7. Wireless Local Area Networks

Characteristics
IEEE 802.11
HIPERLAN, WATM, BRAN, HIPERLAN2
Bluetooth
RF
Comparison

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
  - Quite cheap networking infrastructures possible
- Drawbacks:
  - Typically very low bandwidth compared to wired networks: 1-10 Mbit/s and error rates of about 10^{-4} instead of 10^{-12}
  - 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
  - Lack of security, "open" air interface, War Driving

Design Goals for Wireless LANs

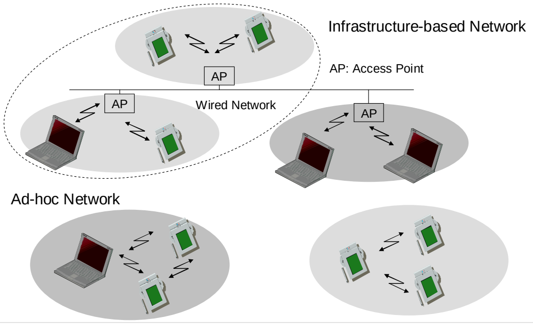
- Global, seamless operation
- Low power for battery use
- No special permissions or licenses needed to use the LAN
- Robust transmission technology
- Simplified spontaneous co-operation at meetings
- Easy to use for everyone, simple management
- Protection of investment in wired networks
- Security:
  - 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

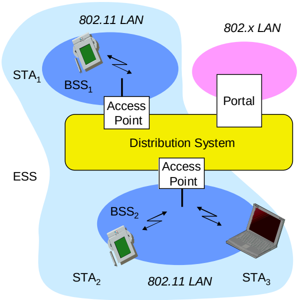
- Infrared:
  - Uses IR diodes, multiple reflections, diffuse light, *e.g.*, walls or furniture
- Advantages:
  - Simple, cheap, available in many mobile devices
  - No licenses needed
  - Simple shielding possible
- Drawbacks:
  - Interference by sunlight, heat sources
  - Many things shield/absorb IR light, LoS
  - Low bandwidth (115 kbit/s … 4 Mbit/s)
- Example:
  - IrDA (Infrared Data Association) interface available everywhere at 900 nm wave length

- 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, *e.g.*, radio can penetrate walls, furniture
- Drawbacks:
  - Very limited license free frequency bands
  - Shielding more difficult, interference with other electrical devices
- Examples:
  - WaveLAN, HIPERLAN, Bluetooth

Comparison: Infrastructure vs. Ad-hoc Nets

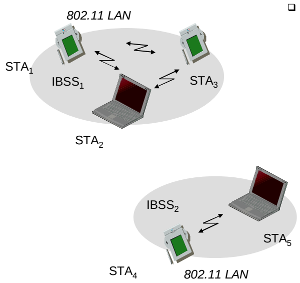


IEEE 802.11 — Architecture of an Infrastructure Network



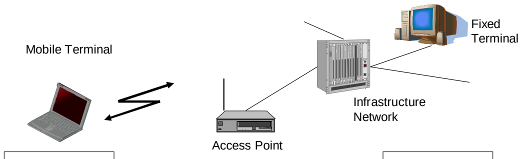
- Station (STA):
  - Terminal with access mechanisms to the wireless medium and radio contact to the access point
- Basic Service Set (BSS):
  - Group of stations using the same radio frequency
- Access Point:
  - Station integrated into the wireless LAN and the distribution system
- Portal:
  - Bridge to other (wired) networks
- Distribution System:
  - Interconnection network to form one logical network (ESS: Extended Service Set) based on several BSS

IEEE 802.11 — Architecture of an Ad-hoc Network



- Direct communication within a limited range:
  - Station (STA):
    - Terminal with access mechanisms to the wireless medium
  - Independent Basic Service Set (IBSS):
    - Group of stations using the same radio frequency

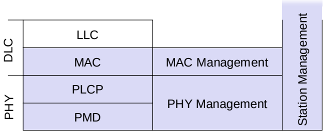
IEEE Standard 802.11



Application			Application
TCP			TCP
IP			IP
LLC	LLC		LLC
802.11 MAC	802.11 MAC	802.3 MAC	802.3 MAC
802.11 PHY	802.11 PHY	802.3 PHY	802.3 PHY

IEEE 802.11 — Layers and Functions

- MAC:
  - Access mechanisms, fragmentation, encryption
- PLCP Physical Layer Convergence Protocol:
  - Clear Channel Assessment (CCA) signal (carrier sense)
- PMD Physical Medium Dependent:
  - Modulation, coding
- MAC Management:
  - Authentication, synchronization, roaming, MIB, power management
- PHY Management:
  - Channel selection, MIB
- Station Management:
  - Coordination of all management functions



IEEE 802.11 — Physical layer

- 3 versions: 2 radio (typical 2.4 GHz), 1 IR:
  - Data rates of 1 Mbit/s mandatory and 2 Mbit/s optional
- FHSS (Frequency Hopping Spread Spectrum):
  - Spreading, de-spreading, signal strength, typical 1 Mbit/s, 79 channels US/EU
  - Min. 2.5 frequency hops/s (USA), two-level GFSK (Gauß FSK) modulation
- DSSS (Direct Sequence Spread Spectrum):
  - DBPSK modulation for 1 Mbit/s (Differential Binary Phase Shift Keying), DQPSK for 2 Mbit/s (Differential Quadrature PSK)
  - Preamble and header of a frame is always transmitted with 1 Mbit/s, rest of transmission 1 or 2 Mbit/s
  - Chipping sequence: +1, -1, +1, +1, -1, +1, +1, +1, -1, -1, -1 (Barker code), 11 Mhz chipping rate
  - Max. radiated power 1 W (USA), 100 mW (EU), min. 1mW
- Infrared:
  - 850-950 nm, diffuse light, typical 10 m range
  - Carrier detection, energy detection, synchronization

IEEE 802.11 — FHSS PHY Packet Format

- Synchronization:
  - Synchronization with 010101... pattern
- SFD (Start Frame Delimiter):
  - 0000110010111101 start pattern
- PLW (PLCP_PDU Length Word):
  - Length of payload including 32 bit CRC of payload, PLW < 4096 byte
- PSF (PLCP Signaling Field):
  - Data of payload (1 or 2 Mbit/s): 0 = 1 Mbit/s, 10 = 2 Mbit/s etc.
- HEC (Header Error Check)
  - CRC with $x^{16}+x^{12}+x^5+1$

80	16	12	4	16	variable	bit
Synchronization	SFD	PLW	PSF	HEC	Payload	
PLCP Preamble		PLCP Header				

IEEE 802.11 — DSSS PHY Packet Format

- Synchronization:
  - Synchronization, gain setting, energy detection, frequency offset compensation
- SFD (Start Frame Delimiter):
  - 1111001110100000
- Signal:
  - Data rate of the payload (0A: 1 Mbit/s DBPSK; 14: 2 Mbit/s DQPSK)
- Service:
  - Future use, 00: 802.11 compliant
- Length:
  - Length of the payload (measured in μs)
- HEC (Header Error Check)
  - Protection of signal, service, and length, $x^{16}+x^{12}+x^5+1$, ITU-T-CRC-16 standard

128	16	8	8	16	16	variable	bit
Synchronization	SFD	Signal	Service	Length	HEC	Payload	
PLCP Preamble		PLCP Header					

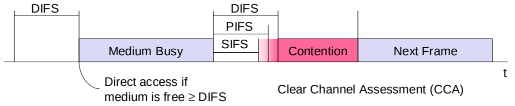
IEEE 802.11 — MAC Layer DFWMAC (1)

- Traffic services (Roaming, Authentication, Energy Savings):
  - Asynchronous Data Service (mandatory):
    - Exchange of data packets based on “best-effort”
    - Support of broadcast and multicast, however, no QoS support
  - Time-Bounded Service (optional):
    - Implemented using PCF
- 3 Access methods:
  - DFWMAC-DCF CSMA/CA (mandatory) (Distributed Foundation Wireless MAC):
    - Collision avoidance via randomized „back-off“ mechanism
    - Minimum distance between consecutive packets
    - ACK packet for acknowledgements (not for broadcasts)
  - DFWMAC-DCF with RTS/CTS (optional):
    - Avoids hidden terminal problem
  - DFWMAC- PCF (optional):
    - Access point polls terminals according to a list

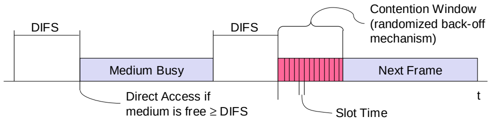
DCF: Distributed Coordination Function
PCF: Point Coordination Function

IEEE 802.11 — MAC Layer DFWMAC (2)

- Priorities (determine waiting time before medium access):
  - Defined through different Inter Frame Spaces (IFS)
  - No guaranteed, hard priorities
  - SIFS (Short Inter Frame Spacing):
    - Highest priority, for ACK, CTS, polling response: DSSS 10 μs, FHSS 28 μs
  - PIFS (Point Coordination Function IFS):
    - Medium priority, for time-bounded service using PCF, polling of terminals, PIFS = SIFS plus time slot duration
  - DIFS (Distributed Coordination Function IFS):
    - Lowest priority, for asynchronous data service, DIFS = SIFS plus 2 time slots

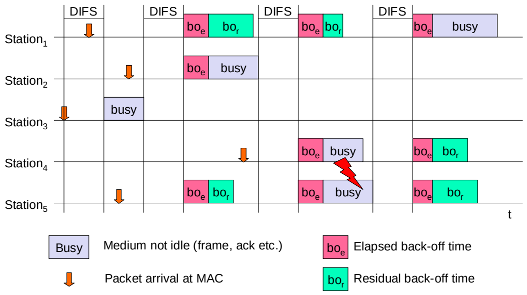


IEEE 802.11 — CSMA/CA Access Method (1)



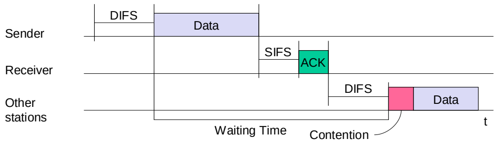
- Station ready to send starts sensing the medium (Carrier Sense based on CCA, Clear Channel Assessment)
- If the medium is *free* for the duration of an Inter-Frame Space (IFS), the station can start sending (IFS depends on service type)
- If the medium is *busy*, the station has to wait for a free IFS, then the station must wait additionally 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)

IEEE 802.11 — Competing Stations/Simple



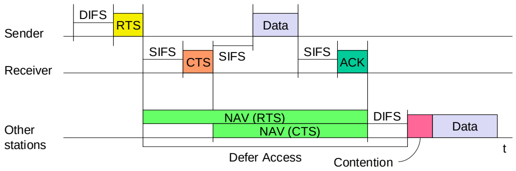
IEEE 802.11 — CSMA/CA Access Method (2)

- 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



IEEE 802.11 — DFWMAC including RTS/CTS

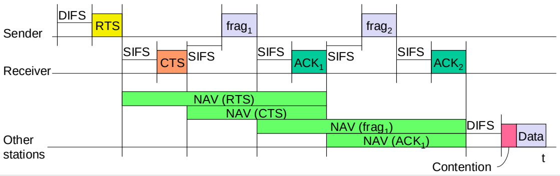
- Sending unicast packets:
  - Station can send RTS with reservation parameter after waiting for DIFS (reservation determines amount of time the data packet needs the medium)
  - Acknowledgement via CTS after SIFS by receiver (if ready to receive)
  - Sender can now send data at once, acknowledgement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



NAV: Net Allocation Vector (includes send duration planned and ACK for this transmission)

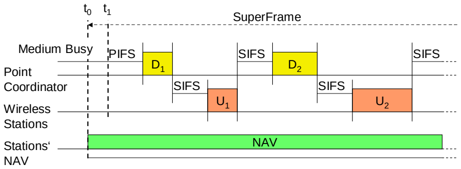
Fragmentation

- Minimization of error rates (transparent to users):
  - Erroneous frames in wireless networks with a larger probability than in wired networks due to larger bit error rate
  - Shorten frames!
  - Sender reserves after DIFS by RTS medium (only first fragment length plus ACK)
  - Receiver acks with CTS including first fragment length plus ACK
  - New fragment frag1 contains a fragment length: ACK1, frag2, and ACK2!



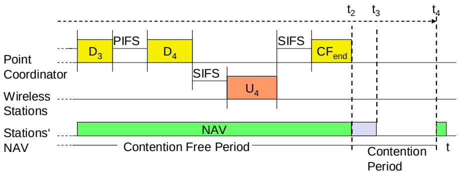
DFWMAC-PCF (1)

- Point Co-ordination Function (PCF):
  - Time-based service required for some applications
  - Access point required to determine access and polling of stations
  - Only applicable in infrastructure mode, ad-hoc not possible -> no QoS!
  - Contention-free period shown:
    - Starting point moved to t1 due to busy medium at t0.
    - Wait for PCF Inter-frame Spacing (PIFS): PIFS < DIFS



DFWMAC-PCF (2)

(Con't)
- Contention-free and contention period shown:
- Station D3 does not have any reply in queue, waiting PIFS
- PC frees contention-free period by CFend signal
- Early release of super-frame, contention period moves from t_3 to t_2



IEEE 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

Byte	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

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

IEEE 802-11 — 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

Address 1: AP or STA
Address 2: Physically sending STA, receives MAC ACK
Address 3: Logically sending STA, BSS
Address 4: similar (optional)

Special Frames: ACK, RTS, CTS

- Acknowledgement:

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

- Request To Send:

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

- Clear To Send:

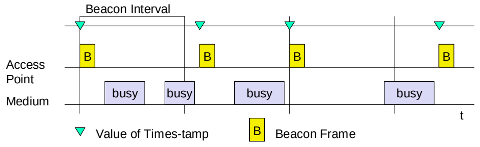
	Byte	2	2	6	4
CTS		Frame Control	Duration	Receiver Address	CRC

IEEE 802.11 — MAC Management

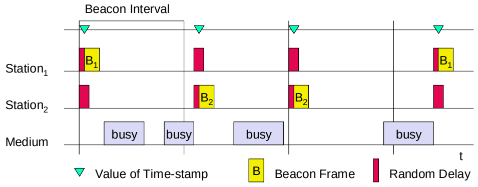
- Synchronization:
  - Try to find a LAN, try to stay within a LAN
  - Timer
- Power management:
  - Sleep-mode without missing a message
  - Periodic sleep, frame buffering, traffic measurements
- Association/Re-association (Roaming):
  - Integration into a LAN
  - Roaming, i.e. change networks by changing access points
  - Scanning, i.e. active search for a network
- MIB - Management Information Base:
  - Managing, read, write

Synchronization using a Beacon (Infrastructure)

- Synchronization:
  - Timing Synchronization Function for all clocks
  - FHSS sequence synchronization in stations and BSS
  - Beacons periodically indicates start of interval
  - TSF (Timing Synchronization Function) part of the standard



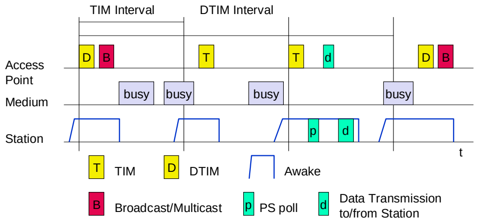
Synchronization using a Beacon (ad-hoc)



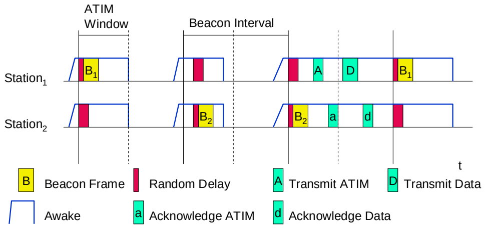
Power Management

- Idea:
  - Switch the transceiver off, if not needed
  - States of a station: sleep and awake
- Timing Synchronization Function (TSF):
  - Stations wake up at the same time
- Infrastructure:
  - Traffic Indication Map (TIM):
    - List of unicast receivers transmitted by AP
  - Delivery Traffic Indication Map (DTIM):
    - List of broadcast/multicast receivers transmitted by AP
- Ad-hoc:
  - Ad-hoc Traffic Indication Map (ATIM):
    - Announcement of receivers by stations buffering frames
    - More complicated - no central AP
    - Collision of ATIMs possible (scalability?)

Power Saving with Wake-up Patterns (Infrastructure)



Power Saving with Wake-up Patterns (Ad-hoc)



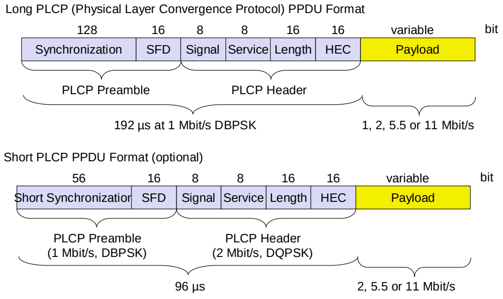
IEEE 802.11 — Roaming

- ❑ 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
- ❑ Re-association Request:
  - – Station sends a request to one or several AP(s)
- ❑ Re-association Response:
  - – Success: AP has answered, station can now participate
  - – Failure: continue scanning
- ❑ AP accepts Re-association 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

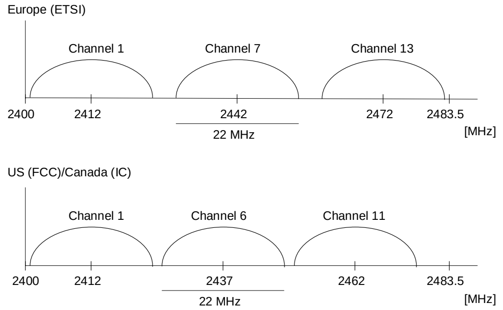
- ❑ Data rate:
  - – 1, 2, 5.5, 11 Mbit/s, depending on SNR
  - – User data rate max. approx. 6 Mbit/s
- ❑ Transmission range:
  - – 300 m outdoor, 30 m indoor
  - – Max. data rate ~10 m indoor
- ❑ Frequency:
  - – Free 2.4 GHz ISM-band
- ❑ Security:
  - – Limited, WEP insecure, BSSID
- ❑ Cost:
  - – 100 € per adapter, 250 € per base station, dropping
- ❑ Availability:
  - – Many products, many vendors
- ❑ Connection set-up time:
  - – Connectionless/always on
- ❑ Quality-of-Service:
  - – Typically best effort, no guarantees (unless polling is used, limited support in products)
- ❑ Manageability:
  - – Limited (no automated key distribution, sym. Encryption)
- ❑ Special advantages/drawbacks:
  - – Advantage: many installed systems, lot of experience, available worldwide, free ISM-band, many vendors, integrated in laptops, simple system
  - – Drawback: heavy interference on ISM-band, no service guarantees, slow relative speed only

IEEE 802.11b — PHY Frame Formats



DBPSK: Differential Binary PSK, DQPSK: Differential Quadrature PSK

Channel Selection (Non-overlapping)



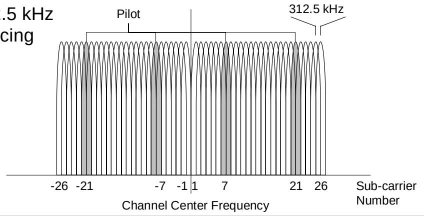
WLAN: IEEE 802.11a

- ❑ Data rates:
  - – 6, 9, 12, 18, 24, 36, 48, 54 Mbit/s (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
- ❑ 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:
  - – Typically best effort, no guarantees (same as all IEEE 802.11 standards)
- ❑ Manageability:
  - – Limited (no automated key distribution, sym. Encryption)
- ❑ Special advantages/drawbacks:
  - – Advantage: fits into 802.x standards, free ISM-band, available, simple system, uses less crowded 5 GHz band
  - – Drawback: stronger shading due to higher frequency, no QoS

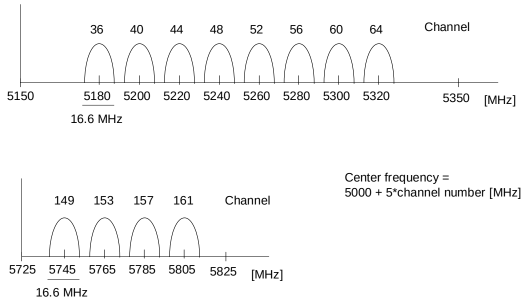
OFDM in IEEE 802.11a (and HiperLAN2)

- ❑ OFDM with 52 used sub-carriers (64 in total):
  - – Reduction of symbol rate -> a bit distributed across multiple sub-carriers
    - • 250.000 symbols/s and 0.8 μs guard space
  - – 48 data + 4 pilot (robustness against F drifts)
  - – Plus 12 virtual sub-carriers
- ❑ 312.5 kHz spacing

OFDM: Orthogonal FDM

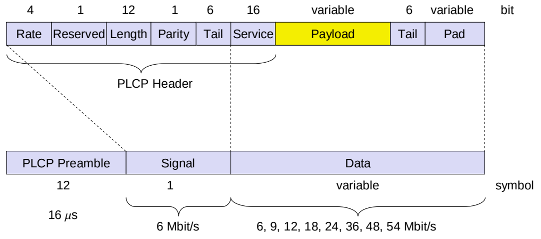


Operating Channels for IEEE 802.11a/US U-NII



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

IEEE 802.11a — PHY Frame Format



WLAN: IEEE 802.11 — Future Developments (12/2003)

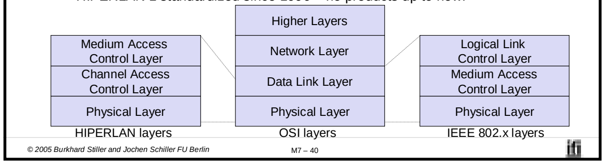
- 802.11d: Regulatory Domain Update – completed
- 802.11e: MAC Enhancements – QoS – completed
  - Enhance the current 802.11 MAC to expand support for applications with Quality of Service requirements, and in the capabilities and efficiency of the protocol.
- 802.11f: Inter-Access Point Protocol – ongoing
  - Establish an Inter-Access Point Protocol for data exchange via the distribution system.
- 802.11g: Data Rates > 20 Mbit/s at 2.4 GHz; 54 Mbit/s, OFDM – completed

OFDM: Orthogonal FDM

- 802.11h: Spectrum Managed 802.11a (DCS, TPC) – ongoing
- 802.11i: Enhanced Security Mechanisms – ongoing
  - Enhance the current 802.11 MAC to provide improvements in security.
- Study Groups:
  - 5 GHz (harmonization ETSI/IEEE) – closed
  - Radio Resource Measurements – started
  - High Throughput – ongoing

ETSI — HIPERLAN

- ETSI standard:
  - European standard, cf. GSM, DECT, ...
  - Enhancement of local networks and inter-working with fixed networks
  - Integration of time-sensitive services from the early beginning
- HIPERLAN family:
  - One standard cannot satisfy all requirements
    - Range, bandwidth, QoS support
    - Commercial constraints
  - HIPERLAN 1 standardized since 1996 – no products up to now!



Overview: Original HIPERLAN Protocol Family

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

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

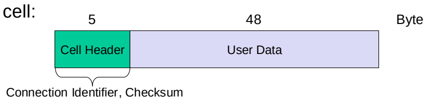
Key Developments: Why Wireless ATM?

- Seamless connection to wired ATM, an integrated services high-performance network supporting different types a traffic streams
- ATM networks scale well: private and corporate LANs, WAN
- B-ISDN uses ATM as backbone infrastructure and integrates several different services in one universal system
- Mobile phones and mobile communications have an ever increasing importance in everyday life
- Current wireless LANs do not offer adequate support for multimedia data streams
- Merging mobile communication and ATM leads to wireless ATM from a telecommunication provider point of view
- Goal: seamless integration of mobility into B-ISDN
- Problem:
  Very high complexity of the system – never reached products

ATM — Basic Principles

- Favored by the telecommunication industry for advanced high-performance networks, *e.g.*, B-ISDN, as transport mechanism
- Statistical (asynchronous, on demand) TDM (ATDM, STDM)
- Cell header determines the connection the user data belongs to
- Mixing of different cell-rates is possible:
  - Different bit-rates, constant or variable, feasible
- Interesting for data sources with varying bit-rate:
  - *E.g.*, guaranteed minimum bit-rate
  - Additionally bursty traffic if allowed by the network

- ATM cell:



ATM Forum Wireless ATM Working Group

- ATM Forum founded *Wireless ATM Working Group* 06/1996
- Task:
  - Development of specifications to enable the use of ATM technology also for wireless networks with a large coverage of current network scenarios (private and public, local and global)
  - Compatibility to existing ATM Forum standards important
- It should be possible to easily upgrade existing ATM networks with mobility functions and radio access
- Two sub-groups of work items:

Radio Access Layer (RAL) Protocols:
- Radio access layer
- Wireless media access control
- Wireless data link control
- Radio resource control
- Hand-over issues

Mobile ATM Protocol Extensions:
- Hand-over signaling
- Location management
- Mobile routing
- Traffic and QoS Control
- Network management

BRAN — Broadband Radio Access Networks

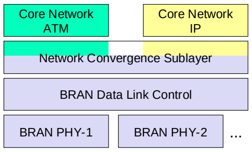
- Motivation:
  - Deregulation, privatization, new companies, new services
  - How to reach the customer?
    - Alternatives: xDSL, cable, satellite, radio
- Radio access:
  - Flexible (supports traffic mix, multiplexing for higher efficiency, can be asymmetrical)
  - Quick installation
  - Economic (incremental growth possible)
- Market:
  - Private customers (Internet access, tele-xy...)
  - Small and medium sized business (Internet, MM conferencing, VPN)
- Scope of standardization:
  - Access networks, indoor/campus mobility, 25 -155 Mbit/s, 50 m - 5 km
  - Coordination with ATM Forum, IETF, ETSI, IEEE, ...

Broadband Network Types

- Common characteristics:
  - ATM QoS (CBR, VBR, UBR, ABR)
- HIPERLAN/2:
  - Short range (< 200 m), indoor/campus, 25 Mbit/s user data rate
  - Access to telecommunication systems, multimedia applications, mobility (<10 m/s)
- HIPERACCESS:
  - Wider range (< 5 km), outdoor, 25 Mbit/s user data rate
  - Fixed radio links to customers ("last mile"), alternative to xDSL or cable modem, quick installation
  - Several (proprietary) products exist with 155 Mbit/s plus QoS
- HIPERLINK – currently no activities:
  - Intermediate link, 155 Mbit/s
  - Connection of HIPERLAN access points or connection between HIPERACCESS nodes

BRAN and Legacy Networks

- Independence:
  - BRAN as access network independent from the fixed network
  - Inter-working of TCP/IP and ATM under study
- Layered model:
  - Network Convergence Sub-layer as superset of all requirements for IP and ATM



Coordination:
- IETF (TCP/IP)
- ATM forum (ATM)
- ETSI (UMTS)
- CEPT, ITU-R, ... (radio frequencies)

HiperLAN2

- Official name: BRAN HIPERLAN Type 2:
  - H/2, HIPERLAN/2 also used
- Characteristics:
  - High data rates for users: 54 Mbit/s at 5 GHz
  - More efficient than 802.11a
  - Connection oriented
  - QoS support
  - Dynamic frequency selection
  - Security support
    - Strong encryption/authentication
  - Mobility support
  - Network and application independent
    - Convergence layers for Ethernet, IEEE 1394, ATM, 3G
  - Power save modes
  - Plug and Play

HiperLAN2 Global Forum

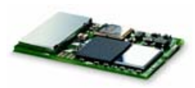
Http://www.hiperlan2.com

Ad-hoc Networking Today

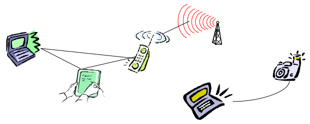
- Almost no (large) ad-hoc systems exist
- Playing with multi-hop on WLAN:
  - Mobihoc, Mobicom
- NS-2 plots get boring in the long run:
  - Specific MAC layer problem analysis
- So why is nobody doing the real thing?
  - Bulky
  - Short standalone operating times
  - Hard to manage multitude of devices
  - Limitations on features and communication front-ends
  - Often only point to point
  - SDK's only for selected "customers"

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 (was: Bluetooth.)
  - 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, http://www.bluetooth.org
  - 1999: Erection of a rune stone at Ericsson/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
  - More than 2500 members
  - Common specification and certification of products

Bluetooth™

Ericsson 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.

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…)

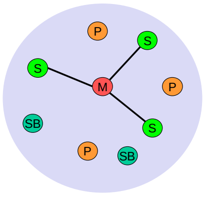
This could be the "original" colors of the stone.
Inscription:
"auk tani karthi kristna" (and made the Danes Christians)

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

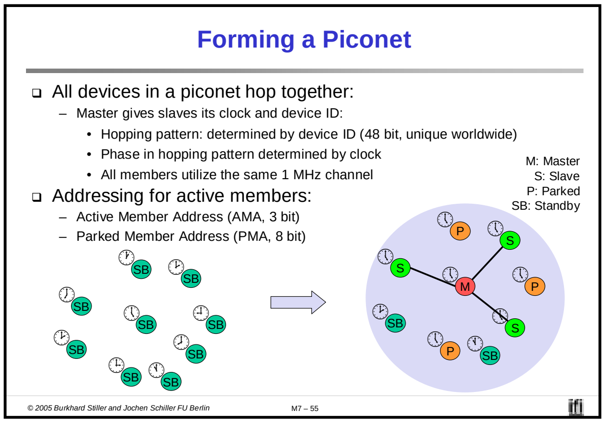
Piconet

- 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
S: Slave

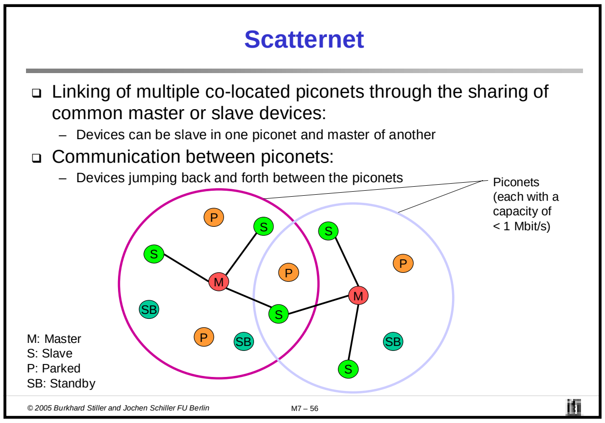
P: Parked
SB: Standby



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
    - All members utilize the same 1 MHz channel
- Addressing for active members:
  - Active Member Address (AMA, 3 bit)
  - Parked Member Address (PMA, 8 bit)

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

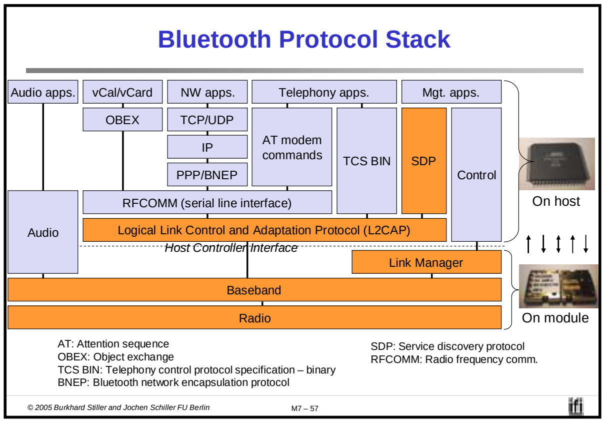


Scatternet

- 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 < 1 Mbit/s)

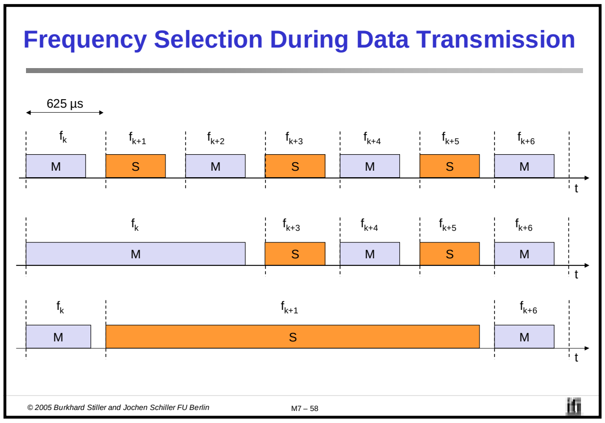
M: Master
S: Slave
P: Parked
SB: Standby



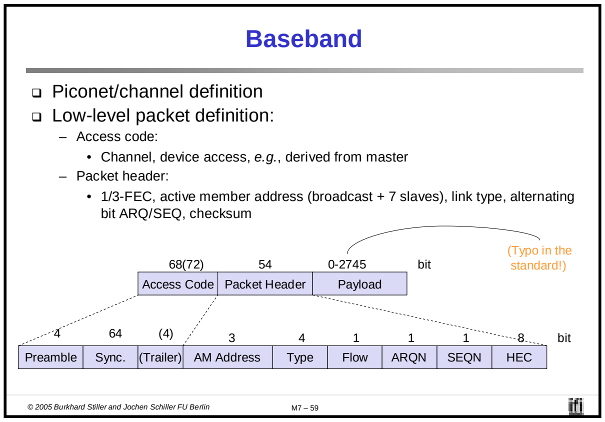
Bluetooth Protocol Stack

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



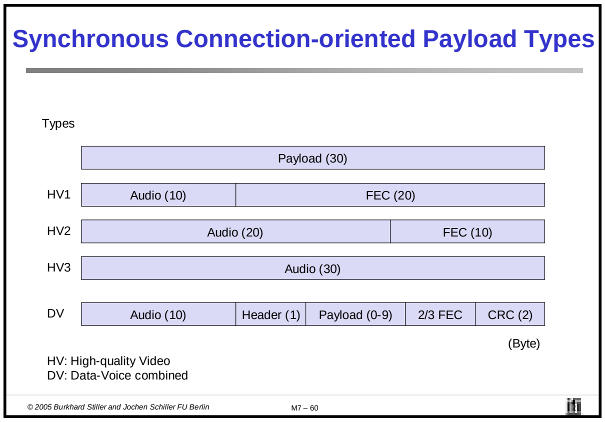
Baseband

- 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

Access Code	Packet Header	Payload	
68(72)	54	0-2745	bit

(Typo in the standard!)

Preamble	Sync.	(Trailer)	AM Address	Type	Flow	ARQN	SEQN	HEC	
4	64	(4)	3	4	1	1	1	8	bit



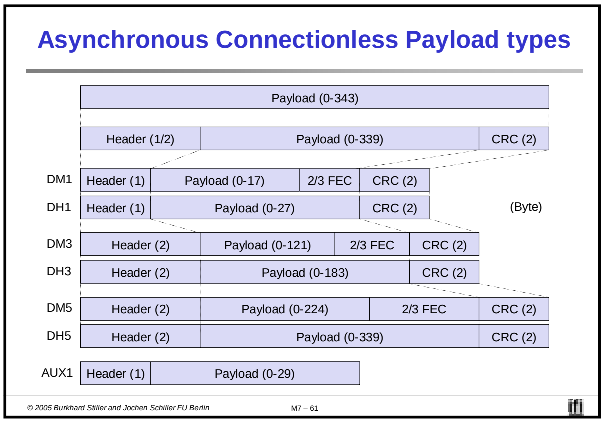
Synchronous Connection-oriented Payload Types

Types

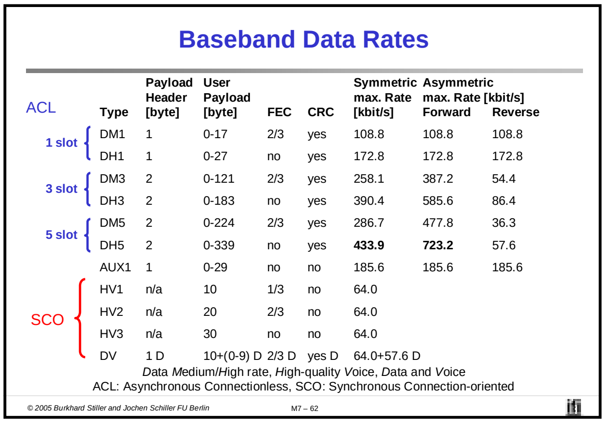
	Payload (30)				
HV1	Audio (10)	FEC (20)			
HV2	Audio (20)	FEC (10)			
HV3	Audio (30)				
DV	Audio (10)	Header (1)	Payload (0-9)	2/3 FEC	CRC (2)

(Byte)

HV: High-quality Video
DV: Data-Voice combined



Asynchronous Connectionless Payload types

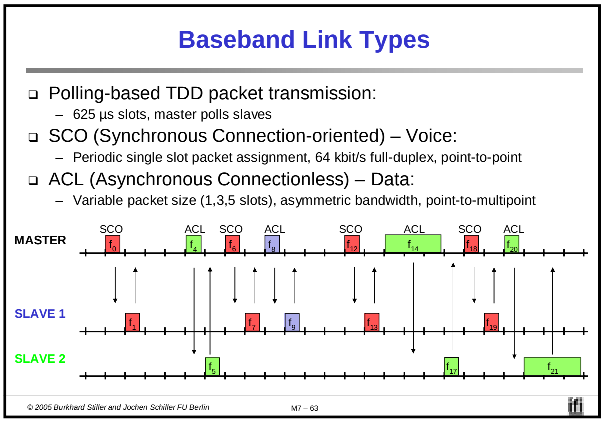


Baseband Data Rates

	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	n/a	10	1/3	no	64.0		
	HV2	n/a	20	2/3	no	64.0		
	HV3	n/a	30	no	no	64.0		
	DV	1 D	10+(0-9) D	2/3 D	yes D	64.0+57.6 D		

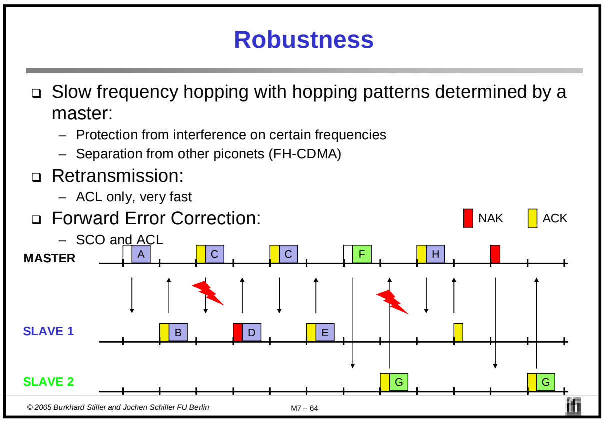
*D*ata *M*edium/*H*igh rate, *H*igh-quality *V*oice, *D*ata and *V*oice

ACL: Asynchronous Connectionless, SCO: Synchronous Connection-oriented



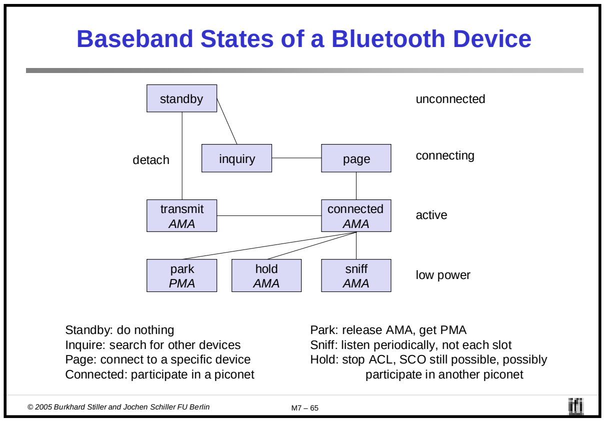
Baseband Link Types

- Polling-based TDD packet transmission:
  - 625 µs 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

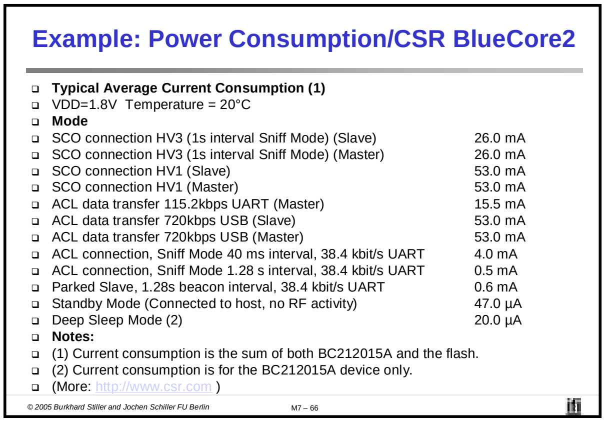
- Slow frequency hopping with hopping patterns determined by a master:
  - Protection from interference on certain frequencies
  - Separation from other piconets (FH-CDMA)
- Retransmission:
  - ACL only, very fast
- Forward Error Correction:
  - SCO and ACL



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



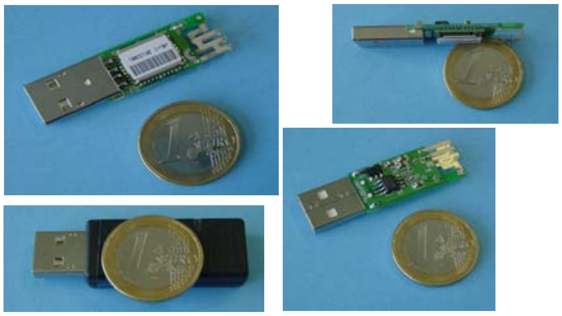
Example: Power Consumption/CSR BlueCore2

- **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 40 ms interval, 38.4 kbit/s UART	4.0 mA
ACL connection, Sniff Mode 1.28 s interval, 38.4 kbit/s UART	0.5 mA
Parked Slave, 1.28s beacon interval, 38.4 kbit/s 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: http://www.csr.com)

Example: Bluetooth/USB Adapter (2003: 30 €)

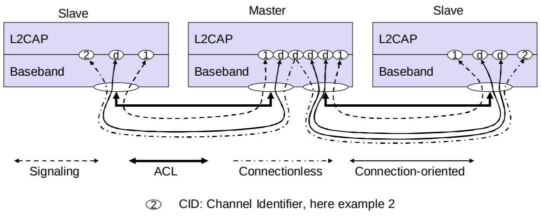


L2CAP — Logical Link Layer Control and Adaptation Layer Protocol

- Simple data link protocol on top of baseband
  - Applied to ACL only
- Connection oriented, connectionless, and signaling channels
- Protocol multiplexing:
  - RFCOMM, SDP, telephony control
- Segmentation and 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 Link Control
and Adaptation Protocol

L2CAP Logical Channels



Signaling ACL Connectionless Connection-oriented

② CID: Channel Identifier, here example 2

L2CAP Packet Formats

Connectionless PDU

2	2	≥2	0-65533	Byte
Length	CID=2	PSM	Payload	

Connection-oriented PDU

2	2	0-65535	Byte
Length	CID	Payload	

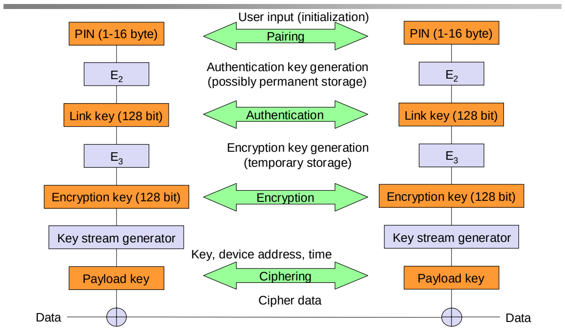
Signaling command PDU

2	2		Byte
Length	CID=1	One or more commands	

1	1	2	≥0
Code	ID	Length	Data

PSM: Protocol/Service Multiplexor

Security



SDP — Service Discovery Protocol

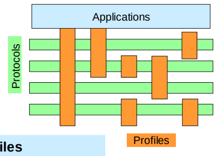
- Inquiry/response protocol for discovering services:
  - Searching for and browsing services in radio proximity
  - Adapted to the highly dynamic environment
  - Can be complemented by others like SLP, Jini, Salutation, …
  - Defines discovery only, not the usage of services
  - Caching of discovered 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)

Additional Protocols to Support Legacy Protocols and Applications

- ❑ 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

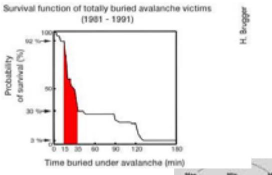


Additional Profiles
Advanced Audio Distribution
PAN
Audio Video Remote Control
Basic Printing
Basic Imaging
Extended Service Discovery
Generic Audio Video Distribution
Hands Free
Hardcopy Cable Replacement

Avalanche Rescue through Sensors

Avalanche victims fatalities:

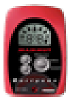
- ❑ 0-15 min: 8% fatalities
- ❑ **15-35 min: most victims suffocate**
- ❑ 35-90 min: 27% survive with air pockets
- ❑ 90 -130 min: suffocation even with air pockets
- ❑ > 130 min: 3% survive e.g. air channels

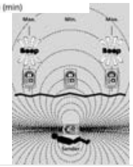


→ time really matters!

Today's beacon technology very crude:

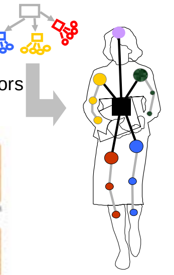
- ❑ Periodical pulses: the louder, the closer
- ❑ 457 kHz, 0.1W
- ❑ 80 m range

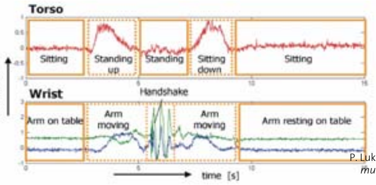




Physical Activity Detection Network

- ❑ Use multiple motion sensors for context awareness
- ❑ Idea: Many sensors reveal „more context“
- ❑ Architecture required to combine those sensors
- ❑ Map hierarchical topology to human body

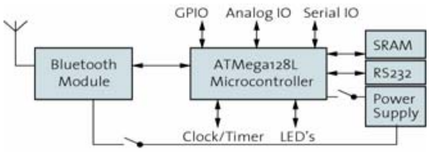




P. Lukowicz et al. *WearNET: A distributed multi-sensor system for context aware wearables*. Ubicomp 2002.

Hardware Requirements

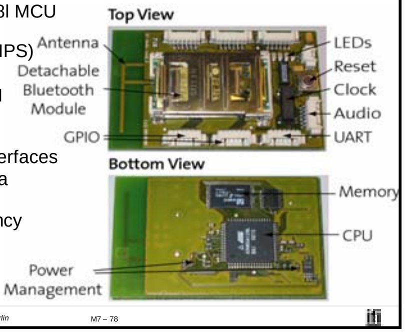
- ❑ Autonomous wireless communication and computing platform based on a Bluetooth radio module and a micro controller.



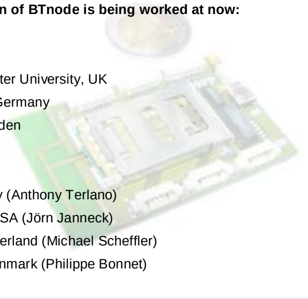
- ❑ Requirements:
  - Small form factor, low component count
  - Standardized wireless interface
  - Flexible and cost effective deployment of large quantities of networking nodes

BTnode Hardware Details

- ❑ Atmel ATmega 128l MCU 8-Bit RISC (max. 8 MHz ~8 MIPS)
- ❑ Real time clock
- ❑ 128 kB Flash ROM 64 kB SRAM 4 kB EEPROM
- ❑ Generic sensor interfaces
- ❑ UART and I2C data interface
- ❑ Power and frequency management
- ❑ Integrated PIFA antenna



Who is using BTnodes today?



Successful deployment of more than 200 units with more than 21 groups world-wide, second generation of BTnode is being worked at now:

- TIK, ETH Zurich
- DSG, ETH Zurich
- Computing Department, Lancaster University, UK
- TecO, University of Karlsruhe, Germany
- PLAY, Interactive Institute, Sweden
- VTT, Finland
- IFE Wearable Lab, ETH Zurich
- NTTDoCoMo, Munich, Germany (Anthony Terlano)
- Ptolemy Group, UC Berkeley, USA (Jörn Janneck)
- Art of Technology, Zurich, Switzerland (Michael Scheffler)
- DistLab, Diku, Copenhagen, Denmark (Philippe Bonnet)
- …

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:**
  - 30 € adapter, drop to 5 € if integrated
- **Availability:**
  - Integrated into some products, several vendors
- **Connection set-up time:**
  - Depends on power-mode
  - Max. 2.56 s, avg. 0.64 s
- **Quality-of-Service:**
  - Guarantees, ARQ/FEC
- **Manageability:**
  - Public/private keys needed, key management not specified, simple system integration
- **Special advantages/drawbacks:**
  - Advantage: already integrated into several products, available worldwide, free ISM-band, several vendors, simple system, simple ad-hoc networking, peer to peer, scatternets
  - Drawback: 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: Coexistence:
  - 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 (20 Mbit/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)

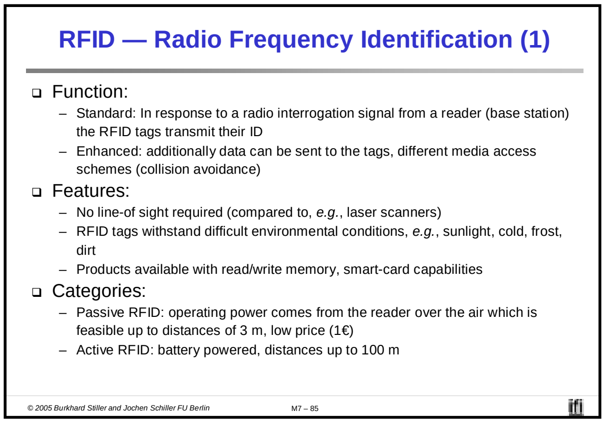
- 802.15-4: Low-Rate, Very Low-Power:
  - Low data rate solution with multi-month to multi-year battery life and very low complexity
  - Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation
  - Data rates of 20-250 kbit/s, latency down to 15 ms
  - Master-Slave or Peer-to-Peer operation
  - Support for critical latency devices, such as joysticks
  - CSMA/CA channel access (data centric), slotted (beacon) or un-slotted
  - Automatic network establishment by the PAN coordinator
  - Dynamic device addressing, flexible addressing format
  - Fully handshake 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

WLAN: Home Radio Frequencies (RF)

- Data rate:
  - 0.8, 1.6, 5, 10 Mbit/s
- Transmission range:
  - 300m outdoor, 30m indoor
- Frequency:
  - 2.4 GHz ISM
- Security:
  - Strong encryption, no open access
- Cost:
  - Adapter 130 €, base station 230 €
- Availability:
  - Several products from different vendors
- Connection set-up time:
  - 10 ms bounded latency
- Quality-of-Service:
  - Up to 8 streams A/V, up to 8 voice streams, priorities, best-effort
- Manageability:
  - Like DECT and IEEE 802 LANs
- Special advantages/drawbacks:
  - Advantage: extended QoS support, host/client and peer/peer, power saving, security
  - Drawback: future uncertain due to DECT-only devices plus 802.11a/b for data

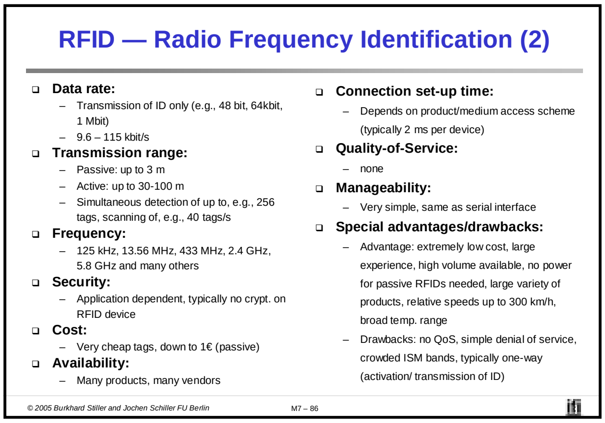
RF Controllers — ISM bands

- Data rate:
  - Typical up to 115 kbit/s (serial interface)
- Transmission range:
  - 5-100 m, depending on power (typical 10-500 mW)
- Frequency;
  - Typical 27 (EU, US), 315 (US), 418 (EU), 426 (Japan), 433 (EU), 868 (EU), 915 (US) MHz (depending on regulations)
- Security:
  - Some products with added processors
- Cost:
  - Cheap: 10 € - 50 €
- Availability:
  - Many products, many vendors
- Connection set-up time:
  - N/A
- Quality-of-Service:
  - none
- Manageability:
  - Very simple, same as serial interface
- Special advantages/drawbacks
  - Advantage: very low cost, large experience, high volume available
  - Drawback: no QoS, crowded ISM bands (particularly 27 and 433 MHz), typical no Medium Access Control, 418 MHz experiences interference with TETRA



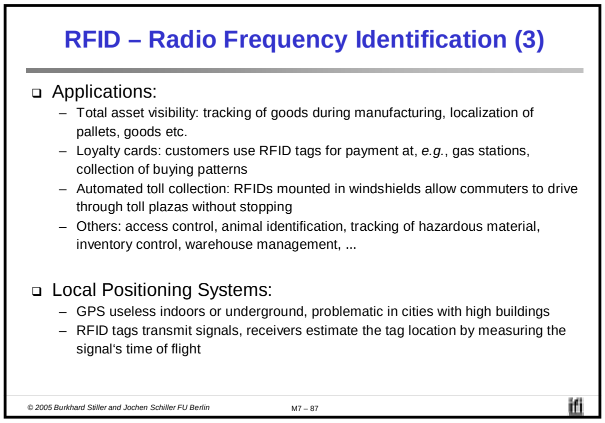
RFID — Radio Frequency Identification (1)

- ❑ 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, *e.g.*, sunlight, cold, frost, dirt
  - 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



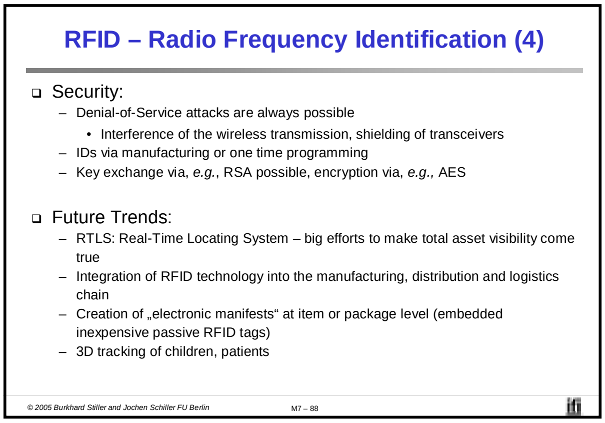
RFID — Radio Frequency Identification (2)

- ❑ **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, typically 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 (typically 2 ms per device)
- ❑ **Quality-of-Service:**
  - none
- ❑ **Manageability:**
  - Very simple, same as serial interface
- ❑ **Special advantages/drawbacks:**
  - 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
  - Drawbacks: no QoS, simple denial of service, crowded ISM bands, typically one-way (activation/ transmission of ID)



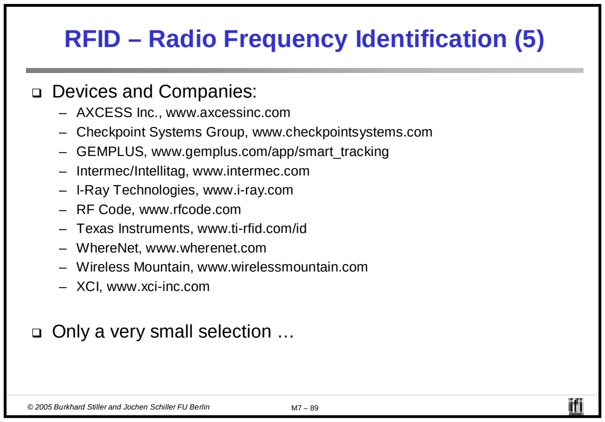
RFID – Radio Frequency Identification (3)

- ❑ 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



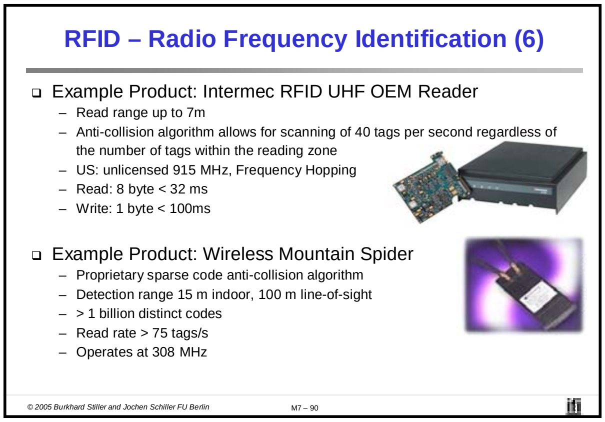
RFID – Radio Frequency Identification (4)

- ❑ Security:
  - Denial-of-Service attacks are always possible
    - Interference of the wireless transmission, shielding of transceivers
  - IDs via manufacturing or one time programming
  - Key exchange via, *e.g.*, RSA possible, encryption via, *e.g.,* AES
- ❑ Future Trends:
  - RTLS: Real-Time Locating System – big efforts to make total asset visibility come true
  - Integration of RFID technology into the manufacturing, distribution and logistics chain
  - Creation of „electronic manifests“ at item or package level (embedded inexpensive passive RFID tags)
  - 3D tracking of children, patients



RFID – Radio Frequency Identification (5)

- ❑ Devices and Companies:
  - AXCESS Inc., www.axcessinc.com
  - Checkpoint Systems Group, www.checkpointsystems.com
  - GEMPLUS, www.gemplus.com/app/smart_tracking
  - Intermec/Intellitag, www.intermec.com
  - I-Ray Technologies, www.i-ray.com
  - RF Code, www.rfcode.com
  - Texas Instruments, www.ti-rfid.com/id
  - WhereNet, www.wherenet.com
  - Wireless Mountain, www.wirelessmountain.com
  - XCI, www.xci-inc.com
- ❑ Only a very small selection …



RFID – Radio Frequency Identification (6)

- ❑ Example Product: Intermec RFID UHF OEM Reader
  - Read range up to 7m
  - Anti-collision algorithm allows for scanning of 40 tags per second regardless of the number of tags within the reading zone
  - US: unlicensed 915 MHz, Frequency Hopping
  - Read: 8 byte < 32 ms
  - Write: 1 byte < 100ms
- ❑ Example Product: Wireless Mountain Spider
  - Proprietary sparse code anti-collision algorithm
  - Detection range 15 m indoor, 100 m line-of-sight
  - > 1 billion distinct codes
  - Read rate > 75 tags/s
  - Operates at 308 MHz

RFID – Radio Frequency Identification (7)

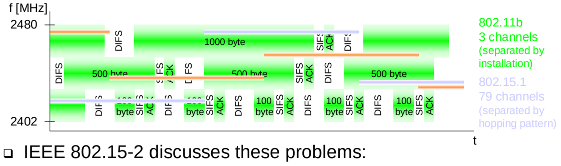
- ❑ Relevant Standards
  - American National Standards Institute
    - ANSI, www.ansi.org, www.aimglobal.org/standards/rfidstds/ANSIT6.html
  - Automatic Identification and Data Capture Techniques
    - JTC 1/SC 31, www.uc-council.com/sc31/home.htm, www.aimglobal.org/standards/rfidstds/sc31.htm
  - European Radio Communications Office
    - ERO, www.ero.dk, www.aimglobal.org/standards/rfidstds/ERO.htm
  - European Telecommunications Standards Institute
    - ETSI, www.etsi.org, www.aimglobal.org/standards/rfidstds/ETSI.htm
  - Identification Cards and related devices
    - JTC 1/SC 17, www.sc17.com, www.aimglobal.org/standards/rfidstds/sc17.htm,
  - Identification and communication
    - ISO TC 104 / SC 4, www.autoid.org/tc104_sc4_wg2.htm, www.aimglobal.org/standards/rfidstds/TC104.htm
  - Road Transport and Traffic Telematics
    - CEN TC 278, www.nni.nl, www.aimglobal.org/standards/rfidstds/CENTC278.htm
  - Transport Information and Control Systems
    - ISO/TC204, www.sae.org/technicalcommittees/gits.htm, www.aimglobal.org/standards/rfidstds/ISOTC204.htm

RFID – Radio Frequency Identification (8)

- ❑ ISO Standards
  - ISO 15418
    - MH10.8.2 Data Identifiers
    - EAN.UCC Application Identifiers
  - ISO 15434 - Syntax for High Capacity ADC Media
  - ISO 15962 - Transfer Syntax
  - ISO 18000
    - Part 2, 125-135 kHz
    - Part 3, 13.56 MHz
    - Part 4, 2.45 GHz
    - Part 5, 5.8 GHz
    - Part 6, UHF (860-930 MHz, 433 MHz)
  - ISO 18047 - RFID Device Conformance Test Methods
  - ISO 18046 - RF Tag and Interrogator Performance Test Methods

802.11 versus 802.15/Bluetooth

- ❑ Bluetooth may act like a rogue member of the 802.11 network:
  - Does not know anything about gaps, inter frame spacing



- ❑ 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)