Introduction to Wireless Networks

Chapter 2: Introduction to IEEE 802.11

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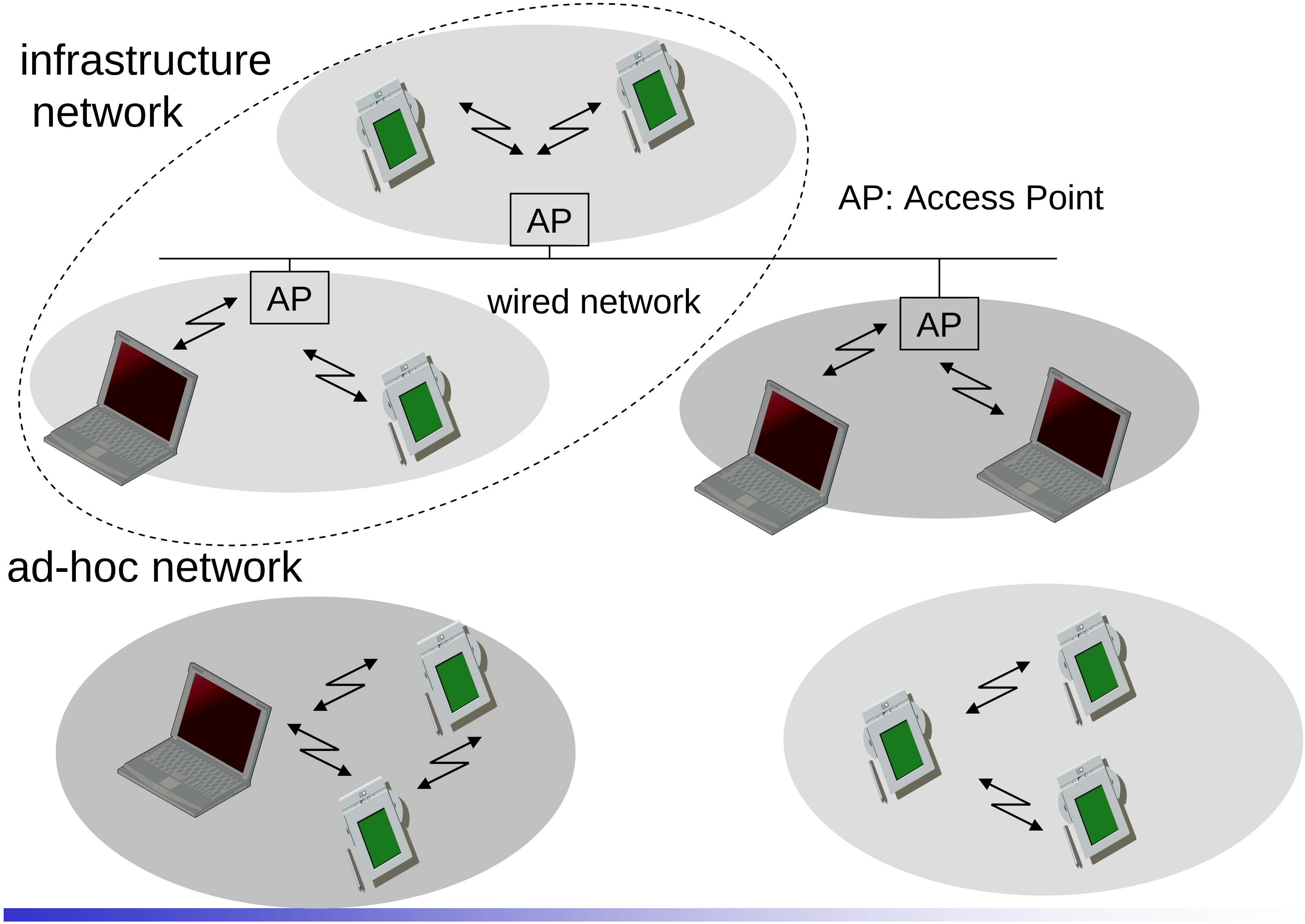
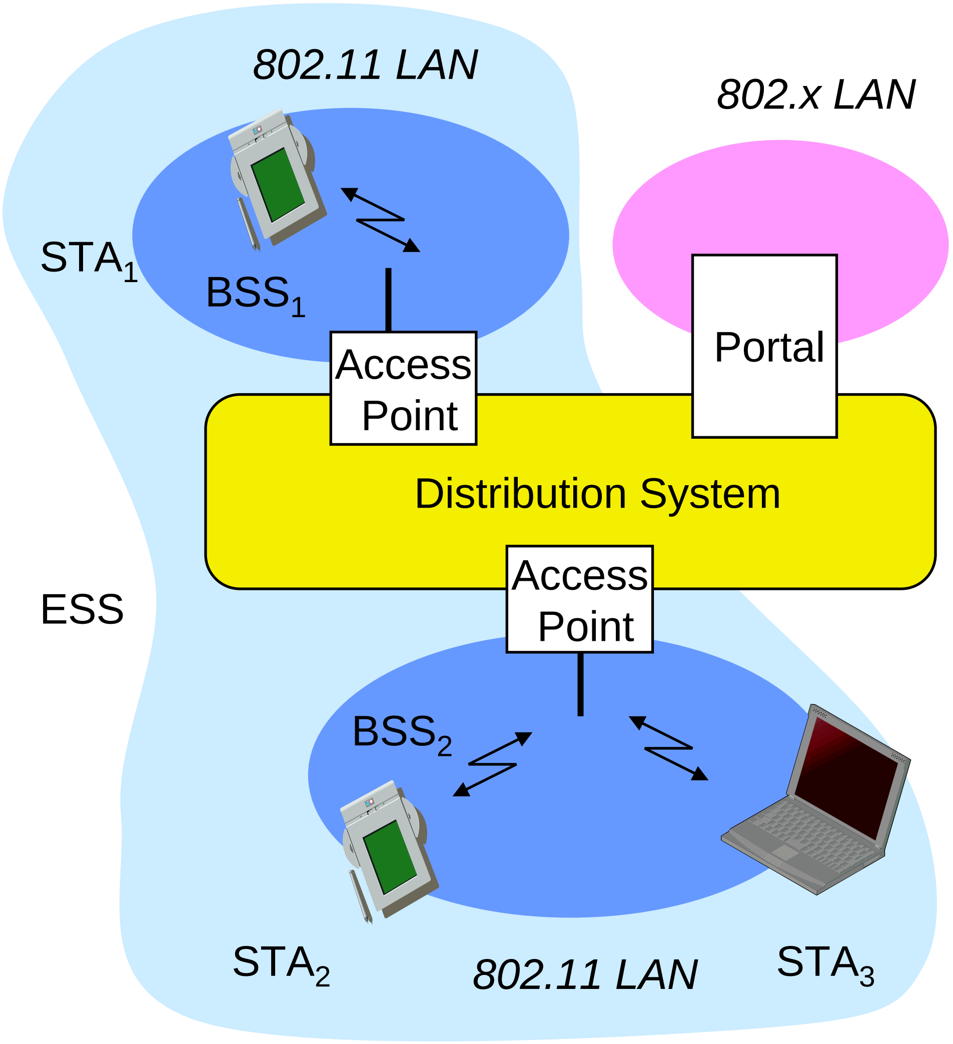
Chapter 2: Introduction to IEEE 802.11

- ❑IEEE 802.11
  - ❑ PHY
  - ❑ MAC
  - ❑ Roaming
  - ❑ .11a, b, g, h, i …
- ❑ HIPERLAN
  - ❑ Standards overview
  - ❑ HiperLAN2
  - ❑ QoS

Comparison: infrastructure vs. ad-hoc networks



802.11 - Architecture of an infrastructure network



Station (STA)

- ❑ terminal with access mechanisms to the wireless medium and radio contact to the access point

Basic Service Set (BSS)

- ❑ group of stations using the same radio frequency

Access Point

- ❑ station integrated into the wireless LAN and the distribution system

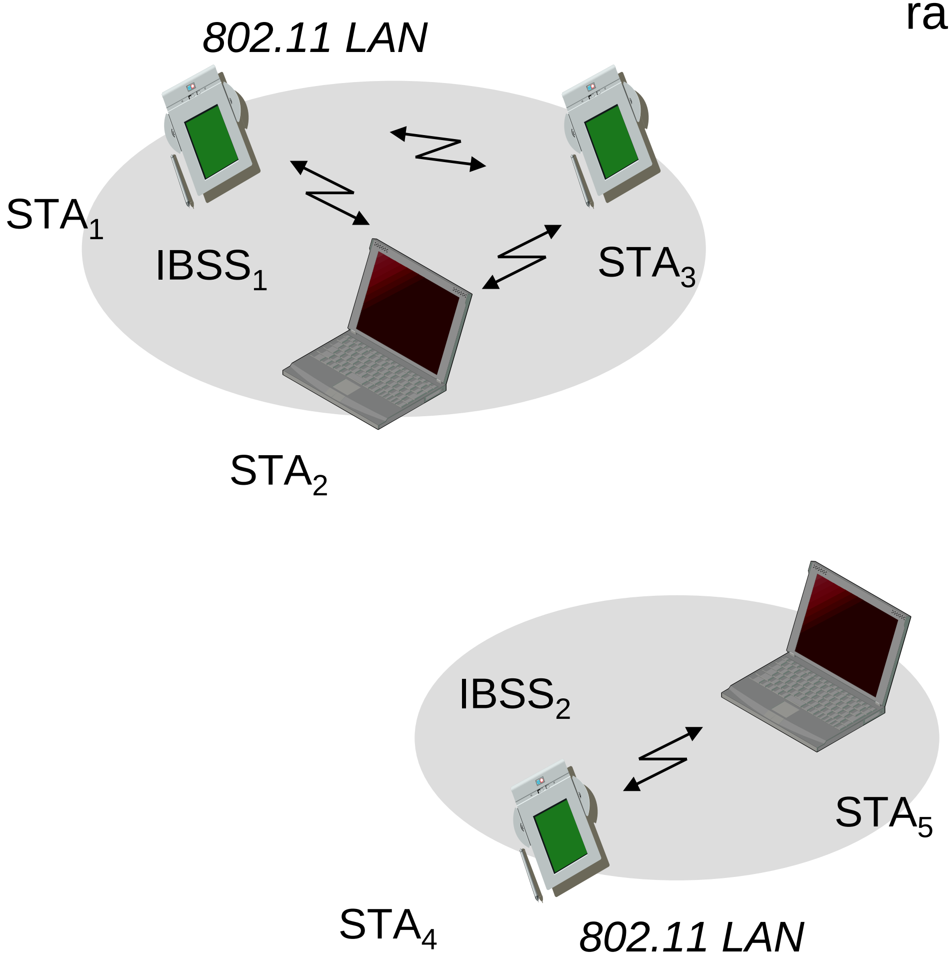
Portal

- ❑ bridge to other (wired) networks

Distribution System

- ❑ interconnection network to form one logical network (ESS: Extended Service Set) based on several BSS

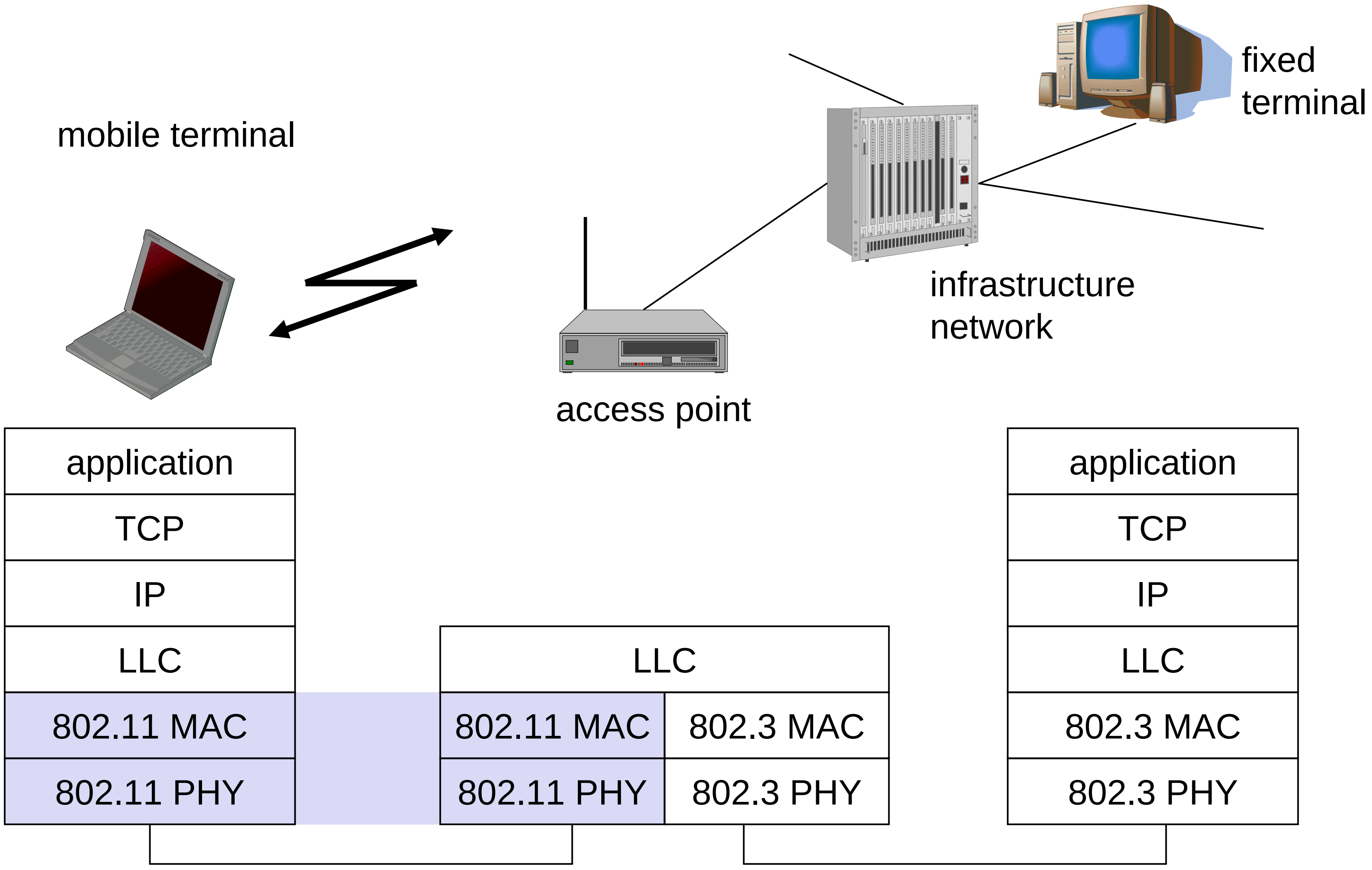
802.11 - Architecture of an ad-hoc network



Direct communication within a limited range

- ❑ Station (STA):
  terminal with access mechanisms to the wireless medium
- ❑ Independent Basic Service Set (IBSS):
  group of stations using the same radio frequency

IEEE standard 802.11



application			application
TCP			TCP
IP			IP
LLC	LLC		LLC
802.11 MAC	802.11 MAC	802.3 MAC	802.3 MAC
802.11 PHY	802.11 PHY	802.3 PHY	802.3 PHY

802.11 - Layers and functions

MAC

- ❑ access mechanisms, fragmentation, encryption

MAC Management

- ❑ synchronization, roaming, MIB, power management

PLCP Physical Layer Convergence Protocol

- ❑ clear channel assessment signal (carrier sense)

PMD Physical Medium Dependent

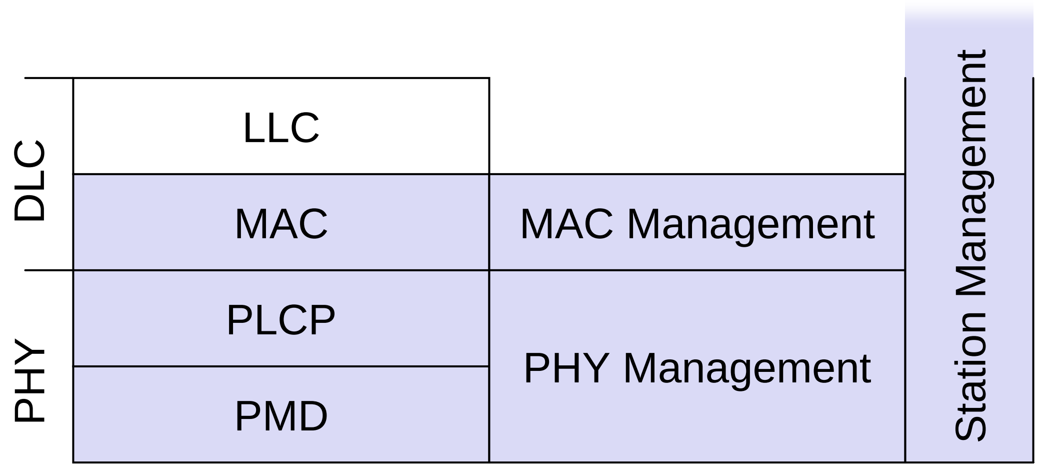
- ❑ modulation, coding

PHY Management

- ❑ channel selection, MIB

Station Management

- ❑ coordination of all management functions


DLC
LLC
MAC
MAC Management
PHY
PLCP
PMD
PHY Management
Station Management

802.11 - Physical layer

3 versions: 2 radio (typ. 2.4 GHz), 1 IR

- ❑ data rates 1 or 2 Mbit/s

FHSS (Frequency Hopping Spread Spectrum)

- ❑ spreading, despreading, signal strength, typ. 1 Mbit/s
- ❑ min. 2.5 frequency hops/s (USA), two-level GFSK modulation

DSSS (Direct Sequence Spread Spectrum)

- ❑ DBPSK modulation for 1 Mbit/s (Differential Binary Phase Shift Keying), DQPSK for 2 Mbit/s (Differential Quadrature PSK)
- ❑ preamble and header of a frame is always transmitted with 1 Mbit/s, rest of transmission 1 or 2 Mbit/s
- ❑ chipping sequence: +1, -1, +1, +1, -1, +1, +1, +1, -1, -1, -1 (Barker code)
- ❑ max. radiated power 1 W (USA), 100 mW (EU), min. 1mW

Infrared

- ❑ 850-950 nm, diffuse light, typ. 10 m range
- ❑ carrier detection, energy detection, synchonization

FHSS PHY packet format

Synchronization

- ❑ synch with 010101... pattern

SFD (Start Frame Delimiter)

- ❑ 0000110010111101 start pattern

PLW (PLCP_PDU Length Word)

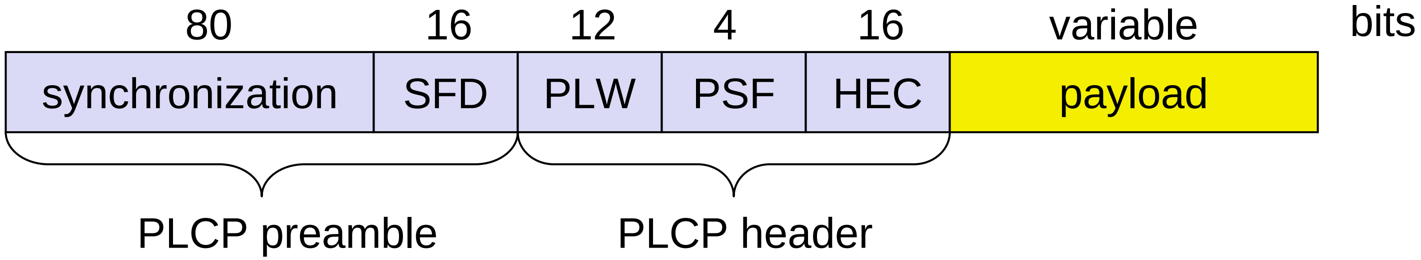
- ❑ length of payload incl. 32 bit CRC of payload, PLW < 4096

PSF (PLCP Signaling Field)

- ❑ data of payload (1 or 2 Mbit/s)

HEC (Header Error Check)

- ❑ CRC with $x^{16}+x^{12}+x^5+1$



80	16	12	4	16	variable	bits
synchronization	SFD	PLW	PSF	HEC	payload	

PLCP preamble

PLCP header

DSSS PHY packet format

Synchronization

- ❑ synch., gain setting, energy detection, frequency offset compensation

SFD (Start Frame Delimiter)

- ❑ 1111001110100000

Signal

- ❑ data rate of the payload (0A: 1 Mbit/s DBPSK; 14: 2 Mbit/s DQPSK)

Service

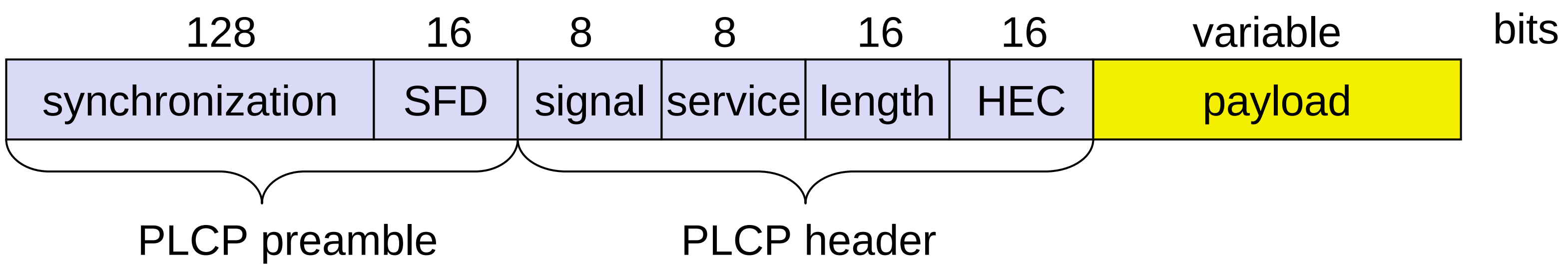
- ❑ future use, 00: 802.11 compliant

Length

- ❑ length of the payload

HEC (Header Error Check)

- ❑ protection of signal, service and length, $x^{16}+x^{12}+x^5+1$



802.11 - MAC layer I – DFWMAC (distributed foundation wireless medium access control)

Traffic services

- ❑ Asynchronous Data Service (mandatory)
  - exchange of data packets based on “best-effort”
  - support of broadcast and multicast
- ❑ Time-Bounded Service (optional)
  - implemented using PCF (Point Coordination Function)

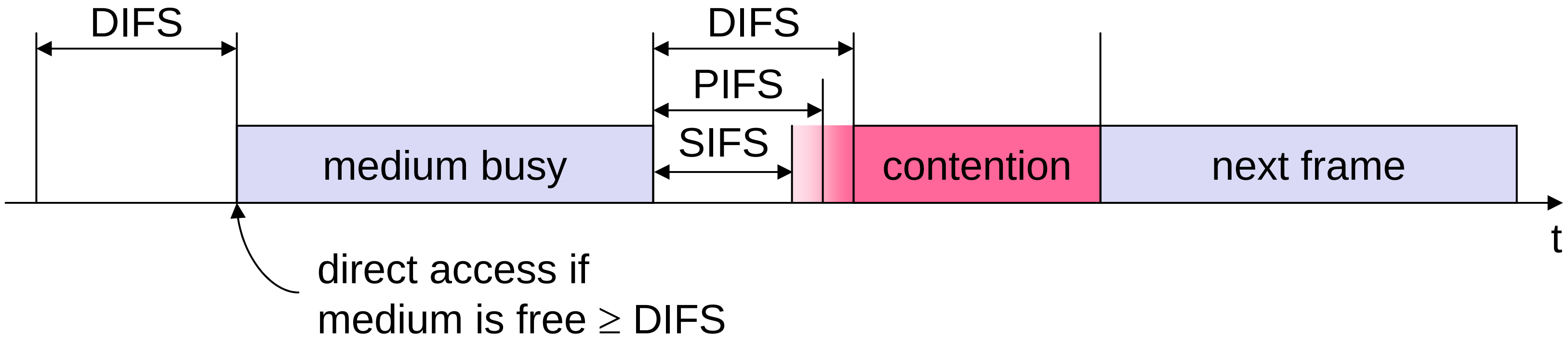
Access methods

- ❑ DFWMAC-DCF CSMA/CA (mandatory)
  - collision avoidance via randomized „back-off“ mechanism
  - minimum distance between consecutive packets
  - ACK packet for acknowledgements (not for broadcasts)
- ❑ DFWMAC-DCF w/ RTS/CTS (optional)
  - Distributed Foundation Wireless MAC
  - avoids hidden terminal problem
- ❑ DFWMAC- PCF (optional)
  - access point polls terminals according to a list

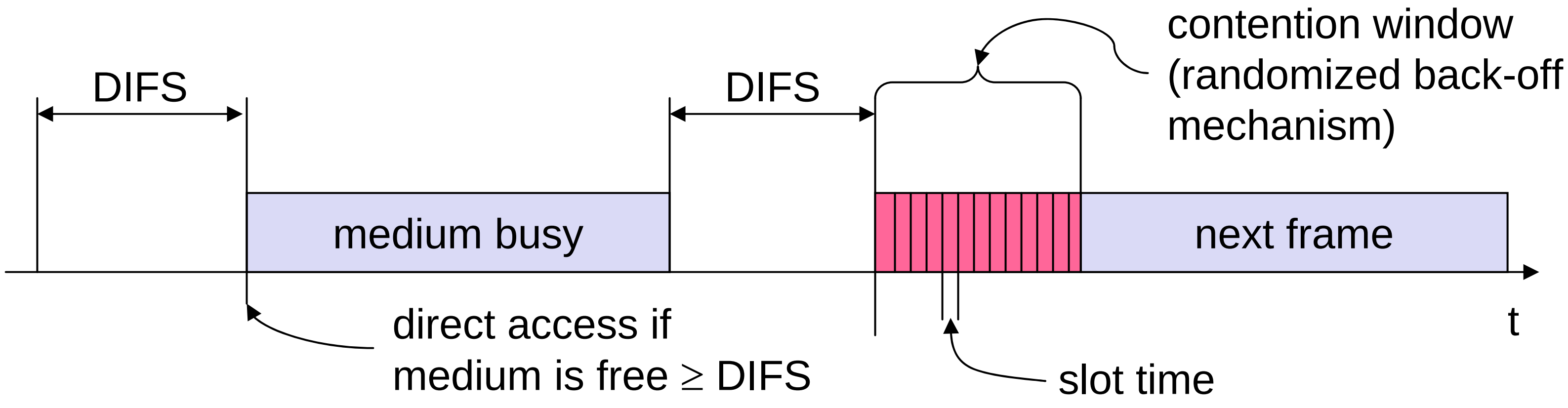
802.11 - MAC layer II

Priorities

- defined through different inter frame spaces
- no guaranteed, hard priorities
- SIFS (Short Inter Frame Spacing)
  - highest priority, for ACK, CTS, polling response
- PIFS (PCF IFS)
  - medium priority, for time-bounded service using PCF
- DIFS (DCF, Distributed Coordination Function IFS)
  - lowest priority, for asynchronous data service

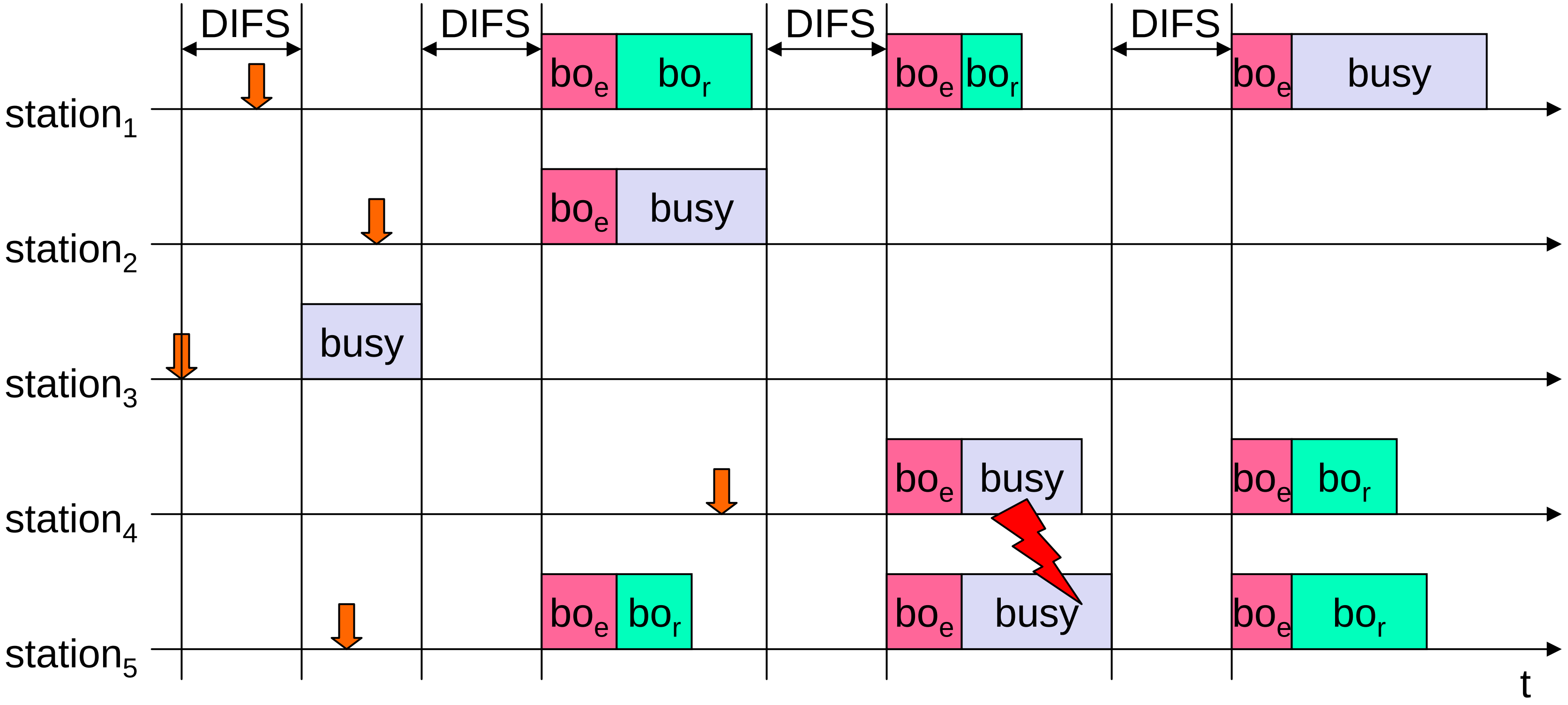


802.11 - CSMA/CA access method I



- 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)

802.11 - competing stations - simple version

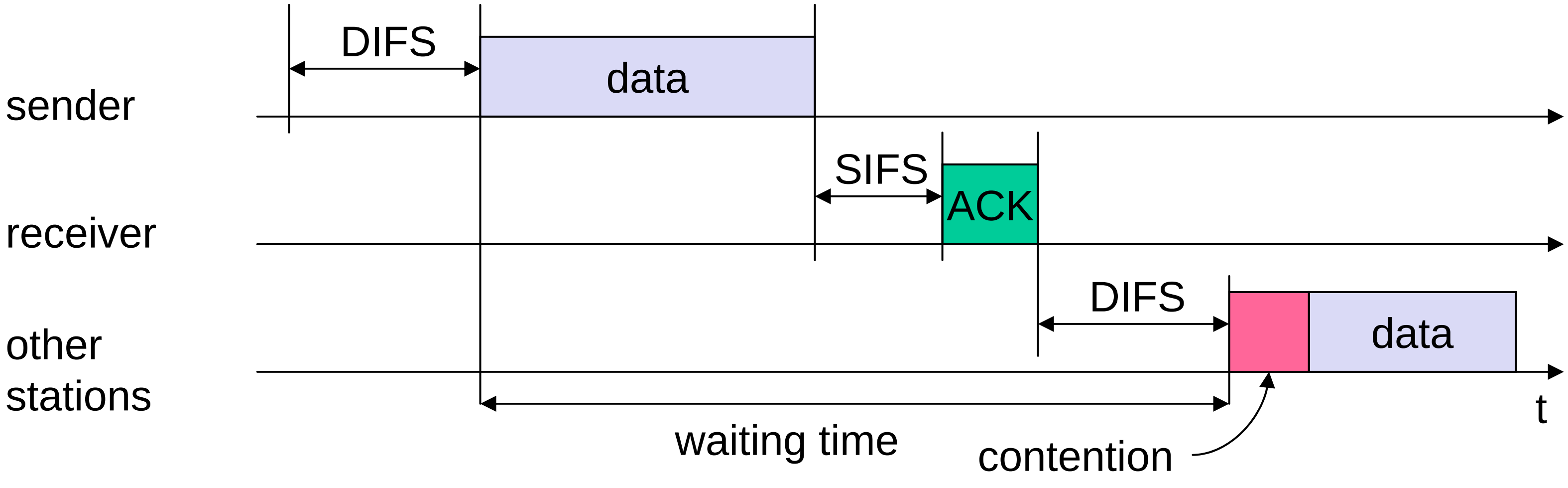


busy	medium not idle (frame, ack etc.)	bo$_e$	elapsed backoff time
⇩	packet arrival at MAC	bo$_r$	residual backoff time

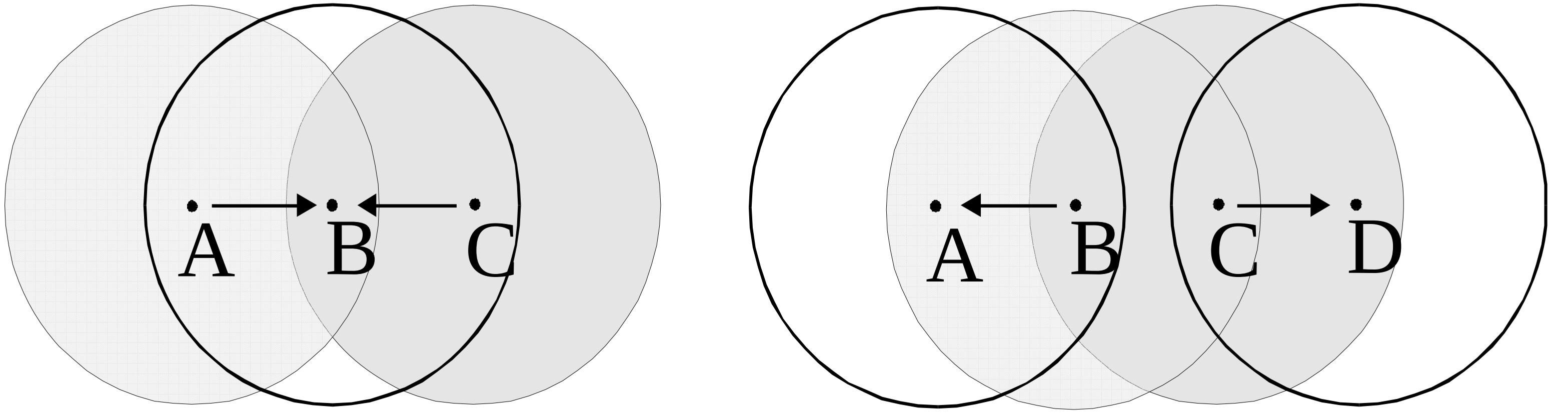
802.11 - CSMA/CA access method II

Sending unicast packets

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



Hidden-Terminal and Exposed-Terminal Problems



(a)

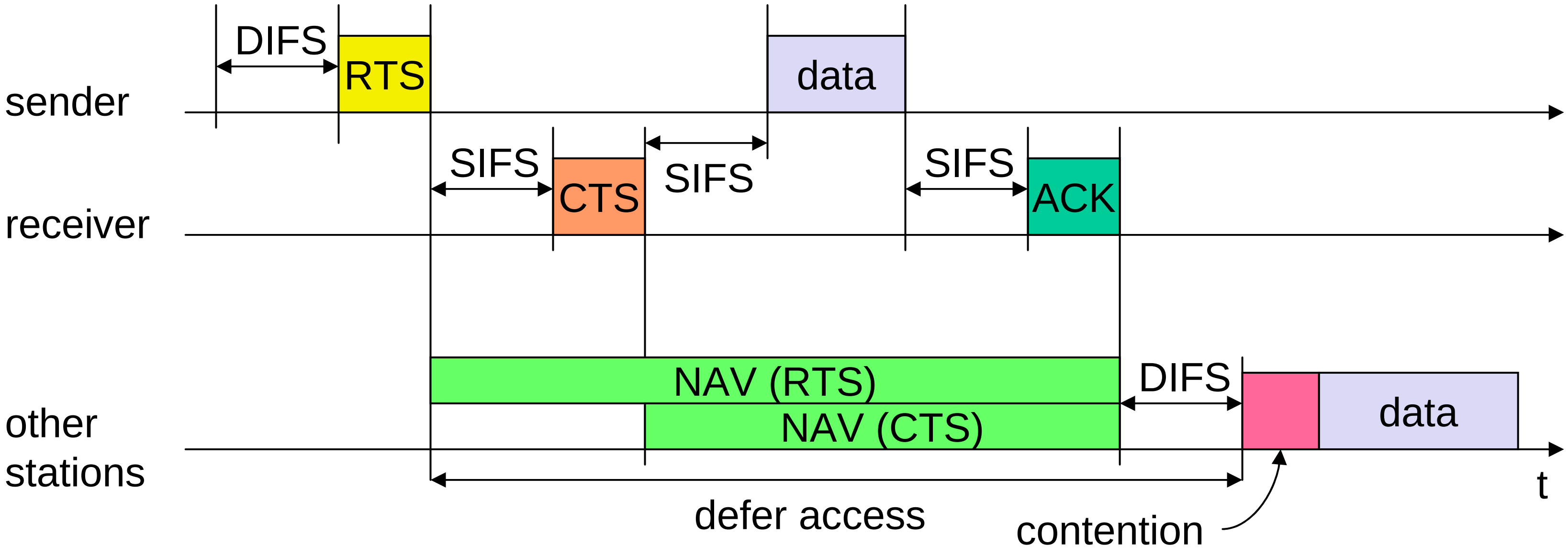
(b)

Fig. 1: (a) the hidden terminal problem,
(b) the exposed terminal problem

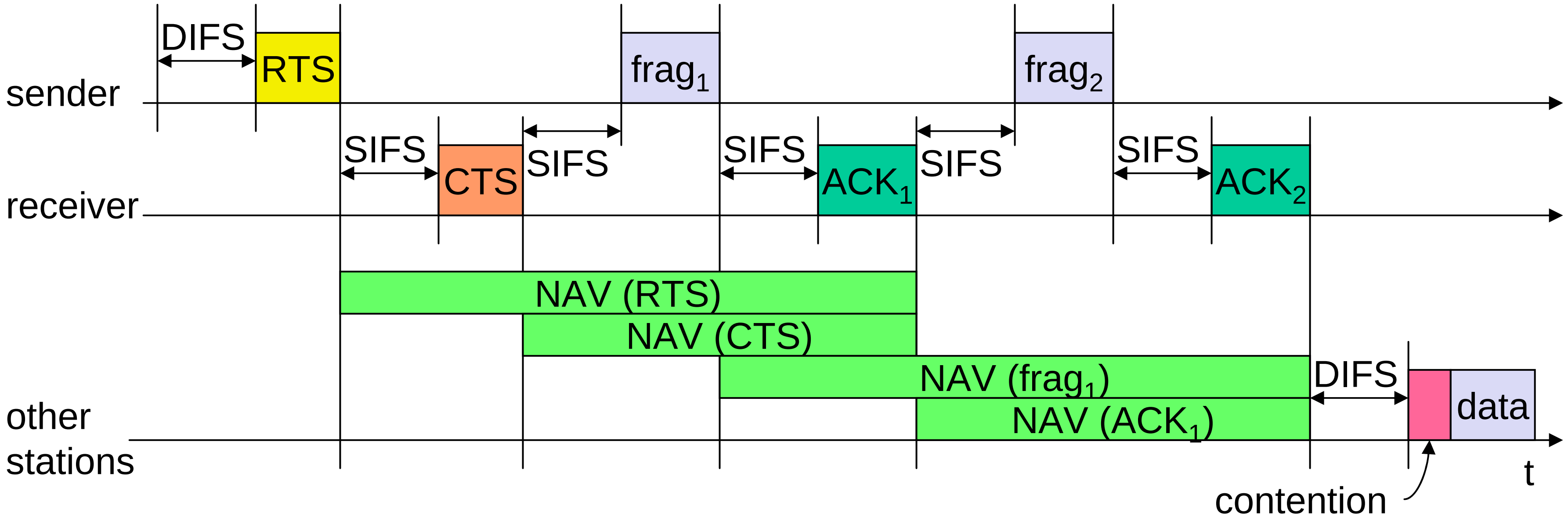
802.11 - DFWMAC

Sending unicast packets

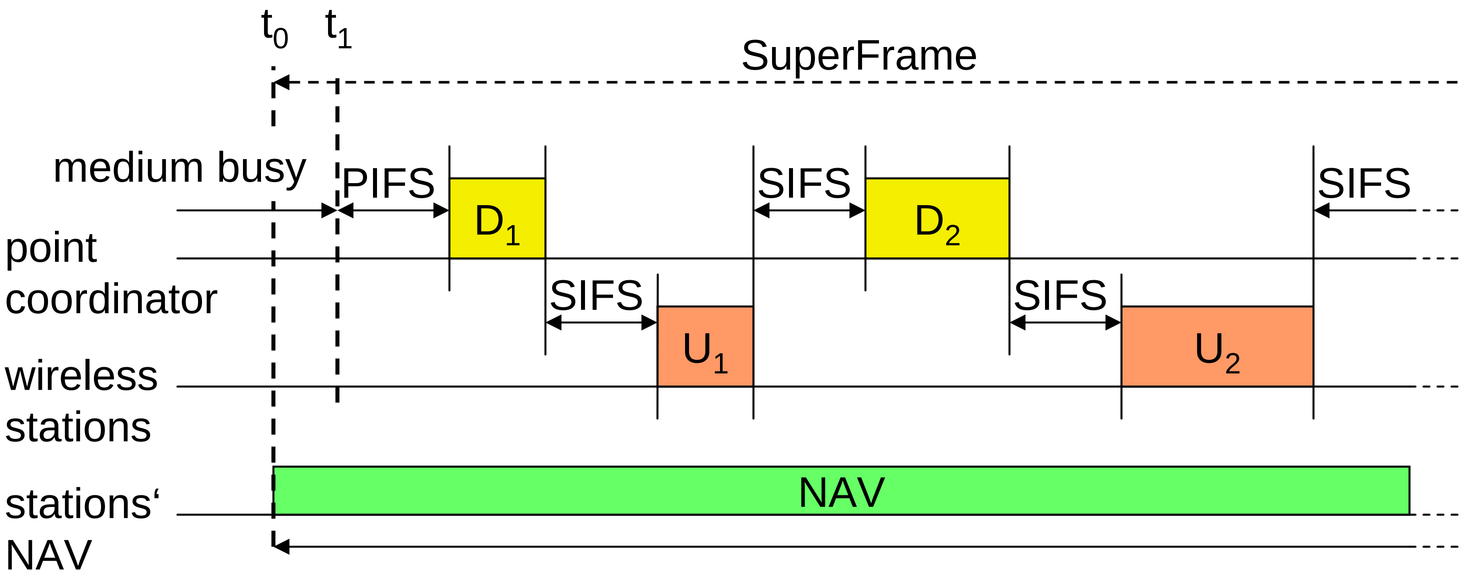
- station can send RTS with reservation parameter after waiting for DIFS (reservation determines amount of time the data packet needs the medium)
- acknowledgement via CTS after SIFS by receiver (if ready to receive)
- sender can now send data at once, acknowledgement via ACK
- other stations store medium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



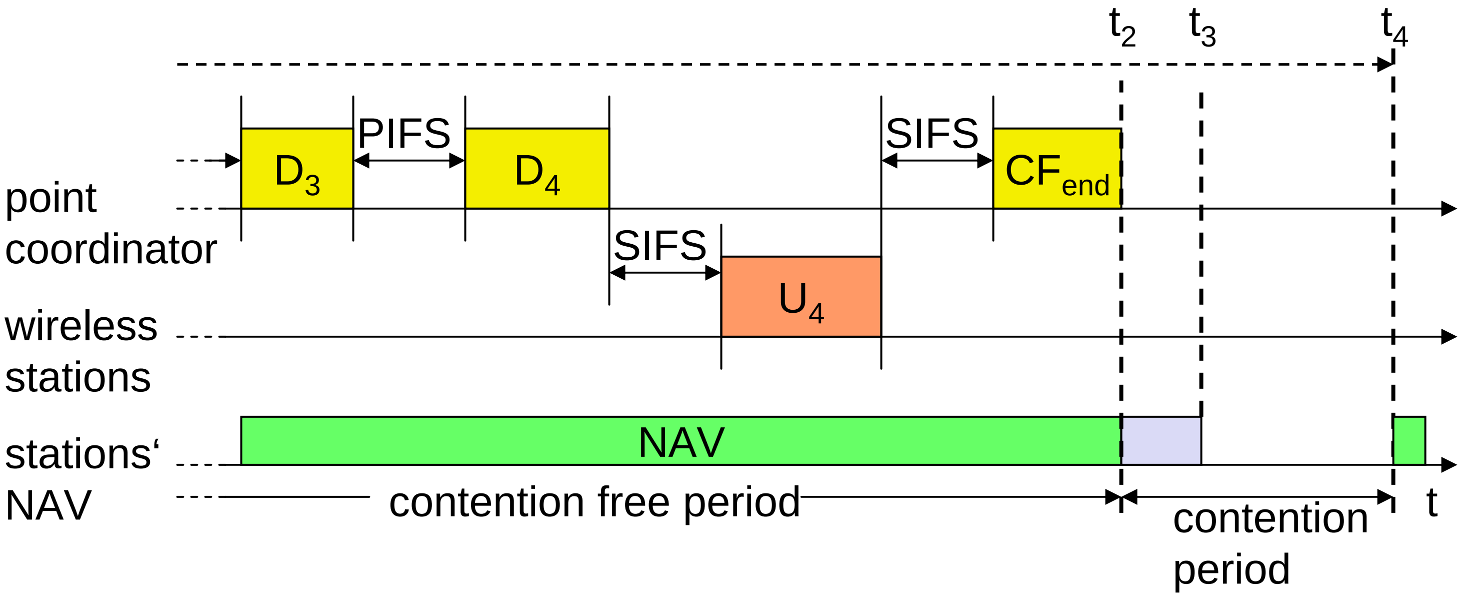
Fragmentation



DFWMAC-PCF I


t0
t1
SuperFrame
medium busy
PIFS
D1
SIFS
D2
SIFS
point coordinator
SIFS
U1
SIFS
U2
wireless stations
stations' NAV
NAV

DFWMAC-PCF II



802.11 - Frame format

Types

- control frames, management frames, data frames

Sequence numbers

- important against duplicated frames due to lost ACKs

Addresses

- receiver, transmitter (physical), BSS identifier, sender (logical)

Miscellaneous

- 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

bits	2	2	4	1	1	1	1	1	1	1	1
	Protocol version	Type	Subtype	To DS	From DS	More Frag	Retry	Power Mgmt	More Data	WEP	Order

MAC address format

scenario	to DS	from DS	address 1	address 2	address 3	address 4
ad-hoc network	0	0	DA	SA	BSSID	-
infrastructure network, from AP	0	1	DA	BSSID	SA	-
infrastructure network, to AP	1	0	BSSID	SA	DA	-
infrastructure network, within DS	1	1	RA	TA	DA	SA

DS: Distribution System
AP: Access Point
DA: Destination Address
SA: Source Address
BSSID: Basic Service Set Identifier
RA: Receiver Address
TA: Transmitter Address

Special Frames: ACK, RTS, CTS

Acknowledgement

bytes	2	2	6	4
ACK	Frame Control	Duration	Receiver Address	CRC

Request To Send

bytes	2	2	6	6	4
RTS	Frame Control	Duration	Receiver Address	Transmitter Address	CRC

Clear To Send

bytes	2	2	6	4
CTS	Frame Control	Duration	Receiver Address	CRC

802.11 - MAC management

Synchronization

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

Power management

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

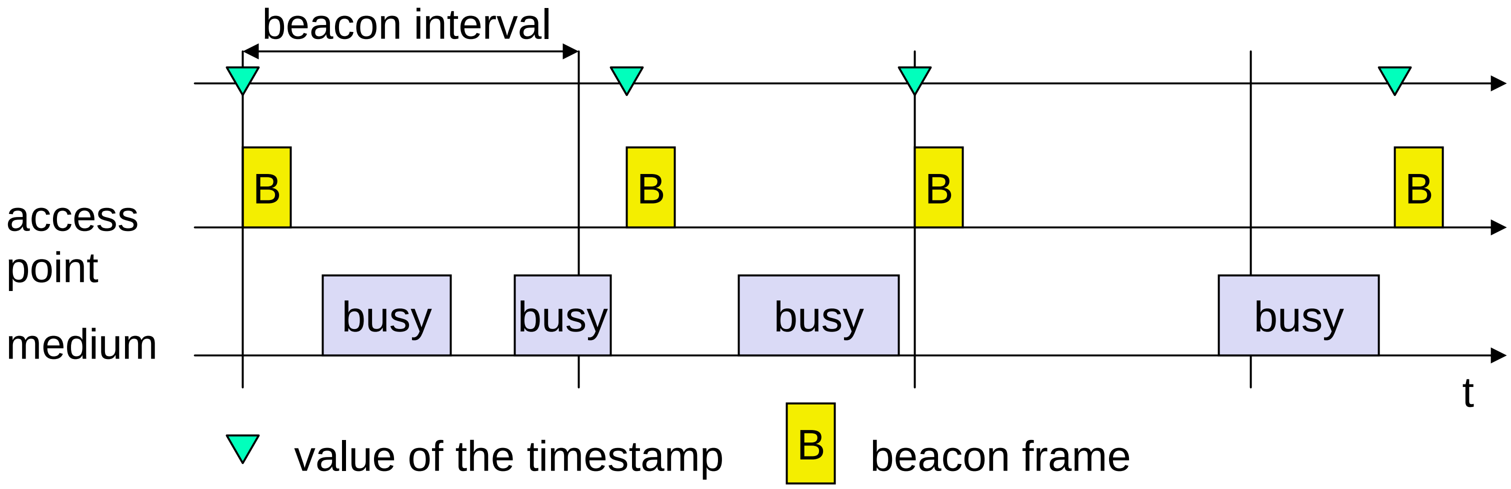
Association/Reassociation

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

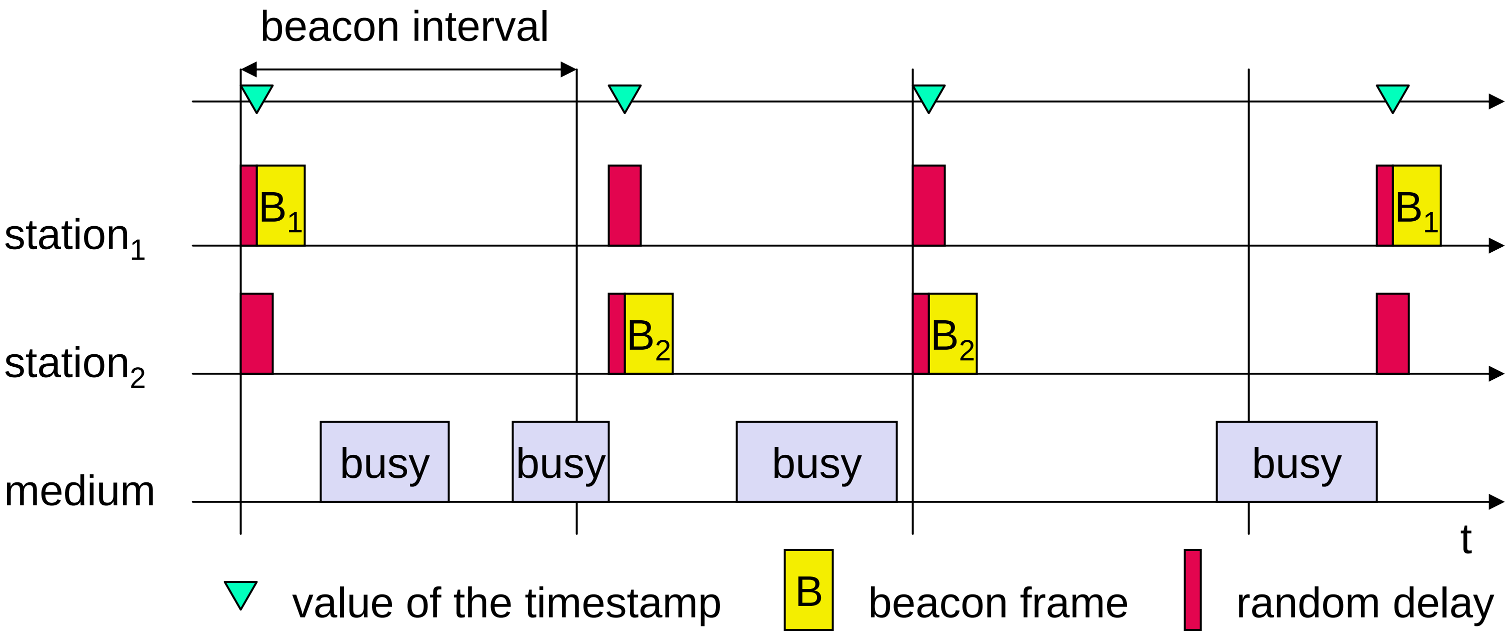
MIB - Management Information Base

- ❑ managing, read, write

Synchronization using a Beacon (infrastructure)



Synchronization using a Beacon (ad-hoc)



Power management

Idea: switch the transceiver off if not needed

States of a station: sleep and awake

Timing Synchronization Function (TSF)

- stations wake up at the same time

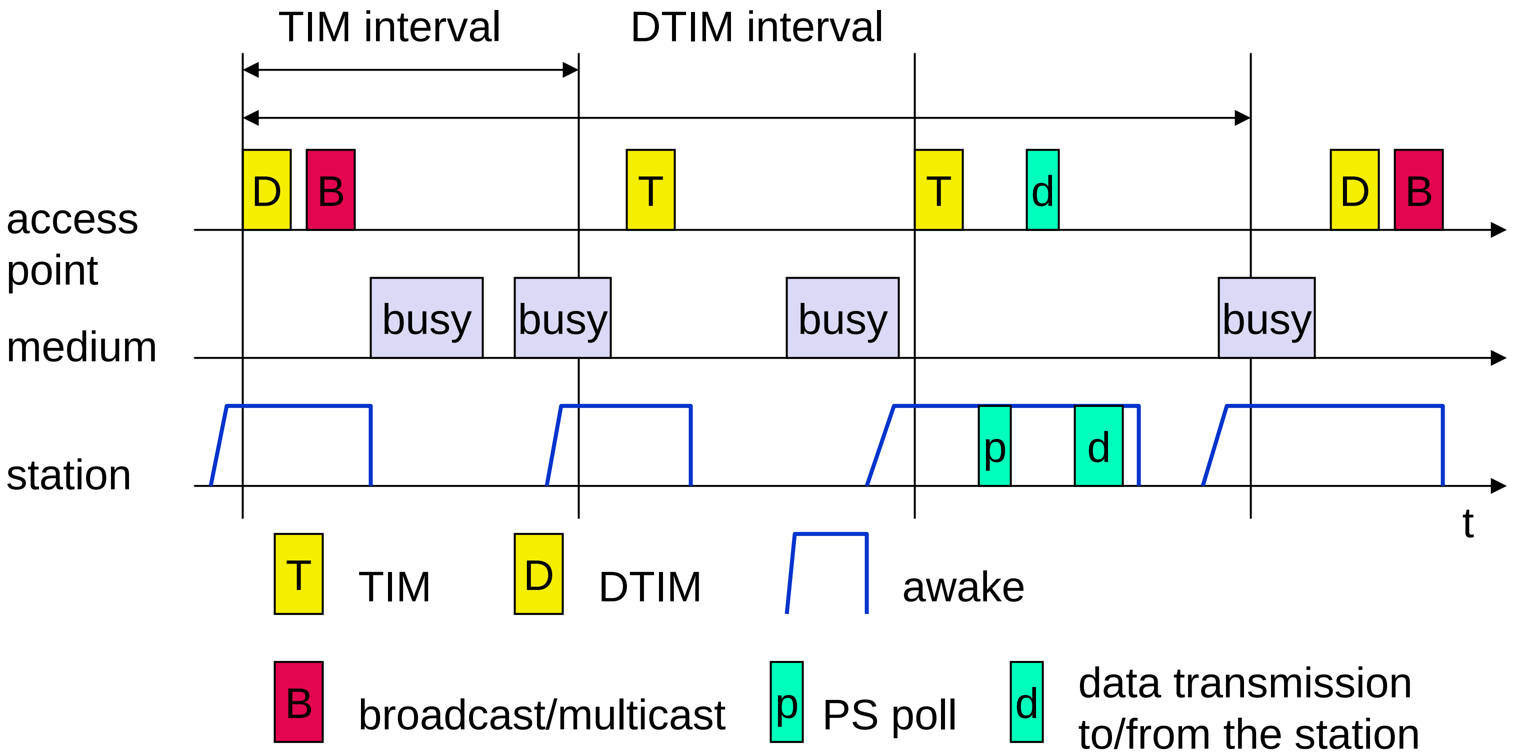
Infrastructure

- Traffic Indication Map (TIM)
    - list of unicast receivers transmitted by AP
- Delivery Traffic Indication Map (DTIM)
    - list of broadcast/multicast receivers transmitted by AP

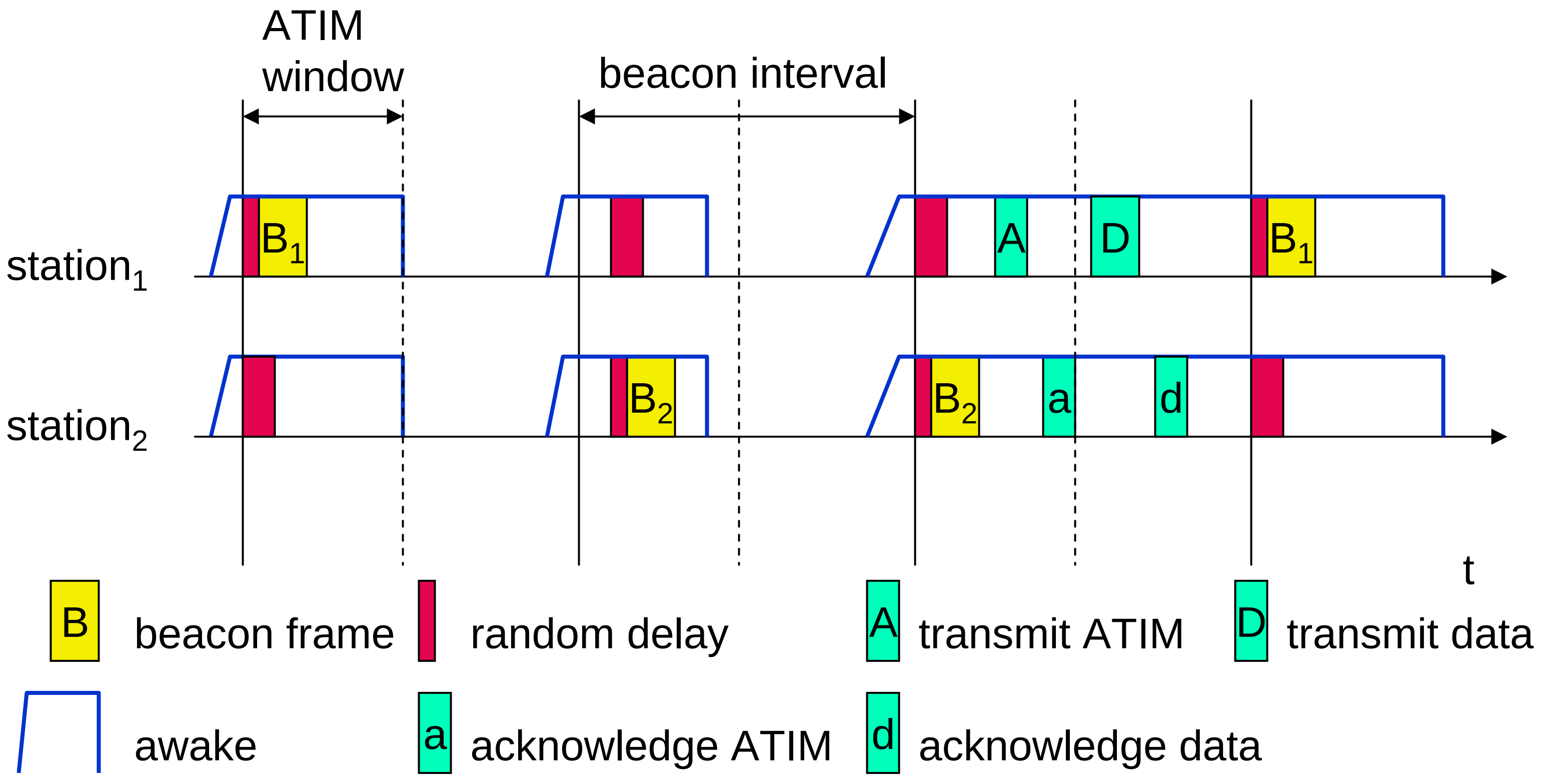
Ad-hoc

- Ad-hoc Traffic Indication Map (ATIM)
    - announcement of receivers by stations buffering frames
    - more complicated - no central AP
    - collision of ATIMs possible (scalability?)

Power saving with wake-up patterns (infrastructure)



Power saving with wake-up patterns (ad-hoc)



ATIM window

beacon interval

station_1

station_2

t

B beacon frame

🟥 random delay

A transmit ATIM

D transmit data

awake

a acknowledge ATIM

d acknowledge data

802.11 - Roaming

No or bad connection? Then perform:

Scanning

- ❑ scan the environment, i.e., listen into the medium for beacon signals or send probes into the medium and wait for an answer

Reassociation Request

- ❑ station sends a request to one or several AP(s)

Reassociation Response

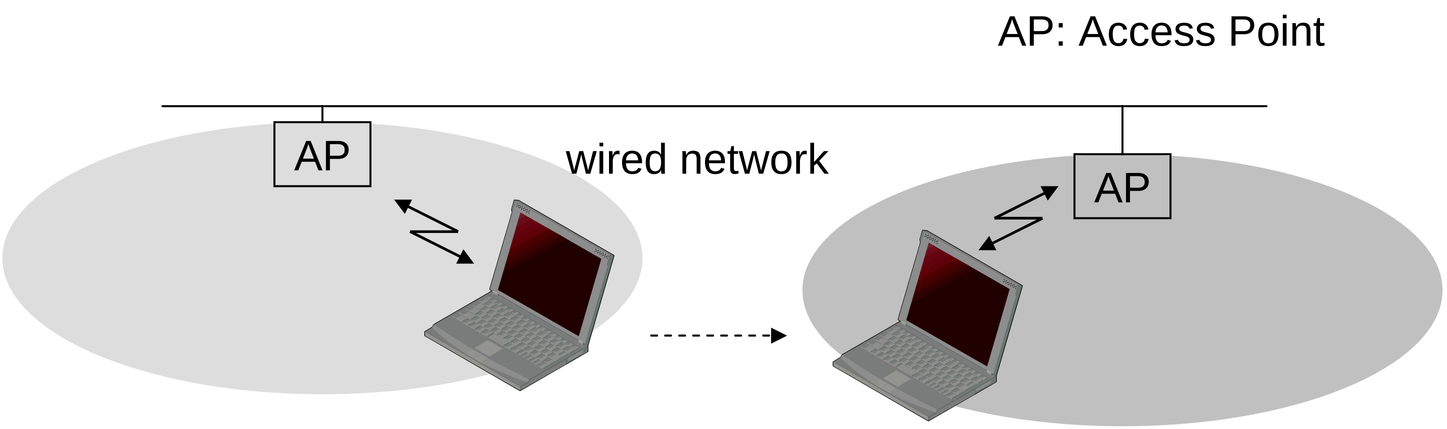
- ❑ success: AP has answered, station can now participate
- ❑ failure: continue scanning

AP accepts Reassociation Request

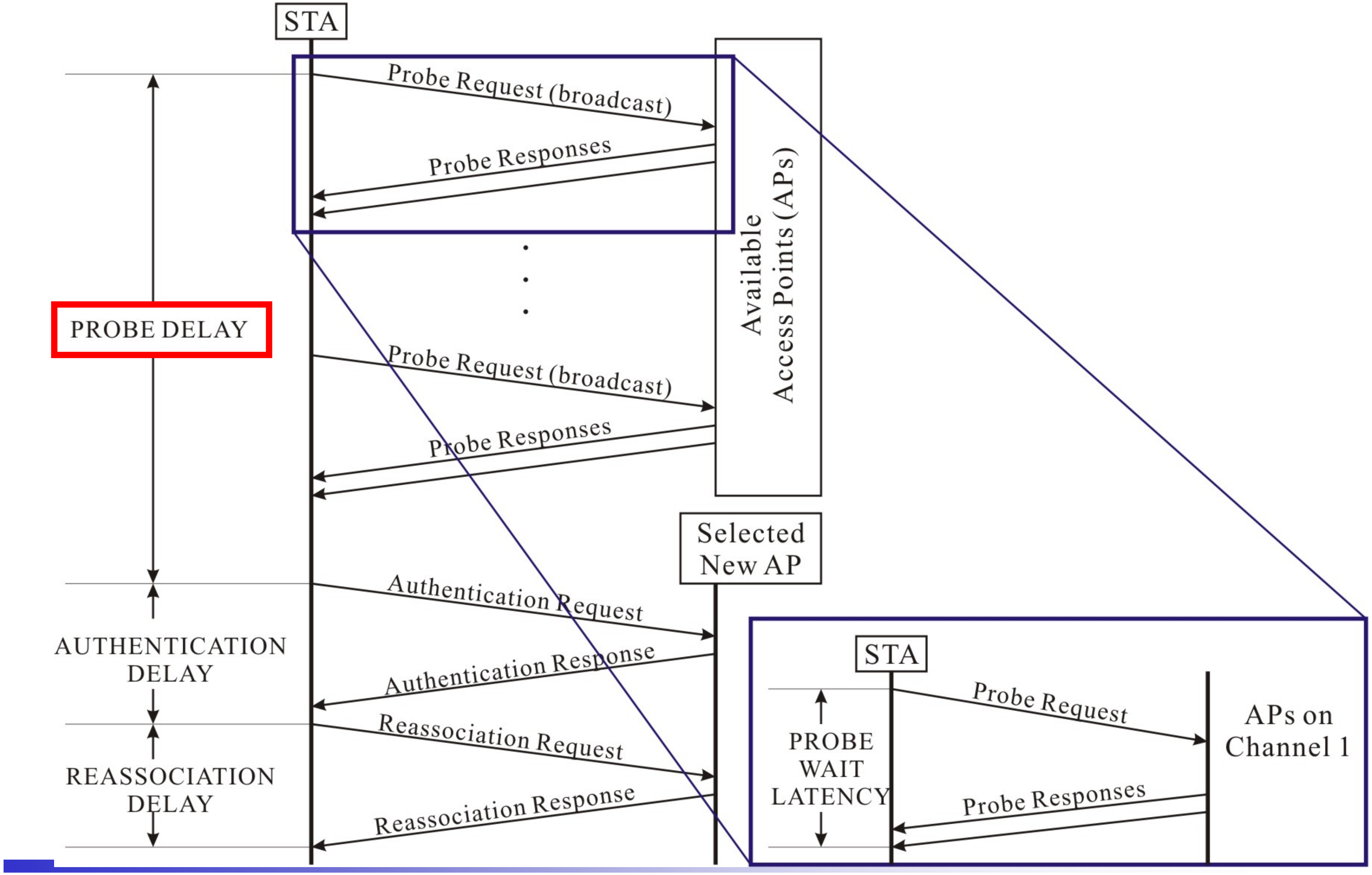
- ❑ signal the new station to the distribution system
- ❑ the distribution system updates its data base (i.e., location information)
- ❑ typically, the distribution system now informs the old AP so it can release resources

Layer-2 handoff

infrastructure network



Layer-2 handoff procedure in WLAN



Paper studying

Yuh-Shyan Chen, Ming-Chin Chuang, and Chung-Kai Chen, "DeuceScan: Deuce-Based Fast Handoff Scheme in IEEE 802.11 Wireless Networks," ***IEEE Trans. on Vehicular Technology***, March 2008. (2006 SCI=1.071, ranking=17/59=28.81%)

WLAN: IEEE 802.11b

Data rate

- 1, 2, 5.5, 11 Mbit/s, depending on SNR
- User data rate max. approx. 6 Mbit/s

Transmission range

- 300m outdoor, 30m indoor
- Max. data rate ~10m indoor

Frequency

- Free 2.4 GHz ISM-band

Security

- Limited, WEP insecure, SSID

Cost

- 100€ adapter, 250€ base station, dropping

Availability

- Many products, many vendors

Connection set-up time

- Connectionless/always on

Quality of Service

- Typ. Best effort, no guarantees (unless polling is used, limited support in products)

Manageability

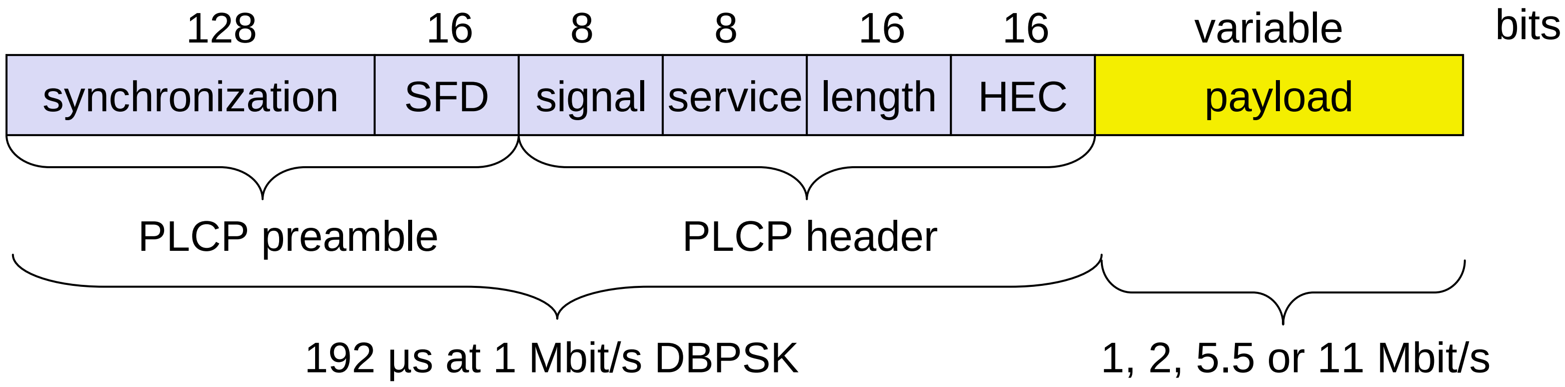
- Limited (no automated key distribution, sym. Encryption)

Special Advantages/Disadvantages

- Advantage: many installed systems, lot of experience, available worldwide, free ISM-band, many vendors, integrated in laptops, simple system
- Disadvantage: heavy interference on ISM-band, no service guarantees, slow relative speed only

IEEE 802.11b – PHY frame formats

Long PLCP PPDU format



128	16	8	8	16	16	variable	bits
synchronization	SFD	signal	service	length	HEC	payload	

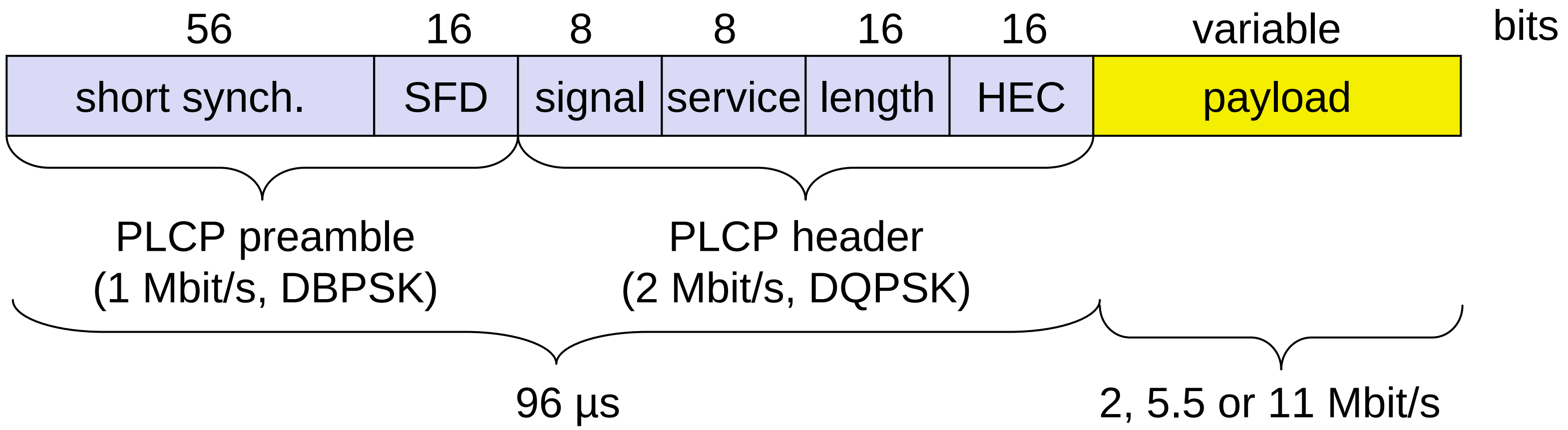
PLCP preamble

PLCP header

192 µs at 1 Mbit/s DBPSK

1, 2, 5.5 or 11 Mbit/s

Short PLCP PPDU format (optional)



56	16	8	8	16	16	variable	bits
short synch.	SFD	signal	service	length	HEC	payload	

PLCP preamble
(1 Mbit/s, DBPSK)

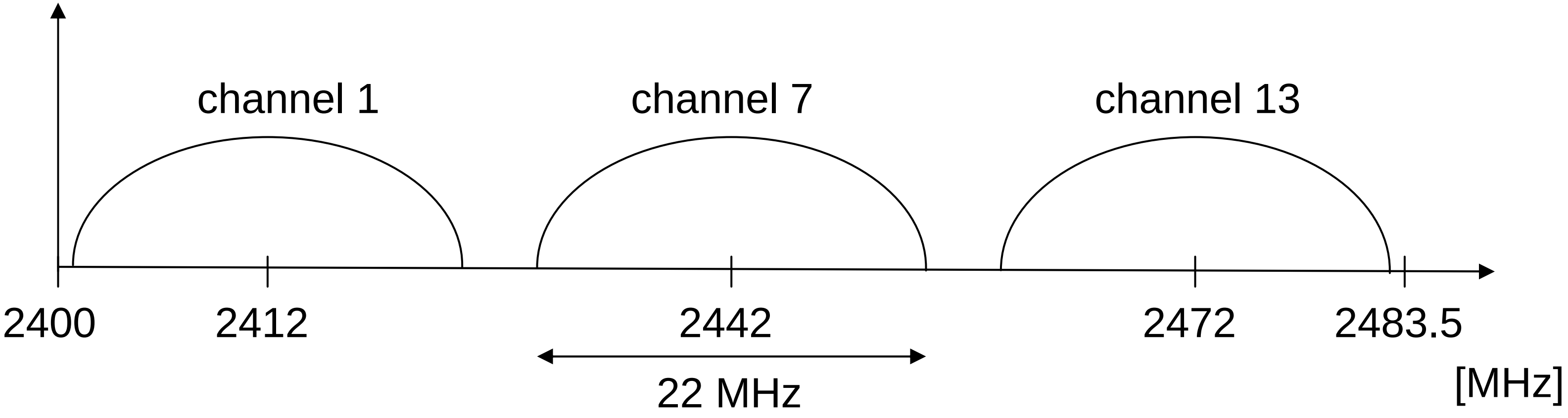
PLCP header
(2 Mbit/s, DQPSK)

96 µs

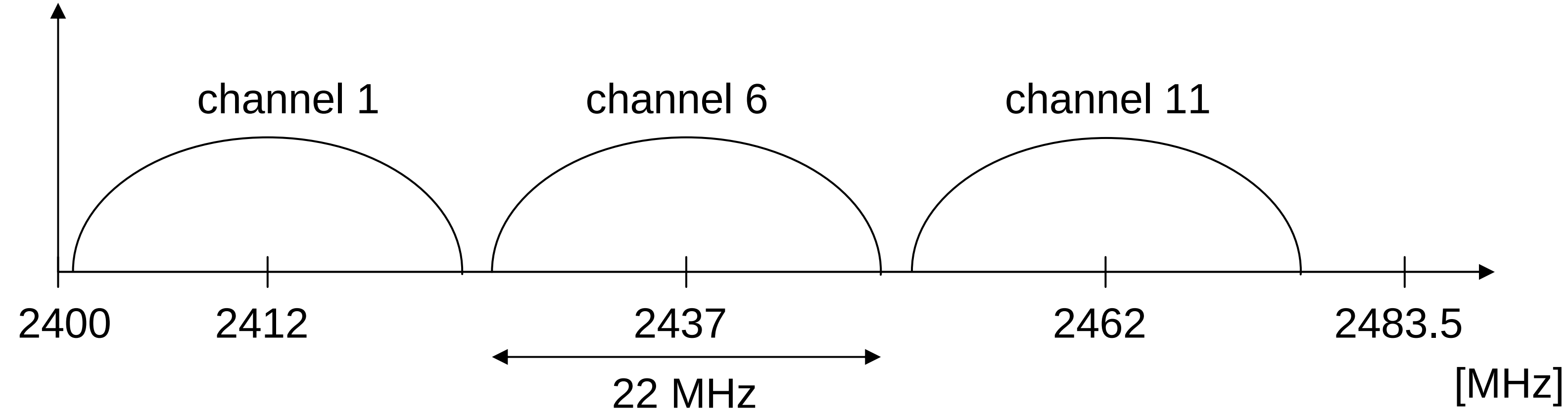
2, 5.5 or 11 Mbit/s

Channel selection (non-overlapping)

Europe (ETSI)



US (FCC)/Canada (IC)



WLAN: IEEE 802.11a

Data rate

- 6, 9, 12, 18, 24, 36, 48, 54 Mbit/s, depending on SNR
- User throughput (1500 byte packets): 5.3 (6), 18 (24), 24 (36), 32 (54)
- 6, 12, 24 Mbit/s mandatory

Transmission range

- 100m outdoor, 10m indoor
  - E.g., 54 Mbit/s up to 5 m, 48 up to 12 m, 36 up to 25 m, 24 up to 30m, 18 up to 40 m, 12 up to 60 m

Frequency

- Free 5.15-5.25, 5.25-5.35, 5.725-5.825 GHz ISM-band

Security

- Limited, WEP insecure, SSID

Cost

- 280€ adapter, 500€ base station

Availability

- Some products, some vendors

Connection set-up time

- Connectionless/always on

Quality of Service

- Typ. best effort, no guarantees (same as all 802.11 products)

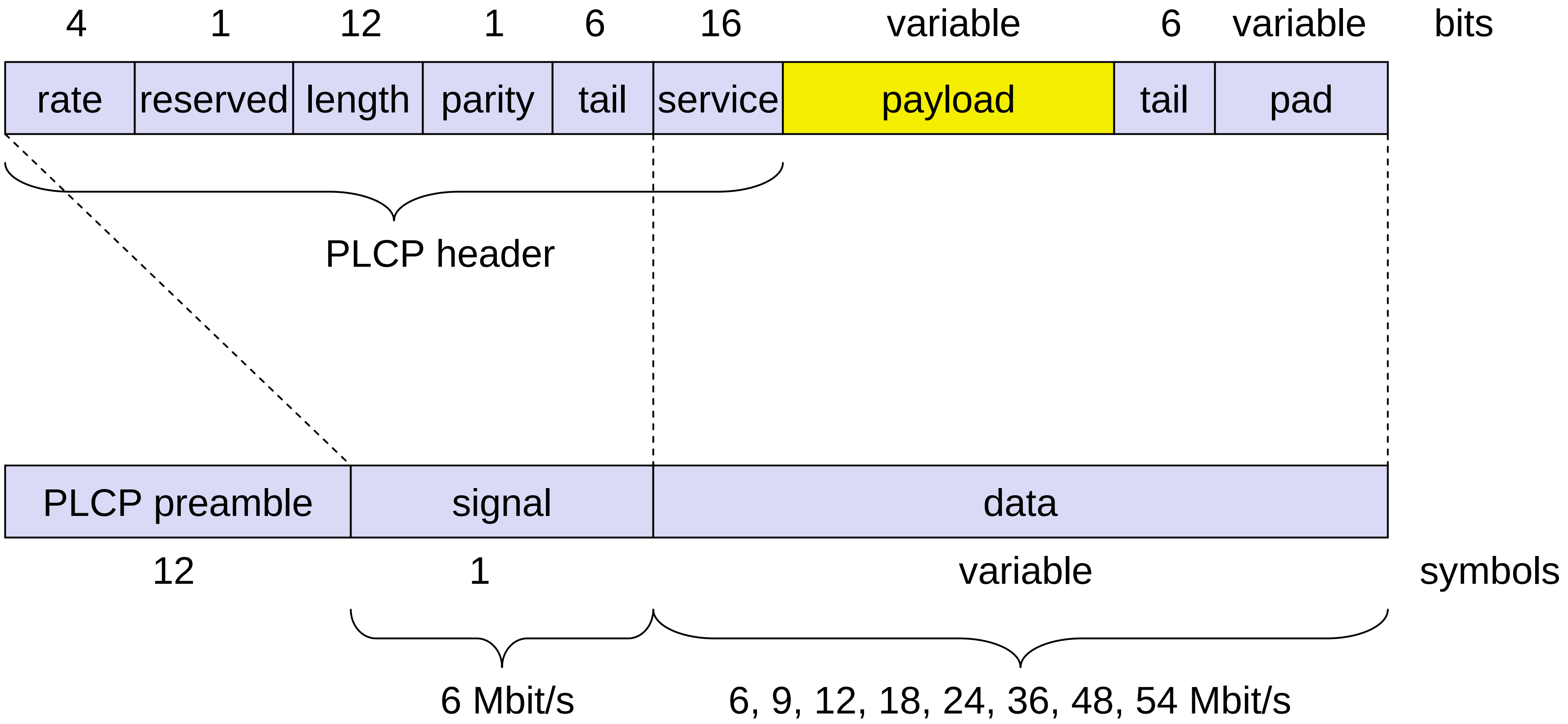
Manageability

- Limited (no automated key distribution, sym. Encryption)

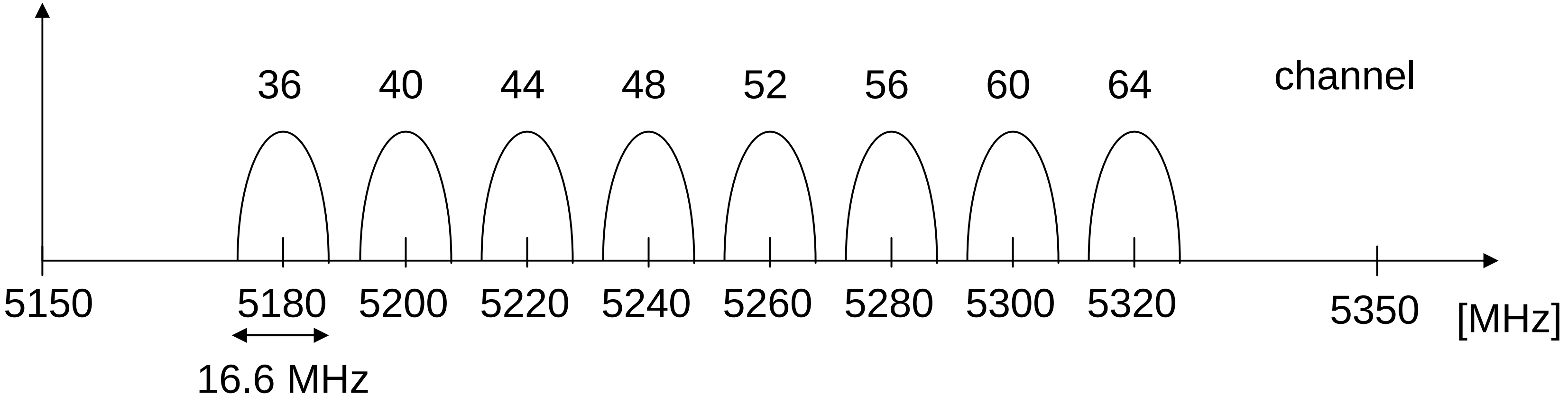
Special Advantages/Disadvantages

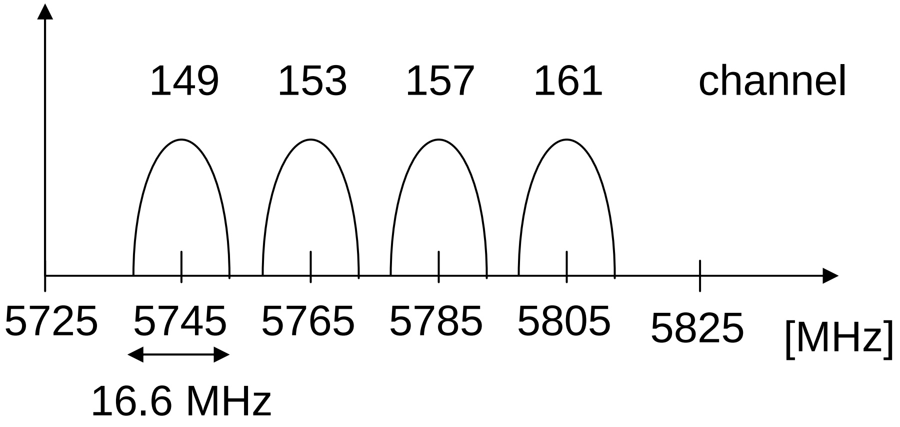
- Advantage: fits into 802.x standards, free ISM-band, available, simple system, uses less crowded 5 GHz band
- Disadvantage: stronger shading due to higher frequency, no QoS

IEEE 802.11a – PHY frame format



Operating channels for 802.11a / US U-NII



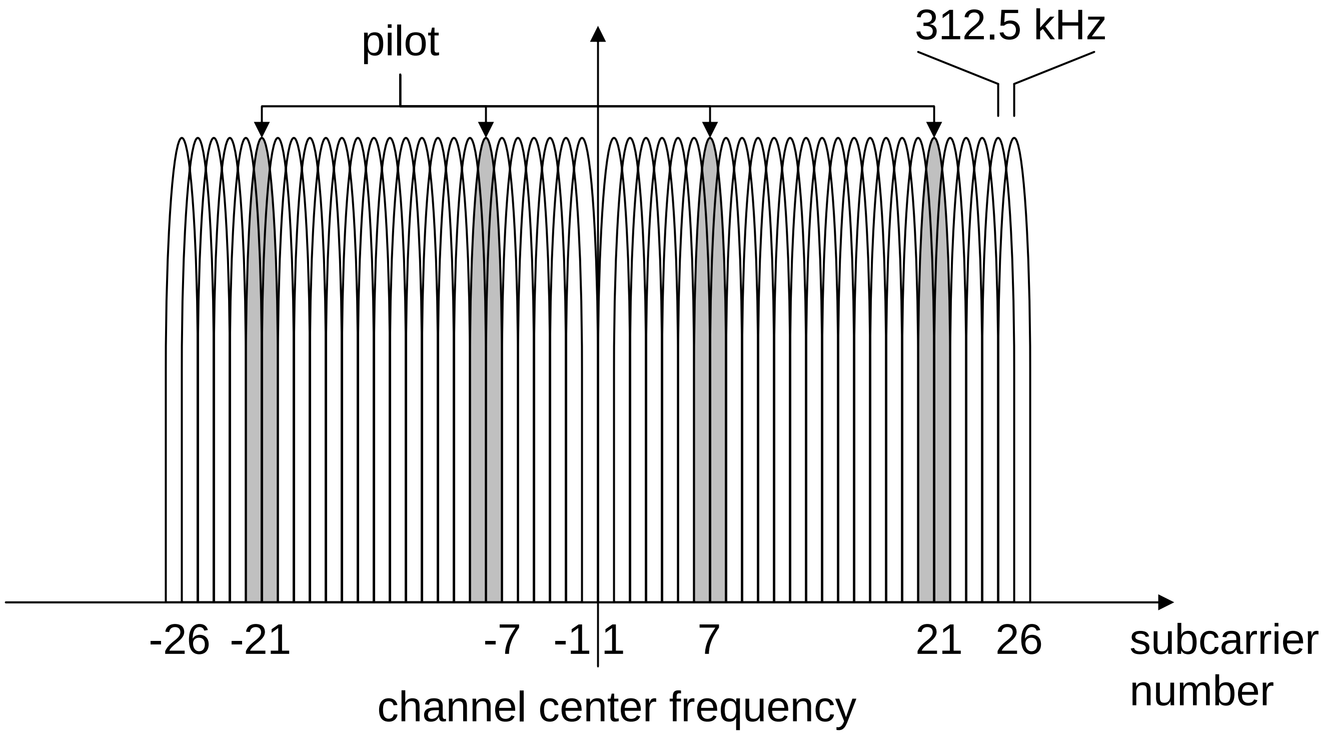


center frequency =
5000 + 5*channel number [MHz]

OFDM in IEEE 802.11a (and HiperLAN2)

OFDM with 52 used subcarriers (64 in total)

- ❑ 48 data + 4 pilot
- ❑ (plus 12 virtual subcarriers)
- ❑ 312.5 kHz spacing



WLAN: IEEE 802.11 – future developments (08/2002)

802.11d: Regulatory Domain Update – completed

802.11e: MAC Enhancements – QoS – ongoing

- ❑ Enhance the current 802.11 MAC to expand support for applications with Quality of Service requirements, and in the capabilities and efficiency of the protocol.

802.11f: Inter-Access Point Protocol – ongoing

- ❑ Establish an Inter-Access Point Protocol for data exchange via the distribution system.

802.11g: Data Rates > 20 Mbit/s at 2.4 GHz; 54 Mbit/s, OFDM – ongoing

802.11h: Spectrum Managed 802.11a (DCS, TPC) – ongoing

802.11i: Enhanced Security Mechanisms – ongoing

- ❑ Enhance the current 802.11 MAC to provide improvements in security.

Study Groups

- ❑ 5 GHz (harmonization ETSI/IEEE) – closed
- ❑ Radio Resource Measurements – started
- ❑ High Throughput – started

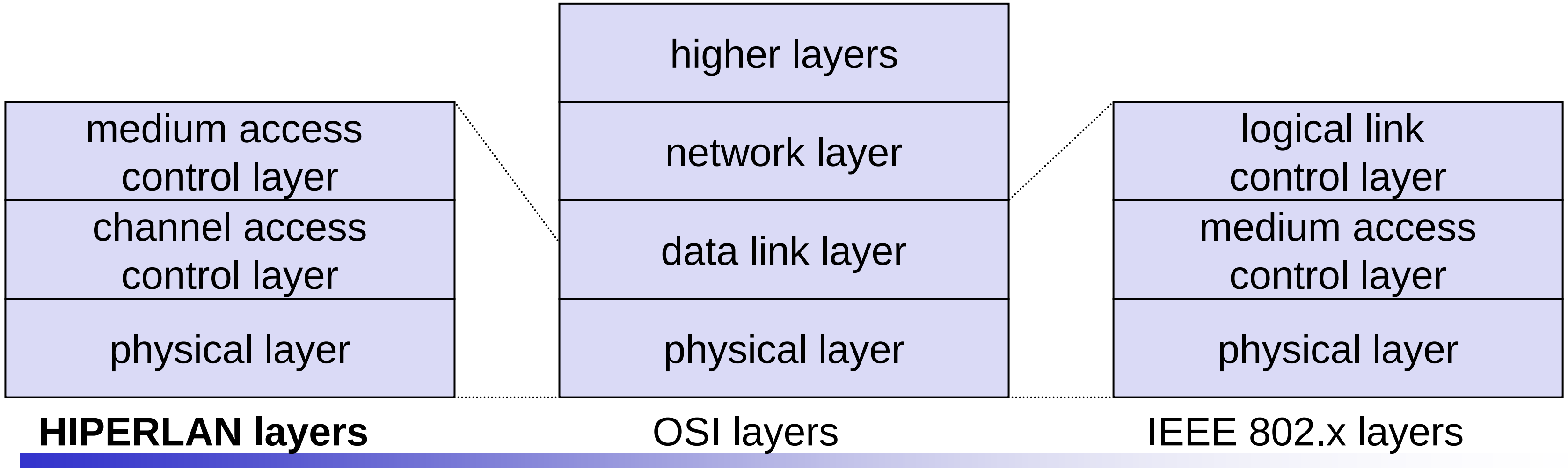
ETSI - HIPERLAN

ETSI standard

- ❑ European standard, cf. GSM, DECT, ...
- ❑ Enhancement of local Networks and interworking with fixed networks
- ❑ integration of time-sensitive services from the early beginning

HIPERLAN family

- ❑ one standard cannot satisfy all requirements
  - ● range, bandwidth, QoS support
  - ● commercial constraints
- ❑ HIPERLAN 1 standardized since 1996 – no products!



HIPERLAN layers	OSI layers	IEEE 802.x layers
	higher layers	
medium access control layer	network layer	logical link control layer
channel access control layer	data link layer	medium access control layer
physical layer	physical layer	physical layer

Overview: original HIPERLAN protocol family

<table>
<tr><th></th><th>HIPERLAN 1</th><th>HIPERLAN 2</th><th>HIPERLAN 3</th><th>HIPERLAN 4</th></tr>
<tr><td>Application</td><td>wireless LAN</td><td>access to ATM fixed networks</td><td>wireless local loop</td><td>point-to-point wireless ATM connections</td></tr>
<tr><td>Frequency</td><td colspan="3">5.1-5.3GHz</td><td>17.2-17.3GHz</td></tr>
<tr><td>Topology</td><td>decentralized ad-hoc/infrastructure</td><td>cellular, centralized</td><td>point-to-multipoint</td><td>point-to-point</td></tr>
<tr><td>Antenna</td><td colspan="2">omni-directional</td><td colspan="2">directional</td></tr>
<tr><td>Range</td><td>50 m</td><td>50-100 m</td><td>5000 m</td><td>150 m</td></tr>
<tr><td>QoS</td><td>statistical</td><td colspan="3">ATM traffic classes (VBR, CBR, ABR, UBR)</td></tr>
<tr><td>Mobility</td><td colspan="2">&lt;10m/s</td><td colspan="2">stationary</td></tr>
<tr><td>Interface</td><td>conventional LAN</td><td colspan="3">ATM networks</td></tr>
<tr><td>Data rate</td><td>23.5 Mbit/s</td><td colspan="2">&gt;20 Mbit/s</td><td>155 Mbit/s</td></tr>
<tr><td>Power conservation</td><td colspan="2">yes</td><td colspan="2">not necessary</td></tr>
</table>

HIPERLAN 1 never reached product status,
the other standards have been renamed/modfied !

Homework #2

1. What’s the hidden-terminal and exposed-terminal problems occurred in DFWMAC-DCF CSMA/CA ?
2. How to use RTS/CTS messages (DFWMAC-DCF w/ RTS/CTS) to **reduce** the hidden-terminal problem ?
3. How the PCF (Point Coordination Function) works ?
4. What’s the main operations of IEEE 802.11 roaming (layer-2 handoff procedure) ?
5. What’s the power management in infrastructure and ad hoc modes ?