Computer Networking

Local Area Networks

Prof. Andrzej Duda
duda@imag.fr

http://duda.imag.fr

1

LANs

Our goals:

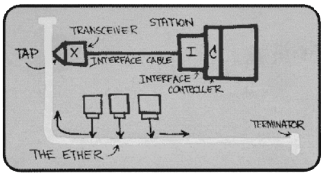
- understand principles behind LANs:
  - sharing a broadcast channel: multiple access
  - link layer addressing
  - LAN interconnection
- instantiation and implementation of various LAN technologies

Overview:

- multiple access protocols
- example LANs:
  - Ethernet
  - 802.11
  - token ring
  - token bus
- link layer addressing
- LAN interconnection
  - hubs, bridges, switches

2

Characteristics



Metcalfe's Etheret sketch

- Short distances (100 m - 1 km)
- High bit rate (10 Mb/s, 100 Mb/s, 1 Gb/s)
- Shared communication channel
- Used in a distributed environment
  - shared equipment, shared data

3

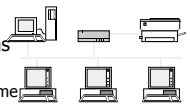
Data link layer in LANs

- Shared channel
  - multiplexing (TDM, FDM, or CDM)
    - fixed allocation: wasted badwidth if no active sources
  - statistical multiplexing (multiple access)
    - suitable for bursty traffic - channel used at the full capacity
- Most of LANs
  - no retransmission (up to upper layers)
- WLANs
  - ACK of delivery

4

Multiple Access protocols

- single shared communication channel
- two or more simultaneous transmissions by nodes: interference
  - only one node can send successfully at a time



- *multiple access protocol:*
  - distributed algorithm that determines how stations share channel, i.e., determine when station can transmit
  - communication about channel sharing must use channel itself!
  - what to look for in multiple access protocols:
    - synchronous or asynchronous
    - information needed about other stations
    - robustness (e.g., to channel errors)
    - performance

5

Multiple Access Protocols

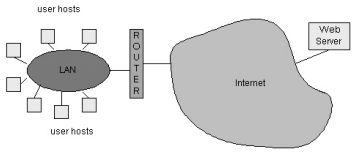
Three broad classes:

- Random Access (Ethernet, 802.11)
  - allow collisions
  - "recover" from collisions
- Tokens - "Taking turns" (Token Ring, FDDI)
  - tightly coordinate shared access to avoid collisions
- Distributed Queue (DQDB)
  - use the channel in the arrival order
- Goal: efficient, fair, simple, decentralized

6

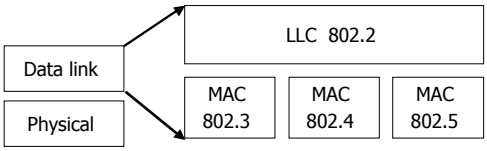
LAN technologies

- Data link layer:
  - services, multiple access
- LAN technologies
  - addressing
  - Ethernet, 802.11
  - repeaters, hubs, bridges, switches
  - virtual LANs



7

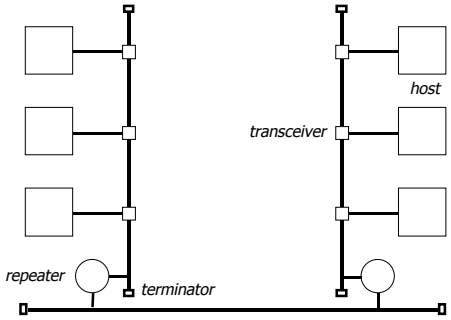
LAN Reference model



- LLC - Logical Link Control: IEEE 802.2 (ISO 8802.2)
- MAC - Medium Access Control
  - IEEE 802.3 (ISO 8802.3): CSMA/CD
  - IEEE 802.4 (ISO 8802.4): token bus
  - IEEE 802.5 (ISO 8802.5): token ring
  - IEEE 802.11: CSMA/CA

8

IEEE 802.3 - Ethernet



9

Coding

- Synchronous transmission
  - receiving station locks on 10 MHz - preamble
- Manchester coding

10

Random Access protocols

- When node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes
- two or more transmitting nodes -> "collision",
- random access protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access protocols:
  - ALOHA, slotted ALOHA
  - CSMA, CSMA/CD (Ethernet), CSMA/CA (802.11)

11

CSMA/CD (Collision Detection)

- CSMA/CD *(Carrier Sense Multiple Access/ Collision Detection)*
  - carrier sensing, deferral if ongoing transmission
  - collisions *detected* within short time
  - colliding transmissions aborted, reducing channel wastage
  - persistent transmission
- collision detection:
  - easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - difficult in wireless LANs: receiver shut off while transmitting

12

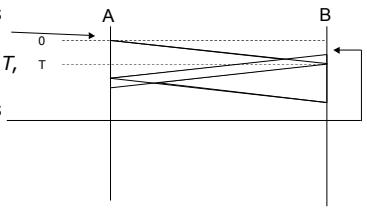
CSMA/CD algorithm

```
i = 1
while (i <= maxAttempts) do
        listen until channel is idle
        transmit and listen
        wait until (end of transmission) or
                (collision detected)
        if collision detected then
                stop transmitting, send jam bits (32 bits)
        else
                wait for interframe delay (9.6 μs)
                leave
        wait random time
        increment i
end do
```

13

CSMA / CD Collision

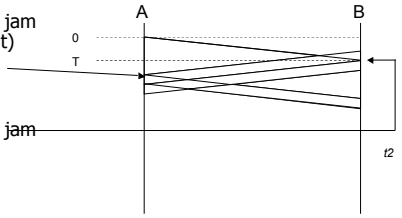
- A senses idle channel, starts transmitting
- shortly before *T*, B senses idle channel, starts transmitting



14

CSMA / CD Jam Signal

- B senses collision, continues to transmit the jam signal (32-bit)
- A senses collision, continues to transmit the jam signal



15

Random retransmission interval

```
r = random (0, 2^k -1)
k = min (10, AttemptNb)
```

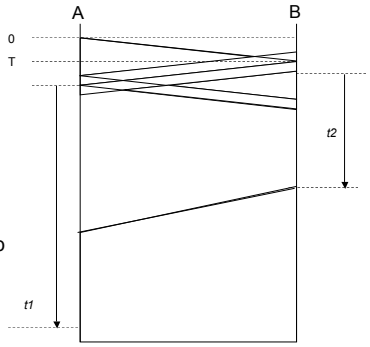
$$t_r = r \cdot 51.2\,\mu s, \quad r \in [0, 2^k - 1]$$

- **slot time** = 51.2 μs
- 1st collision, *r* = 0, 1
- 2nd collision, *r* = 0, 1, 2, 3
- 10th, *r* = 0, 1, …, 1023
- 15th, stop

16

CSMA / CD Retransmission

- A waits random time *t1*
- B waits random time *t2=slottime < t1 =2*slottime*
- B senses channel idle and transmits
- A senses channel busy and *defers* to B
- A now waits until channel is idle



17

CSMA/CD performance

- Maximum utilization of Ethernet (approximation)

$$\rho \approx 1 / (1 + C\alpha)$$

where $\alpha = 2Db / L$,

D = propagation delay, b = bit rate,

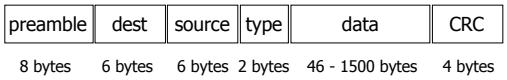
L = frame size

C is a constant:

- C = 3.1 is a pessimistic value;
- C = 2.5 is an approximate value based on simulations

18

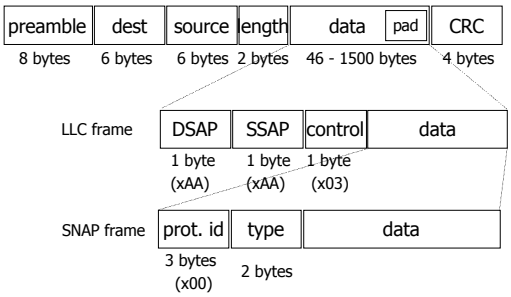
Frame format (Ethernet v.2)



- Preamble
  - synchronization : 10101010….0101011
- Addresses
  - unique, unicast and multicast (starts with the first bit 1)
  - broadcast: 11111…11111
- Type
  - upper layer protocol (IP, IPX, ARP, etc.)

19

Frame format (802.3)

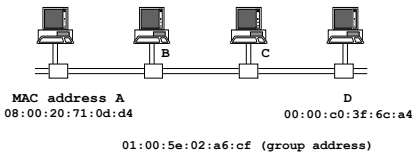


- SNAP (Subnet Access Protocol) used in bridge management (any length of data: 0 - 1492)

20

Addressing

- MAC address: 48 bits = adapter identifier
- sender puts destination MAC address in the frame
- all stations read all frames; keep only if destination address matches
- all 1 address (`FF:FF:FF:FF:FF:FF`) = broadcast



21

Addressing

- Data on Ethernet is transmitted least significant bit of first byte first (a bug dictated by Intel processors)
- Canonical representation thus inverts the order of bits inside a byte (the first bit of the address is the least significant bit of the first byte)
- examples of addresses:
  - `01:00:5e:02:a6:cf (a group address)`
  - `08:00:20:71:0d:d4 (a SUN machine)`
  - `00:00:c0:3f:6c:a4 (a PC )`
  - `00:00:0c:02:78:36 (a CISCO router)`
  - `FF:FF:FF:FF:FF:FF the broadcast address`

22

Interconnecting LANs

Why not just one big LAN?

- Limited amount of supportable traffic: on single LAN, all stations must share bandwidth
- limited distance
- large "collision domain" (can collide with many stations)
- processing broadcast frames

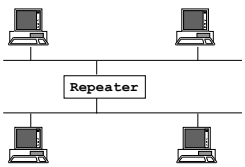
LAN evolution

- increase the bit rate: 10Mb/s, 100Mb/s, 1 Gb/s
- from hubs to switches

23

Repeaters

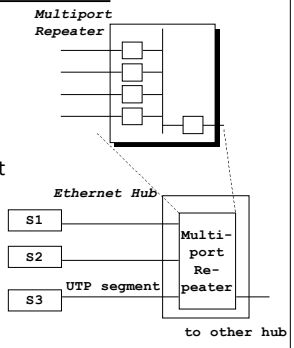
- Function of a simple, 2 port repeater:
  - repeat bits received on one port to other port
  - if collision sensed on one port, repeat random bits on other port
- One network with repeaters = ***one collision domain***
- Repeaters perform only physical layer functions (bit repeaters)



24

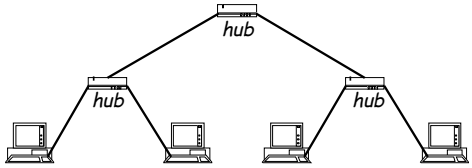
From Repeaters to Hubs

- Multiport repeater (*n* ports), logically equivalent to:
  - *n* simple repeater
  - connected to one internal Ethernet segment
- Multi-port repeaters make it possible to use point-to-point segments (Ethernet in the box)
  - ease of management
  - fault isolation



25

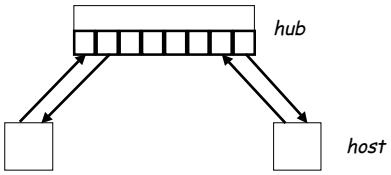
10 BASE T Hubs



- Tree topology (star)
  - hub *(répéteur multiport)*
  - max. 4 hubs

26

10 BASE T

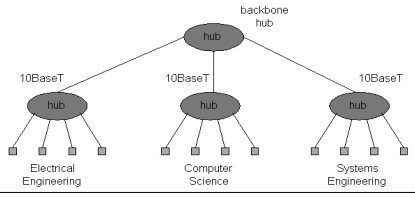


- Two pairs
  - emission
  - reception
- RJ-45 jack
- Hub - host
  - straight cable
- Hub - hub
  - inversed cable

27

10BaseT and 100BaseT

- 10/100 Mbps rate; latter called "fast ethernet"
- T stands for Twisted Pair
- Hub to which nodes are connected by twisted pair, thus "star topology"
- CSMA/CD supported by hubs



28

Gigabit Ethernet

- use standard Ethernet frame format
- allows for point-to-point links and shared broadcast channels
- in shared mode, CSMA/CD is used; short distances between nodes to be efficient
- Full-Duplex at 1 Gbps for point-to-point links

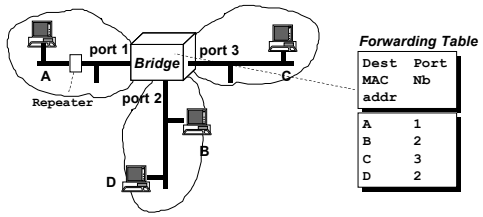
29

Gigabit Ethernet

- 1000 BASE T
  - over twisted pair (25 m)
- 1000 BASE SX
  - short wavelength (850 nm) over multimode (500 m)
- 1000 BASE LX
  - long wavelength (1300 nm) over multimode (550 m) and single-mode fiber (10 km)
- 1000 BASE LH (Long Haul)
  - greater distance over 10 µm single-mode (500 m)
- 1000 BASE ZX
  - extended wavelength (1550 nm) over 10 µm single-mode (70 km)

30

Bridges



- Bridges are intermediate systems, or switches, that forward MAC frames to destinations based on MAC addresses
- Transparent bridges: learn the Forwarding Table

31

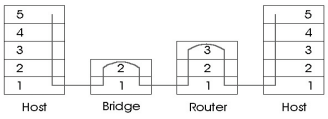
Bridges – interconnection at layer 2

- Link Layer devices: operate on Ethernet frames, examining frame header and selectively forwarding frame based on its destination
- Bridge isolates collision domains since it buffers frames
- When needs to forward a frame on a segment, bridge uses CSMA/CD to access the segment and transmit
- Can connect different type Ethernets, since it is a buffering device
- Two main types of bridges: transparent bridges and spanning tree bridges (guarantee no loops)

32

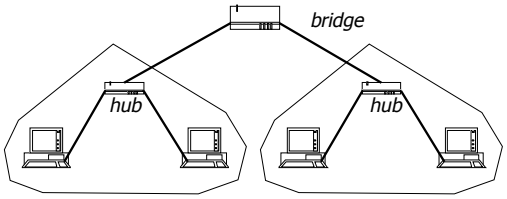
Bridges vs. Routers

- both store-and-forward devices
  - routers: network layer devices (examine network layer headers)
  - bridges are Link Layer devices (look into MAC headers)
- routers are more complex
- bridges are plug-and-play



33

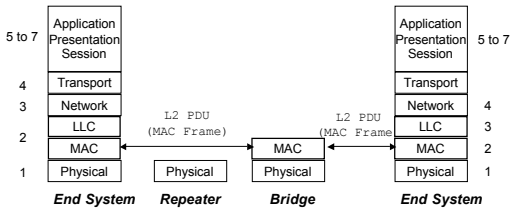
Collision domains



- Bridges separate collision domains
  - a bridged LAN maybe much larger than a repeated LAN
  - there may be several frames transmitted in parallel in a bridged LAN

34

Repeaters and Bridges in OSI Model

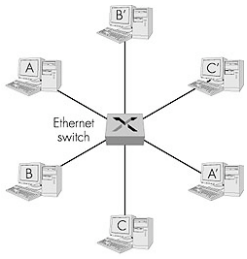


- Bridges are layer 2 intermediate systems
- Repeaters are in layer 1 intermediate systems
- Routers are layer 3 intermediate systems (IP routers)

35

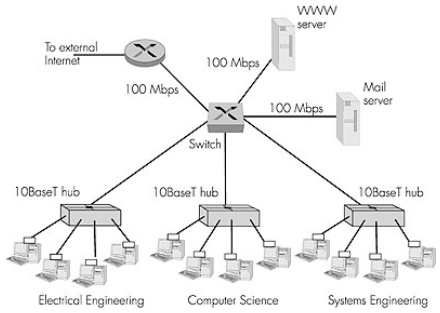
Ethernet Switches – layer 2

- layer 2 (frame) forwarding, filtering using LAN addresses
- Switching: A-to-B and A'-to-B' simultaneously, no collisions
- large number of interfaces
- often: individual hosts, star-connected into switch
  - Ethernet, but no collisions!



36

Ethernet Switches (more)



37

Switching

- *Store-and-forward*
  - receive frame, check if valid, retransmit
  - 50 μs delay for a 64 bytes frame
- *Cut through*
  - address read, retransmit
  - 20 μs delay for a 64 bytes frame
  - transmission of non-valid frames

38

Full duplex Ethernet

- A shared medium Ethernet cable is half duplex
- Full duplex Ethernet = a point to point cable, used in both directions
  - no access method, no CSMA/CD
- 100 Mb/s and Gigabit Ethernet switches use full duplex links to avoid distance limitations and to guarantee bandwidth for stations
- Requires full duplex adapters at stations

39

Gigabit Ethernet

- 1000 BASE T
  - over twisted pair (25 m)
- 1000 BASE SX
  - short wavelength (850 nm) over multimode (500 m)
- 1000 BASE LX
  - long wavelength (1300 nm) over multimode (550 m) and single-mode fiber (10 km)
- 1000 BASE LH (Long Haul)
  - greater distance over 10 μm single-mode (500 m)
- 1000 BASE ZX
  - extended wavelength (1550 nm) over 10 μm single-mode (70 km)

40

Wireless LAN: 802.11b

- 802.11b: wireless LAN
  - nominal bit rate of 11 Mb/s, degraded to 5.5, 2, 1 Mb/s
  - 6.5 Mb/s at application layer (file transfer)
  - shared radio channel, 2.4 GHz band, 13 channels (3 non overlapping of 22 MHz)
  - DSSS *(Direct Sequence Spread Spectrum),* 1 bit chipping sequence
  - coverage 50m, open air 100m
- MAC layer
  - DCF (Distributed Coordination Function)
    - CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance), similar to Ethernet, no collision detection
  - PCF (Point Coordination Function)
    - polling, optional

41

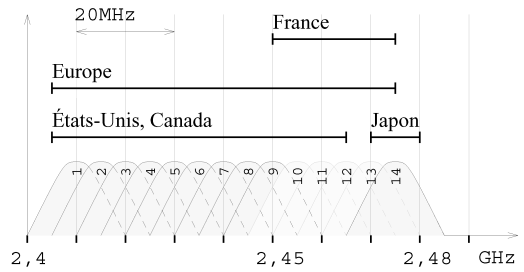
802.11 - Physical layer

- 802.11b
  - frequency band of 2.4 GHz: [2,4 GHz ; 2,48 GHz]
  - nominal bit rate of 11 Mb/s
  - passes through concrete
- 802.11g
  - frequency band of 2.4 GHz
  - nominal bit rate of > 22 Mb/s
- 802.11a
  - frequency band of 5 GHz: [5,15 GHz ; 5,825 GHz]
  - nominal bit rate of 54 Mb/s
    - 6, 9, 12, 18, 24, 36, 48, 54 Mb/s, (6, 12, 24 Mb/s mandatory)
  - LOS - Line-of-Sight (no obstacles)

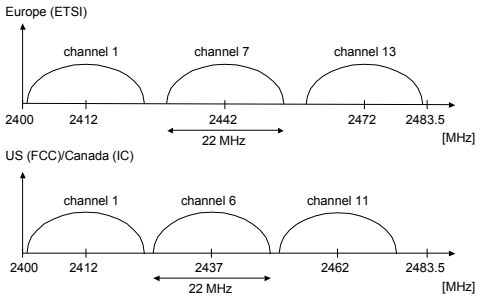
42

802.11 - Physical layer

802.11b : canaux

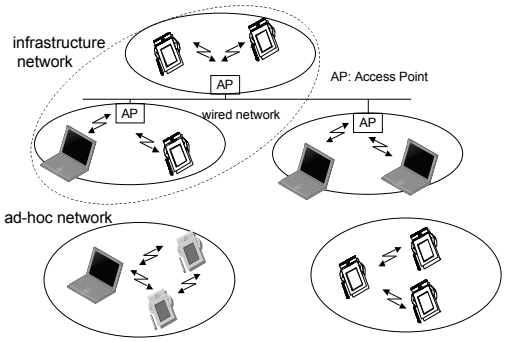


Channel selection



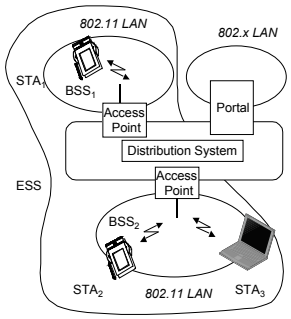
44

Infrastructure vs. ad-hoc



45

802.11 - infrastructure

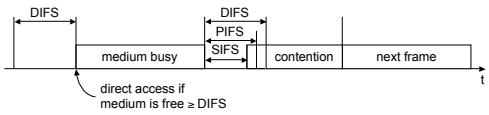


- Station (STA)
  - terminal with access mechanisms to the wireless medium and radio contact to the access point
- Basic Service Set (BSS)
  - group of stations using the same radio frequency
- Access Point
  - station integrated into the wireless LAN and the distribution system
- Portal
  - bridge to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

46

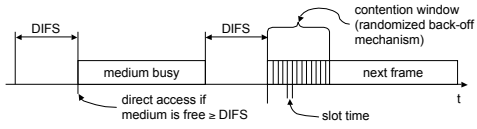
802.11

- Inter-frame spacing
  - SIFS (Short Inter Frame Spacing)
    - 10 µs, for ACK, CTS, polling response
  - PIFS (PCF IFS)
    - for time-bounded service using PCF
  - DIFS (DCF IFS)
    - 50 µs, for contention access



47

802.11 DCF - CSMA/CA

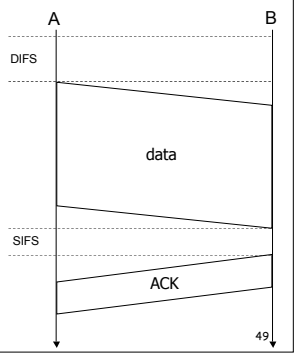


- Channel idle during DIFS, transmit frame
- If the medium is busy, wait for a free DIFS and a random back-off time (collision avoidance, multiple of slot-time)
- If another station uses the medium during the back-off time of the station, the back-off timer stops (fairness)

48

CSMA/CA *(Collision Avoidance)*

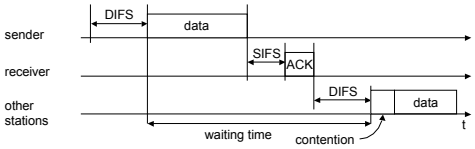
- Channel idle during DIFS, transmit frame
- Frame received correctly, wait SIFS, and send ACK



49

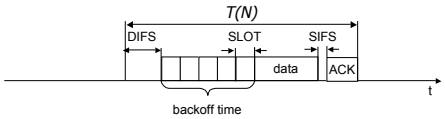
802.11 - CSMA/CA

- 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



50

Contention

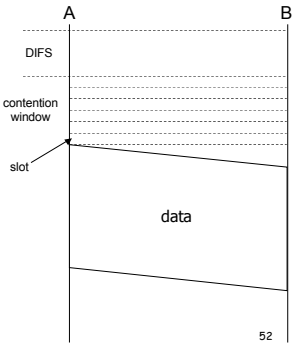


- Backoff time - random interval
  - Contention Window: uniform distribution [0, CW] * SLOT
  - CW: CW_{min} = 31, CW_{max} = 1023
  - SLOT = 20 μs
- *T(N)* should also include time wasted in collisions

51

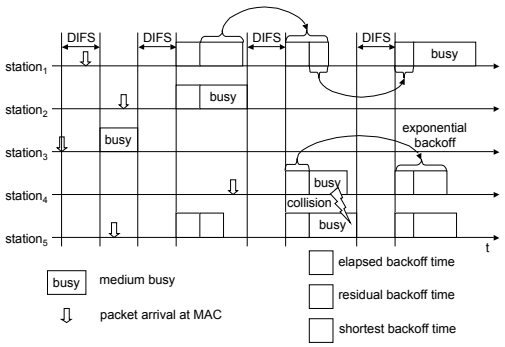
CSMA/CA *(Collision Avoidance)*

- If channel busy, defer. Then, if idle during DIFS, wait random interval (multiple of the slot) and transmit
- If channel busy, wait again until medium idle for at least DIFS
- Contention window doubles with each collision - exponential back-off



52

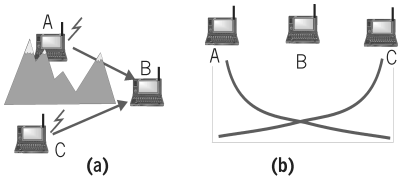
802.11 - contention



53

Hidden Terminal effect

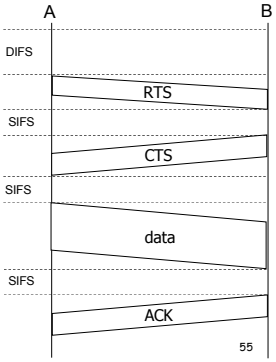
- Hidden terminals: A and B cannot hear each other because of obstacles or signal attenuation; so, their packets collide at B



54

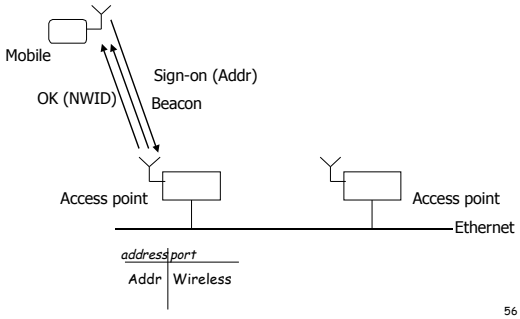
RTS/CTS Extension

- CTS *(Clear To Send)* "freezes" stations within range of receiver (hidden from transmitter); this prevents collisions by hidden station during data transfer
- RTS *(Request To Send)* and CTS are very short: collisions are very unlikely (the end result is similar to Collision Detection)



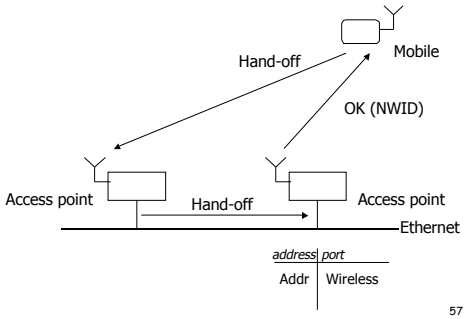
55

Register to Access Point



56

Hand-off



57

Bluetooth

- Replaces cables
  - short range (10m), low power, cheap
  - 2.4 GHz band
  - FHSS *(Frequency Hopping Spread Spectrum)*
  - piconet
    - all devices share the same hopping sequence
    - one master, seven slaves
  - bit rate: around 1 Mb/s
    - symmetric connections - 432.6 kb/s
    - asymmetric - 721 kb/s, 57.6 Kb/s
  - access method: polling, reservation

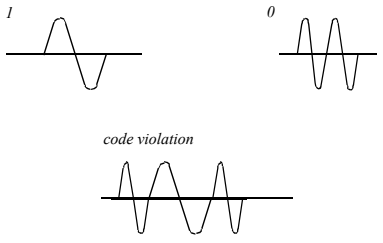
58

IEEE 802.4

- Token Bus
  - industrial LAN
- Physical layer
  - modulation *(broadband)*
  - coaxial cable 75 Ω
  - 1, 5, 10 Mb/s bit rate
- Access method
  - token on a virtual ring

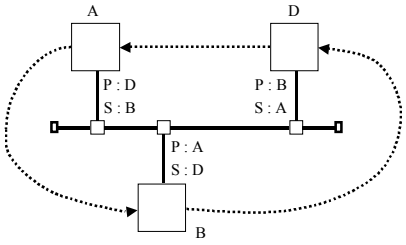
59

Physical layer



60

Topology



- Physical bus, virtual ring

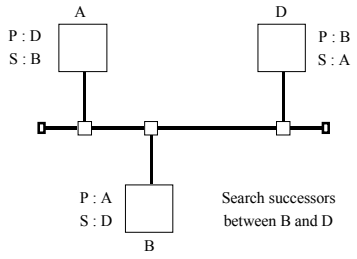
61

Access method

- Token
  - station can send one or several frames during the token holding interval
  - several priorities per station
- Virtual ring
  - two addresses: Successor, Predecessor
  - token holder passes it to its successor
  - ring maintenance:
    - each *N* tours, invite to enter

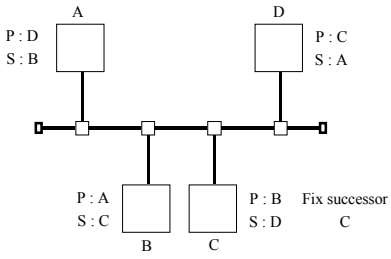
62

Adding a station



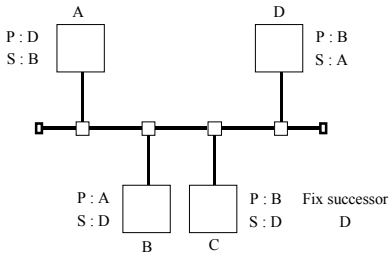
63

Adding a station



64

Departure of a station



65

Frame format

preamble	start	FC	dest	source	data	CRC	end
≥ 1 bytes	1 byte	1 byte	2-6 bytes	2-6 bytes	0 - 8191 bytes	4 bytes	1 byte

- Preamble
  - synchronization
- Start and End
  - frame delimitation: NN0NN000, N - code violation
- FC - *Frame Control*
  - type of a frame: Token, Search Successor, Fix Successor

66

IEEE 802.5

- Token Ring
- Physical layer
  - differential Manchester coding
    - bits: H-L, L-H
    - violation: H-H, L-L
  - bit rate 4, 16 Mb/s
- Access method
  - token on a physical ring

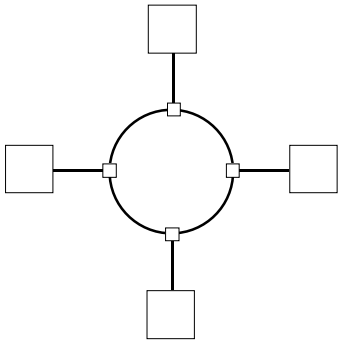
67

Topology

- Physical ring
  - repeater
    - 1 bit shift register, on the fly modification
- Twisted pair cabling
  - star topology - wiring concentrator MAU *(Multistation Access Unit)*, max. 8 stations
    - one pair - reception; one pair - transmission
- Coverage
  - station - MAU: 300 m, if one MAU; 100 m, if several MAU
  - MAU - MAU: 200 m

68

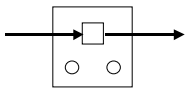
Ring



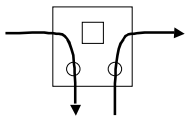
69

Repeater

- Listen
  - address/token recognition
  - copy/repeat
  - modify one bit (token hold)



- Transmission
  - buffer insertion
  - remove frame



70

Access method

- Token
  - token holding time limited to 10 ms
  - variants
    - 4 Mb/s: transmitting station generates token after removing the frame
    - 16 Mb/s: transmitting station generates token after the end of the frame *(daisy chain)*

71

Access method

- Priorities
  - token with different priorities (0 - 7)
  - priority reservation
    - a station can request generation of a token with a given priority
  - global priorities (vs. local priorities in 802.4)

72

Maintenance

- Monitoring station
  - elected at power up based on the address
  - every station may become monitor
  - initialize the ring
    - inserts a register of 24 bits (3 bytes) - token frame
  - monitor the ring:
    - presence of the token
    - absence of multiple tokens
    - purge if a frame is not removed

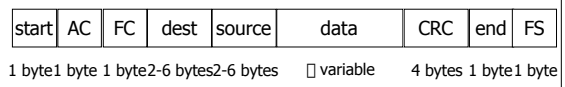
73

Problems

- Lost token
  - no token during an interval, purge the ring and regenerate the token
  - abandoned frames
    - monitoring station sets bit M in each frame
    - if frame received with M set, it is an abandoned frame
    - purge and regenerate the token

74

Frame format



1 byte 1 byte 1 byte 2-6 bytes 2-6 bytes variable 4 bytes 1 byte 1 byte

- Start
  - frame delimitation - code violation
- AC - Access Control
  - token (1 bit)
  - priority (3 bits)
  - priority reservation (3 bits)
  - bit M - monitor (1 bit)

75

Frame format

- FC - *Frame Control* - type of frame
  - Claim Token (station wants to become monitor)
  - Purge (initialize the ring)
  - Monitor Present (if no such a frame, a station will try to become a monitor station)
- Data
  - token holding time: 10 ms
    - 4 Mb/s - 4464 bytes
    - 16 Mb/s - 17914 bytes

76

Frame format

- CRC
  - on FC … data
- End
  - code violation
- FS - *Frame Status*
  - bit C: frame accepted
  - bit A: address recognized

77

FDDI *(Fiber Distributed Data Interface)*

- Dual fiber ring
  - multi-mode fiber
  - up to 500 stations
  - 100 km per ring (MAN - Metropolitan Area Network)
- Coding
  - 125 MHz clock, 100 Mb/s bit rate
  - 4B5B coding
    - 4 bits coded as 5 binary symbols
    - some symbols used for delimitation
  - NRZI signal

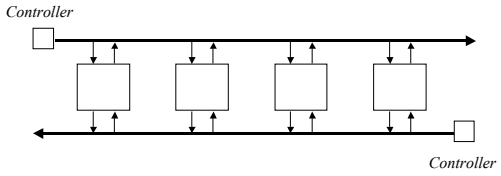
78

Access method

- Token ring, similar to 802.5
  - *daisy chain*
- Frame format similar to 802.5, 4352 bytes of data
- FDDI-II
  - synchronous traffic
    - monitoring station transmits a special frame every 125 μs
    - up to 96 PCM voice channels

79

802.6 - DQDB *(Distributed Queue Dual Bus)*



- Dual bus
  - 160 km at 44 Mb/s (T3), 155 Mb/s

80

Access method

- Controller
  - generates a train of 53 bytes cells
- Cell format
  - addresses, *Request* bit, *Busy* bit,
  - 44 bytes of data

81

Access method

- Distributed queue of transmission requests
  - before transmit, set *Request* bit in a cell on the opposite bus
  - upper stations learn the request and leave one empty cell per request
  - set *Busy* bit in the first empty cell and insert data
- Advantages
  - no overhead, good throughput
- Drawback
  - not symmetric topology

82

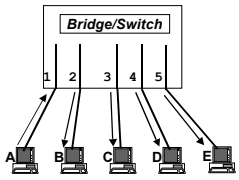
LLC *(Logical Link Control)*

- IEEE 802.2
  - used in some LAN protocols (SNAP)
- HDLC family (PPP)
- Three types of services
  - 1: datagram
  - 2: connected mode (similar to X.25 LAPB)
  - 3: acknowledged datagram

83

VLAN - Virtual LAN

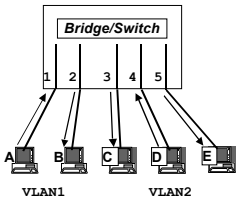
- Keep the advantages of Layer 2 interconnection
  - auto-configuration (addresses, topology - Spanning Tree)
  - performance of switching
- Enhance with functionalities of Layer 3
  - extensibility
  - spanning large distances
  - traffic filtering
- Limit broadcast domains
- Security
  - separate subnetworks



84

Virtual LANs

- No traffic between different VLANs
- VLANs build on bridges or switches



85

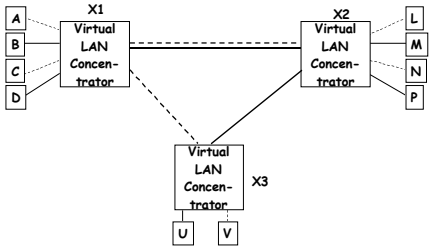
VLANs

- How to define which port belongs to a VLAN?
  - per port
    - simple, secure, not flexible for moving hosts (one host per port)
  - per MAC address
    - several hosts per port, flexible for moving hosts, not secure, difficult to manage, problems with protocols Layer 3 (should be coupled with dynamic address negotiation - DHCP)
  - per Layer 3 protocol
    - allows to limit frame broadcast (VLAN1: IP, VLAN2: IPX)
  - per Layer 3 address
    - one VLAN per IP subnetwork
    - flexible for moving hosts
    - may be less efficient (requires inspecting packets)

86

Remote VLANs

- works at layer 2
- uses an interconnection network (ATM) or a proprietary protocol



87

Summary

- Original Ethernet is a shared medium: one collision domain per LAN
- Bridges are connectionless intermediate systems that interconnect LANs
- Using bridging, we can have several collision domains per LAN
- Ethernet switches use bridging
- State of the art
  - switched 100 Mb/s Ethernet to the host
  - 1 Gb Ethernet between switches
- Wireless LANs become increasingly popular
  - WiFi, Bluetooth

88

89