IEEE 802.15

Mobile Communication Technology according to IEEE

Local wireless networks
WLAN 802.11

WiFi

802.11a → 802.11h

802.11i/e/…/w

802.11b → 802.11g

Personal wireless nw
WPAN 802.15

ZigBee

802.15.4 → 802.15.4a/b

802.15.5

802.15.3 → 802.15.3a/b

802.15.2

802.15.1

Bluetooth

Wireless distribution networks
WMAN 802.16 (Broadband Wireless Access)

WiMAX

+ Mobility

802.20 (Mobile Broadband Wireless Access)

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) due to shared medium
- 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 vary long time to establish global solutions like, e.g., IMT-2000

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

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

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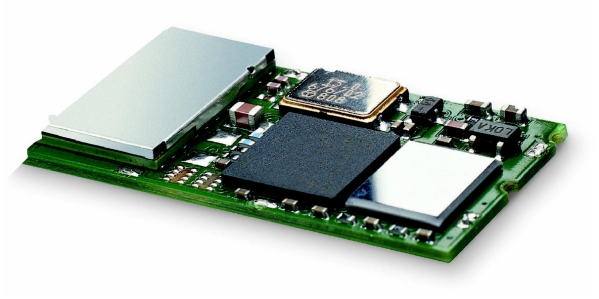
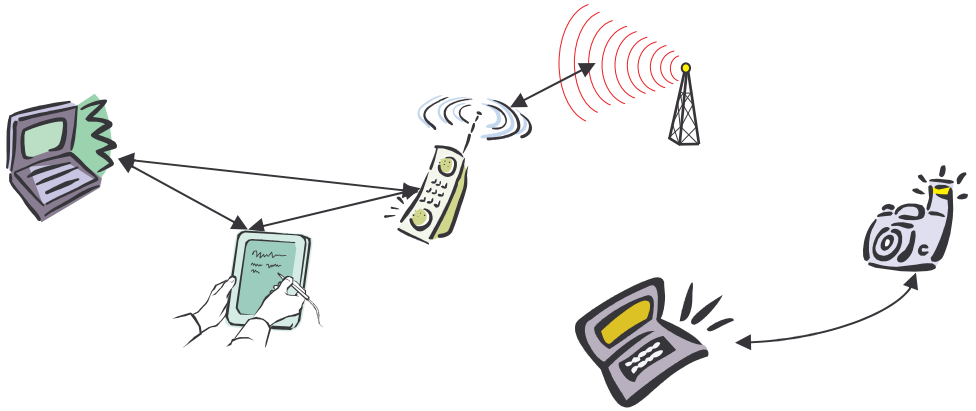
Bluetooth

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 (2005: €16/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).



IEEE 802.15 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
- 2005: 5 million chips/week

Bluetooth™

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

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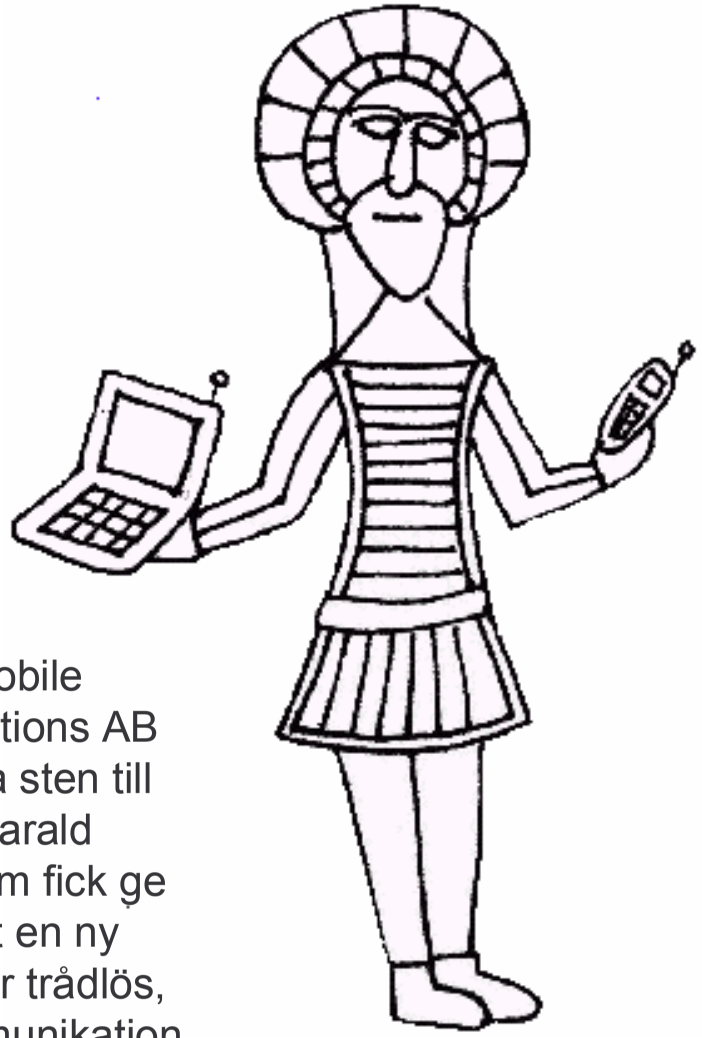
History and hi-tech…



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 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.

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

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…)

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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

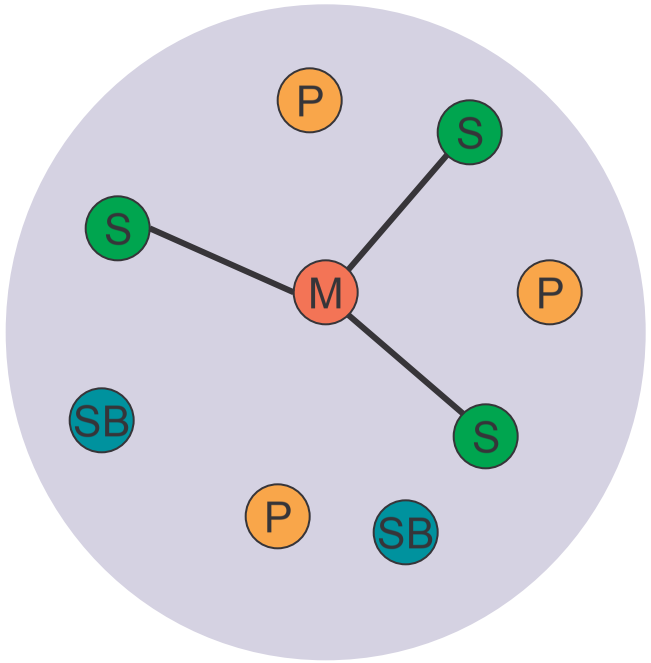
One unit acts as master and the others as slaves for the lifetime of the piconet

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
S=Slave
P=Parked
SB=Standby

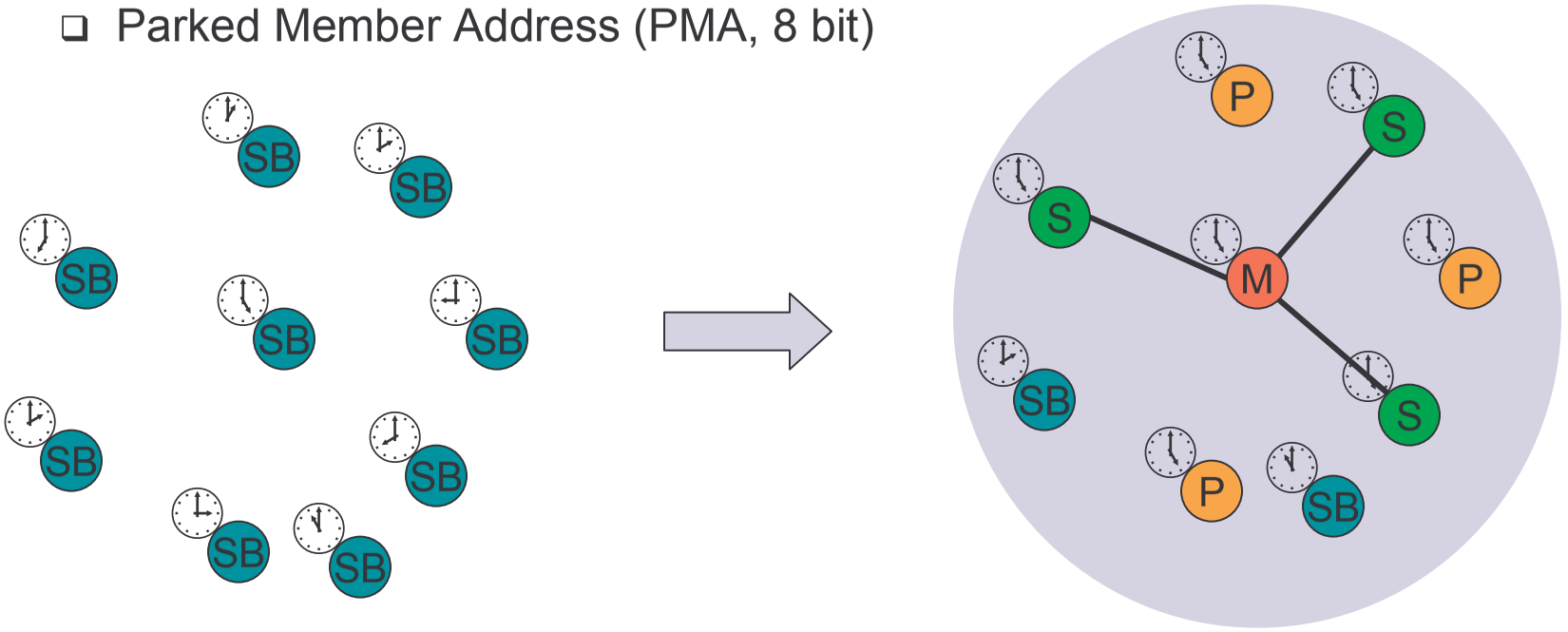
Forming a piconet

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

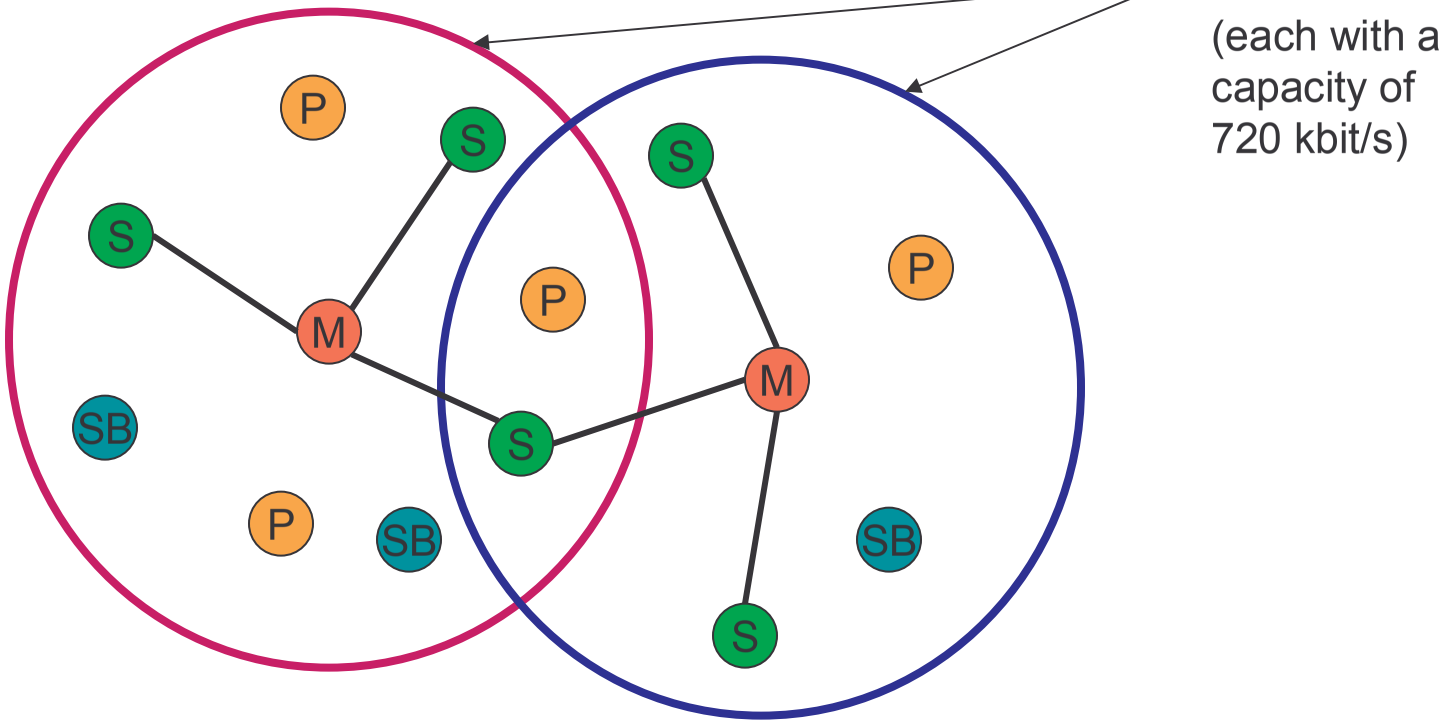
Addressing

- Active Member Address (AMA, 3 bit)
- Parked Member Address (PMA, 8 bit)



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



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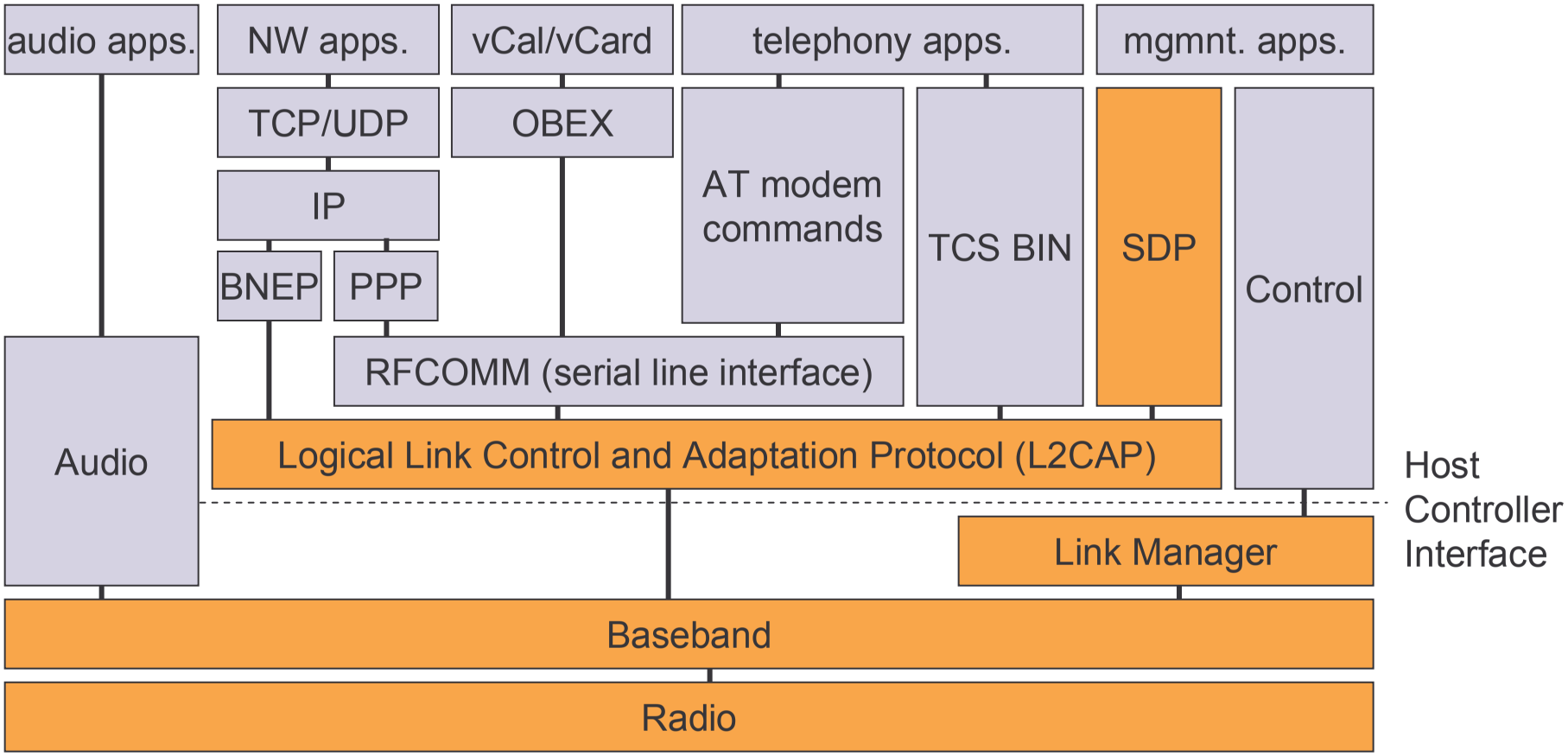
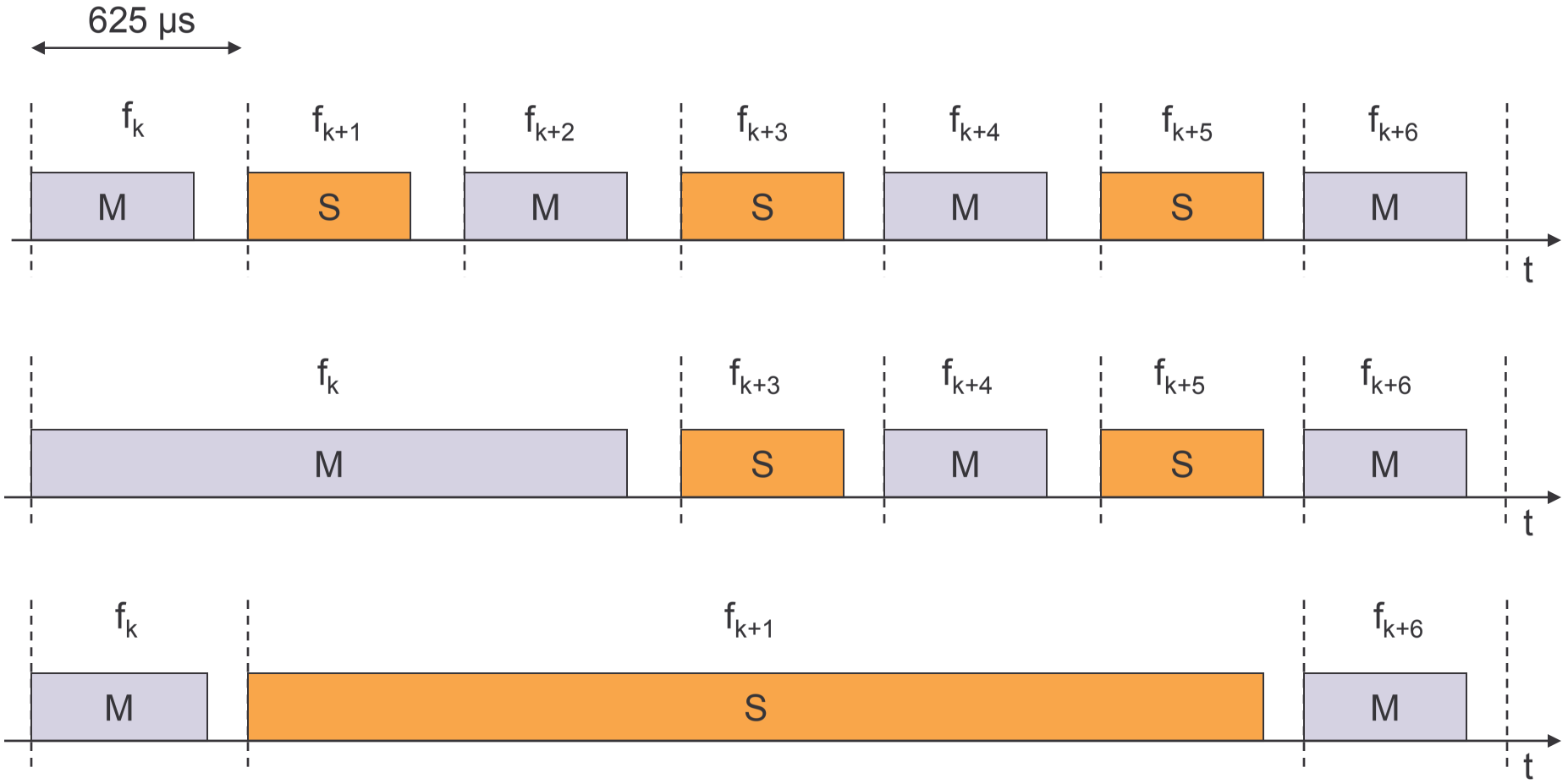
Bluetooth protocol stack



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

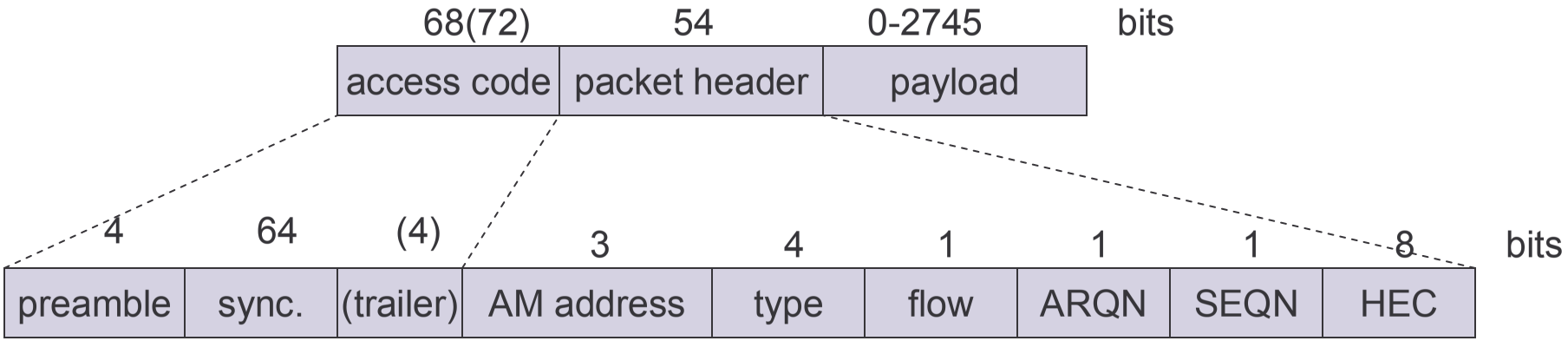


Baseband

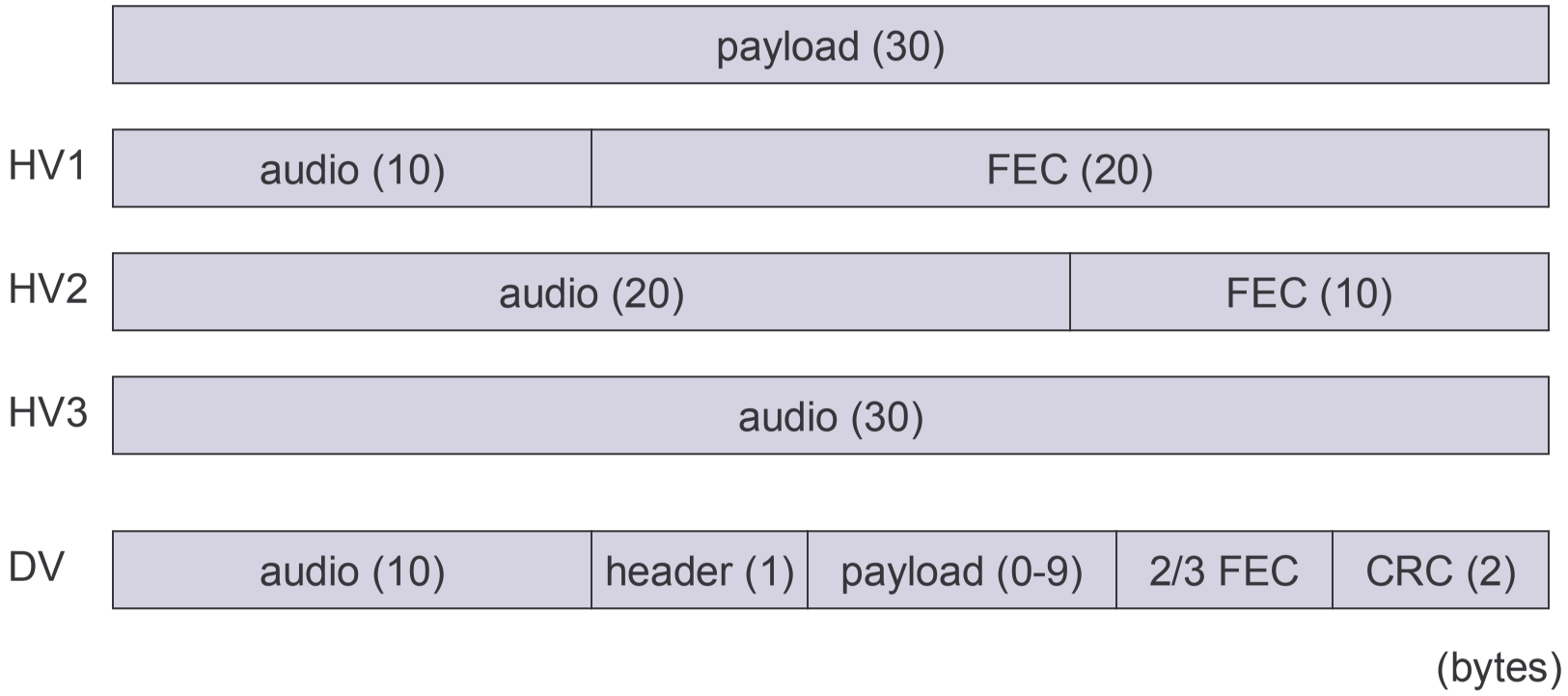
Piconet/channel definition

Low-level packet definition

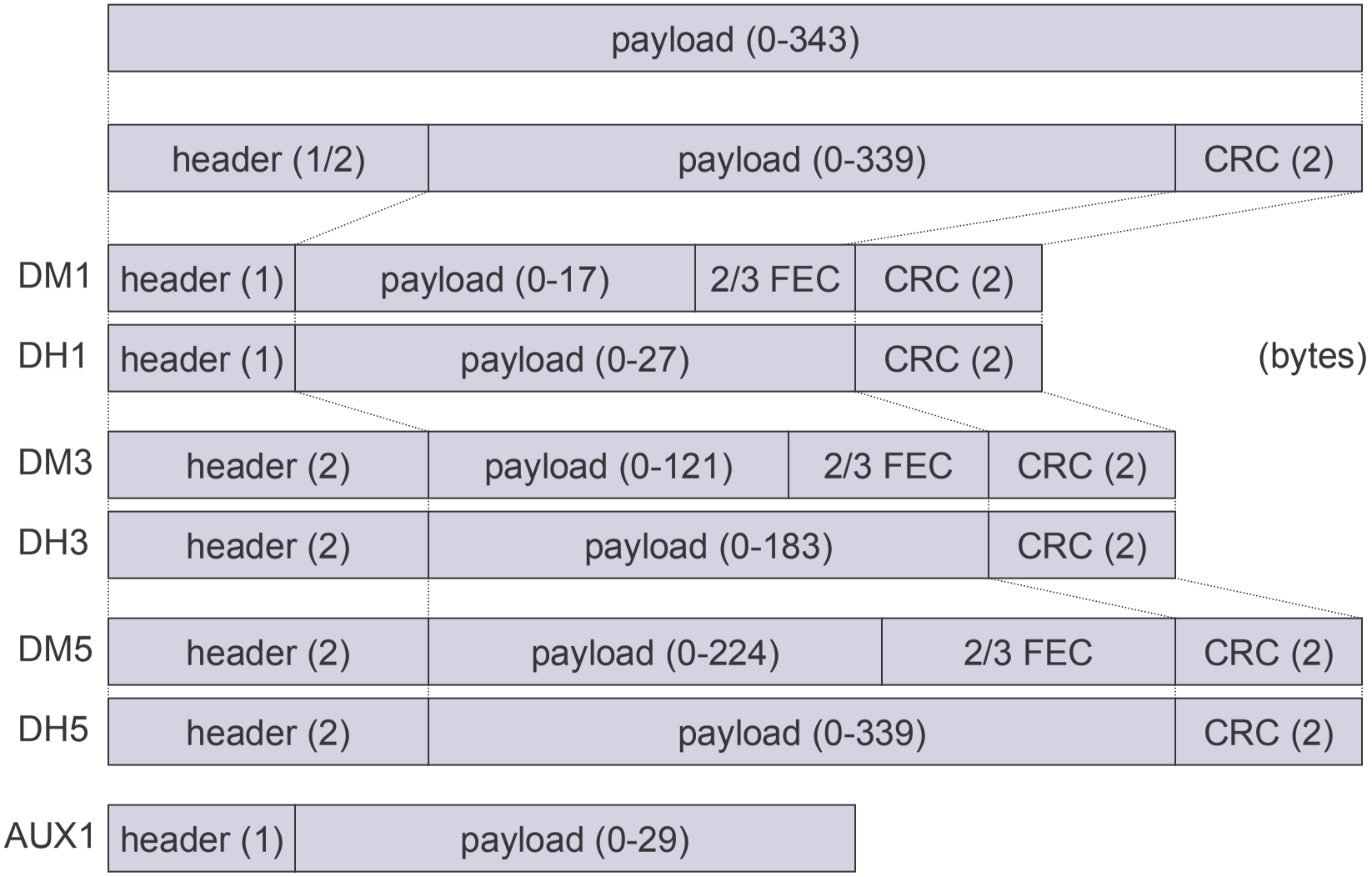
- Access code
  - Channel, device access, e.g., derived from master
- Packet header
  - 1/3-FEC, active member address (broadcast + 7 slaves), link type, alternating bit ARQ/SEQ, checksum



SCO payload types



ACL Payload types



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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

Baseband link types

Polling-based TDD packet transmission

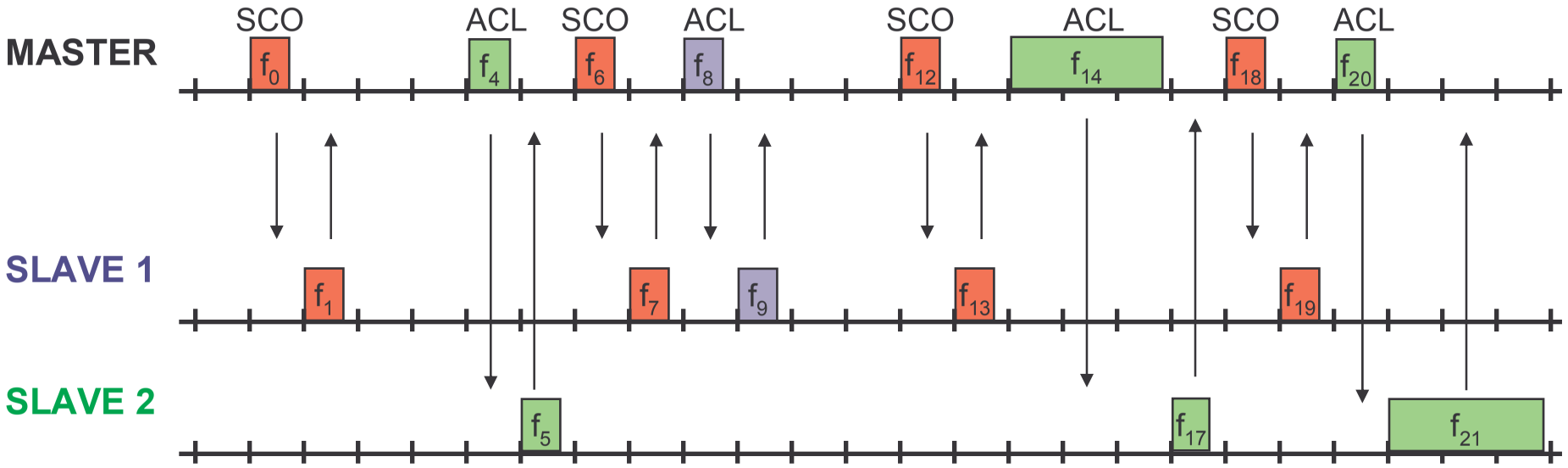
- 625μs slots, master polls slaves

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

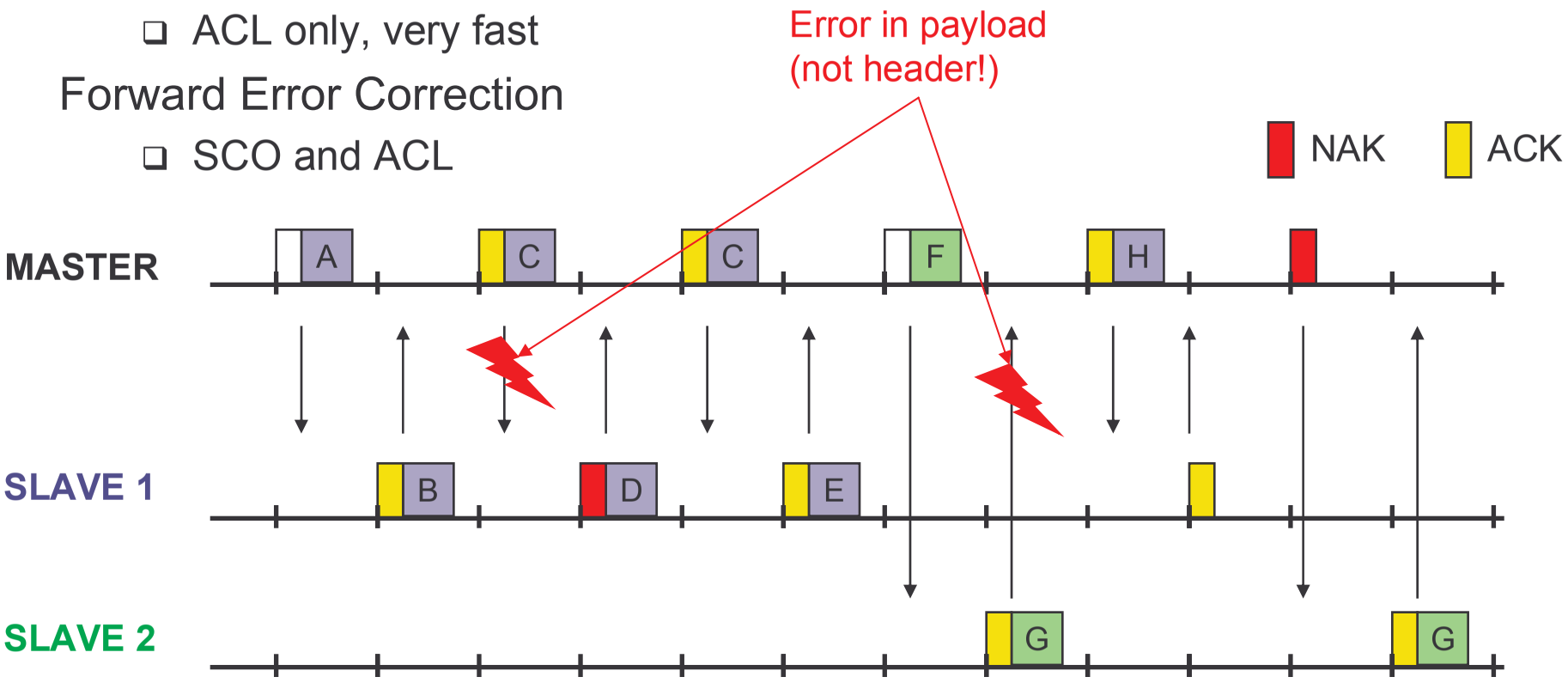
- Protection from interference on certain frequencies
- Separation from other piconets (FH-CDMA)

Retransmission

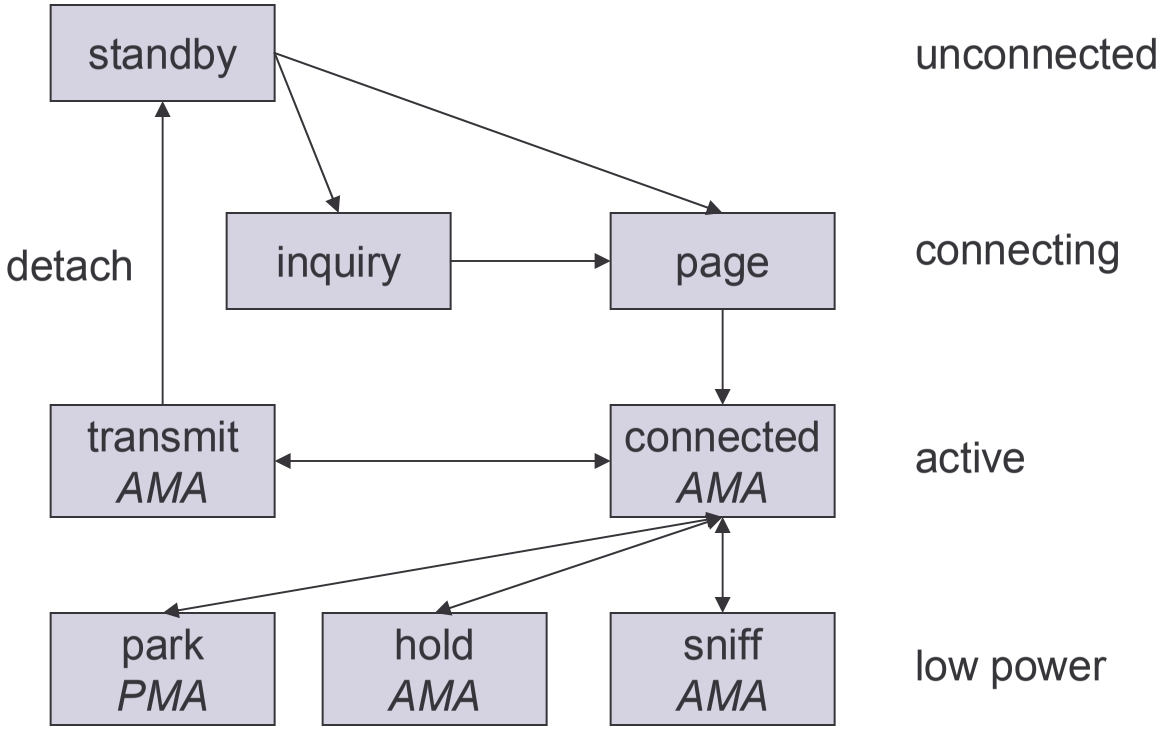
- ACL only, very fast

Forward Error Correction

- SCO and ACL



Baseband 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

Example: Power consumption/CSR BlueCore2

Typical Average Current Consumption (1)

VDD=1.8V Temperature = 20°C

Mode	
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)

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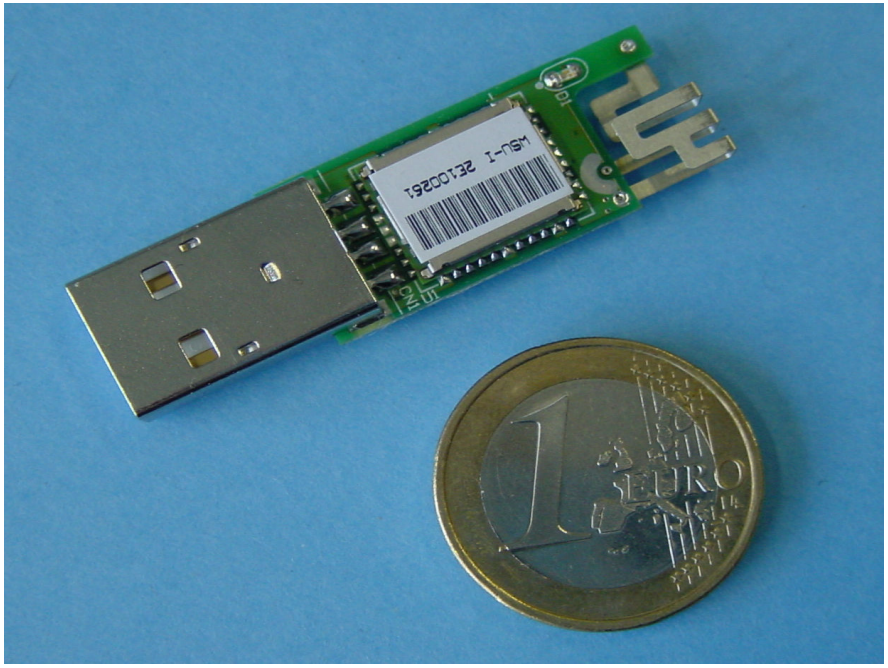
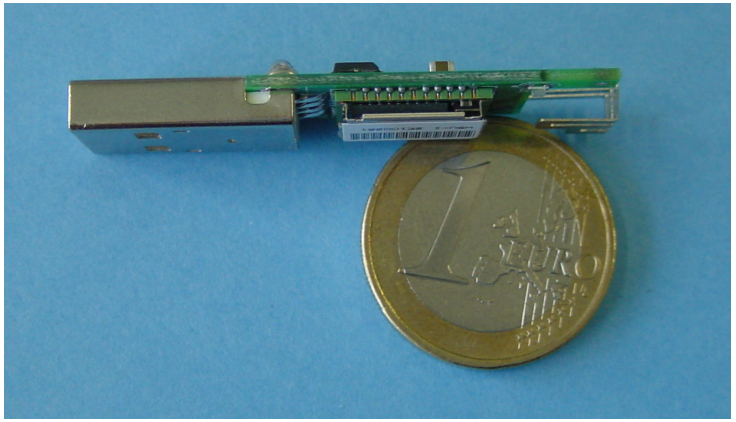
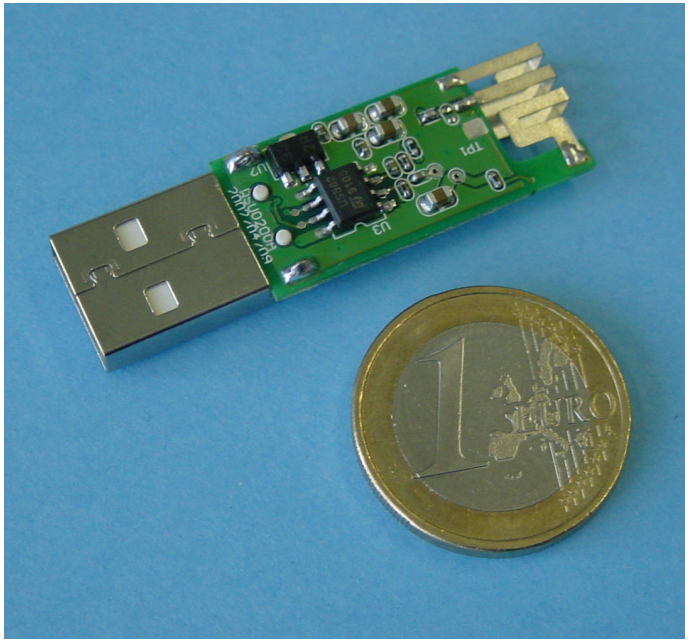
Example: Bluetooth/USB adapter (2002: €50, 2005: €16)







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 used from baseband

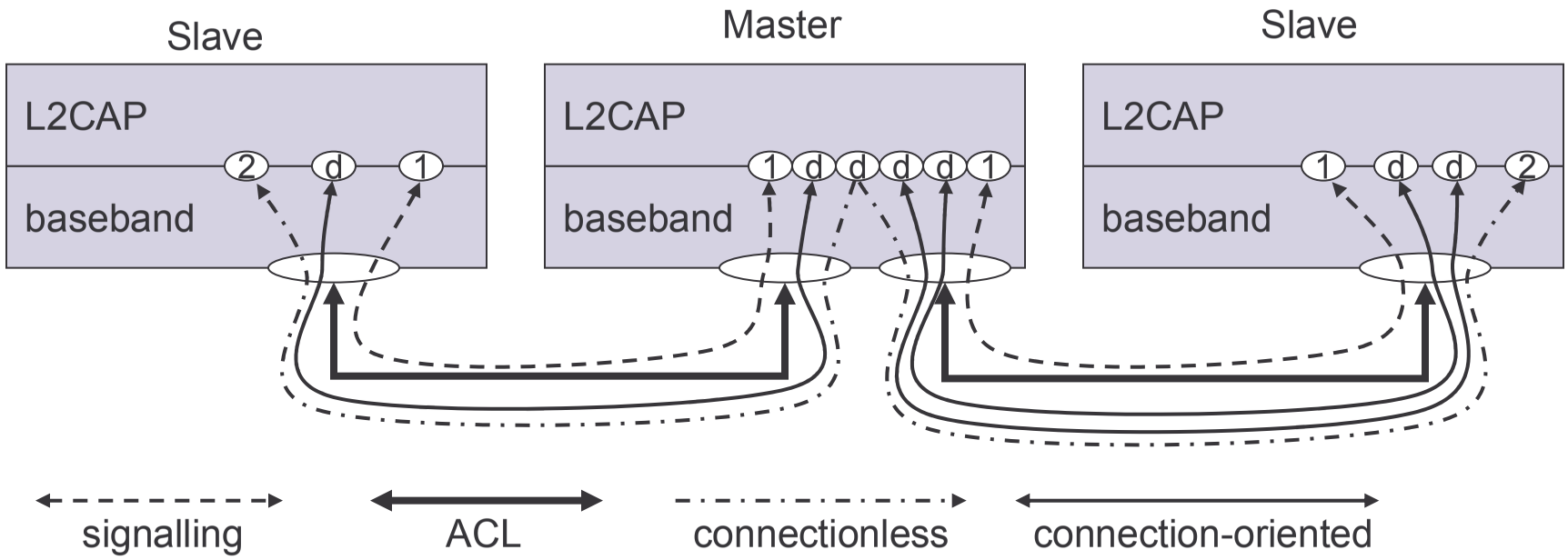
QoS flow specification per channel

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

Group abstraction

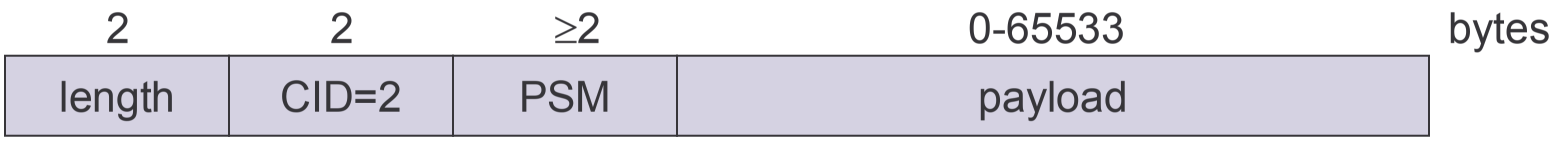
- Create/close group, add/remove member

L2CAP logical channels

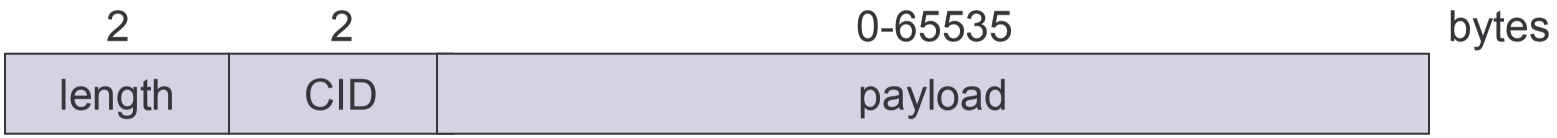


L2CAP packet formats

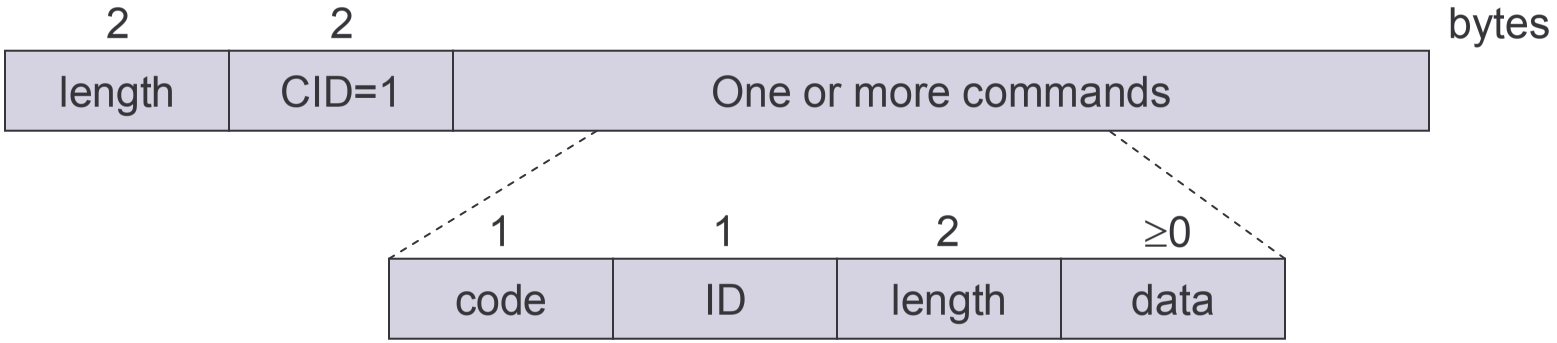
Connectionless PDU



Connection-oriented PDU



Signalling command PDU



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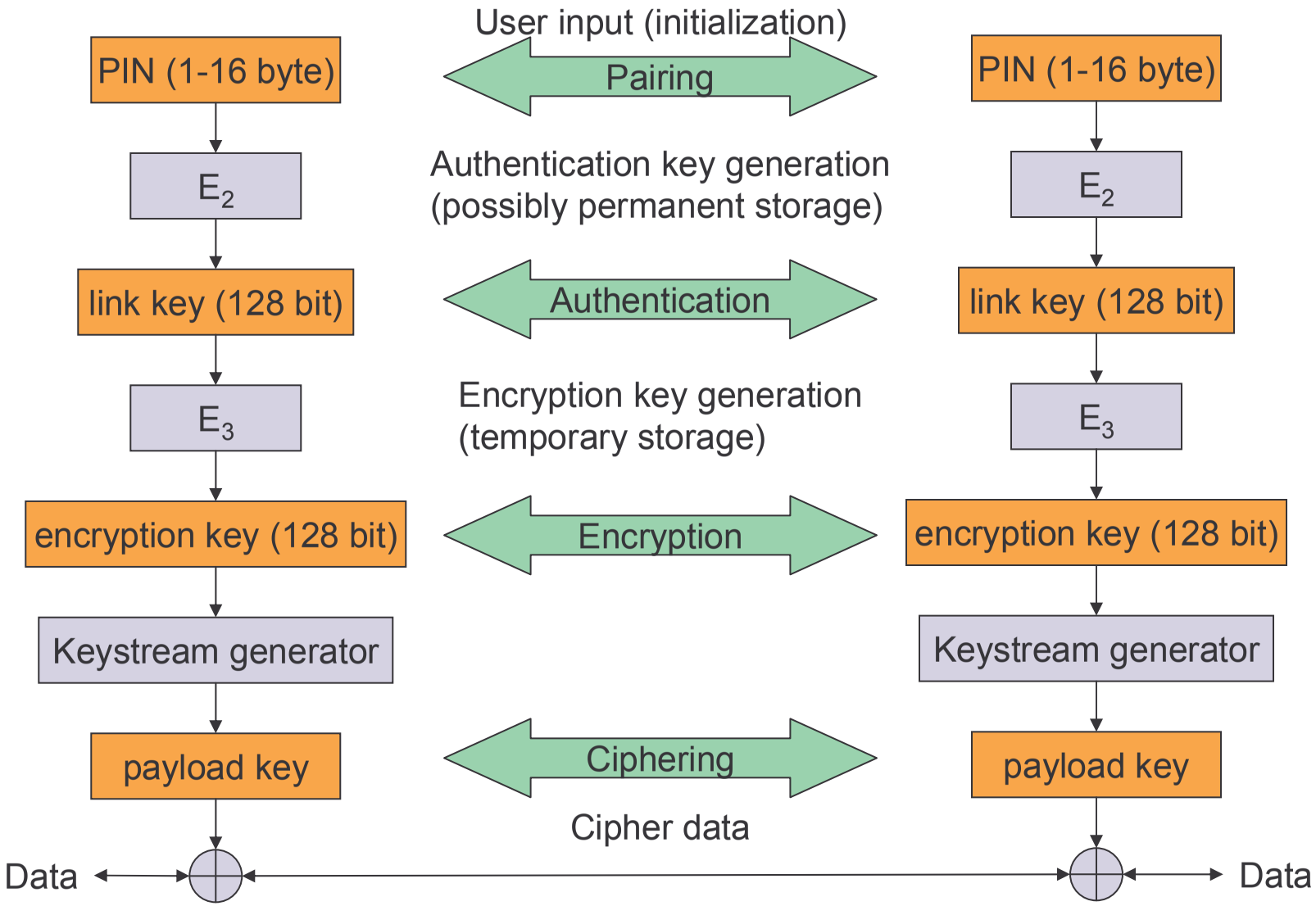
Security



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
- values may be derived from 128 bit Universally Unique Identifiers (UUID)

IEEE 802.15 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

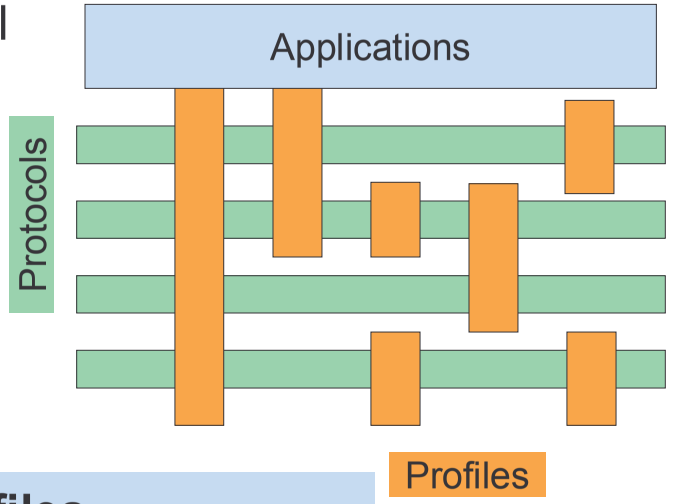
WAP

- Interacting with applications on cellular phones

IEEE 802.15 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

IEEE 802.15 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

Availability
- Integrated into many 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

IEEE 802.15 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

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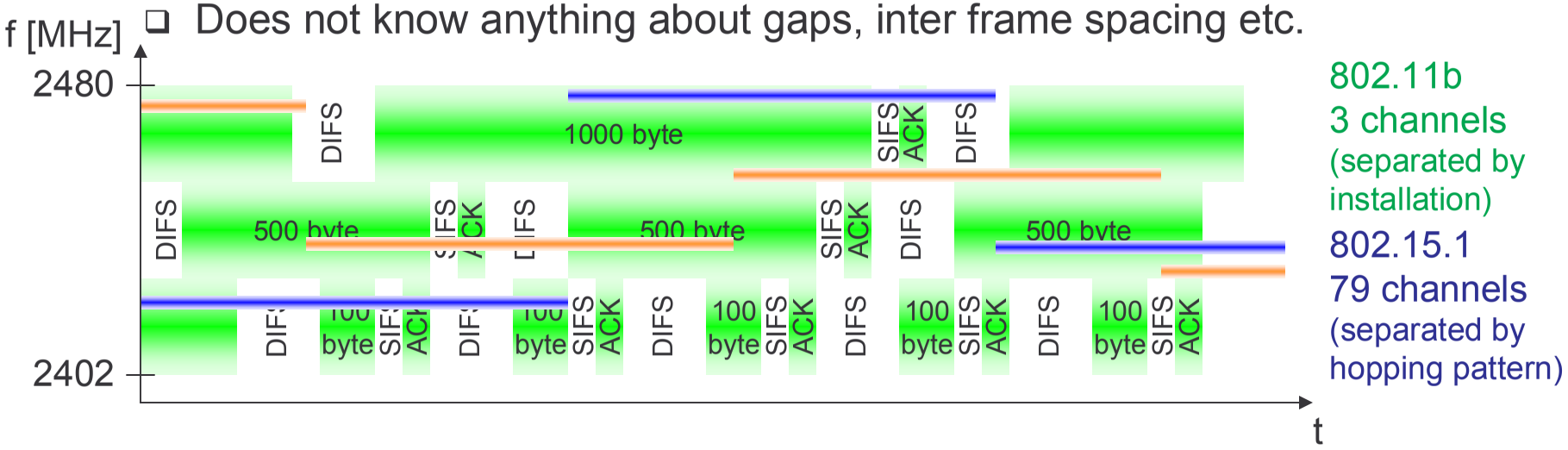
802.11 vs.(?) 802.15/Bluetooth

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)