Medium Access Control (MAC) and Wireless LANs

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Outline

❑ Wireless LAN Technology

❑ Medium Access Control for Wireless

❑ IEEE 802.11

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Wireless LAN Applications

❑ LAN Extension

❑ Cross-building interconnect

❑ Nomadic Access

❑ Ad hoc networking

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LAN Extension

❑ Wireless LAN linked into a wired LAN on same premises

o Wired LAN

- Backbone
- Support servers and stationary workstations

o Wireless LAN

- Stations in large open areas
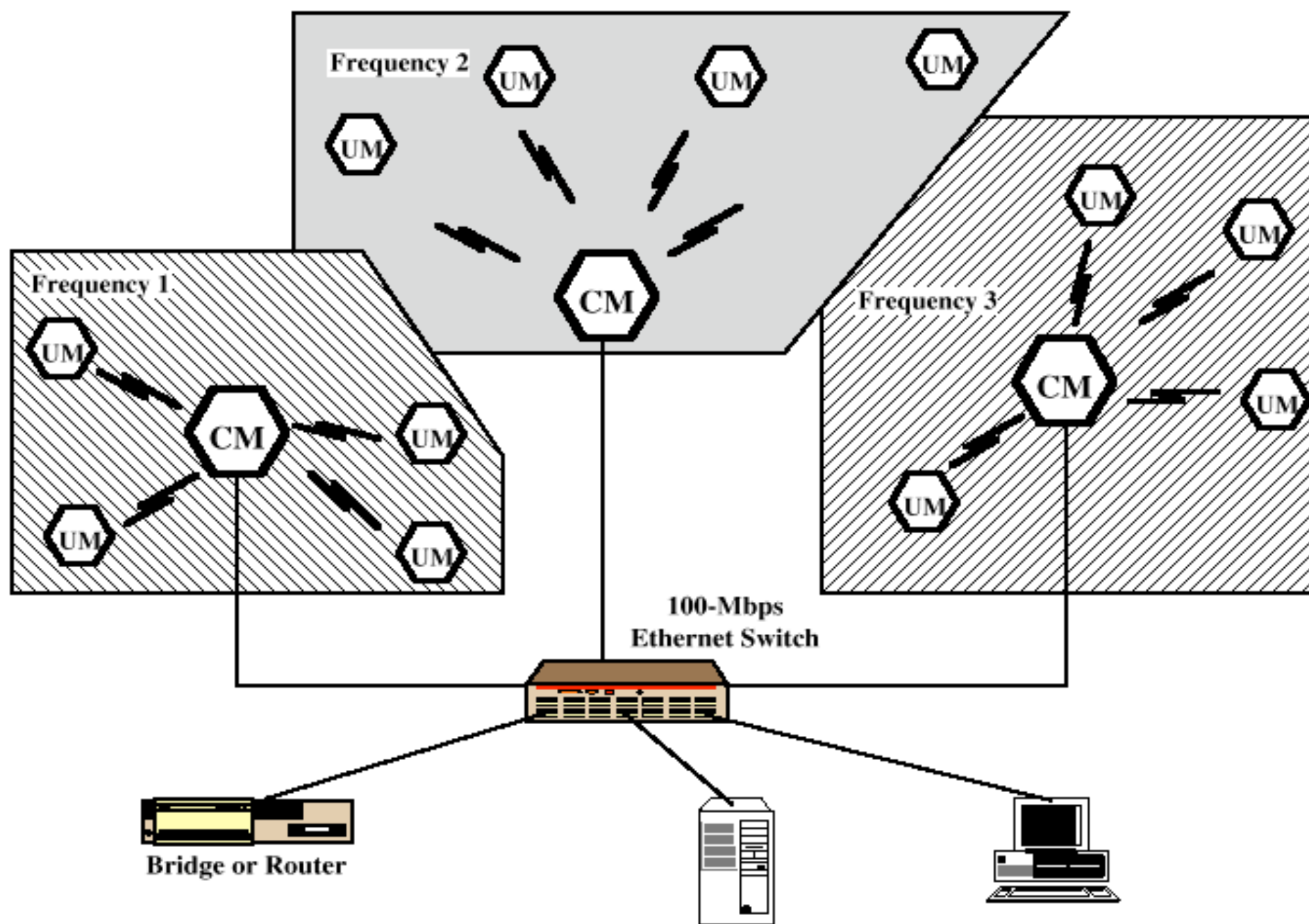- Manufacturing plants, stock exchange trading floors, and warehouses

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Frequency 2

UM UM UM

UM

CM

Frequency 1

UM

CM

UM

UM

UM

Frequency 3

UM

UM

CM

UM

UM

100-Mbps
Ethernet Switch

Bridge or Router

Figure 13.2   Example Multiple-Cell Wireless LAN Configuration

Cross-Building Interconnect

❑ Connect LANs in nearby buildings
   o Wired or wireless LANs

❑ Point-to-point wireless link is used

❑ Devices connected are typically bridges or routers

Nomadic Access

❑ Wireless link between LAN hub and mobile data terminal equipped with antenna

❑ Uses:
- o Transfer data from portable computer to office server
- o Extended environment such as campus

Ad Hoc Networking

❑ Temporary peer-to-peer network set up to meet immediate need

❑ Example:

  o Group of employees with laptops convene for a meeting; employees link computers in a temporary network for duration of meeting

  o Military applications

  o Disaster scenarios

Wireless LAN Parameters

❑ Throughput

❑ Number of nodes

❑ Connection to backbone LAN

❑ Service area

❑ Battery power consumption

❑ Transmission robustness and security

❑ Collocated network operation

❑ License-free operation

❑ Handoff/roaming

❑ Dynamic configuration

Wireless LAN Categories

❑ Infrared (IR) LANs

❑ Spread spectrum LANs

❑ Narrowband microwave

Strengths of Infrared Over Microwave Radio

❑ Spectrum for infrared virtually unlimited

- o Possibility of high data rates

❑ Infrared spectrum unregulated

❑ Equipment inexpensive and simple

❑ Reflected by light-colored objects

- o Ceiling reflection for entire room coverage

❑ Doesn't penetrate walls

- o More easily secured against eavesdropping
- o Less interference between different rooms

Drawbacks of Infrared Medium

❑ Indoor environments experience infrared background radiation

   o Sunlight and indoor lighting

   o Ambient radiation appears as noise in an infrared receiver

   o Transmitters of higher power required

   • Limited by concerns of eye safety and excessive power consumption

   o Limits range

Spread Spectrum LANs

❑ Multiple cell arrangement

❑ Most popular type of wireless LAN

❑ Two configurations:

    o Hub topology: infrastructure mode

    o Peer-to-peer topology: multi-hop ad hoc network

Spread Spectrum LAN configurations

❑ Hub topology:
  o Mounted on the ceiling and connected to backbone
  o Need MAC protocol
  o May act as multiport repeater
  o Automatic handoff of mobile stations
  o Stations in cell either:
    • Transmit to / receive from hub only
    • Broadcast using omnidirectional antenna

❑ Peer-to-peer mode:
  o No hub
  o Need a distributed MAC protocol

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Narrowband Microwave LANs

❑ Use of a microwave radio frequency band for signal transmission

❑ Relatively narrow bandwidth

❑ Licensed & unlicensed

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Medium Access Control Protocols

❑ Schedule-based: Establish transmission schedules statically or dynamically
  o TDMA
  o FDMA
  o CDMA
❑ Contention-based:
  o Let the stations contend for the channel
  o Random access protocols
❑ Reservation-based:
  o Reservations made during a contention phase
  o Size of packet in contention phase much smaller than a data packet
❑ Space-division multiple access:
  o Serve multiple users simultaneously by using directional antennas

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Schedule-based access methods

❑ FDMA (Frequency Division Multiple Access)
  o assign a certain frequency to a transmission channel between a sender and a receiver
  o permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)

❑ TDMA (Time Division Multiple Access)
  o assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time

❑ CDMA (Code Division Multiple Access)
  o signals are spread over a wideband using pseudo-noise sequences
  o codes generate signals with "good-correlation" properties
  o signals from another user appear as "noise"
  o the receiver can "tune" into this signal if it knows the pseudo random number, tuning is done via a correlation function

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Contention-based protocols

❑ Aloha

❑ CSMA (Carrier-sense multiple access)

   o Ethernet

❑ MACA (Multiple access collision avoidance)

❑ MACAW

❑ CSMA/CA and IEEE 802.11

Ingredients of MAC Protocols

❑ Carrier sense (CS)

o Hardware capable of sensing whether transmission taking place in vicinity

❑ Collision detection (CD)

o Hardware capable of detecting collisions

❑ Collision avoidance (CA)

o Protocol for avoiding collisions

❑ Acknowledgments

o When collision detection not possible, link-layer mechanism for identifying failed transmissions

❑ Backoff mechanism

o Method for estimating contention and deferring transmissions

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Carrier Sense Multiple Access

❑ Every station senses the carrier before transmitting

❑ If channel appears free
  o Transmit (with a certain probability)

❑ Otherwise, wait for some time and try again

❑ Different CSMA protocols:
  o Sending probabilities
 o Retransmission mechanisms

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Aloha

❑ Proposed for packet radio environments where every node can hear every other node

❑ Assume collision detection

❑ In Slotted Aloha, stations transmit at the beginning of a slot

❑ If collision occurs, then each station waits a random number of slots and retries

  o Random wait time chosen has a geometric distribution

  o Independent of the number of retransmissions

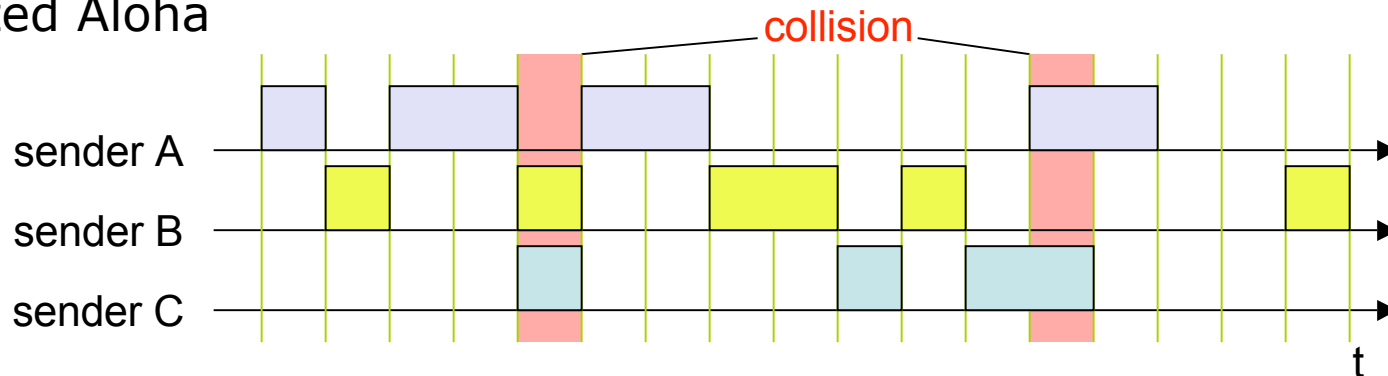❑ Analysis in standard texts on networking theory

Aloha/Slotted aloha

❑ Mechanism
  o random, distributed (no central arbiter), time-multiplexed
  o Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries

❑ Aloha

❑ Slotted Aloha

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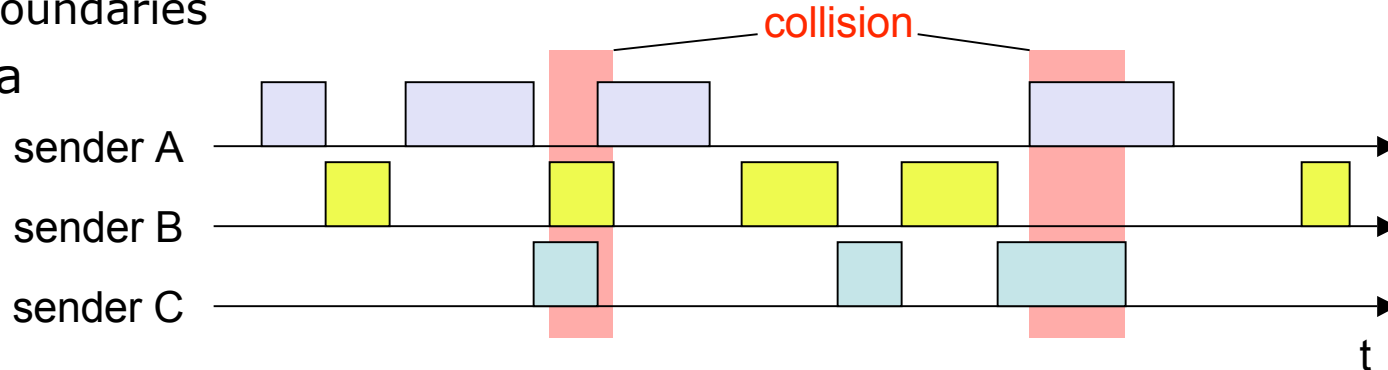
Carrier Sense Protocols

❑ Use the fact that in some networks you can *sense* the medium to check whether it is currently free
  - o 1-persistent CSMA
  - o non-persistent CSMA
  - o p-persistent protocol
  - o CSMA with collision detection (CSMA/CD): not applicable to wireless systems

❑ 1-persistent CSMA
  - o when a station has a packet:
    - • it waits until the medium is free to transmit the packet
    - • if a collision occurs, the station waits a random amount of time
  - o first transmission results in a collision if several stations are waiting for the channel

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Carrier Sense Protocols (*Cont'd*)

❑ Non-persistent CSMA
  - o when a station has a packet:
    - if the medium is free, transmit the packet
    - otherwise wait for a random period of time and repeat the algorithm
  - o higher delays, but better performance than pure ALOHA

❑ p-persistent protocol
  - o when a station has a packet wait until the medium is free:
    - transmit the packet with probability *p*
    - wait for next slot with probability 1-*p*
  - o better throughput than other schemes but higher delay

❑ CSMA with collision Detection (CSMA/CD)
  - o stations abort their transmission when they detect a collision
  - o e.g., Ethernet, IEEE802.3 but not applicable to wireless systems

Ethernet

❑ CSMA with collision detection (CSMA/CD)
❑ If the adaptor has a frame and the line is idle: transmit
❑ Otherwise wait until idle line then transmit
❑ If a collision occurs:
  o Binary exponential backoff: wait for a random number $\in [0, 2^i-1]$ of slots before transmitting
  o After ten collisions the randomization interval is frozen to max 1023
 o After 16 collisions the controller throws away the frame

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Comparison of MAC Algorithms

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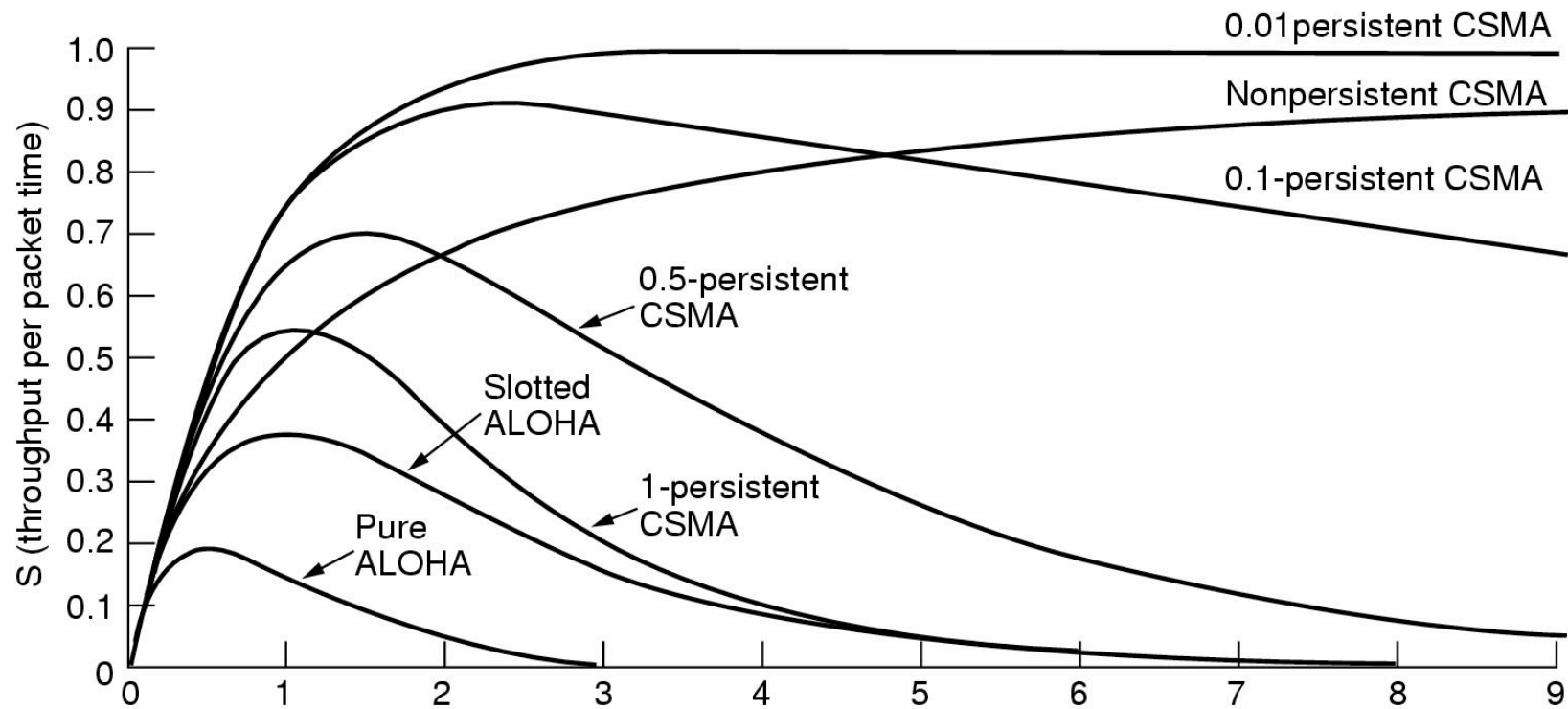
Motivation for Wireless MAC

❑ Can we apply media access methods from fixed networks?

❑ Example CSMA/CD
  - o **C**arrier **S**ense **M**ultiple **A**ccess with **C**ollision **D**etection
  - o send as soon as the medium is free, listen into the medium if a collision occurs (original method in IEEE 802.3)

❑ Problems in wireless networks
  - o signal strength decreases proportional to the square of the distance
  - o the sender would apply CS and CD, but the collisions happen at the receiver
  - o it might be the case that a sender cannot "hear" the collision, i.e., CD does not work
  - o furthermore, CS might not work if, e.g., a terminal is "hidden"

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Hidden and exposed terminals

❑ Hidden terminals
  - o A sends to B, C cannot receive A
  - o C wants to send to B, C senses a "free" medium (CS fails)
  - o collision at B, A cannot receive the collision (CD fails)
 - o A is "hidden" for C

A   B   C
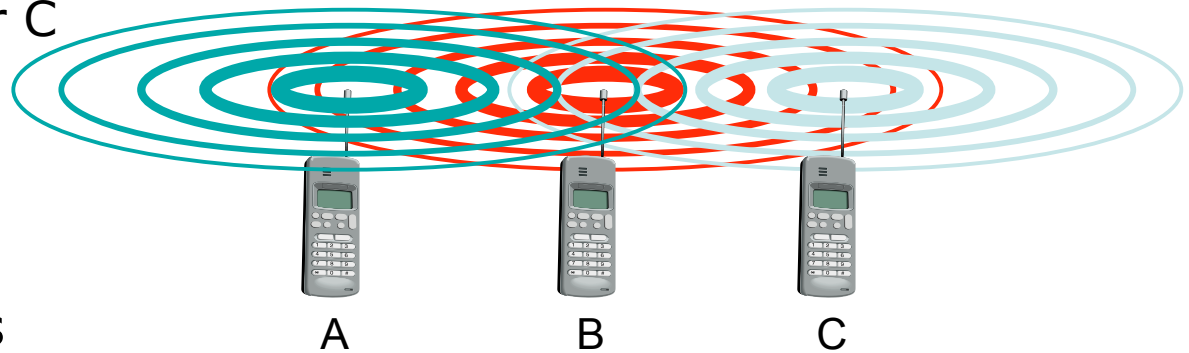
❑ Exposed terminals
  - o B sends to A, C wants to send to another terminal (not A/B)
  - o C has to wait, CS signals a medium in use
  - o but A is outside the radio range of C, therefore waiting is not necessary
  - o C is "exposed" to B

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Near and far terminals

❑ Terminals A and B send, C receives
   o signal strength decreases proportional to the square of the distance
   o the signal of terminal B therefore drowns out A's signal
   o C cannot receive A

A   B   C
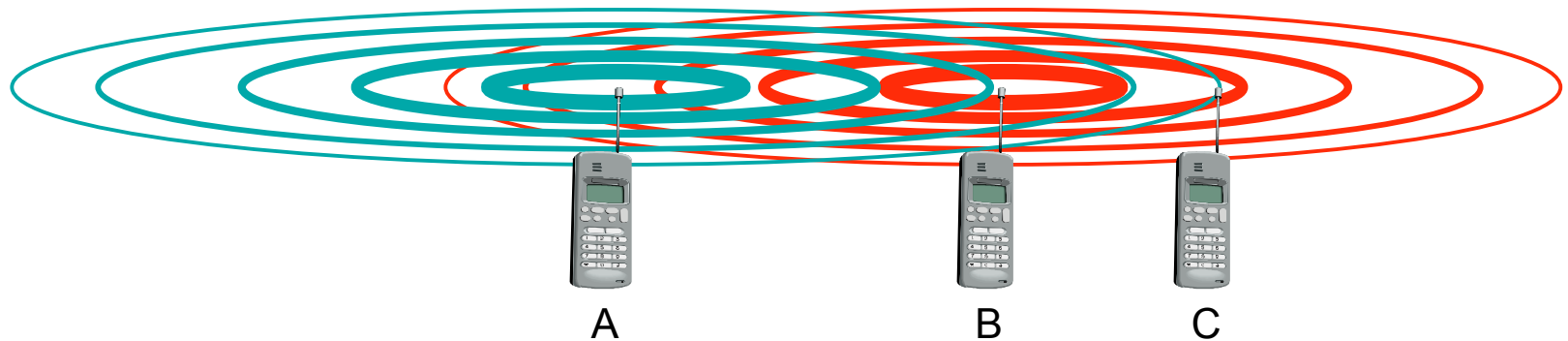
❑ If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer
❑ Also severe problem for CDMA-networks - precise power control needed!

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MACA - collision avoidance

❑ No carrier sense (CS)
❑ MACA (Multiple Access with Collision Avoidance) uses short signaling packets for collision avoidance
  o RTS (request to send): sender requests the right to send from a receiver with a short RTS packet before it sends a data packet
  o CTS (clear to send): the receiver grants the right to send as soon as it is ready to receive
❑ Signaling packets contain
  o sender address
  o receiver address
  o packet size
❑ Variants of this method can be found in IEEE 802.11.

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MACA examples

❑ MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B

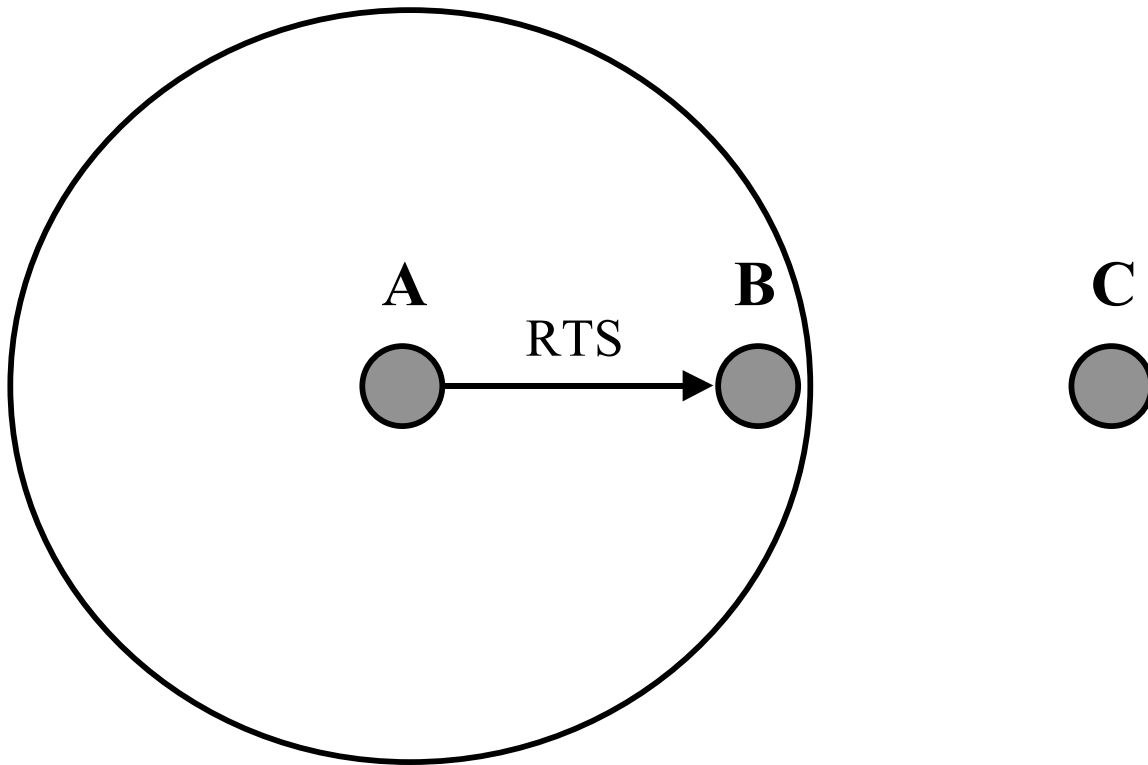
```
        RTS →
A  ←  CTS        CTS →  C
        B
```
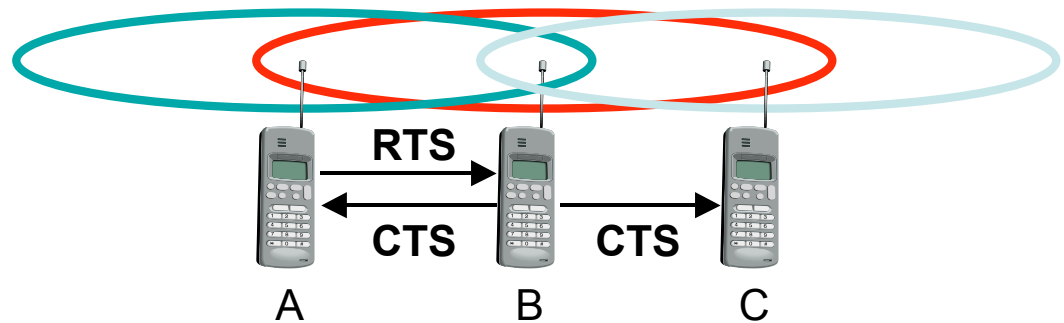
❑ MACA avoids the problem of exposed terminals?
  - B wants to send to A, C to another terminal
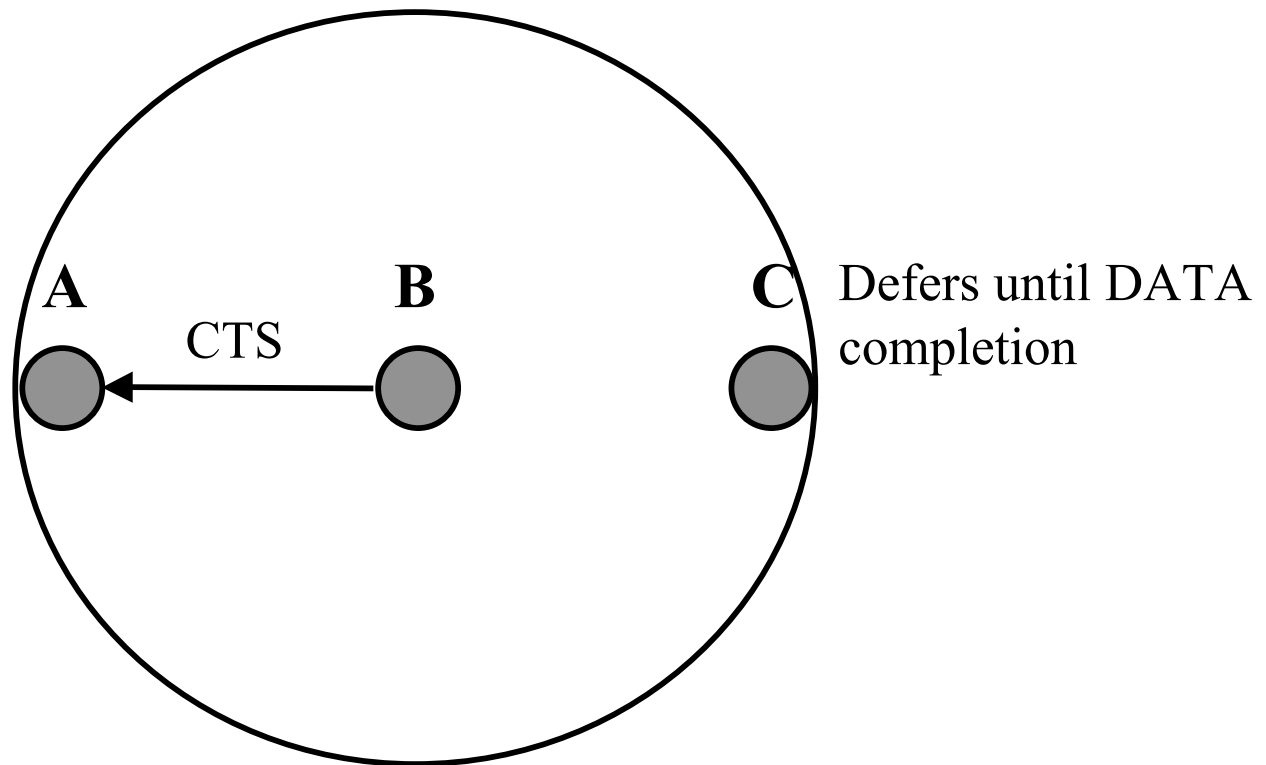 - now C does not have to wait for it cannot receive CTS from A


```
        ← RTS        RTS →
A         CTS →         C
        B
```

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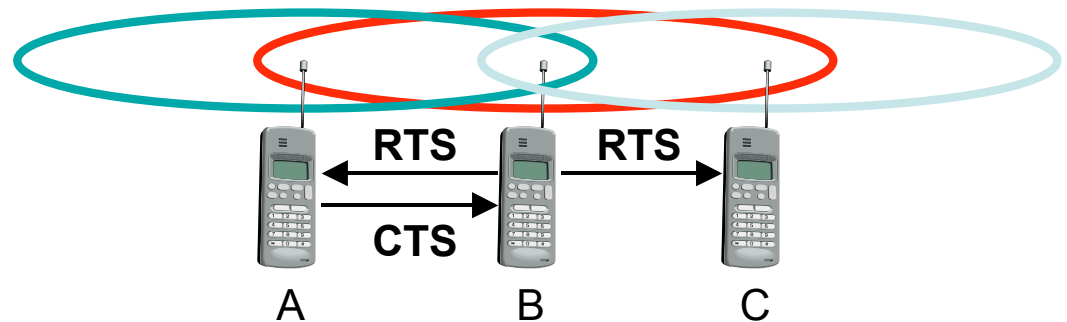
MACA in Action

❑ If C also transmits RTS, collision at B

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MACA in Action

❑ C knows the expected DATA length from CTS

A

B

C   Defers until DATA
    completion

CTS

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MACA in Action

❑ Avoids the hidden terminal problem

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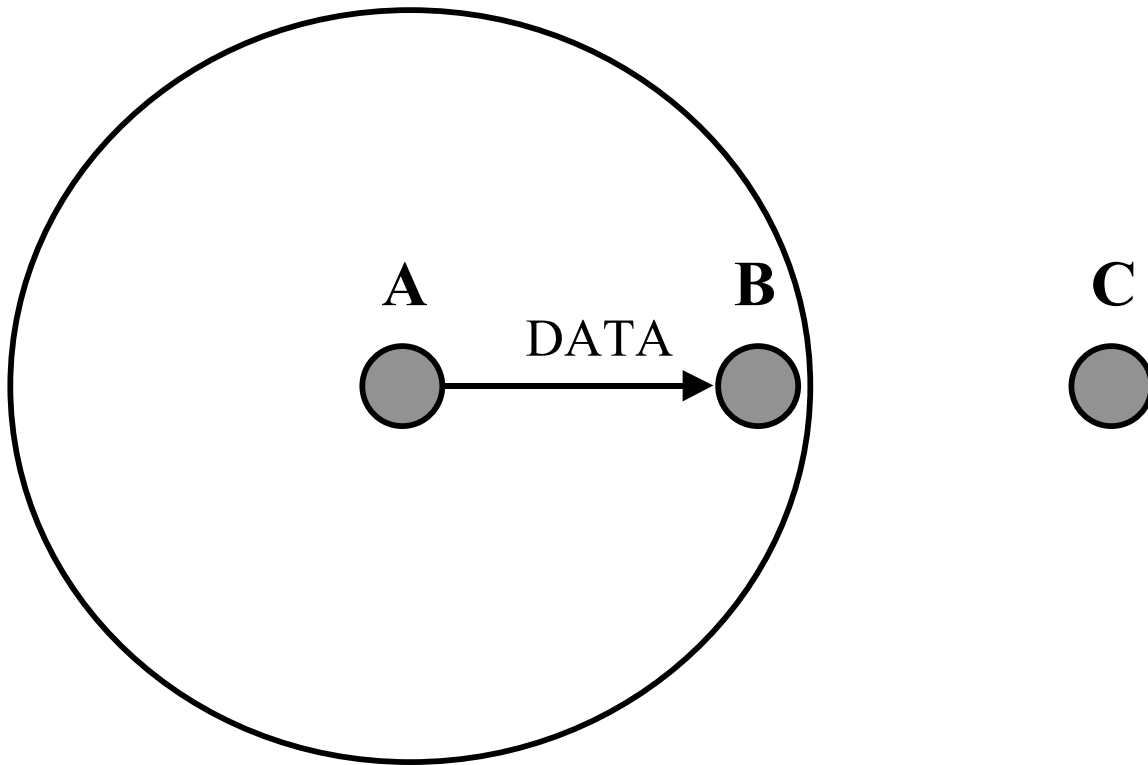
MACA in Action

❑ CTS packets have fixed size

Defers until CTS

A   B   C   D

RTS

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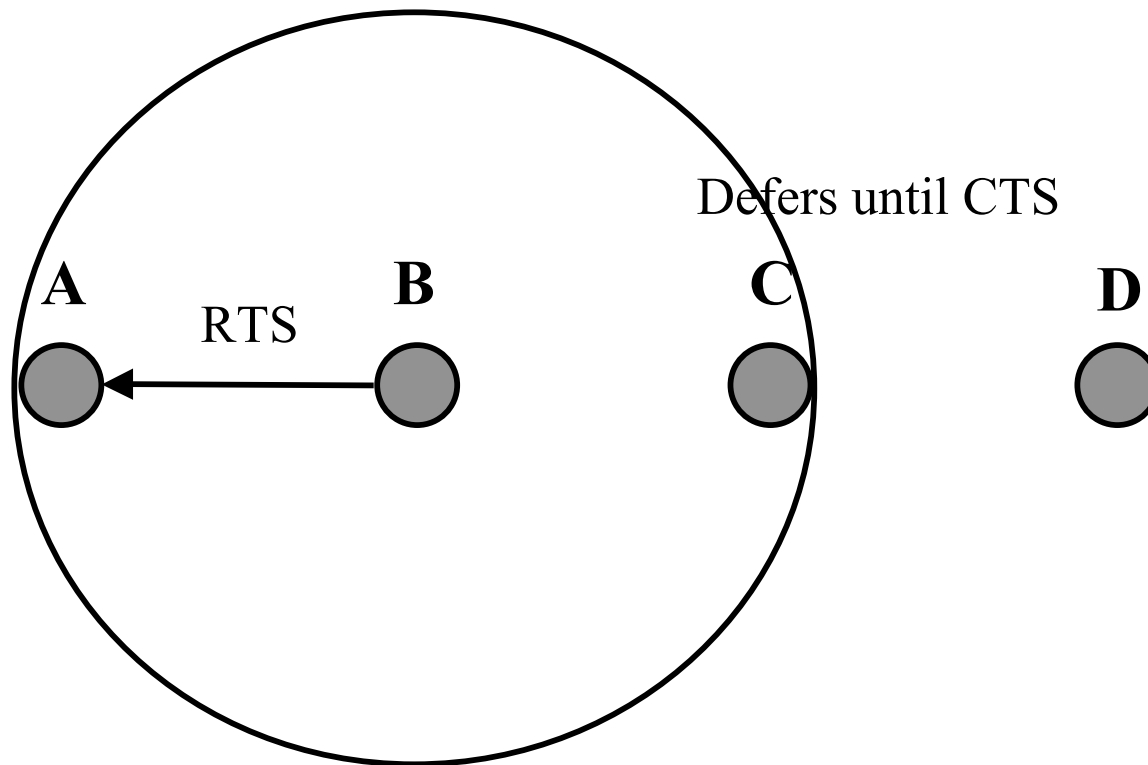
MACA in Action

❑ C does not hear a CTS

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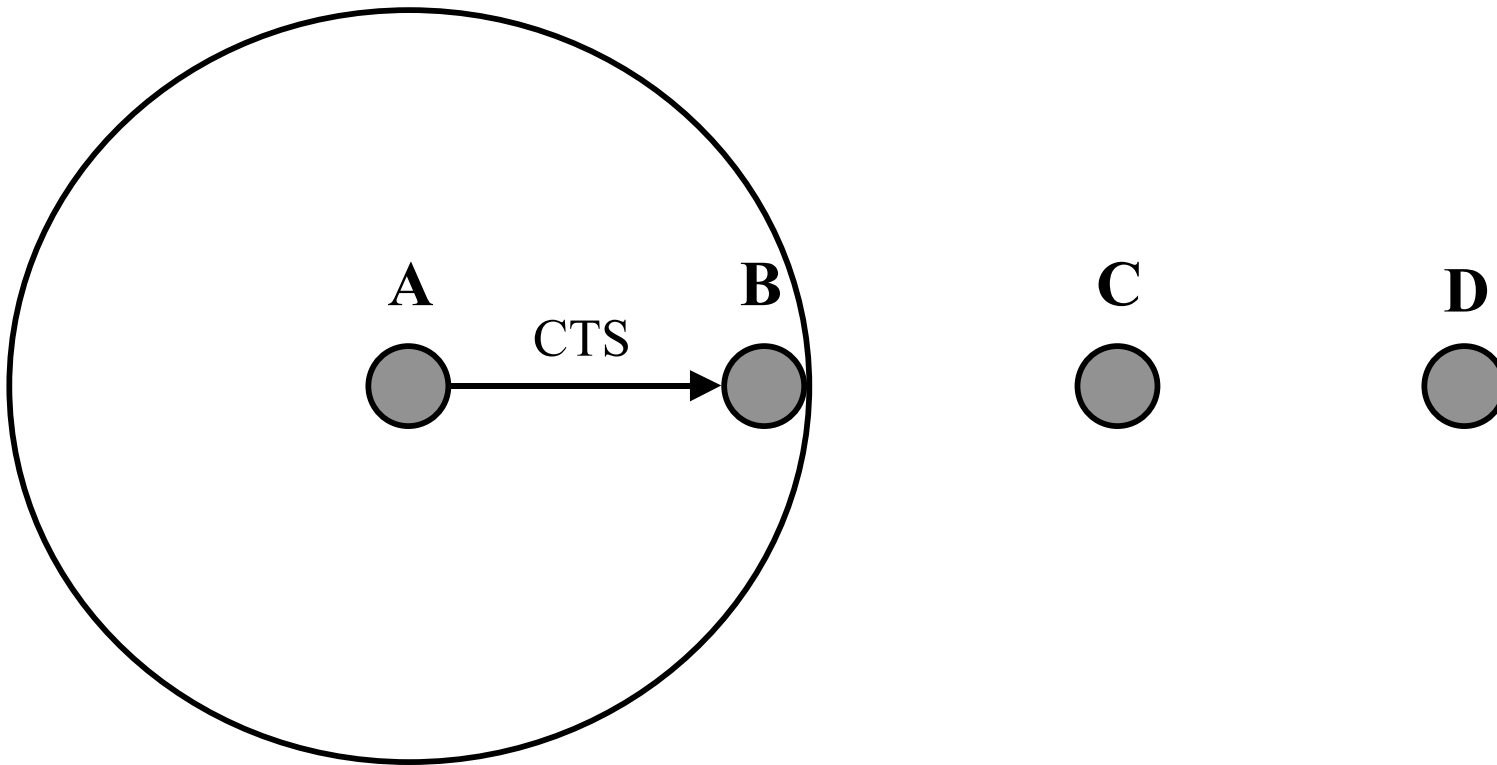
MACA in Action

❑ C is free to send to D; no exposed terminal

A   DATA   **B**   **C**   **D**

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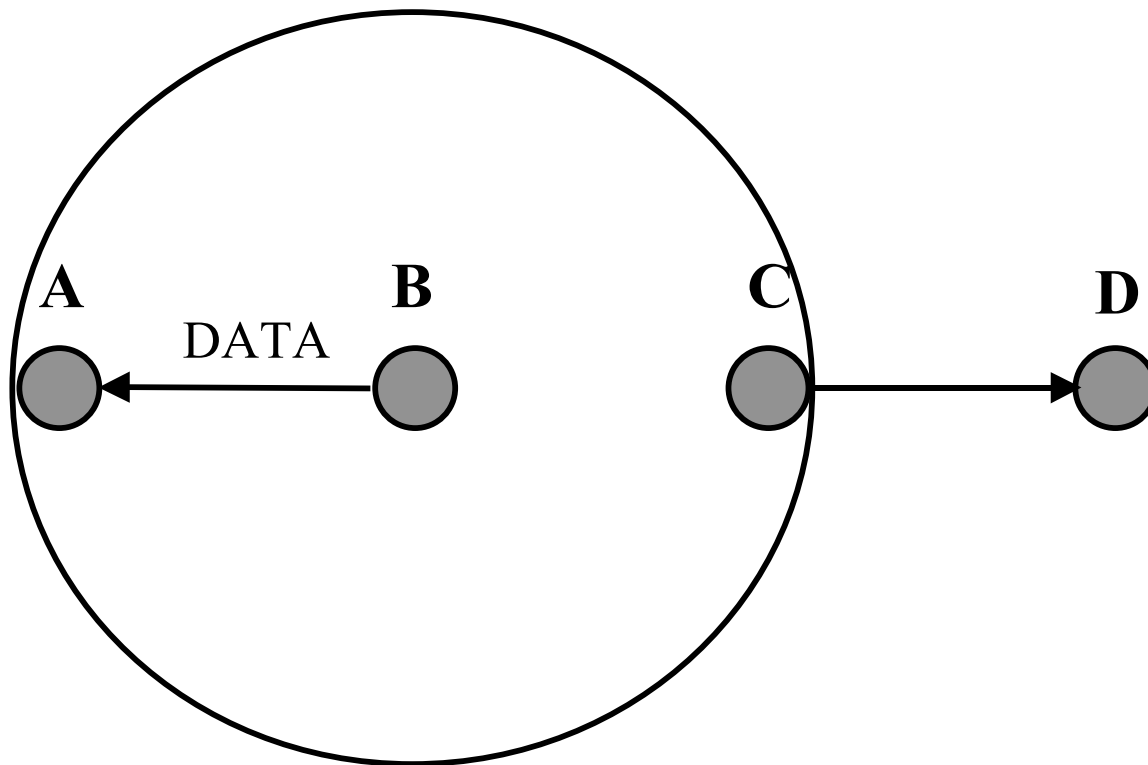
MACA in Action

❑ Is C really free to send to D?

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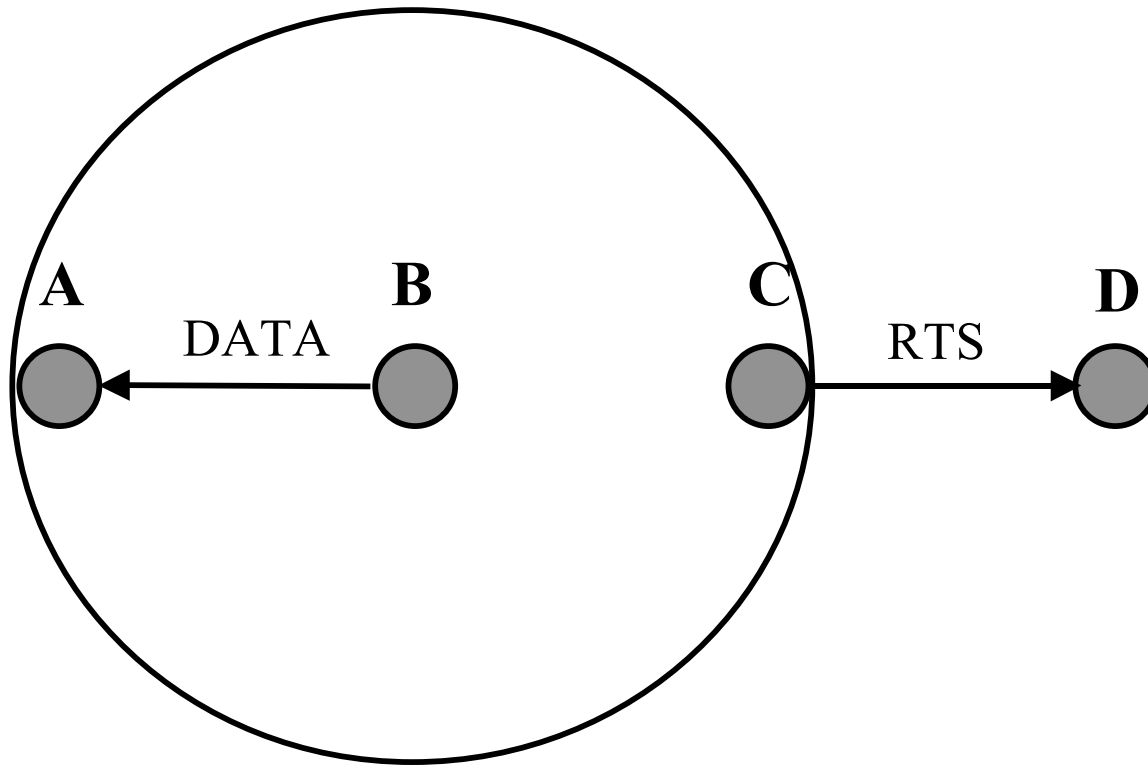
MACA in Action

❑ In fact, C increases its backoff counter!

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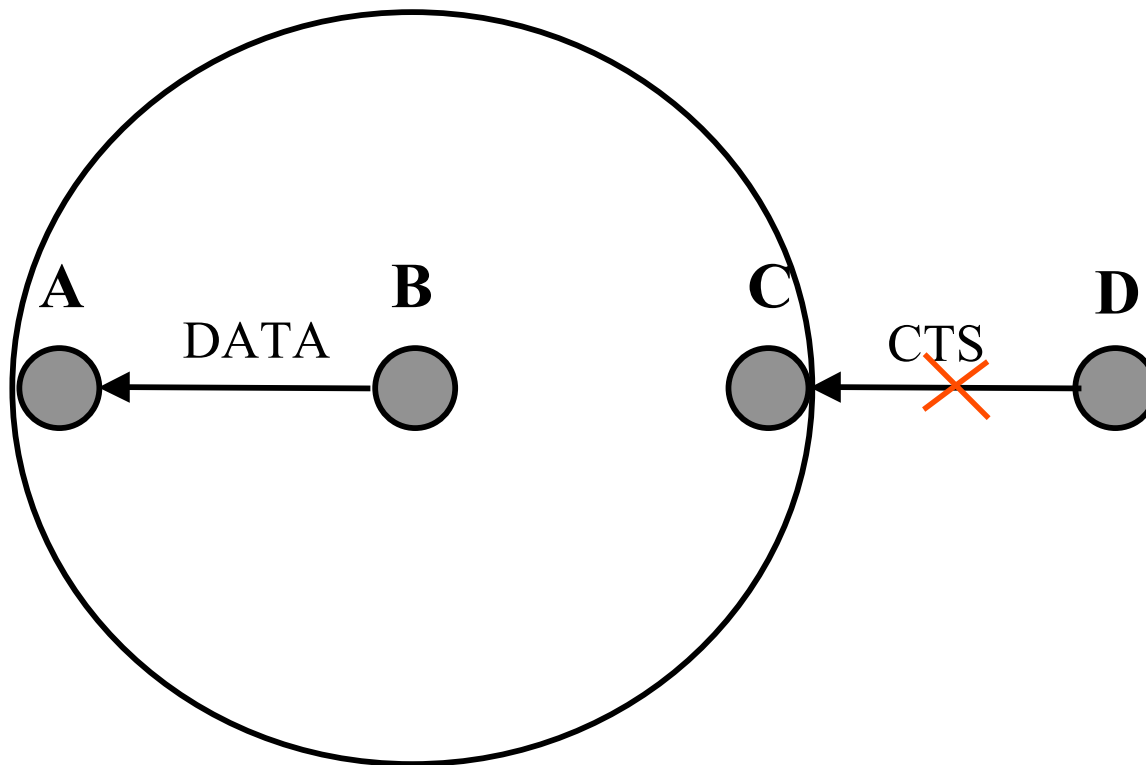
The CSMA/CA Approach

❑ Add carrier sense; C will sense B's transmission and refrain from sending RTS

A   B   C   D

DATA

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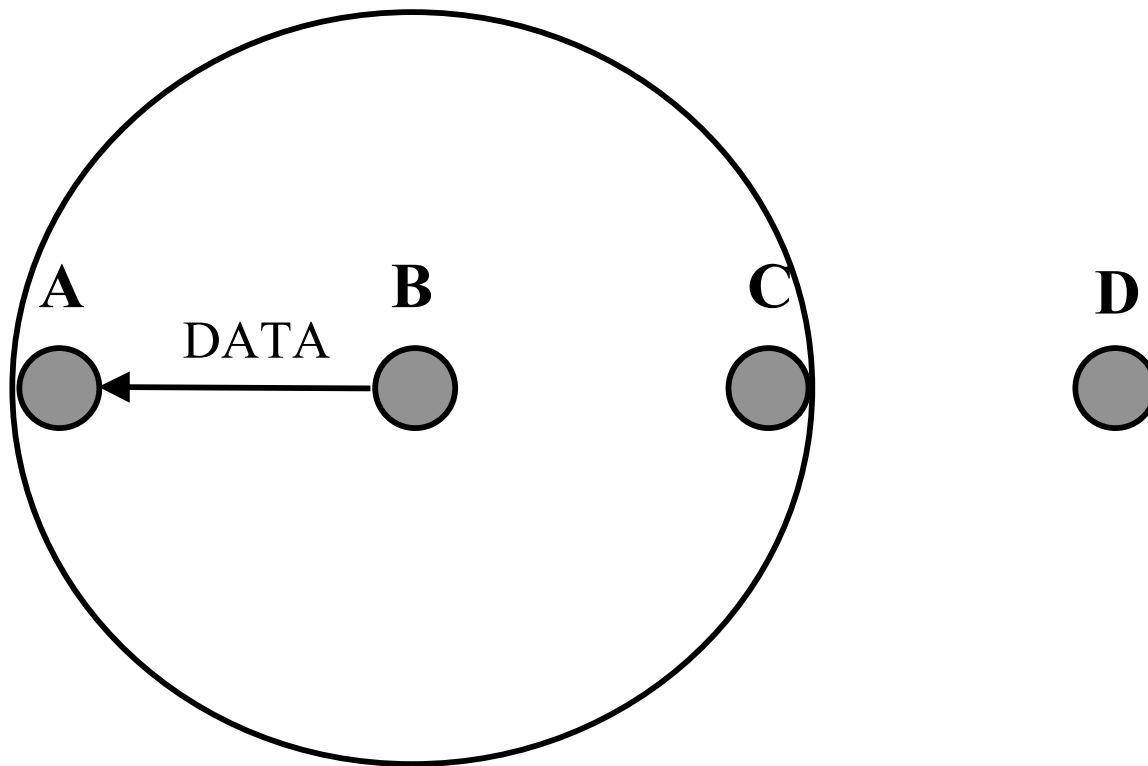
False Blocking

- ❑ F sends RTS to E; D sends RTS to C
- ❑ E is falsely blocked

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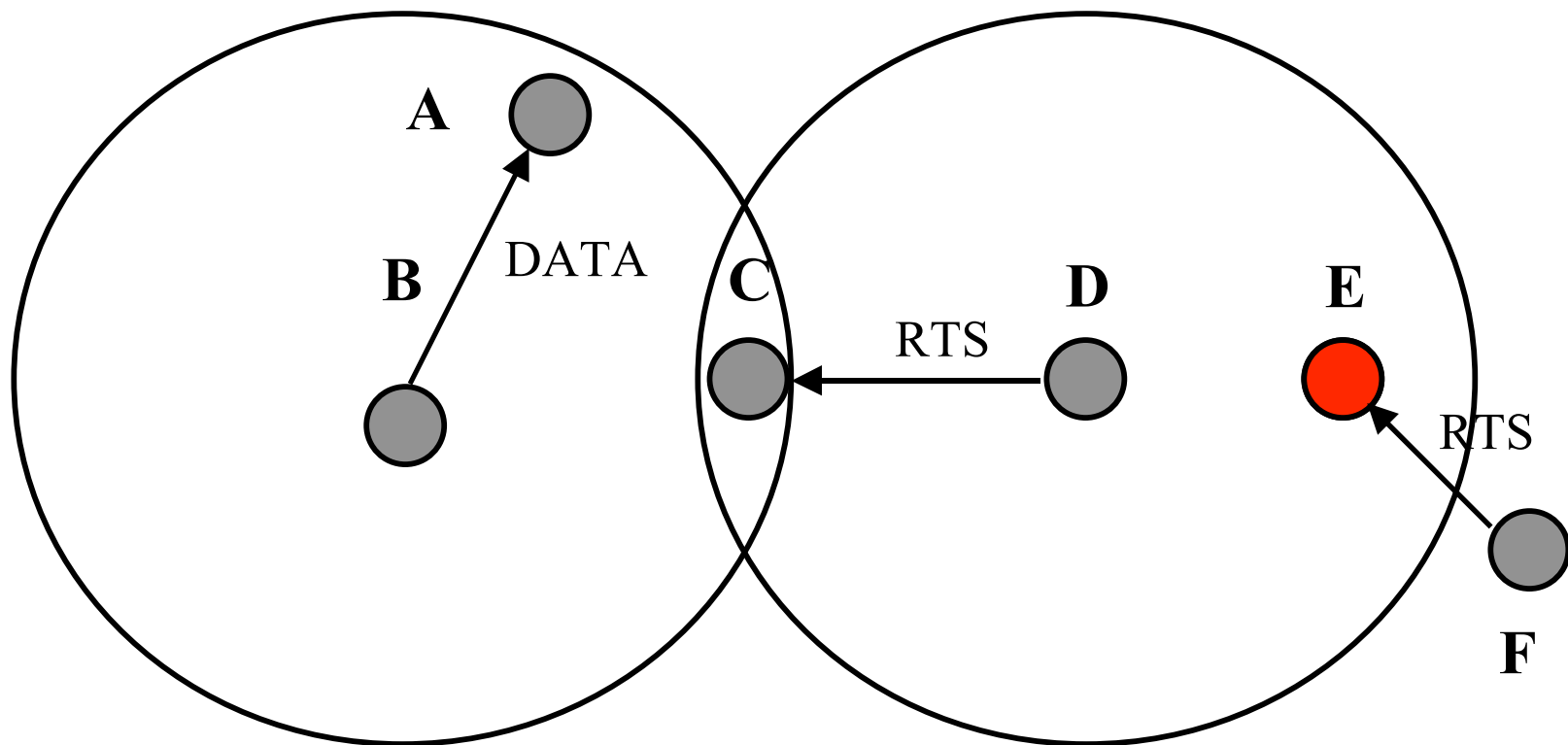
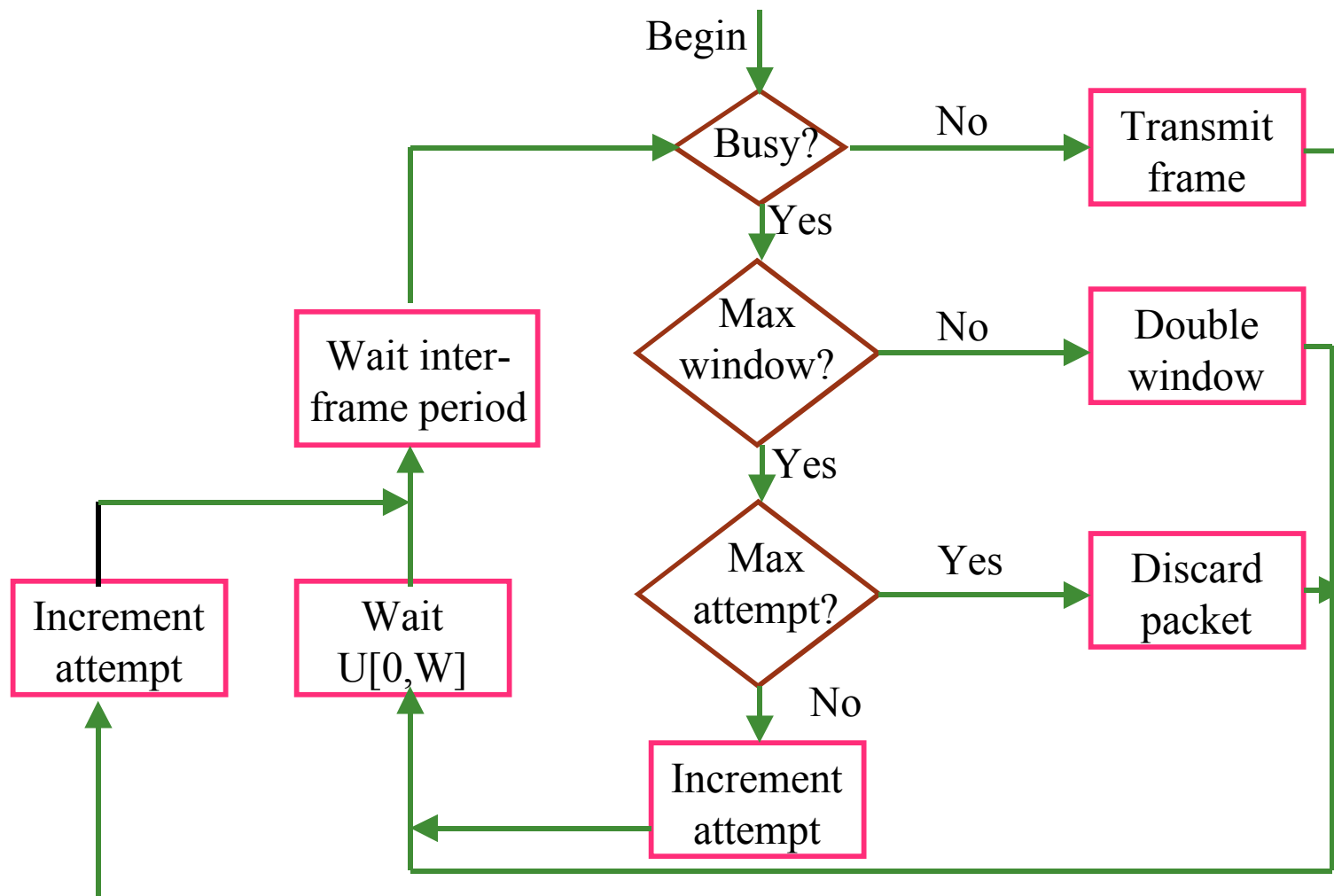# Alternative Approach: MACAW

❑ No carrier sense, no collision detection

❑ Collision avoidance:
- o Sender sends RTS
- o Receiver sends CTS
- o Sender sends DS
- o Sender sends DATA
- o Receiver sends ACK
- o Stations hearing DS defer until end of data transmission

❑ Backoff mechanism:
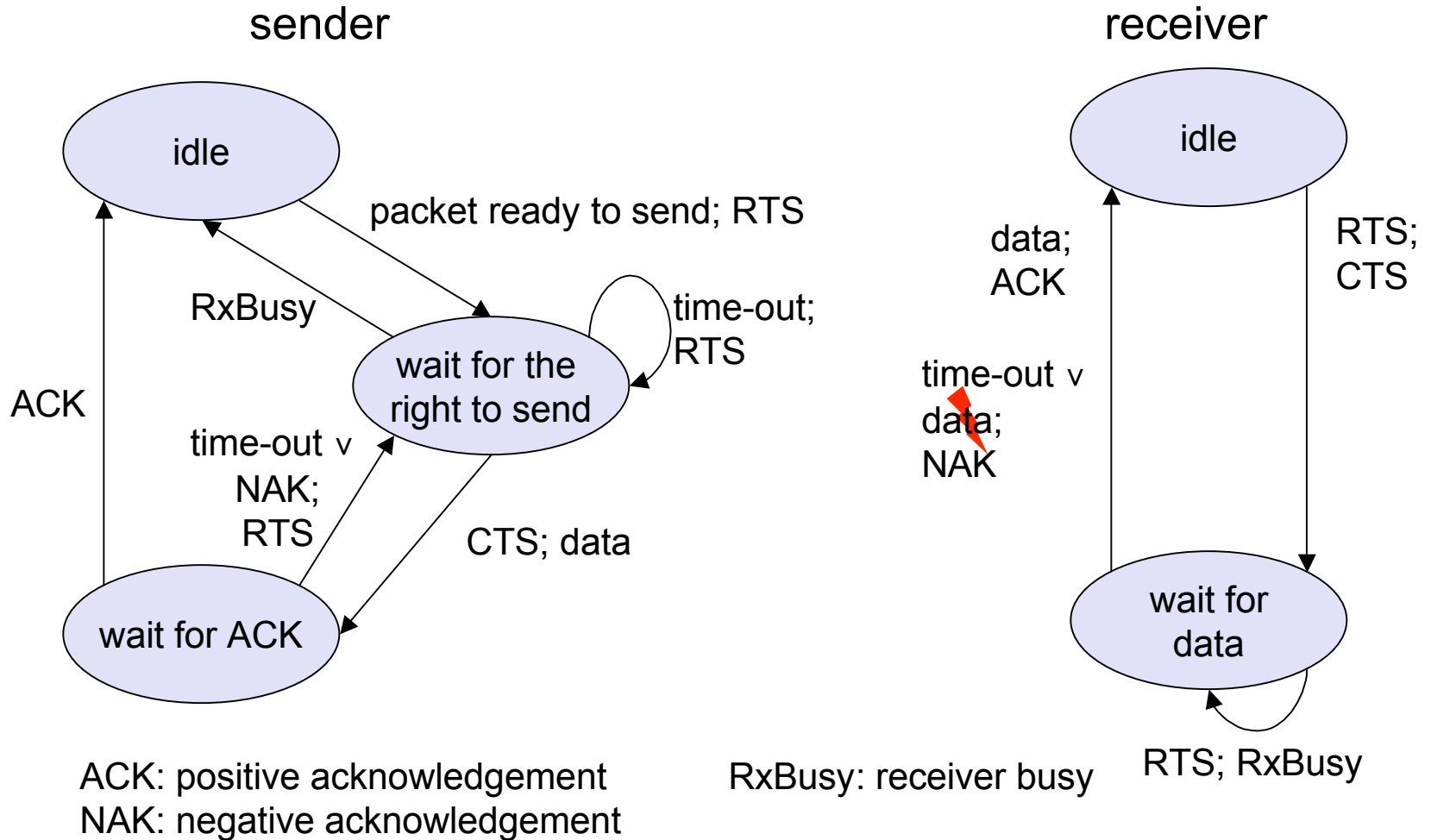- o Exponential backoff with significant changes for improving fairness and throughput

The IEEE 802.11 Protocol

❑ Two medium access schemes

❑ Point Coordination Function (PCF)

    o Centralized

    o For infrastructure mode

❑ Distributed Coordination Function (DCF)

    o For ad hoc mode

    o CSMA/CA

    o Exponential backoff

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CSMA/CA with Exponential Backoff

Begin

Busy? — No → Transmit frame

Busy? — Yes ↓

Max window? — No → Double window

Max window? — Yes ↓

Max attempt? — Yes → Discard packet

Max attempt? — No ↓

Increment attempt

Wait inter-frame period

Wait U[0,W]

Increment attempt

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MAC in IEEE 802.11

sender

idle

packet ready to send; RTS

RxBusy

time-out;
RTS

wait for the
right to send

ACK

time-out ∨
NAK;
RTS

CTS; data

wait for ACK

receiver

idle

data;
ACK

RTS;
CTS

time-out ∨
data;
NAK

wait for
data

RTS; RxBusy

ACK: positive acknowledgement   RxBusy: receiver busy
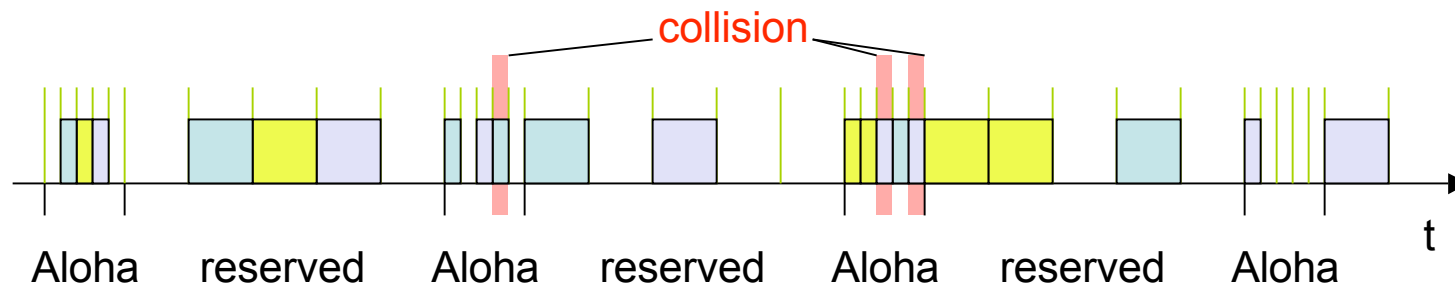NAK: negative acknowledgement

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Demand Assigned Multiple Access

❑ Channel efficiency only 18% for Aloha, 36% for Slotted Aloha (assuming Poisson distribution for packet arrival and packet length)

❑ Reservation can increase efficiency to 80%
  o a sender *reserves* a future time-slot
  o sending within this reserved time-slot is possible without collision
  o reservation also causes higher delays
  o typical scheme for satellite links

❑ Examples for reservation algorithms:
  o *Explicit Reservation (Reservation-ALOHA)*
  o *Implicit Reservation (PRMA)*
  o *Reservation-TDMA*
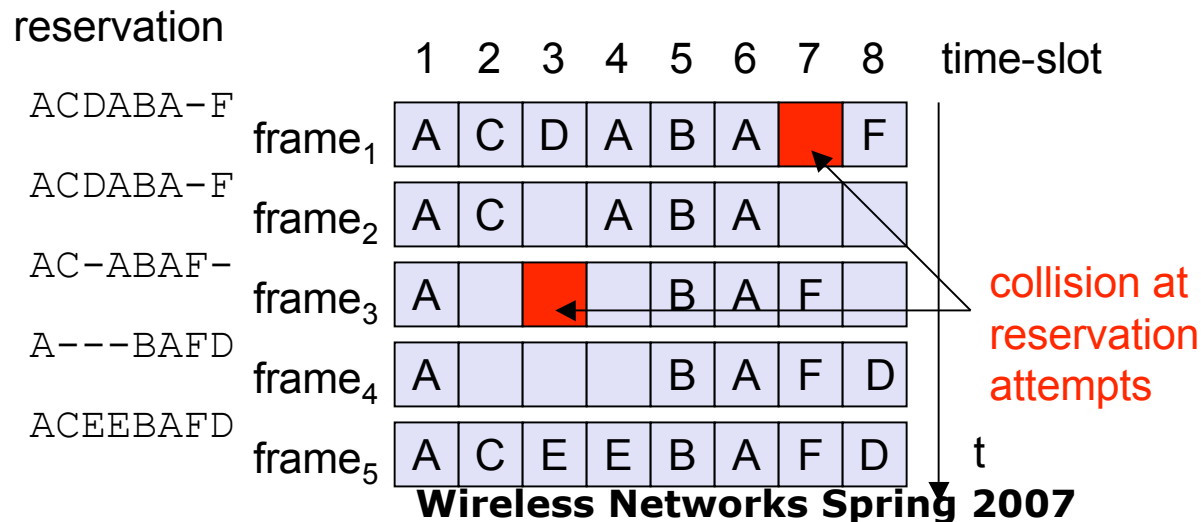
DAMA: Explicit Reservation

❑Explicit Reservation (Reservation Aloha):
- o two modes:
  - *ALOHA mode* for reservation:
    competition for small reservation slots, collisions possible
  - *reserved mode* for data transmission within successful reserved slots
    (no collisions possible)
- o it is important for all stations to keep the reservation list
  consistent at any point in time and, therefore, all stations have
  to synchronize from time to time

collision

Aloha   reserved   Aloha   reserved   Aloha   reserved   Aloha
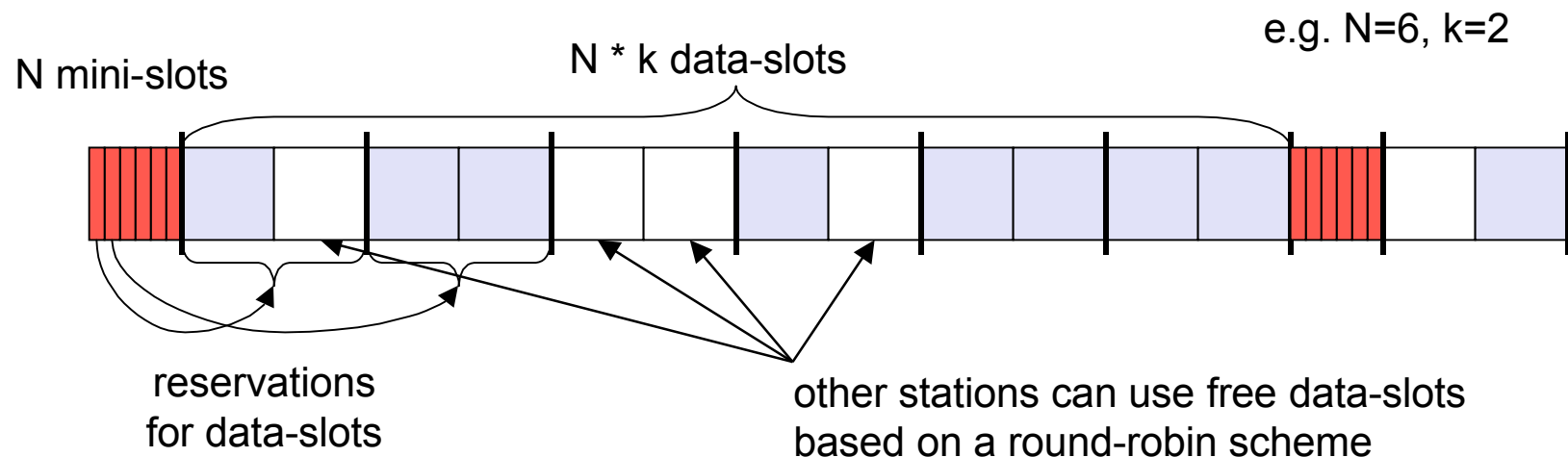
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DAMA: PRMA

❑Implicit reservation (PRMA - Packet Reservation MA):

o a certain number of slots form a frame, frames are repeated

o stations compete for empty slots according to the slotted aloha principle

o once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send

o competition for this slots starts again as soon as the slot was empty in the last frame

reservation

		1	2	3	4	5	6	7	8	time-slot
ACDABA-F	frame₁	A	C	D	A	B	A		F	
ACDABA-F	frame₂	A	C		A	B	A			
AC-ABAF-	frame₃	A				B	A	F		
A---BAFD	frame₄	A				B	A	F	D	
ACEEBAFD	frame₅	A	C	E	E	B	A	F	D	t

collision at reservation attempts

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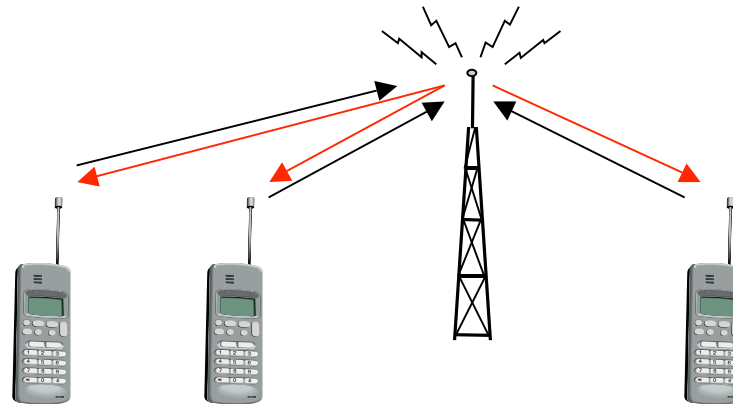
DAMA: Reservation-TDMA

❑ Reservation Time Division Multiple Access
- o every frame consists of N mini-slots and x data-slots
- o every station has its own mini-slot and can reserve up to k data-slots using this mini-slot (i.e. x = N * k).
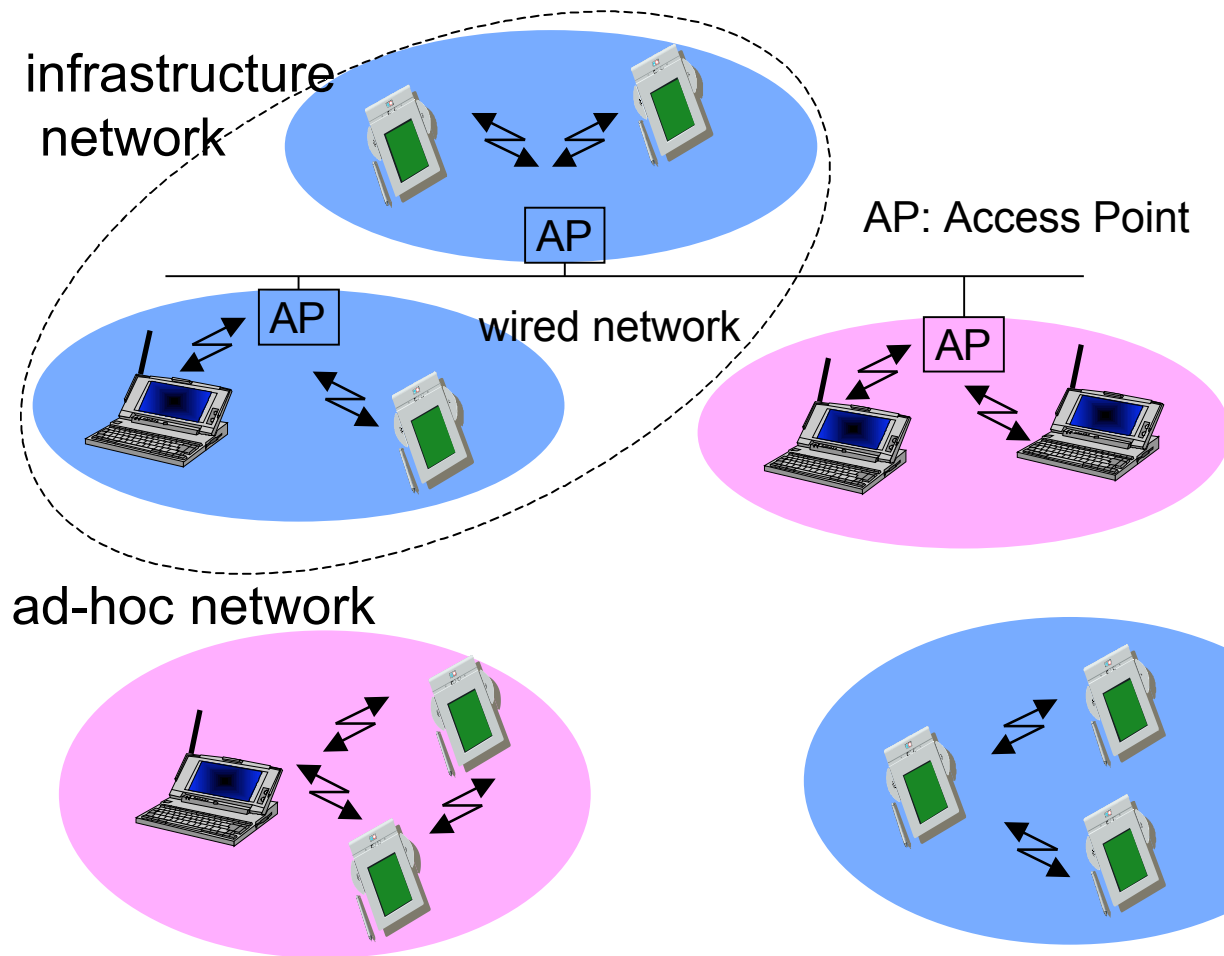- o other stations can send data in unused data-slots according to a round-robin sending scheme (best-effort traffic)

e.g. N=6, k=2

N * k data-slots

N mini-slots

reservations for data-slots

other stations can use free data-slots based on a round-robin scheme
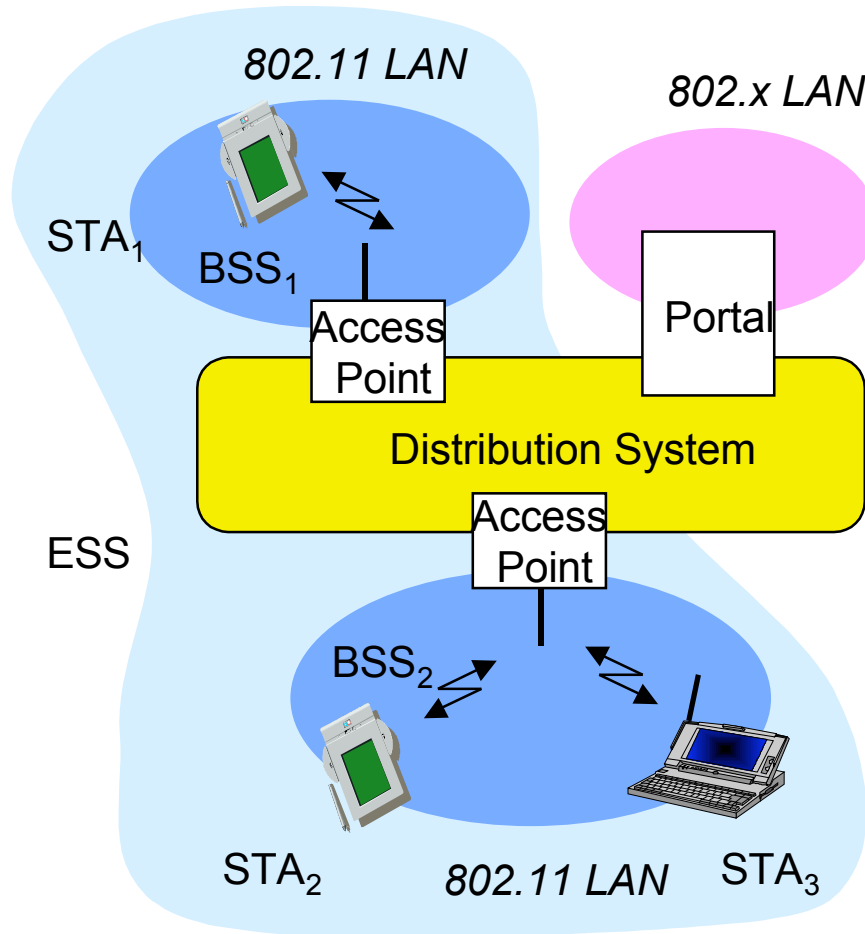
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ISMA (Inhibit Sense)

❑ Current state of the medium is signaled via a "busy tone"

- o the base station signals on the downlink (base station to terminals) if the medium is free or not
- o terminals must not send if the medium is busy
- o terminals can access the medium as soon as the busy tone stops
- o the base station signals collisions and successful transmissions via the busy tone and acknowledgements, respectively (media access is not coordinated within this approach)
- o mechanism used, e.g., for CDPD (USA, integrated into AMPS)

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IEEE802.11

infrastructure network

AP

AP: Access Point

AP

wired network

AP

ad-hoc network

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802.11 infrastructure mode

802.11 LAN

802.x LAN

STA$_1$

BSS$_1$

Access Point

Portal

Distribution System

ESS

Access Point

BSS$_2$

STA$_2$ *802.11 LAN*   STA$_3$

❑Station (STA)
  o terminal with access mechanisms to the wireless medium and radio contact to the access point

❑Basic Service Set (BSS)
  o group of stations using the same radio frequency

❑Access Point
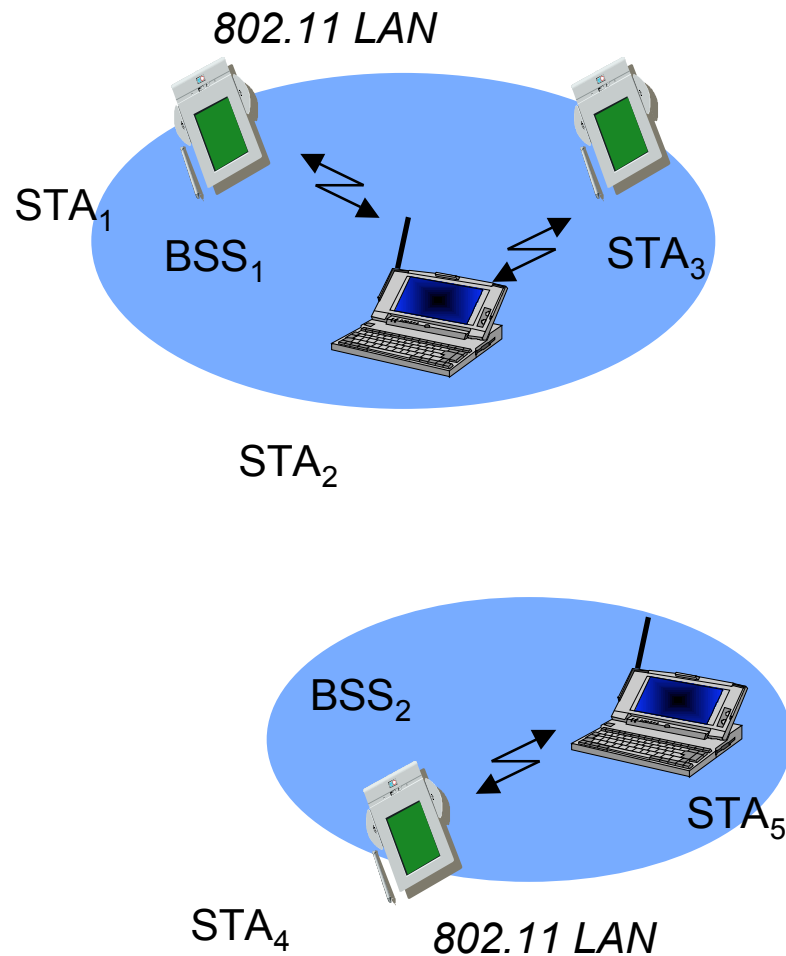 o station integrated into the wireless LAN and the distribution system

❑Portal
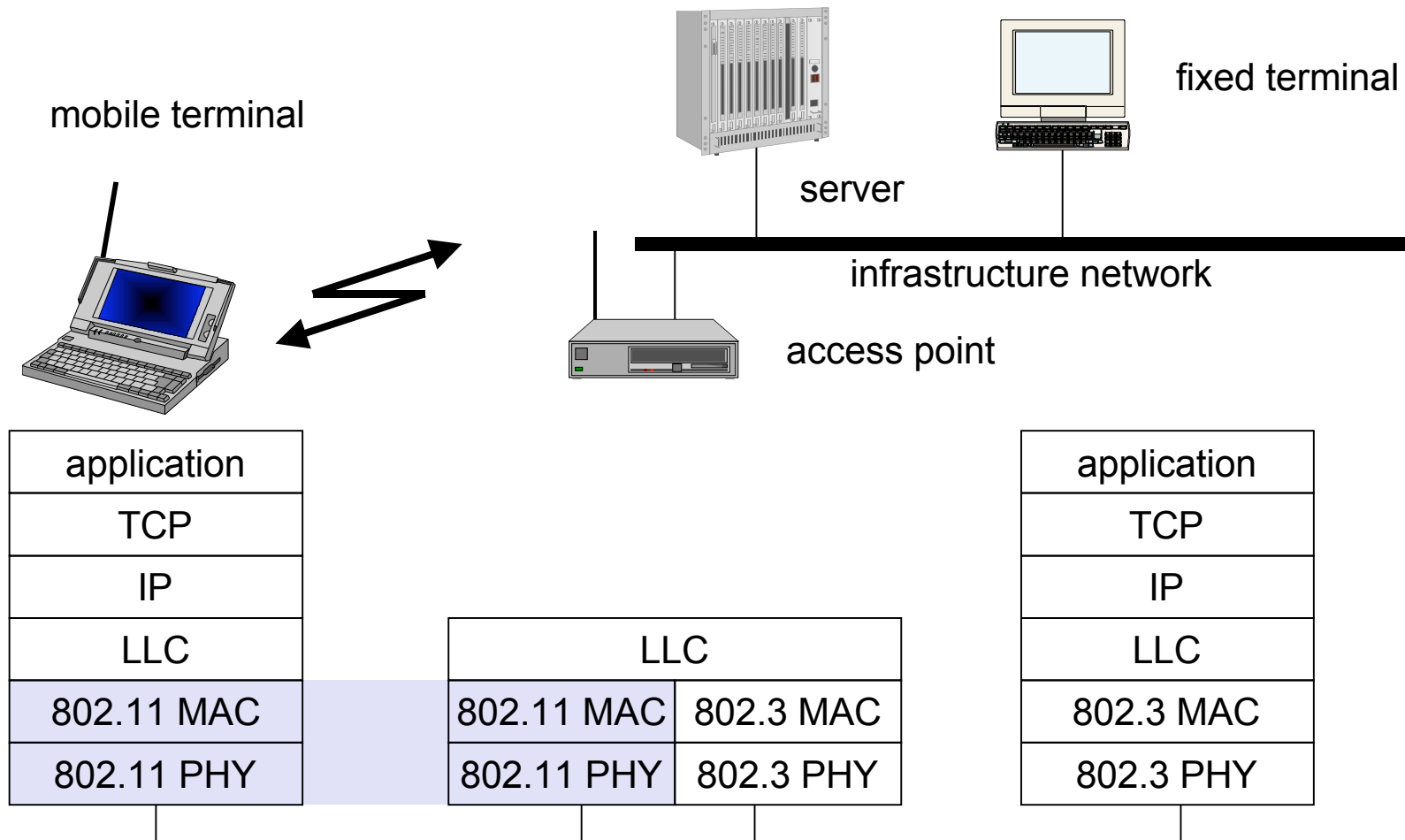 o bridge to other (wired) networks

❑Distribution System
  o interconnection network to form one logical network (EES: Extended Service Set) based on several BSS

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802.11: ad-hoc mode

802.11 LAN

STA$_1$

BSS$_1$

STA$_3$

STA$_2$

BSS$_2$

STA$_5$

STA$_4$

802.11 LAN

❑ Direct communication within a limited range

- o Station (STA): terminal with access mechanisms to the wireless medium
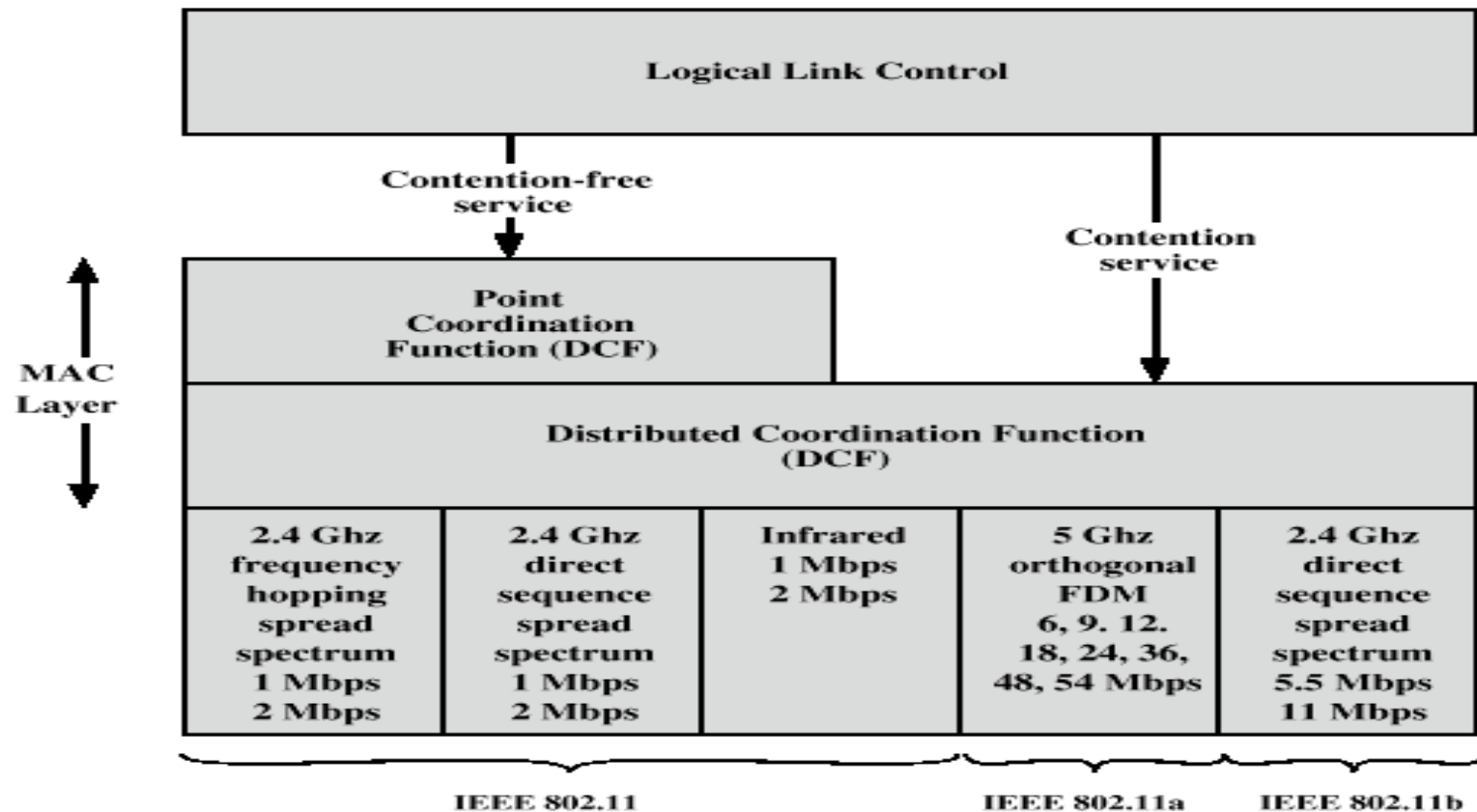- o Basic Service Set (BSS): group of stations in range and using the same radio frequency

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IEEE standard 802.11

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Logical Link Control

Contention-free
service

Contention
service

MAC
Layer

**Point
Coordination
Function (DCF)**

**Distributed Coordination Function
(DCF)**

| 2.4 Ghz frequency hopping spread spectrum 1 Mbps 2 Mbps | 2.4 Ghz direct sequence spread spectrum 1 Mbps 2 Mbps | Infrared 1 Mbps 2 Mbps | 5 Ghz orthogonal FDM 6, 9. 12. 18, 24, 36, 48, 54 Mbps | 2.4 Ghz direct sequence spread spectrum 5.5 Mbps 11 Mbps |

IEEE 802.11   IEEE 802.11a   IEEE 802.11b

Figure 14.5   IEEE 802.11 Protocol Architecture

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802.11 - Physical layer

❑ 2 radio ranges (2.4 GHz and 5 GHz), 1 IR
  o data rates ranging from 1 Mbps to 54 Mbps
❑ FHSS (Frequency Hopping Spread Spectrum) 2.4 GHz
  o spreading, de-spreading, signal strength, typically 1 Mbit/s
  o min. 2.5 frequency hops/s (USA), two-level GFSK modulation
❑ DSSS (Direct Sequence Spread Spectrum) 2.4 GHz
  o DBPSK or DQPSK modulation (Differential Binary Phase Shift Keying or Differential Quadrature PSK)
  o Chipping sequence: +1, -1, +1, +1, -1, +1, +1, +1, -1, -1, -1 (Barker code)
  o Maximum radiated power 1 W (USA), 100 mW (EU), min. 1mW
❑ Infrared
  o 850-950 nm, diffuse light, typically 10 m range
  o Data rates 1-2 Mbps

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IEEE 802.11a and IEEE 802.11b

❑ IEEE 802.11a

   o Makes use of 5-GHz band

   o Provides rates of 6, 9 , 12, 18, 24, 36, 48, 54 Mbps

   o Uses orthogonal frequency division multiplexing (OFDM)

   o Sub-carrier modulated using BPSK, QPSK, 16-QAM or 64-QAM

❑ IEEE 802.11b

   o Provides data rates of 5.5 and 11 Mbps

   o DSSS and complementary code keying (CCK) modulation

802.11 - MAC layer

❑ Traffic services
  o Asynchronous Data Service (mandatory)
    • exchange of data packets based on "best-effort"
    • support of broadcast and multicast
  o Time-Bounded Service (optional)
    • implemented using PCF (Point Coordination Function)
❑ Access methods
  o DCF CSMA/CA (mandatory)
    • collision avoidance via exponential backoff
    • Minimum distance (IFS) between consecutive packets
    • ACK packet for acknowledgements (not for broadcasts)
  o DCF with RTS/CTS (optional)
    • Distributed Foundation Wireless MAC
    • avoids hidden terminal problem
  o PCF (optional)
   • access point polls terminals according to a list

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802.11 - MAC layer

❑ Priorities
  o defined through different inter frame spaces
  o SIFS (Short Inter Frame Spacing)
    • highest priority, for ACK, CTS, polling response
  o PIFS (PCF IFS)
    • medium priority, for time-bounded service using PCF
  o DIFS (DCF, Distributed Coordination Function IFS)
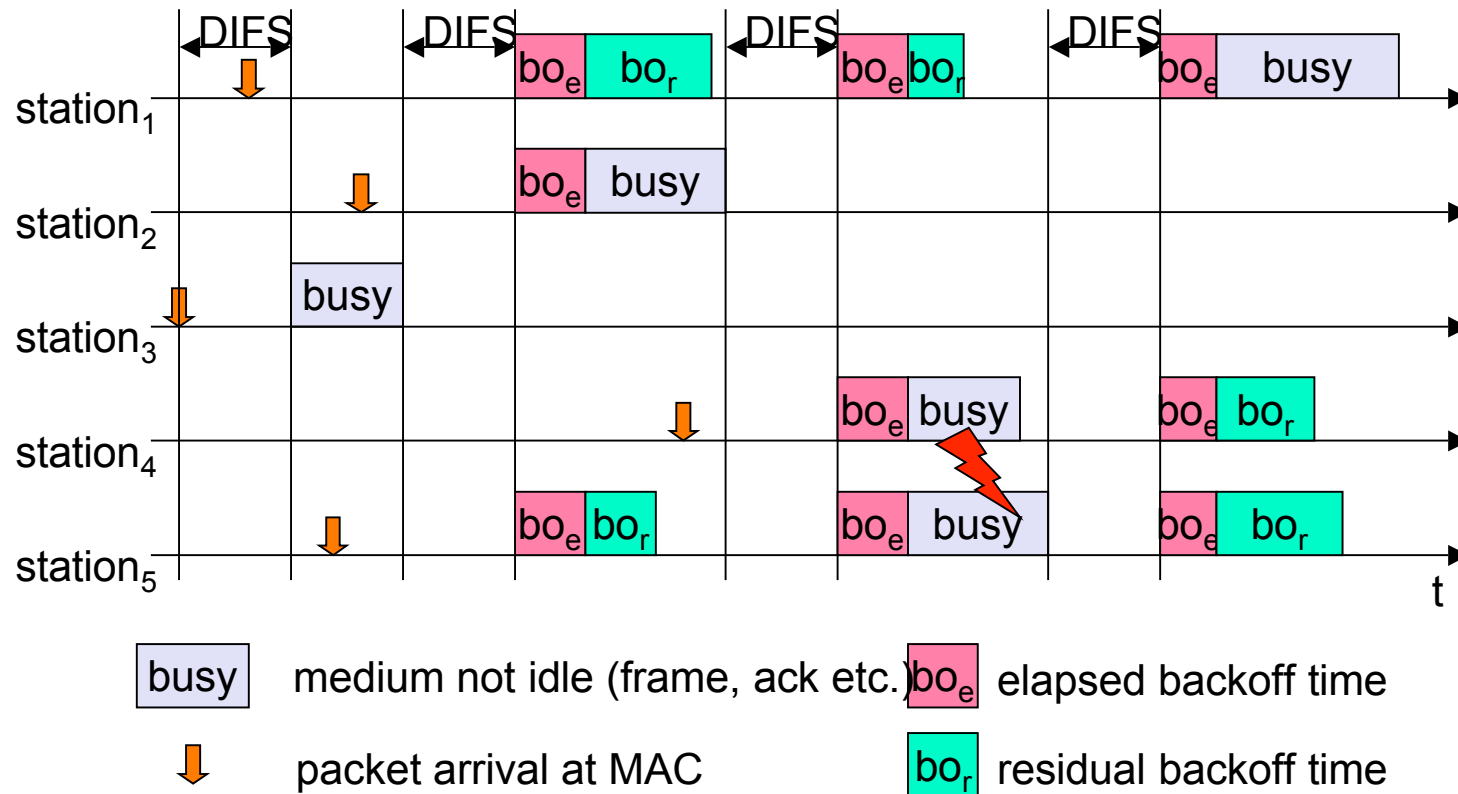   • lowest priority, for asynchronous data service

direct access if
medium is free ≥ DIFS

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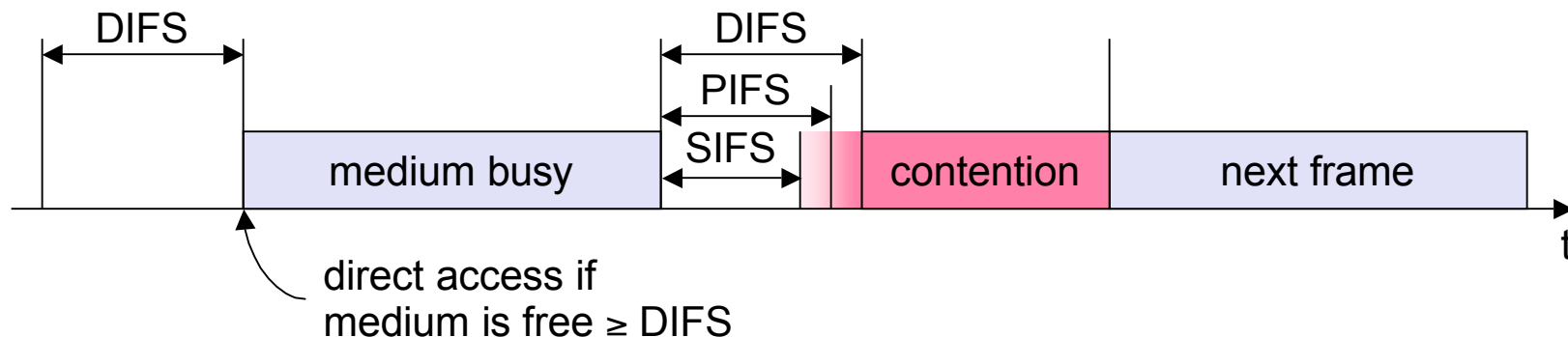
CSMA/CA access method
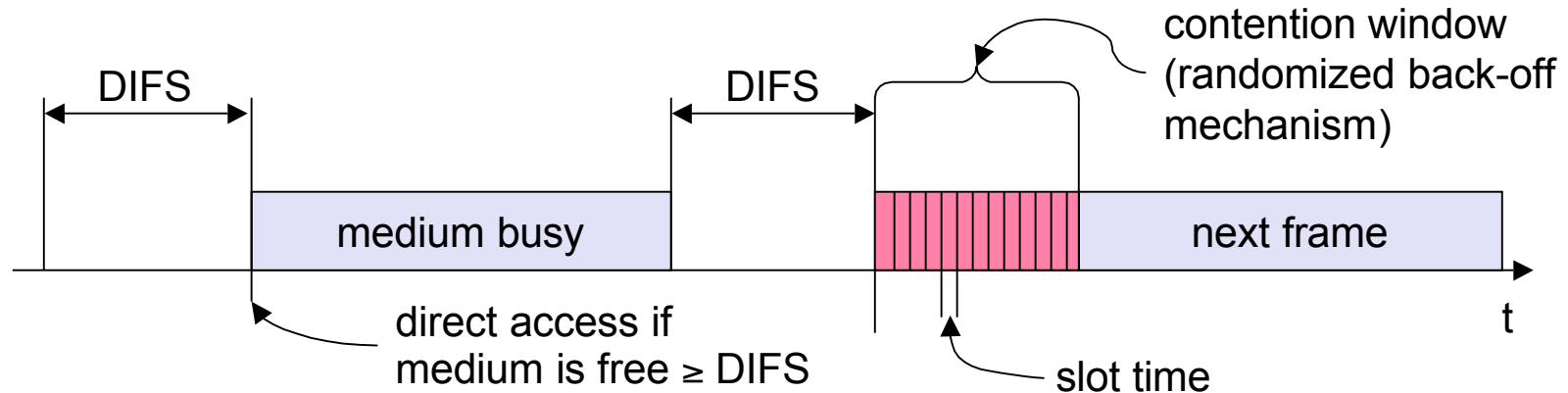
- ❑ Station ready to send starts sensing the medium (Carrier Sense based on CCA, Clear Channel Assessment)
- ❑ If the medium is free for the duration of an Inter-Frame Space (IFS), the station can start sending (IFS depends on service type)
- ❑ If the medium is busy, the station has to wait for a free IFS, then the station must additionally wait a random back-off time (collision avoidance, multiple of slot-time)
- ❑ If another station occupies the medium during the back-off time of the station, the back-off timer stops (fairness)

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Contending stations

busy	medium not idle (frame, ack etc.)	bo_e elapsed backoff time
⬇	packet arrival at MAC	bo_r residual backoff time

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802.11 access scheme details

❑ Sending unicast packets
  o station has to wait for DIFS before sending data
  o receivers acknowledge at once (after waiting for SIFS) if the packet was received correctly (CRC)
 o automatic retransmission of data packets in case of transmission errors

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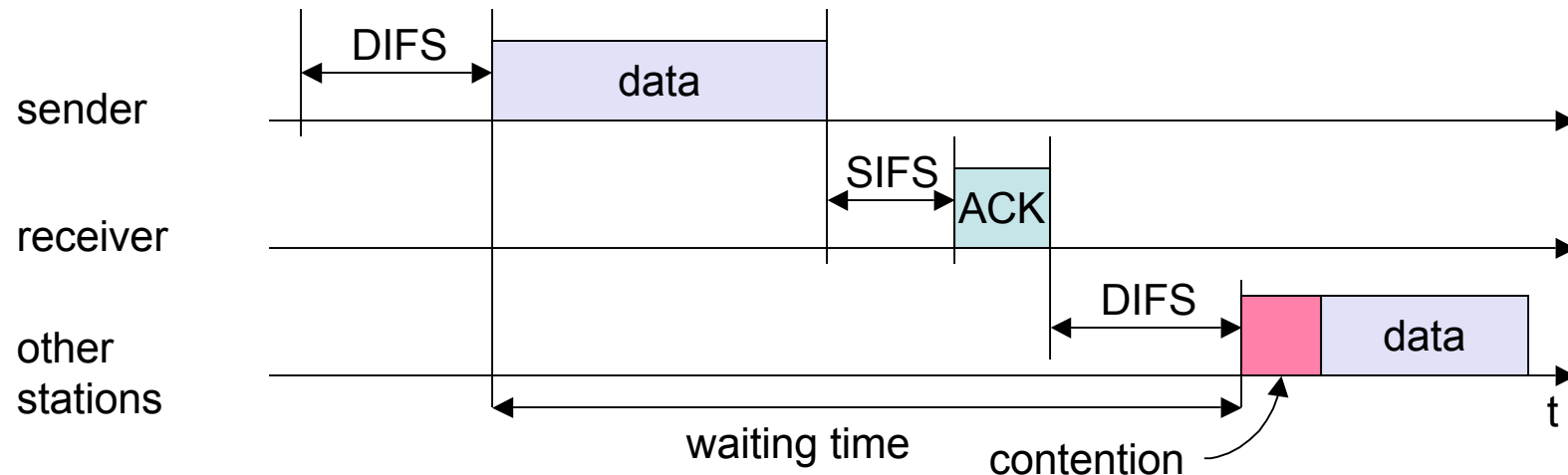
802.11 access scheme details

- ❑ Sending unicast packets
  - o station can send RTS with reservation parameter after waiting for DIFS (reservation determines amount of time the data packet needs the medium)
  - o ack via CTS after SIFS by receiver (if ready to receive)
  - o sender can now send data at once, acknowledgement via ACK
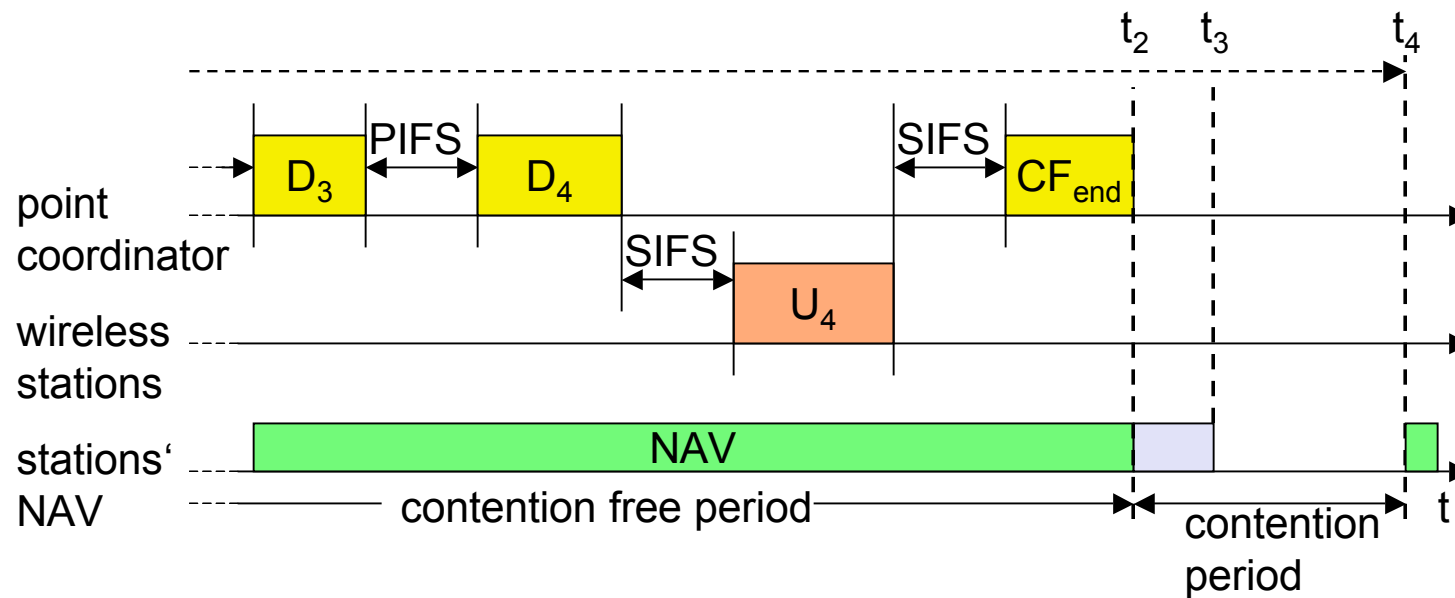 - o other stations store reservations distributed via RTS and CTS

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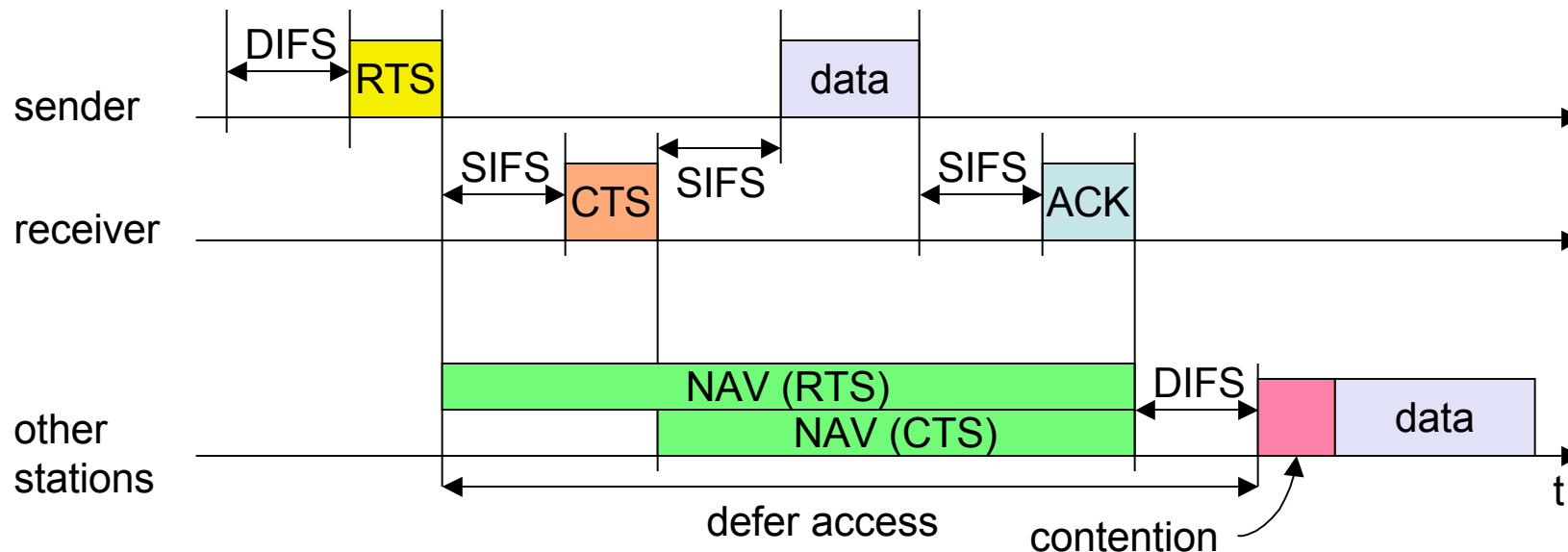
Fragmentation
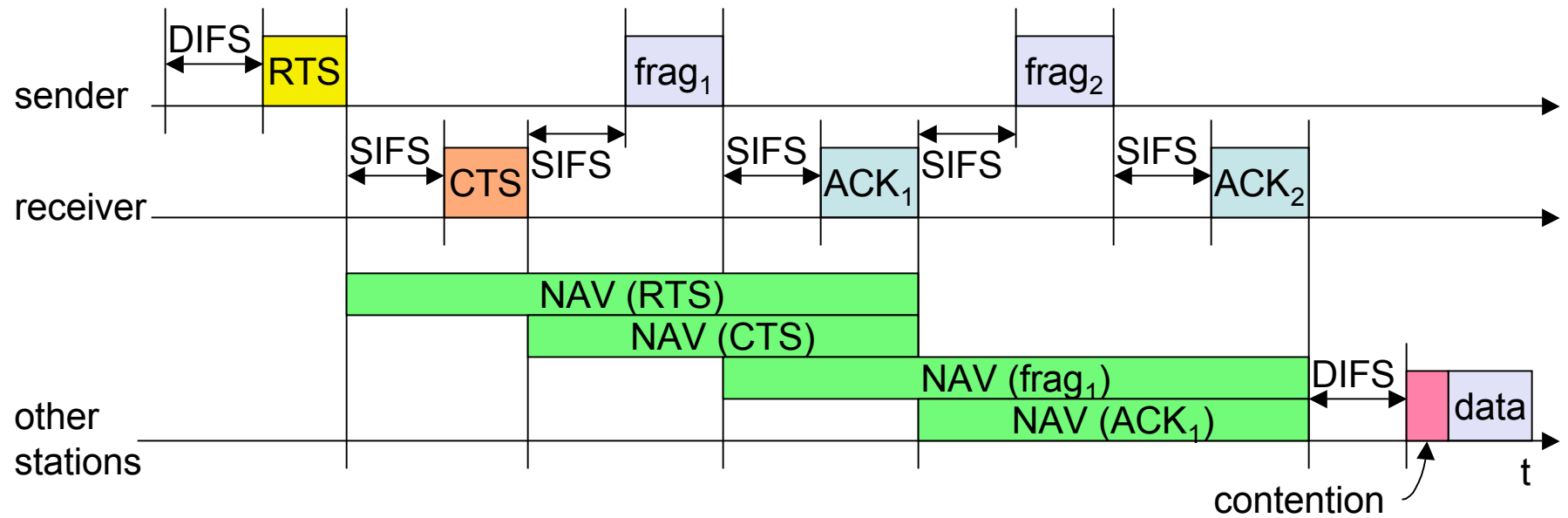
Point Coordination Function

Point Coordination Function

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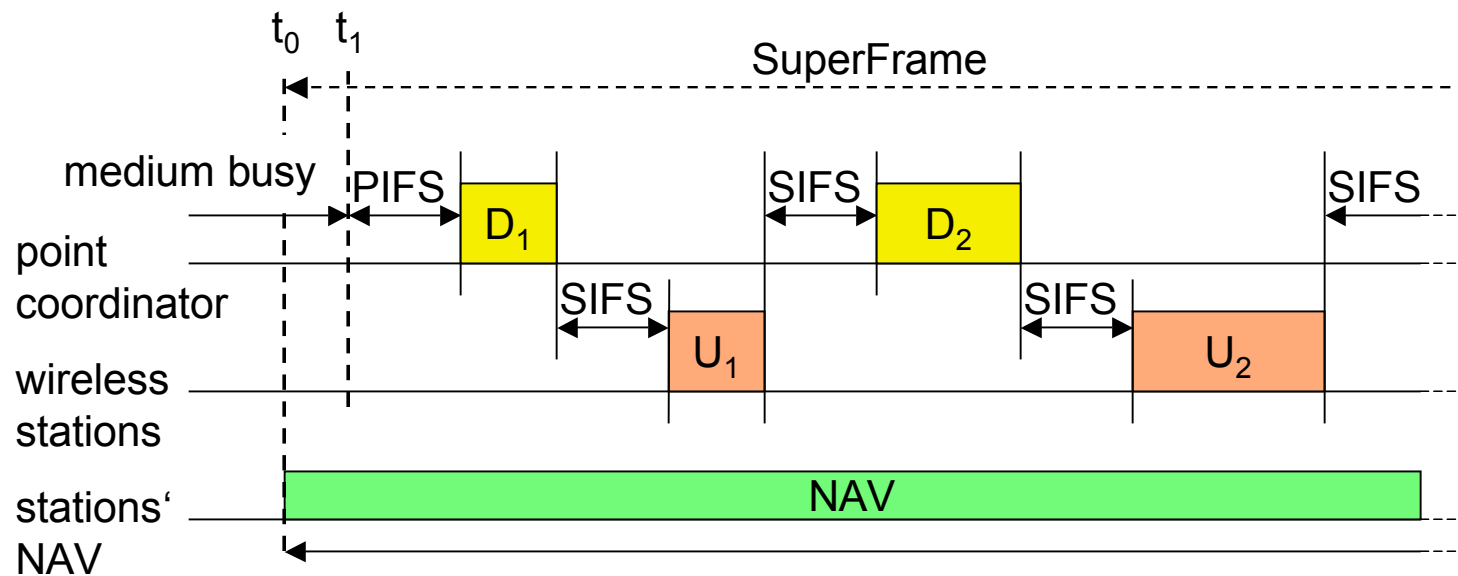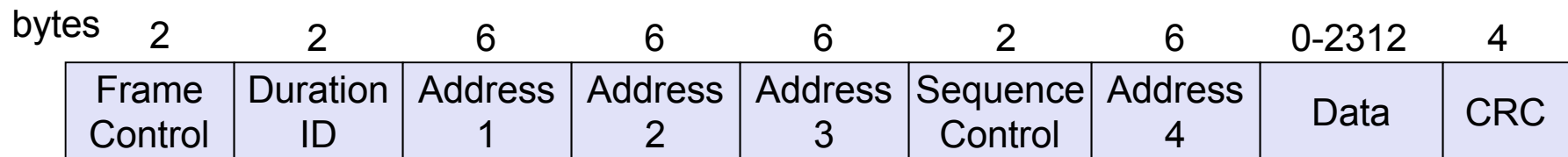
802.11 - Frame format

- ❑ Types
  - o control frames, management frames, data frames
- ❑ Sequence numbers
  - o important against duplicated frames due to lost ACKs
- ❑ Addresses
  - o receiver, transmitter (physical), BSS identifier, sender (logical)
- ❑ Miscellaneous
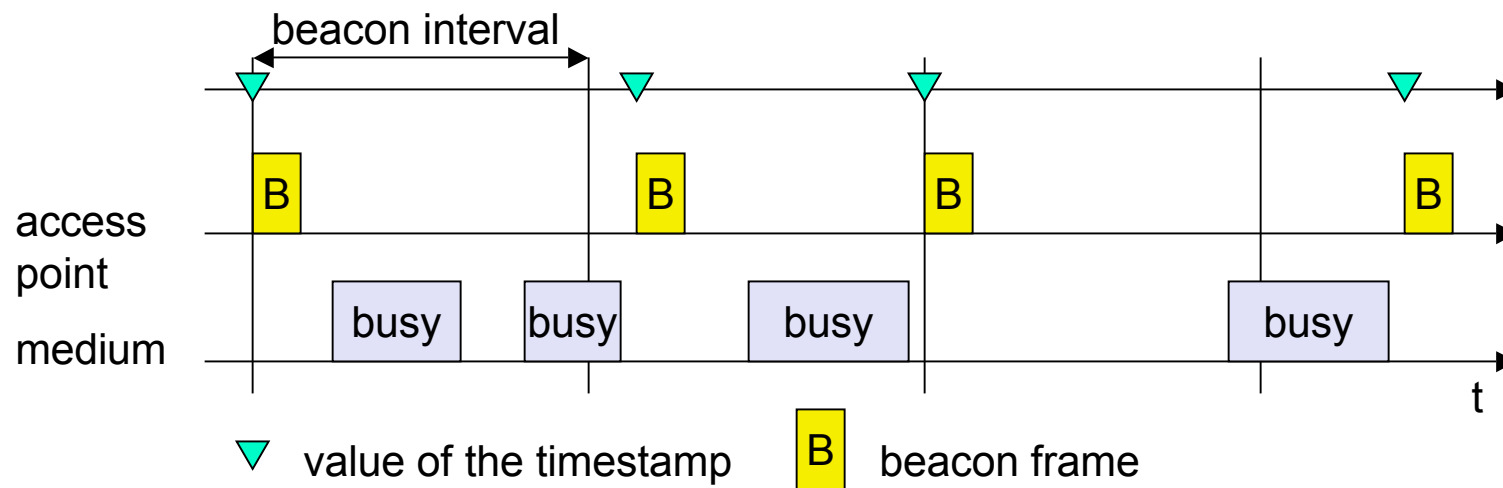 - o sending time, checksum, frame control, data

bytes 2	2	6	6	6	2	6	0-2312	4
Frame Control	Duration ID	Address 1	Address 2	Address 3	Sequence Control	Address 4	Data	CRC

Version, Type, Subtype, To DS, From DS, More Fragments, Retry, Power Management, More Data, Wired Equivalent Privacy (WEP), and Order
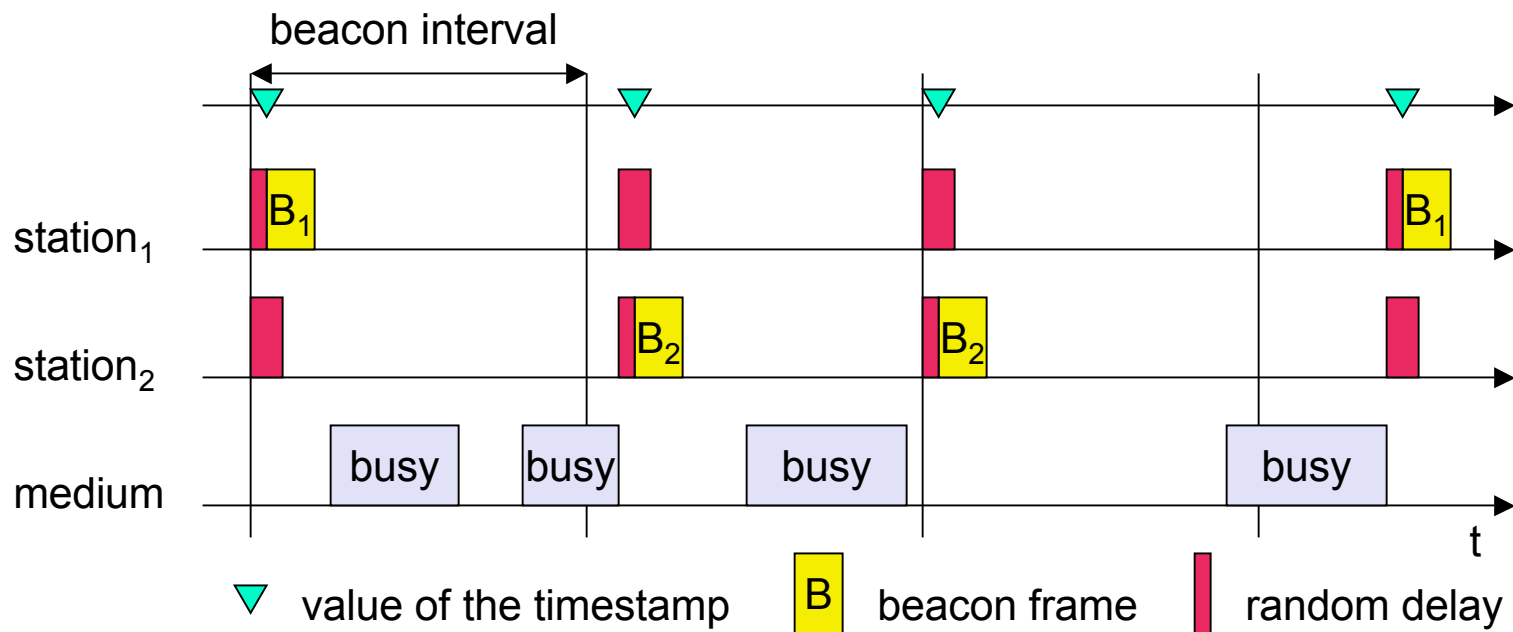
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802.11 MAC management

❑ Synchronization
  o try to find a LAN, try to stay within a LAN
  o timer etc.

❑ Power management
  o sleep-mode without missing a message
  o periodic sleep, frame buffering, traffic measurements

❑ Association/Reassociation
  o integration into a LAN
  o roaming, i.e. change networks by changing access points
  o scanning, i.e. active search for a network

❑ MIB - Management Information Base
  o managing, read, write

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Synchronization (infrastructure)

beacon interval

access
point

medium

t

▽ value of the timestamp   B beacon frame

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Synchronization (ad-hoc)

Power management

❑ Idea: switch the transceiver off if not needed

❑ States of a station: sleep and awake

❑ Timing Synchronization Function (TSF)

   o stations wake up at the same time

❑ Infrastructure

   o Traffic Indication Map (TIM)

      • list of unicast receivers transmitted by AP

   o Delivery Traffic Indication Map (DTIM)

      • list of broadcast/multicast receivers transmitted by AP

❑ Ad-hoc

   o Ad-hoc Traffic Indication Map (ATIM)

      • announcement of receivers by stations buffering frames

      • more complicated - no central AP

      • collision of ATIMs possible

Power saving (infrastructure)

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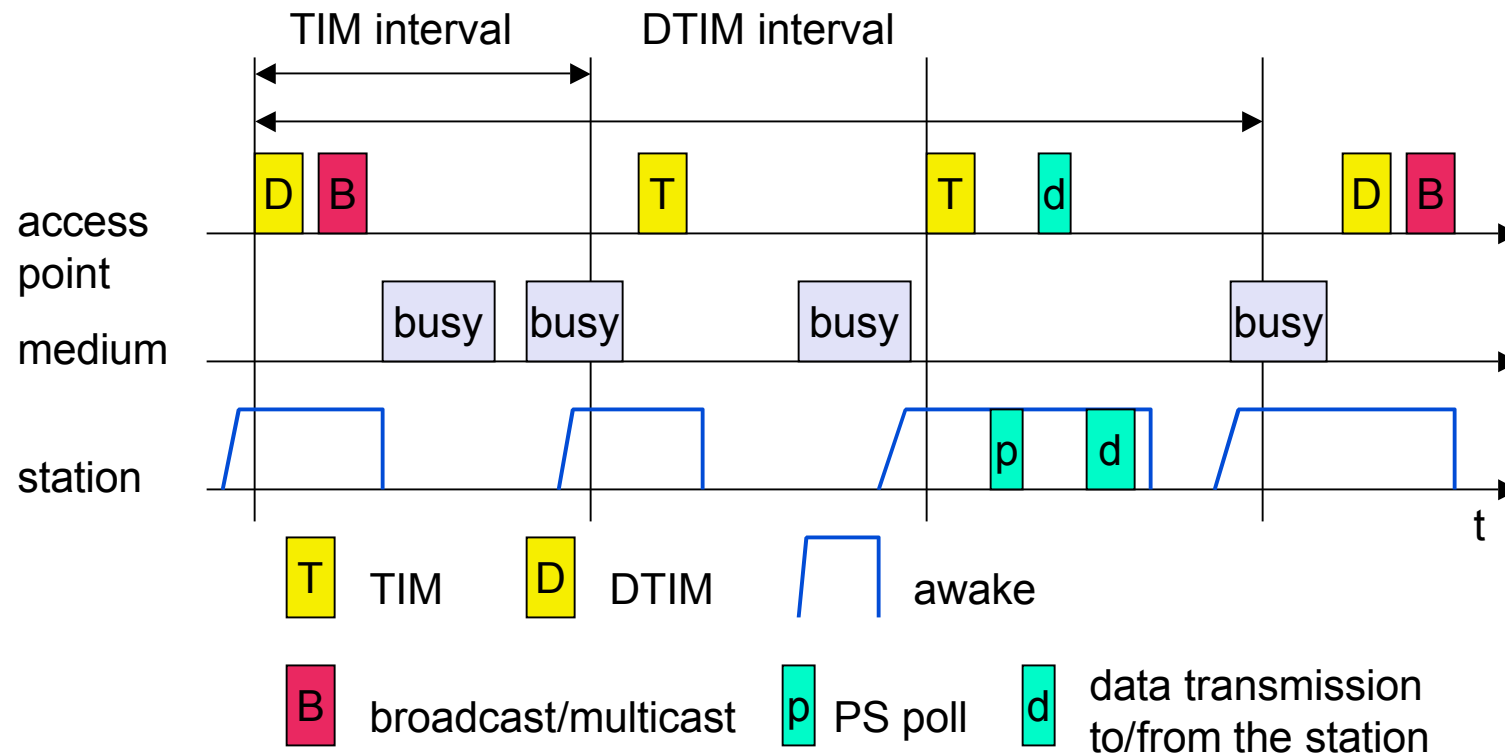
Power saving (ad-hoc)
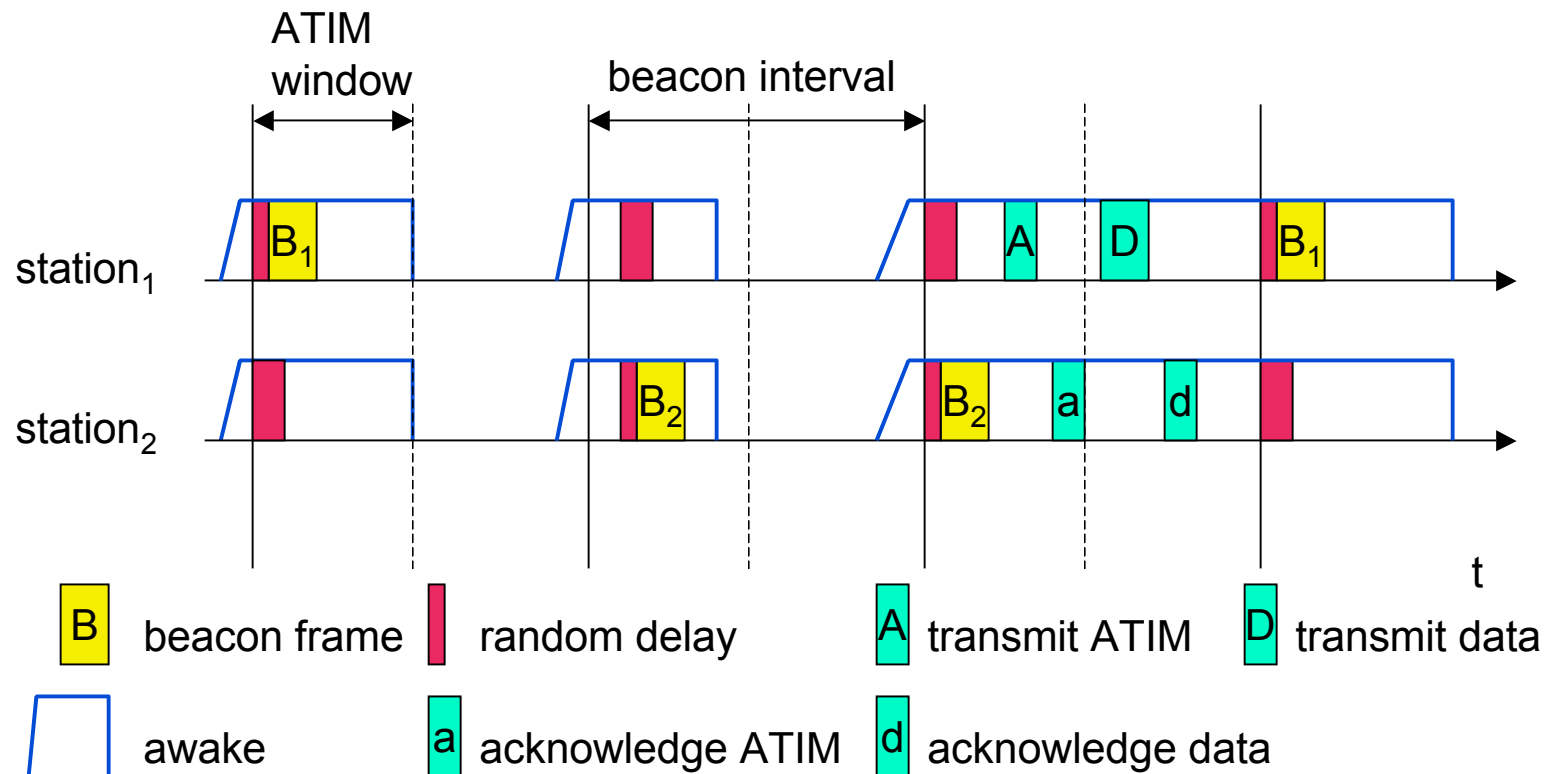
802.11 - Roaming

❑ No or bad connection?
❑ Scanning
  o scan the environment, i.e., listen into the medium for beacon signals (passive) or send probes (active) into the medium and wait for an answer
❑ Reassociation Request
  o station sends a request to one or several AP(s)
❑ Reassociation Response
  o success: AP has answered, station can now participate
  o failure: continue scanning
❑ AP accepts Reassociation Request
  o signal the new station to the distribution system
  o the distribution system updates its data base (i.e., location information)
  o typically, the distribution system now informs the old AP so it can release resources

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