Mobile Computing

Part I: Wireless LANs

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- IEEE 802.11
  - MAC
  - Roaming
  - Versions
- Bluetooth
  - IEEE 802.15-x
- Interference
  - 802.11 vs.(?) 802.15

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 like, e.g., earthquakes, fire - or users pulling a plug...

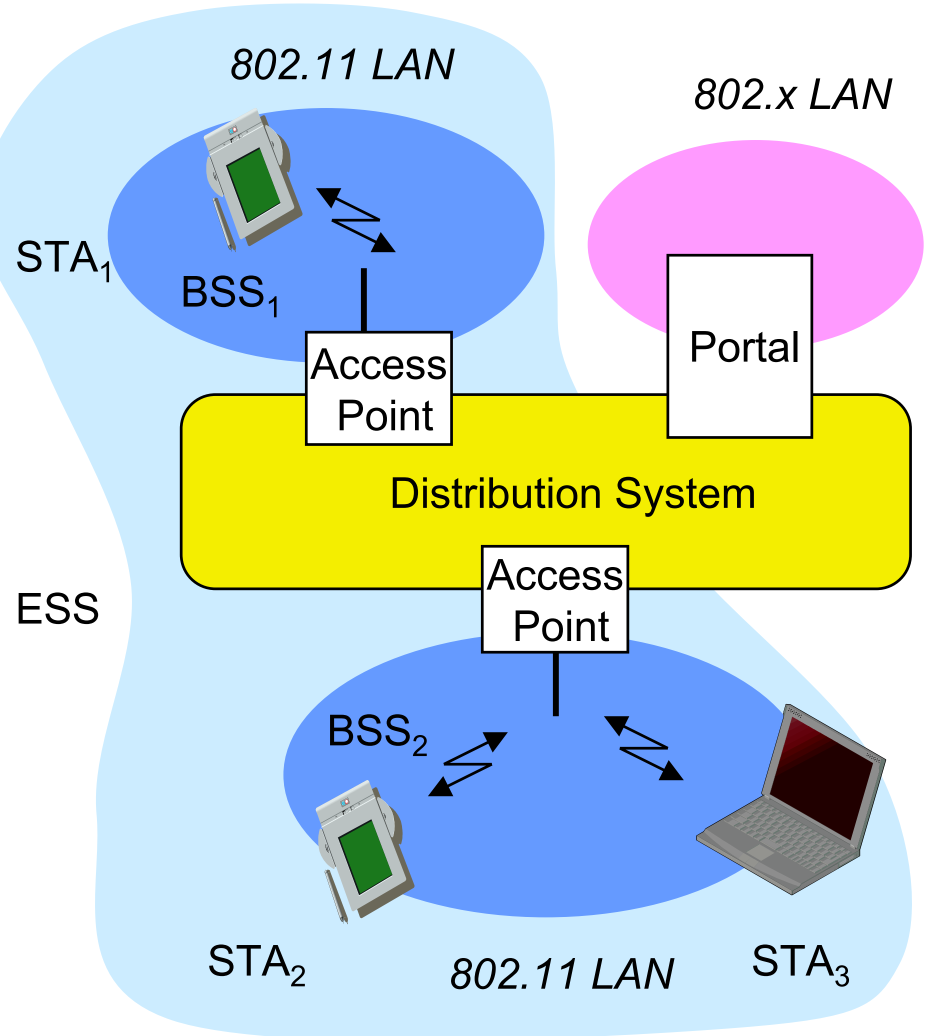
Disadvantages

- typically very low bandwidth compared to wired networks (1-10 Mbit/s)
- many proprietary solutions, especially for higher bit-rates, standards take their time (e.g. IEEE 802.11)
- products have to follow many national restrictions if working wireless, it takes a very long time to establish global solutions like, e.g., 802.11a/HIPERLAN/2

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
- easy to use for everyone, 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

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

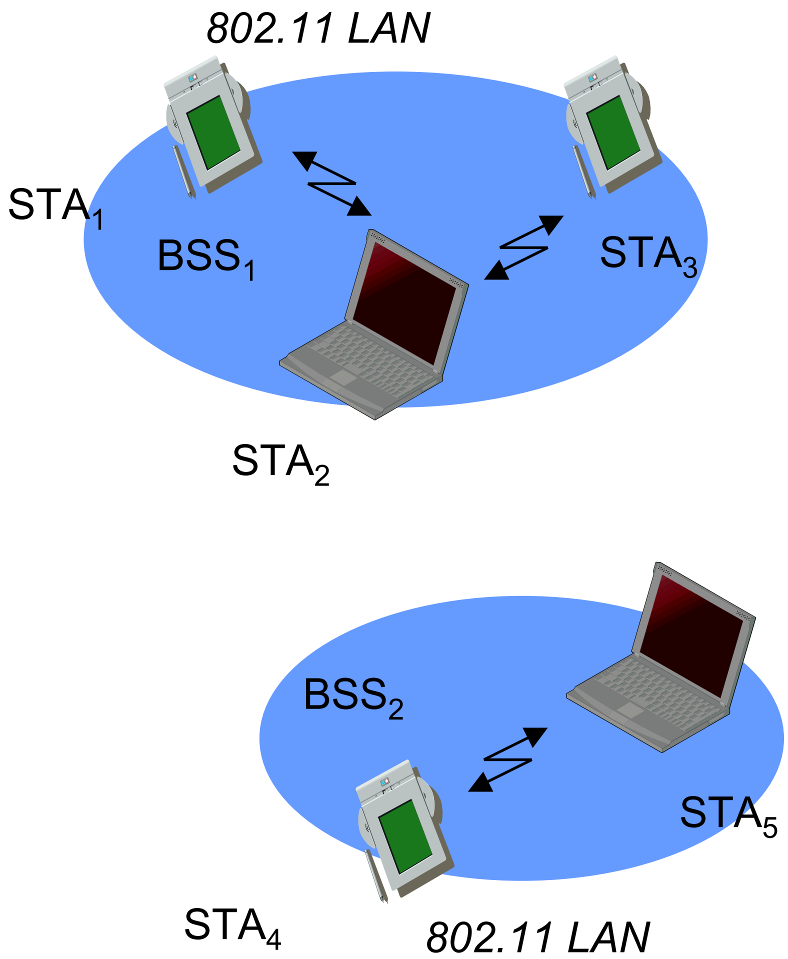
Portal

- bridge to other (wired) networks

Distribution System

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

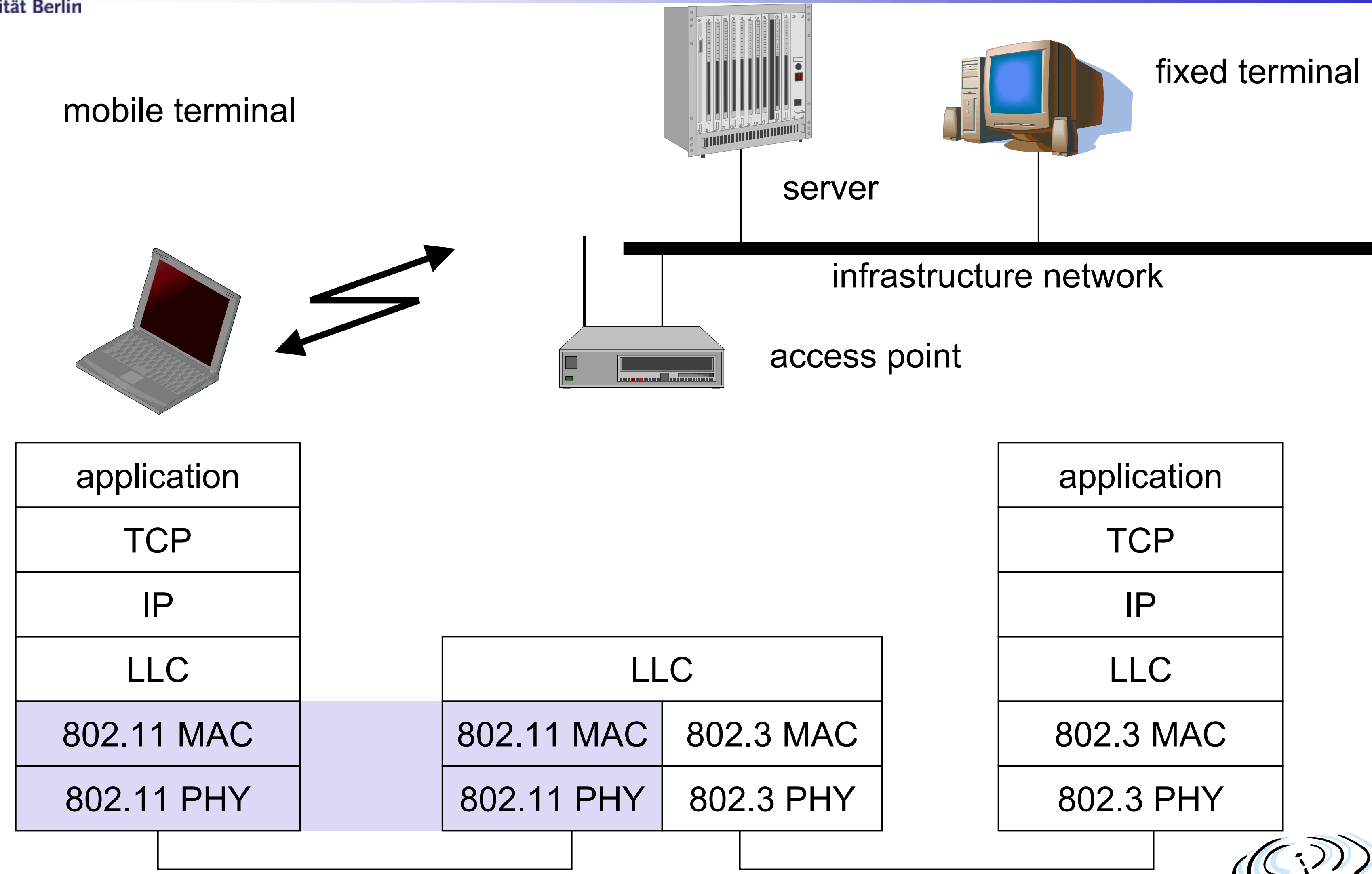
802.11 - Architecture of an ad-hoc network



Direct communication within a limited range

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

IEEE standard 802.11



802.11 - MAC layer I - 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)

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

Motivation for a special MAC

Can we apply media access methods from fixed networks?

Example CSMA/CD

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

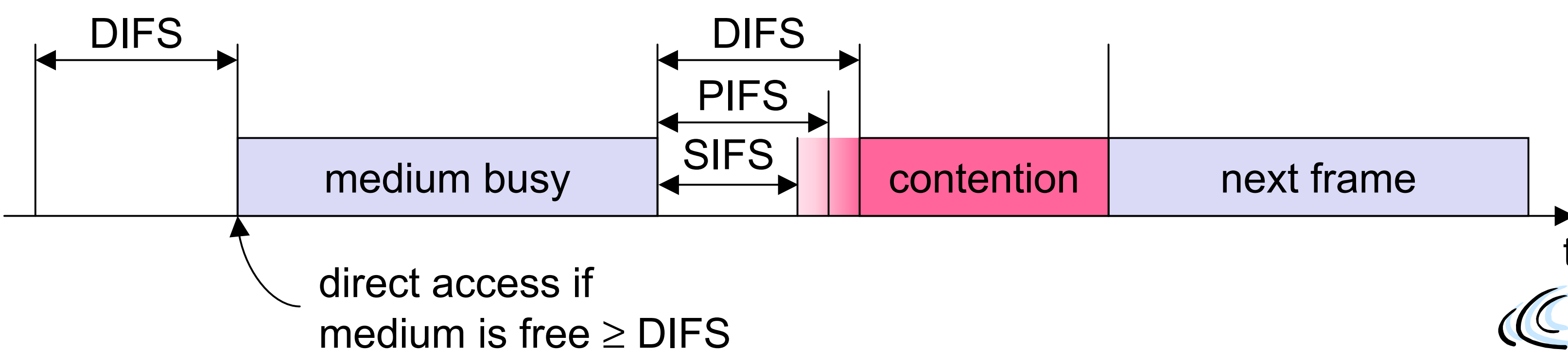
Problems in wireless networks

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

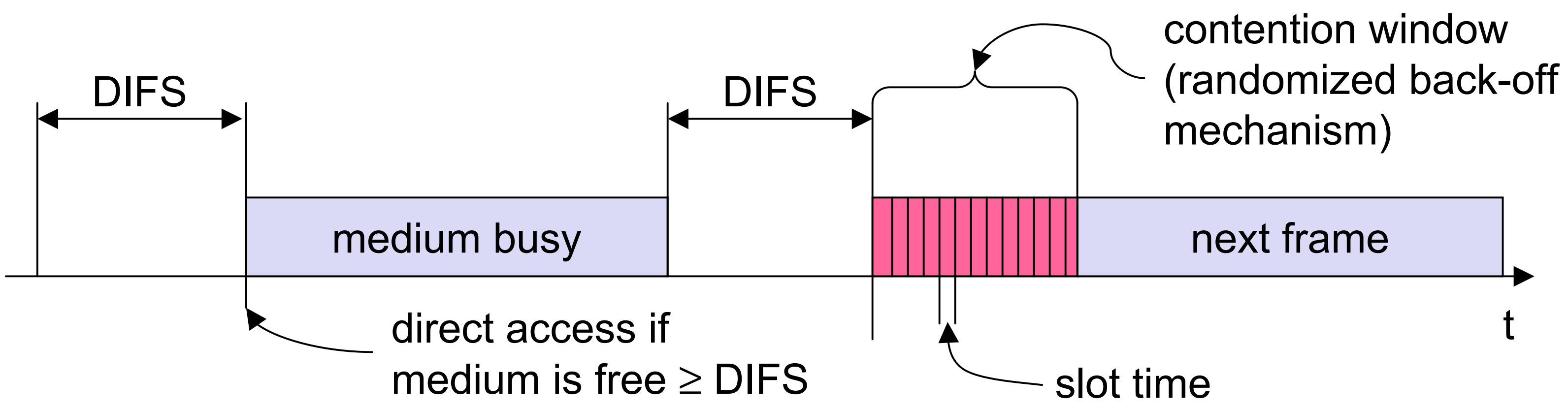
802.11 - MAC layer II

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

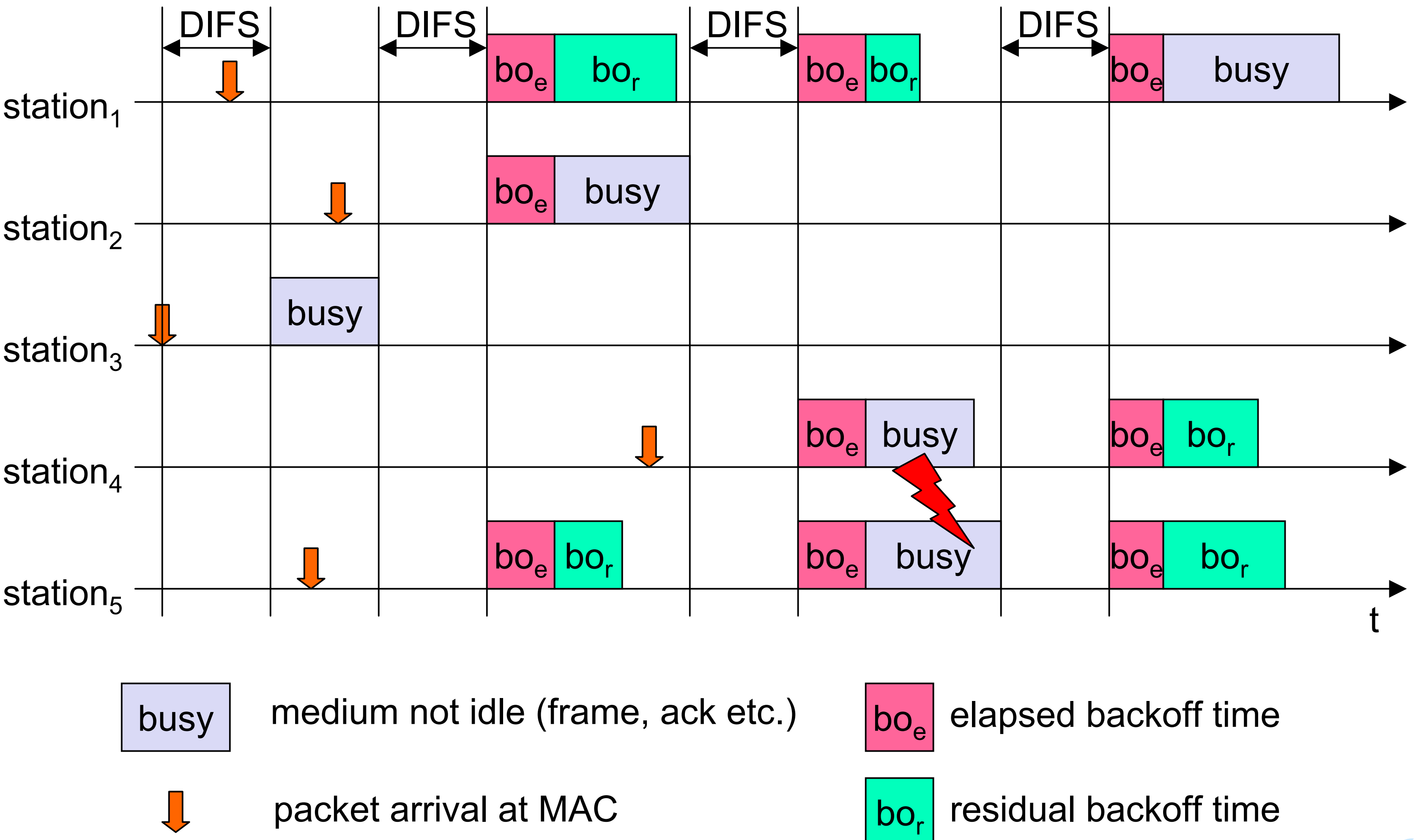


802.11 - CSMA/CA access method I



- 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)

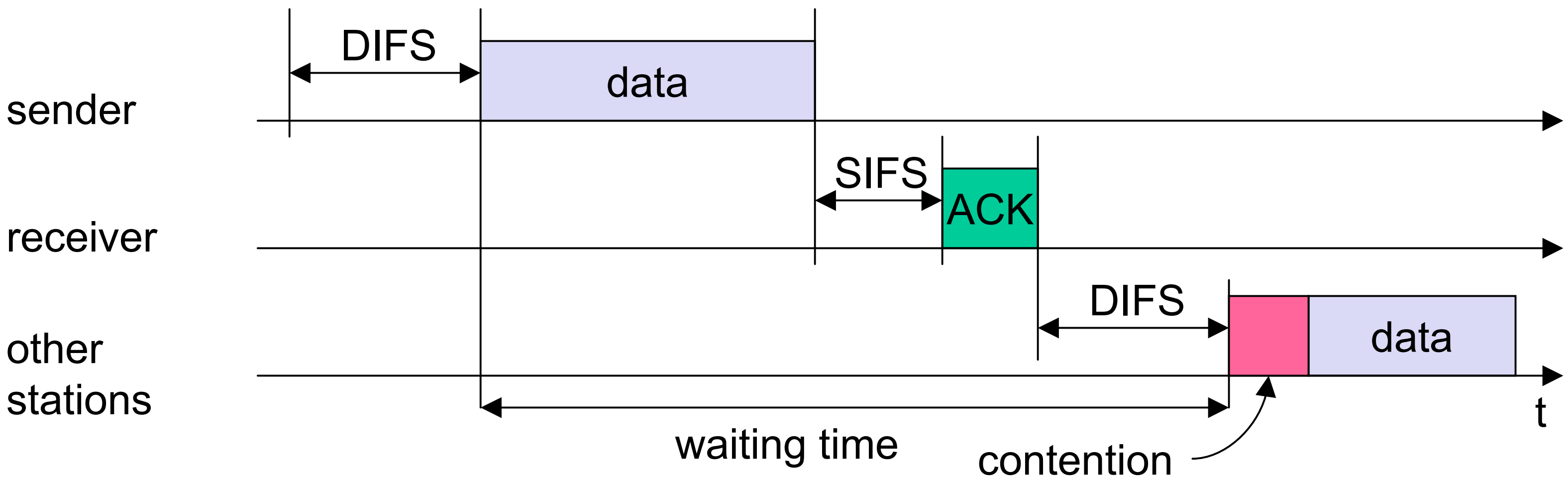
802.11 - competing stations - simple version



802.11 - CSMA/CA access method II

Sending unicast packets

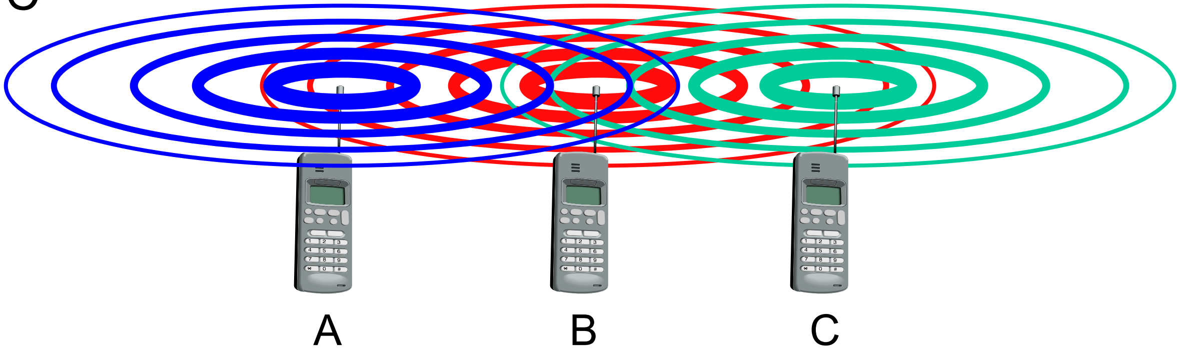
- station has to wait for DIFS before sending data
- receivers acknowledge at once (after waiting for SIFS) if the packet was received correctly (CRC)
- automatic retransmission of data packets in case of transmission errors



Motivation - hidden and exposed terminals

Hidden terminals

- A sends to B, C cannot receive A
- C wants to send to B, C senses a “free” medium (CS fails)
- collision at B, A cannot receive the collision (CD fails)
- A is “hidden” for C



Exposed terminals

- B sends to A, C wants to send to another terminal (not A or B)
- C has to wait, CS signals a medium in use
- but A is outside the radio range of C, therefore waiting is not necessary
- C is “exposed” to B

MACA - collision avoidance

MACA (Multiple Access with Collision Avoidance) uses short signaling packets for collision avoidance

- RTS (request to send): a sender request the right to send from a receiver with a short RTS packet before it sends a data packet
- CTS (clear to send): the receiver grants the right to send as soon as it is ready to receive

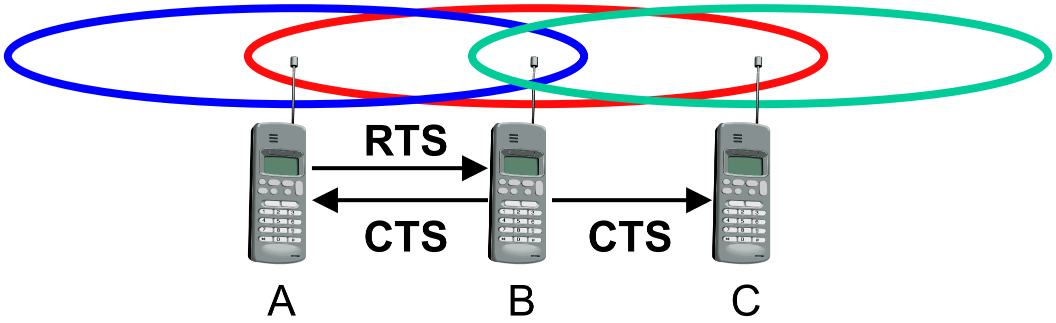
Signaling packets contain

- sender address
- receiver address
- packet size

MACA examples

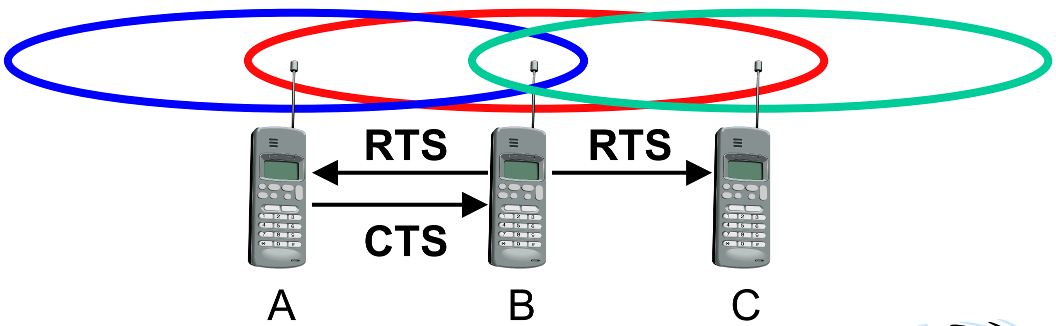
MACA avoids the problem of hidden terminals

- A and C want to send to B
- A sends RTS first
- C waits after receiving CTS from B



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



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

version, type, fragmentation, security, ...

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

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

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

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

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

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: not certified in Europe, currently US-only (harmonization going on), stronger shading due to higher frequency, no QoS

WLAN: IEEE 802.11 – future developments

802.11d: Regulatory Domain Update

802.11e: MAC Enhancements – QoS

- 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

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

802.11g: Data Rates > 20 Mbit/s at 2.4 GHz

802.11h: Spectrum Managed 802.11a

802.11i: Enhanced Security Mechanisms

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

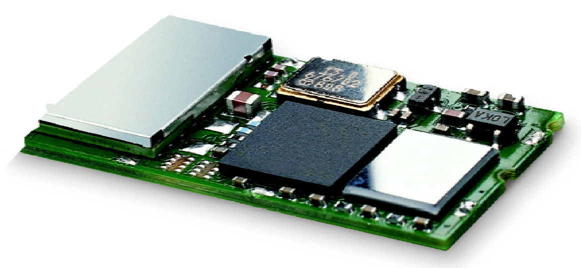
5 GHz Globalization & Harmonization

- Harmonize ETSI/BRAN and IEEE efforts (HIPERLAN/2, 802.11a)
- Main efforts on DLC since PHY is essentially harmonized

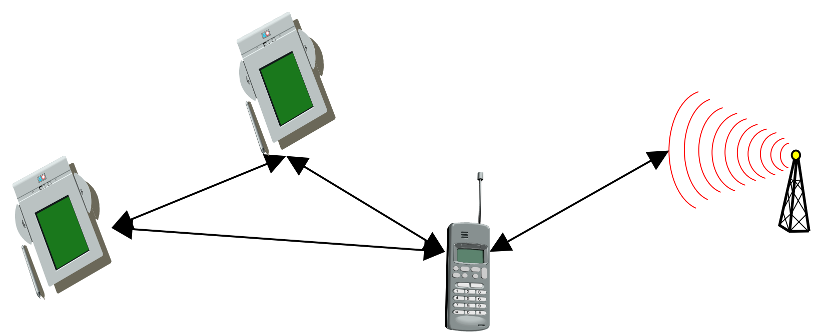
Bluetooth

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, goal: 5€/device (2002: 50€/USB bluetooth)
- 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).



Bluetooth

History

- 1994: Ericsson (Mattison/Haartsen), “MC-link” project
- Renaming of the project: Bluetooth according to Harald “Blåtand” Gormsen [son of Gorm], King of Denmark in the 10th century
- 1998: foundation of Bluetooth SIG, www.bluetooth.org (was: Bluetooth)
- 1999: erection of a rune stone at Ercisson/Lund ;-)
- 2001: first consumer products for mass market, spec. version 1.1 released

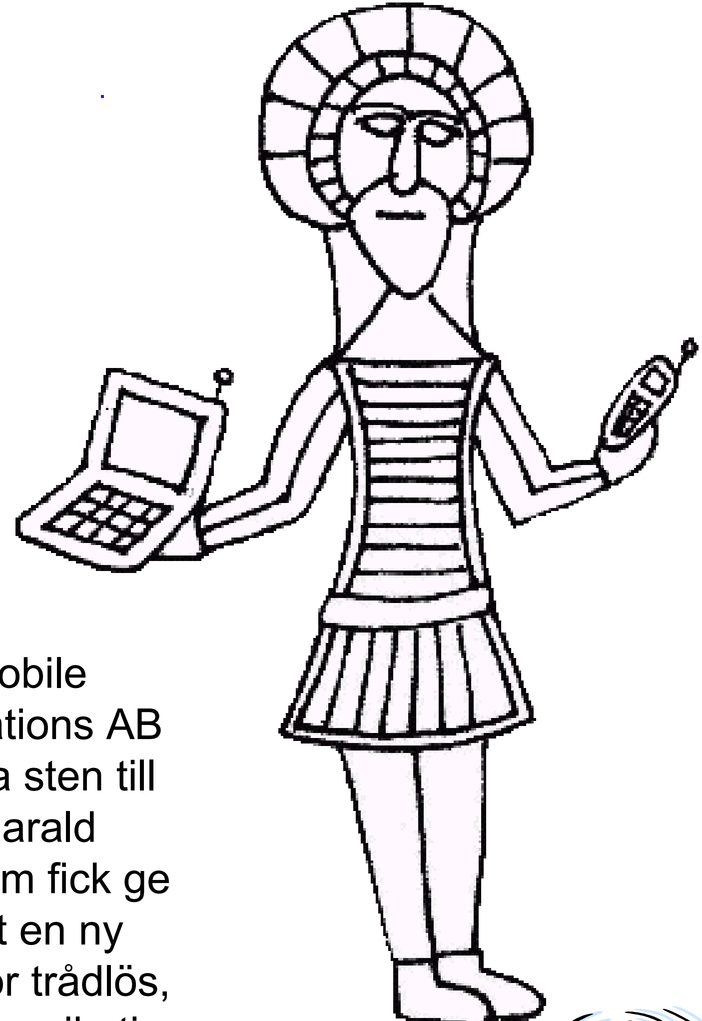
Special Interest Group

- Original founding members: Ericsson, Intel, IBM, Nokia, Toshiba
- Added promoters: 3Com, Agere (was: Lucent), Microsoft, Motorola
- > 2500 members
- Common specification and certification of products

Bluetooth™

History and hi-tech…

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.



…and the real runstone

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

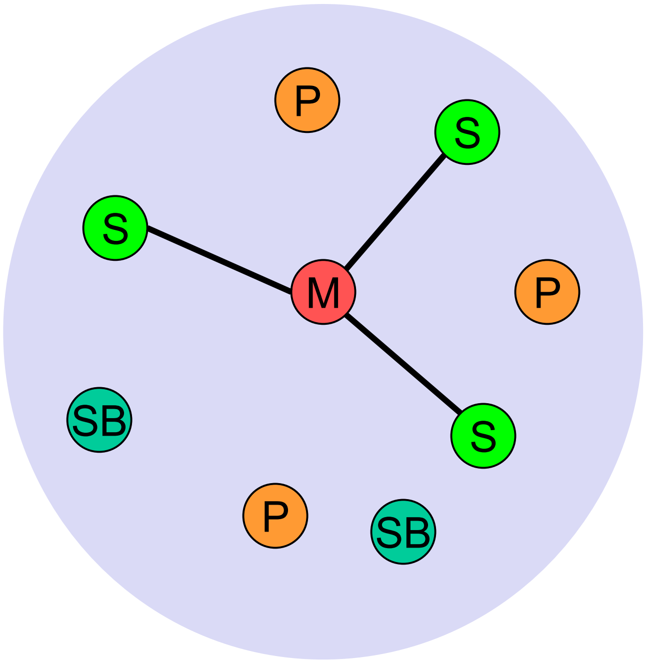
One unit acts as master and the others as slaves for the lifetime of the piconet

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 P=Parked
S=Slave SB=Standby

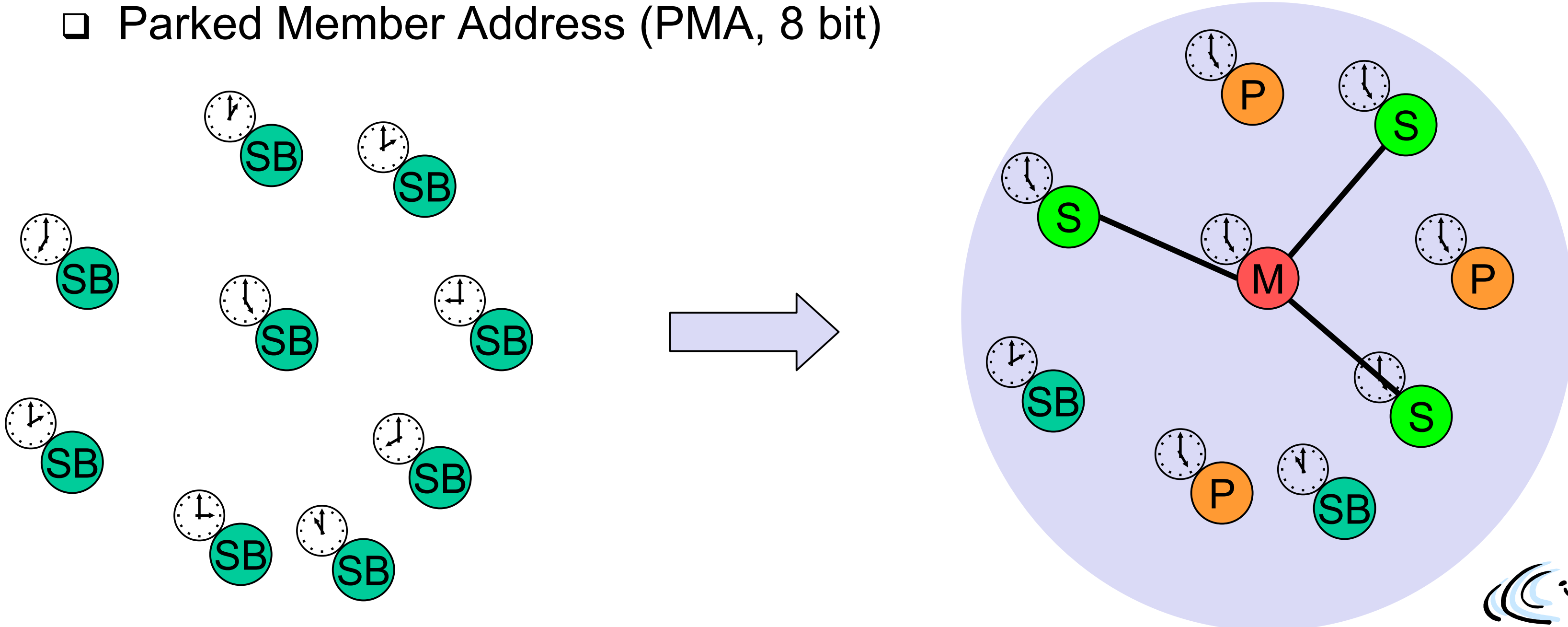
Forming a piconet

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)



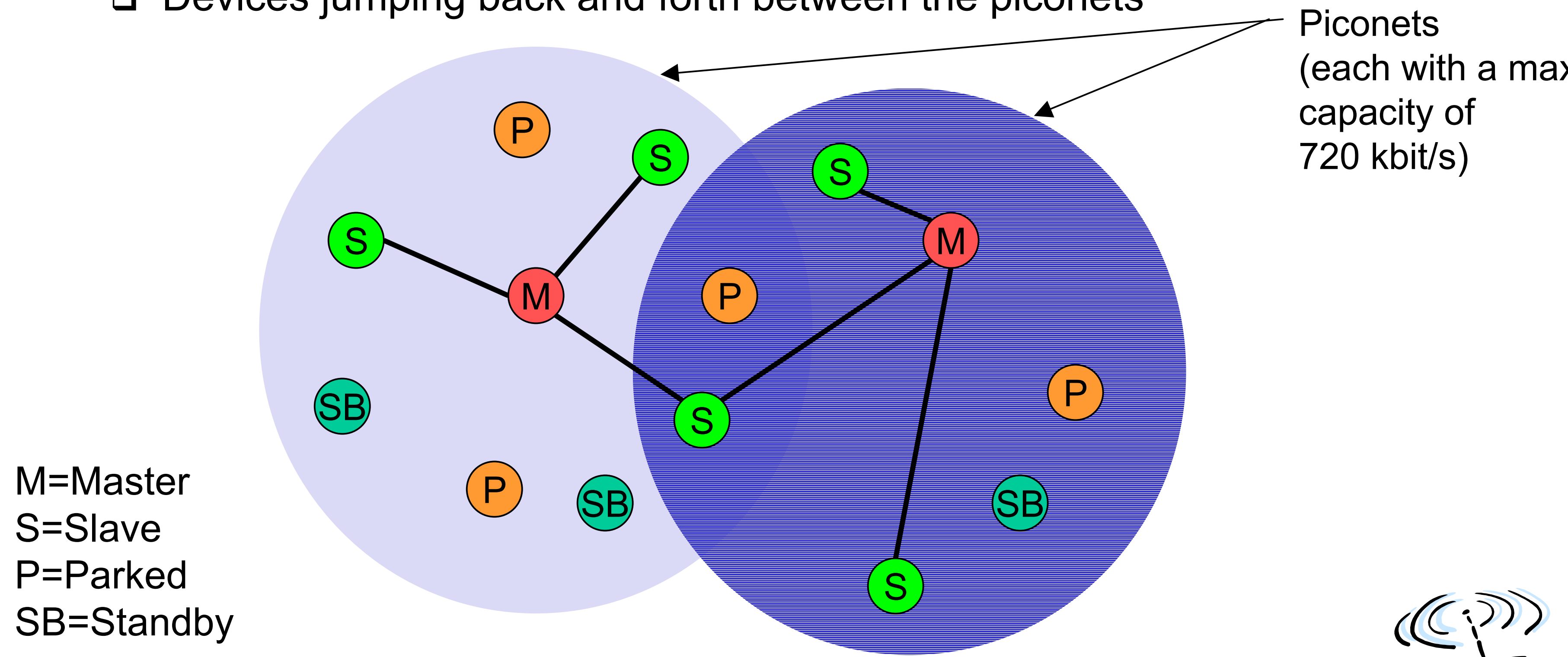
Scatternet

Linking of multiple co-located piconets through the sharing of common master or slave devices

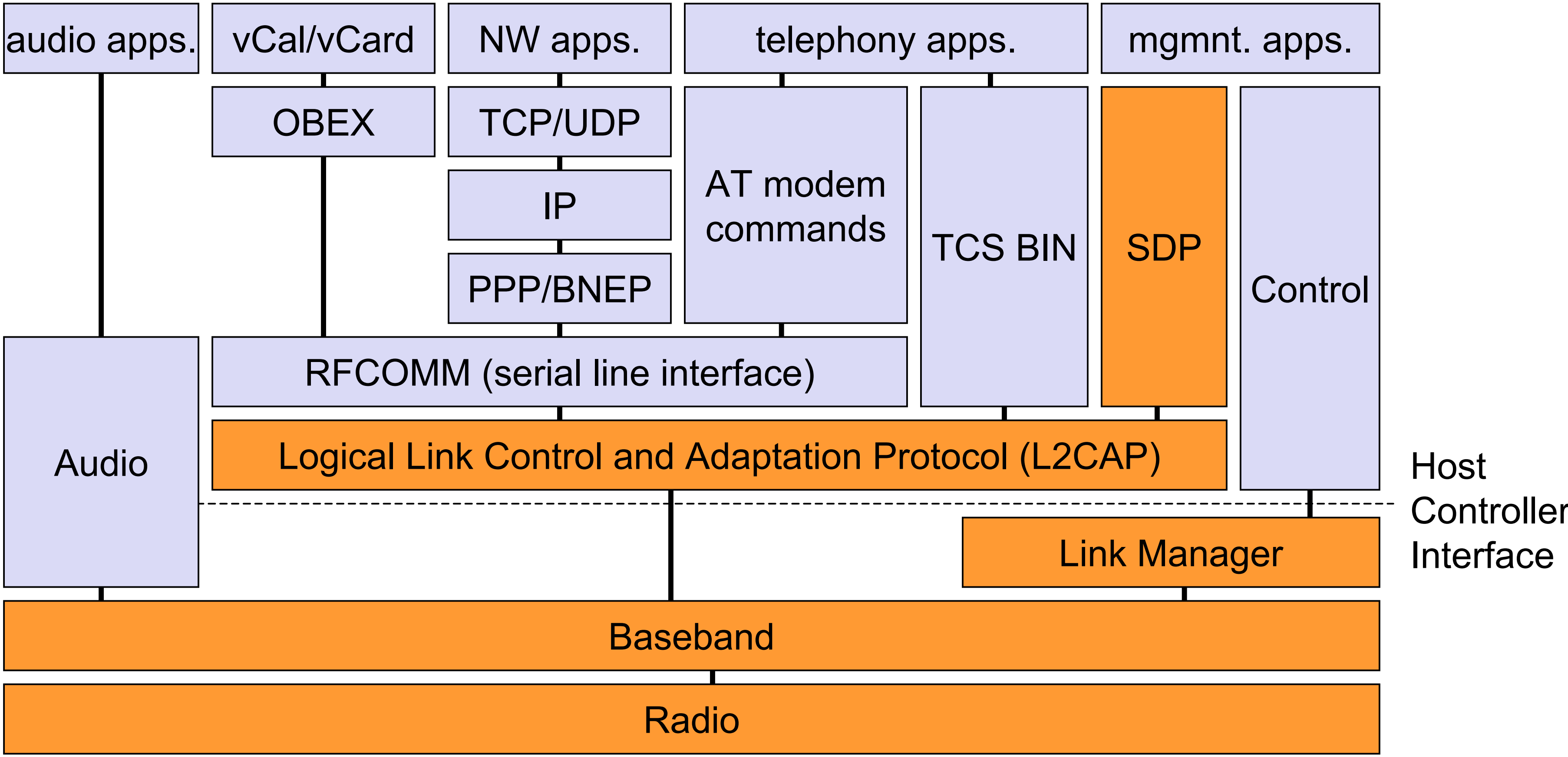
- Devices can be slave in one piconet and master of another

Communication between piconets

- Devices jumping back and forth between the piconets



Bluetooth protocol stack



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

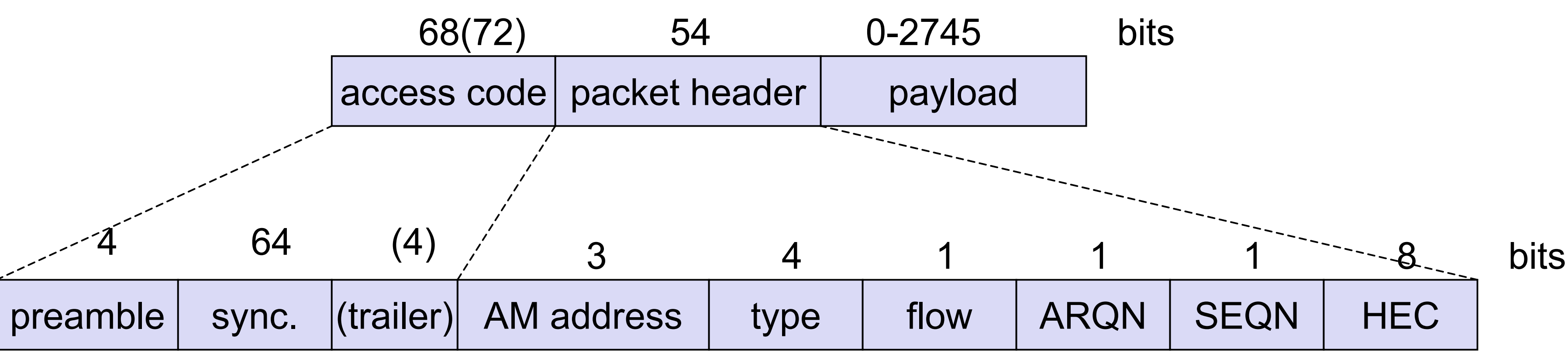
SDP: service discovery protocol
RFCOMM: radio frequency comm.

Baseband

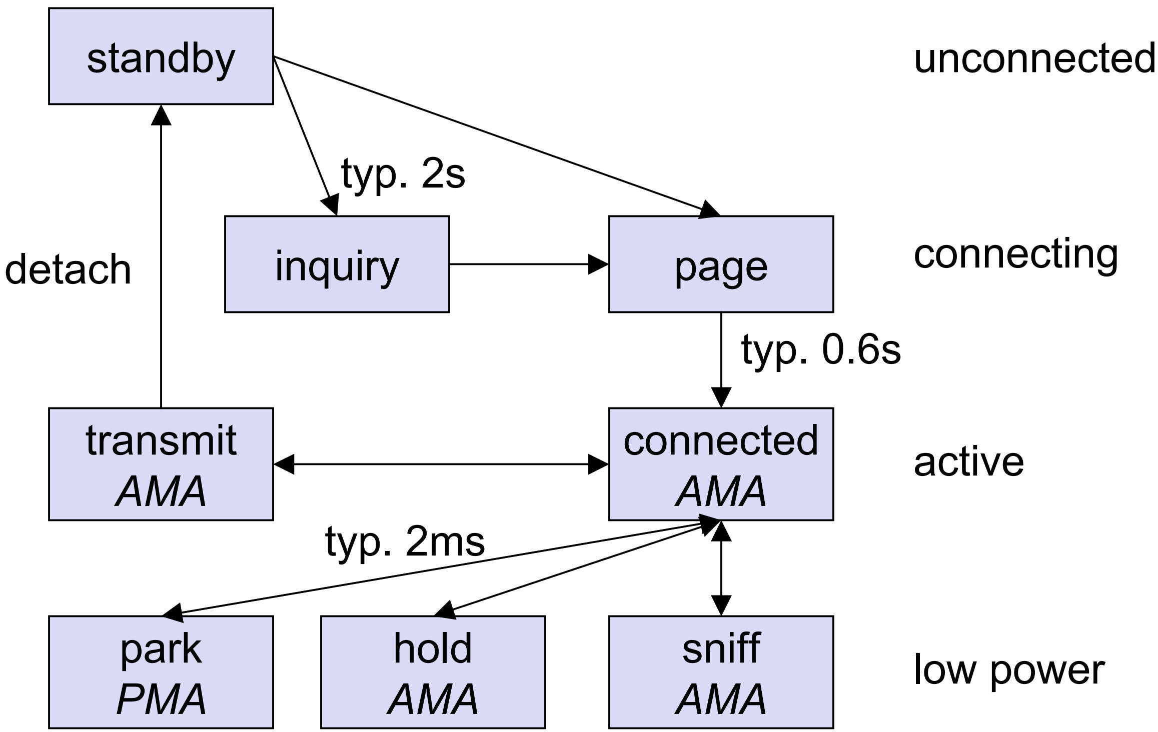
Piconet/channel definition

Low-level packet definition

- Access code
  - Channel, device access, e.g., derived from master
- Packet header
  - 1/3-FEC, active member address (1 master, 7 slaves), link type, alternating bit ARQ/SEQ, checksum



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 ACLs, SCO still possible, possibly participate in another piconet

Example: Power consumption/CSR BlueCore2

Typical Average Current Consumption (1)

VDD=1.8V Temperature = 20°C

Mode	**Avg Unit**
SCO connection HV3 (1s interval Sniff Mode) (Slave)	26.0 mA
SCO connection HV3 (1s interval Sniff Mode) (Master)	26.0 mA
SCO connection HV1 (Slave)	53.0 mA
SCO connection HV1 (Master)	53.0 mA
ACL data transfer 115.2kbps UART (Master)	15.5 mA
ACL data transfer 720kbps USB (Slave)	53.0 mA
ACL data transfer 720kbps USB (Master)	53.0 mA
ACL connection, Sniff Mode 40ms interval, 38.4kbps UART	4.0 mA
ACL connection, Sniff Mode 1.28s interval, 38.4kbps UART	0.5 mA
Parked Slave, 1.28s beacon interval, 38.4kbps UART	0.6 mA
Standby Mode (Connected to host, no RF activity)	47.0 µA
Deep Sleep Mode(2)	20.0 µA

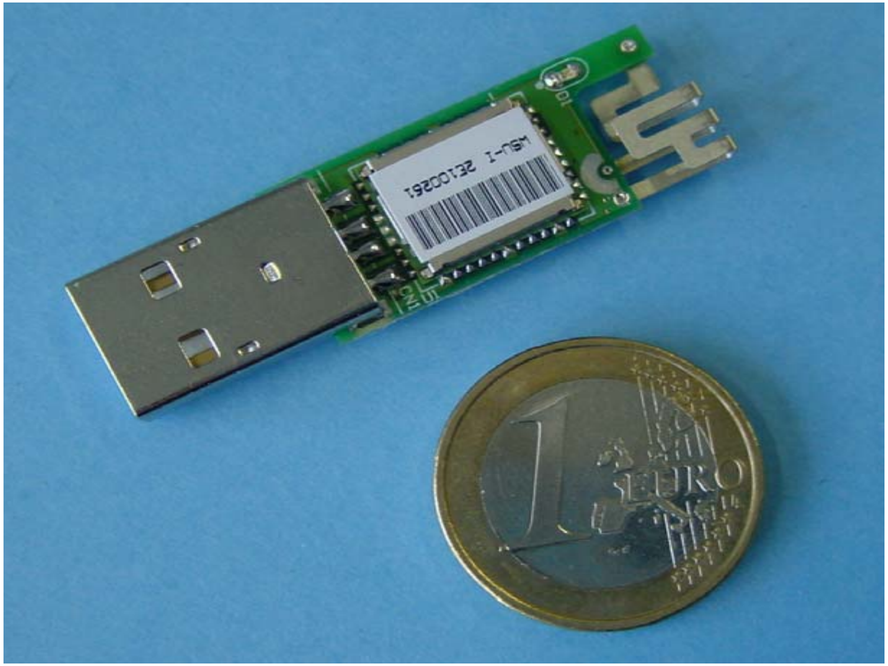
Notes:

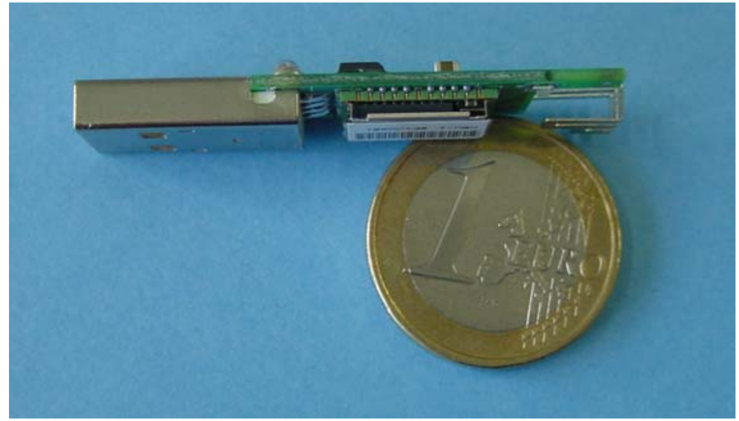
(1) Current consumption is the sum of both BC212015A and the flash.

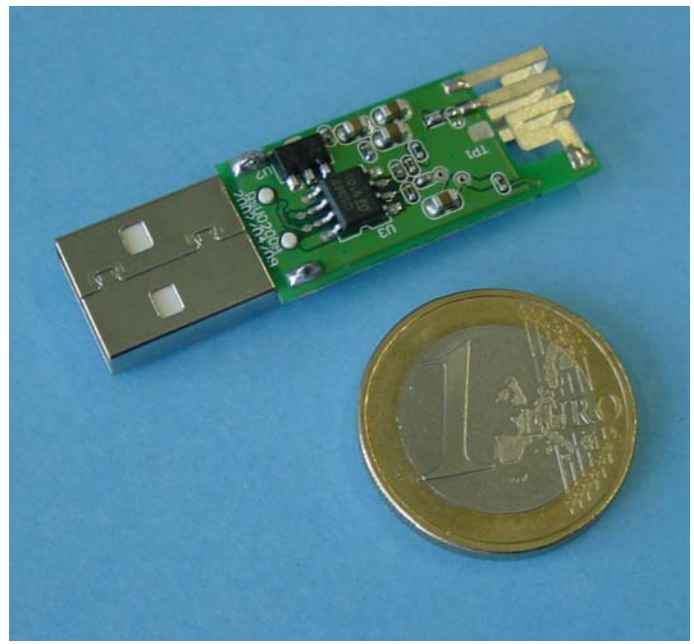
(2) Current consumption is for the BC212015A device only.

(More: www.csr.com)

Example: Bluetooth/USB adapter (2002: 50€)







Baseband link types

Polling-based TDD packet transmission

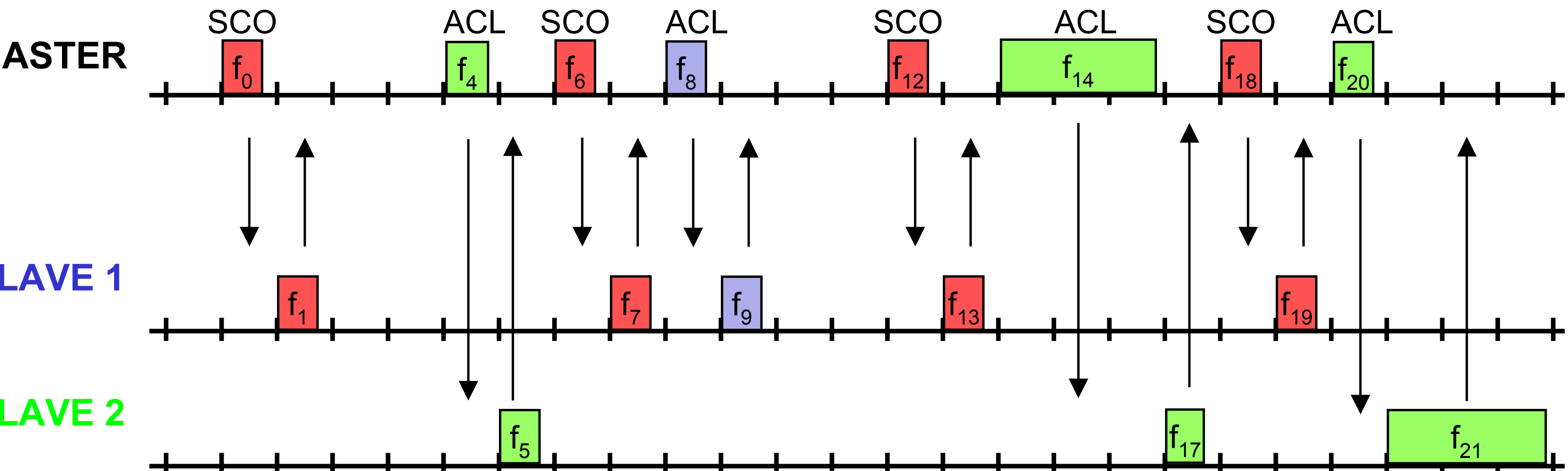
- 625µs slots, master polls slaves

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



Robustness

Slow frequency hopping with hopping patterns determined by a master

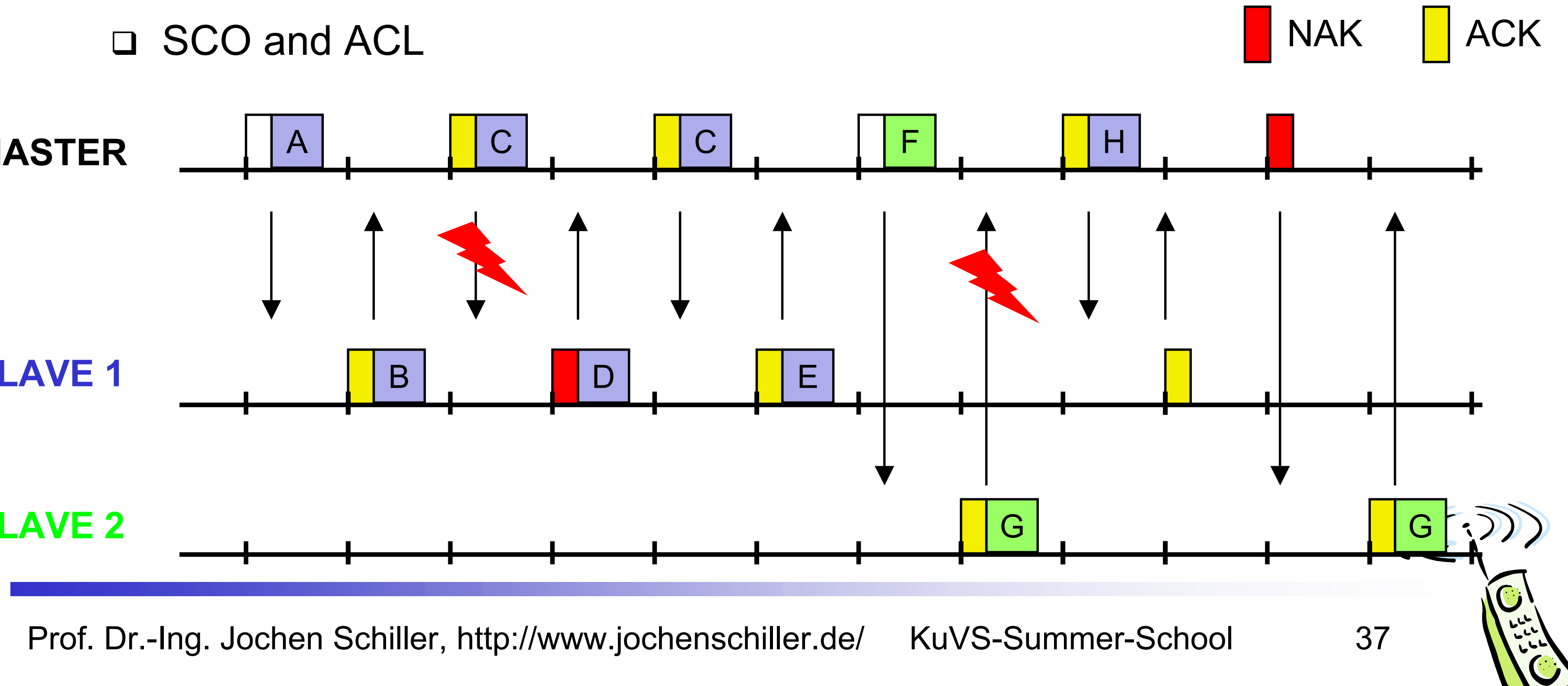
- Protection from interference on certain frequencies
- Separation from other piconets (FH-CDMA)

Retransmission

- ACL only, very fast

Forward Error Correction

- SCO and ACL

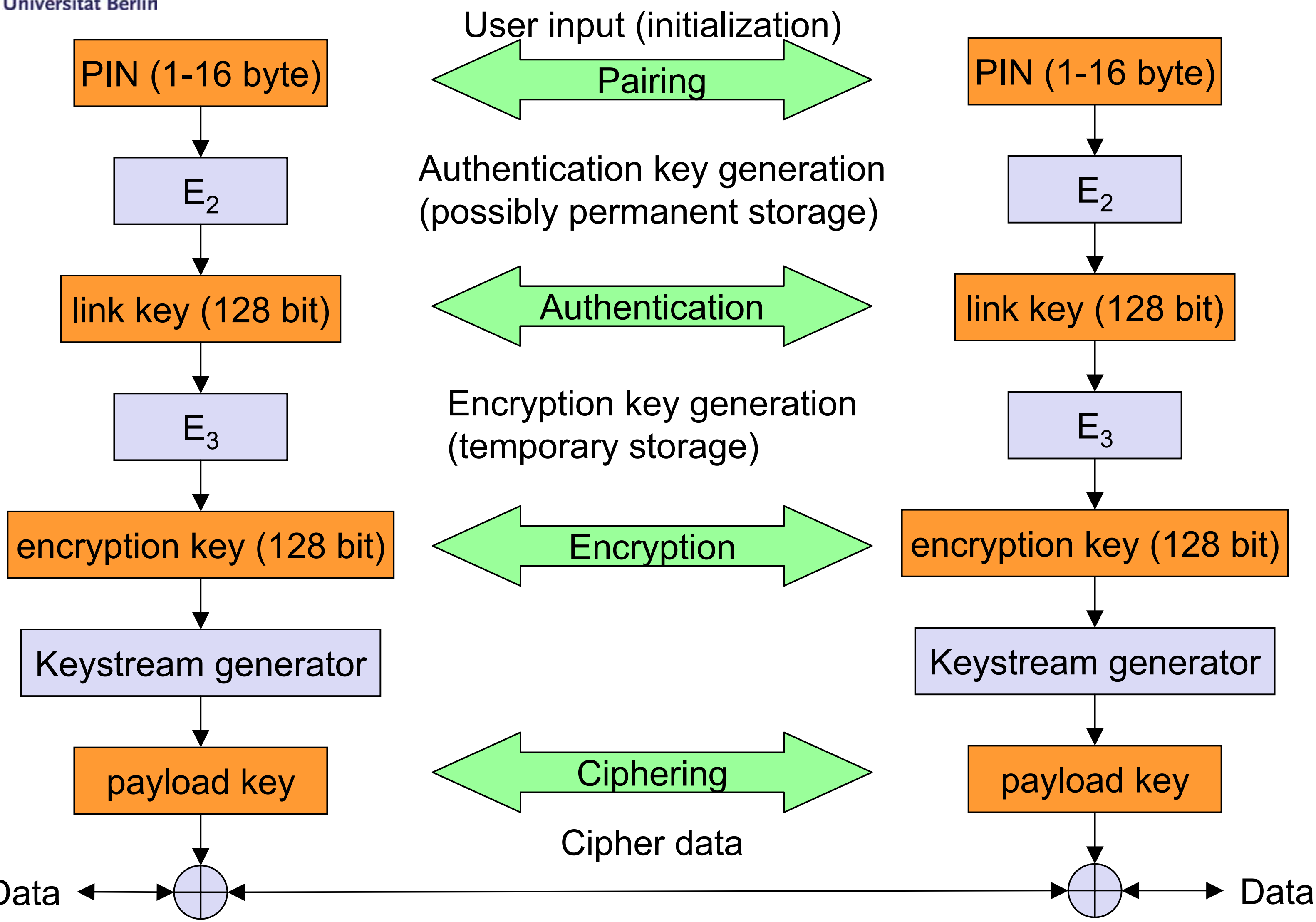


Baseband data rates

	Type	Payload Header [byte]	User Payload [byte]	FEC	CRC	Symmetric max. Rate [kbit/s]	Asymmetric max. Rate [kbit/s] Forward	Reverse
ACL 1 slot	DM1	1	0-17	2/3	yes	108.8	108.8	108.8
	DH1	1	0-27	no	yes	172.8	172.8	172.8
3 slot	DM3	2	0-121	2/3	yes	258.1	387.2	54.4
	DH3	2	0-183	no	yes	390.4	585.6	86.4
5 slot	DM5	2	0-224	2/3	yes	286.7	477.8	36.3
	DH5	2	0-339	no	yes	**433.9**	**723.2**	57.6
	AUX1	1	0-29	no	no	185.6	185.6	185.6
SCO	HV1	na	10	1/3	no	64.0		
	HV2	na	20	2/3	no	64.0		
	HV3	na	30	no	no	64.0		
	DV	1 D	10+(0-9) D	2/3 D	yes D	64.0+57.6 D		

*D*ata *M*edium/*H*igh rate, *H*igh-quality *V*oice, *D*ata and *V*oice

Security


User input (initialization)
PIN (1-16 byte)
Pairing
PIN (1-16 byte)
E2
Authentication key generation
(possibly permanent storage)
E2
link key (128 bit)
Authentication
link key (128 bit)
E3
Encryption key generation
(temporary storage)
E3
encryption key (128 bit)
Encryption
encryption key (128 bit)
Keystream generator
Keystream generator
payload key
Ciphering
payload key
Cipher data
Data
Data

L2CAP - Logical Link Control and Adaptation Protocol

Simple data link protocol on top of baseband

Connection oriented, connectionless, and signalling channels

Protocol multiplexing

- RFCOMM, SDP, telephony control

Segmentation & reassembly

- Up to 64kbyte user data, 16 bit CRC

QoS flow specification per channel

- Follows RFC 1363, specifies delay, jitter, bursts, bandwidth

Group abstraction

- Create/close group, add/remove member

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 an 16 bit ID (name) and a value
- IDs may be derived from 128 bit Universally Unique Identifiers (UUID)

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

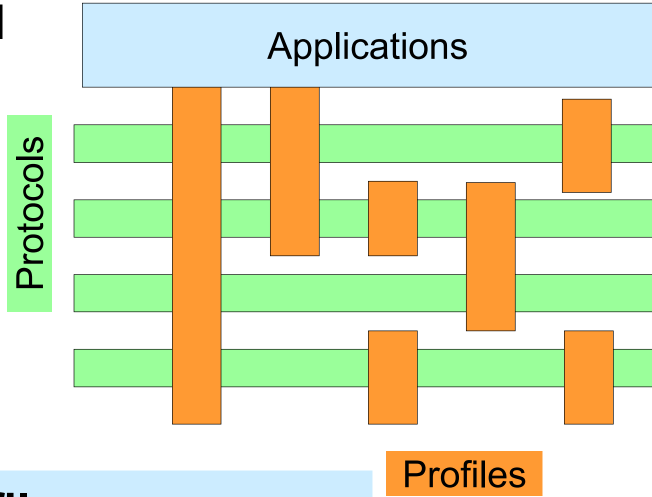
- Exchange of objects, IrDA replacement

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

WPAN: IEEE 802.15-1 – Bluetooth

Data rate
- Synchronous, connection-oriented: 64 kbit/s
- Asynchronous, connectionless
  - 433.9 kbit/s symmetric
  - 723.2 / 57.6 kbit/s asymmetric

Transmission range
- POS (Personal Operating Space) up to 10 m
- with special transceivers up to 100 m

Frequency
- Free 2.4 GHz ISM-band

Security
- Challenge/response (SAFER+), hopping sequence

Cost
- 50-150€ adapter, expected to drop to 5-20€ if integrated

Availability
- Integrated into some products, several vendors

Connection set-up time
- Depends on power-mode
- Max. 2.56s, avg. 0.64s

Quality of Service
- Guarantees, ARQ/FEC

Manageability
- Public/private keys needed, key management not specified, simple system integration

Special Advantages/Disadvantages
- Advantage: already integrated into several products, available worldwide, free ISM-band, several vendors, simple system, simple ad-hoc networking, peer to peer, scatternets
- Disadvantage: interference on ISM-band, limited range, max. 8 devices/network&master, high set-up latency

WPAN: IEEE 802.15 – future developments 1

802.15-2: Coexistance

- Coexistence of Wireless Personal Area Networks (802.15) and Wireless Local Area Networks (802.11), quantify the mutual interference

802.15-3: High-Rate

- Standard for high-rate (20Mbit/s or greater) WPANs, while still low-power/low-cost
- Data Rates: 11, 22, 33, 44, 55 Mbit/s
- Quality of Service isochronous protocol
- Ad hoc peer-to-peer networking
- Security
- Low power consumption
- Low cost
- Designed to meet the demanding requirements of portable consumer imaging and multimedia applications

WPAN: IEEE 802.15 – future developments 2

802.15-4: Low-Rate, Very Low-Power

- Low data rate solution with multi-month to multi-year battery life and very low complexity
- Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation
- Data rates of 2-250 kbit/s, latency 10-50 ms (or > 1 s if sleeping)
- Master-Slave or Peer-to-Peer operation
- Up to 254 network devices or 64516 distribution nodes
- Support for critical latency devices, such as joysticks
- CSMA/CA channel access (data centric)
- Automatic network establishment by the coordinator
- Dynamic device addressing
- Fully handshaked protocol for transfer reliability
- Power management to ensure low power consumption
- 16 channels in the 2.4 GHz ISM band, 10 channels in the 915 MHz US ISM band and one channel in the European 868 MHz band

ISM band interference

Many sources of interference

- Microwave ovens, microwave lightning
- 802.11, 802.11b, 802.11g, 802.15, Home RF
- Even analog TV transmission, surveillance
- Unlicensed metropolitan area networks
- …

Levels of interference

- Physical layer: interference acts like noise
  - Spread spectrum tries to minimize this
  - FEC/interleaving tries to correct
- MAC layer: algorithms not harmonized
  - E.g., Bluetooth might confuse 802.11

OLD

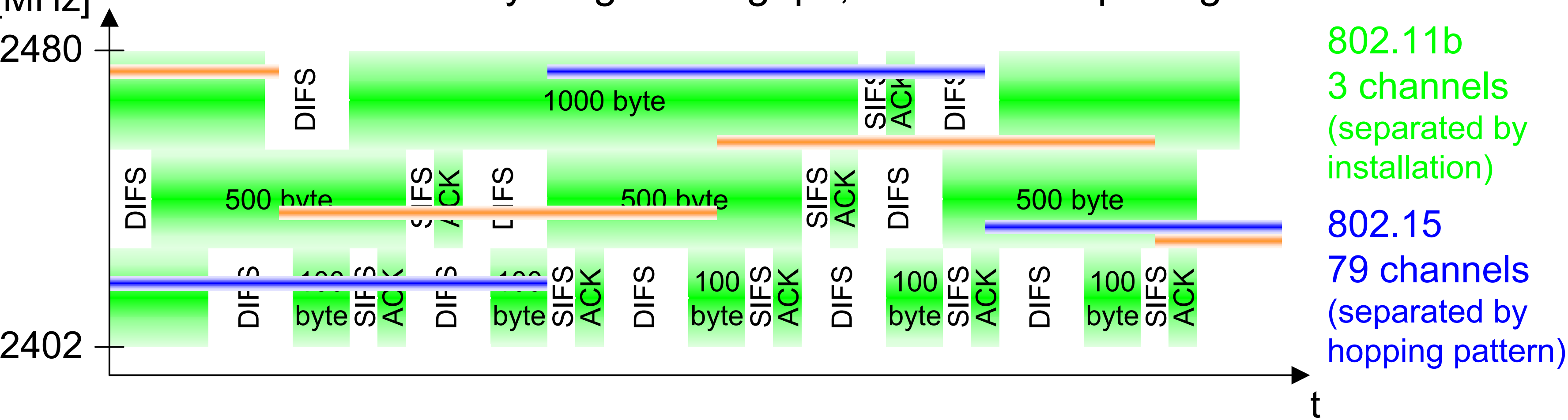
NEW

© Fusion Lighting, Inc.

802.11 vs.(?) 802.15/Bluetooth

Bluetooth may act like a rogue member of the 802.11 network

- Does not know anything about gaps, inter frame spacing etc.



IEEE 802.15-2 discusses these problems

- Proposal: Adaptive Frequency Hopping
  - a non-collaborative Coexistence Mechanism

Real effects? Many different opinions, publications, tests, formulae, …

- Results from complete breakdown to almost no effect
- Bluetooth (FHSS) seems more robust than 802.11b (DSSS)

Questions?

IEEE 802.11, 802.11a, 802.11b, 802.11g, …

Bluetooth/IEEE 802.15-1, -2, -3, -4

or:

Home RF

HIPERLAN/2

RFID

…