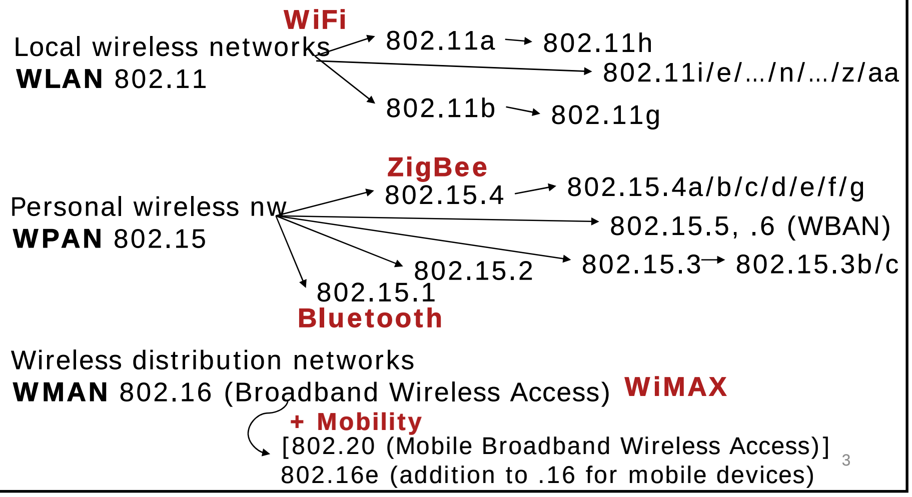
Mobile Communication: Wireless LANs

Dominic Duggan

Based on materials by Jochen Schiller

WIRELESS LANS

Mobile Communication Technology (IEEE)



Local wireless networks
WLAN 802.11

WiFi

802.11a → 802.11h
802.11i/e/…/n/…/z/aa
802.11b → 802.11g

Personal wireless nw
WPAN 802.15

ZigBee
802.15.4 → 802.15.4a/b/c/d/e/f/g
802.15.5, .6 (WBAN)
802.15.3 → 802.15.3b/c
802.15.2
802.15.1
Bluetooth

Wireless distribution networks
WMAN 802.16 (Broadband Wireless Access) WiMAX

+ Mobility
[802.20 (Mobile Broadband Wireless Access)]
802.16e (addition to .16 for mobile devices)

Characteristics of wireless LANs

- Advantages
  - very flexible within the reception area
  - Ad-hoc networks without previous planning possible
  - (almost) no wiring difficulties (e.g. historic buildings, firewalls)
  - more robust against disasters
- Disadvantages
  - typically very low bandwidth compared to wired networks
  - many proprietary solutions, especially for higher bit-rates, standards take their time (e.g. IEEE 802.11n)
  - products have to follow many national restrictions if working wireless

Design goals for wireless LANs

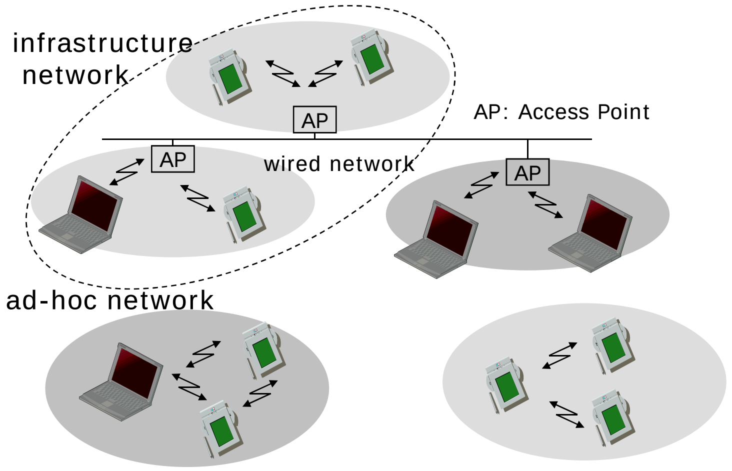
- global, seamless operation
- low power for battery use
- no special permissions or licenses needed to use the LAN
- robust transmission technology
- simplified spontaneous cooperation at meetings
- simple management
- protection of investment in wired networks
- security (no one should be able to read my data), privacy (no one should be able to collect user profiles), safety (low radiation)
- transparency concerning applications and higher layer protocols, but also location awareness if necessary
- …

Comparison: infrared vs. radio transmission

- Infrared
  - uses IR diodes, diffuse light, multiple reflections (walls, furniture etc.)
- Advantages
  - simple, cheap, available in many mobile devices
  - no licenses needed
  - simple shielding possible
- Disadvantages
  - interference by sunlight, heat sources etc.
  - many things shield or absorb IR light
  - low bandwidth
- Example
  - IrDA (Infrared Data Association) interface available everywhere

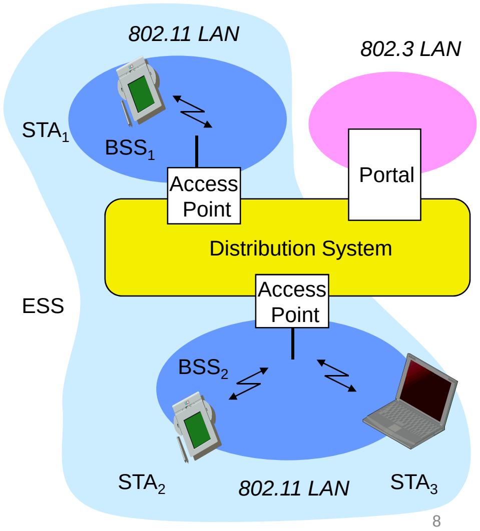
- Radio
  - typically using the license free ISM band at 2.4 GHz
- Advantages
  - experience from wireless WAN and mobile phones can be used
  - coverage of larger areas possible (radio can penetrate walls, furniture etc.)
- Disadvantages
  - very limited license free frequency bands
  - shielding more difficult, interference with other electrical devices
- Example
  - Many different products

Comparison: infrastructure vs. ad-hoc networks



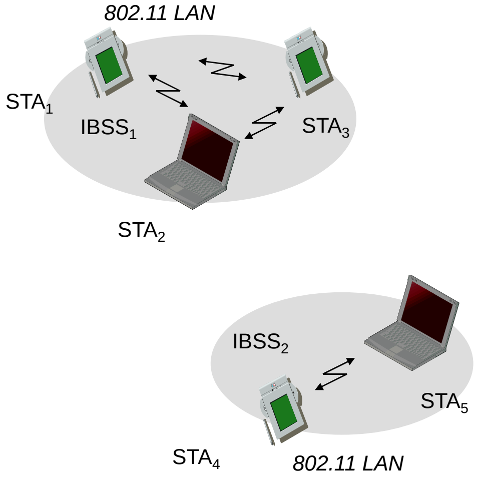
802.11 - Architecture of an infrastructure network

- Station (STA)
  - terminal with 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

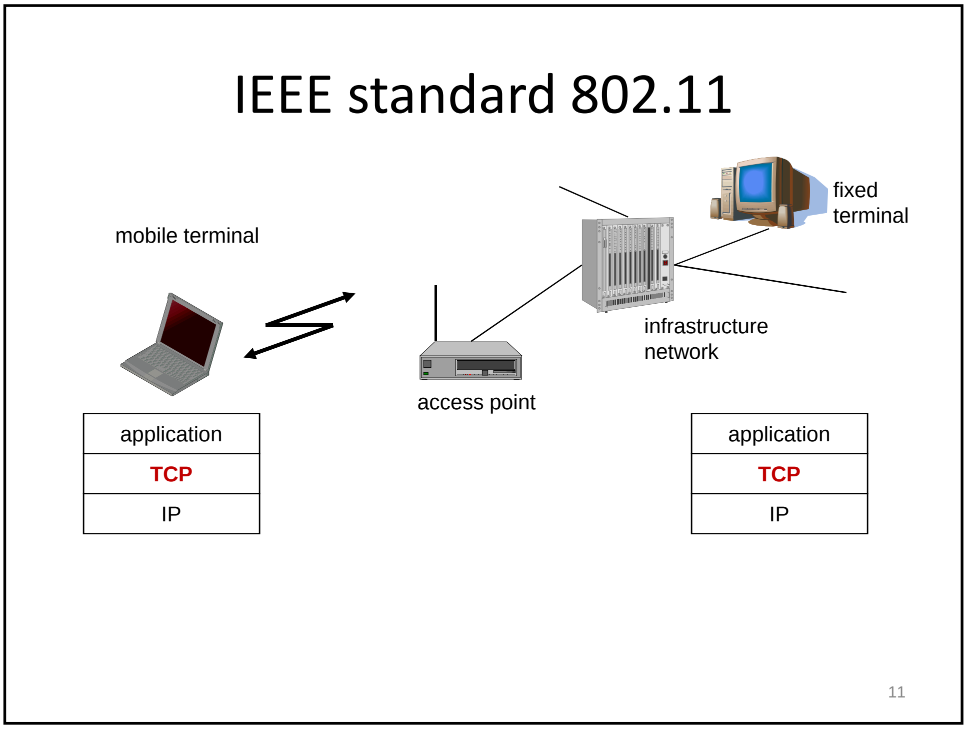


802.11 - Architecture of an ad-hoc network

- 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



802.11 WIRELESS LAN



IEEE standard 802.11

application	application
TCP	**TCP**
IP	IP

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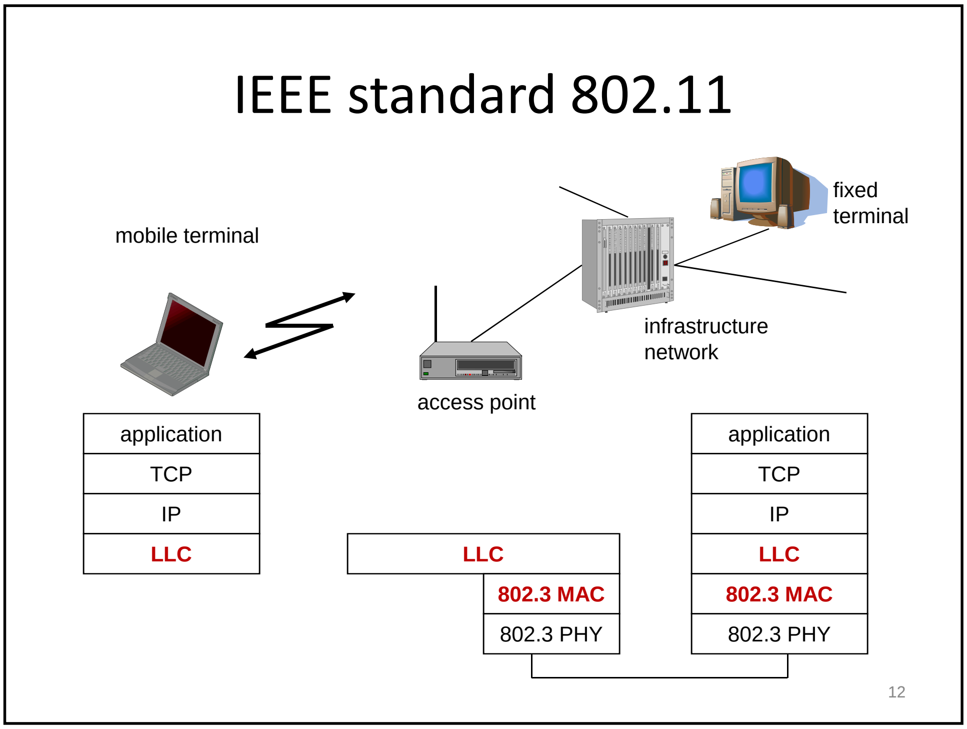

IEEE standard 802.11

application		application
TCP		TCP
IP		IP
LLC	**LLC**	**LLC**
	802.3 MAC	**802.3 MAC**
	802.3 PHY	802.3 PHY

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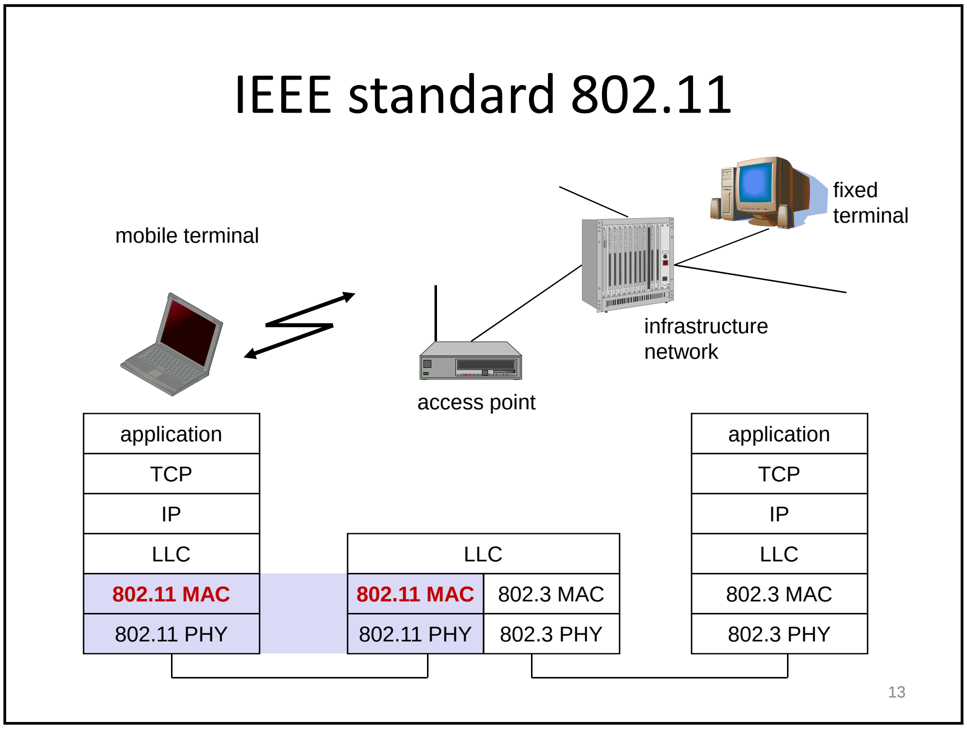

IEEE standard 802.11

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

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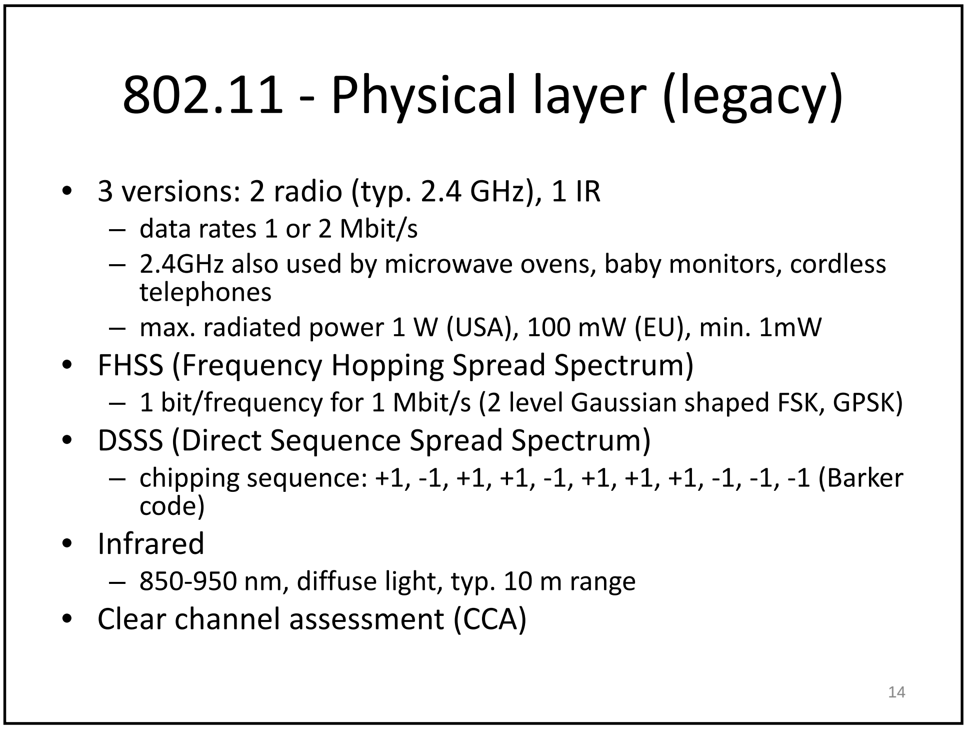

802.11 - Physical layer (legacy)

- 3 versions: 2 radio (typ. 2.4 GHz), 1 IR
  - data rates 1 or 2 Mbit/s
  - 2.4GHz also used by microwave ovens, baby monitors, cordless telephones
  - max. radiated power 1 W (USA), 100 mW (EU), min. 1mW
- FHSS (Frequency Hopping Spread Spectrum)
  - 1 bit/frequency for 1 Mbit/s (2 level Gaussian shaped FSK, GPSK)
- DSSS (Direct Sequence Spread Spectrum)
  - chipping sequence: +1, -1, +1, +1, -1, +1, +1, +1, -1, -1, -1 (Barker code)
- Infrared
  - 850-950 nm, diffuse light, typ. 10 m range
- Clear channel assessment (CCA)

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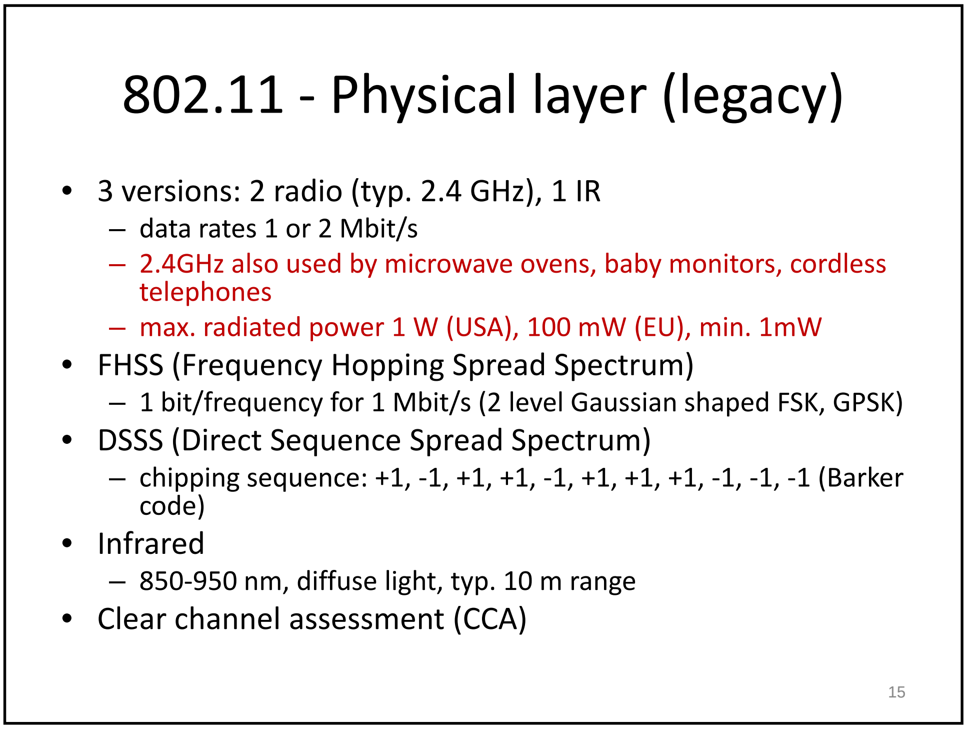

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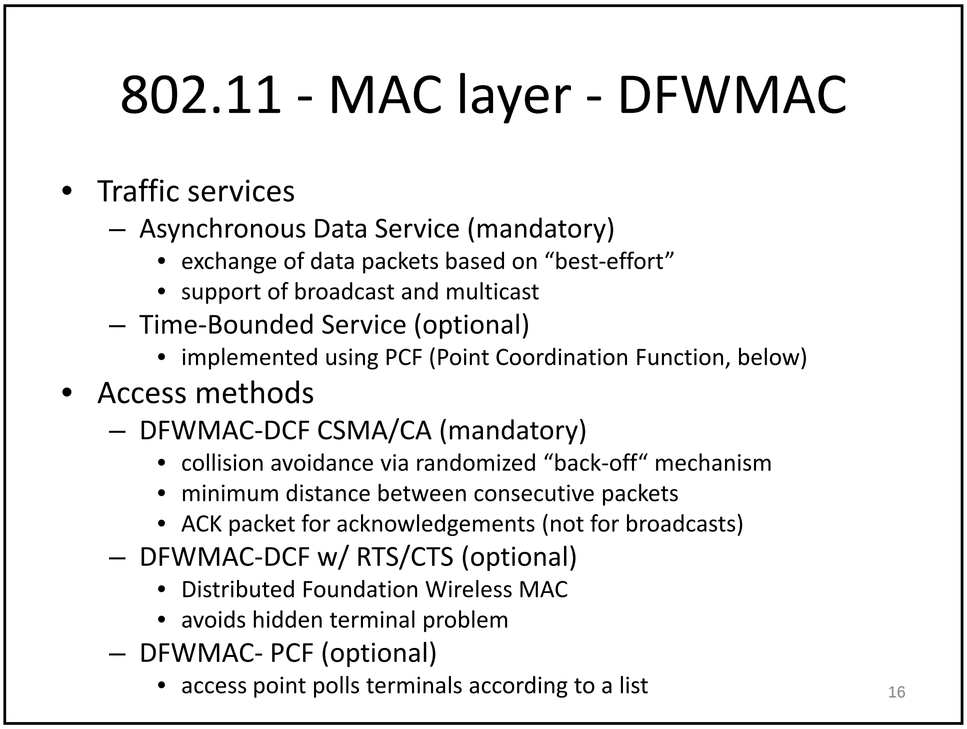

802.11 - MAC layer - DFWMAC

- 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, below)
- 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

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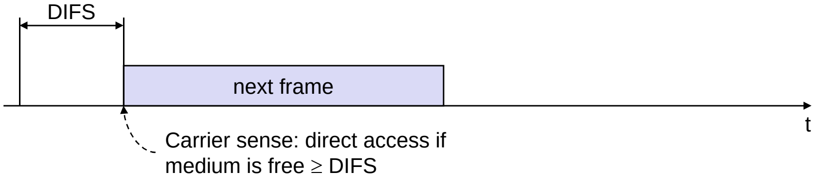
802.11 MEDIUM ACCESS CONTROL

802.11 - CSMA/CA – Access Method I

- Inter frame space (IFS):
  - Minimum time to wait before transmitting between frames
  - DIFS (lowest priority) for asynchronous data service
  - SIFS (highest priority) for control messages (ACK, CTS, etc)



Carrier sense: direct access if medium is free ≥ DIFS

802.11 - CSMA/CA – Access Method I

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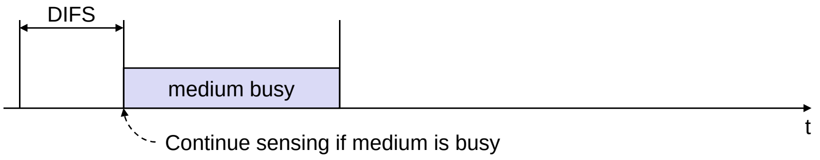
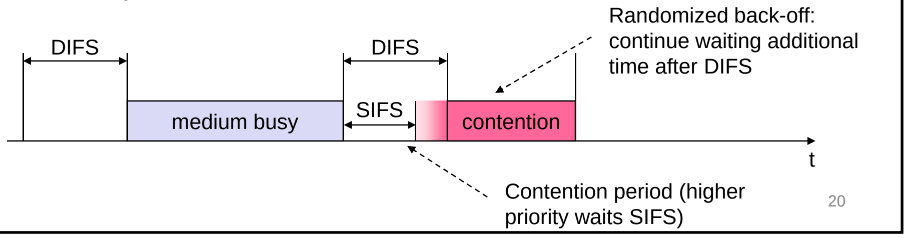


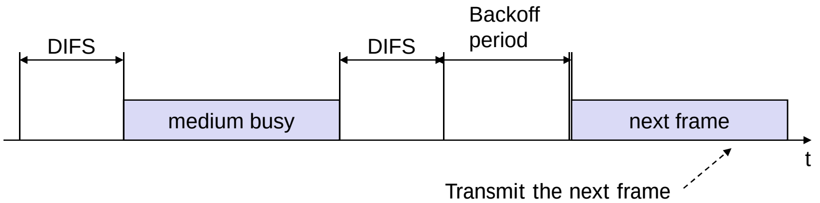
802.11 - CSMA/CA – Access Method I

- Inter frame space (IFS):
  - DIFS (lowest priority) for asynchronous data service
  - SIFS (highest priority) for control messages
- 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)


Randomized back-off: continue waiting additional time after DIFS
DIFS
DIFS
SIFS
medium busy
contention
t
Contention period (higher priority waits SIFS)

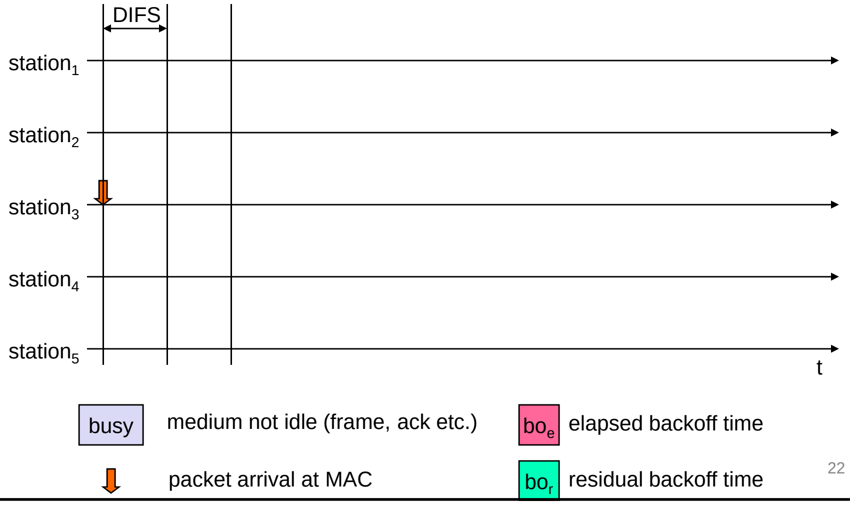
802.11 - CSMA/CA – Access Method I

- Inter frame space (IFS):
  - DIFS (lowest priority) for asynchronous data service
  - SIFS (highest priority) for control messages
- If another station occupies the medium during the back-off time of the station, the back-off timer stops (fairness)

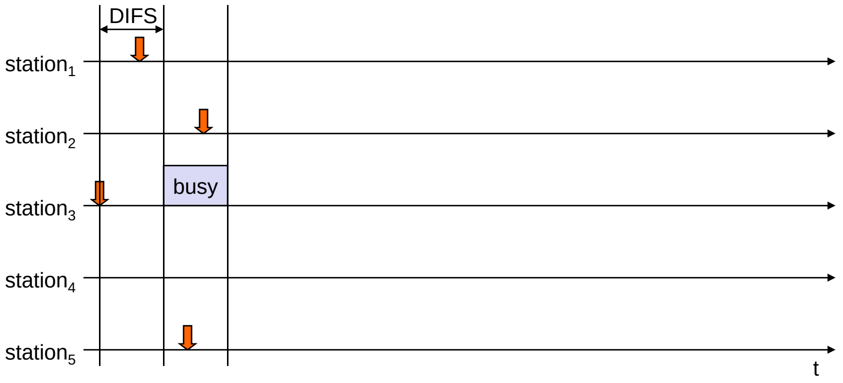


Transmit the next frame if the carrier is still idle

802.11 – CSMA/CA - Example



802.11 – CSMA/CA - Example



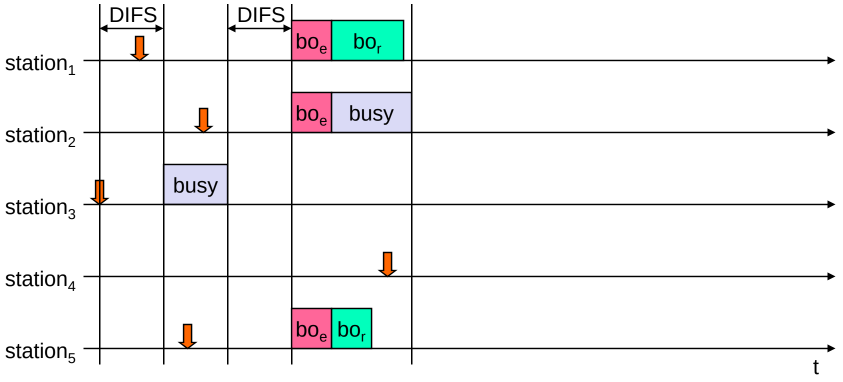
busy medium not idle (frame, ack etc.)

bo$_e$ elapsed backoff time

packet arrival at MAC

bo$_r$ residual backoff time

802.11 – CSMA/CA - Example



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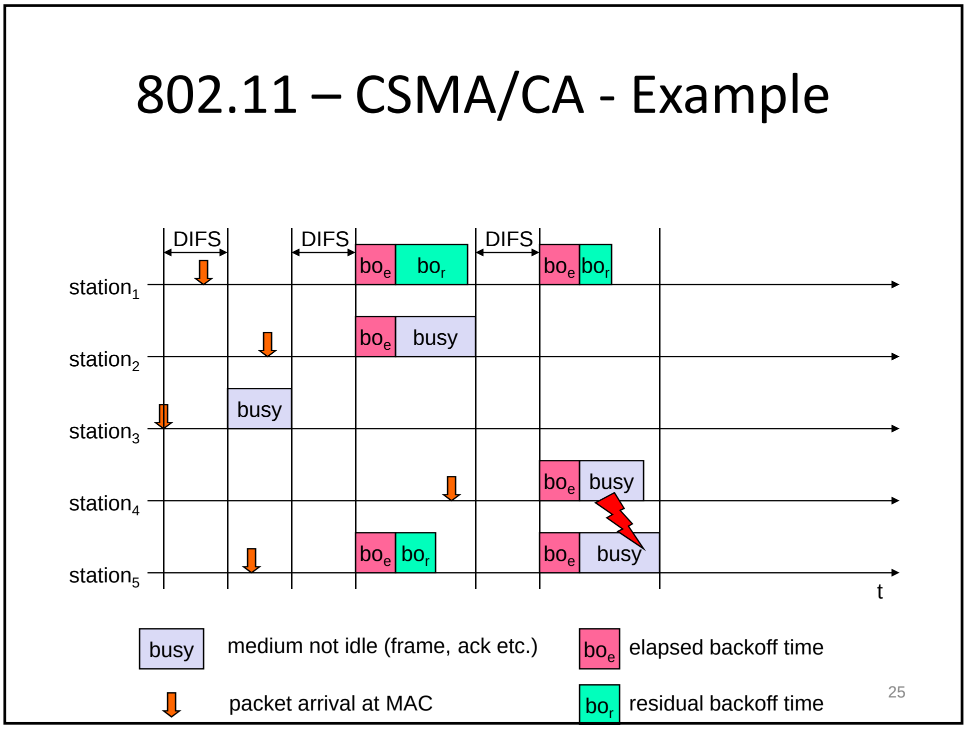


802.11 – CSMA/CA - Example

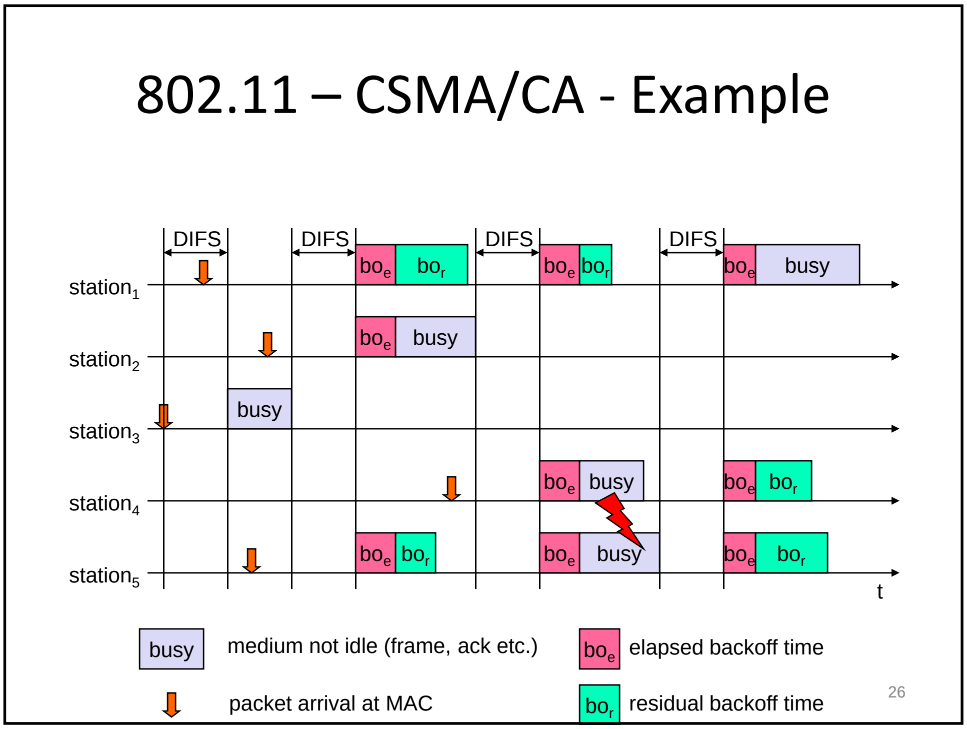
busy medium not idle (frame, ack etc.)

⇩ packet arrival at MAC

bo_e elapsed backoff time

bo_r residual backoff time

25



802.11 – CSMA/CA - Example

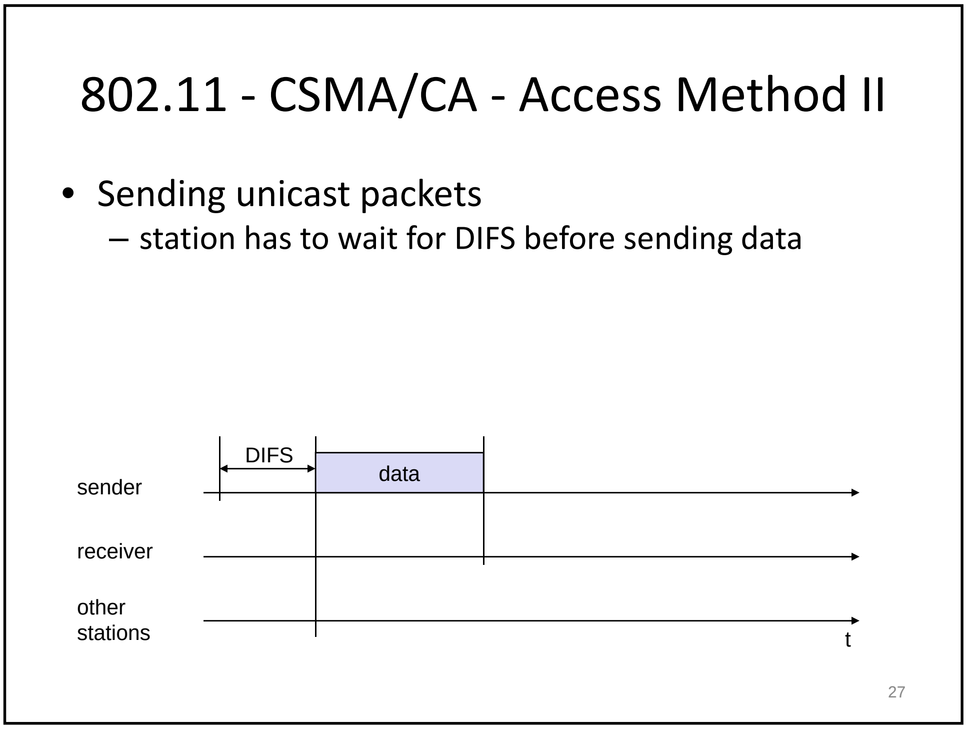
busy medium not idle (frame, ack etc.)

⇩ packet arrival at MAC

bo_e elapsed backoff time

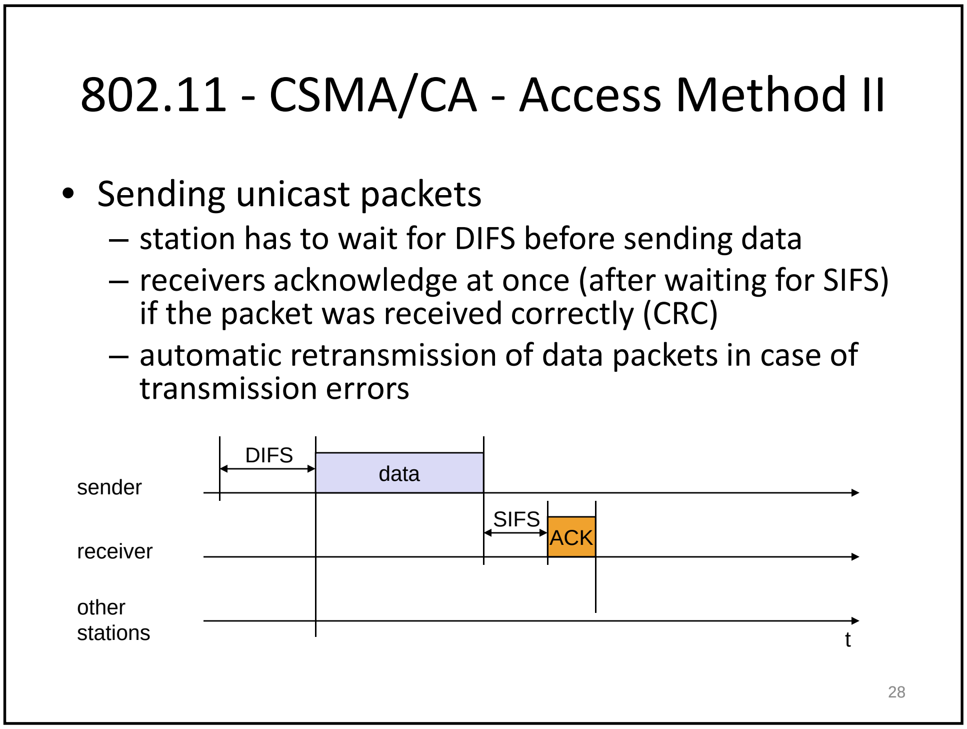
bo_r residual backoff time

26



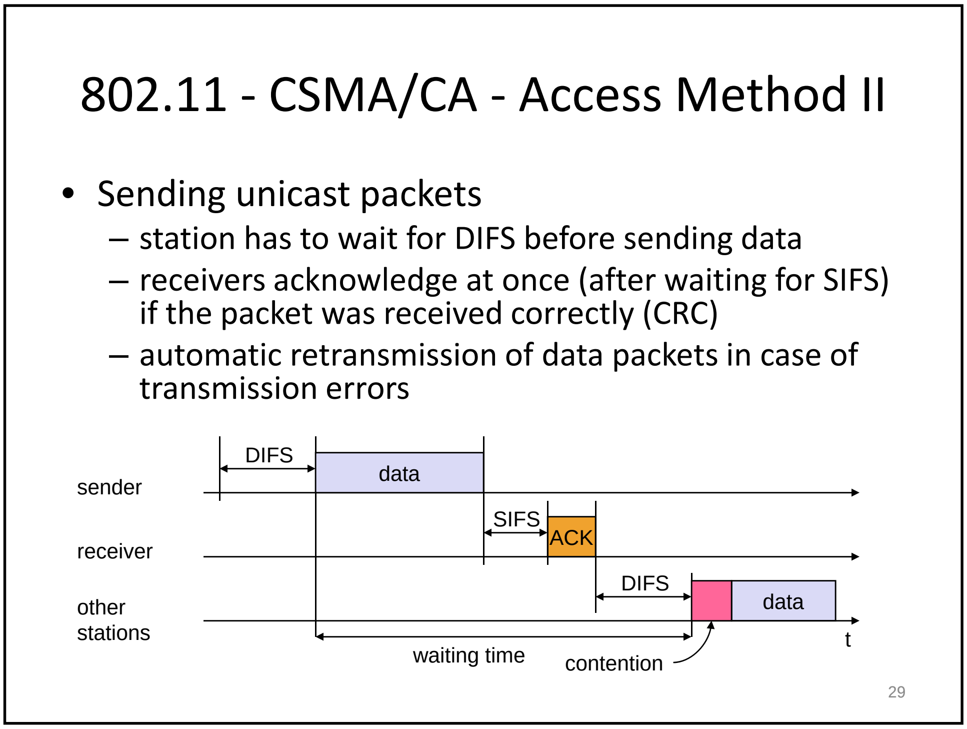
802.11 - CSMA/CA - Access Method II

- Sending unicast packets
  - station has to wait for DIFS before sending data



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



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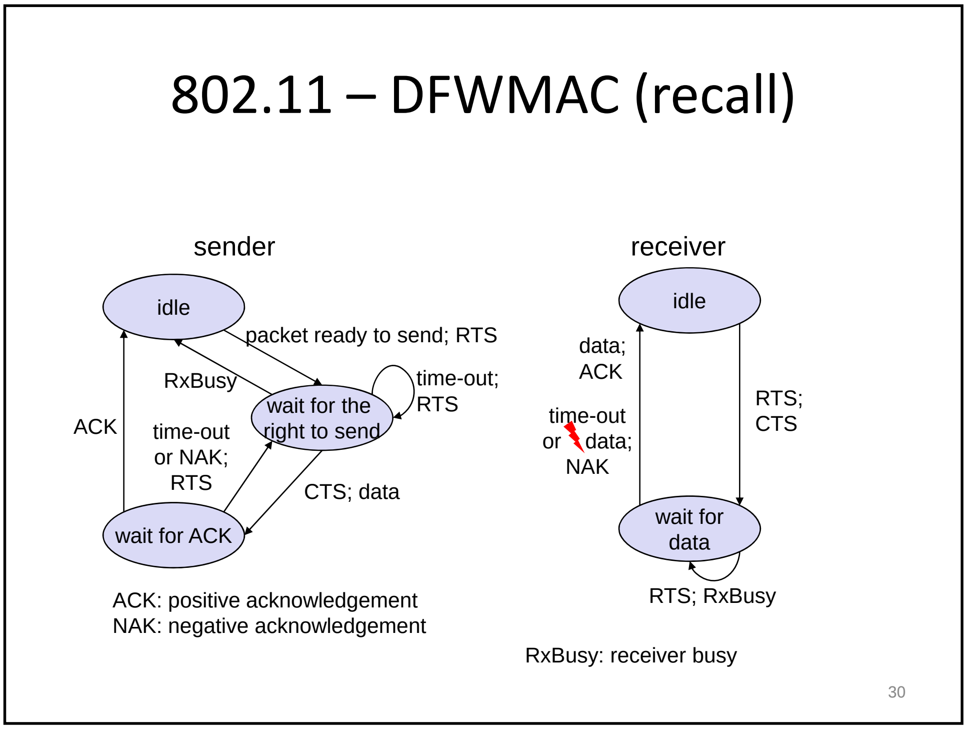
sender
receiver
other stations
DIFS
data
SIFS
ACK
DIFS
data
t
waiting time
contention

29



802.11 – DFWMAC (recall)

sender
idle
packet ready to send; RTS
RxBusy
wait for the right to send
time-out; RTS
ACK
time-out or NAK; RTS
CTS; data
wait for ACK
receiver
idle
data; ACK
time-out or data; NAK
RTS; CTS
wait for data
RTS; RxBusy

ACK: positive acknowledgement
NAK: negative acknowledgement

RxBusy: receiver busy

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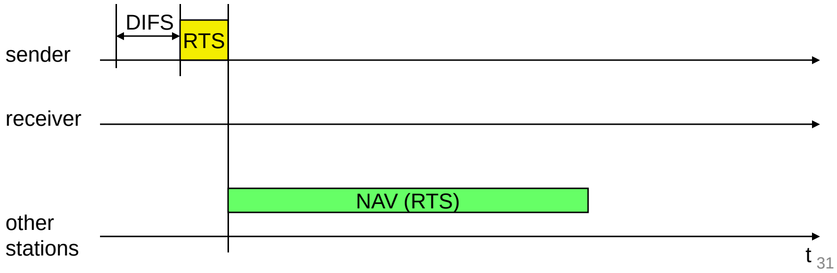
NAV = net allocation vector

802.11 - DFWMAC

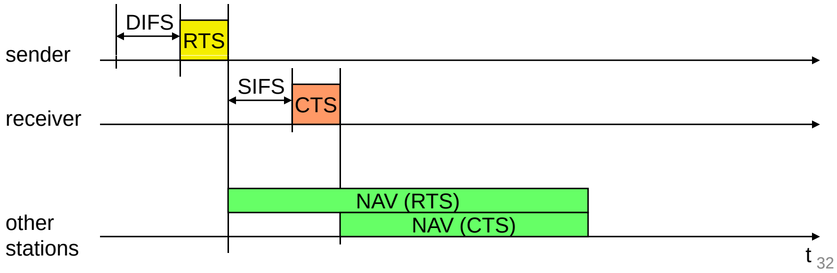
- Sending unicast packets
  - Station sends RTS with reservation parameter (determines amount of time the data packet needs the medium)
  - Other stations store medium reservations



NAV = net allocation vector

802.11 - DFWMAC

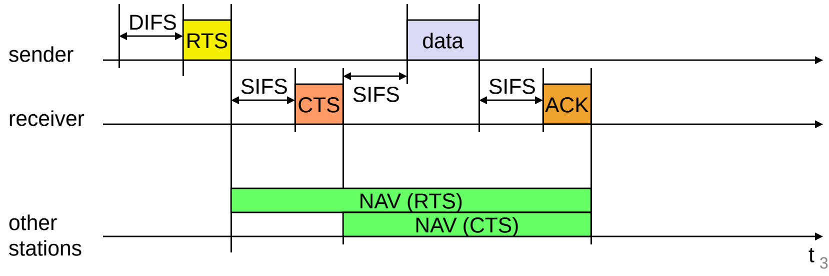
- Sending unicast packets
  - Station sends RTS with reservation parameter (determines amount of time the data packet needs the medium)
  - Ack via CTS after SIFS by receiver (if ready to receive)
  - Other stations store medium reservations



NAV = net allocation vector

802.11 - DFWMAC

- Sending unicast packets
  - Station sends RTS with reservation parameter (determines amount of time the data packet needs the medium)
  - Ack via CTS after SIFS by receiver (if ready to receive)
  - Sender can send data at once, acknowledgement via ACK
  - Other stations store medium reservations



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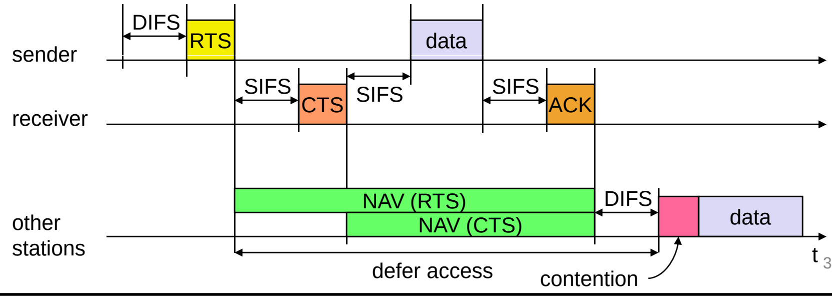


802.11 WRAP UP

Power Management

- Automatic Power Save Delivery (APSD)
  - 802.11e (now 802.11-2007) QoS
  - To extend battery life, device can turn off its radio and power it on when it is expected to receive or transmit
    - Packets arriving at the AP for the station are buffered and delivered when the station wakes up
  - Scheduled APSD
    - Prearranged wake-up times, set by AP, allow the AP to deliver packets buffered for the station
  - Unscheduled APSD
    - Receipt of a packet from the station signals that the station is awake to receive packets buffered at the AP
    - Periodic broadcast messages can notify a device when packets are buffered at the AP

Roaming

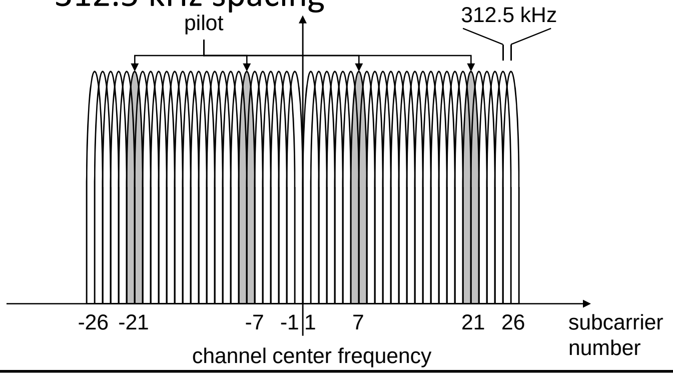
- No or bad connection? Then perform:
- Scanning
  - scan the environment, i.e., listen into the medium for beacon signals or send probes into the medium and wait for an answer
- Reassociation Request
- Reassociation Response
  - failure: continue scanning
- AP accepts Reassociation Request
  - inform the old AP so it can release resources
- Fast roaming – 802.11r (now 802.11-2007)
  - e.g. for vehicle-to-roadside networks

Aside: Multi-carrier modulation (MCM)

- Recall: multi-channel propagation
- Inter-symbol interference (ISI)
  - The higher the rate of symbols transmitted, the higher the ISI
- Recall: digital modulation—convert digital signal (symbols) to analog
- MCM: take a high symbol rate signal on one carrier and turn it into several lower symbol rate signals on multiple subcarriers
- Example: Orthogonal FDM (OFDM)

OFDM in IEEE 802.11a

- OFDM with 52 used subcarriers
  - 48 data + 4 pilot
  - 312.5 kHz spacing



WLAN Data Rates

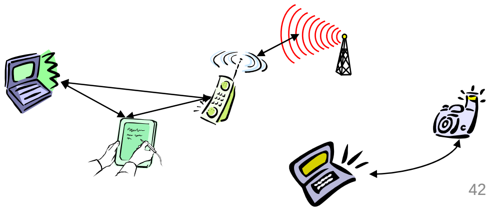
- 802.11b: Data rate
  - 1, 2, 5.5, 11 Mbit/s, depending on SNR
  - User data rate max. approx. 6 Mbit/s
- 802.11g: Data Rates > 20 Mbit/s at 2.4 GHz; 54 Mbit/s, OFDM
- 802.11n: Higher data rates above 100Mbit/s
  - MIMO antennas (Multiple Input Multiple Output), up to 600Mbit/s are currently feasible
  - However, still a large overhead due to protocol headers and inefficient mechanisms
- 802.11ac (>1Gbps in 5GHz), 802.11ad (10Gbps in 60GHz)
  - Scheduled for end of 2012

BLUETOOTH

Bluetooth

- Basic idea
  - Universal radio interface for ad-hoc wireless connectivity
  - Interconnecting computer and peripherals, handheld devices, PDAs, cell phones – replacement of IrDA
  - Embedded in other devices, low cost
  - Short range (10 m), low power consumption, license-free 2.45 GHz ISM
  - Voice and data transmission, approx. 1 Mbit/s gross data rate

One of the first modules (Ericsson).



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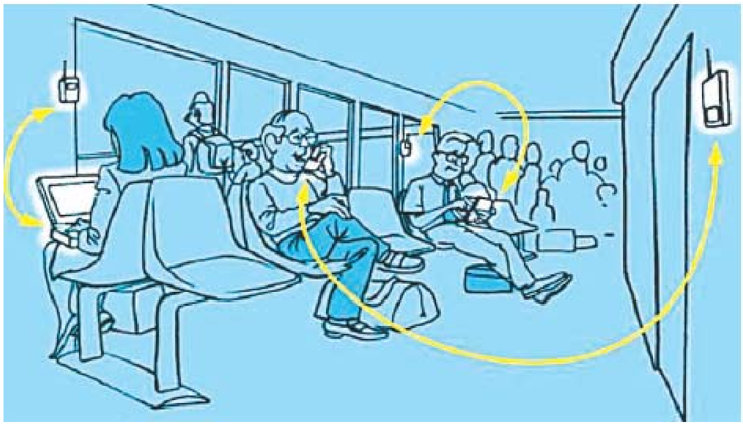
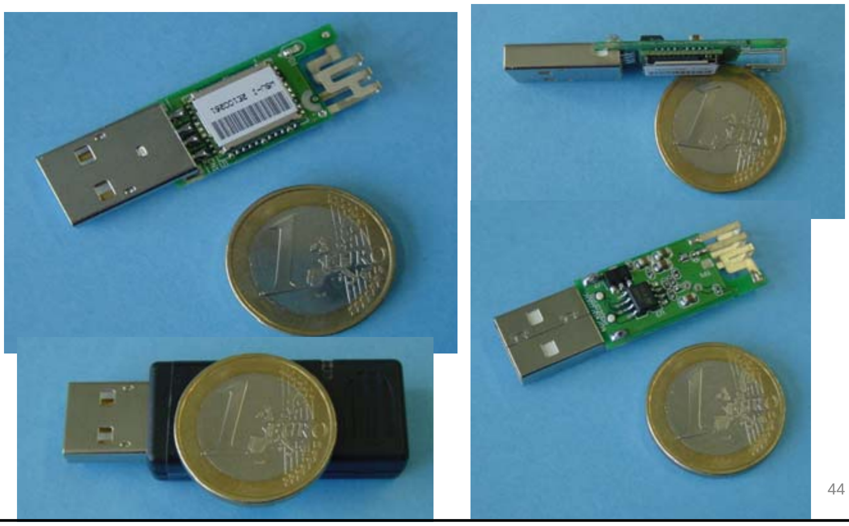
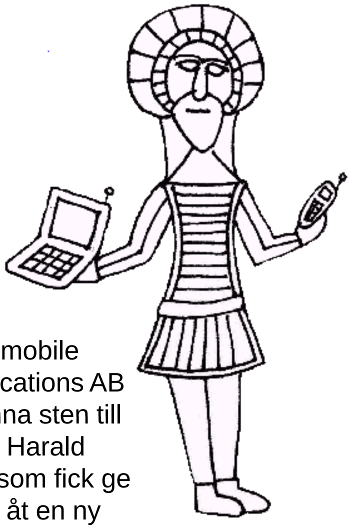
Personal Area Networks



Example: Bluetooth/USB adapter (2002: $50, today: some cents if integrated)

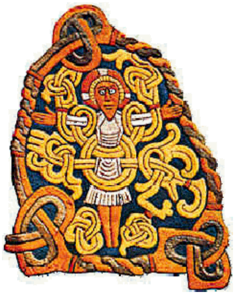




1999:
Ericsson mobile communications AB reste denna sten till minne av Harald Blåtand, som fick ge sitt namn åt en ny teknologi för trådlös, mobil kommunikation.

The real rune stone…

Located in Jelling, Denmark, erected by King Harald "Blåtand" in memory of his parents. The stone has three sides – one side showing a picture of Christ.



- Inscription:
- "Harald king executes these sepulchral monuments after Gorm, his father and Thyra, his mother. The Harald who won the whole of Denmark and Norway and turned the Danes to Christianity."
- Btw: Blåtand means "of dark complexion"
- (not having a blue tooth…)

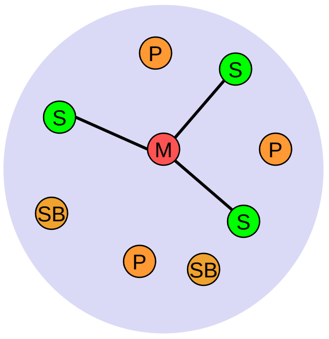
- This could be the "original" colors of the stone.
- Inscription:
- "auk tani karthi kristna" (and made the Danes Christians)

Characteristics

- 2.4 GHz ISM band, 79 (23) RF channels, 1 MHz carrier spacing
  - Channel 0: 2402 MHz … channel 78: 2480 MHz
  - G-FSK modulation, 1-100 mW transmit power
- FHSS and TDD
  - Frequency hopping with 1600 hops/s
  - Hopping sequence in a pseudo random fashion, determined by a master
  - Time division duplex for send/receive separation
- Voice link – SCO (Synchronous Connection Oriented)
  - FEC (forward error correction), no retransmission, 64 kbit/s duplex, point-to-point, circuit switched
- Data link – ACL (Asynchronous ConnectionLess)
  - Asynchronous, fast acknowledge, point-to-multipoint, up to 433.9 kbit/s symmetric or 723.2/57.6 kbit/s asymmetric, packet switched
- Topology
  - Overlapping piconets (stars) forming a scatternet

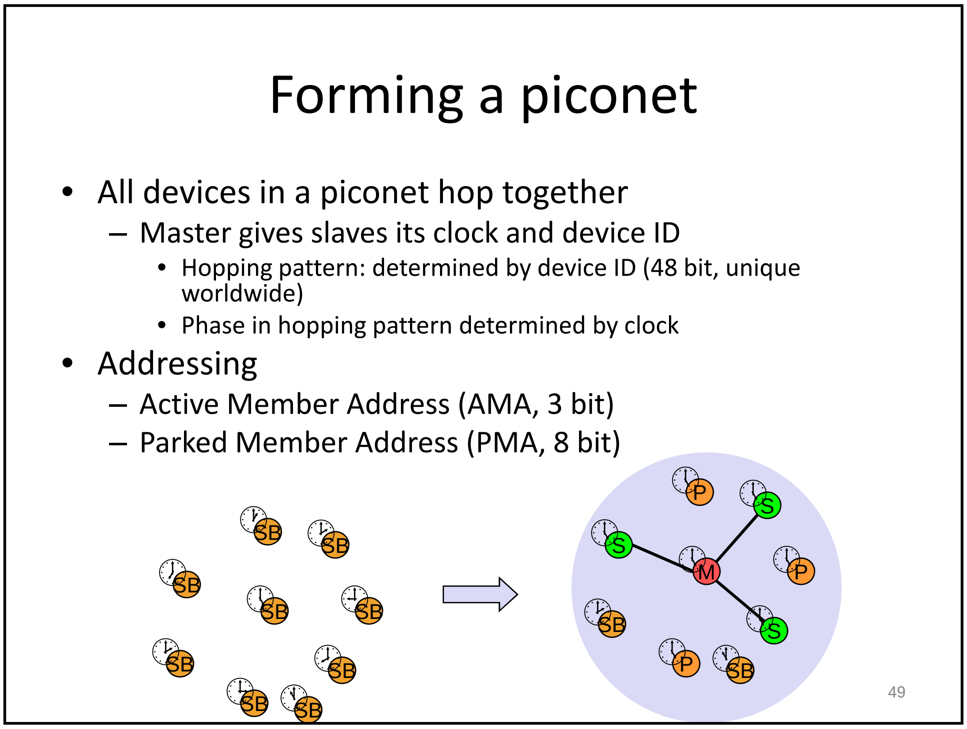
Piconet

- Collection of devices connected in an ad hoc fashion
- Master and slaves
- Master determines hopping pattern, slaves have to synchronize
- Each piconet has a unique hopping pattern
- Participation in a piconet = synchronization to hopping sequence
- Each piconet has one master and up to 7 simultaneous slaves (> 200 could be parked)



M=Master
S=Slave

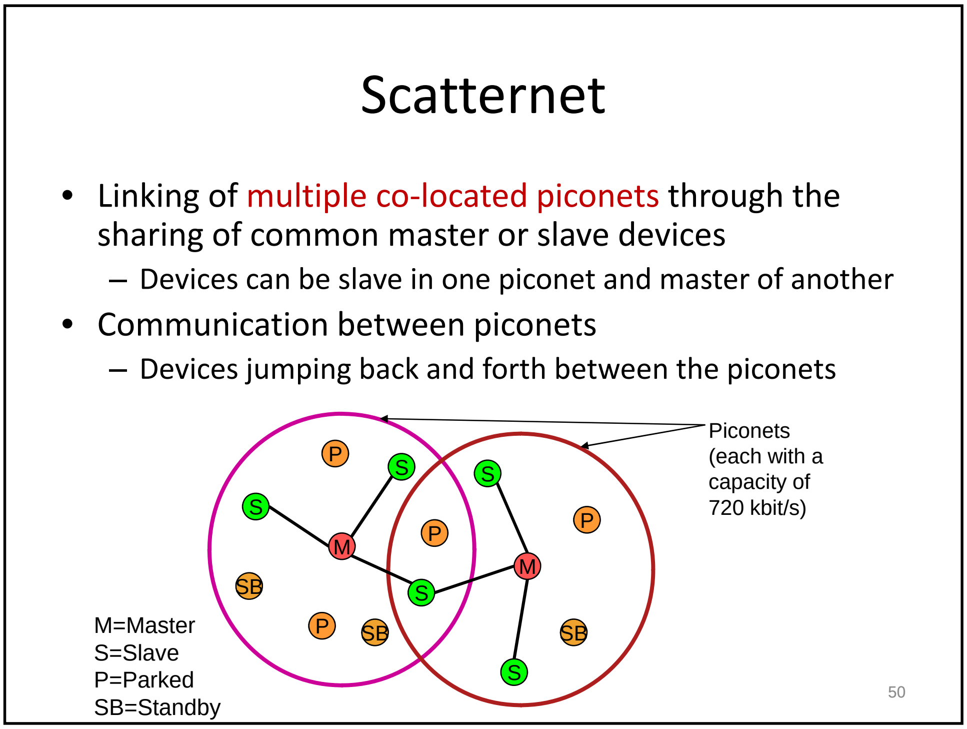
P=Parked
SB=Standby



Forming a piconet

- All devices in a piconet hop together
  - Master gives slaves its clock and device ID
    - Hopping pattern: determined by device ID (48 bit, unique worldwide)
    - Phase in hopping pattern determined by clock
- Addressing
  - Active Member Address (AMA, 3 bit)
  - Parked Member Address (PMA, 8 bit)

49



Scatternet

- Linking of multiple co-located piconets through the sharing of common master or slave devices
  - Devices can be slave in one piconet and master of another
- Communication between piconets
  - Devices jumping back and forth between the piconets

Piconets
(each with a
capacity of
720 kbit/s)

M=Master
S=Slave
P=Parked
SB=Standby

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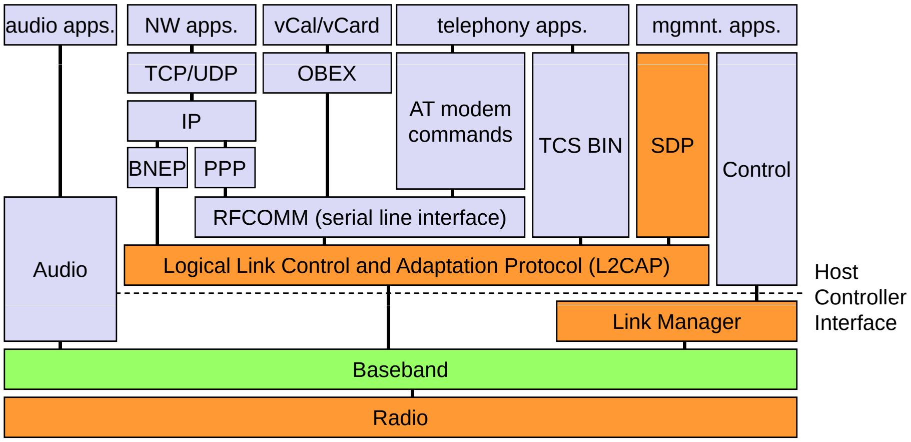
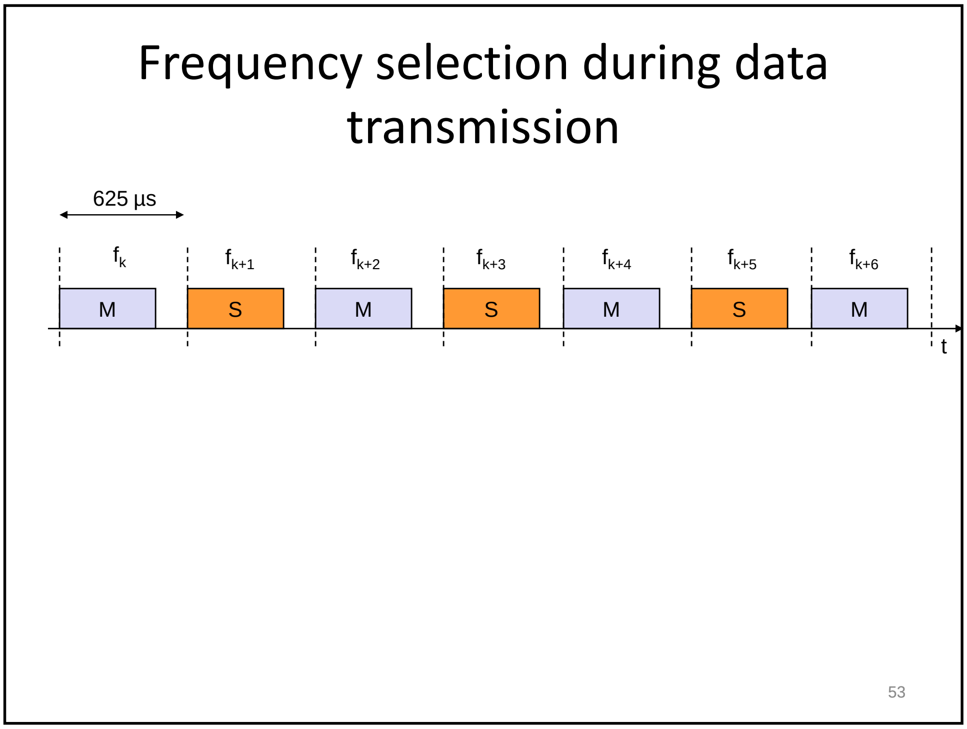
BLUETOOTH BASEBAND

Bluetooth protocol stack



AT: attention sequence
OBEX: object exchange
TCS BIN: telephony control protocol specification – binary
BNEP: Bluetooth network encapsulation protocol

SDP: service discovery protocol
RFCOMM: radio frequency comm.



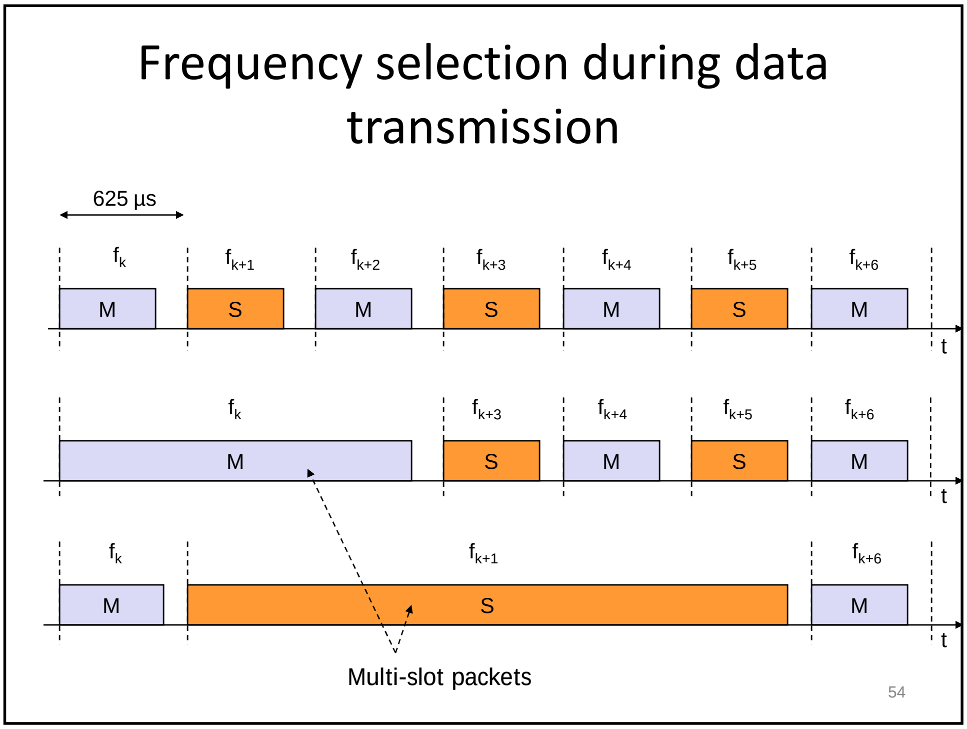
Frequency selection during data transmission

625 µs

f_k f_{k+1} f_{k+2} f_{k+3} f_{k+4} f_{k+5} f_{k+6}

M S M S M S M

t



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M S M S M

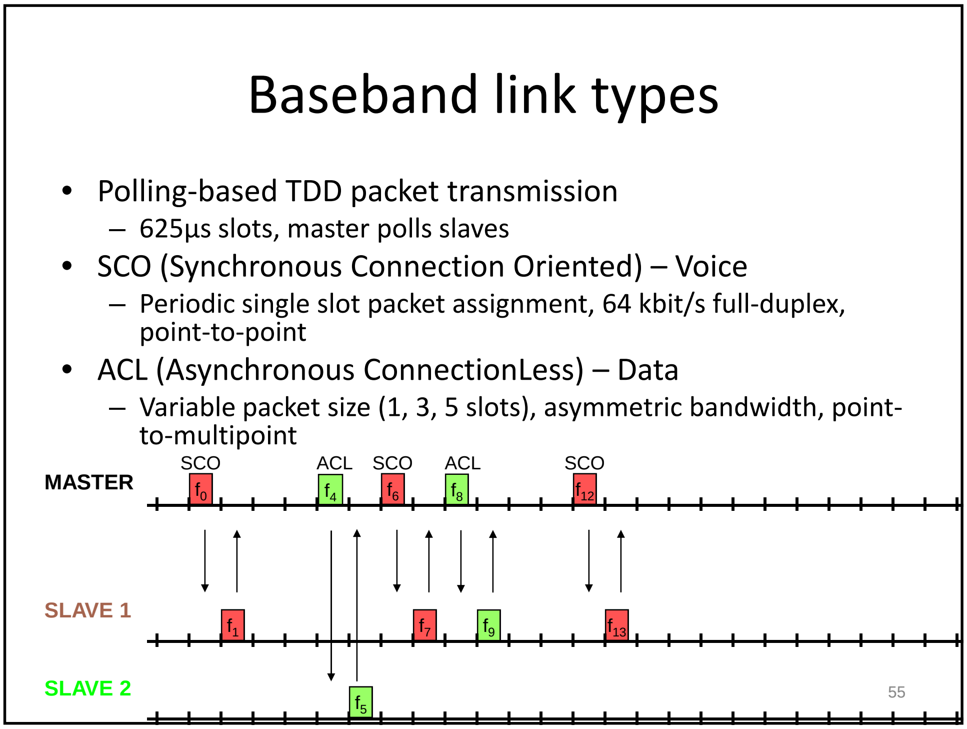
t

f_k f_{k+1} f_{k+6}

M S M

t

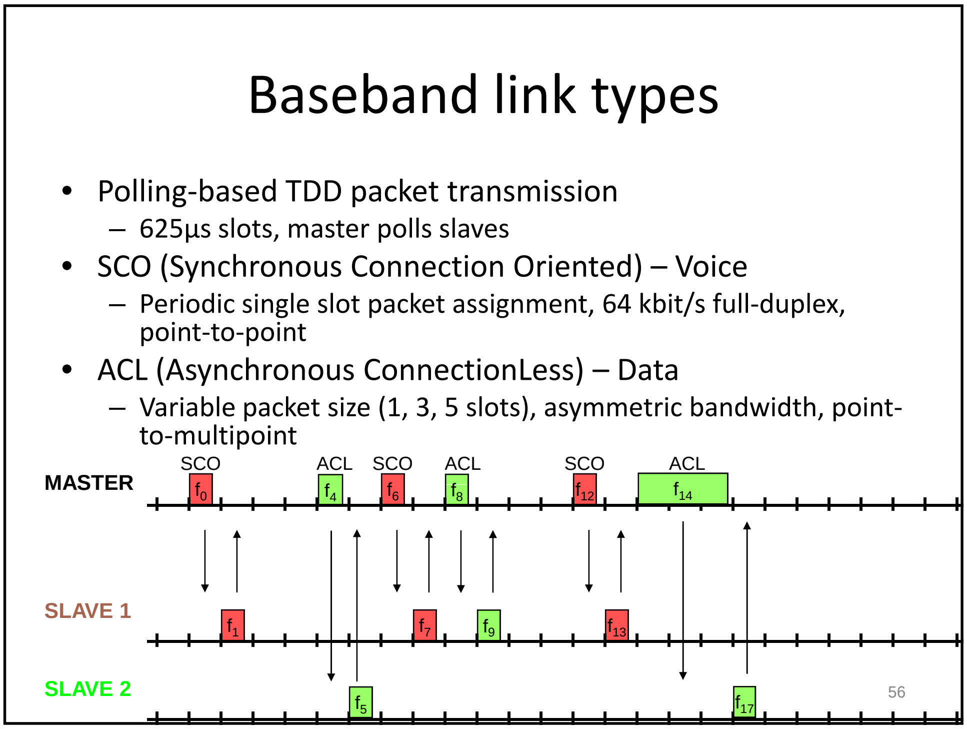
Multi-slot packets



Baseband link types

- Polling-based TDD packet transmission
  - 625µs slots, master polls slaves
- SCO (Synchronous Connection Oriented) – Voice
  - Periodic single slot packet assignment, 64 kbit/s full-duplex, point-to-point
- ACL (Asynchronous ConnectionLess) – Data
  - Variable packet size (1, 3, 5 slots), asymmetric bandwidth, point-to-multipoint

55



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56

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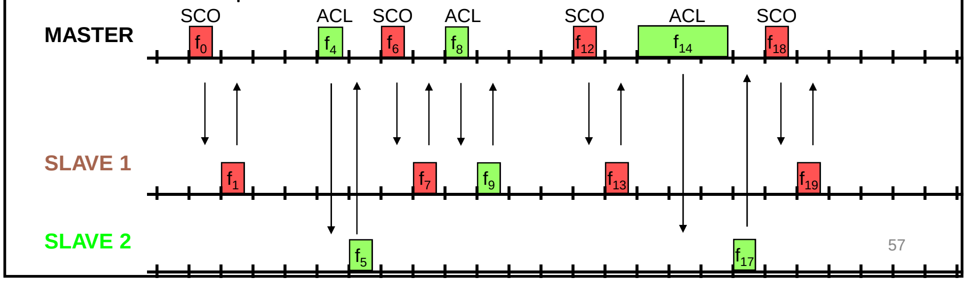

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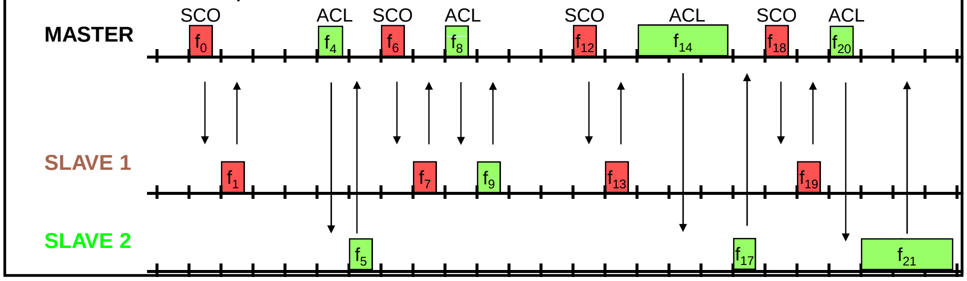
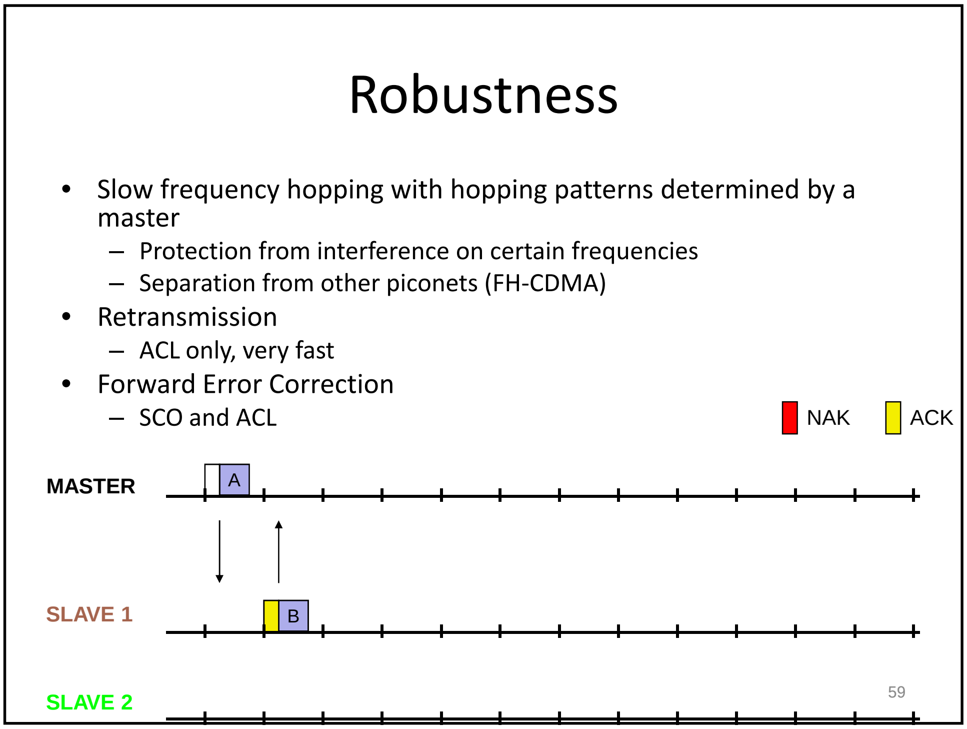
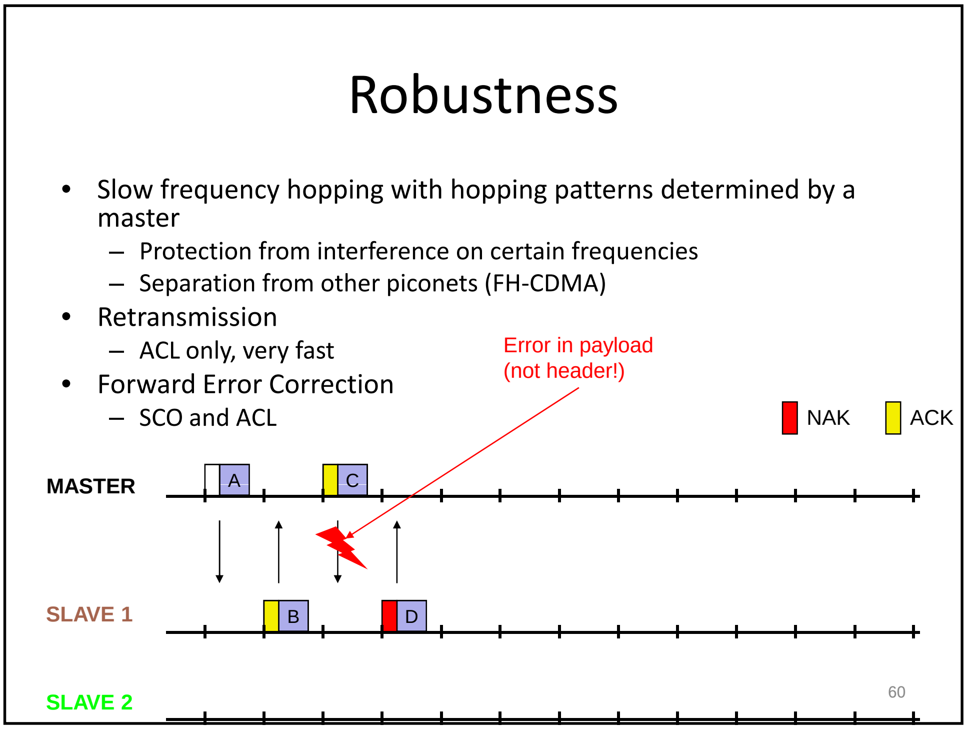




Robustness

- Slow frequency hopping with hopping patterns determined by a master
  - Protection from interference on certain frequencies
  - Separation from other piconets (FH-CDMA)
- Retransmission
  - ACL only, very fast
- Forward Error Correction
  - SCO and ACL



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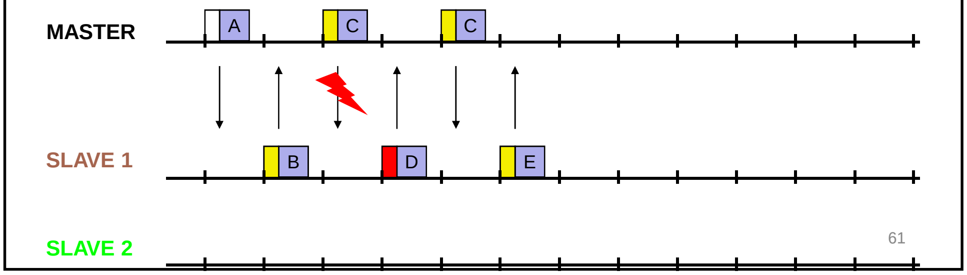
🟥 NAK 🟨 ACK



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- Forward Error Correction
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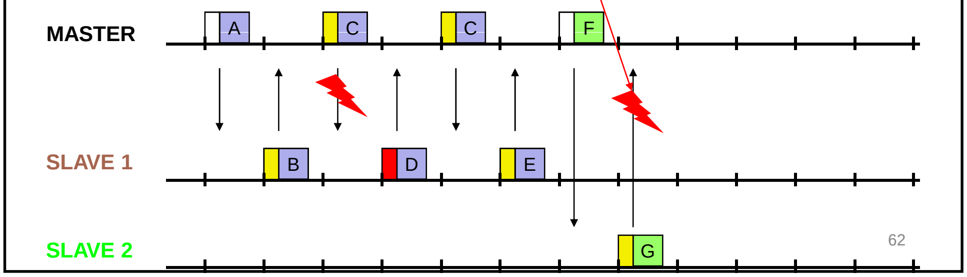
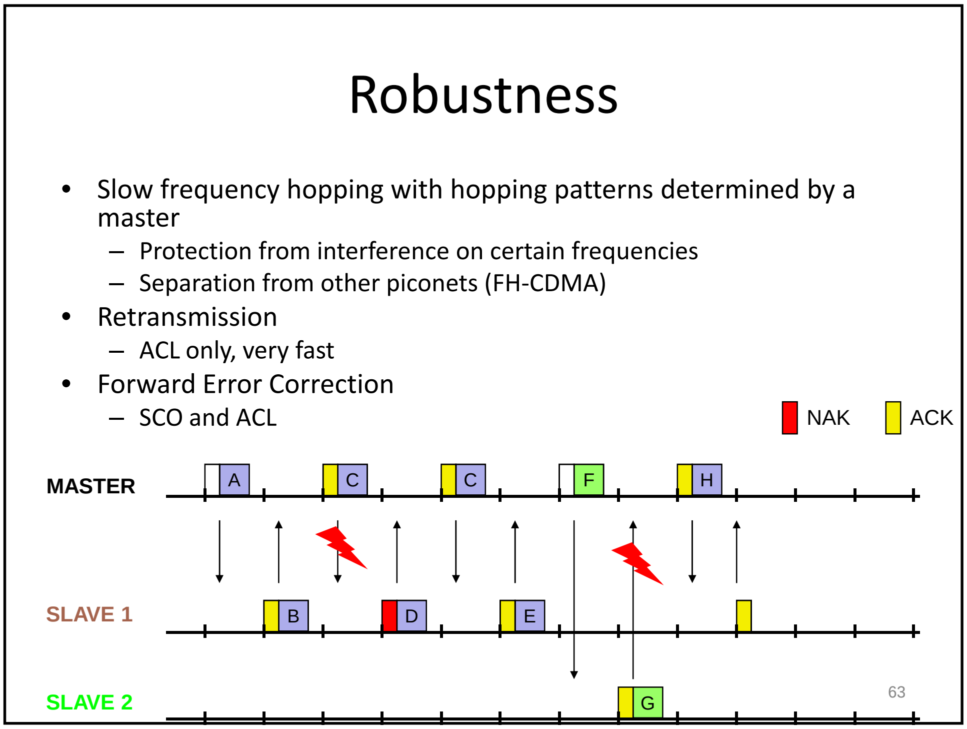
Error in payload (not header!)

🟥 NAK 🟨 ACK





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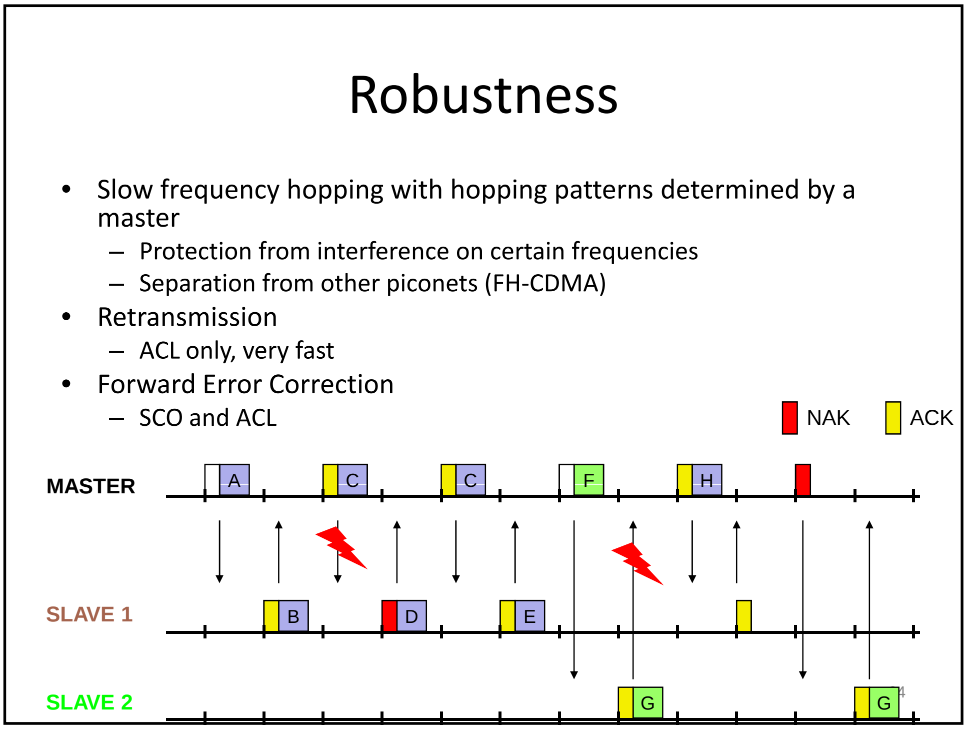
🟥 NAK 🟨 ACK

63



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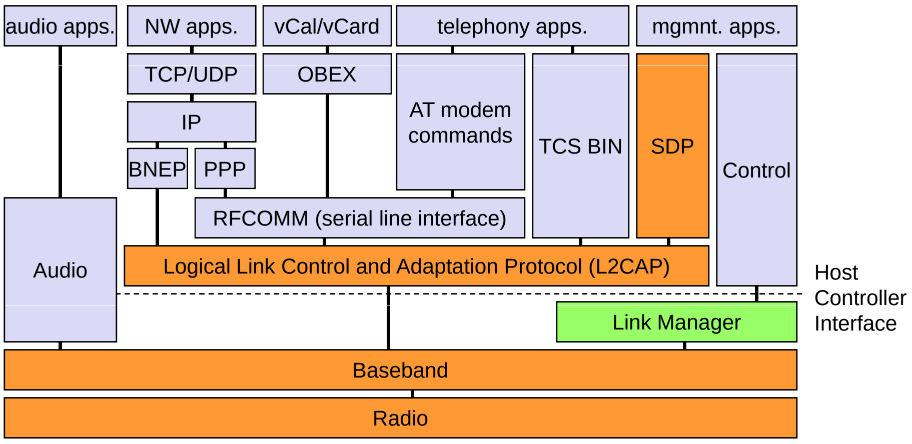
🟥 NAK 🟨 ACK

4

BLUETOOTH LINK CONTROL

Bluetooth protocol stack



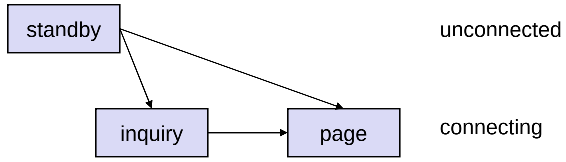
66

Baseband states of a Bluetooth device

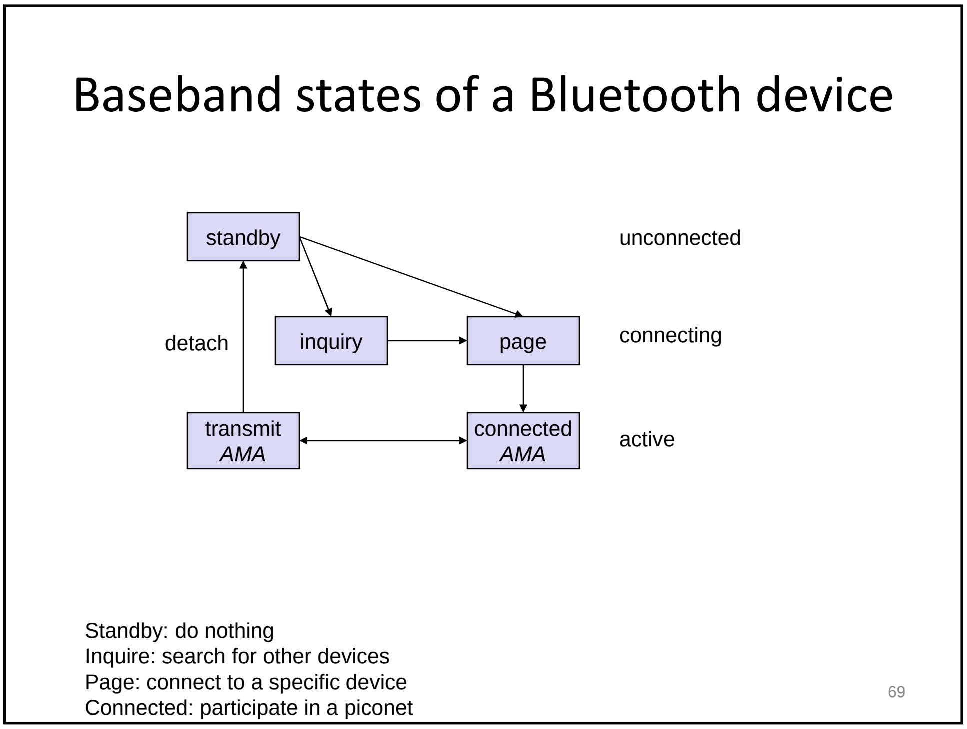
standby
unconnected

Standby: do nothing

Baseband states of a Bluetooth device



Standby: do nothing
Inquire: search for other devices
Page: connect to a specific device



Baseband states of a Bluetooth device

standby

unconnected

detach

inquiry

page

connecting

transmit
AMA

connected
AMA

active

Standby: do nothing
Inquire: search for other devices
Page: connect to a specific device
Connected: participate in a piconet

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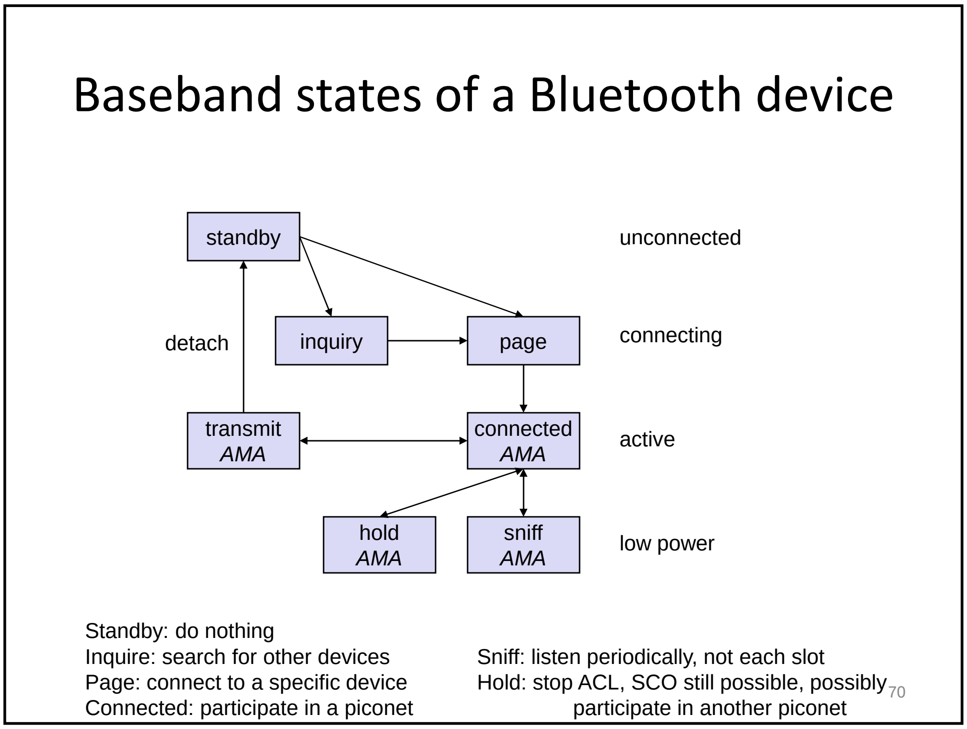

Baseband states of a Bluetooth device

standby

unconnected

detach

inquiry

page

connecting

transmit
AMA

connected
AMA

active

hold
AMA

sniff
AMA

low power

Standby: do nothing
Inquire: search for other devices
Page: connect to a specific device
Connected: participate in a piconet

Sniff: listen periodically, not each slot
Hold: stop ACL, SCO still possible, possibly participate in another piconet

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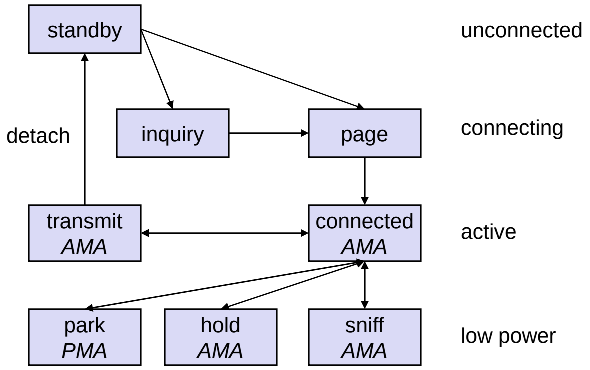
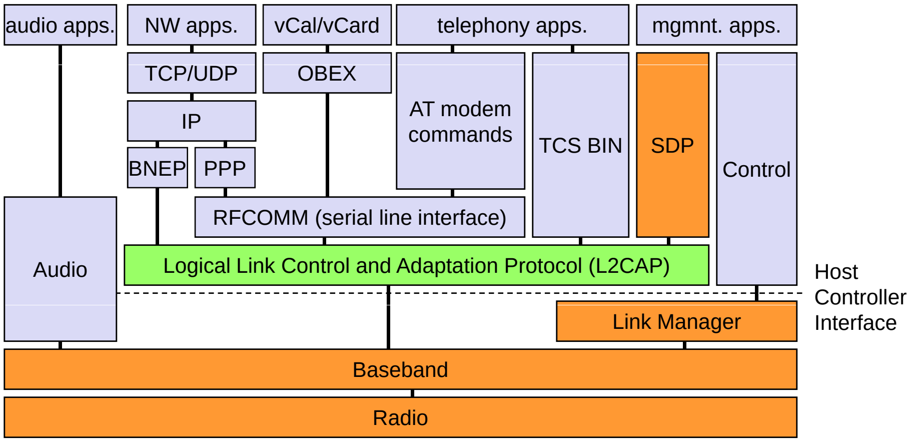
Baseband states of a Bluetooth device



Standby: do nothing
Inquire: search for other devices
Page: connect to a specific device
Connected: participate in a piconet

Park: release AMA, get PMA
Sniff: listen periodically, not each slot
Hold: stop ACL, SCO still possible, possibly participate in another piconet

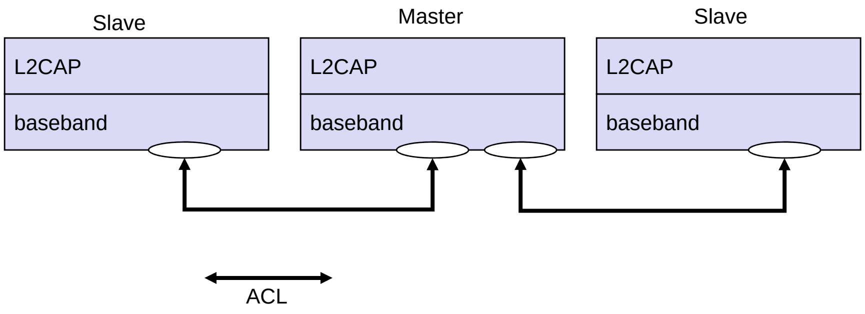
Bluetooth protocol stack



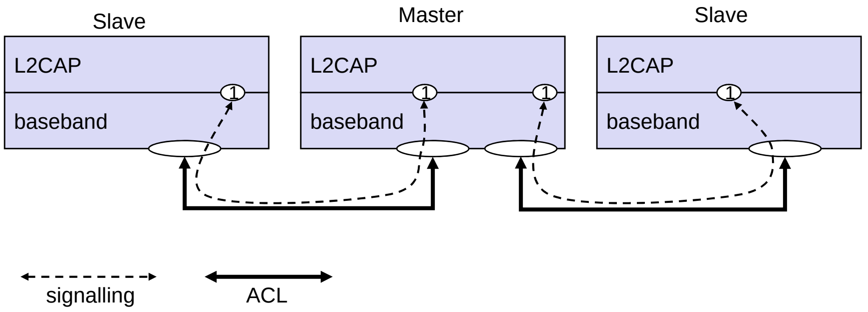
L2CAP - Logical Link Control and Adaptation Protocol

- Simple data link protocol on top of baseband
- Connection oriented, connectionless, and signaling channels
- Protocol multiplexing
  - RFCOMM, SDP, telephony control
- Segmentation & reassembly
  - Up to 64kbyte user data, 16 bit CRC used from baseband
- QoS flow specification per channel
  - Follows RFC 1363, specifies delay, jitter, bursts, bandwidth
- Group abstraction
  - Create/close group, add/remove member

L2CAP logical channels



L2CAP logical channels



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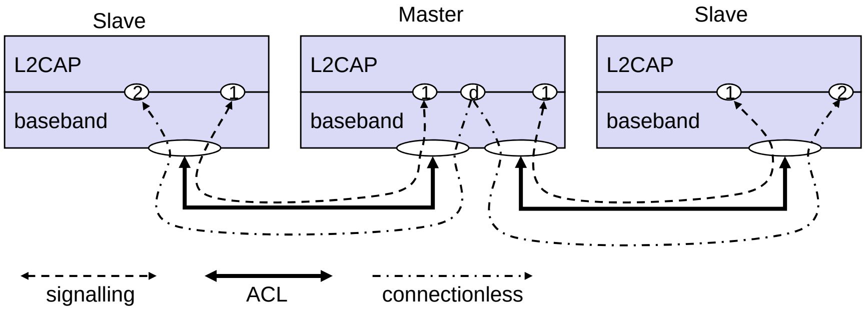
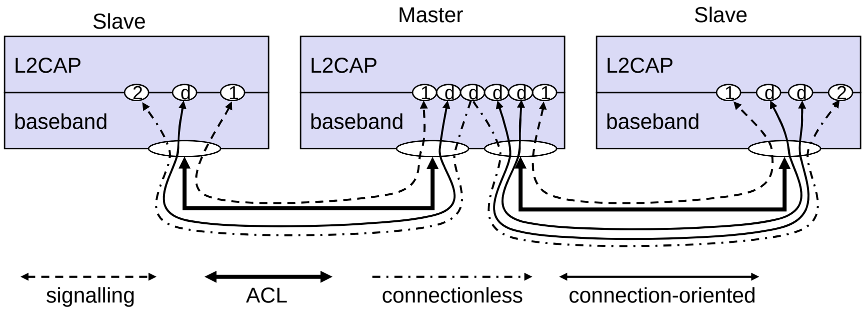
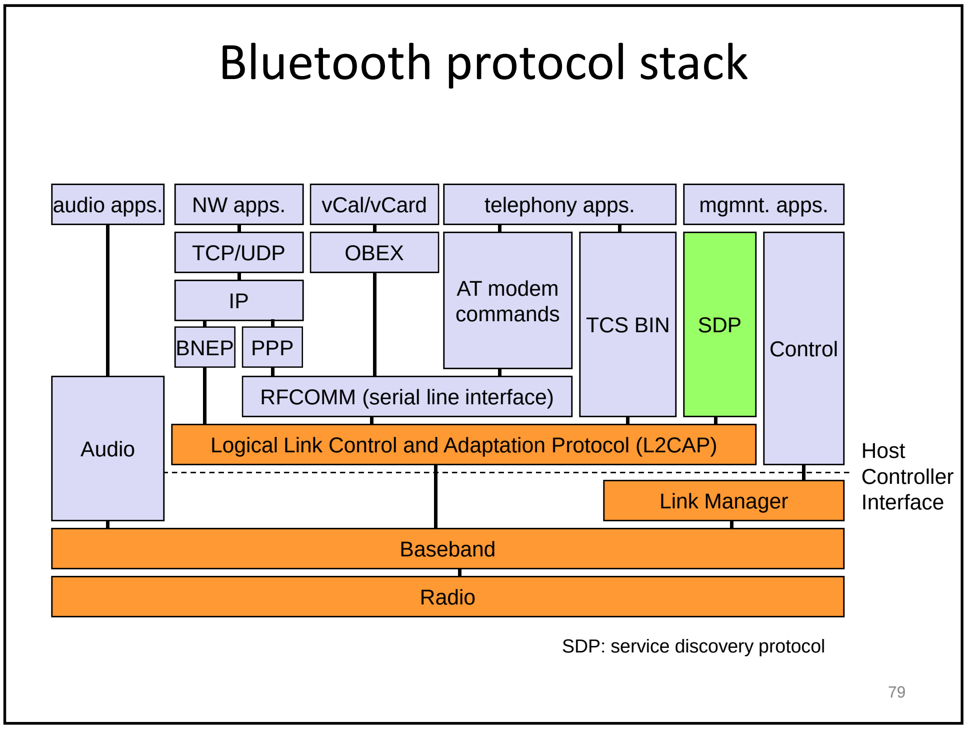


L2CAP logical channels



BLUETOOTH OTHER PROTOCOLS



Bluetooth protocol stack

SDP: service discovery protocol

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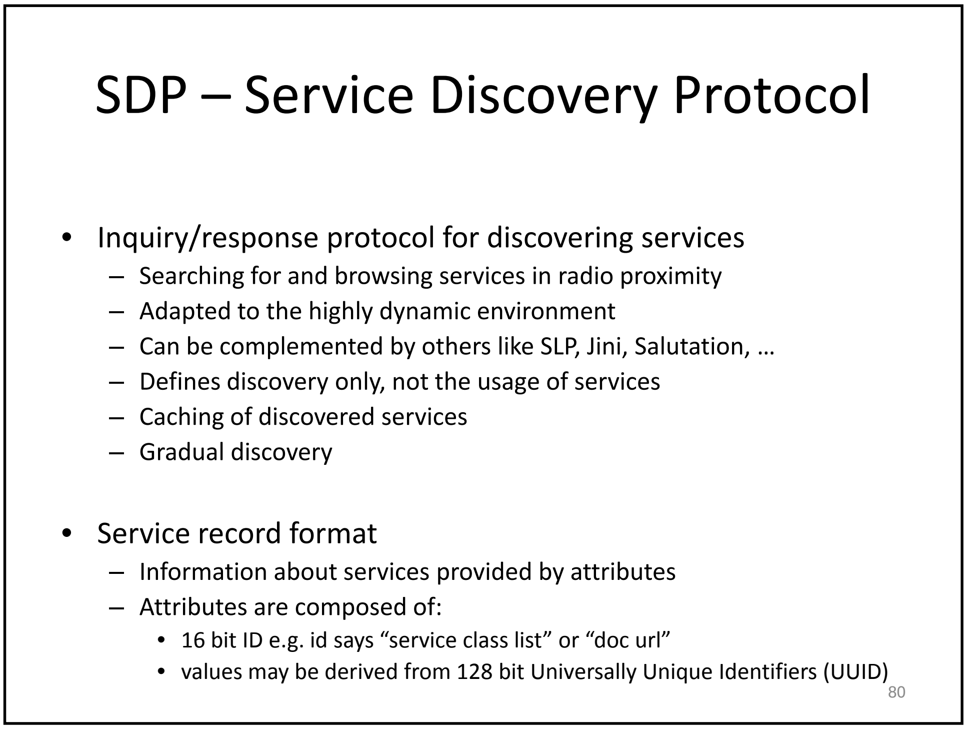

SDP – Service Discovery Protocol

- Inquiry/response protocol for discovering services
  - Searching for and browsing services in radio proximity
  - Adapted to the highly dynamic environment
  - Can be complemented by others like SLP, Jini, Salutation, …
  - Defines discovery only, not the usage of services
  - Caching of discovered services
  - Gradual discovery
- Service record format
  - Information about services provided by attributes
  - Attributes are composed of:
    - 16 bit ID e.g. id says “service class list” or “doc url”
    - values may be derived from 128 bit Universally Unique Identifiers (UUID)

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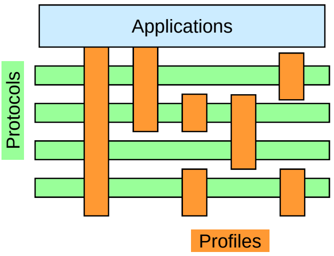
Additional protocols to support legacy protocols/apps.

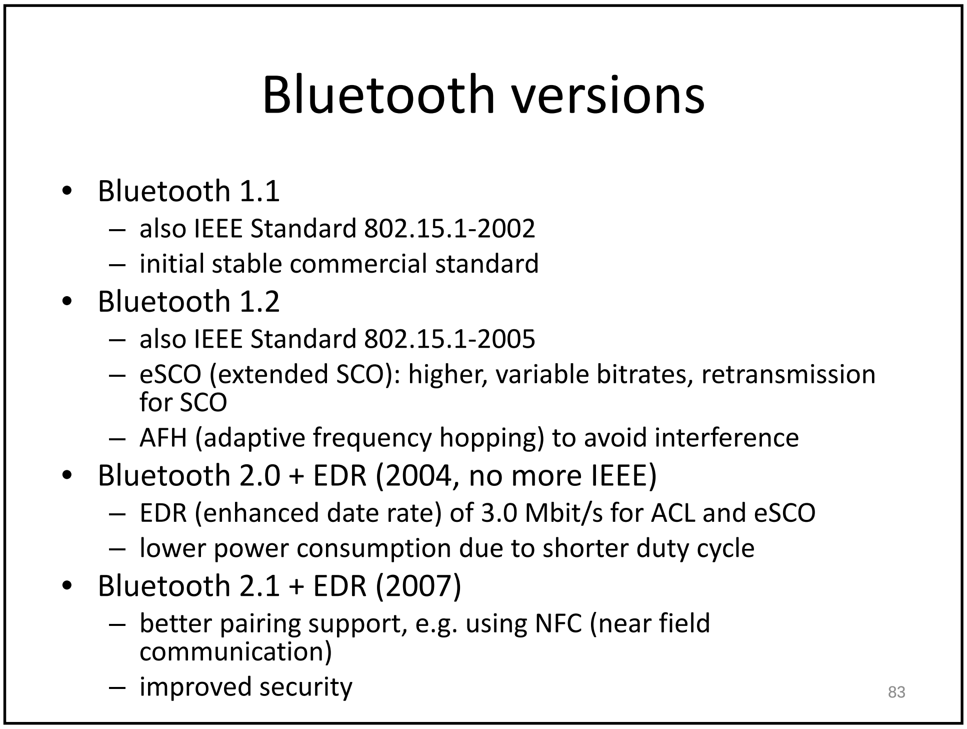
- RFCOMM
  - Emulation of a serial port (supports a large base of legacy applications)
  - Allows multiple ports over a single physical channel
- Telephony Control Protocol Specification (TCS)
  - Call control (setup, release)
  - Group management
- OBEX
  - Exchange of objects, IrDA replacement
- WAP
  - Interacting with applications on cellular phones

Profiles



- Represent default solutions for a certain usage model
  - Vertical slice through the protocol stack
  - Basis for interoperability
- Generic Access Profile
- Service Discovery Application Profile
- Cordless Telephony Profile
- Intercom Profile
- Serial Port Profile
- Headset Profile
- Dial-up Networking Profile
- Fax Profile
- LAN Access Profile
- Generic Object Exchange Profile
- Object Push Profile
- File Transfer Profile
- Synchronization Profile

Additional Profiles
Advanced Audio Distribution
PAN
Audio Video Remote Control
Basic Printing
Basic Imaging
Extended Service Discovery
Generic Audio Video Distribution
Hands Free
Hardcopy Cable Replacement



Bluetooth versions

- Bluetooth 1.1
  - also IEEE Standard 802.15.1-2002
  - initial stable commercial standard
- Bluetooth 1.2
  - also IEEE Standard 802.15.1-2005
  - eSCO (extended SCO): higher, variable bitrates, retransmission for SCO
  - AFH (adaptive frequency hopping) to avoid interference
- Bluetooth 2.0 + EDR (2004, no more IEEE)
  - EDR (enhanced date rate) of 3.0 Mbit/s for ACL and eSCO
  - lower power consumption due to shorter duty cycle
- Bluetooth 2.1 + EDR (2007)
  - better pairing support, e.g. using NFC (near field communication)
  - improved security