Communication Systems
Local Area Network (LAN) & Media Access Control (MAC)

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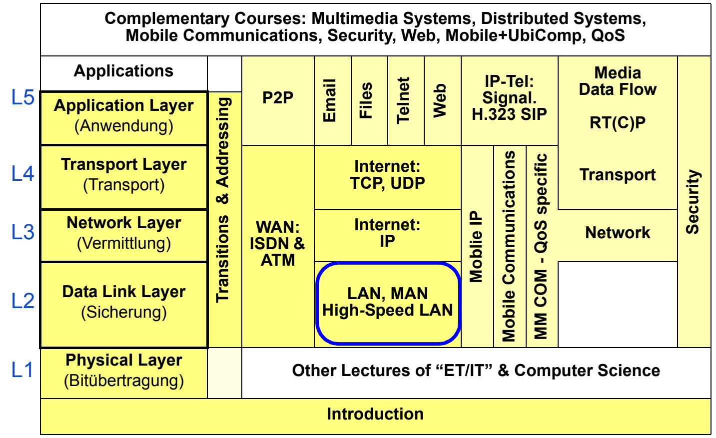
Scope



Overview

1. **What are Local Area Networks (LANs)**
2. **Medium Access Control (MAC)**
3. **Reference Model**
4. **802.2: Logical Link Control**
5. **IEEE 802.3: CSMA / CD**
6. **IEEE 802.5: Token Ring**
7. **IEEE 802.4: Token Bus**
8. **Comparison of 802.3 and 802.5**

1. What are Local Area Networks (LANs)

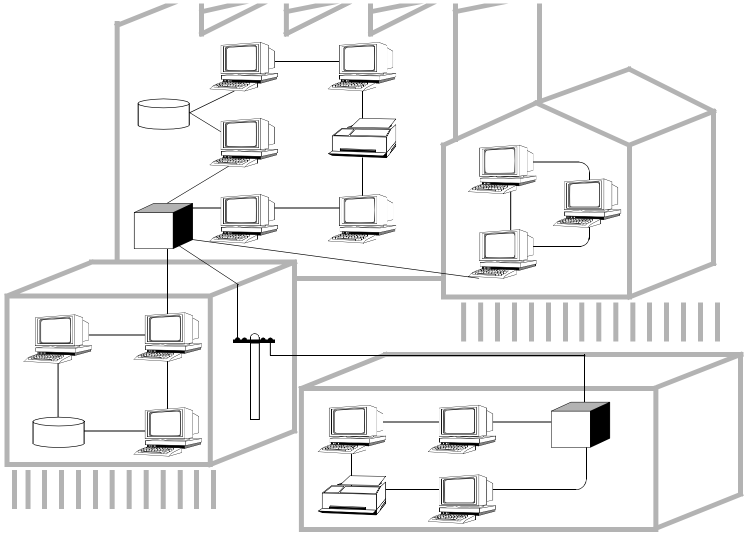
Processor Distance	CPUs are in a common ..	Example
...	...	...
10 m	room	LAN
100 m	building	
1 km	campus	
...	...	...

A LAN (Local Area Network) is
- **a network for the bit-serial transmission of information between components that are**
  - independent and
  - connected to each other
- **legally, it is controlled by the user**
- **its range is usually limited to the area within the property boundaries**

Source: ISO TC 97

(International Standardization Organization - Technical Committee 97)

What are Local Area Networks (LANs) (2)



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Features of Local Area Networks

- **relatively high speed (>1 Mbps)**
- **easy / reasonably priced connection**
- **no telecommunication regulations**
- **distance limited to a few kilometers**
- **transmission of varying types of information**
  - texts, general data
  - images, animated images
  - audio, video
- **connecting different devices**
  - computers
  - terminals / printers
  - storage units
  - ...

Common aspect of LANs:

- **several senders/sources share a channel/medium**

⇒ **Medium Access Control**

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2. Medium Access Control (MAC)

Reasons for the need of MAC

- **if**
  several persons (senders/sources) share a channel/medium
  then
  it is very likely that two or more will start communicating at the same time

⇒ **schemes needed to avoid chaos**

Important sublayer of L2

- **especially for LANs**
- **technically lower part of L2**

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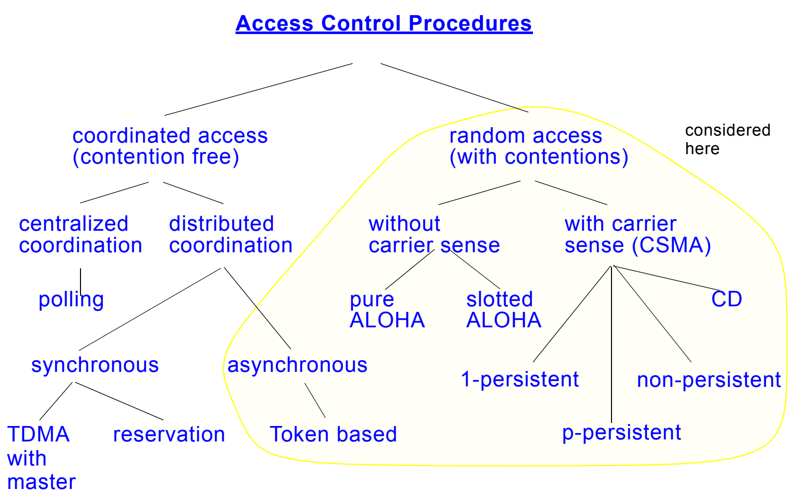
Channel Allocation Problem

Static Channel Allocation in LANs and MANs

- **using schemes such as FDM or TDM**
- **simple**
- **does not work well with bursty traffic**
- **inefficient and with poor performance**

⇒ **Dynamic Channel Allocation in LANs and MANs needed**

Dynamic Channel Allocation Schemes



Dynamic Channel Allocation – Terms / Assumptions

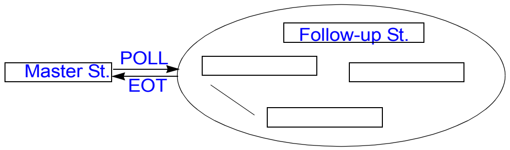
1. **Station Model**
   - N independent stations (computers, ...) generating frames for transmission
   - station blocks until frame has been successfully transmitted
2. **Single Channel Assumption**
   - single channel for all communication (all can send / receive)
3. **Collision Assumption**
   - 2 frames transmitted simultaneously overlap → signal is garbled → collision
   - stations can detect collisions
4. **(a) Continuous Time**
   - frame transmission can begin at any instant; no master clock

   (b) Slotted Time
   - time is divided into discrete intervals (slots)
   - frame transmission always begins at start of slot
   - slot may contain 0, 1, 2, ... frames (idle, successful transmission, collision)
5. **(a) Carrier Sense**
   - stations know whether channel is in use or not before trying to use it
   - if channel sensed as busy, no station will attempt to transmit until it goes idle

   (b) No Carrier Sense
   - stations cannot sense channel before trying to use it

Polling

Master Control Station




```
LOOP
   FOR I = 1 TO N
   DO
    POLL Station I;
        /* Request Data / Give Permission To Send */
    wait for EOT from Station I; /* End of Transmission*/
END; END;
```

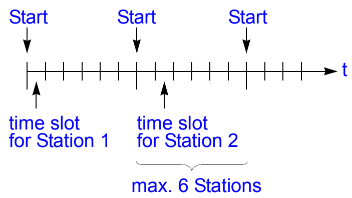
Follow-up (slave) Station X

```
LOOP
   Wait for Poll for Station X;
   IF Data available to be send
    THEN Send Data;
   EOT to Master Control Station;
END;
```

Features:
- **simple and controlled but ...**
  - Master Control Station failure leads to complete outage
  - wasted capacity (polling unnecessary) if no data to be send

TDMA (Time Division Multiple Access) with Master

Station X




```
Waiting for Start Pulse;
I := 1;
LOOP
   IF I = X THEN Send for
         the duration ΔT;
   I := (I MOD N) + 1;
   Wait for the next pulse;
END;
```

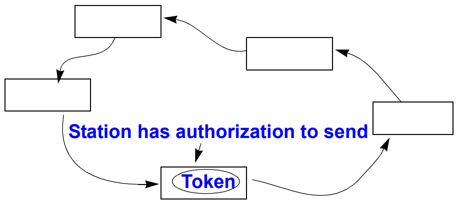
with

```
   I: slot number
   ΔT: slot duration
```

Features:
- **poor channel utilization for stations with low transmission demands**
- **fixed (and partially unused) channel capacity even when number of stations varies**
- **centralized pulse synchronization**

Token - based

- stations form a virtual or a physical ring
- a token (authorization to send) circulates on this ring
- a station can send, if it has a token



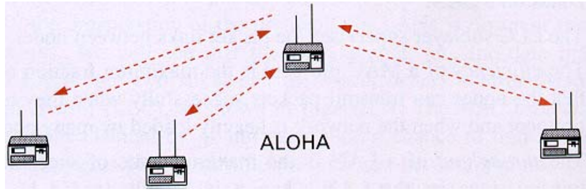
Station X

```
LOOP
   wait for Token;
   IF Data to send
    THEN Send Message;
   Transmit Token to the Next Station;
END;
```

Features:
- Waiting time (for Token)
- deterministic scheme (fair)

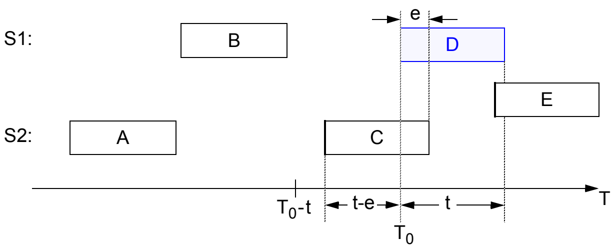
(Pure) ALOHA

History
- University of Hawaii, 1970
- originally via radio station with 9.600 bps
  - 413 MHz: central host (to everybody) on ground
  - 407 MHz: all stations to host



Principle:
- sending without any coordination whatsoever
- sender listens at the (return-)channel (after sending)
  - host sends ACKs if data received successfully
- in case of collision
  - retransmit after a random time interval

ALOHA: Example of a Collision



t . . . time for sending a frame

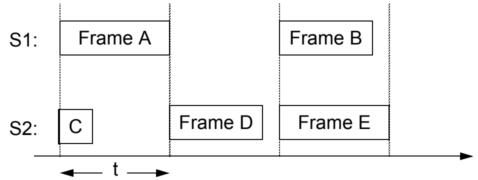
Collision
- considering frame D, a collision occurs if
  - another frame has been generated between T_0-t and T_0 or between T_0 and T_0+t
- collision window: $\lim_{\varepsilon \to 0} 2t - \varepsilon = 2t$

Disadvantage:
- large number of collisions

Slotted ALOHA

History
- University of Hawaii, 1972

Principle like Unslotted ALOHA, but discrete approach:
- time divided into slots
- start sending only at beginning of a slot



Collision
- if the beginning of a frame is between T_0 and T_0+t, i.e., it cannot start at T_0-t and last intoT_0+t
- the time pattern reduces collision window by half (= t)

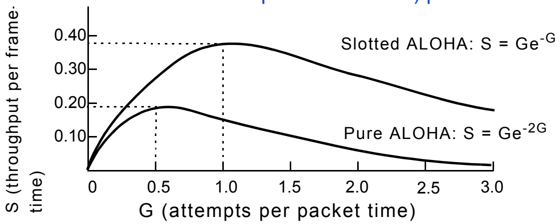
Requires centralized synchronization

Disadvantage:
- many collisions, but less than with Unslotted ALOHA

ALOHA: Throughput

Assumptions here: a multitude of stations

- **t: time for sending a frame**
- **S: AMOUNT OF NEW requests to send per frame sending time t Poisson's distribution**
  - S > 1 — more channel capacity required than available, i.e. almost always collision
  - 0 < S < 1 — more realistic / useful
- **G: ALL requests to send**
  - (retransmissions added to new requests to send S) per frame time



Maximum channel usage

- **Pure ALOHA: $1/2e$ ≈ 0.184**
- **Slotted ALOHA: $1/e$ ≈ 0.368**

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CSMA (Carrier Sense Multiple Access)

ALOHA and Slotted ALOHA:

- **station sends (if request to send exists) and realizes only AFTERWARDS, if it was actually able to send**

CSMA Principle

- **check the channel BEFORE sending**
- **channel status**
  - busy:
    - do not send but wait
    - keep checking continuously until channel is available or wait some time and re-check channel
  - idle:
    - transmit frame
    - possibility for collision still exists!
  - collision:
    - wait for a random time then start again with channel checking

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CSMA Variant 1-Persistent

Principle

- **Request to send → check channel**
- **channel status**
  - busy:
    - continuous re-checking until channel becomes idle
  - idle:
    - send
    - I.E., SEND WITH PROBABILITY 1
  - collision:
    - wait random time, then re-check channel

Properties

- **if channel is available: send with probability 1 (thus 1-persistent)**
- **MINIMIZING THE DELAY OF OWN STATION**
- **but many collisions during higher loads**
  - low throughput

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CSMA Variant Non-Persistent

Principle

- **Request to send → check channel**
- **channel status**
  - busy:
    - wait random time without checking the channel continuously
    - channel **RE-CHECK ONLY AFTER A RANDOM TIME INTERVAL**
  - idle:
    - send
  - collision:
    - wait for a random time, then re-check channel

Properties

- **assumption that other stations want to send also,**
  - therefore it is better to have the intervals for the re-checks randomly determined
- **improved overall channel utilization (efficiency)**
- **but longer delays for single stations**

CSMA Variant P-Persistent

Applied with "slotted" channels

Principle

- **Request to send → check channel**
- **channel status**
  - busy:
    - wait for the next slot, re-check (continuously)
  - idle:
    - SEND WITH PROBABILITY P,
    - wait with probability 1-p for the next slot,
    - check next slot

      idle:
      send with probability p,
      wait for next slot with probability 1-p, ...etc.

      busy: wait random time, re-check channel
  - collision:
    - wait random time, re-check channel

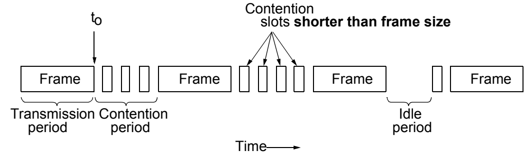
Properties

- **compromise between delay and throughput**
- **defined by parameter p**

CSMA Variant CD

Carrier Sense Multiple Access with Collision Detection

- **CSMA 1-persistent with CD**



Principle:

- **sending stations abort transmissions as soon as they detect a collision**
  - saves time and bandwidth
  - frequently used (802.3, Ethernet)
  - algorithm
    - while sending a frame: station must detect collision (comparing received with transmitted signal: signal encoding must allow collisions to be detection)

Contention period:

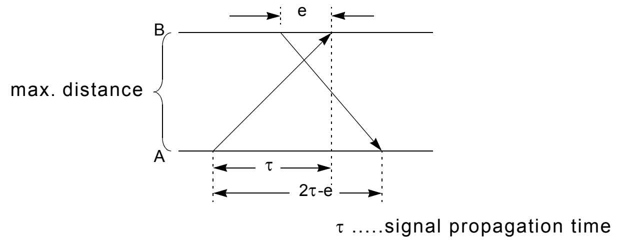
- **Extreme case: short frame, maximum distance between stations**

CSMA Variant CD: Contention Period (2)

Extreme Case:

- **short frame, maximum distance between stations**

collision window



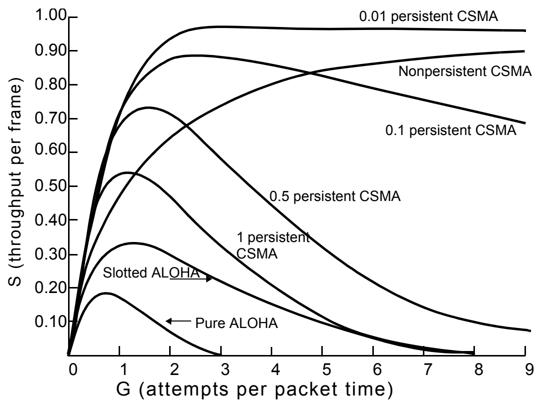
station can be certain only after 2τ

- **that it has occupied the channel**
- **(1 km coax cable: $\tau \approx 5\ \mu s$)**

Comparing ALOHA, CSMA .., CSMA CD

		channel is checked (regarding decision to send, not with regard to collision)			behavior in case of desire to send and if one of the following states has been determined			time slot
		before	during	after	busy	idle	collision	
ALOHA	pure			X	sender does not know these conditions		re-transmit after random time interval	
	slotted			X				X
CSMA	nonpersist.	X		(X)	re-check channel only after random time interval	sends immediately	wait random time interval then re-check channel and send (if possible) (depends on algorithm "idle/busy")	
	1 persist.	X		(X)	continuous wait until channel is i			
	p persist.	X		(X)	initially: continuous wait until chnl/slot idle	sends with probability p, waits with probability 1-p (for next slot, then re-checks status)		X
CSMA/CD		X	X		depends on procedure, 1-persistent = Ethernet		terminates transmission immediately, waits random time	

Comparing Performances: CSMA, ALOHA



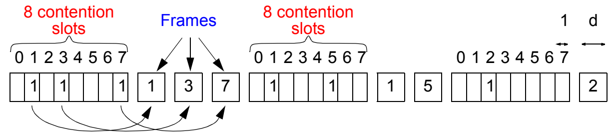
S **channel usage**
i.e. new requests to send per (frame) send time t
note: possibly long delay

G **load (attempts per frame-time)**
i.e. all requests to send (re-transmissions added to new requests to send S) per frame-time

Collision-Free: Reservation

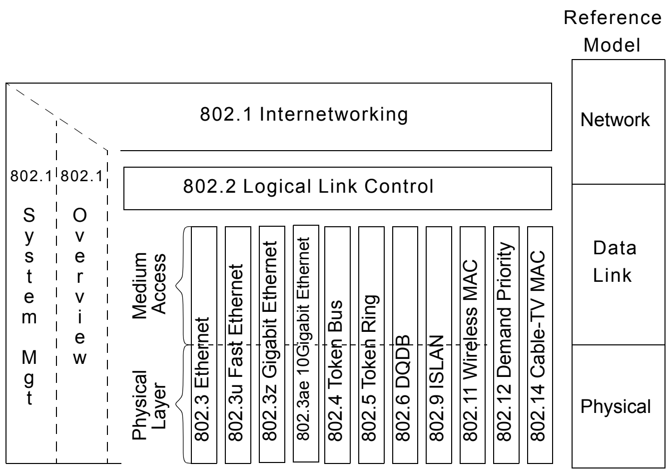
Principle:
- **transmission sequence among stations defined by PREVIOUSLY distributed RESERVATION REQUESTS**
- **alternating**
  - distribution of reservation requests and
  - sending of reference data

Example: Basic bitmap protocol for 8 stations
- **contention slots: station *j* (j=0..7) announces that it has a frame to send**
- **all stations get complete knowledge about which stations wish to transmit**



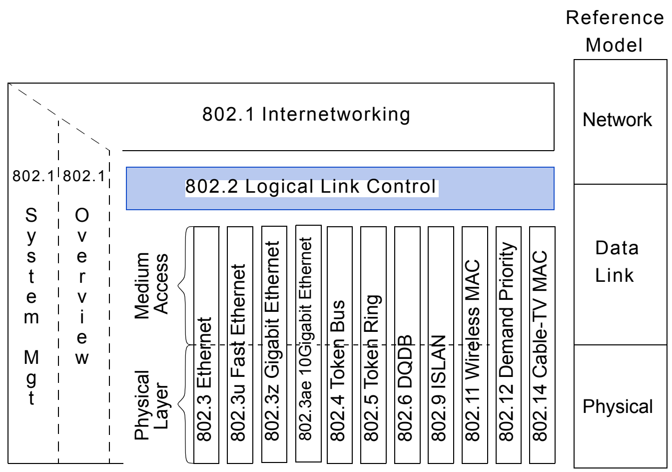
Features:
- **Waiting time due to contention period**
- **exact timing necessary**
- **contention slots need some capacity too**

3. Reference Model



e.g.
- **IEEE 802.3** **Ethernet**
- **IEEE 802.3u** **Fast Ethernet**

4. 802.2: Logical Link Control



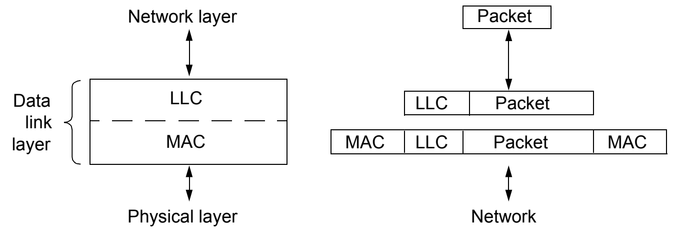
802.2: Logical Link Control (LLC) (2)

Function
- **subset of HDLC**
  - High Level Data Link Control HDLC
- **common interface**
  - to L3 for all underlying LAN/MAN/WAN components

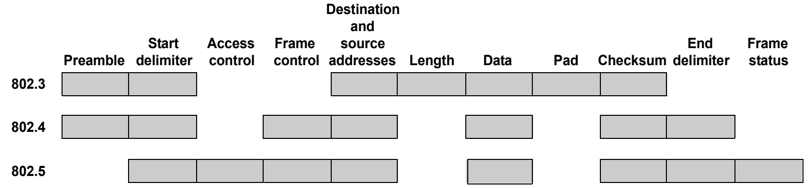
Services
- **unacknowledged connection-less (unreliable datagram)**
  - upper layers ensure
    - that sequence is maintained, error correction, flow control
- **acknowledged connection-less (acknowledged datagram)**
  - each datagram is followed by exactly one acknowledgement
- **connection-oriented**
  - connect and disconnect
  - data transmission incl. acknowledgement, guaranteed delivery to receiver
  - maintaining the sequence
  - flow control

LLC Frame

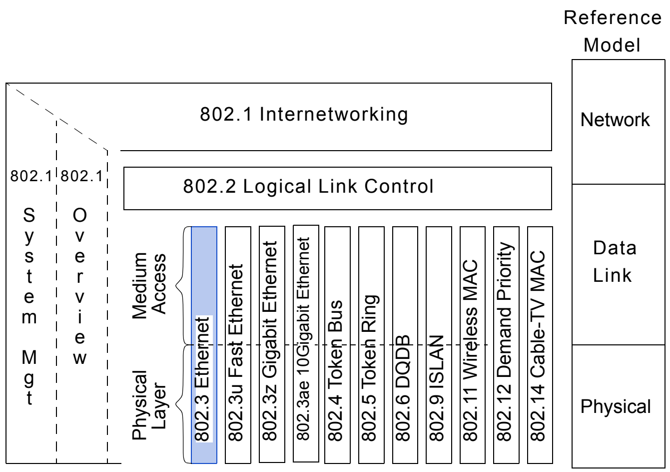
Format
- **includes LLC Service Access Points SAPs for source and destination**



Varying AC frames:
- **formats**



5. IEEE 802.3: CSMA / CD



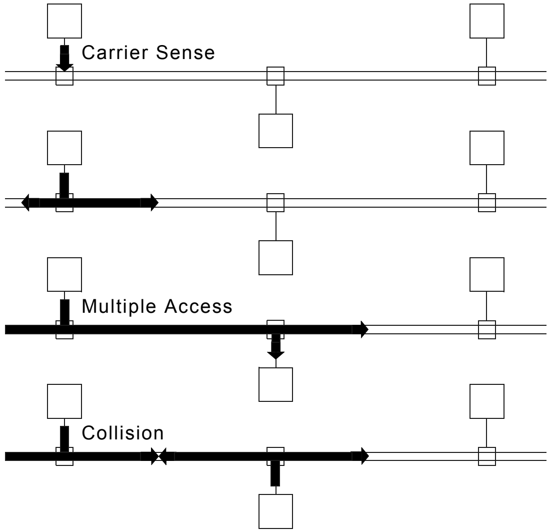
IEEE 802.3: CSMA / CD (2)

History
- **1976: Ethernet by Xerox, Robert Metcalf (2,94 Mbps)**
- **1980: Ethernet industrial standard by Xerox, Digital and Intel (10 Mbps)**
- **1985: IEEE 802.3 based on Ethernet**

IEEE 802.3
- **specifies a family based on the 1-persistent CSMA/CD systems**
- **1 - 10 and 100 Mbps, on different media**
- **Ethernet is a protocol of this family**

1-persistent CSMA / CD
- **L1:**
  - Manchester Encoding
    - (on all cables except for 10BROAD36 broadband, here DPSK)

IEEE 802.3: CSMA / CD (3)



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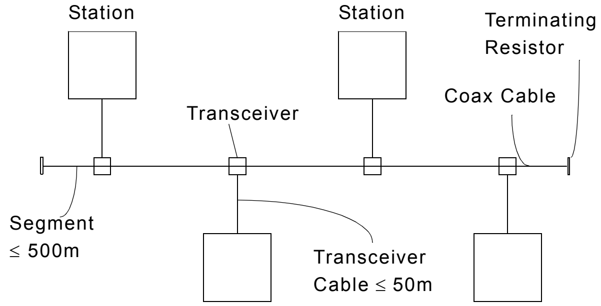
5.1 802.3: Configurations

Rule (in general)

- **Always EXACTLY ONE WAY between 2 stations in the Ethernet**

Small configuration



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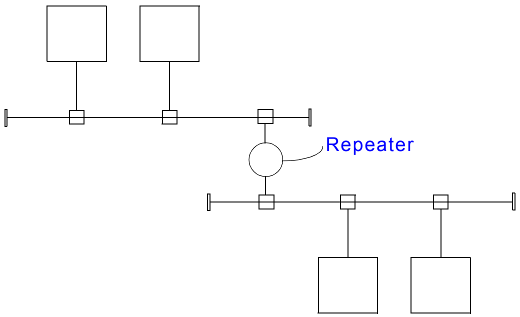
802.3: Configurations (2)

Medium-sized configuration



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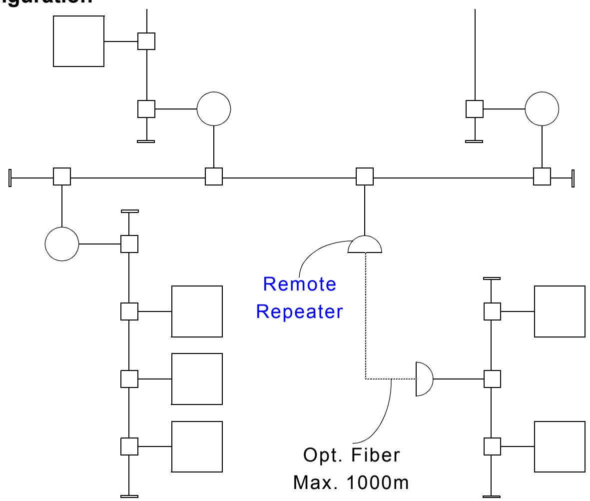
802.3: Configurations (3)

Large configuration



5.2 802.3: Hardware Components

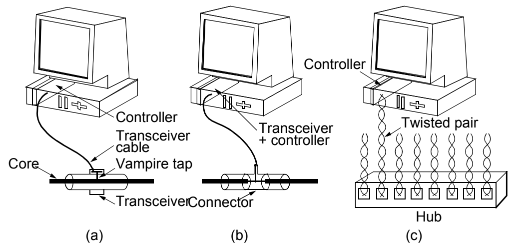
Mainly used media (lines)

Name	Cable	Max. segment	Nodes/seg.	Advantages
10Base5	Thick coax	500m	100	(was) good for backbones
10Base2	Thin coax	200m	30	Cheapest system
10Base-T	Twisted pair	100m	1024	Easy maintanance
10Base-F	Fiber optics	1000m	1024	Between buildings

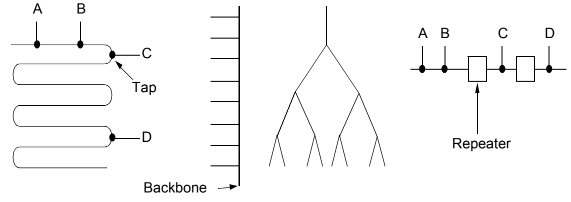
(for traditional Ethernet with 10Mb/s)

802.3: Hardware Components (2)

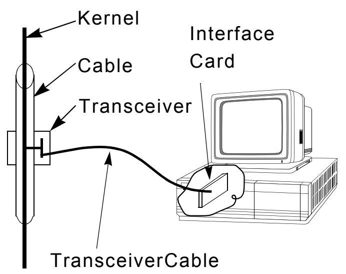
Port types



Topologies



802.3: Hardware Components (3)

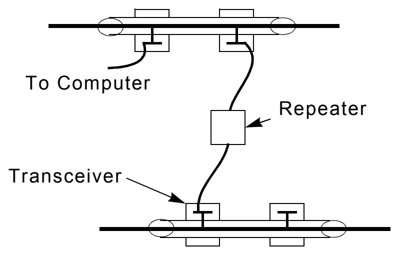


Transceiver
- connection to the Ethernet cable
- electronics assembly for carrier and collision recognition

Ethernet cable
- Thick/Thin Ethernet, Twisted Pair (single or double)
  today usually UTP ("Unshielded Twisted Pair")
- max. length: 500 m (or depend. on resp. cable type 500m/200m, 100m)

Transceiver cable
- connects transceiver and interface card, max. length: 50 m

802.3: Hardware Components (4)

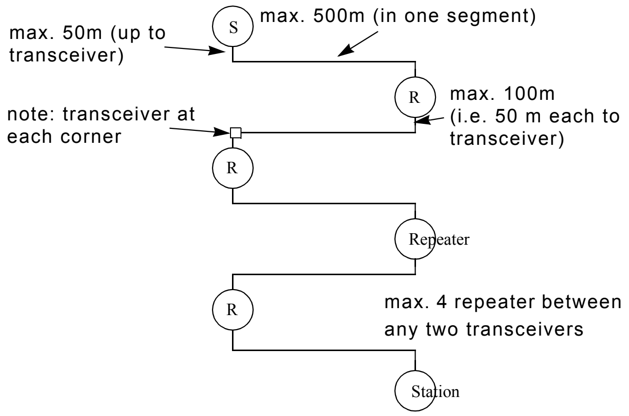


Repeater
- connects several cable segments
- repeater connects over a distance of max. 100 m
  - because of 2 x connections to the transceiver at 50 m per 2 cable segments
- max. distance between 2 repeaters: 2,5 km
  - i.e. between the connections to the individual segments
- max. 4 repeaters on one path between 2 (random) transceivers

5.3 Maximum Distance between Two Stations

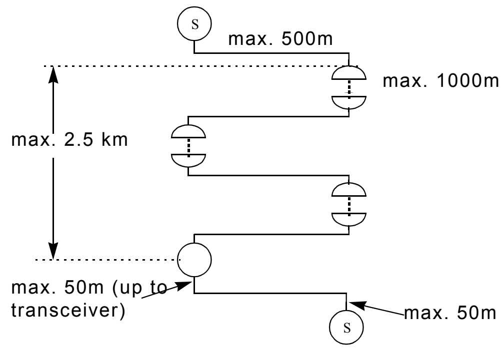
Example: Thick-Ethernet and fiber optic cable

Max. distance between 2 stations: 3 km

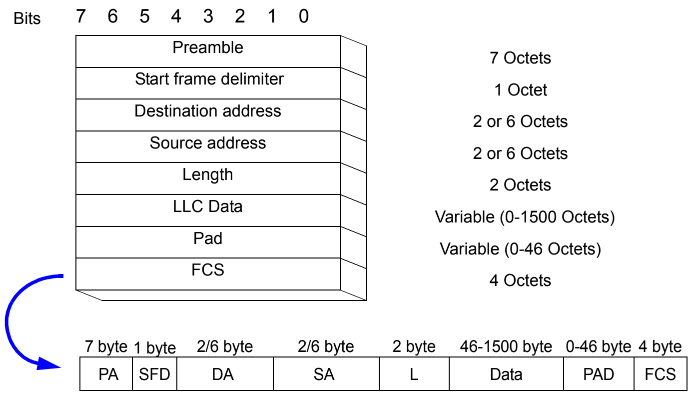


Maximum Distance between Two Stations (2)

Max. distance between 2 stations: 3,7 km



5.4 802.3: Frame Format



Preamble:
- **always 7 times 10101010**
- **allows synchronization of the receiver's clock with sender's**

Start Frame Delimiter:
- **beginning of the frame (10101011)**

802.3: Frame Format (2)

Destination Address and Source Address:
- **individually, group, all:**
  - unicast → individual address
  - multicast → group address
  - broadcast → all address bits are "1"

1. addressing in 16 bit / 2 byte format:

I/G	15-Bit Address

I/G = 0 Individual Address

I/G = 1 Group Address

802.3: Frame Format (3)

2. addressing in 6 byte / 48 bit format (COMMON PRACTICE):

I/G	U/L	46-Bit Address

I/G = 0 Individual Address

I/G = 1 Group Address

U/L = 0 Globally Administered Address

U/L = 1 Locally Administered Address

- common practice (with 10 Mbps only this format)
- address assignment: ...
- local address assignment
  - can be done on site by authorized entity
- global address assignment
  - IEEE assigns worldwide unique 46 bit addresses
  - 7,03 x 10^{13} potential addresses
  - L3 (network layer) has to locate address

802.3: Frame Format (4)

Length:
- **number of bytes in LLC Data**
- **encoded within 2 bytes**

LLC Data:
- **0 - 1500 bytes actual data**

Pad:

Preamble	7 Octets
Start frame delimiter	1 Octet
Destination address	2 or 6 Octets
Source address	2 or 6 Octets
Length	2 Octets
LLC Data	Var. (0-1500 Octets)
Pad	Var. (0-46 Octets)
FCS	4 Octets

64 ... 1518 byte (Destination address to FCS)

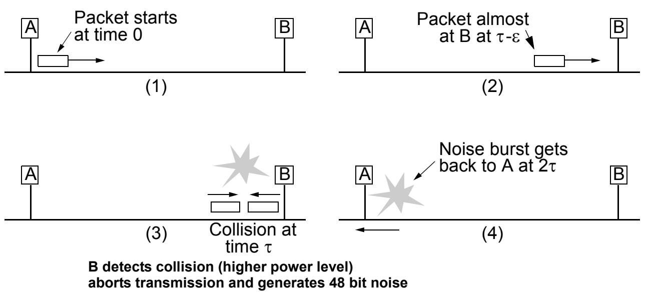
- **min. frame length = 64 bytes (=6+6+2+46+4)**
  - for collision detection
- **shorter frame length ⇒ invalid frame**

⇒ **potentially padding bytes to achieve the minimum frame length**

802.3: Frame Format (5)

Reason (for minimum length):
- **transceiver interrupts frame transmission during collision**
  - i.e. short invalid frames appear

- **algorithm**
  - station should recognize DURING frame transmission whether a collision occured
  - extreme case: short frame, station at maximum distance

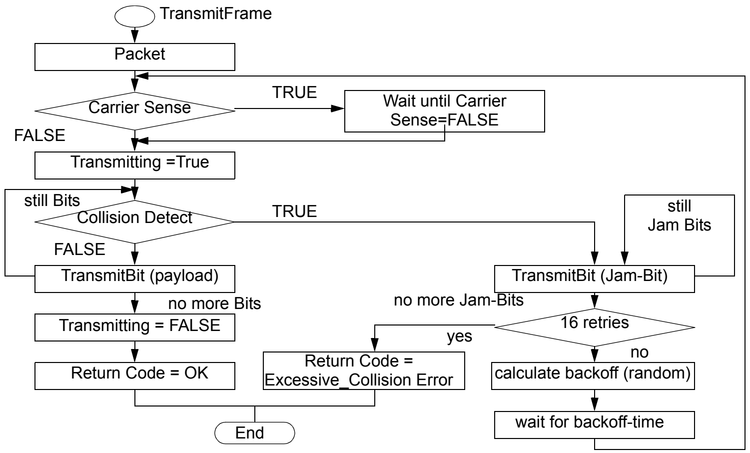


802.3: Frame Format (6)

- **behavior if parametrized differently:**
  - with higher data rates
    the minimum frame size must be larger
    e.g. for 1 Gbps (expansion 2,5 km) 6400 bytes
  - or
    if data rate increased but frame size the same:
    shorter distance

Frame Check Sum
- **CRC**
- **to detect errors**

5.5 802.3: Control Flow

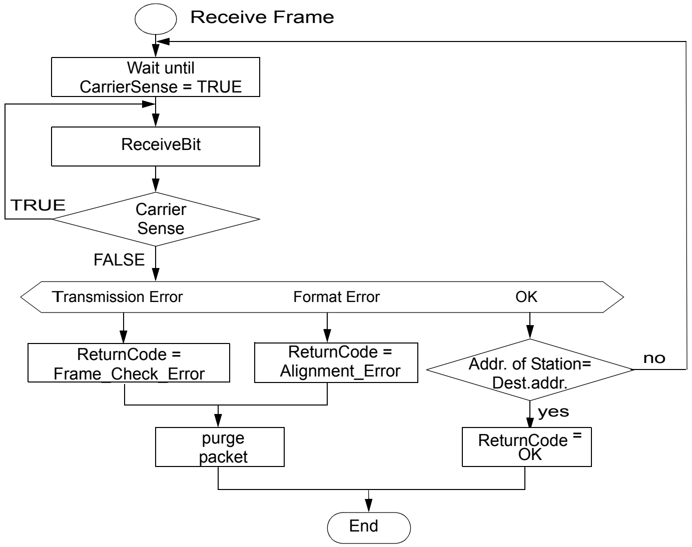


backoff = r •Δt with Δt = send time for 512 Bits (51,2 μs)

0 $\leq$ r < 2^k with k = min (n, 10)

n = number of unsuccessful attempts to send

802.3: Control Flow (2)



5.6 802.3: Collision Treatment

Time is divided into discrete slots

- slot length equal to worst case round-trip propagation time (2τ)

Binary Exponential Backoff Algorithm

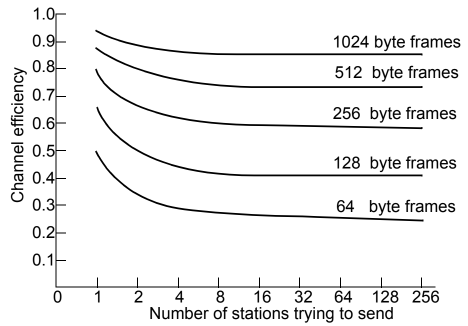
... collision after first request to send	next attempt after waiting for ... frames
1st	0 or 1
2nd	0, 1, 2 or 3
3rd	0, 1, 2, 3, 4, 5, 6 or 7
...	
nth	0,..., 2^n-1
16th	error message to L3

Effects, behavior ...

802.3: Collision Treatment (2)

Behavior

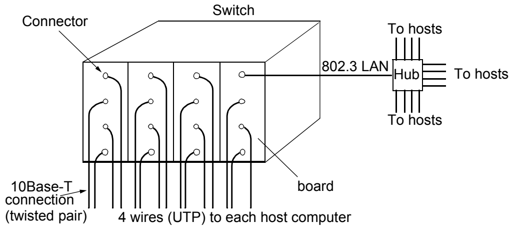
- during increasing load — longer waiting periods
- if more stations — lower utilization
- if longer frames — higher utilization



5.7 Switched 802.3 LANs

Increasing the throughput by
- **higher data rates (100Base-T, requires new adapters)**
- **switching function in 802.3**

SWITCH (instead of HUBs) as relaying center



- **station sends frame**
- **switch tries to locate**
  - first: the receiver within the "board"
  - and then (only if not located): at a different location

collision domain
- **individual connections combined to this**
- **but no collisions with other domains**

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5.8 802.3: Summary CSMA / CD

Properties

- \+ **most widely spread**
- \+ **no network shutdown needed to connect new stations**
- \+ **no modems**
- \+ **practically no waiting time if low utilization**

- \- **analog components for collision detection**
- \- **minimum frame size (64 bytes)**
- \- **not deterministic (no maximum waiting time)**
- \- **no prioritization**
- \- **when load increases, probability for collisions also increases**

$\Rightarrow$ **poor throughput during high load periods**

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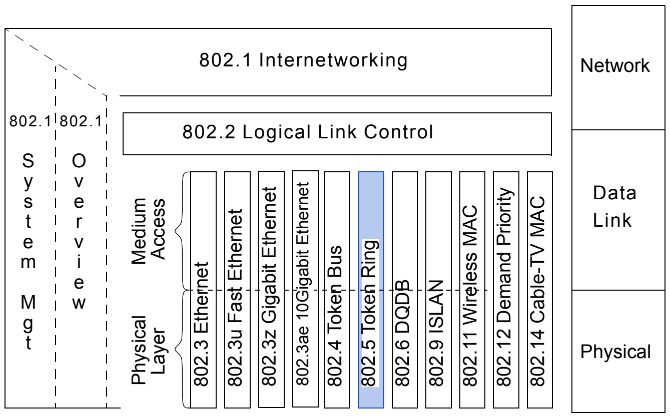
6. IEEE 802.5: Token Ring



History
- **Z-Ring: prototype of a Token Ring (IBM Zurich)**
- **IBM chooses Token Ring as the inhouse LAN standard**
  - 1985: IEEE 802.5
  - 1986: IBM Token Ring product

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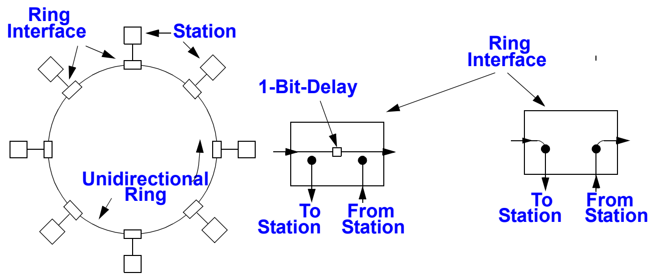
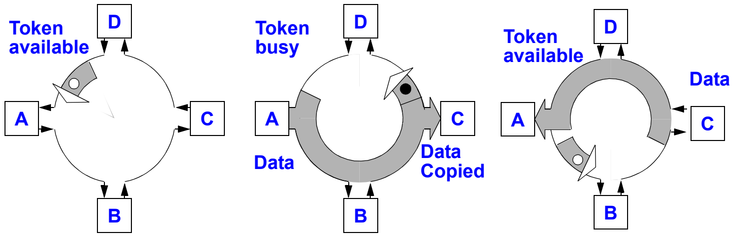
6.1 802.5: Ring Topology



Ring
- **not really a broadcast medium, but**
  - a concatenation of point-to-point lines
- **station copies information bit by bit from one line to the next (active station)**

6.2 802.5: MAC Protocol

Token Protocol



Principle

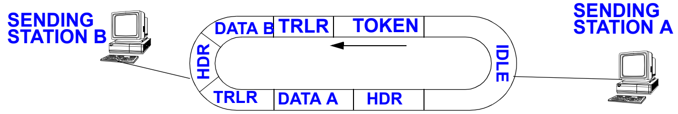
- **token**
  - frame with special bit pattern
- **one token circulates on the ring**
  1. before station is permitted to send
     - it must own and remove the token from the ring
  2. station may keep the token for a pre-defined time and may send several frames
  3. after sending
     - the station generates a new token

802.5 MAC Protocol: Early Token Release

Token Ring behavior during increased data rate

- **until now always data on the line, this means long bits**
- **however, frames occupy only a minor part of the ring during higher speeds (the remainder is lost)**

Principle



- **append token directly to the last data transmission, always only 1 token in circulation**

```
Sender A:
 sends data
 appends free token to data
Sender B:
 takes token
 appends its data to frame
 appends free token
```

Application

- **16 Mbps Token Ring and, in a modified variant, on FDDI**

802.5: Token and Frames

Typical (measured) values:

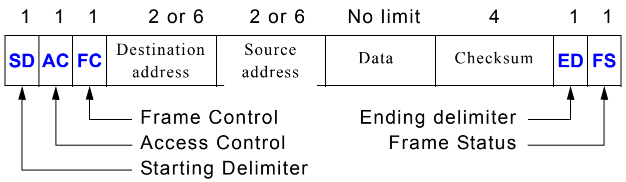
- **token circulates 20 times and**
- **one frame circulates with e.g. 256 byte**

Token

- **3 byte length**

1	1	1
SD	AC	ED

Frame



AC contains TOKENBIT T

| SD | AC | mit T = 1: "Start of Frame"-Sequence

T = 0: Token

T = 1: Data

- "Remove Token from Ring": T := 1

6.3 802.5: Physical Layer

Parameter

- **medium:**
  - twisted copper cable (Shielded Twisted Pair) or
  - coaxial conductor
- **digital transmission:**
  - differential Manchester encoding
- **transmission rates:**
  - (1 and) 4 Mbps
- **max. 250 stations**

Extensions

- **coax, optical fiber (as FDDI)**
- **increased transmission rates:**
  - 16 Mbps
  - (as Early Token Release, IBM product)

6.4 802.5: Calculations, also Ring Bit Number

Ancillary condition:

- **token has to fit completely onto the network**
  - (otherwise the station sending the token might think that 2 tokens occupy the ring simultaneously)
  - because it is receiving a token while it is still sending

Calculation

```
V . . . signaling speed [approx. 200 m/msec]
L . . . full ring length
K . . . transmission capacity [bit/sec]

Ring circulation time U = L/V
Ring bit number       R = U • K
                      R = L • K/200  (m/microSec)
```

Example:

```
L = 1000 m;   K = 4 Mbps:
R = 20 bit ⇒ 802.5 Token(3byte)does not fit on ring
```

Solution: artificial delay at each station...

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802.5: Calculations, also Ring Bit Number (2)

Solution: artificial delay at each station

Calculation:

```
D . . . delay / station [bit]
N . . . number of connected stations
Ring circulation time  U = L/V + N • D/K
Ring bit number        R = U • K = L • K/V + N • D
```

Example:

```
L = 1 000 m; K = 4 Mbps; N = 50; D = 1 :
⇒  R = 70 bit
```


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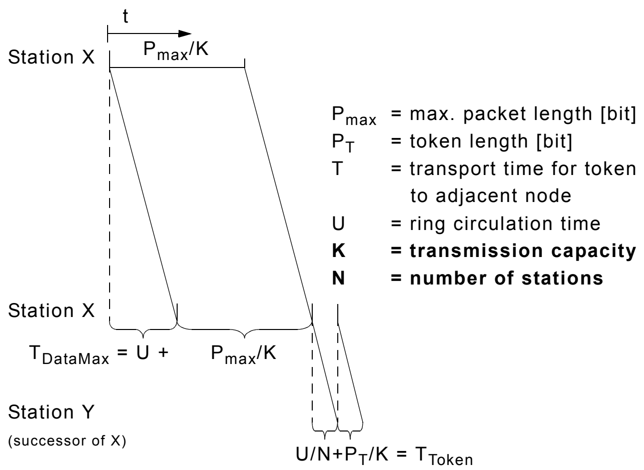
802.5: Maximum Waiting Period

What is the maximum waiting time for a station before it receives permission to send again?



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802.5: Maximum Waiting Period (2)

What is the maximum waiting period for a station before it receives permission to send again?

W = maximum waiting period:

W = all others are sending + token rotates x-times

$$= (N-1)(P_{max}/K + U) + N(P_T/K + U/N)$$
$$= (N-1)(P_{max}/K + U) + NP_T/K + U$$
$$= (N-1)(P_{max}/K + U) + \underbrace{}_{= 0 \text{ for } P_T << P_{max}} U$$

6.5 802.5: MAC Frame Formats

Token Format

SD	**AC**	ED

SD = Starting Delimiter (1 octet)
AC = Access Control (1 octet)
ED = Ending Delimiter (1 octet)

Frame Format

1 Octet	Starting Delimiter (SD)	Start-of-Frame Sequence
1 Octet	Access Control (**AC**)	Start-of-Frame Sequence
1 Octet	Frame Control (FC)	FCS Coverage
2 or 6 Octets	Destination Address (DA)	FCS Coverage
2 or 6 Octets	Source Address (SA)	FCS Coverage
>=0 Octets	INFO	FCS Coverage
4 Octets	Frame Check Sequence (FCS)	FCS Coverage
1 Octet	End Delimiter (ED)	End-of-Frame Sequence
1 Octet	Frame Status (FS)	End-of-Frame Sequence

MSB LSB
Bits Within Frame Transmitted Left-to-Right

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802.5: MAC Formats

Access Control (AC)

Direction of Transmission →

MSB	P	P	P	T	M	R	R	R	LSB

P = **Priority bits**
T = Token bit
M = Monitor bit
R = Reservation bits

T Token bit: token identifier

M Monitor bit: to recognize orphaned messages

Priority management

P . . . token priority

R . . . priority for reserving the next token

- e.g. station wants to send frame containing priority N
  - but receives token only if P ≤ N
  - can reserve next token with priority N (R := N), if R ≤ N

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802.5: MAC Formats: Priorities

- **Priority classes:**

Priority	Use
0	normal data transfer
1 - 3	available for data transfer
4	bridges
5 - 6	reserved
7	station management

- **example: access by priority**

```
Station A: sends data at low priority 0
   Station B:
   reserves priority token by setting access control
   field
Station A: generates prioritized token
   Station B:
    gets prioritized token and sends data with high
    priority
   Receiver of Station B:
    receives data and
    releases token with previous priority
```


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802.5: MAC Formats

Frame Status (FS)

A	C	r	r	A	C	r	r

A = address-recognized bits

C = frame-copied bits

r = reserved bits

RECEIVER SETS BITS

A=0 ∧ C=0: destination station does not exist

A=1 ∧ C=0: destination exists, but frame is not accepted

A=1 ∧ C=1: destination exists and frame is accepted

Comment: these bits (Frame Status) are not included in checksum, because

- **this field is set after whole frame has been received**

⇒ duplicate included to increase reliability

802.5: Management Tasks

Stations
- **detect monitor failure**
- **determine another monitor (Claim Token procedure)**

monitor recognizes and corrects errors, e.g.
- **orphaned frames**
- **lost tokens**

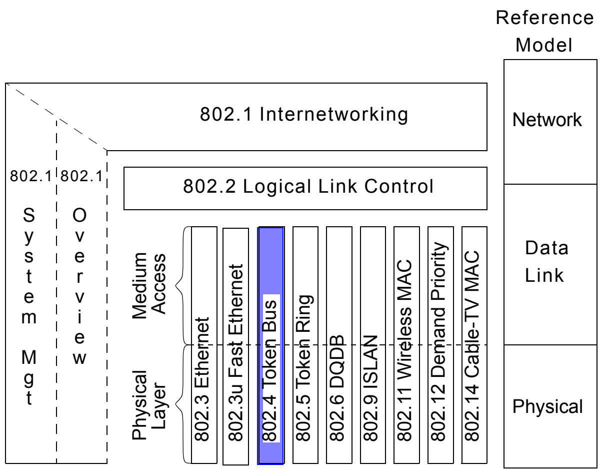
6.6 802.5: Summary Token Ring

Properties

- \+ **digital technology only**
- \+ **multitude of transmission media**
- \+ **wiring centers: automatic recognition and repair of cable breaks**
- \+ **deterministic behavior (max. waiting time)**
- \+ **priorities**
- \+ **random frame lengths**
- \+ **good throughput even during increased utilization**

- \- **central monitor**
- \- **delays because of need to wait for token**

7. IEEE 802.4: Token Bus



HISTORY:
- **developed and recommended by General Motors in context with MAP (Manufacturing Automation Protocol)**

8. Comparison of 802.3 and 802.5

	802.3: CSMA / CD
+	cost efficient
+	most widely spread
+	connecting stations without shutting down the network
+	no modems
+	practically no waiting time during low utilization
-	analog components for collision recognition
-	minimum frame size (64 Bytes)
-	not deterministic (no maximum waiting time)
-	if utilization increases • collisions also increase • poor throughput during high utilization periods

	802.5: Token Ring
+	multitude of transmission media
+	wiring centers: automatic recognition and repair of cable breaks
+	deterministic behavior (max. waiting time)
+	priorities
+	random frame lengths
+	good throughput during high utilization
-	central monitor
-	delays due to need to wait for token(s)
-	more expensive than 802.3, Ethernet