Bluetooth

FEUP
MPR

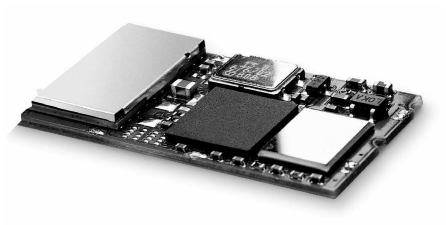
Acknowledgements

- Based on Jochen Schiller slides

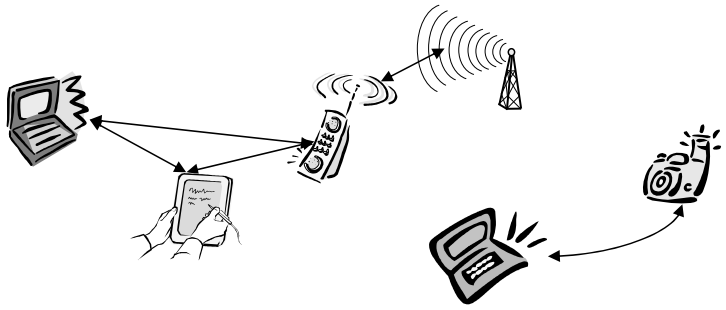
- Supporting text
  - » Jochen Schiller, “Mobile Comunications”, Addison-Wesley
  - » Section 7.5 – Bluetooth

Bluetooth

- » Universal radio interface for ad-hoc wireless connectivity
- » Interconnecting
  computer and peripherals, handheld devices, PDAs, cell phones
- » Embedded in other devices, goal: 5€/device
- » 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).

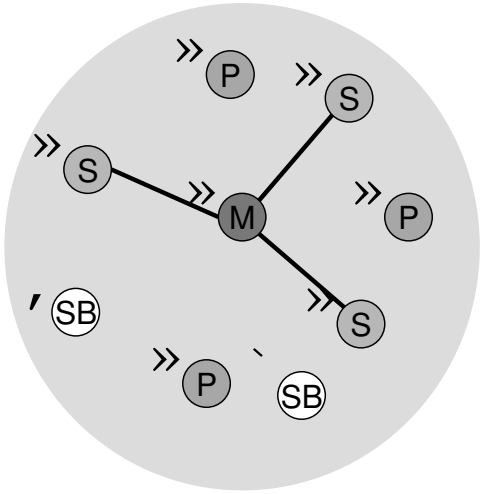


Characteristics

- ♦ 2.4 GHz ISM band, 79 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
- ♦ Voice link – SCO (Synchronous Connection Oriented)
  - – FEC, 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

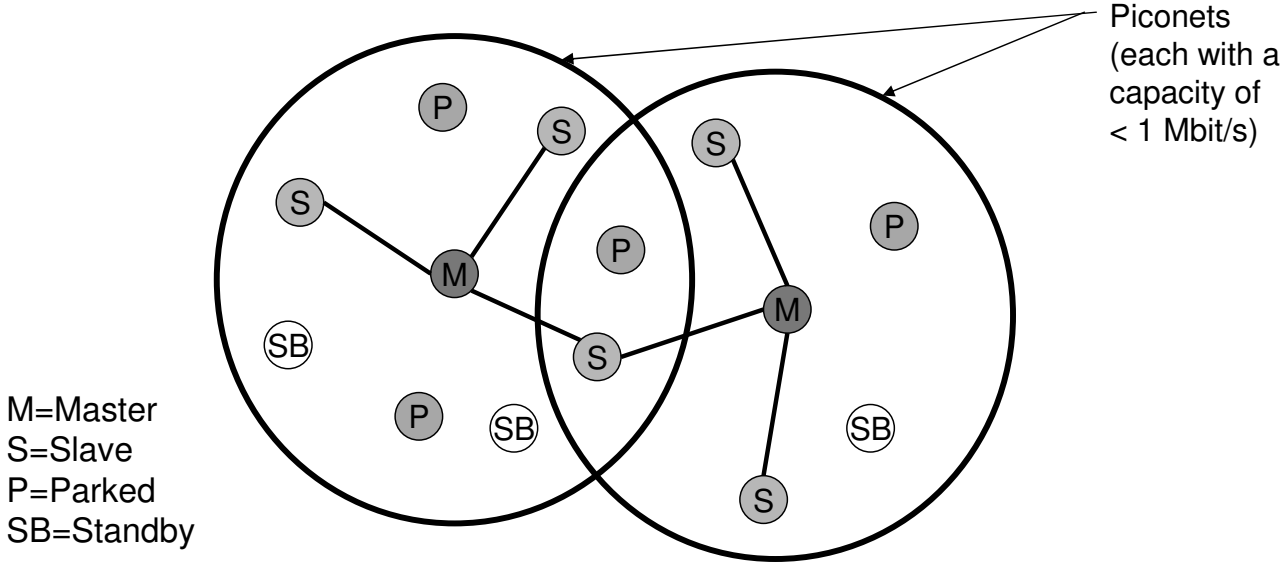
- Collection of devices connected in an ad hoc
- One unit acts as master
  the others as slaves, for the lifetime of the piconet
- Master determines hopping pattern
  each piconet has a unique hopping pattern
  hopping pattern determined by device ID
    48 bit, unique worldwide
  slaves have to synchronize
- Each piconet has
  one master
  up to 7 simultaneous slaves
    Active Member Address: AMA, 3 bit
  200 could be parked
    Parked Member Address: PMA, 8 bit



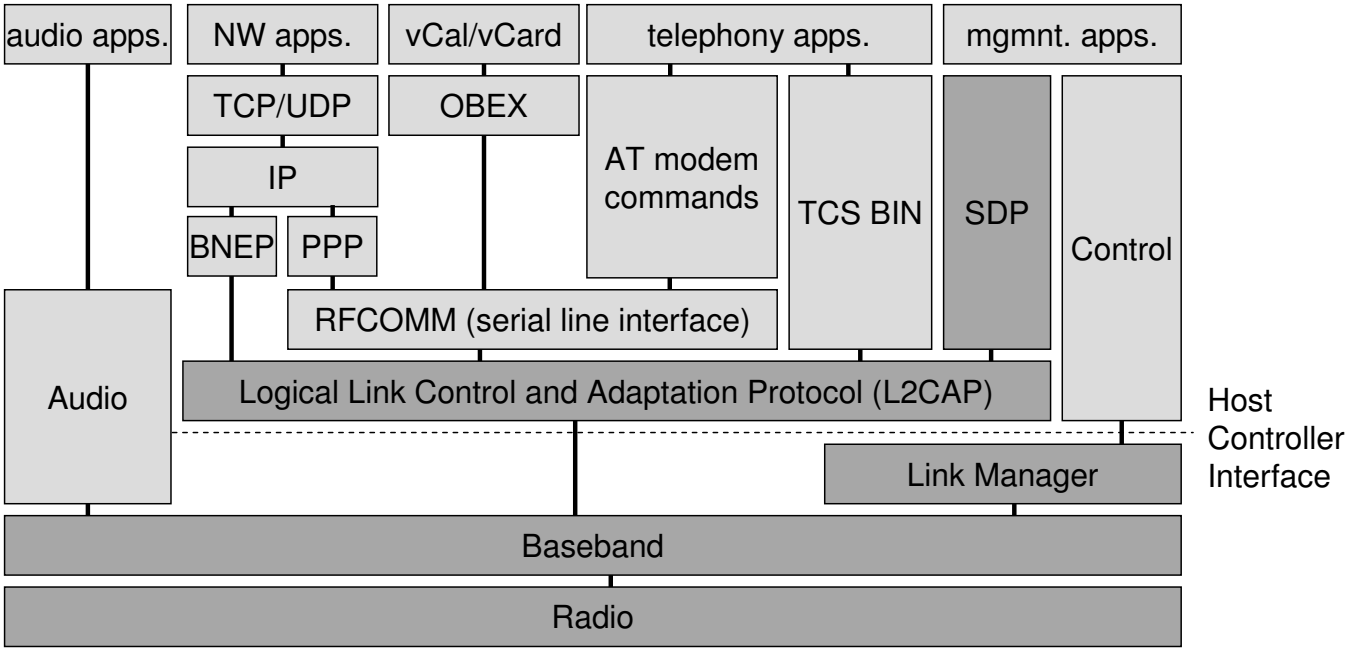
M=Master P=Parked
S=Slave SB=Standby

Scatternet

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



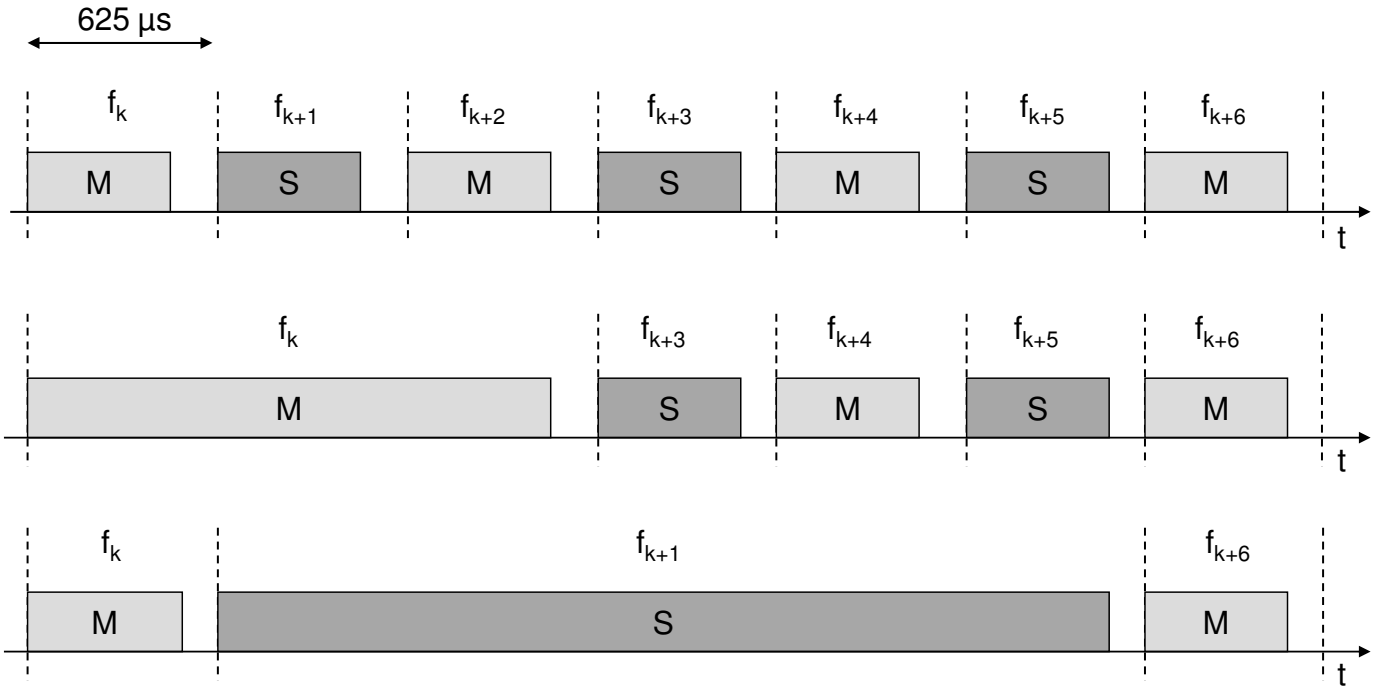
Bluetooth Protocol Stack



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.

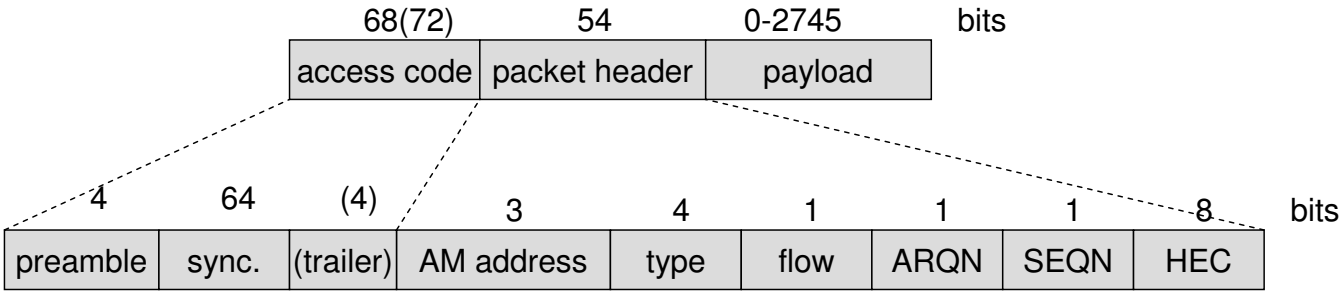
Frequency Selection during Data Transmission



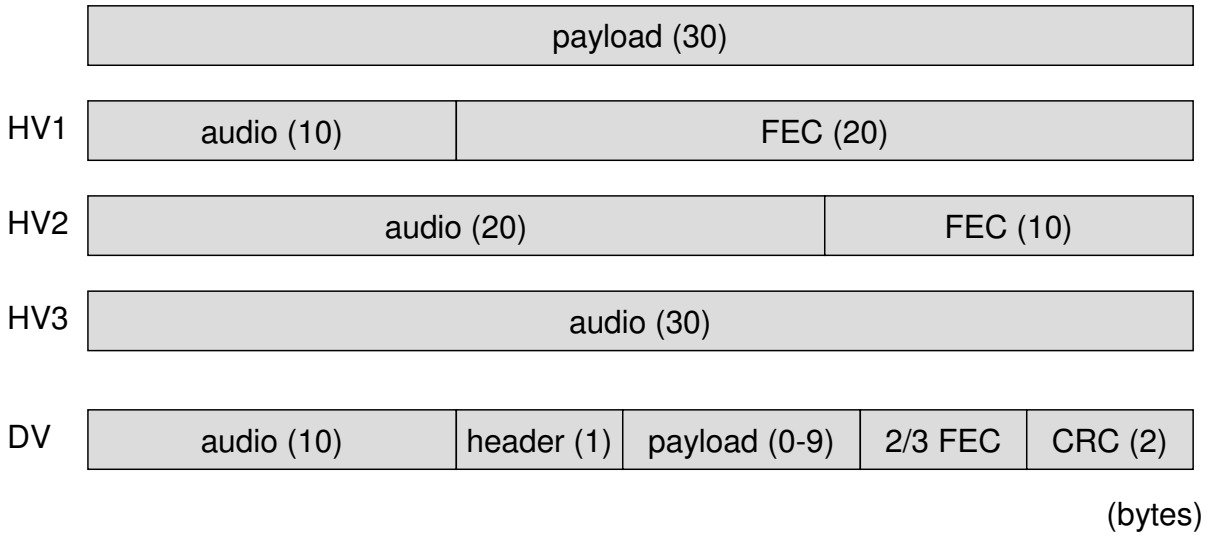
Baseband

- Low-level packet definition
  - » Access code
  - » Packet header

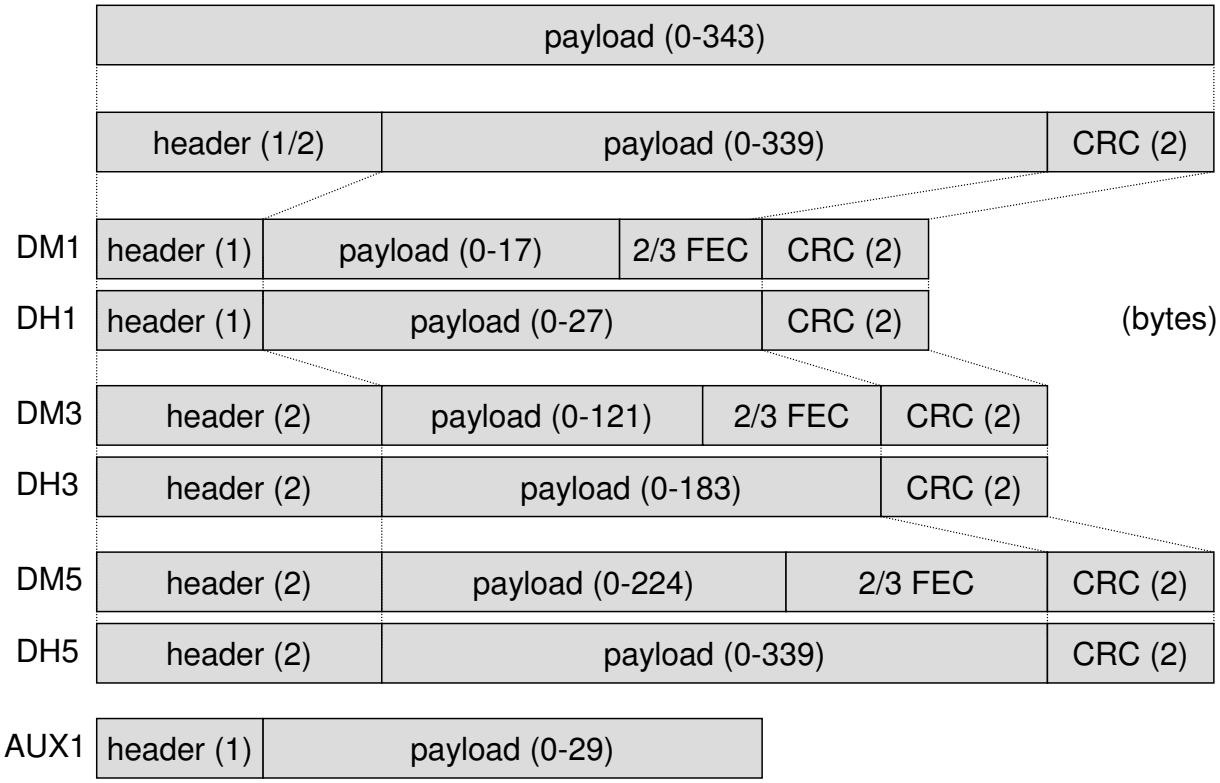
    1/3-FEC, active member address (broadcast + 7 slaves), link type, alternating bit ARQ/SEQ, checksum



SCO Payload Types



ACL Payload types



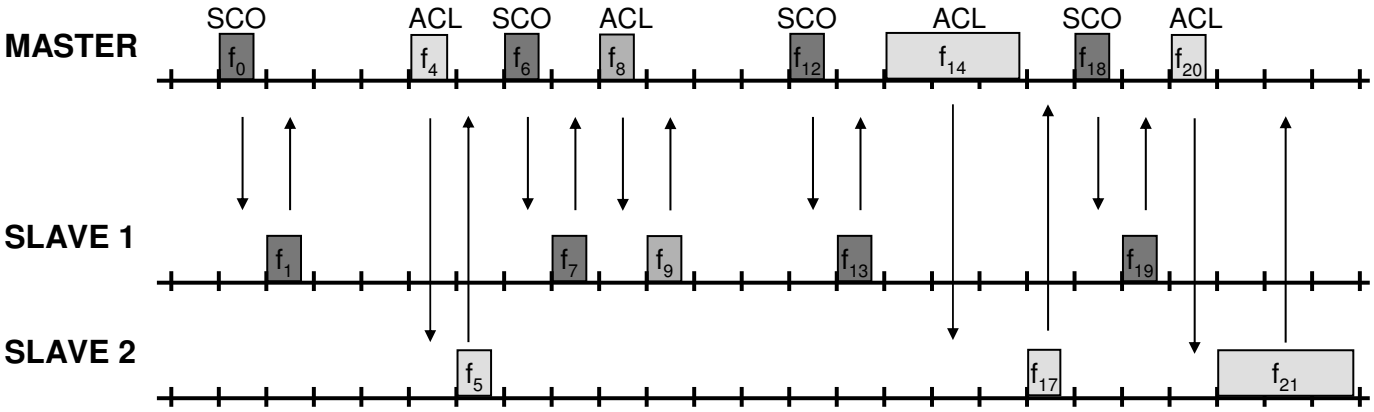
Baseband Data Rates

	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

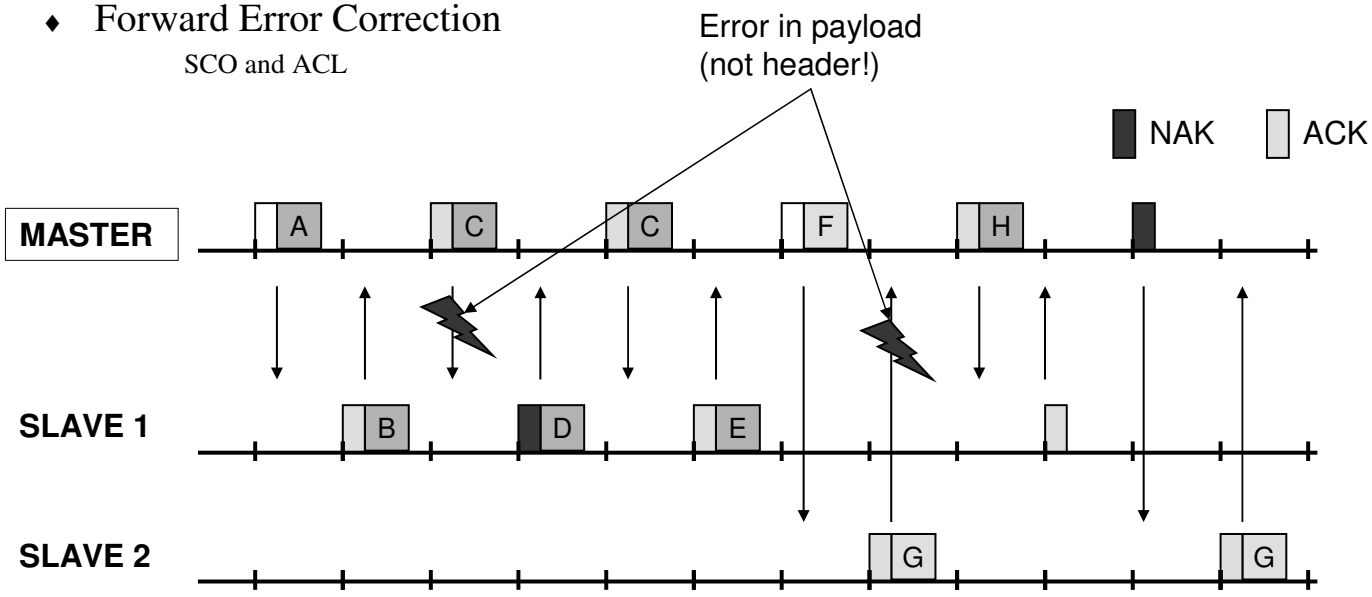
Baseband Link Types

- 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

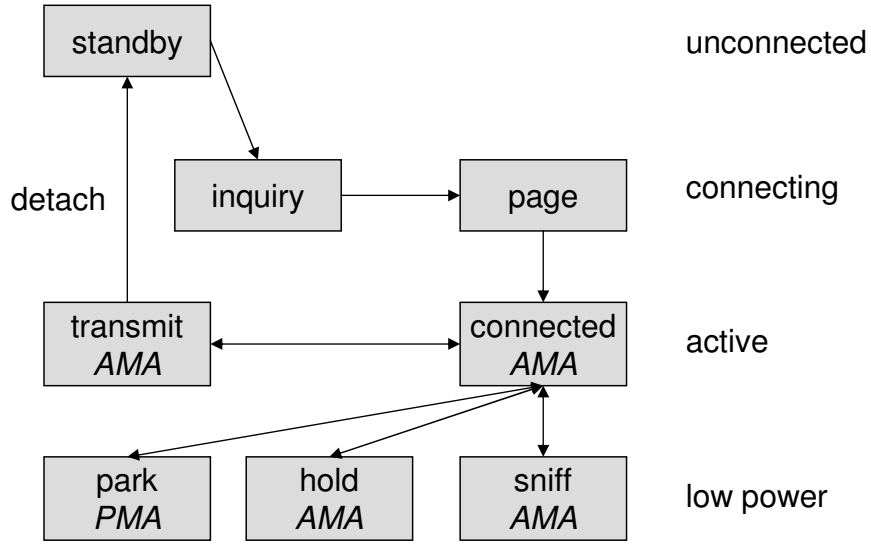


Robustness

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



Baseband States of a Bluetooth Device



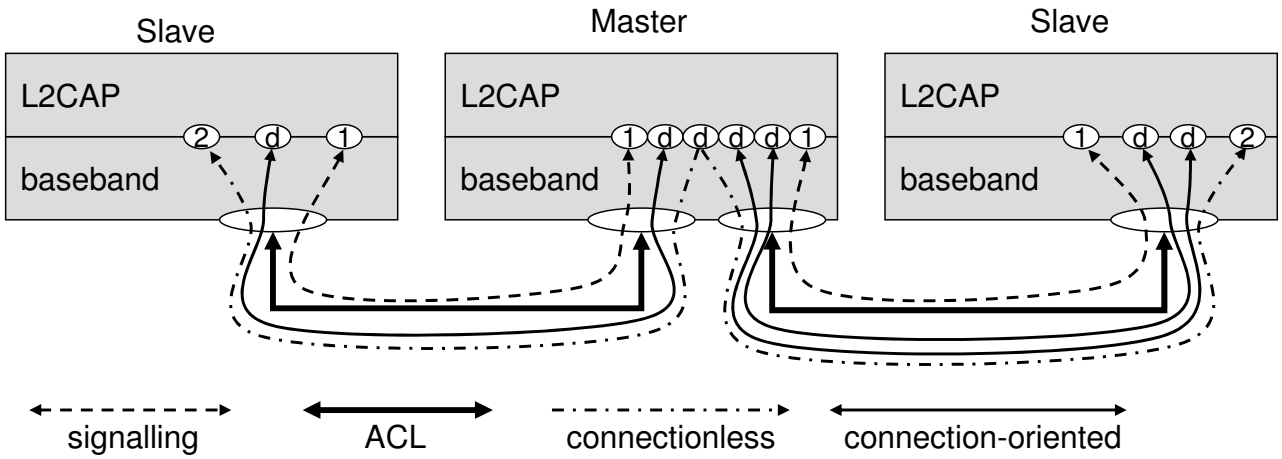
Standby: do nothing
Inquire: search for other devices
Page: connect to a specific device
Connected: participate in a piconet

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

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
- QoS specification per channel
  delay, jitter, bursts, bandwidth
- Group abstraction
  – Create/close group, add/remove member

L2CAP logical channels



L2CAP packet formats

Connectionless PDU

2	2	≥2	0-65533	bytes
length	CID=2	PSM	payload	

Connection-oriented PDU

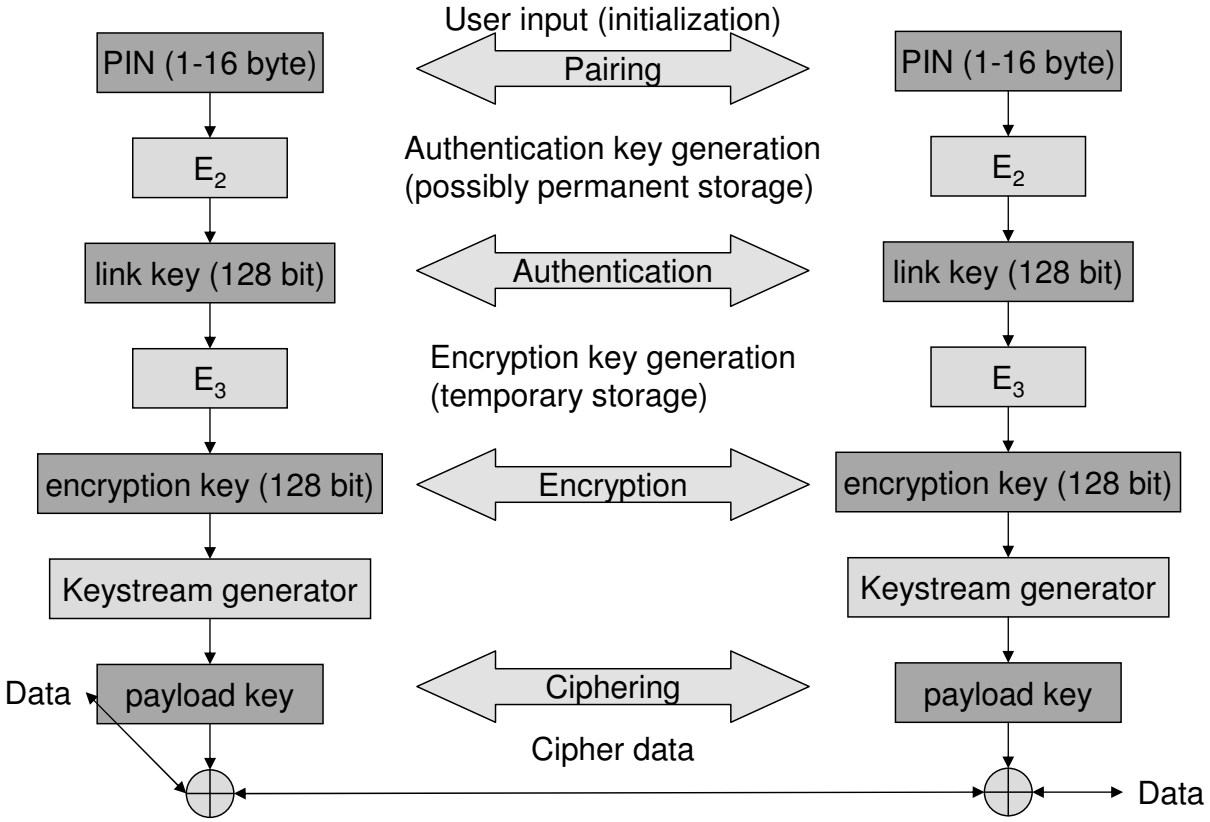
2	2	0-65535	bytes
length	CID	payload	

Signalling command PDU

2	2		bytes
length	CID=1	One or more commands	

1	1	2	≥0
code	ID	length	data

Security



Additional Protocols

- SDP – Service Discovery Protocol
  - » Inquiry/response protocol for discovering services in radio proximity
  - » Adapted to dynamic environment
- RFCOMM
  - » Emulation of a serial port
- Telephony Control Protocol Specification (TCS)
  - » Call control (setup, release)
  - » Group management

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
  - 10 m
  - 100 m, with special transceivers
  - Frequency 2.4 GHz ISM-band
- Connection set-up time
  - Depends on power-mode
  - max. 2.56s, avg. 0.64s
- Quality of Service
  - guarantees, ARQ/FEC

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 20-250 kbit/s, latency down to 15 ms
  - Master-Slave or Peer-to-Peer operation
  - Support for critical latency devices, such as joysticks
  - CSMA/CA channel access (data centric), slotted (beacon) or unslotted
  - Automatic network establishment by the PAN coordinator
  - Dynamic device addressing, flexible addressing format
  - 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

RFID – Radio Frequency Identification (1)

- Data rate
  - » Transmission of ID only (e.g., 48 bit, 64kbit, 1 Mbit)
  - » 9.6 – 115 kbit/s
- Transmission range
  - » Passive: up to 3 m
  - » Active: up to 30-100 m
  - » Simultaneous detection of up to, e.g., 256 tags, scanning of, e.g., 40 tags/s
- Frequency
  - » 125 kHz, 13.56 MHz, 433 MHz, 2.4 GHz, 5.8 GHz and many others
- Security
  - » Application dependent, typ. no crypt. on RFID device
- Cost
  - » Very cheap tags, down to 1€ (passive)
- Availability
  - » Many products, many vendors
- Connection set-up time
  - » Depends on product/medium access scheme (typ. 2 ms per device)
- Quality of Service
  - » none
- Manageability
  - » Very simple, same as serial interface
- Special Advantages/Disadvantages
  - » Advantage: extremely low cost, large experience, high volume available, no power for passive RFIDs needed, large variety of products, relative speeds up to 300 km/h, broad temp. range
  - » Disadvantage: no QoS, simple denial of service, crowded ISM bands, typ. one-way (activation/ transmission of ID)

RFID – Radio Frequency Identification (2)

- Function
  - Standard: In response to a radio interrogation signal from a reader (base station) the RFID tags transmit their ID
  - Enhanced: additionally data can be sent to the tags, different media access schemes (collision avoidance)
- Features
  - No line-of sight required (compared to, e.g., laser scanners)
  - RFID tags withstand difficult environmental conditions (sunlight, cold, frost, dirt etc.)
  - Products available with read/write memory, smart-card capabilities
- Categories
  - Passive RFID: operating power comes from the reader over the air which is feasible up to distances of 3 m, low price (1€)
  - Active RFID: battery powered, distances up to 100 m

RFID – Radio Frequency Identification (3)

- Applications
  - Total asset visibility: tracking of goods during manufacturing, localization of pallets, goods etc.
  - Loyalty cards: customers use RFID tags for payment at, e.g., gas stations, collection of buying patterns
  - Automated toll collection: RFIDs mounted in windshields allow commuters to drive through toll plazas without stopping
  - Others: access control, animal identification, tracking of hazardous material, inventory control, warehouse management, ...
- Local Positioning Systems
  - GPS useless indoors or underground, problematic in cities with high buildings
  - RFID tags transmit signals, receivers estimate the tag location by measuring the signal‘s time of flight

ISM band interference

- Many sources of interference
  - Microwave ovens, microwave lightning
  - 802.11, 802.11b, 802.11g, 802.15
  - 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

802.11 vs. 802.15/Bluetooth