Course Overview

- Introduction and History
- Data in Wireless Cellular Systems
- Data in Wireless Local Area Networks
- Internet Protocols
- Routing and Ad-Hoc Networks
- TCP over Wireless Link
- Services and Service Discovery
- System Support for Mobile Applications

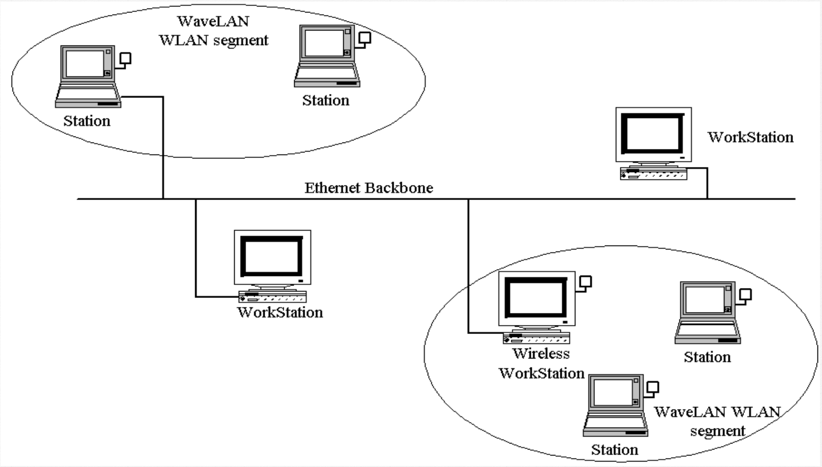
Wireless Local Area Networks

- “Traditional” LANs: WaveLan, Proxim, IEEE 802.11
- More specific “personal” LANs, also called “Personal Area Networks”: Bluetooth, IEEE 802.15
- High-speed wireless LANs (approaching ATM data rates): HiperLAN

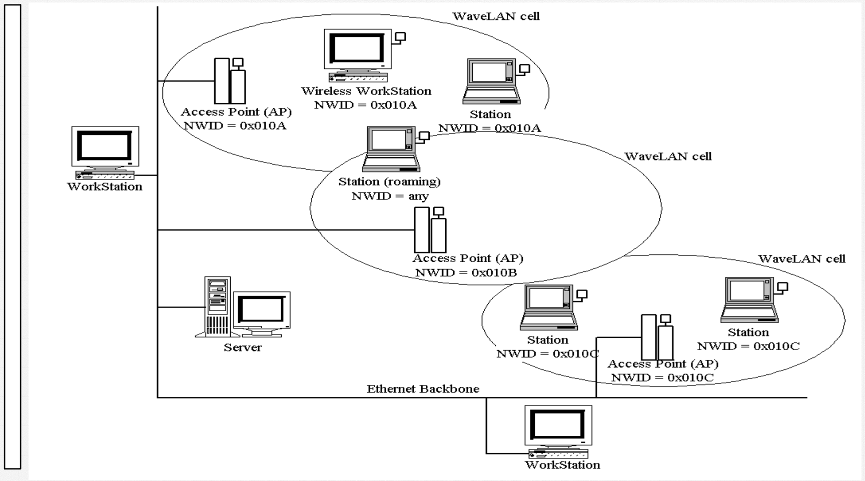
WaveLAN

- Commercial product, developed by Lucent Technologies (de-facto market leader), available since early 1990s
- Development closely aligned with early IEEE 802.11 standard effort, first product generation differs in key aspects from final IEEE 802.11 standard
- Will discuss WaveLAN version 1, newer version 2 follows finally approved 802.11 standard (plus enhancements to allow for data rates up to 10 Mbps)
- Physical layer:
  - 915 MHz (902-928 MHz) or 2.4 GHz (2.412-2.475 GHz) ISM band
  - Bands are divided into frequency channels of 26 MHz each
  - Modulation scheme: DSSS, raw data rate of 2 Mbps

WaveLAN: Configurations



WaveLAN: Configurations



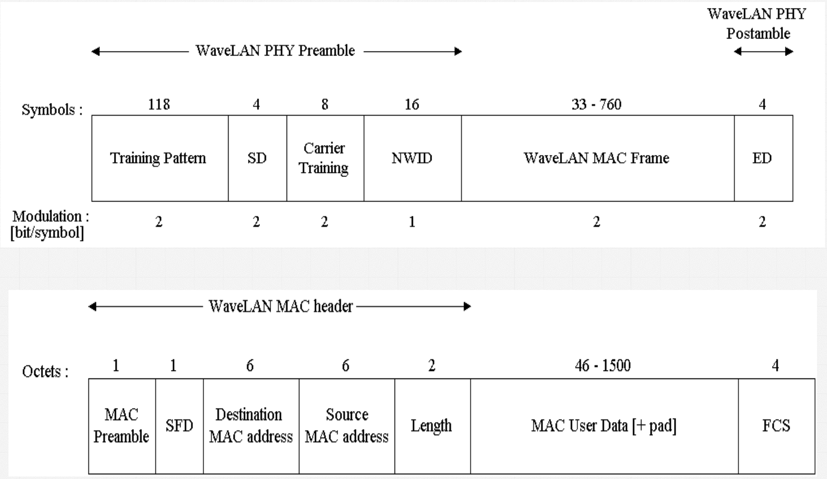
WaveLAN: Protocol Stack

<table>
<tr><td rowspan="2">Normal Application Data
(e.g., TCP)

and

Standard Network Operating System Protocols (e.g., IP)</td><td>WaveLAN Higher Protocols</td></tr>
<tr><td>Sub-Network Access Protocol</td></tr>
<tr><td colspan="2">Medium Access Control (MAC) Sublayer</td></tr>
<tr><td colspan="2">Physical Layer (PHY)</td></tr>
</table>

WaveLAN: Frame Formats



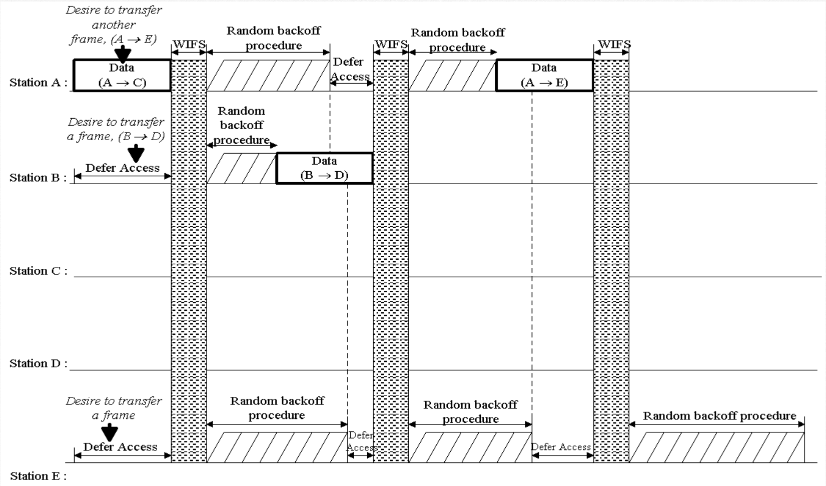
	← WaveLAN PHY Preamble →					WaveLAN PHY Postamble ←→
Symbols :	118	4	8	16	33 - 760	4
	Training Pattern	SD	Carrier Training	NWID	WaveLAN MAC Frame	ED
Modulation : [bit/symbol]	2	2	2	1	2	2

	← WaveLAN MAC header →						
Octets :	1	1	6	6	2	46 - 1500	4
	MAC Preamble	SFD	Destination MAC address	Source MAC address	Length	MAC User Data [+ pad]	FCS

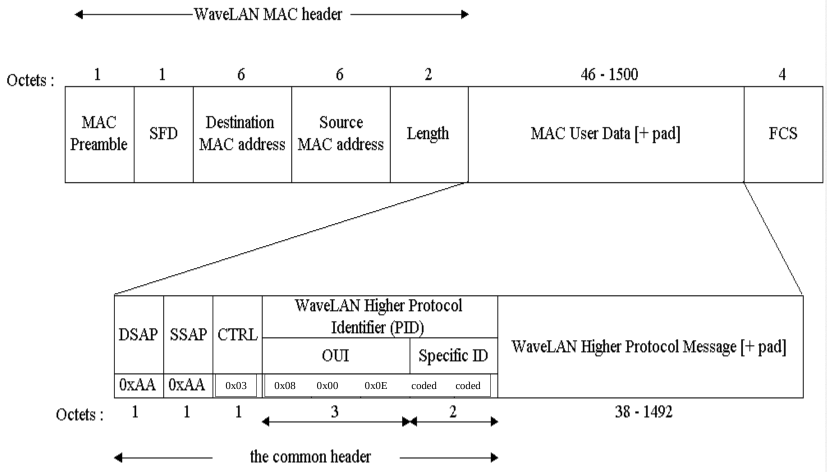
WaveLAN MAC Protocol

- Basically CSMA/CA
- Sense media before transmission, if free, transmit
- Defer:
  - wait until end of current transmission, plus fixed delay (WaveLAN InterFrame Space, WIFS) of 60 µsec
  - apply random backoff procedure: pick number between 0 and 31 (antenna slot number S)
  - each slot corresponds to 23 µs
  - wait S*23 µs, sense media again, if busy, double backoff range until we reach range 0-255
  - drop packet after 15 attempts
- If station has more than one packet to send: wait WIFS plus backoff-period in range 0-15 (avoid monopolization)

WaveLAN: MAC Protocol (Example)



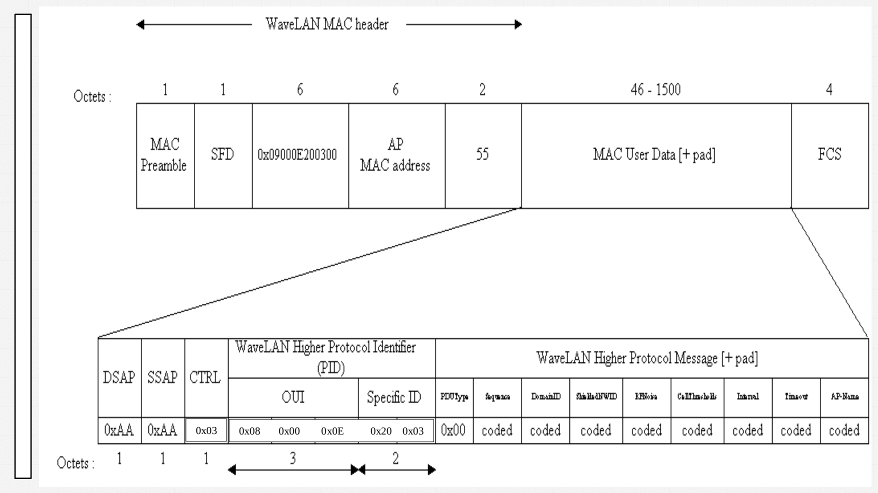
WaveLAN: Higher Protocols



Octets :	1	1	6	6	2	46 - 1500	4
	MAC Preamble	SFD	Destination MAC address	Source MAC address	Length	MAC User Data [+ pad]	FCS

DSAP	SSAP	CTRL	WaveLAN Higher Protocol Identifier (PID)		WaveLAN Higher Protocol Message [+ pad]
			OUI	Specific ID	
0xAA	0xAA	0x03	0x08 0x00 0x0E	coded coded	
Octets : 1	1	1	3	2	38 - 1492

WaveLAN: Beacon (Higher Protocol Example)



WaveLAN MAC header

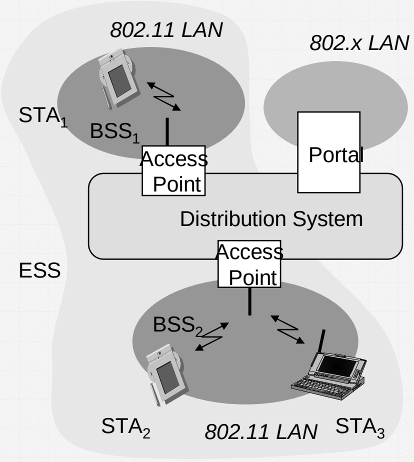
Octets :	1	1	6	6	2	46 - 1500	4
	MAC Preamble	SFD	0x09000E200300	AP MAC address	55	MAC User Data [+ pad]	FCS

DSAP	SSAP	CTRL	WaveLAN Higher Protocol Identifier (PID)					WaveLAN Higher Protocol Message [+ pad]								
			OUI			Specific ID		PDUType	Sequence	DomainID	ShieldedNWID	RFNoise	CellThresholds	Interval	Timeout	AP-Name
0xAA	0xAA	0x03	0x08	0x00	0x0E	0x20	0x03	0x00	coded	coded	coded	coded	coded	coded	coded	coded
Octets : 1	1	1	3			2										

IEEE 802.11

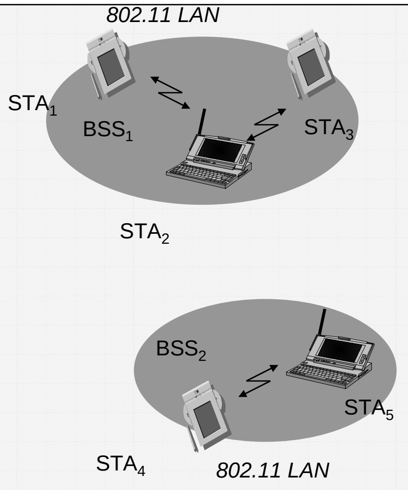
- Standard for wireless local area networks, approved by IEEE in 1997
- Scope: physical layer (PHY) and media access control sublayer (MAC) for wireless connectivity for fixed, portable, and moving stations with a local area
- Supports data rates of 1 or 2 Mbps, using infrared or radio
- Supports two basic architectures: independent basic support set (IBSS) and infrastructure networks
- Most recent commercial products (including the new WaveLAN generation) are compatible with 802.11

802.11 Infrastructure Network



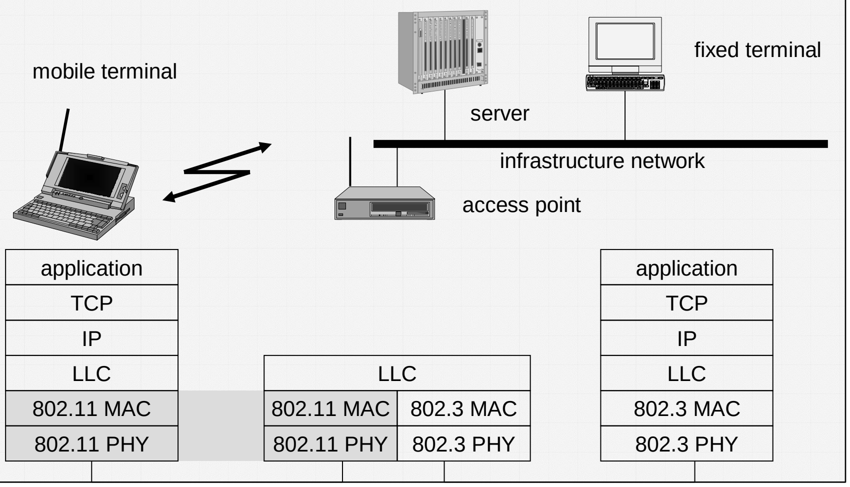
- Station (STA)
  - terminal with access mechanisms to the wireless medium and radio contact to the access point
- Basic Service Set (BSS)
  - group of stations using the same radio frequency
- Access Point
  - station integrated into the wireless LAN and the distribution system
- Portal
  - bridge to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

802.11 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 Family of Standards



mobile terminal

server

fixed terminal

infrastructure network

access point

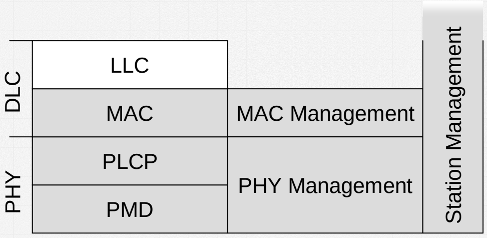
application
TCP
IP
LLC
802.11 MAC
802.11 PHY

LLC
802.11 MAC | 802.3 MAC
802.11 PHY | 802.3 PHY

application
TCP
IP
LLC
802.3 MAC
802.3 PHY

802.11 Layers and Functions

- MAC
  - access mechanisms, fragmentation, encryption
- MAC Management
  - synchronization, roaming, MIB, power management



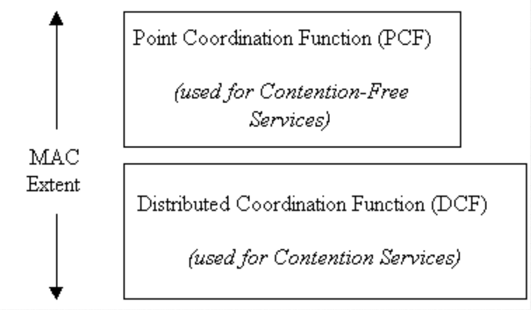
DLC
LLC
MAC
MAC Management
PHY
PLCP
PMD
PHY Management
Station Management

- PLCP Physical Layer Convergence Protocol
  - clear channel assessment signal (carrier sense)
- PMD Physical Medium Dependent
  - modulation, coding
- PHY Management
  - channel selection, MIB
- Station Management
  - coordination of all management functions

802.11 Physical Layer

- 3 versions: 2 radio (typ. 2.4 GHz), 1 IR
  - data rates 1 or 2 Mbit/s
- FHSS (Frequency Hopping Spread Spectrum)
  - spreading, despreading, signal strength, typ. 1 Mbit/s
  - min. 2.5 frequency hops/s (USA), two-level GFSK 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)
  - max. radiated power 1 W (USA), 100 mW (EU), min. 1mW
- Infrared
  - 850-950 nm, diffuse light, typ. 10 m range
  - carrier detection, energy detection, synchonization

IEEE 802.11 MAC Architecture


MAC Extent
Point Coordination Function (PCF)
(used for Contention-Free Services)
Distributed Coordination Function (DCF)
(used for Contention Services)

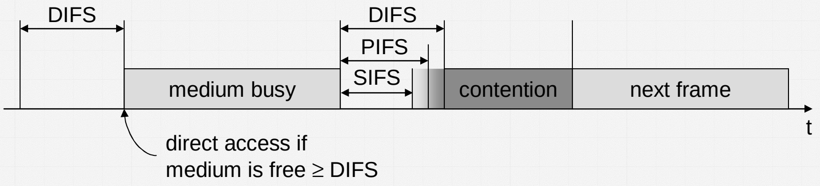
DCF: all stations content for service (based on CSMA/CA scheme), is fundamental access method
PCF: contention-free services

802.11 MAC Layer

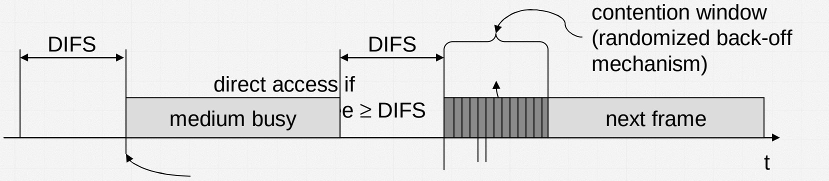
- Traffic services
  - Asynchronous Data Service (mandatory)
    - exchange of data packets based on “best-effort”
    - support of broadcast and multicast
  - Time-Bounded Service (optional)
    - implemented using PCF (Point Coordination Function)
- Access methods
  - DCF CSMA/CA (mandatory)
    - collision avoidance via randomized „back-off“ mechanism
    - minimum distance between consecutive packets
    - ACK packet for acknowledgements (not for broadcasts)
  - DCF w/ RTS/CTS (optional)
    - Distributed Foundation Wireless MAC (DFWMAC)
    - avoids hidden terminal problem
  - PCF (optional)
    - access point polls terminals according to a list

802.11 MAC Layer

- 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

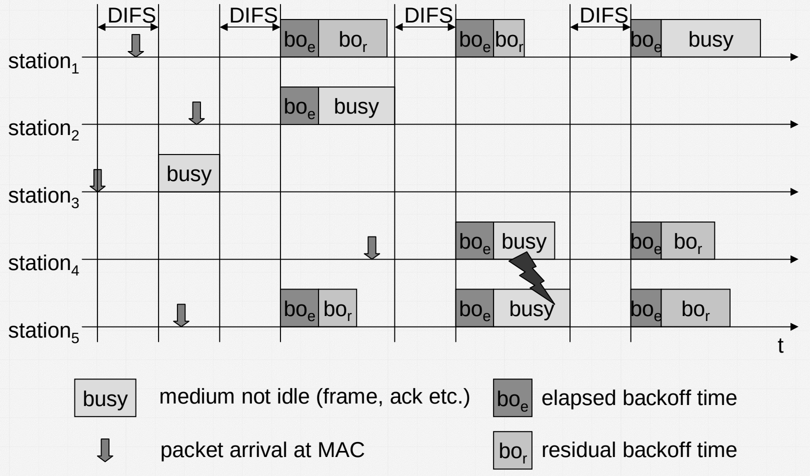


802.11 MAC: CSMA/CA



- 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 MAC: Competing Stations

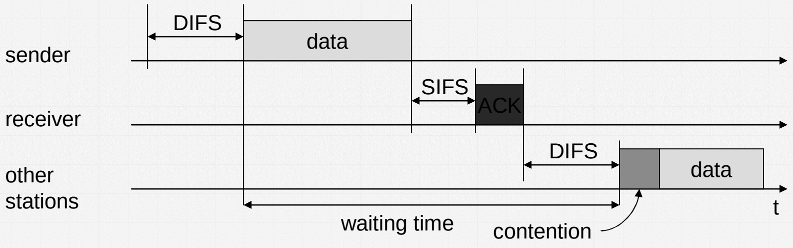


IEEE 802.11 DCF Protocol

- Sense media before transmission
- If media is free, transmit if media stays idle for a fixed amount of time (DCF Interframe Space, DIFS)
- Defer:
  - wait until end of current transmission, plus DIFS
  - apply random backoff procedure: pick number between 0 and 7, check whether medium is idle during each backoff slot
  - if media is busy, suspend backoff process at beginning of current slot
  - after media was idle for selected number of slots, transmit immediately
  - if this transmission results in collision, backoff again, doubling the backoff
- Upon receipt of packet:
  - receiver waits short interval (Short Interframe Space, SIFS)
  - transmits acknowledgement frame (ACK) back to sender
- If sender receives no ACK within ACKTimeout interval, assume collision

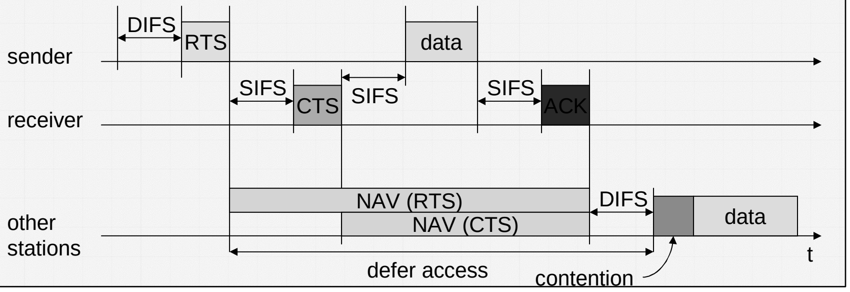
802.11 MAC: CSMA/CA

- 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



802.11 MAC: RTS/CTS

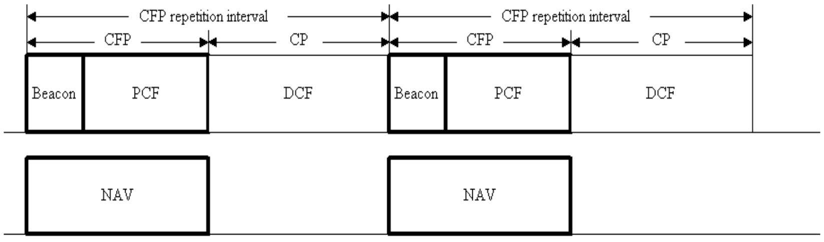
- Sending unicast packets
  - station can send RTS with reservation parameter after waiting for DIFS (reservation determines amount of time the data packet needs the medium)
  - acknowledgement via CTS after SIFS by receiver (if ready to receive)
  - sender can now send data at once, acknowledgement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



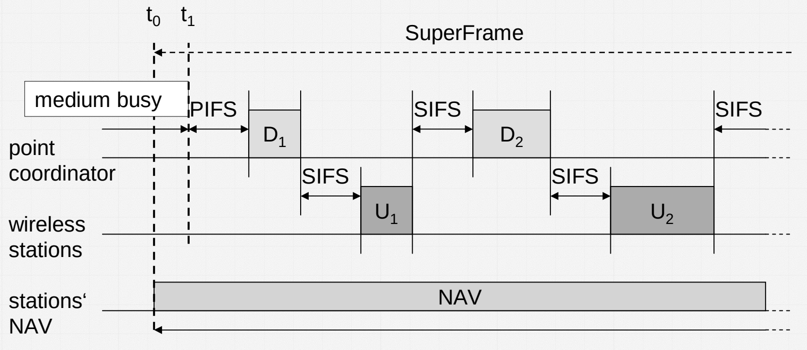
IEEE 802.11: DCF and PCF Coexistence

•PCF is optional, only applicable in infrastructure network
•PCF has to coexist with DCF, sits logically on top of DCF (see below)
•PCF relies on point coordinator, which operates at the Access Point (AP)
•Point coordinator polls stations and allows transmission without contending for channel

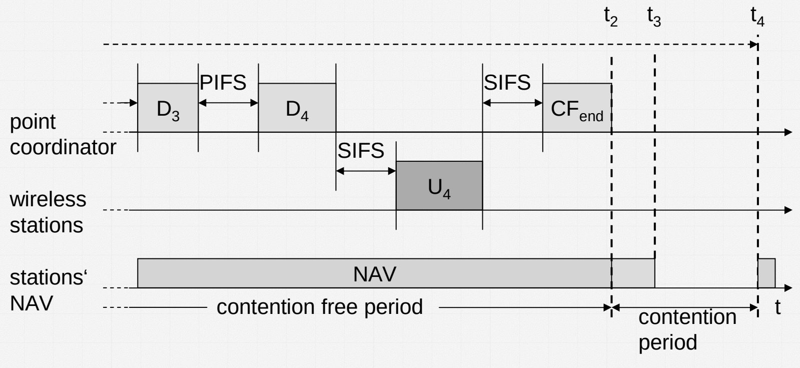
•CFP (contention-free period) initiated by beacon after media has been idle for a PCF Interframe Space (PIFS), all stations will defer access for maximum duration of CFP
•Coordinator can poll stations or prematurely terminate CFP by transmitting CFP-End frame



802.11 MAC:
Point Coordination Function



802.11 MAC:
Point Coordination Function



802.11 MAC 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

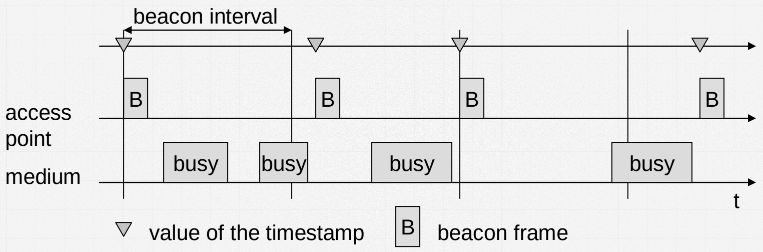
scenario	to DS	from DS	address 1	address 2	address 3	address 4
ad-hoc network	0	0	DA	SA	BSSID	-
infrastructure network, from AP	0	1	DA	BSSID	SA	-
infrastructure network, to AP	1	0	BSSID	SA	DA	-
infrastructure network, within DS	1	1	RA	TA	DA	SA

DS: Distribution System
AP: Access Point
DA: Destination Address
SA: Source Address
BSSID: Basic Service Set Identifier
RA: Receiver Address
TA: Transmitter Address

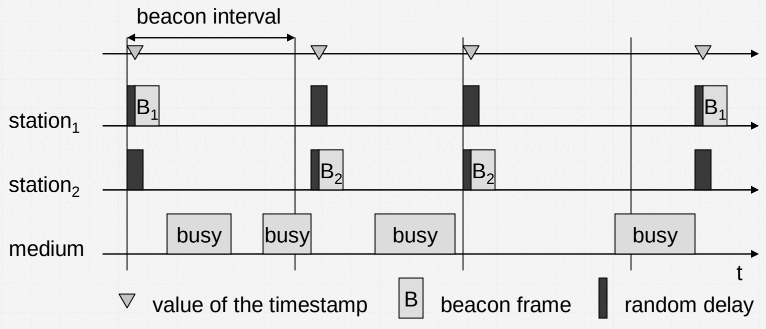
802.11 MAC Management

- 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

Synchronization using a Beacon (Infrastructure Network)



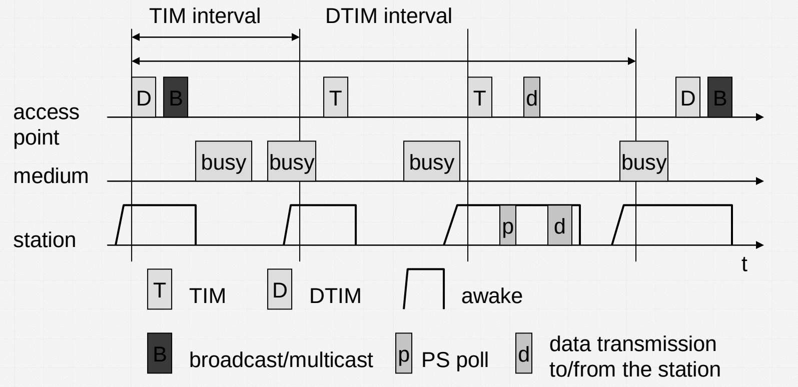
Synchronization using a Beacon (Ad-hoc Network)



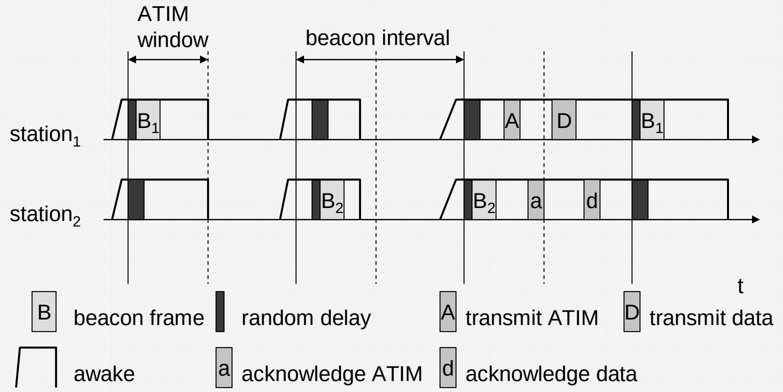
Power Management

- 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 Network)



Power saving with wake-up patterns (Ad-hoc Network)



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

Future Developments

- IEEE 802.11a
  - compatible MAC, but now 5 GHz band
  - transmission rates up to 20 Mbit/s
  - close cooperation with BRAN (ETSI Broadband Radio Access Network)
- IEEE 802.11b
  - higher data rates at 2.4 GHz
  - proprietary solutions already offer 10 Mbit/s
- IEEE WPAN (Wireless Personal Area Networks)
  - market potential
  - compatibility
  - low cost/power, small form factor
  - technical/economic feasibility

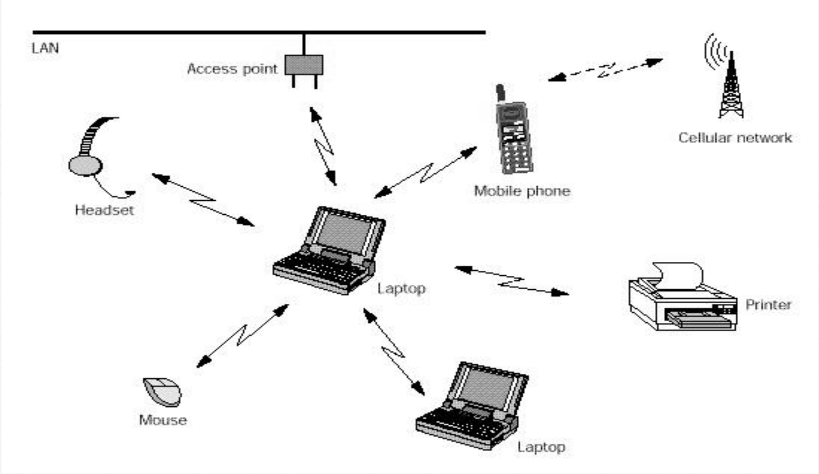
    ➔ Bluetooth

Bluetooth: “Personal Area Networks”

- open specification for wireless communication of data and voice
- based on a low-cost short-range radio link, built into a 9 x 9 mm microchip (design goal: cost of US$ 5/device)
- facilitates protected ad hoc connections for stationary and mobile communication environments
- Bluetooth is a cooperation between computer and telecommunication industries (Ericsson, IBM, Toshiba, Intel, Nokia, …)
- SIG started in February 1998 with above five members, has grown since (64 companies joined in January 1999 alone)

Bluetooth Vision

(see also `http://www.ericsson.se/review/pdf/1998031.pdf`)



Bluetooth General Characteristics

- operates in the 2.4 GHz Industrial-Scientific-Medical (ISM) band
  - nominal link range: 10 cm to 10 m, can be increased to 100 m (transmitting with more power)
- uses Frequence Hop (FH) spread spectrum
- supports up to 8 devices in a piconet (two or more Bluetooth units sharing a channel)
- built-in security
- non line-of-sight transmission through walls and briefcases (distinguishes it from IrDA)
- omni-directional
- supports both isochronous and asynchronous services; easy integration of TCP/IP for networking

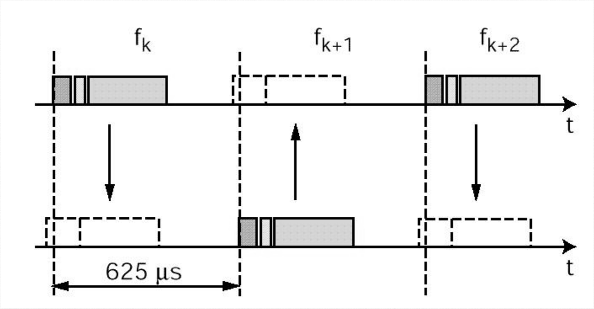
Bluetooth Intended Uses

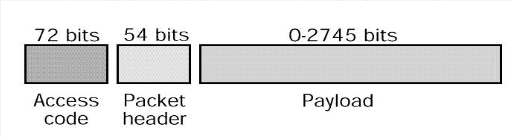
- connect a wide range of computing and telecommunications devices without the need to buy, carry, or connect cables
- delivers opportunities for rapid, ad hoc connections, and in the future, possibly for automatic, unconscious, connections between devices
- power-efficient radio technology can be used in many of the same devices that use IR:
  - Phones and pagers
  - Modems
  - LAN access devices
  - Headsets
  - Notebook, desktop, and handheld computers

Bluetooth Radio

- frequency hopping in 79 hops displaced by 1 MHz, starting at 2.402 GHz and stopping at 2.480 GHz
  - to function on a worldwide basis, Bluetooth requires a radio frequency that is license-free and open to any radio
  - 2.45 GHz ISM band satisfies these requirements, although it must cope with interference from baby monitors, garage door openers, cordless phones and microwave ovens, which also use this frequency.
- due to local regulations the bandwidth is reduced in Japan, France and Spain. This is handled by an internal software switch
- the maximum frequency hopping rate is 1600 hops/s.

Bluetooth Frequency Hopping/Time Division Duplex Scheme





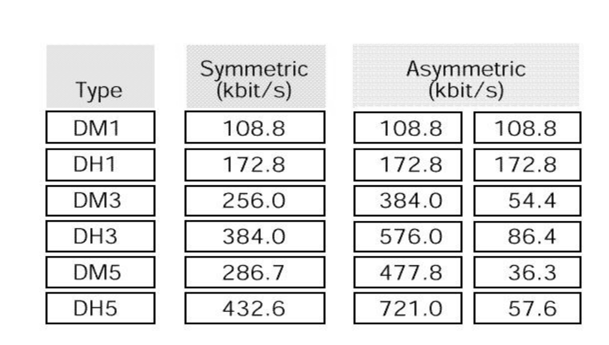
Bluetooth MAC protocol

- Time Division Duplex (TDD) scheme for full-duplex transmissions
  - master device establishes connection, slave devices synchronize their clock with master clock for duration of connection
- Synchronous Connection Oriented (SCO) type (used primarily for voice)
  - channel symmetric, only data packets retransmitted
- Asynchronous Connectionless (ACL) type (used primarily for packet data)
  - master unit controls the link bandwidth and decides how much piconet bandwidth is given to each slave, and the symmetry of the traffic
  - slaves must be polled before they can transmit data.
  - The ACL link also supports broadcast messages from the master to all slaves in the piconet

Bluetooth MAC Protocol

- Error correction:
  - 1/3 rate forward error correction code (FEC)
    - for SCO only
  - 2/3 rate forward error correction code FEC
  - Automatic repeat request (ARQ) scheme for data
    - data transmitted in one slot is directly acknowledged by the recipient in the next slot.
- Authentication and Privacy
  - one-way, two-way, or no authentication possible
  - use stream cipher based on secret keys (0, 40, 64 bits)
  - key management left to higher layer software
  - if stronger protection (longer key is needed), use better encryption at network and/or application level

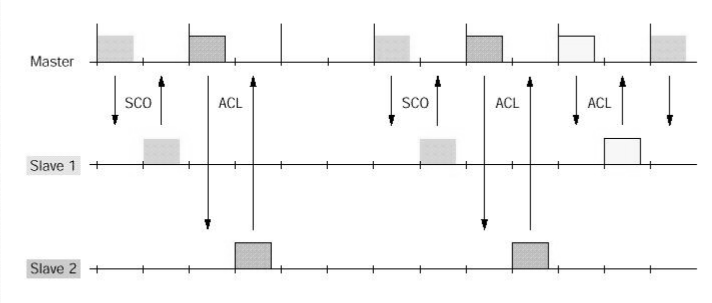
Bluetooth Data Rates



Type	Symmetric (kbit/s)	Asymmetric (kbit/s)	
DM1	108.8	108.8	108.8
DH1	172.8	172.8	172.8
DM3	256.0	384.0	54.4
DH3	384.0	576.0	86.4
DM5	286.7	477.8	36.3
DH5	432.6	721.0	57.6

DMx: packet covers x slots, uses FEC
DHx: packet covers x slots, no error protection

Bluetooth PicoNet Example

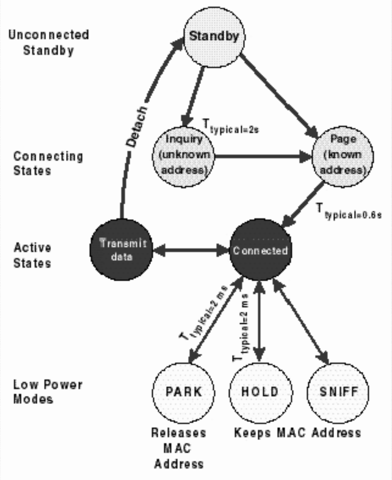


Mixed environment:

Slave 1 supports SCO and ACL link, SCO interval is six slots
Slave 2 supports only ACL link

Slots may be empty when no data is available….

Bluetooth Power States



STANDBY: periodically listen for messages every 1.28 seconds by listening to set of 32 hop frequencies defined for this device (less in France, Spain, Japan)

Connection procedure: one device becomes master, initiates connection by PAGE (if address is known) or INQUIRY, followed by PAGE (if address unknown)

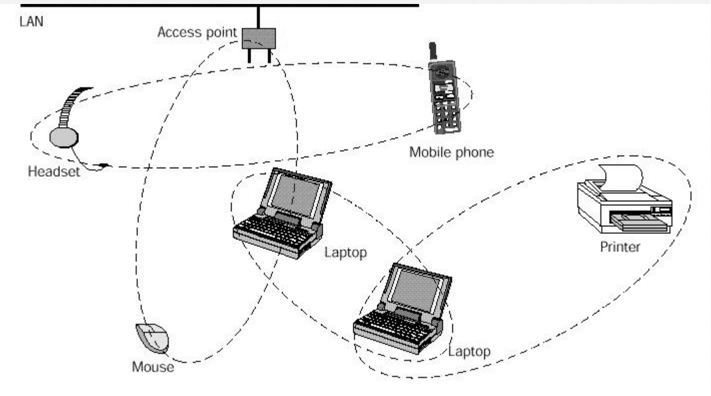
PAGE: send 16 identical page messages on 16 of 32 defined hop frequencies for slave device, if no response, send page on remaining 16 frequencies
- maximum delay: 2.56 seconds
- average delay 0.64 seconds

INQUIRY: similar to PAGE, but may require one additional train to collect responses, used for device discovery

HOLD: power saving mode for slave devices when no data needs to be transmitted

PARK/SNIFF: other power saving modes
SNIFF: listen to traffic at user programmable intervals
PARK: listen to traffic periodically, re-synchronize with master every so often

Bluetooth Scatternets

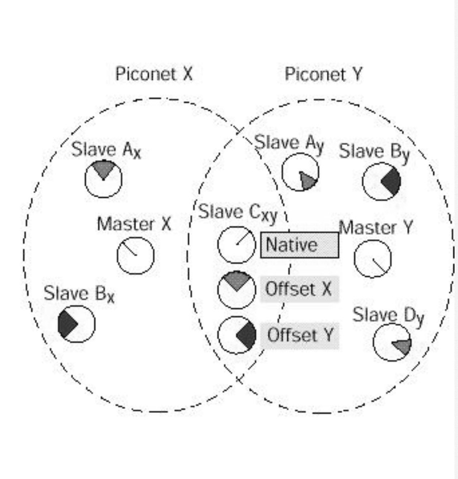


All units in piconet share same 1 MHz channel - what about other frequencies currently not in use?
Scatternet: overlapping set of piconets, use different hopping sequence for each piconet
(multiple ongoing connections in parallel)

Bluetooth Scatternets

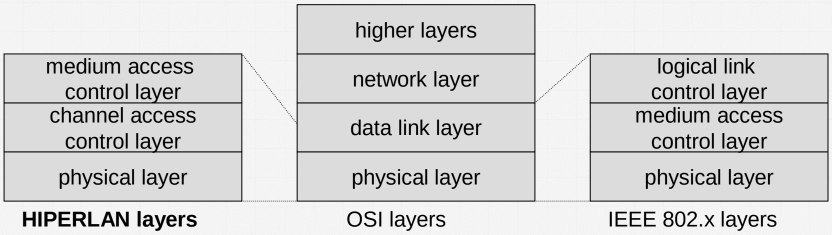
- Multiple overlapping piconets (sets of communicating devices) with own hopping sequence, max of one master and 8 slaves
- Collisions do occur when two piconets use same frequency at the same time
  - as more piconets overlap, performance degrades
  - degradation gradual: 10 overlapping piconets reduce aggregate bandwidth by 10%
- Single device can participate in multiple piconets, though only one at a time
  - need to re-adjust clock to re-sync with master when entering a piconet
  - inform master when device leaves piconet, will suppress data being sent/device being polled

Bluetooth Scatternet



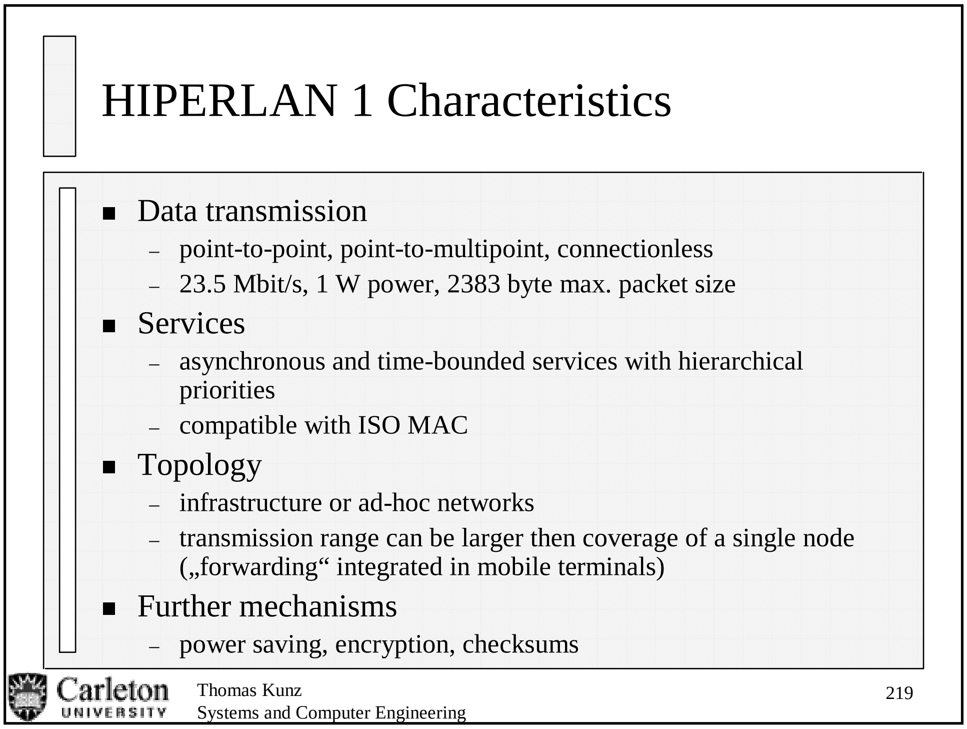
HIPERLAN

- ETSI standard
  - European standard, cf. GSM, DECT, ...
  - Enhancement of local Networks and interworking 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



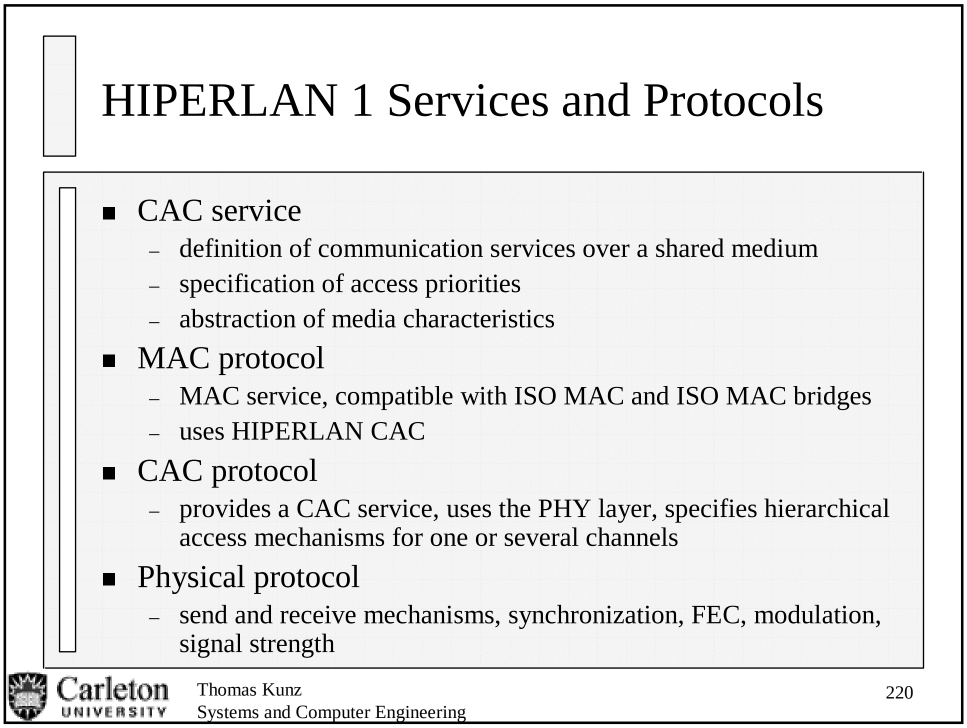
Original HIPERLAN Protocol Family

	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 Characteristics

- Data transmission
  - point-to-point, point-to-multipoint, connectionless
  - 23.5 Mbit/s, 1 W power, 2383 byte max. packet size
- Services
  - asynchronous and time-bounded services with hierarchical priorities
  - compatible with ISO MAC
- Topology
  - infrastructure or ad-hoc networks
  - transmission range can be larger then coverage of a single node („forwarding“ integrated in mobile terminals)
- Further mechanisms
  - power saving, encryption, checksums



HIPERLAN 1 Services and Protocols

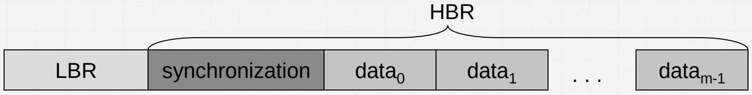
- CAC service
  - definition of communication services over a shared medium
  - specification of access priorities
  - abstraction of media characteristics
- MAC protocol
  - MAC service, compatible with ISO MAC and ISO MAC bridges
  - uses HIPERLAN CAC
- CAC protocol
  - provides a CAC service, uses the PHY layer, specifies hierarchical access mechanisms for one or several channels
- Physical protocol
  - send and receive mechanisms, synchronization, FEC, modulation, signal strength

HIPERLAN 1 Physical Layer

- Scope
  - modulation, demodulation, bit and frame synchronization
  - forward error correction mechanisms
  - measurements of signal strength
  - channel sensing
- Channels
  - 3 mandatory and 2 optional channels (with their carrier frequencies)
  - mandatory
    - channel 0: 5.1764680 GHz
    - channel 1: 5.1999974 GHz
    - channel 2: 5.2235268 GHz
  - optional (not allowed in all countries)
    - channel 3: 5.2470562 GHz
    - channel 4: 5.2705856 GHz

HIPERLAN 1 Physical Layer Frames

- Maintaining a high data-rate (23.5 Mbit/s) is power consuming - problematic for mobile terminals
  - packet header with low bit-rate comprising receiver information
  - only receiver(s) address by a packet continue receiving
- Frame structure
  - LBR (Low Bit-Rate) header with 1.4 Mbit/s
  - 450 bit synchronization
  - minimum 1, maximum 47 frames with 496 bit each
  - for higher velocities of the mobile terminal (> 1.4 m/s) the maximum number of frames has to be reduced



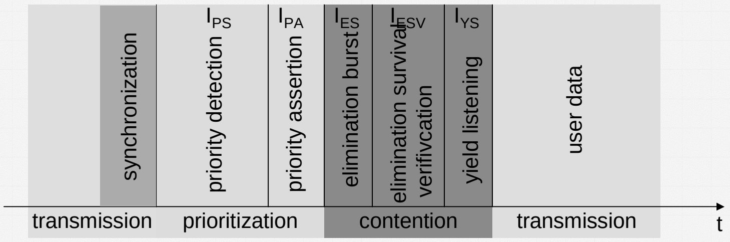
- Modulation
  - GMSK for high bit-rate, FSK for LBR header

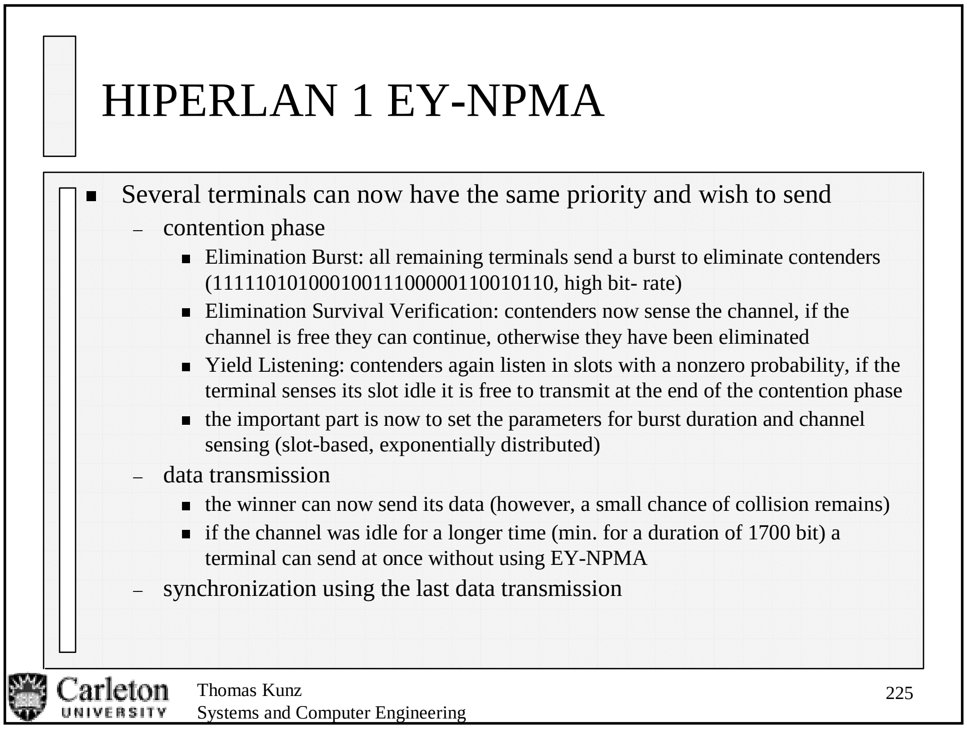
HIPERLAN 1 CAC Sublayer

- Channel Access Control (CAC)
  - assure that terminal does not access forbidden channels
  - priority scheme, access with EY-NPMA
- Priorities
  - 5 priority levels for QoS support
  - QoS is mapped onto a priority level with the help of the packet lifetime (set by an application)
    - if packet lifetime = 0 it makes no sense to forward the packet to the receiver any longer
    - standard start value 500ms, maximum 16000ms
    - if a terminal cannot send the packet due to its current priority, waiting time is permanently subtracted from lifetime
    - based on packet lifetime, waiting time in a sender and number of hops to the receiver, the packet is assigned to one out of five priorities
    - the priority of waiting packets, therefore, rises automatically

HIPERLAN 1 EY-NPMA

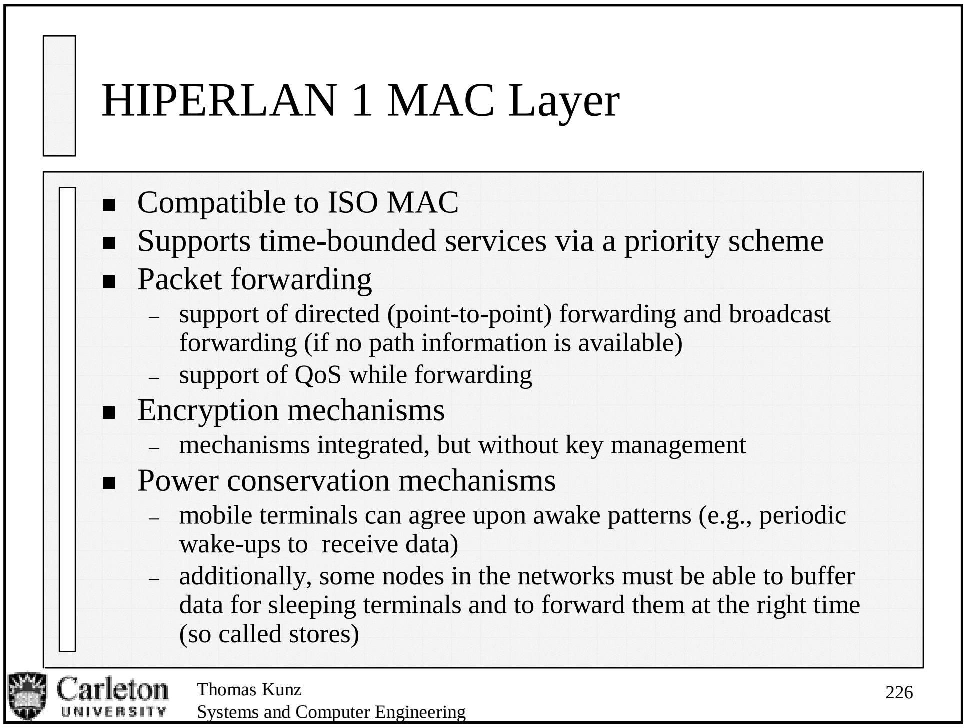
- EY-NPMA (Elimination Yield Non-preemptive Priority Multiple Access)
  - 3 phases: priority resolution, contention resolution, transmission
  - finding the highest priority
    - every priority corresponds to a time-slot to send in the first phase, the higher the priority the earlier the time-slot to send
    - higher priorities can not be preempted
    - if an earlier time-slot for a higher priority remains empty, stations with the next lower priority might send
    - after this first phase the highest current priority has been determined





HIPERLAN 1 EY-NPMA

- Several terminals can now have the same priority and wish to send
  - contention phase
    - Elimination Burst: all remaining terminals send a burst to eliminate contenders (11111010100010011100000110010110, high bit- rate)
    - Elimination Survival Verification: contenders now sense the channel, if the channel is free they can continue, otherwise they have been eliminated
    - Yield Listening: contenders again listen in slots with a nonzero probability, if the terminal senses its slot idle it is free to transmit at the end of the contention phase
    - the important part is now to set the parameters for burst duration and channel sensing (slot-based, exponentially distributed)
  - data transmission
    - the winner can now send its data (however, a small chance of collision remains)
    - if the channel was idle for a longer time (min. for a duration of 1700 bit) a terminal can send at once without using EY-NPMA
  - synchronization using the last data transmission



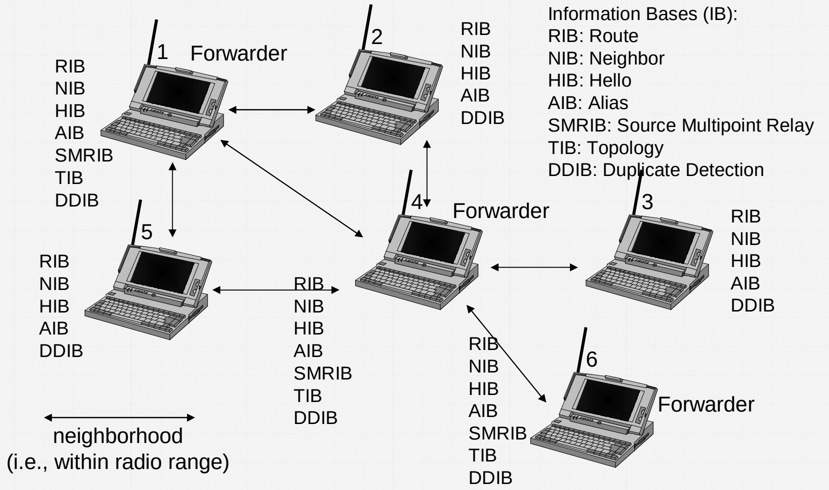
HIPERLAN 1 MAC Layer

- Compatible to ISO MAC
- Supports time-bounded services via a priority scheme
- Packet forwarding
  - support of directed (point-to-point) forwarding and broadcast forwarding (if no path information is available)
  - support of QoS while forwarding
- Encryption mechanisms
  - mechanisms integrated, but without key management
- Power conservation mechanisms
  - mobile terminals can agree upon awake patterns (e.g., periodic wake-ups to receive data)
  - additionally, some nodes in the networks must be able to buffer data for sleeping terminals and to forward them at the right time (so called stores)

Information Bases

- Route Information Base (RIB) - how to reach a destination
  - [destination, next hop, distance]
- Neighbor Information Base (NIB) - status of direct neighbors
  - [neighbor, status]
- Hello Information Base (HIB) - status of destination (via next hop)
  - [destination, status, next hop]
- Alias Information Base (AIB) - address of nodes outside the net
  - [original MSAP address, alias MSAP address]
- Source Multipoint Relay Information Base (SMRIB) - current MP status
  - [local multipoint forwarder, multipoint relay set]
- Topology Information Base (TIB) - current HIPERLAN topology
  - [destination, forwarder, sequence]
- Duplicate Detection Information Base (DDIB) - remove duplicates
  - [source, sequence]

Ad-hoc Networks using HIPERLAN 1



Information Bases (IB):
RIB: Route
NIB: Neighbor
HIB: Hello
AIB: Alias
SMRIB: Source Multipoint Relay
TIB: Topology
DDIB: Duplicate Detection