

Scanning

A station willing to join a BSS must get in contact with the AP. This can happen through:

1. Passive scanning
   - The station scans the channels for a Beacon frame that is periodically (100ms) sent by every AP
2. Active scanning (the station tries to find an AP)
   - The station sends a ProbeRequest frame on a given channel
   - All AP's within reach reply with a ProbeResponse frame

- Active Scanning may be more performing but waste resources

Passive Scan

- Beacons are broadcast frames transmitted periodically (default 100ms). They contain:
  - Timestamp
  - TBTT (Target Beacon Transmission Time) – also called Beacon Interval
  - Capabilities
  - SSID (BSSID is AP MAC address + 26 optional octets)
  - PHY layer information
  - System information (Network, Organization, …)
  - Information on traffic management if present
  - …
- STA answer to beacons with a ProbeResponse containing the SSID

Active Scan

- **Directed probe**: The client sends a probe request with a specific destination SSID; only APs with a matching SSID will reply with a probe response
  - It is often considered "secure" if APs do not broadcast SSIDs and only respond to Directed Probes …
- **Broadcast probe**: The client sends a null SSID in the probe request; all APs receiving the probe-request will respond with a probe-response for each SSID they support
  - Useful for service discovery systems

Authentication

Once an AP is found/selected, a station goes through authentication

- Open system authentication
  - Station sends authentication frame with its identity
  - AP sends frame as an ack / nack
- Shared key authentication (WEP)
  - Stations receive shared secret key through secure channel independent of 802.11
  - Stations authenticate because they use the secret key (weak)
- Per Session Authentication (WPA2)
  - Encryption is AES
  - The key can be shared (home networks) or user-based (enterprise)
  - Encryption is always per-station plus one for broadcast

Association

Once a station is authenticated, it starts the association process, i.e., information exchange about the AP/station capabilities and roaming

- STA → AP: AssociateRequest frame
- AP → STA: AssociationResponse frame
- In case of Roaming: New AP informs old AP via DS

- Only after the association is completed, a station can transmit and receive data frames

Performs the following functions:

- Resource allocation
- Data segmentation and reassemby
- MAC Protocol Data Unit (MPDU) addressing
- MPDU (frame) format
- Error control

MAC Frames

Three frame types are defined

1. **Control:** positive ACK, handshaking for accessing the channel (RTS, CTS)
2. **Data Transfer:** information to be transmitted over the channel
3. **Management:** connection establishment/release, synchronization, authentication.
   Exchanged as data frames but are not reported to the higher layer

Data Transfer

- Asynchronous data transfer for best-effort traffic
  - DCF (Distributed Coordination Function)
  - Coordination is done through Inter Frame Spaces
- Synchronous data transfer for real-time traffic (like audio and video)
  - PCF (Point Coordination Function): based on the polling of the stations and controlled by the AP (PC)
  - Its implementation is optional, not really implemented in devices, but custom implementations are used for P-t-P links

Coordination

- The system is semi-synchronous
    - Maintained through Beacon frames (sent by AP)
- Time is counted in intervals called slots
- A slot is the system unit time
    - its duration depends on the implementation of the physical layer and specifically on the
    - 802.11b: 20μs
    - 802.11a/h/g/n/ac: 9μs
        - g/n are forced to use 20 when coexisting with b

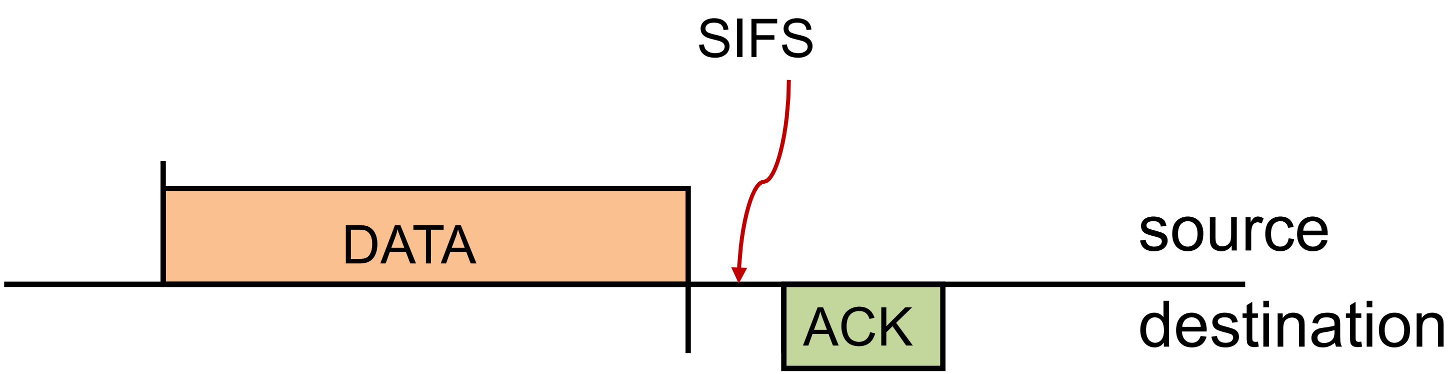
Inter Frame Spaces – IFS

- Interframe space (IFS)
  - time interval between frame transmissions
  - used to establish priority in accessing the channel
- 4 types of IFS:
  - Short IFS (SIFS)
  - Point coordination IFS (PIFS) > SIFS
  - Distributed IFS (DIFS) > PIFS
    - AIFS(c) for Quality Enabled MAC, different for different traffic classes
  - Extended IFS (EIFS) > DIFS
- Duration depends on physical level implementation

Short IFS (SIFS)

- Separates transmissions belonging to the same dialogue
- Gives the highest priority in accessing the channel
- Its duration depends on:
  - Propagation time over the channel
  - Time to convey the information from the PHY to the MAC layer
  - Radio switch time from TX to RX mode
  - 2.4GHz: 10μs
  - 5.5GHz: 16μs

- An exchange of frames that follows a successful contention for the channel
  - E.g.: a data frame followed by and ACK



Point Coordination IFS (PIFS)

- Used to give priority access to Point Coordinator (PC) → Normally the AP
- Only a PC can access the channel between SIFS and DIFS
- PIFS=SIFS + 1 time slot

Distributed IFS (DIFS)

- Used by stations waiting to start a contention (for the channel)

- Set to: PIFS + 1 time slot

  - 802.11b: 50μs
  - 802.11a/h/g/n/ac: 34μs

Extended IFS (EIFS)

- Used by every station when the PHY layer notifies the MAC layer that a transmission has not been correctly received
- Avoids that stations with bad channels disrupt other stations' performance
- Forces fairness in the access if one station does not receive an ACK (e.g., hidden terminal)
- Reduce the priority of the first retransmission (indeed make it equal to all others)
- Set to: DIFS + 1 ACK time

DCF Access Scheme

Basic Characteristics

- Based on the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) scheme:
  - Stations that have data to transmit contend for accessing the channel
  - A station has **to repeat** the contention procedure **every time** it has a data frame to transmit
  - What is Collision Avoidance? → Answer later

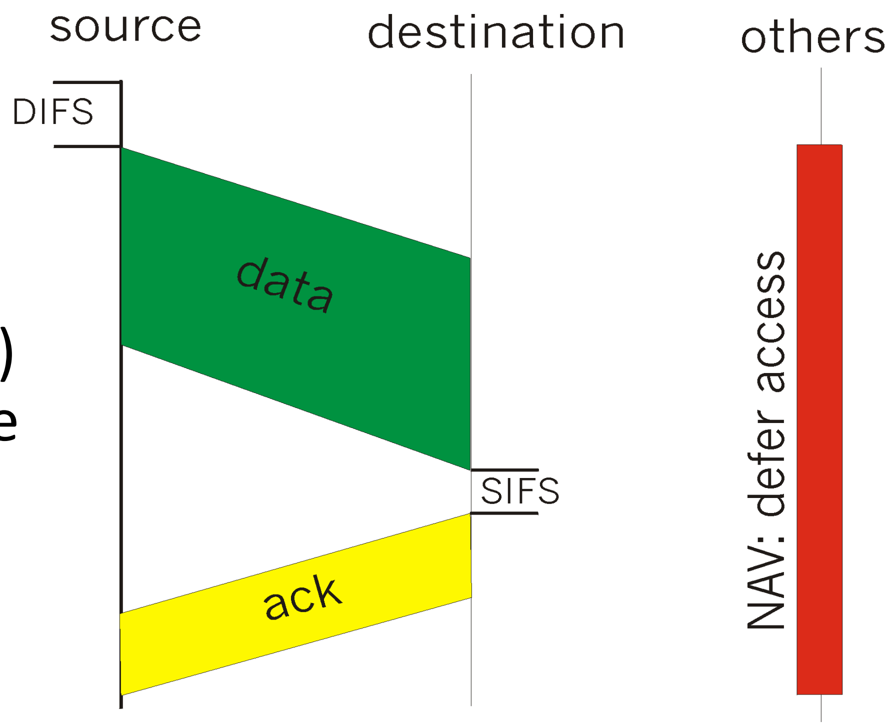
802.11 CSMA sender:

- if sense channel idle for **DISF** sec.

  then transmit frame

- if sense channel busy

  then random access over a contention window CWmin (CA) when the channel becomes free



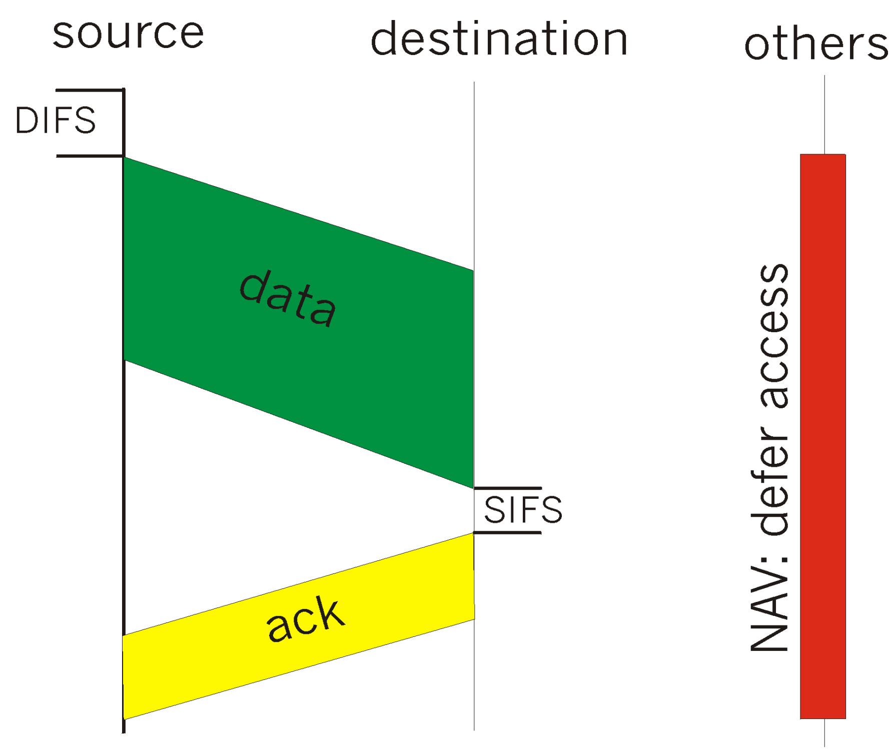
802.11 CSMA receiver:

if received OK

return ACK after **SIFS**

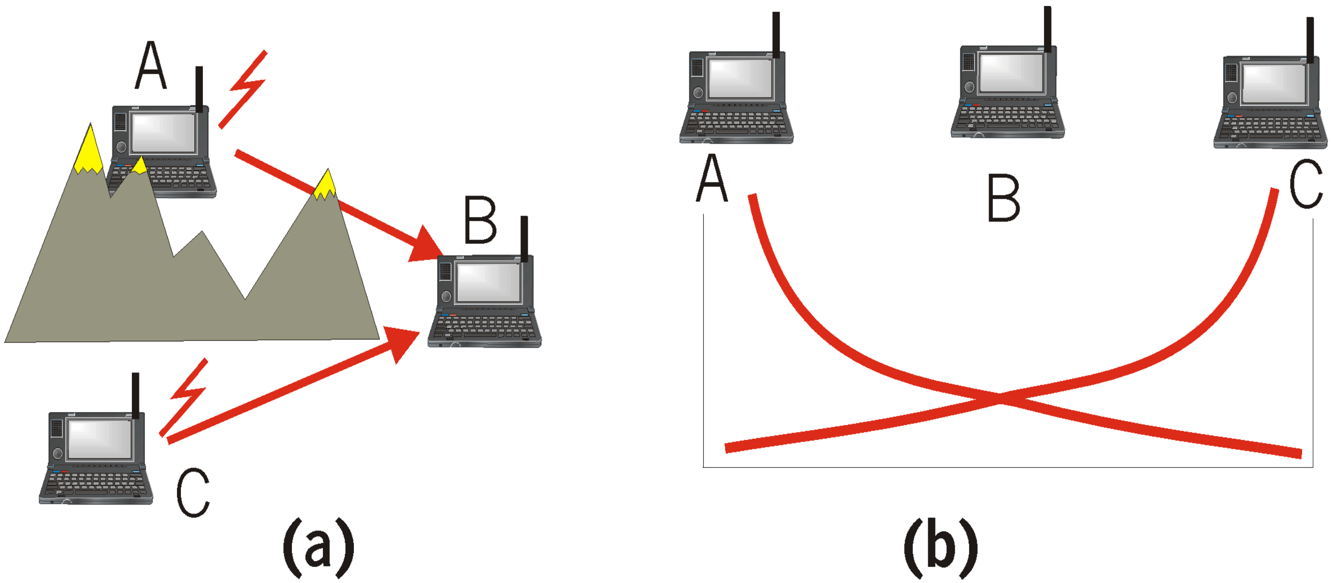
802.11 CSMA Protocol others:

- **NAV**: Network Allocation Vector
  - transmission length field
  - others (hearing data) defer access for NAV time units
  - NAV is contained in the header of **all** frames
  - Allows reducing energy consumption
  - Helps reducing hidden terminals problems



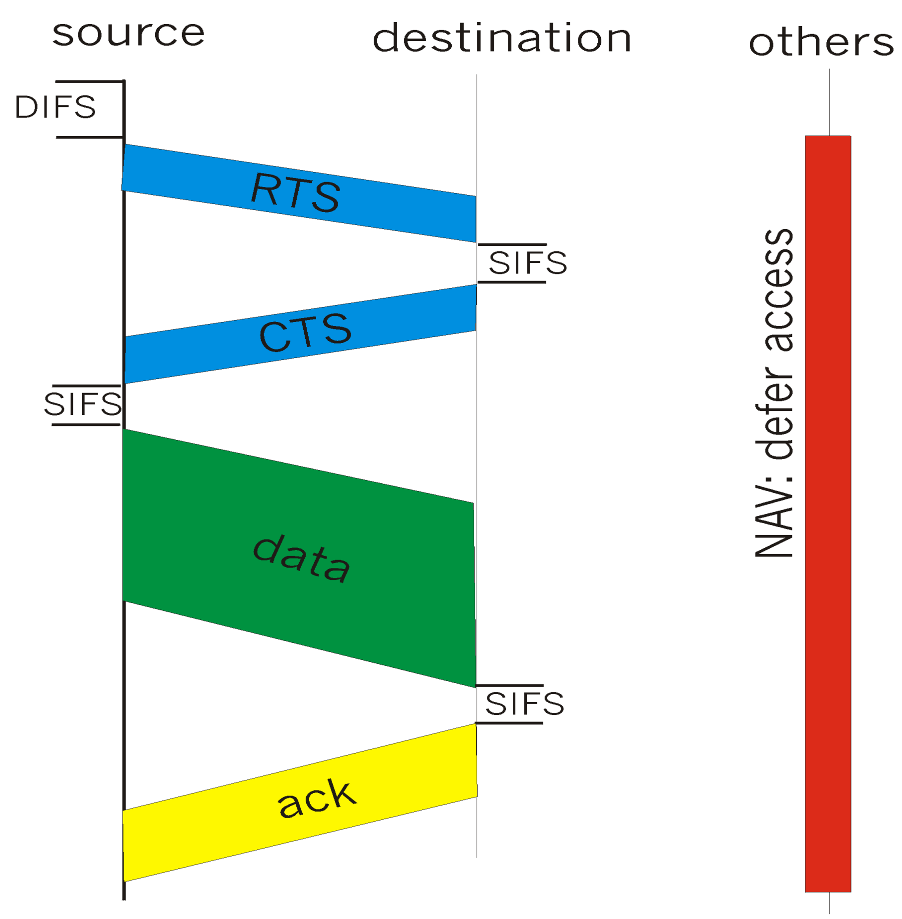
Hidden Terminal Effect

- hidden terminals: **A, C cannot hear each other**
  - obstacles, signal attenuation → (deterministic) collisions at B
- goal: avoid collisions at B
- **CSMA/CA with handshaking**



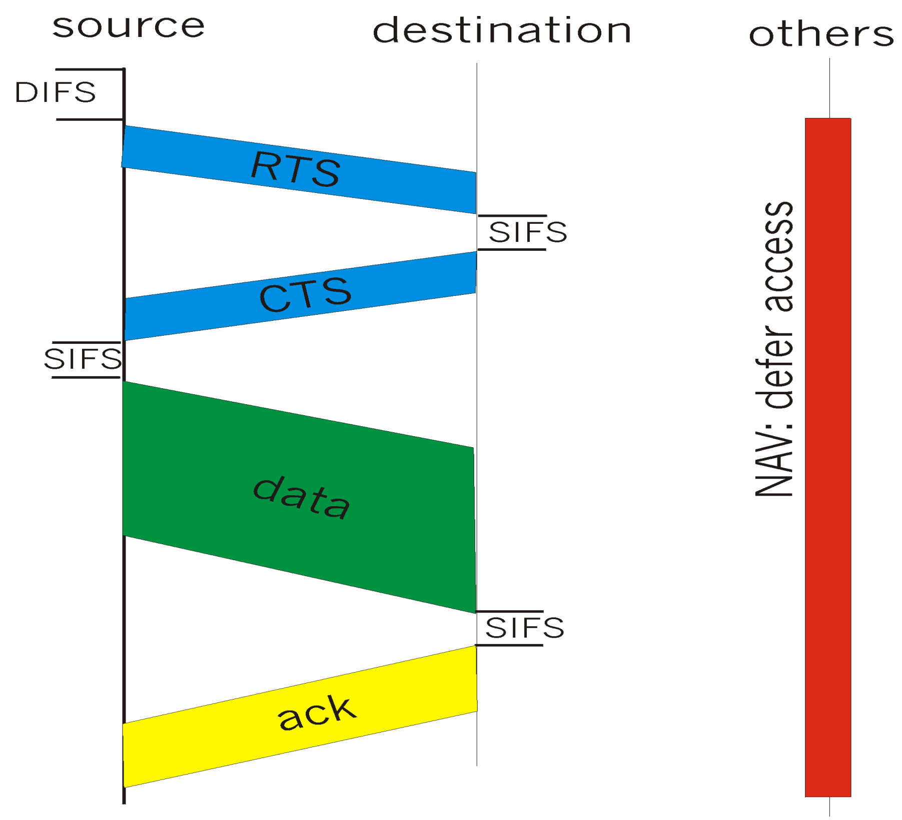
MAC Handshaking

- CSMA/CA: explicit channel reservation
  - sender: send short RTS (request to send)
  - receiver: reply with short CTS (clear to send)
- CTS reserves channel for sender, notifying (possibly hidden) stations
- reduces hidden station collisions
- increase overhead

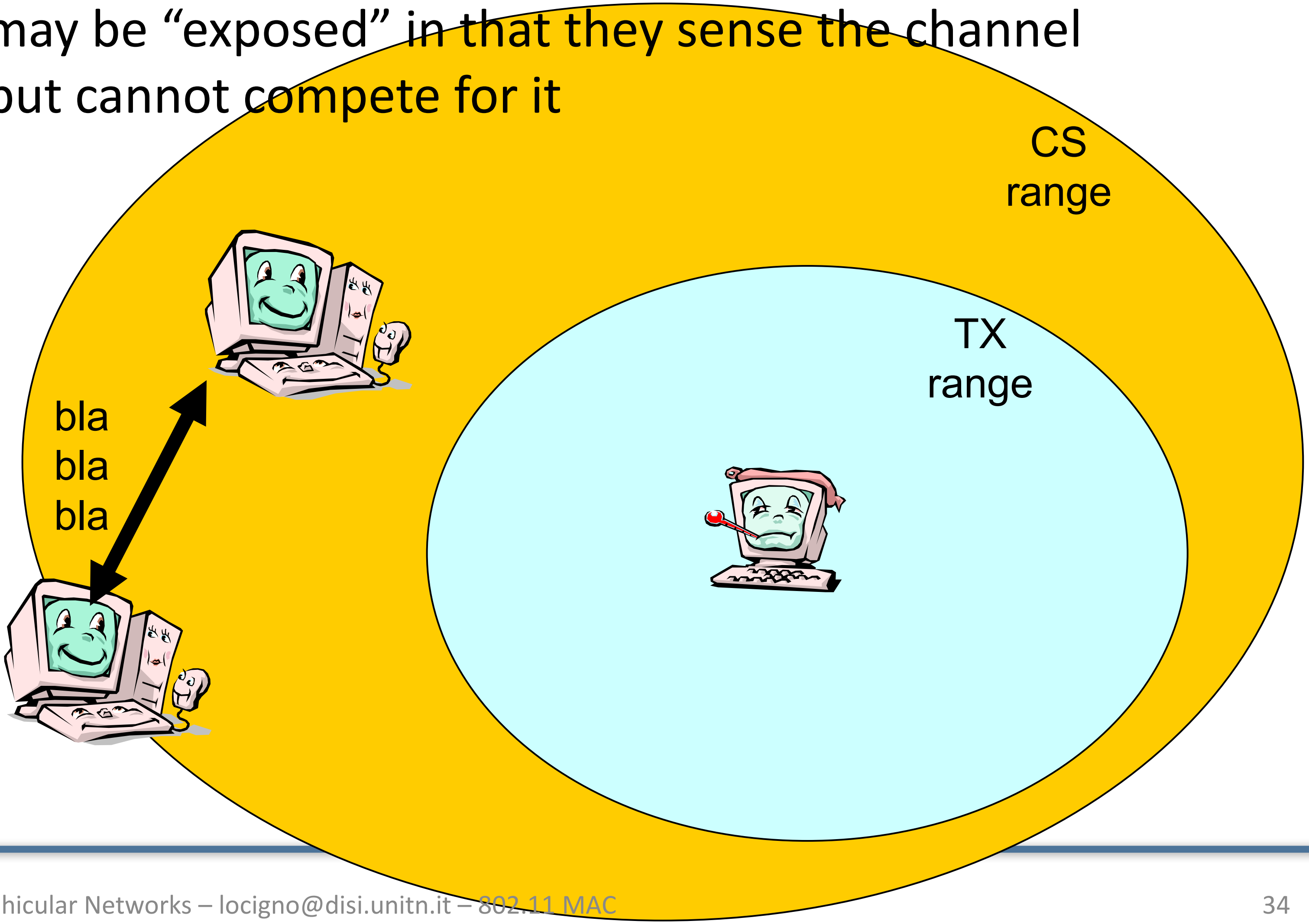


MAC Handshaking

- RTS and CTS are short:
  - collisions of shorter duration, hence less "costly"
- DCF allows:
  - CSMA/CA
  - CSMA/CA with handshaking



- Sensing range is normally larger than receiving range
- Terminals may be "exposed" in that they sense the channel occupied, but cannot compete for it



DCF
Basic & Enhanced Access Mode

Carrier Sensing

- Used to determine whether the channel is busy or idle
- Performed at the physical layer (physical carrier sensing) and at the MAC layer (virtual carrier sensing)
  - Physical carrier sensing: detection of nearby energy sources
  - Virtual carrier sensing: the frame header indicates the remaining duration of the current Channel Access Phase (till ACK is received) → NAV

- Used by the stations nearby the transmitter to store the duration of the dialogue that is occupying the channel
- The channel will become idle when the NAV expires
- Upon the NAV expiration, stations that have data to transmit sense to the channel again

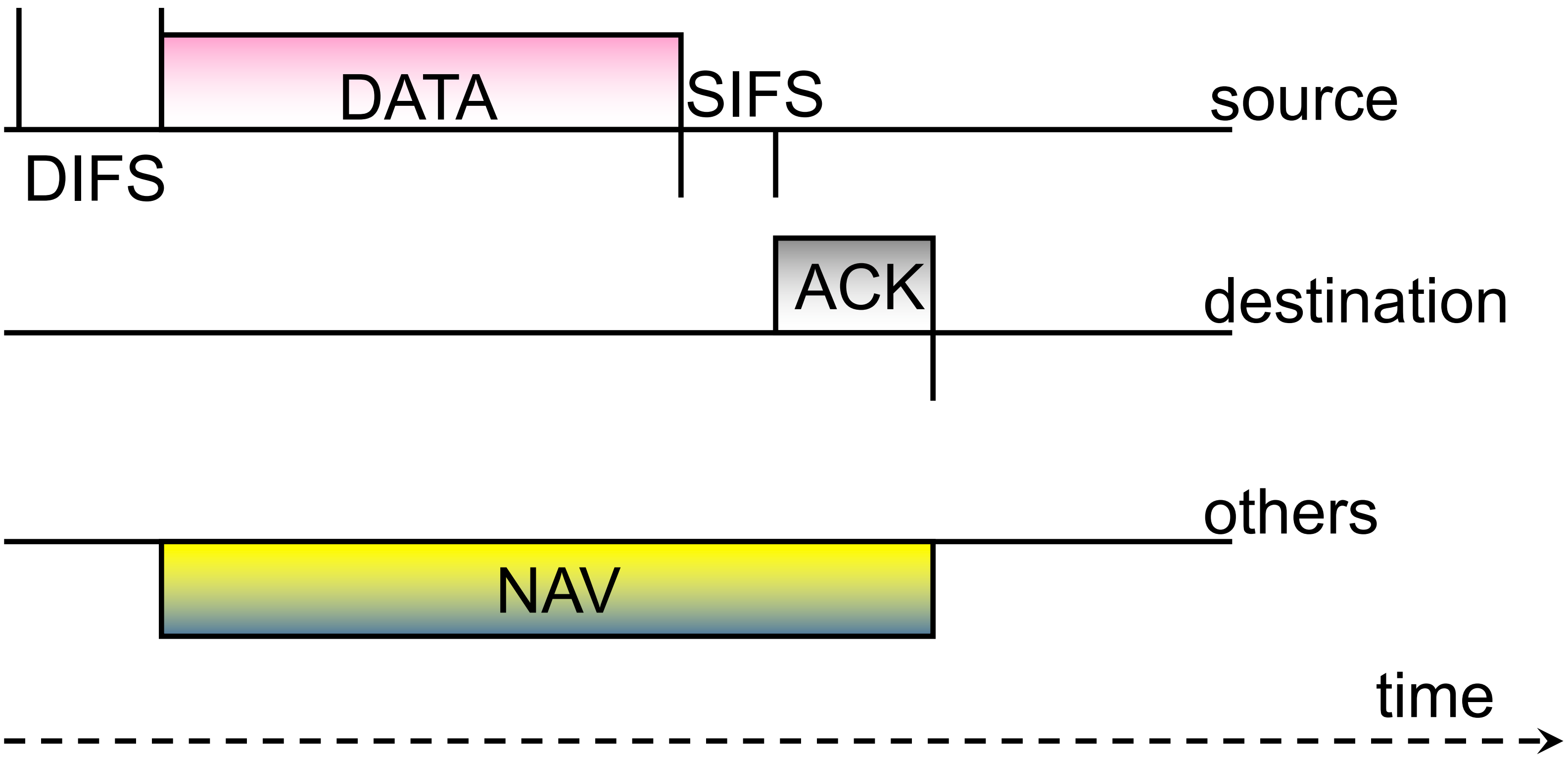
Using DIFS and SIFS

- Transmitter:
  - sense the channel
  - if the channel is idle, wait a time equal to DIFS
  - if the channel remains idle for DIFS, transmit MPDU
- Receiver:
  - compute the checksum verifying whether the transmission is correct
  - if so, it sends an ACK after a time equal to SIFS
  - ACK is only a header with a Tx rate less than or equal to the one used by the transmitter and no larger than
    - 2 Mbit/s in 802.11b
    - 6/12 Mbit/s in 802.11g/a/h/n/ac

Using DIFS and SIFS

- Neighbors:
  - set their NAV to the value indicated in the transmitted MPDU
  - NAV set to: the MPDU tx time + 1 SIFS + ACK time

MPDU Transmission



Frame Retransmissions

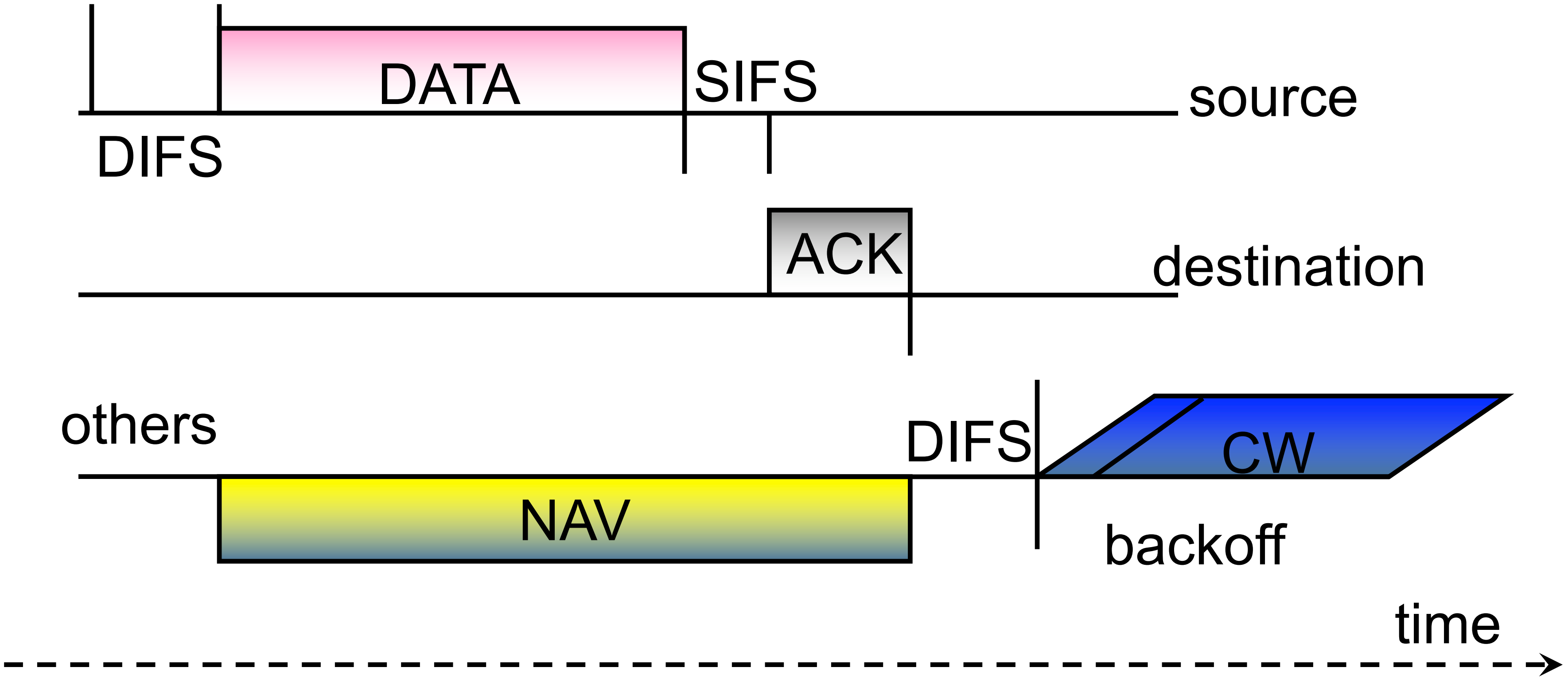
- A frame transmission may fail because of collision or errors on the radio channel
- A failed transmission is re-attempted till a max no. of retransmissions is reached
- ARQ scheme: Stop&Wait

Collision Avoidance (CA)

The backoff procedure is run also if no collisions occurred yet but the channel is busy

- If a station senses the channel busy, it waits for the channel to be idle
- As soon as the channel is idle for DIFS, the station
  - computes the backoff time interval
  - sets the backoff counter to this value
- The station will be able to transmit when its backoff counter reaches 0

MPDU Transmission on busy channel



CW=Contention Window

Backoff Value

- Integer value corresponding to a number of time slots
- The number of slots is a r.v. uniformly distributed in [0,CW-1]
- CW is the Contention Window and at **each transmission attempt of the same frame** is updated as:
  - For i=1, $CW_1=CW_{min}$
  - For i>1, $CW_i=2CW_{i-1}$ with i>1 being the no. of consecutive attempts for transmitting the MPDU
  - For any i, $CW_i \leq CW_{max}$
  - After a successful transmission $CW_1=CW_{min}$

Backoff Decrease

- While the channel is busy, the backoff counter is frozen
- While the channel is idle, and available for transmission (after sensing it free for DIFS) the station decreases the backoff value (-1 every slot) until
  - the channel becomes busy or
  - the backoff counter reaches 0

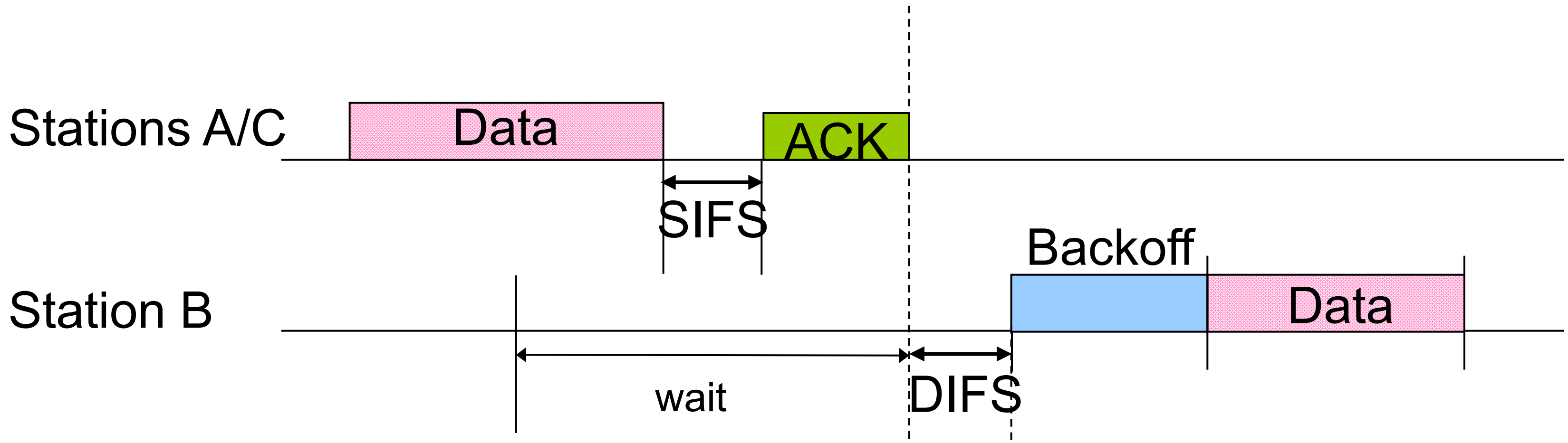
Accessing the Channel

- If more than one station decrease their counter to 0 at the same time → collision

- Colliding stations have to re-compute a new backoff value

- A station that lost a contention keeps counting down the old backoff

Basic DCF: An Example



Recontending for the Channel

- A station recontends for the channel when
  - it has completed the transmission of an MPDU, but still has data to transmit
  - a MPDU transmission fails and the MPDU must be retransmitted → binary backoff

- Before recontending the channel after a successful transmission, a station must perform a backoff procedure with CWmin

DCF
ACCESS WITH HANDSHAKING

Access with Handshake

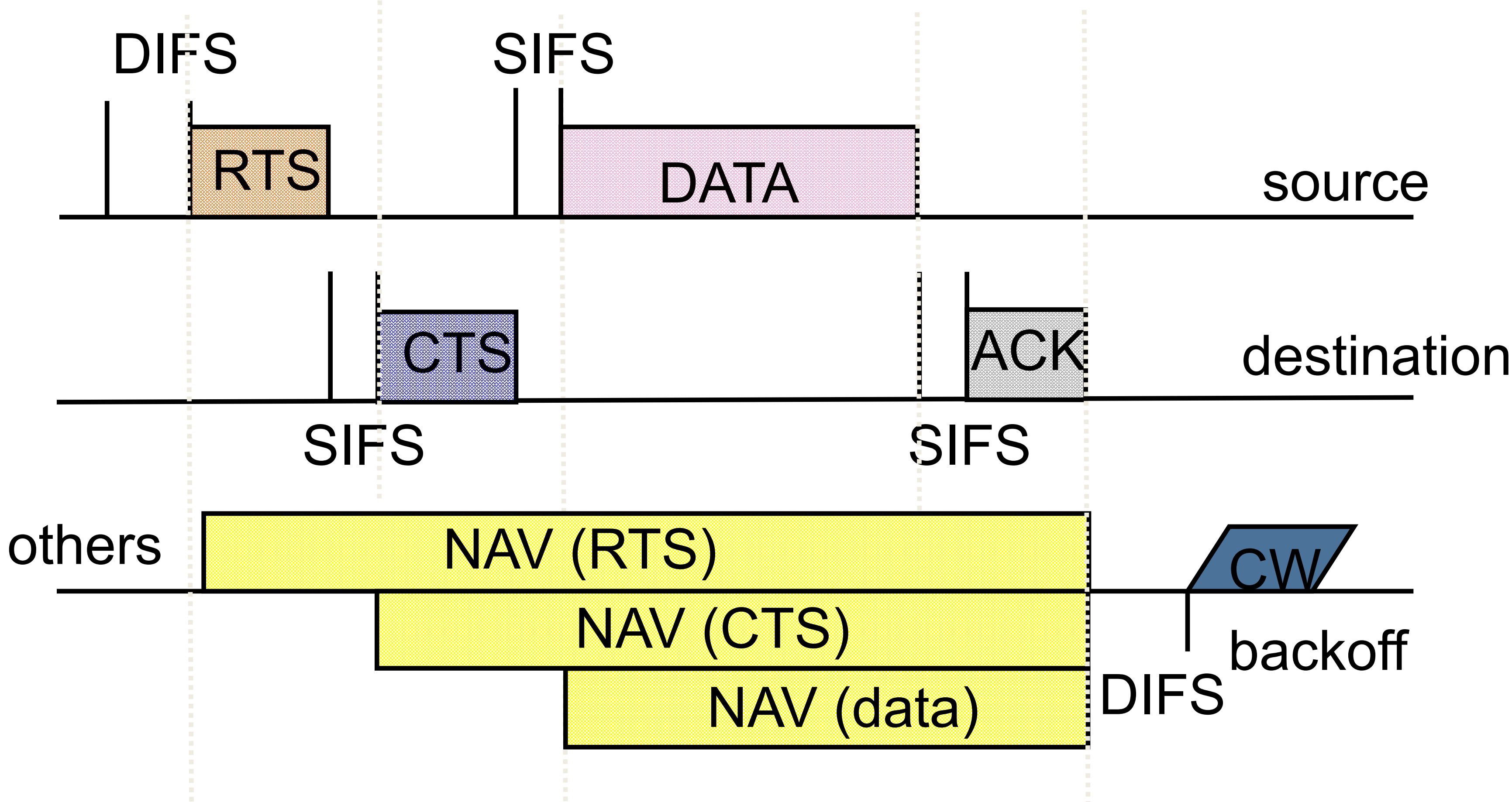
- Used to reserve the channel
- Why?
  - Hidden stations
  - Colliding stations keep transmitting their MPDU; the larger the MPDU involved in the collision, the more bandwidth is wasted
  - Need to avoid collisions, especially when frame is large
  - Particularly useful when a large no. of STAs contend for the channel

RTS/CTS

- Handshaking procedure uses the Request to send (RTS) and Clear to send (CTS) control frames
- RTS / CTS should be always transmitted @1 (b) (6 a/g/h/n/ac) Mbit/s (they are only headers)
- Access with handshaking is used for frames larger than an RTS_Threshold

DCF with Handshaking

- Transmitter:
  - send a RTS (20 bytes long) to the destination
- Neighbors:
  - read the duration field in RTS and set their NAV
- Receiver:
  - acknowledge the RTS reception after SIFS by sending a CTS (14 bytes long)
- Neighbors:
  - read the duration field in CTS and update their NAV
- Transmitter:
  - start transmitting upon CTS reception



DIFS
RTS
SIFS
DATA
source
CTS
ACK
destination
SIFS
SIFS
others
NAV (RTS)
NAV (CTS)
NAV (data)
CW
backoff
DIFS