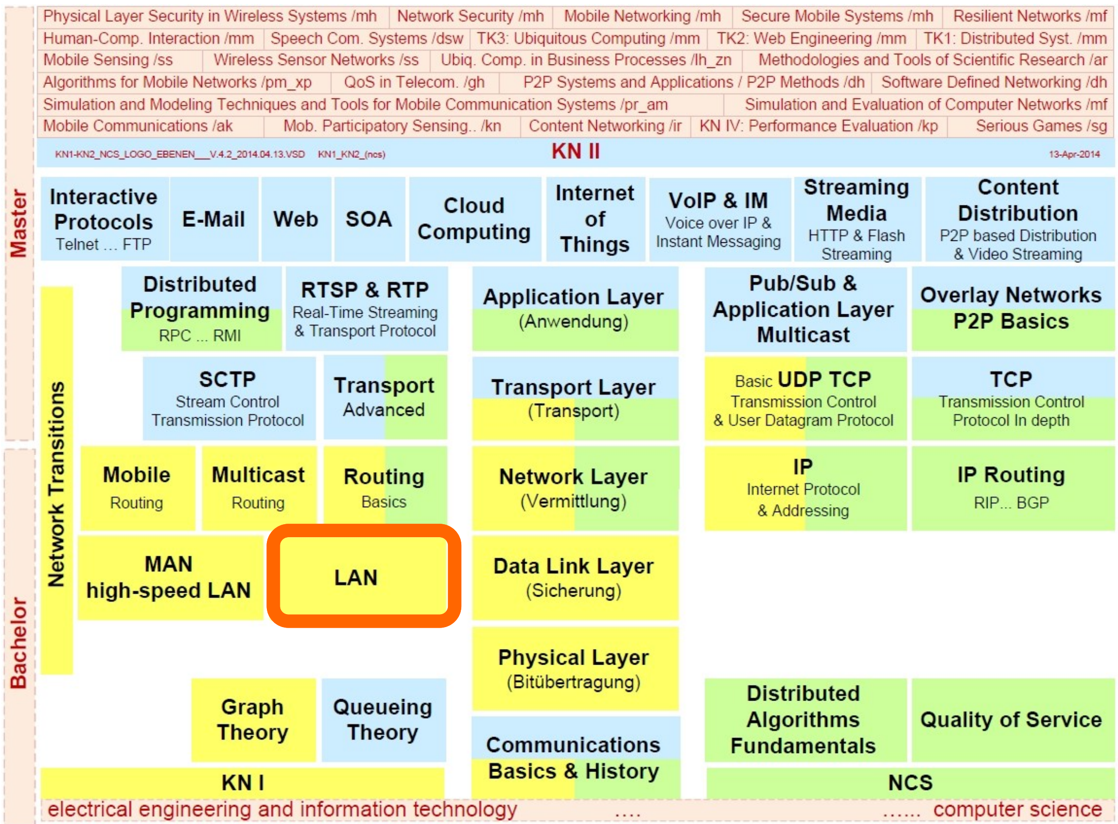
Communication Networks I

L2 Local Area Networks



Prof. Dr.-Ing. **Ralf Steinmetz**
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2 Medium Access Control (MAC)

3 Dynamic Channel Allocation: Contention Free
- 3.1 Polling
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1 What are Local Area Networks (LANs)?

Processor / End System Distance	CPUs / end systems are in a common ..	Example
...	...	...
10 m	room	LAN
100 m	building	
1 km	campus	
...	...	...

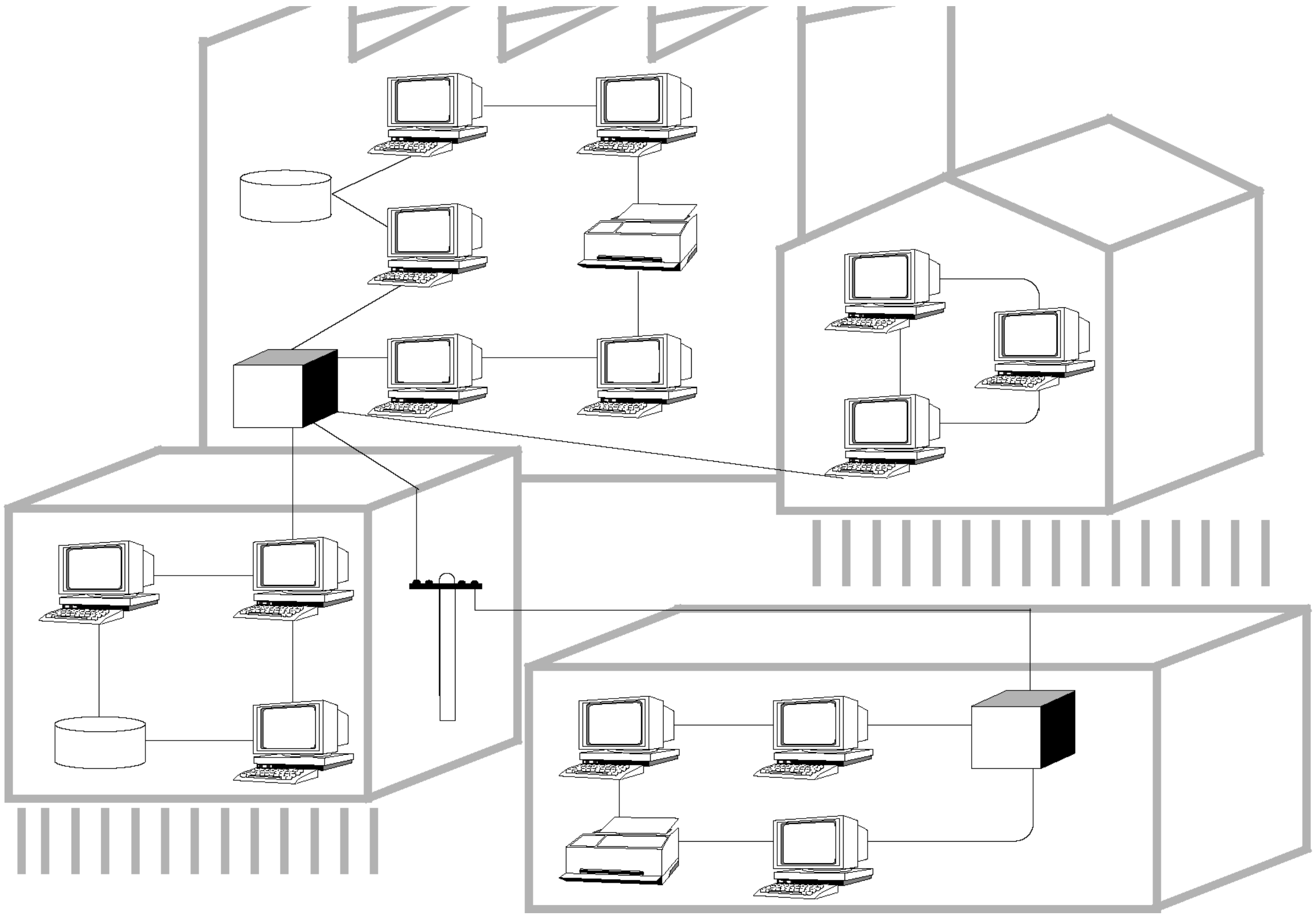
A LAN (Local Area Network) is a network

- 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)?



Features of local area networks …

Features of Local Area Networks

relatively high speed

- most often >100 Mbps

easy / reasonably priced connection

No/few telecommunication regulations

distance limited to a few kilometers

transmission of varying types of data

- texts, general data
- images, animated images
- audio, video,
- haptics, ..

connection of different devices

- computers
- terminals / printers
- storage units
- ...

and

always applies:

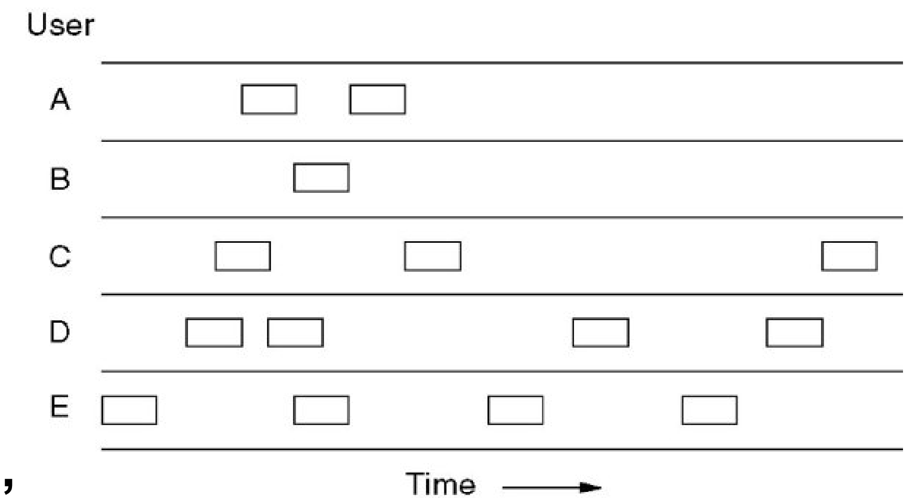
- several senders/sources share a channel/medium

→ MEDIUM ACCESS CONTROL

Need of MAC

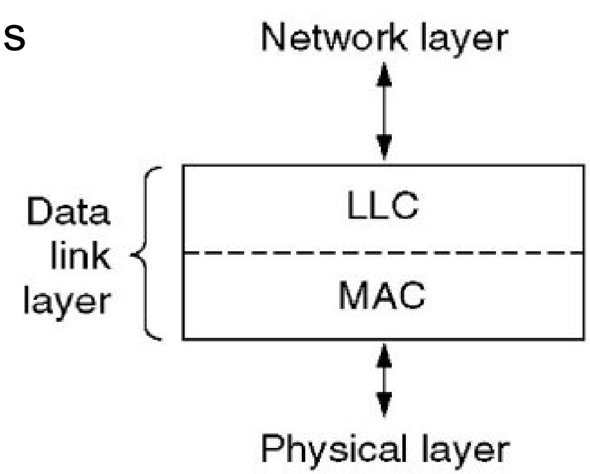
- IF
  - several persons (senders/sources) share a channel/medium
- THEN
  - it is very likely that two or more will start communicating at the same time

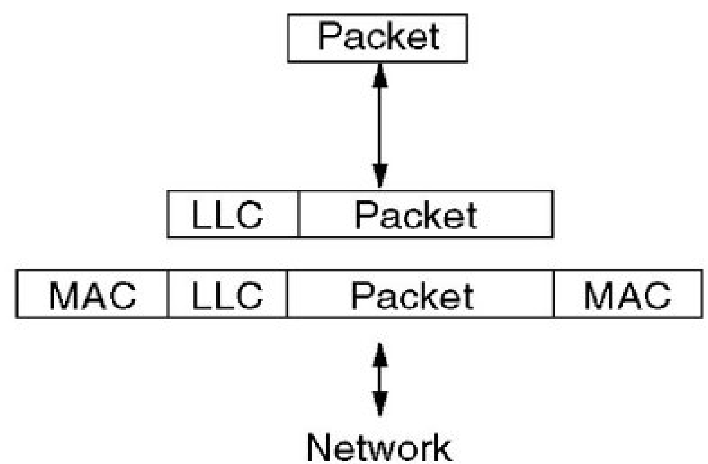
→ **schemes needed to avoid "chaos"**



Important "sub layer" of L2

- especially for LANs
- technically lower part of L2



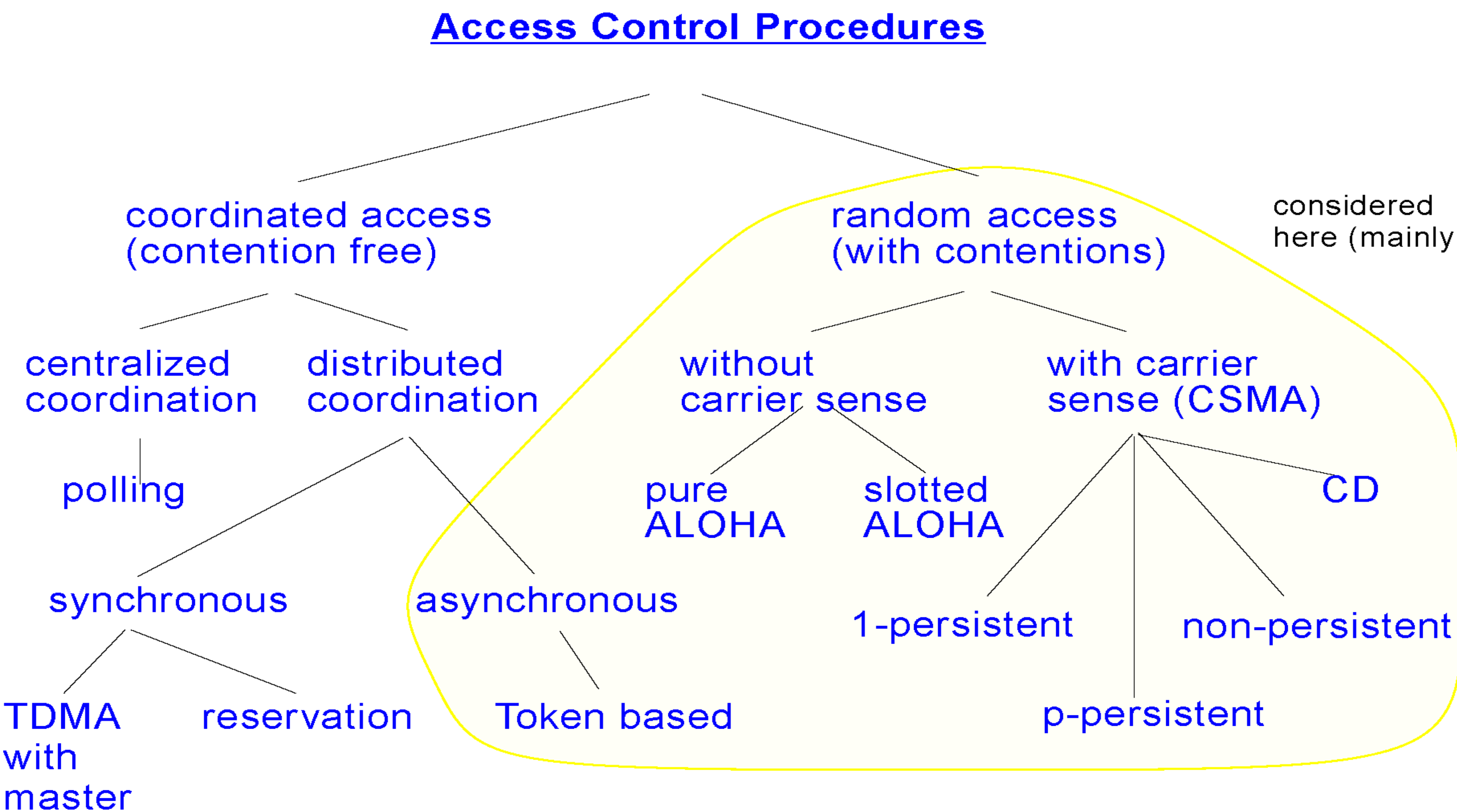


Static Channel Allocation in LANs and MANs

- 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

Station Model
- N independent stations (computers, ...) generating frames for transmission
- station is blocked until frame has been successfully transmitted

Single Channel Assumption
- single channel for all communication (all can send / receive)

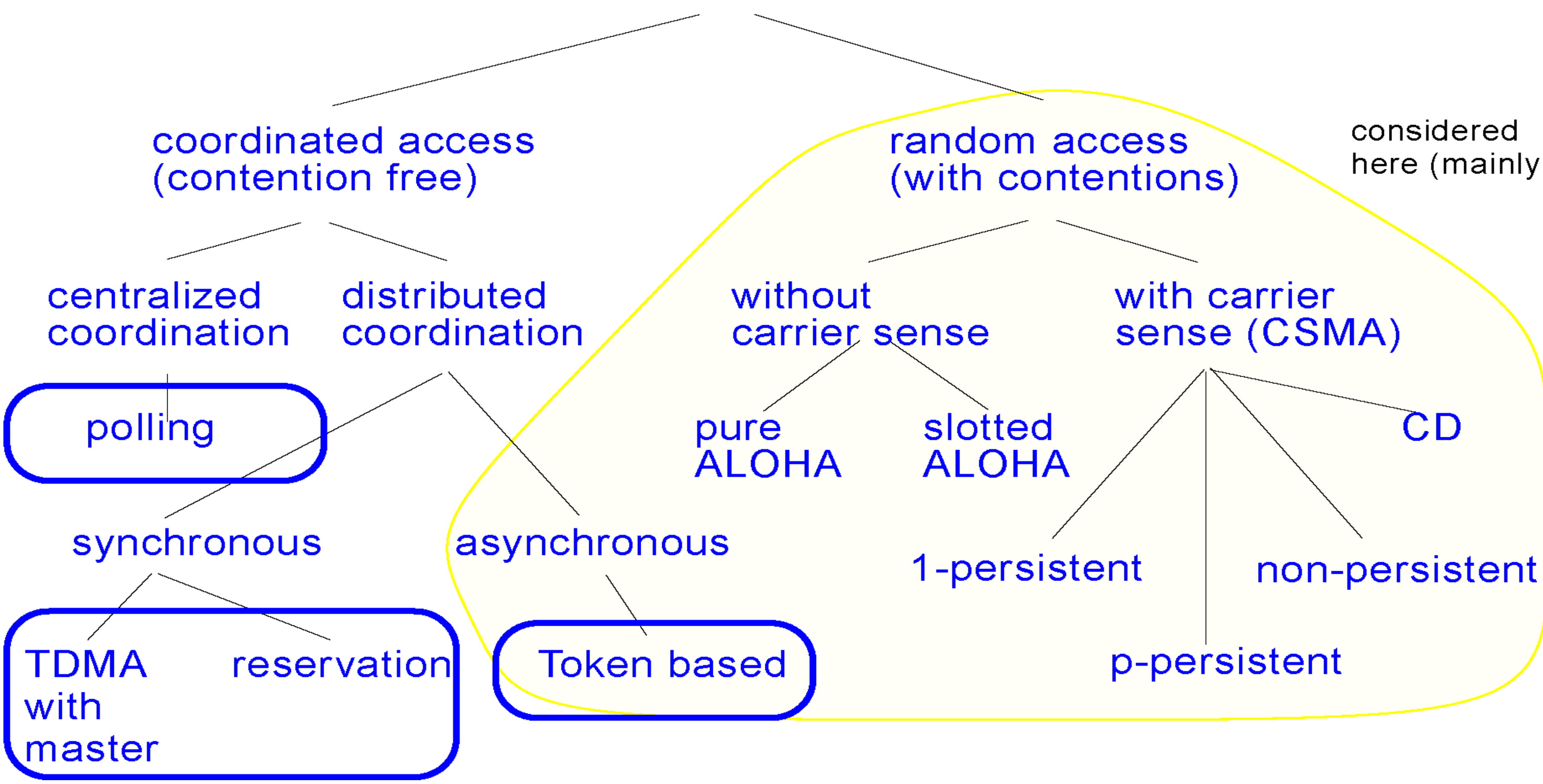
Collision Assumption
- 2 frames transmitted simultaneously
  → overlap
    → signal is garbled
      → collision
- stations can detect collisions

Time
- Continuous Time
  - frame transmission may start at any instant;
  - no master clock

Slotted Time
- time divided into discrete intervals (slots)
- frame transmission always begins at the start of slot
- slot may contain 0, 1, 2, ... frames
  - idle, successful transmission, collision

Without or with Carrier Sense
- 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
- No Carrier Sense
  - stations cannot sense channel before trying to use it

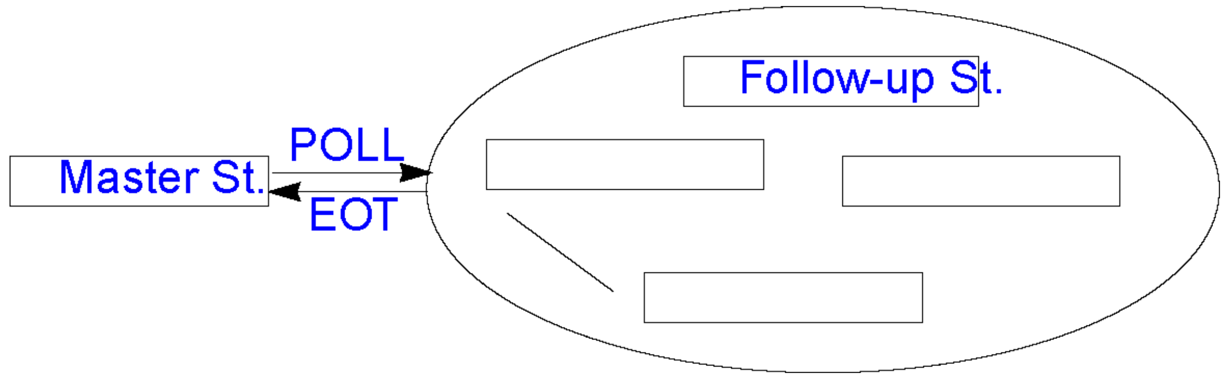
Access Control Procedures



3.1 Polling

Master Control Station

```
LOOP
 FOR I = 1 TO N
 DO
  POLL StationI;
  /*
   Request To Send
  */
  Expected EOT of Station I; /* End of Transmission*/
END; END;
```

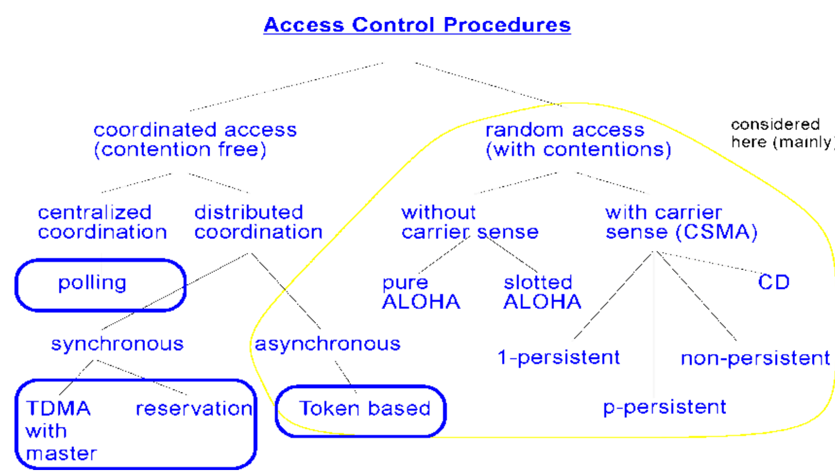


Follow-up Station X

```
LOOP
 Expect Poll for Station X;
 IF Desire to Send to Station I
  THEN Send Message for Station I;
 EOT to Master Control Station;
END;
```

Downside

- Master Control Station failure
- unnecessary querying if requests for transmission do not exist



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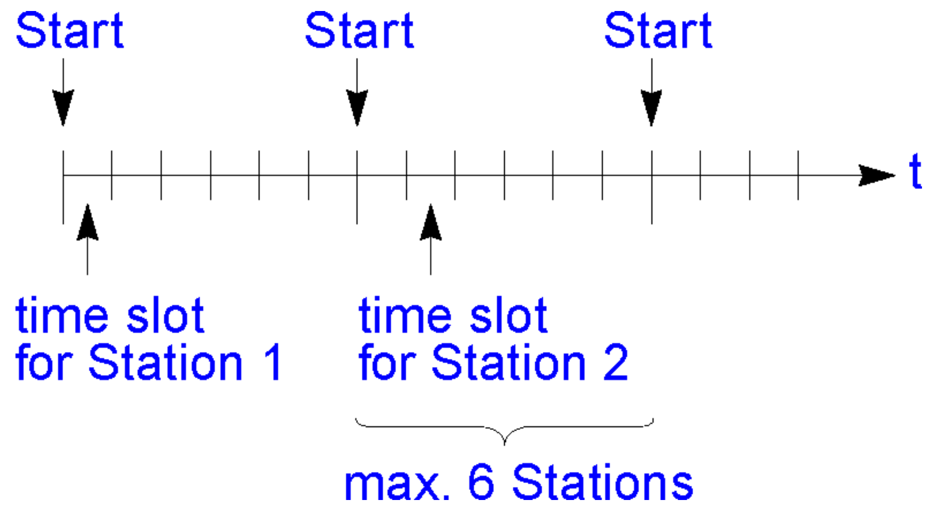
3.2 TDMA (Time Division Multiple Access)

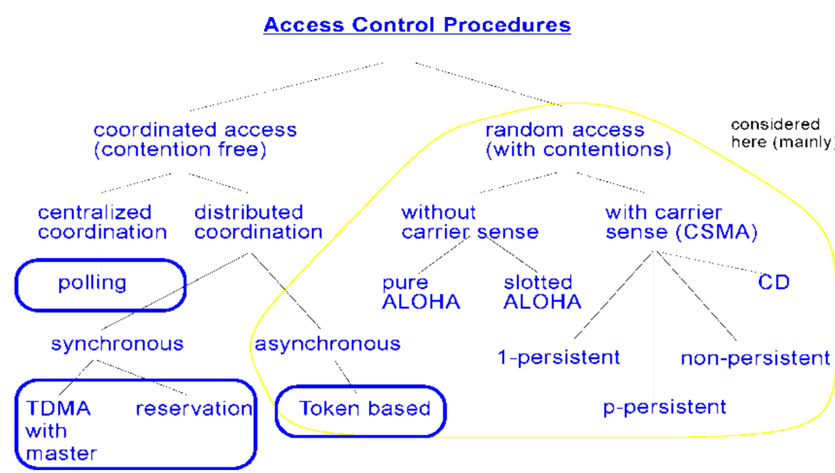
Station X

```
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;
```

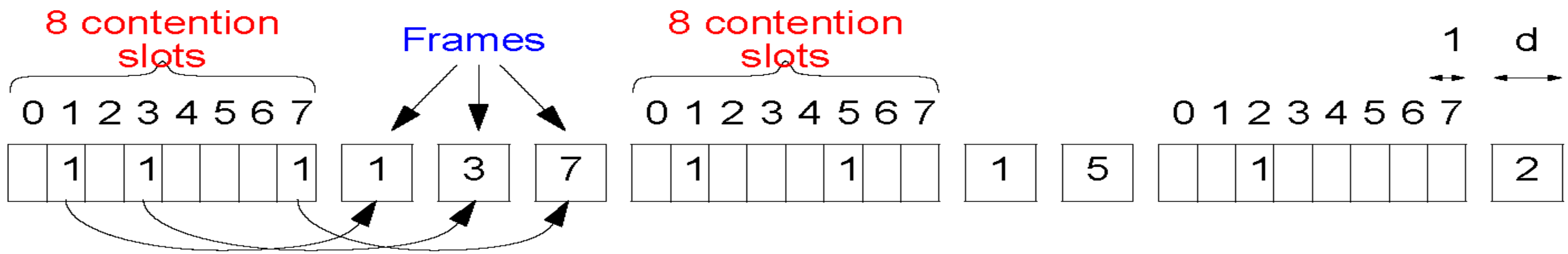


Downside

- poor channel usage
  - at stations with low transmission load
- unused channel capacity is kept available
  at a varying number of stations
- centralized pulse synchronization

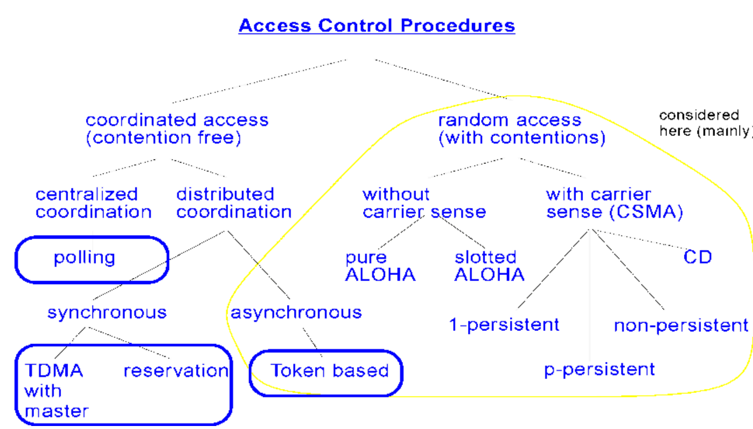


TDMA Collision-Free: Reservation



Principle:

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



Features:

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

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

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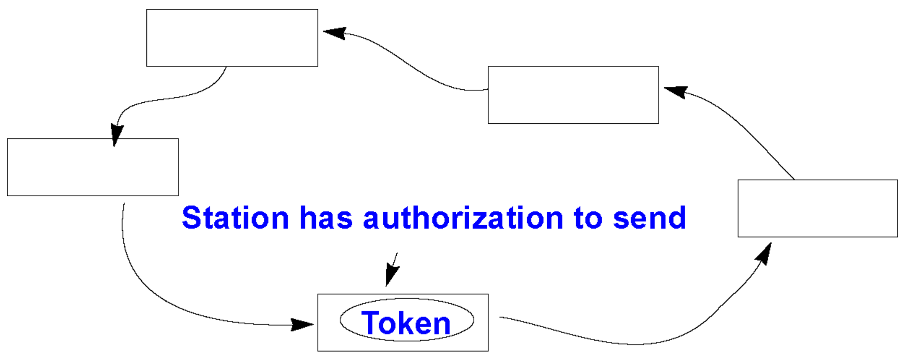
Example:

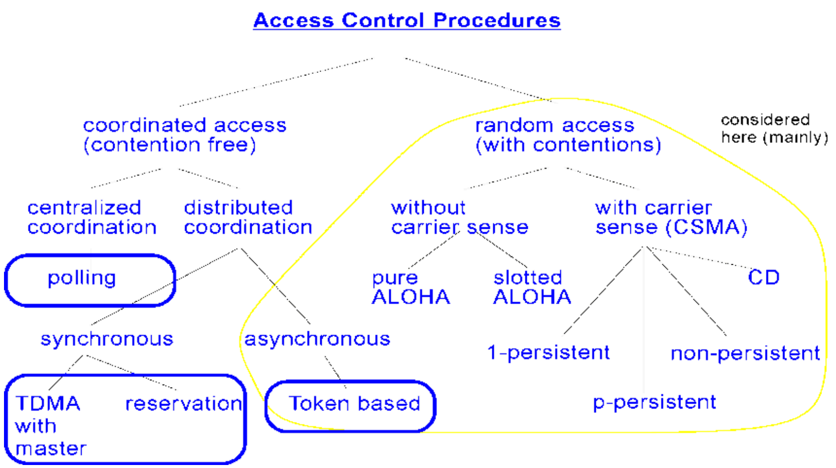
Station X

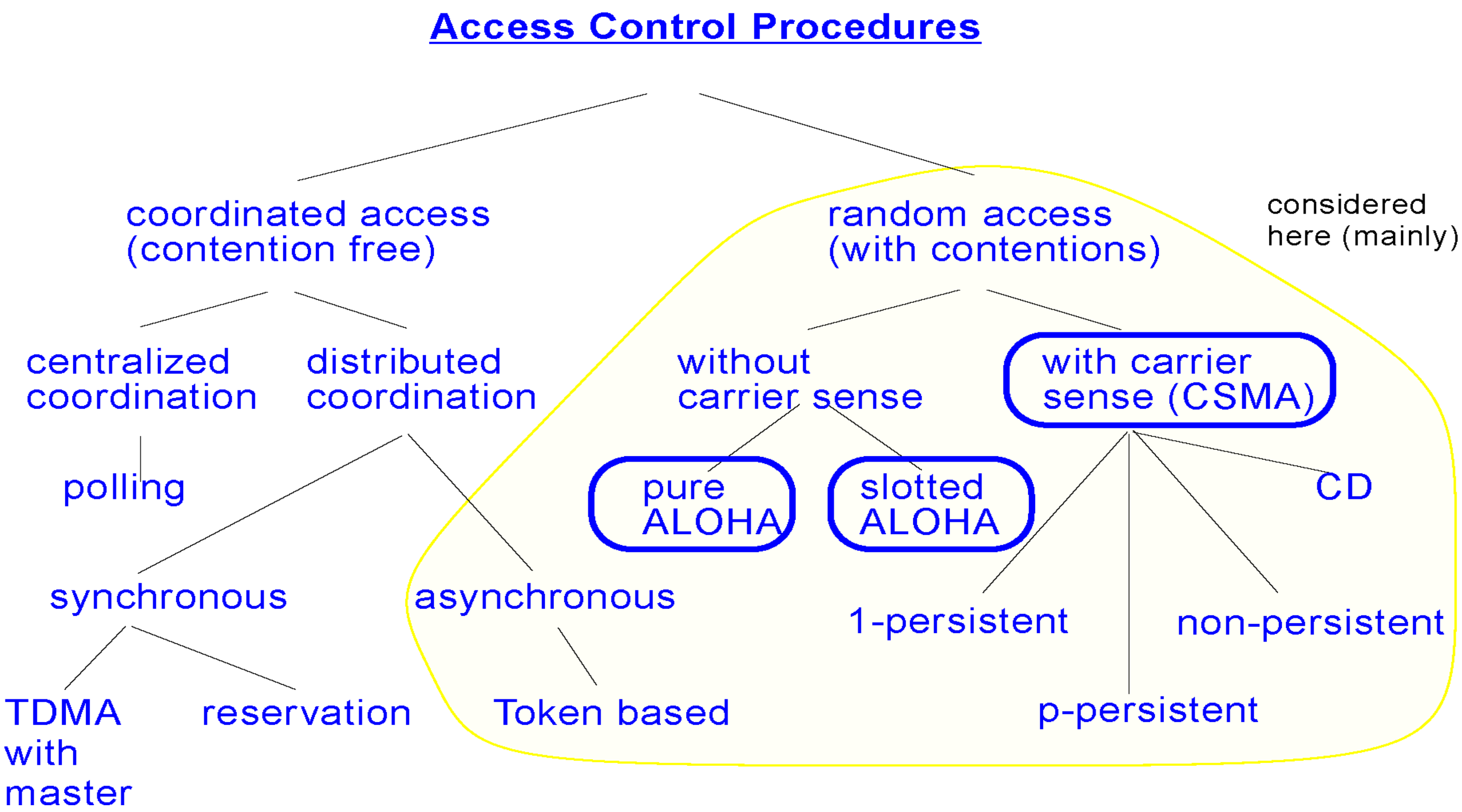
```
LOOP
 Expect Token;
 IF Desire to Send
  THEN Send Reference Message;
 Transmit Token to the Next
  Station;
END;
```



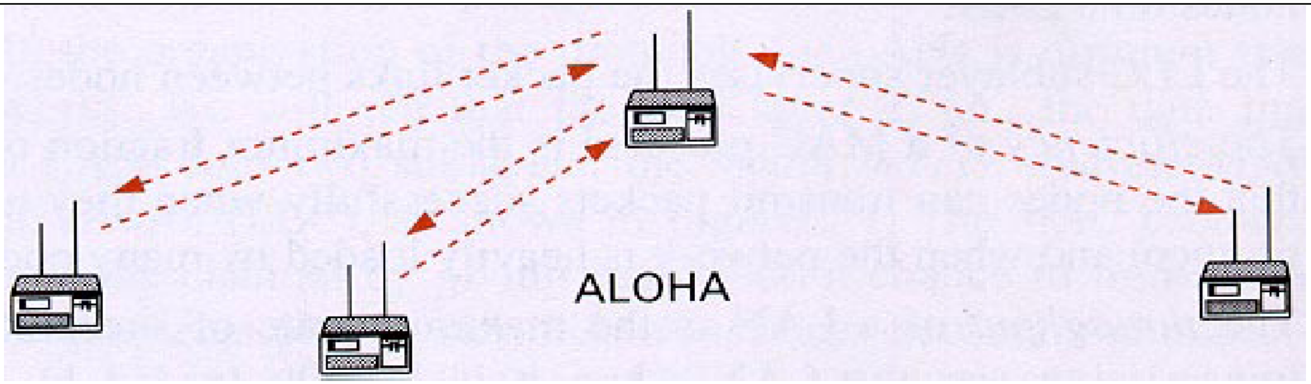
Principle

- 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




Access Control Procedures
coordinated access (contention free)
random access (with contentions)
considered here (mainly)
centralized coordination
distributed coordination
without carrier sense
with carrier sense (CSMA)
polling
pure ALOHA
slotted ALOHA
CD
synchronous
asynchronous
1-persistent
non-persistent
TDMA with master
reservation
Token based
p-persistent

4.1 ALOHA



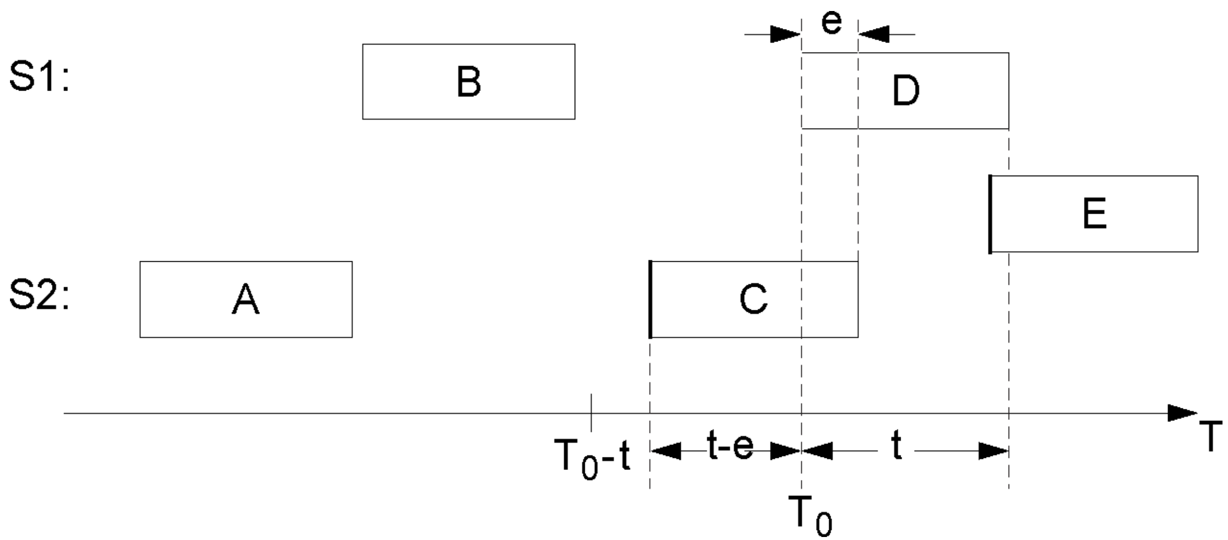
History

- University of Hawaii, 1970
- originally via radio station with 9.600 bps
  - 413 MHz: centralized sender (to everybody) on earth
  - 407 MHz: here all stations send to the sender

Principle:

- sending without any coordination whatsoever
- sender listens at the (return-)channel (after sending)
- in case of collision
  - retransmits after a random time interval

ALOHA: Example of a Collision



t . . . time for sending a frame

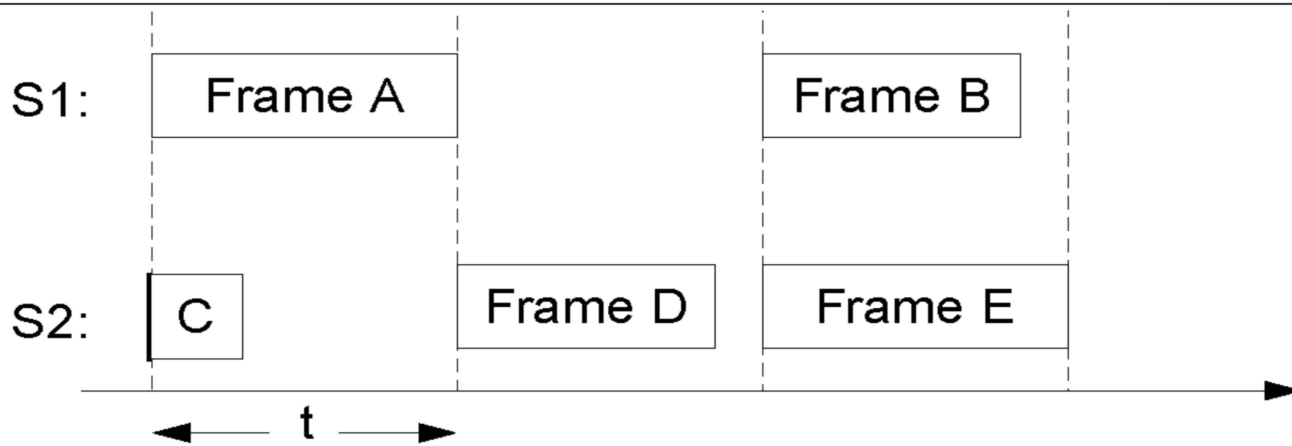
collision

- if (for C, s. a.) the beginning of frame (of D, s. a.) is between T0-t and T0+t
- collision window:

$$\lim_{\varepsilon \to 0} 2t - \varepsilon = 2t$$

Downside: high amount of collisions

Slotted ALOHA



Principle

- like Unslotted ALOHA, only
  - time of sending within a defined time pattern
- 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 lasts intoT_0+t
  - the time pattern cuts the collision window into half (= t)
- requires centralized synchronization

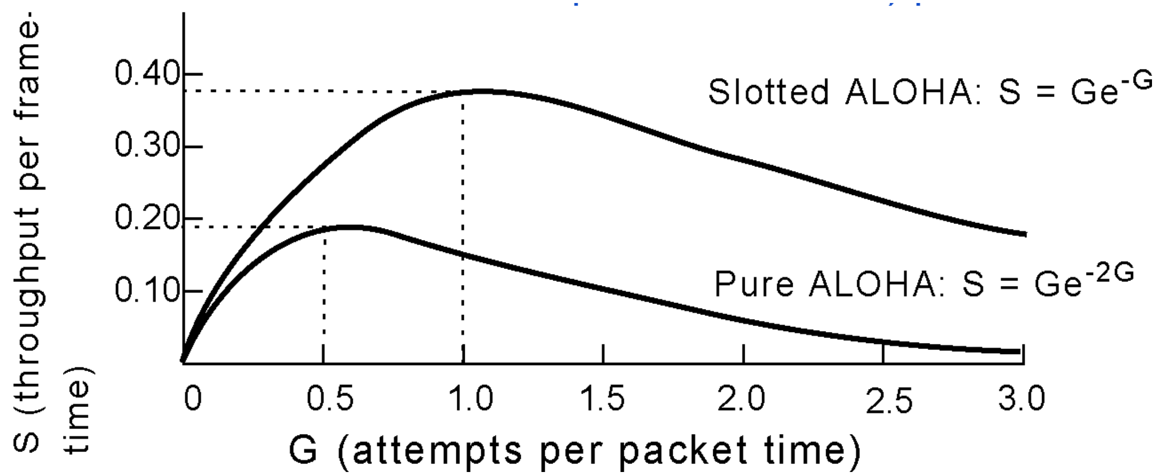
History

- University of Hawaii, 1972

Downside

- many collisions, but less than 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 means more channel capacity required than available,
  - i. e. almost always collision
- 0 < S < 1 means more sensible
- G: ALL requests to send
  - Retransmissions added to new requests to send S
  - per frame time

Maximum channel usage

- Unslotted ALOHA ≈ 18 %
- Slotted ALOHA ≈ 36 %

4.2 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:
    - no sending activity
    - wait until channel is re-checked
      OR
      keep checking continuously until channel is available

  - available:
    - send
    - still possibility for collision exists!

  - collision:
    - wait for a random time

CSMA Variation Non-Persistent

Principle

- Request to send → check channel
- channel status
  - busy:
    - wait without checking the channel continuously,
    - channel RE-CHECK ONLY AFTER A RANDOM TIME INTERVAL
  - available:
    - 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 THROUGHPUT (EFFICIENCY)
- longer delays for single stations

CSMA Variation 1-Persistent

Principle

- Request to send → channel check
- channel status
  - busy:
    - continuous re-checking until channel becomes available
  - available:
    - 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 a lot of collisions at higher load
  - low throughput

CSMA Variation P-Persistent

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Applied with "slotted" channels

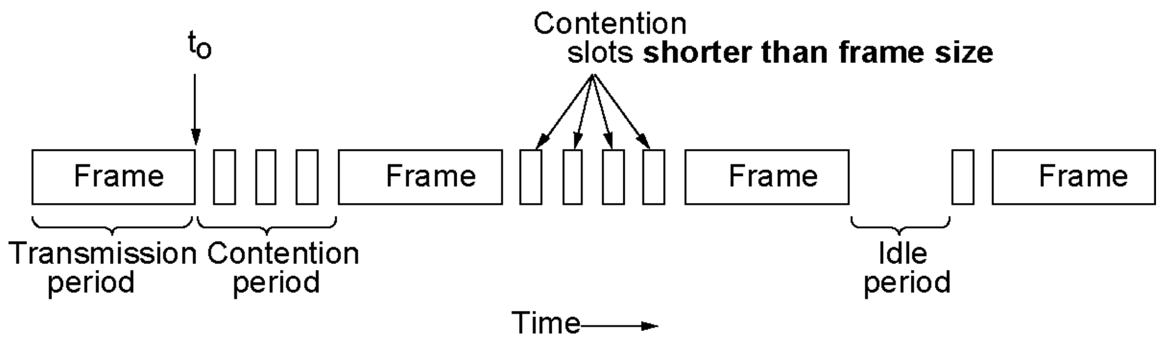
Principle

- Request to send → channel check
- channel status
  - busy:
    - wait for the next slot, re-check (continuously)
  - available:
    - Send with Probability p,
    - wait with probability 1-p for the next slot,
    - check next slot
      - busy: wait random time, re-check channel
      - available: send with probability p,
        wait for next slot with probability 1-p, ...etc.
      - collision: ..etc
  - collision:
    - wait random time, re-check channel

Properties

- COMPROMISE BETWEEN DELAY AND THROUGHPUT
- defined by parameter p

CSMA Variation CD



Carrier Sense Multiple Access with Collision Detection

- CSMA 1-persistent with CD

Principle:

- sending station interrupts transmission as soon as it detects a collision
  - saves time and bandwidth
  - frequently used (802.3, Ethernet)
  - algorithm
    - station has to realize DURING the sending of a frame if a collision occurred

Extreme case:

- short frame, maximum distance to station

CSMA Variation CD: Extreme Case

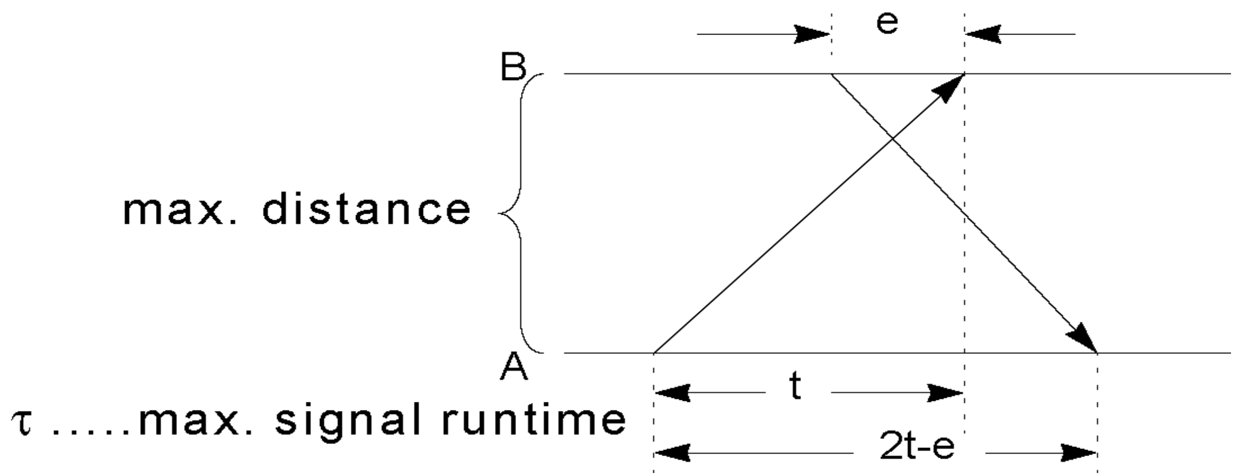
Extreme Case:

- short frame, maximum distance to station

station can be certain only after 2τ

- that it has occupied the channel with no collision
- (1 km coax cable: τ ≈ 5 μs)

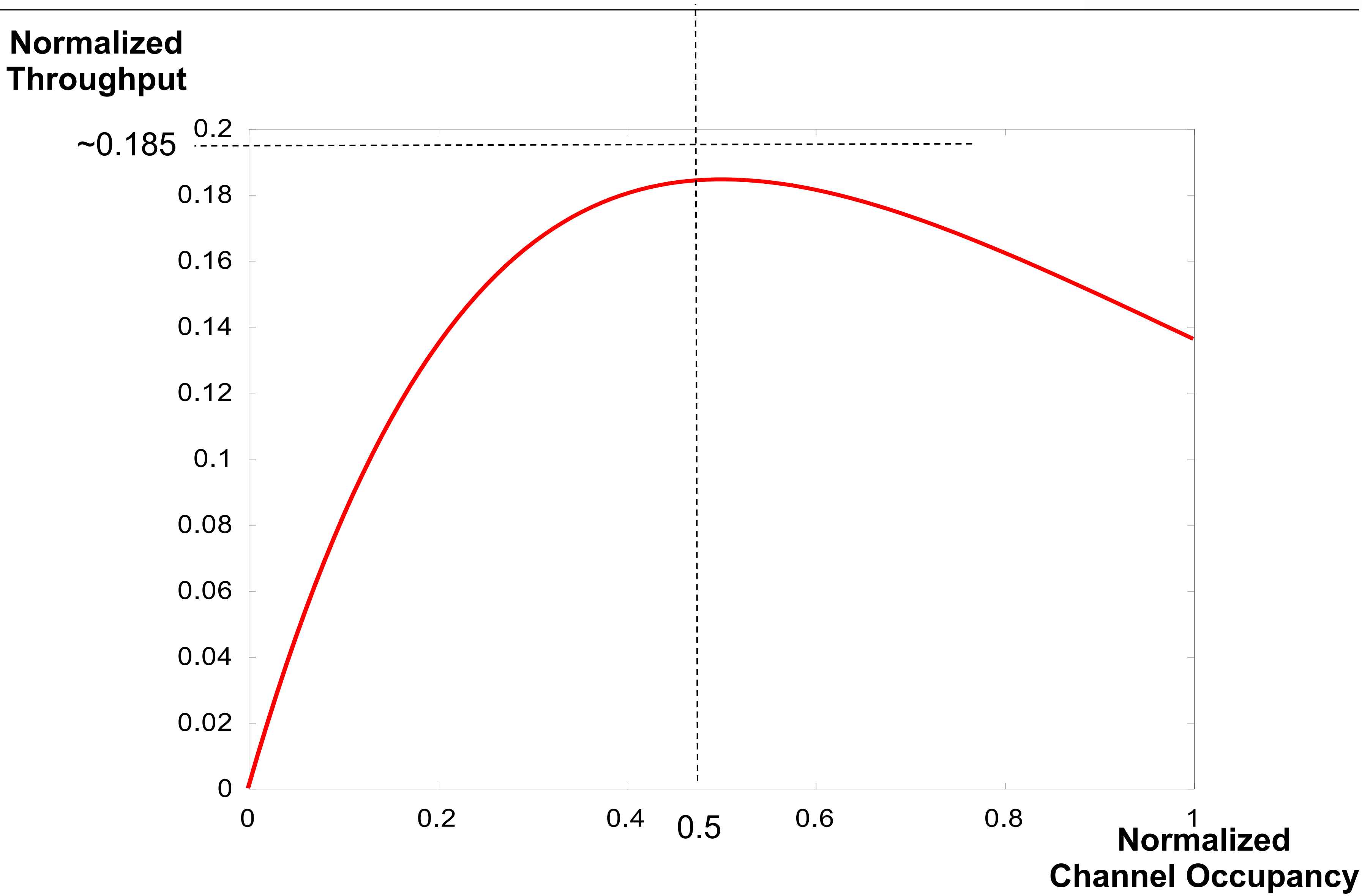
collision window



4.3 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	available	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) (depending on algorithm "available/ busy")	
	1 persist.	X		(X)	Continuous wait until channel is Available			
	p persist.	X		(X)	initially: continuous wait until chnl/slot available	sends with probability p, waits with probability 1-p (for next slot, then re-checks status)		X
CSMA/CD		X	X		depending on procedure, (see above) 1-persistent is e.g. Ethernet		Terminates sending immediately, waits random time	

Throughput of e.g. Aloha



Comparing Performance: CSMA, ALOHA

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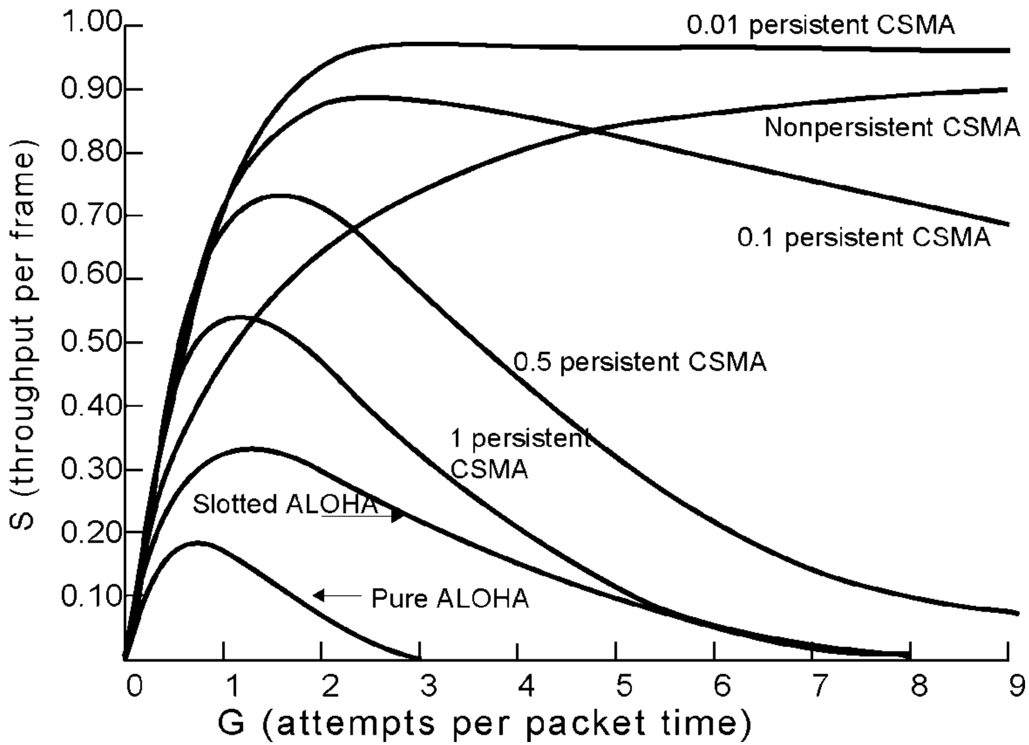
Normalized Throughput



Normalized Channel Occupancy

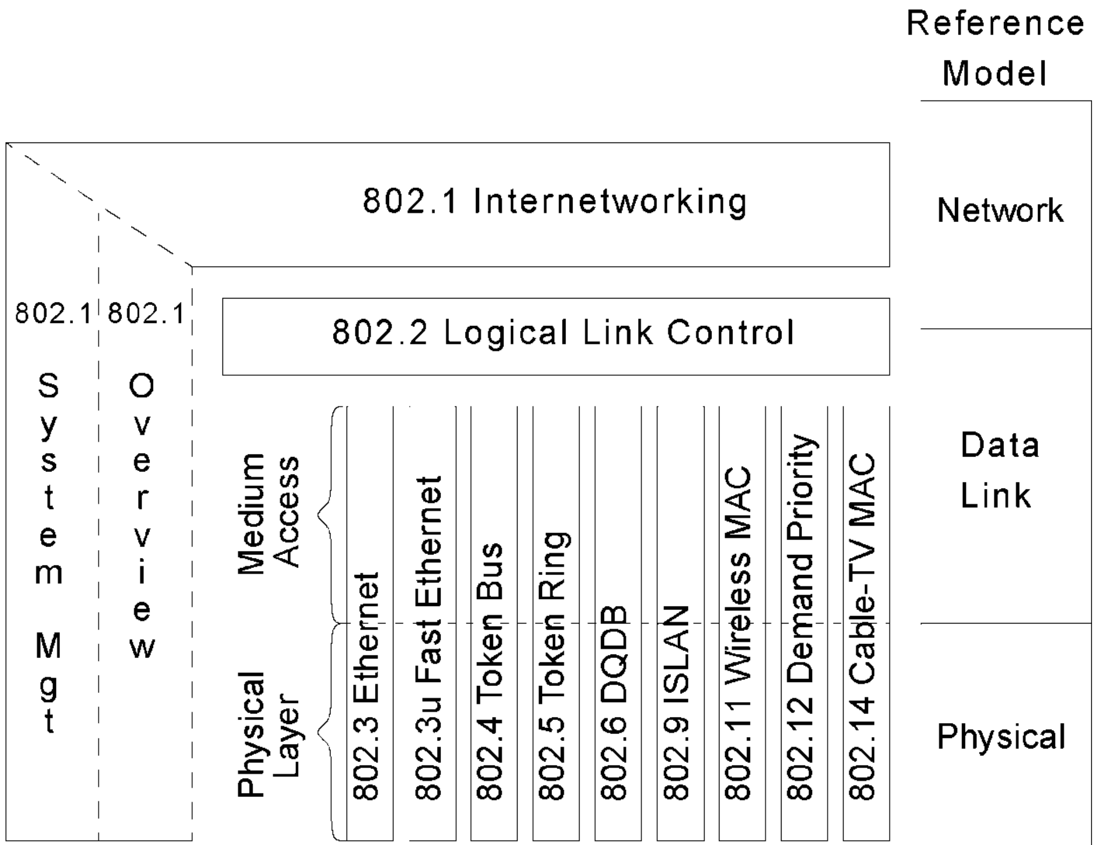
S channel usage / throughput per frame

- i. e. new requests to send, per frame sending time t
- note: possibly long delay

G load (trials per frame-time)

- i.e. all requests to send per frame time
  - re-transmissions added to new requests to send S

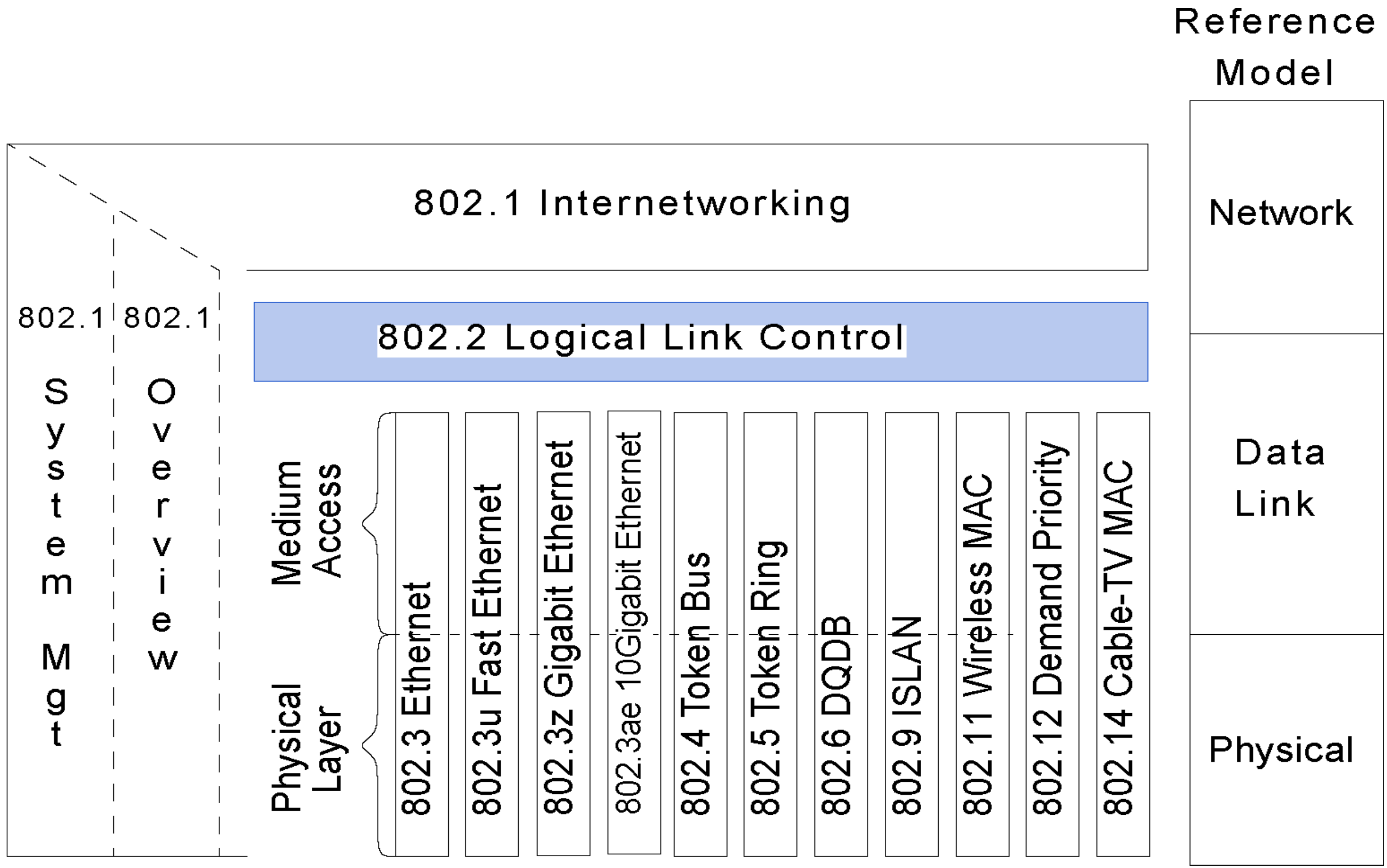
5 Reference Model and Logical Link Control



e. g.

- IEEE 802.3 Ethernet
- IEEE 802.3u Fast Ethernet
- IEEE 802.3..... .....

802.2: Logical Link Control



802.2: Logical Link Control (LLC)

Function

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

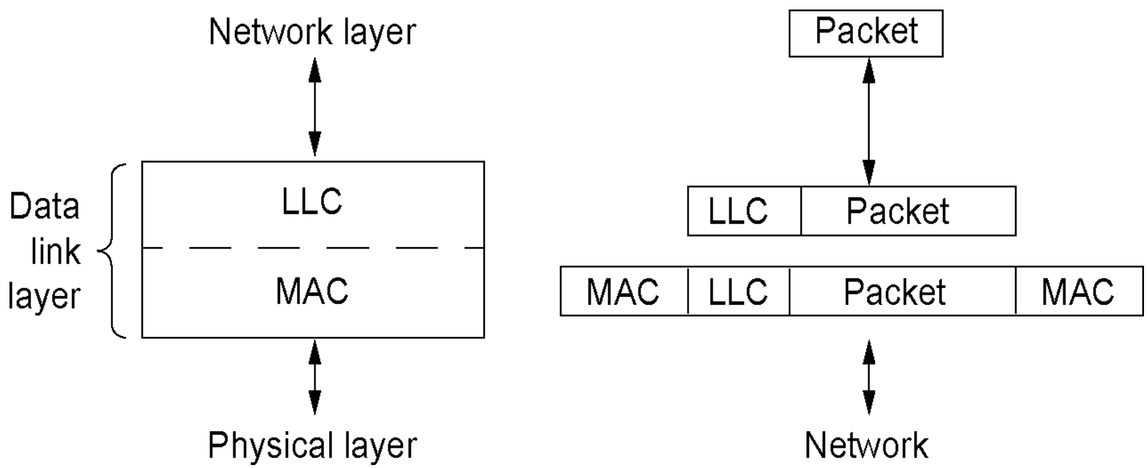
Services

- unacknowledged connectionless (unreliable datagram)
  - upper layers ensure
    - that sequence is maintained, error correction, flow control
- acknowledged connectionless (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

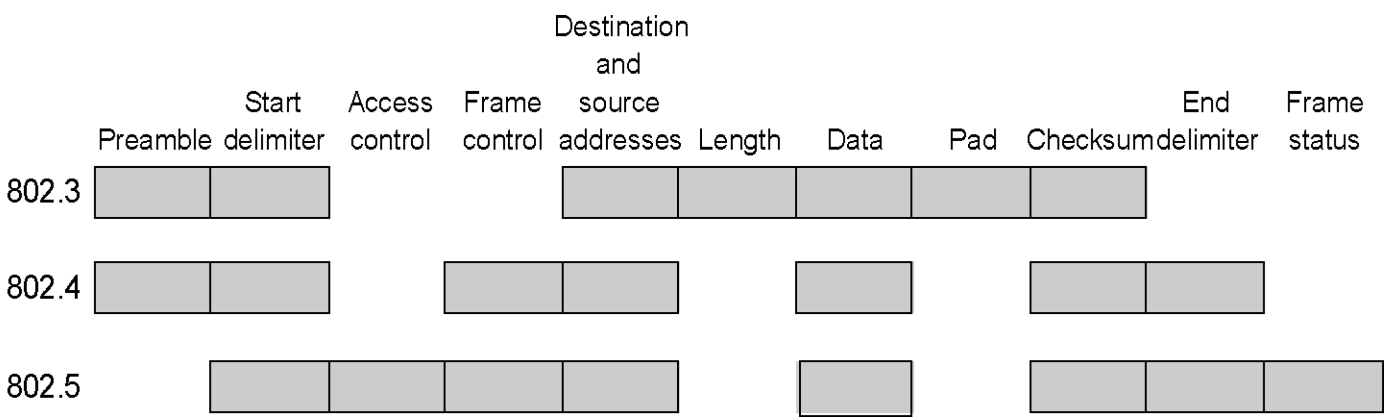
Format

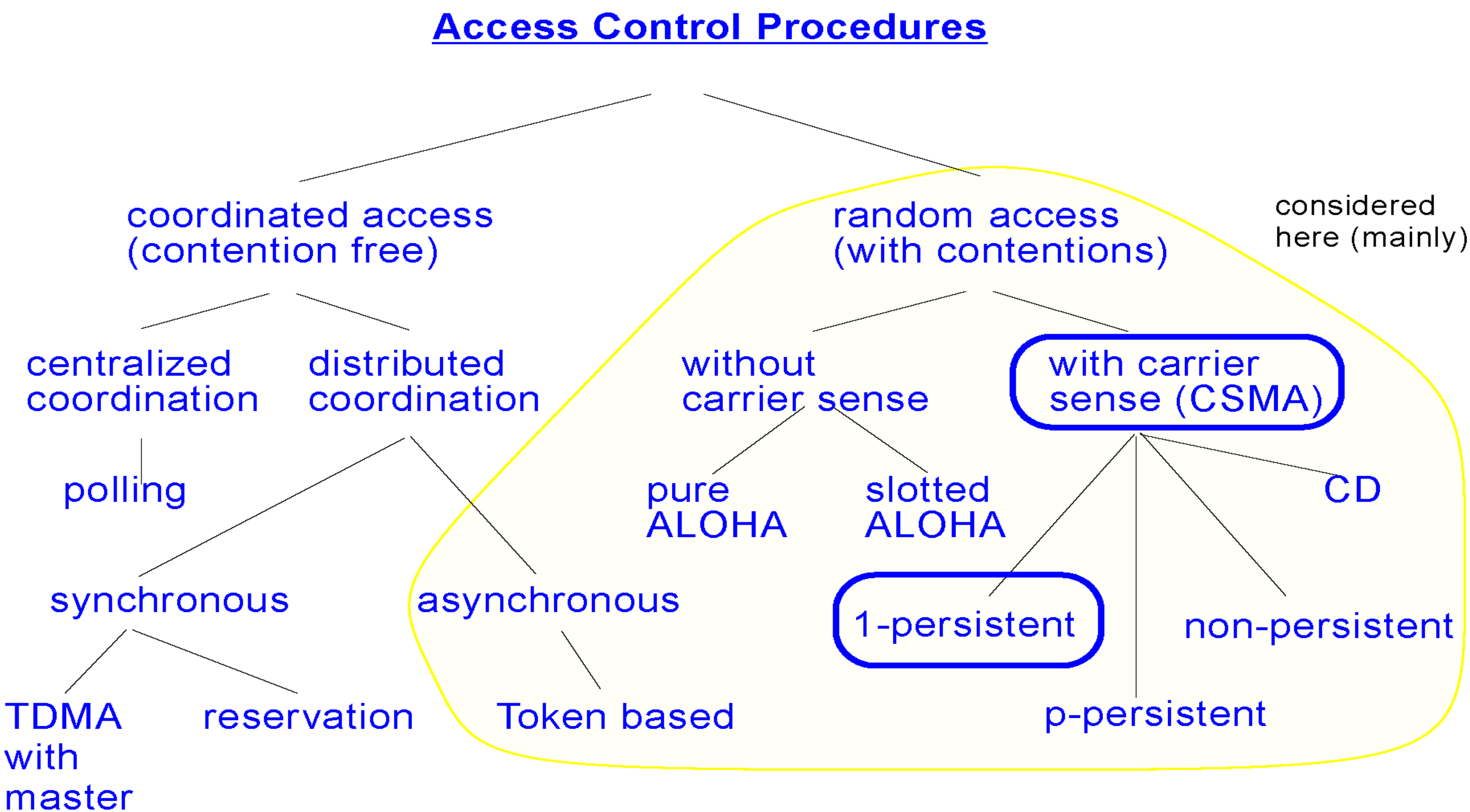
- includes LLC Service Access Points SAPs for source and destination



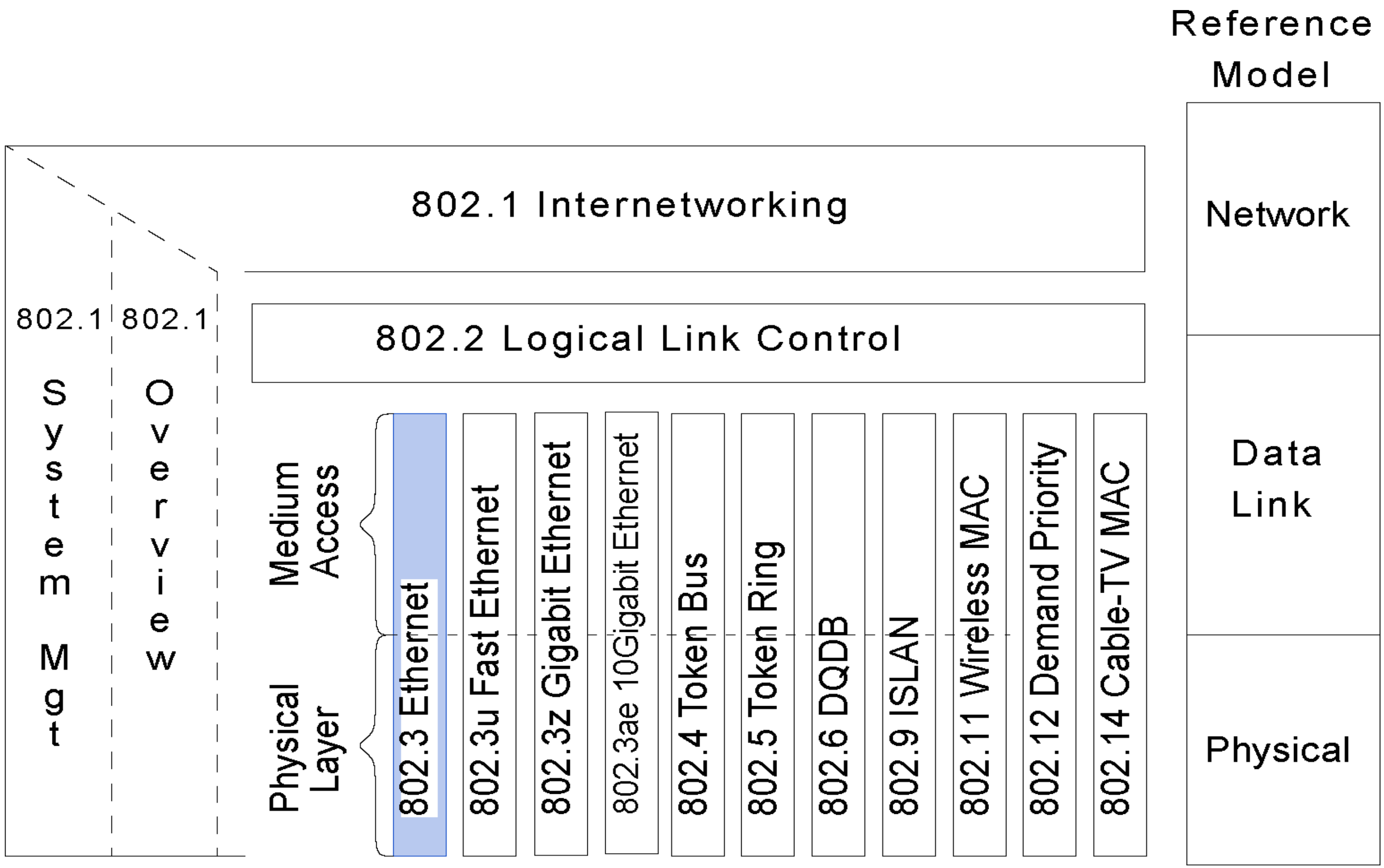
Varying AC frames:

- formats




Access Control Procedures
coordinated access (contention free)
random access (with contentions)
considered here (mainly)
centralized coordination
distributed coordination
without carrier sense
with carrier sense (CSMA)
polling
pure ALOHA
slotted ALOHA
CD
synchronous
asynchronous
1-persistent
non-persistent
TDMA with master
reservation
Token based
p-persistent

6.1 802.3: History and Basics



IEEE 802.3: CSMA / CD

History

- 1976
  - Ethernet by Xerox,
    Robert Metcalf (2,94 Mbps)
- 1980
  - Ethernet industrial standard by Xerox, Digital Equipment (today part of HP) and Intel (10 Mbps)
- 1985
  - IEEE 802.3 based on Ethernet

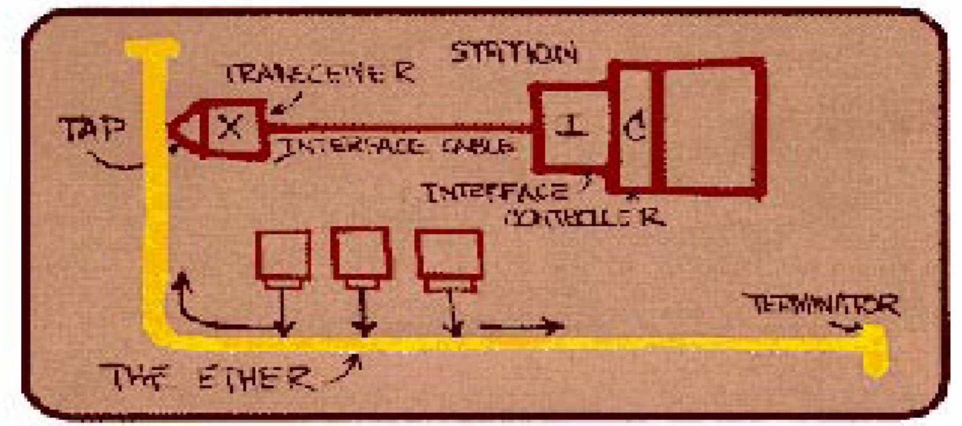


Figure 1. Robert Metcalfe's drawing of the first Ethernet design.

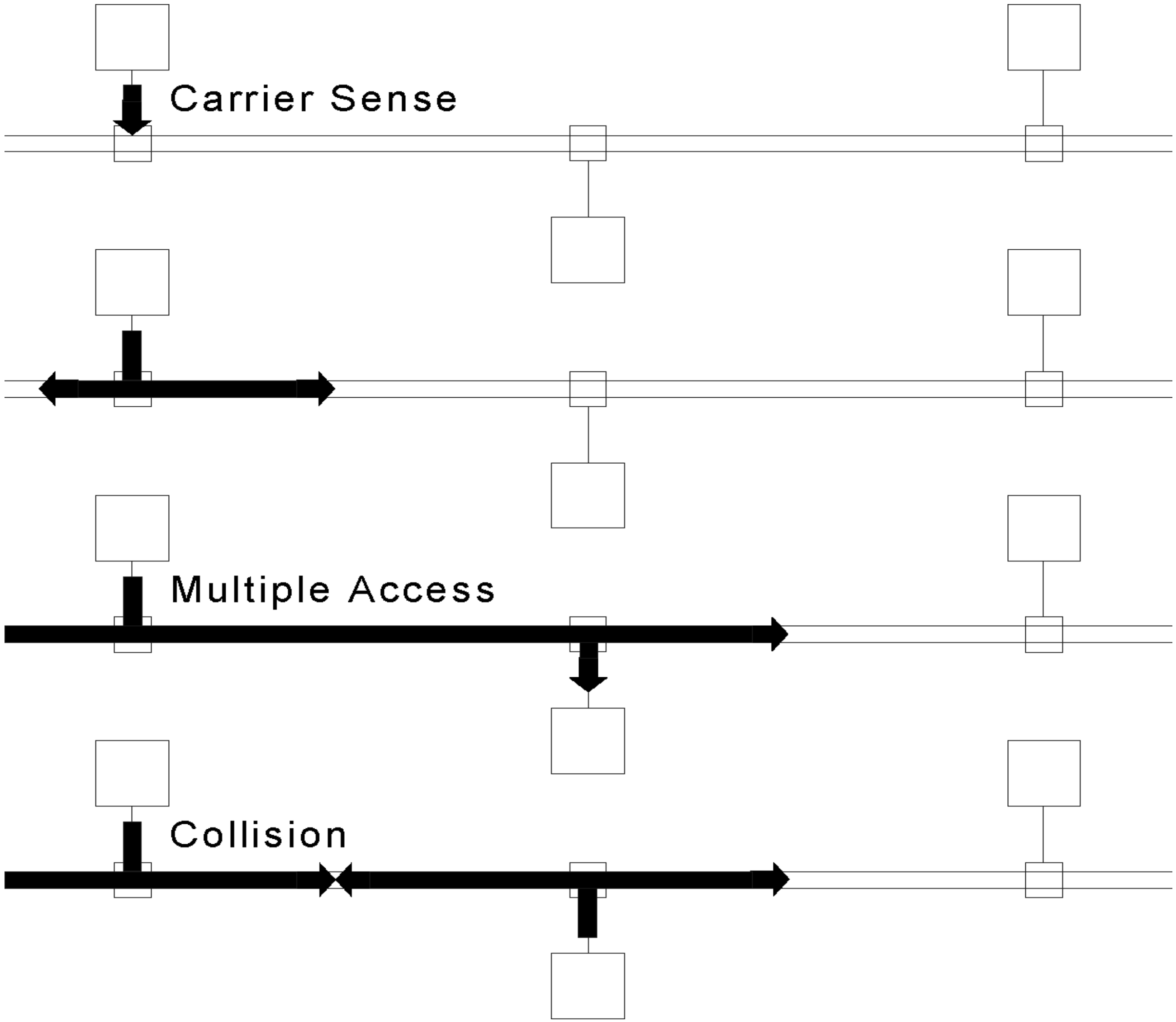
IEEE 802.3

- specifies a family based on the 1-persistent CSMA/CD systems
- (1 -) 10, 100 Mbps, 1, 10, 100, … Gbps on different media
- Ethernet is a protocol of this family

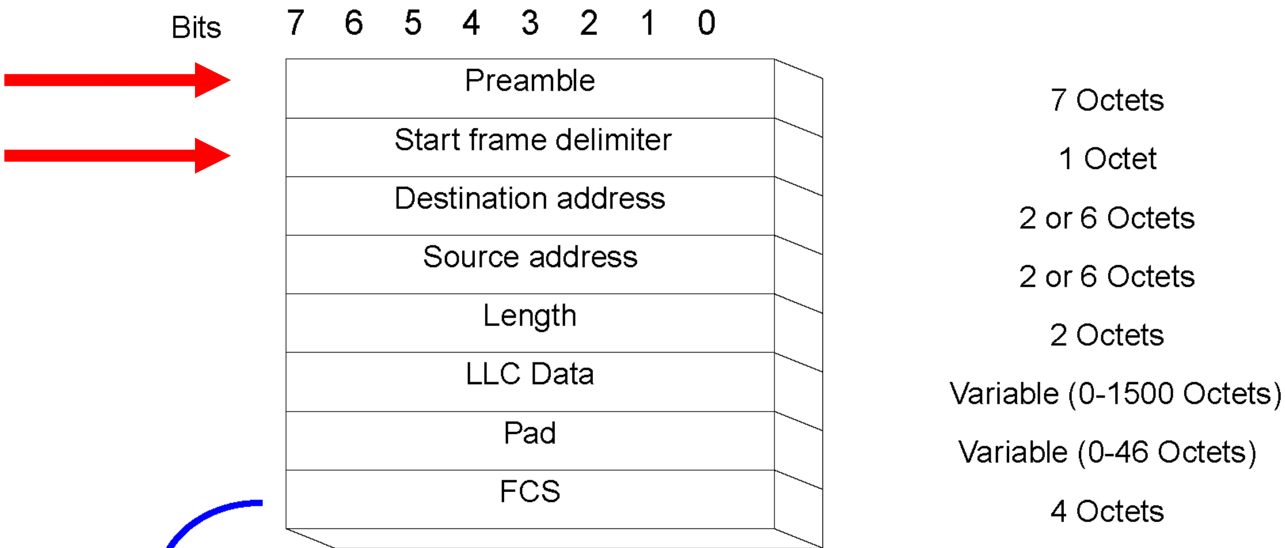
1-persistent CSMA / CD

- L1:
  - Manchester Encoding
    - (on all cables except for 10BROAD36 broadband, here DPSK)

IEEE 802.3: CSMA / CD



6.2 802.3: Frame Format



7 byte	1 byte	2/6 byte	2/6 byte	2 byte	46-1500 byte	0-46 byte	4 byte
PA	SFD	DA	SA	L	Data	PAD	FCS

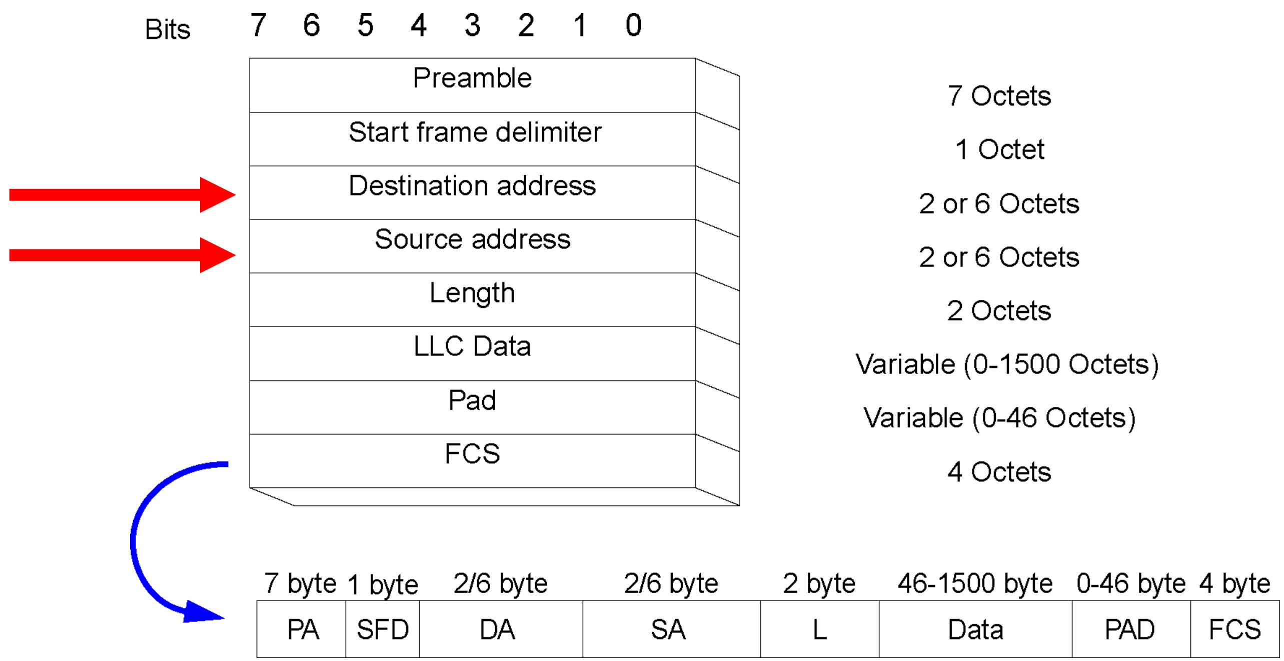
Preamble:

- always 7 times 01010101
- synchronization of the receiver

Start Frame Delimiter:

- beginning of the frame (10101011)

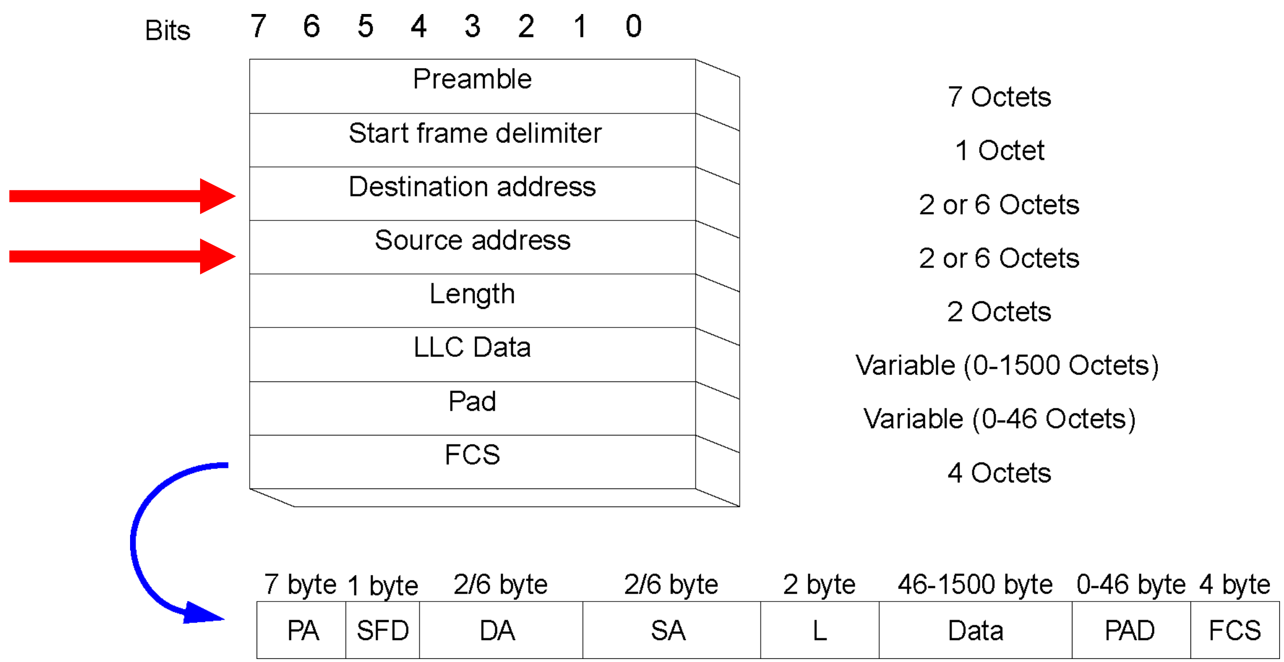
802.3: Frame Format



Destination Address and Source Address:

- individually, group, all:
  - unicast → individual address
  - multicast → group address
  - broadcast → all address bits are "1"

802.3: Frame Format



.. Destination Address and Source Address: (cont)

- 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

.. Destination Address and Source Address: (cont)

- …
- addressing in 6 byte/48 bit format (COMMON PRACTICE)
  - common practice (e.g. 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
    - 7,03E+13 (7,03 x 10^13) potential addresses
    - L3 (network layer) has to locate address

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**

802.3: Frame Format

Bits 7 6 5 4 3 2 1 0	
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	Variable (0-1500 Octets)
Pad	Variable (0-46 Octets)
FCS	4 Octets

7 byte	1 byte	2/6 byte	2/6 byte	2 byte	46-1500 byte	0-46 byte	4 byte
PA	SFD	DA	SA	L	Data	PAD	FCS

Length:

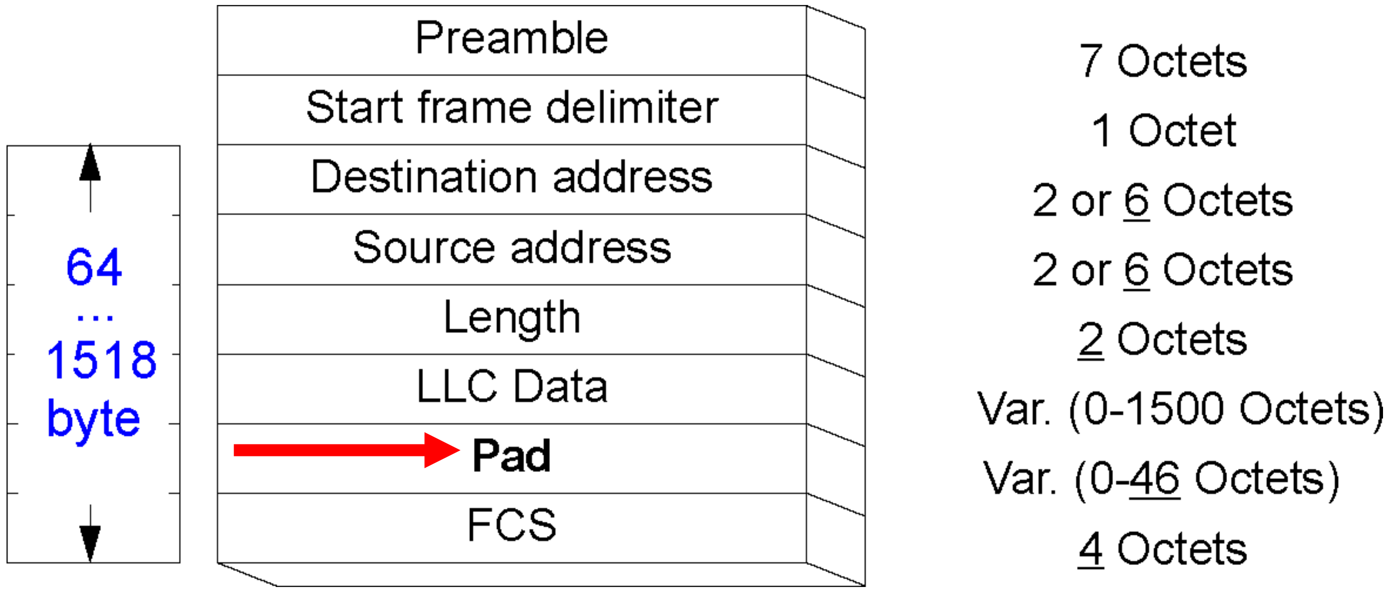
- number of bytes in LLC Data
- encoded within 2 bytes

LLC Data:

- 0 - 1 500 bytes actual data

Frame Check Sum

Pad:



- min. frame length = 64 bytes (=6+6+2+46+4)
  - for a more simplified recognition of collisions please see below
- shorter frame length is an invalid frame

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

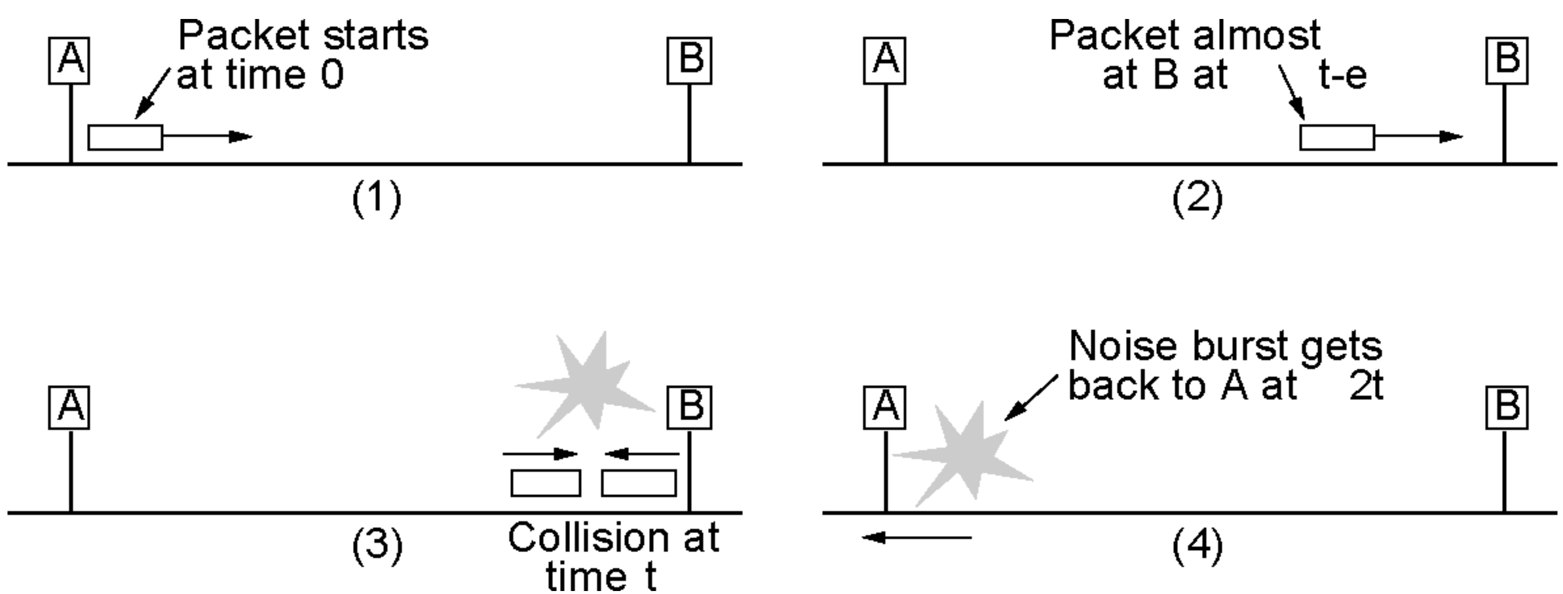
Frame Length – Padding: Some Details

- "IEEE 802.3 packets have minimum size restrictions based on network bandwidth
- When necessary, the data field should be padded (with octets of zero)
  - to meet the 802.3 minimum frame size requirements.
- Padding is
  - not part of the IP packet and is
  - not included in the total length field of the IP header."
- see e.g.
  - www.zvon.org/tmRFC/RFC948/Output/chapter3.html

6.3 802.3: Frame Format – Details on Minimum Length

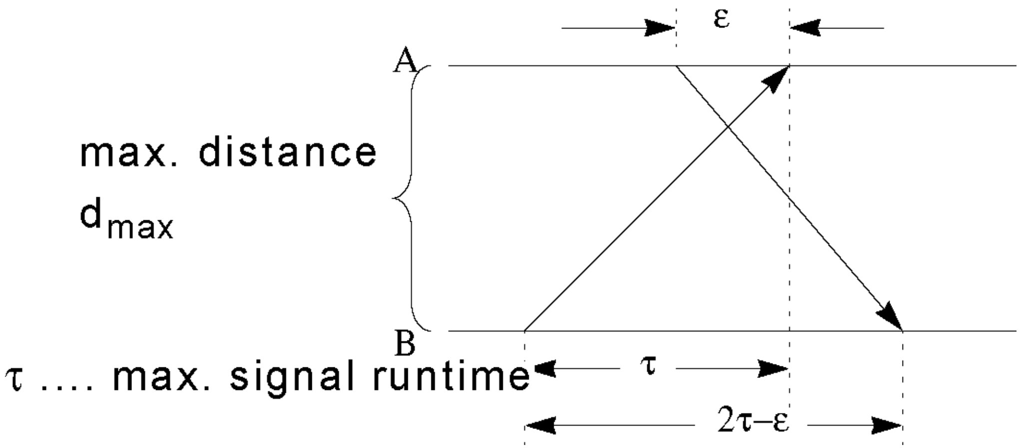
Reason (for minimum length):

- transceiver interrupts frame handover during collision
  - i. e. short invalid frames appear
- algorithm
  - station should recognize during sending of a frame if a collision occurred
  - extreme case:
    - short frame & station at maximum distance



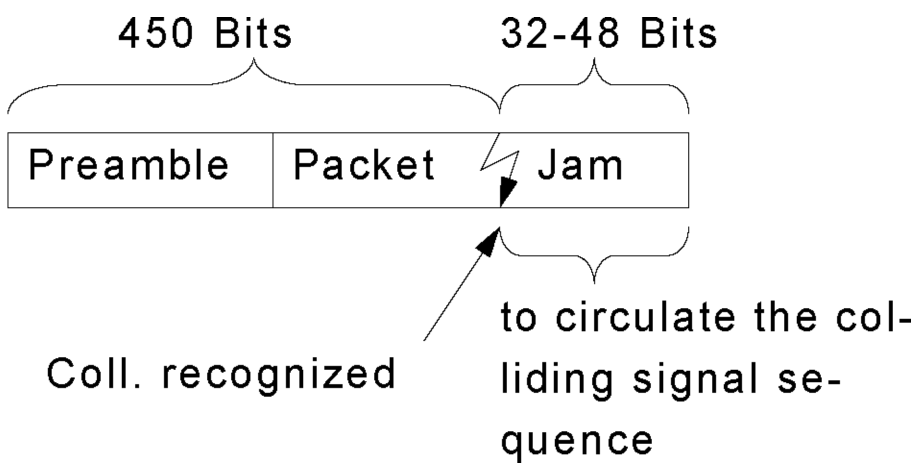
802.3: Frame Format

- collision window



- 802.3 Frame Format

Example: calculation with a length of 450 bit (>56 Byte)



802.3: Frame Format

time to send 450 bits at 10 mbps :

$$\frac{450 \text{ bits}}{10 \times 10^6 \text{ bits/sec}} = 45 \mu\text{sec}$$

- collision window:
  - 2τ , during this time 450 bits still have to exist at least on the line of the length 2*dmax $2\tau \leq 45 \mu\text{sec}$
  - with $\frac{2\mathbf{d_{max}}}{\mathbf{v}} = 2\tau$ $\mathbf{v} = 2 \times 10^5 \frac{\text{km}}{\text{sec}}$ (copper)
  - resulting in $\frac{2 \cdot \mathbf{d_{max}}}{\mathbf{v}} \leq 45 \mu\text{sec}$

$$\mathbf{d_{max}} \leq \frac{45 \mu\text{sec} \cdot 2 \times 10^5 \text{km}}{2 \qquad \text{sec}}$$

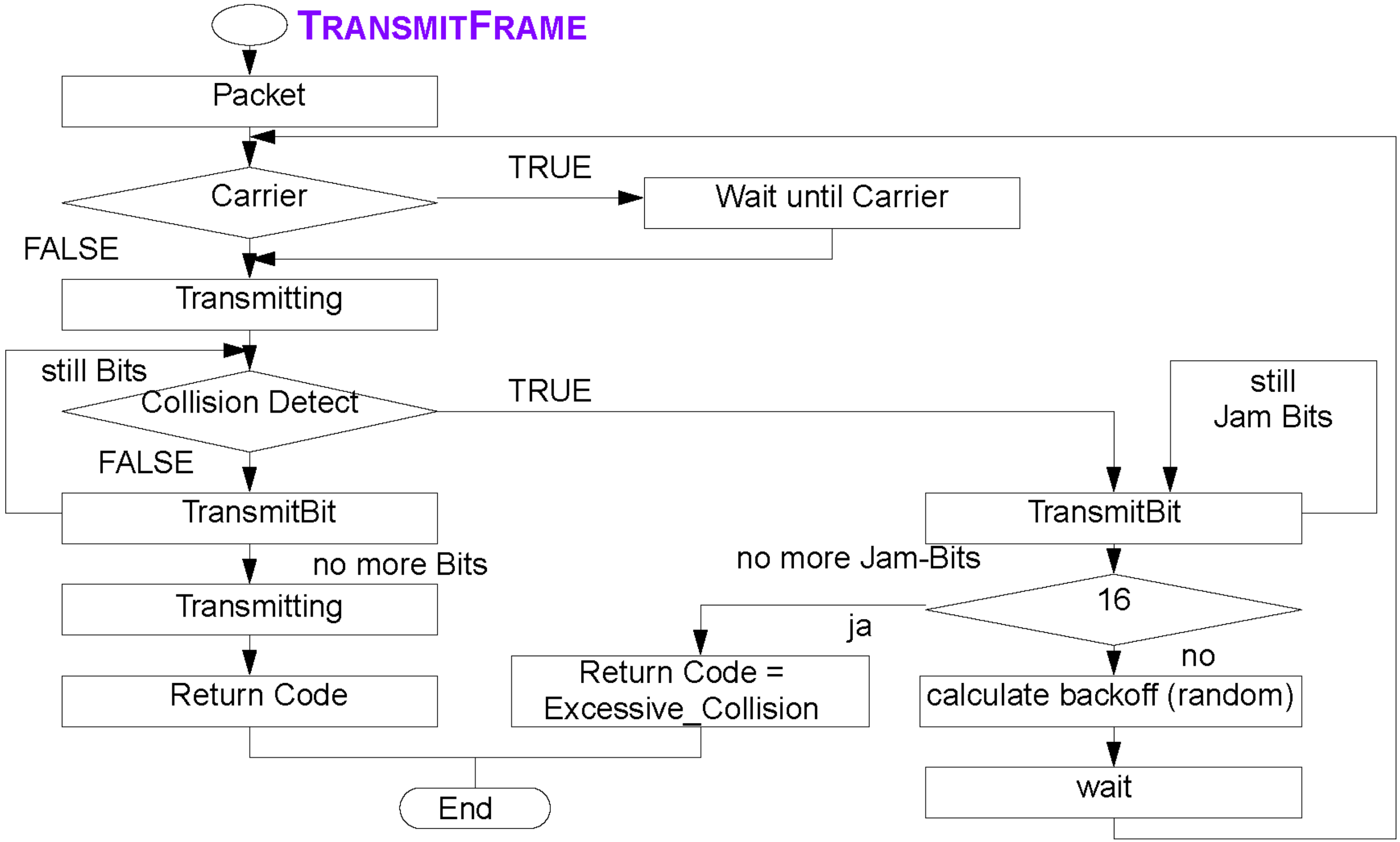
$$\mathbf{d_{max}} \leq 4,5 \text{km}$$

802.3: Frame Format

- comment:
  - the sample calculation above constitutes the calculation of the theoretical maximum distance between two stations

- behavior if parameterized differently:
  - with higher data rates
    - the minimum frame size is large
    - e. g. 1 Gbps (expansion 2,5 km) 6400 bytes
  - data rates increased but frame size the same: shorter distance possible

6.4 802.3: Control Flow

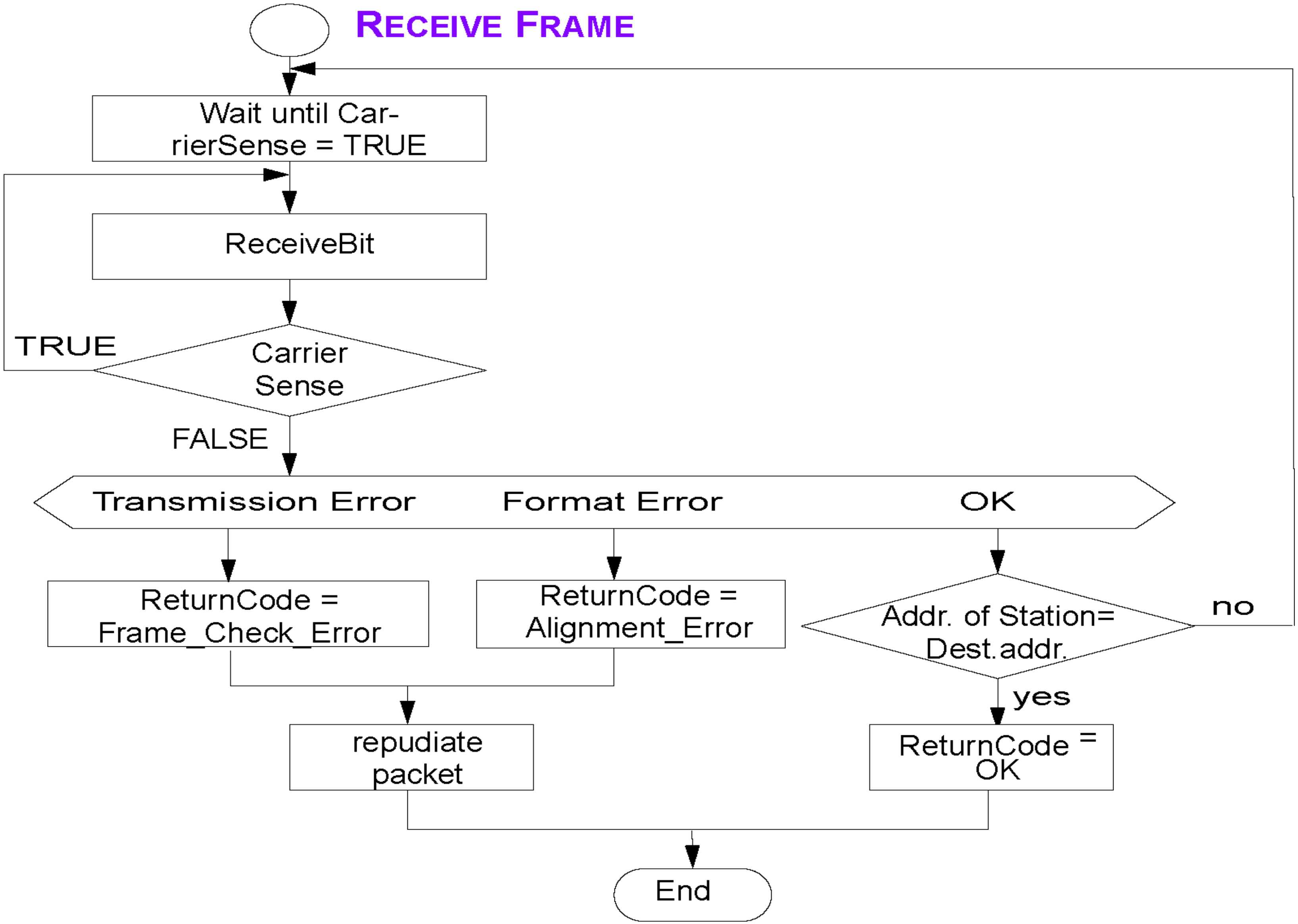


backoff = r • Δt with Δt = send time for 512 Bits (51,2 µs)

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

n = number of unsuccessful attempts to send

802.3: Control Flow



6.5 802.3: Behavior at a Collision

... collision after first request to send	next attempt after a waiting ... 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

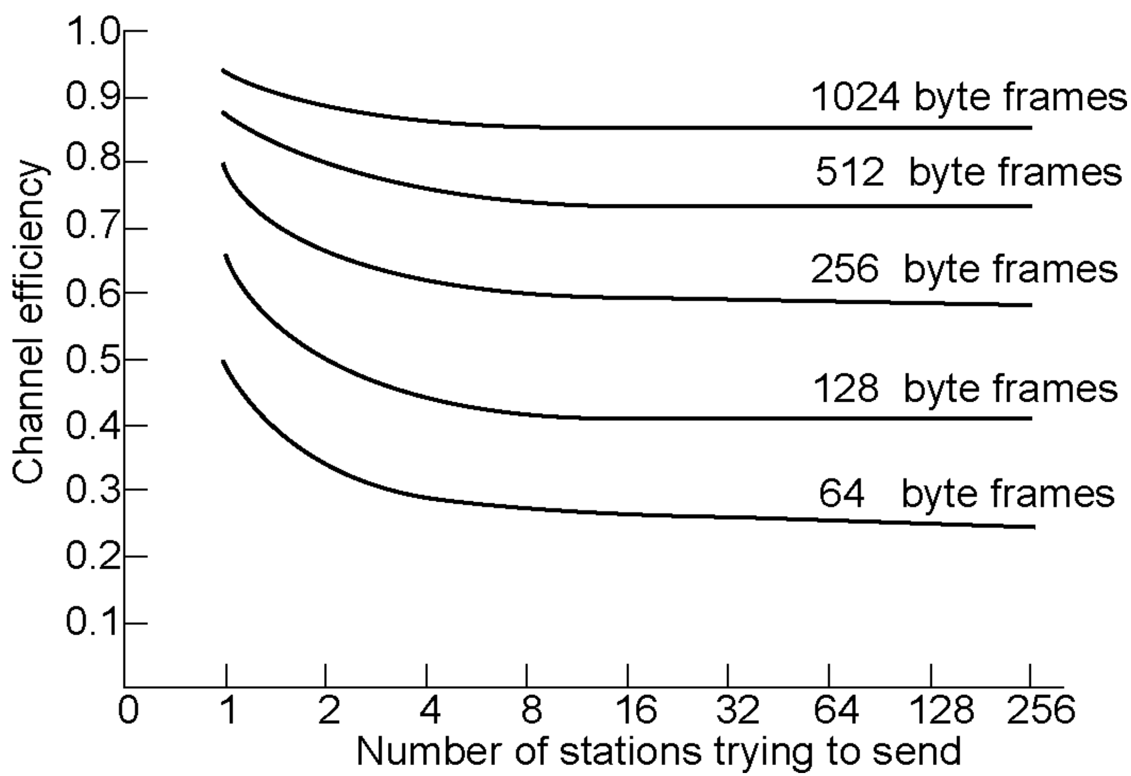
Binary Exponential Backoff Algorithm

Effects, behavior…

802.3:Behavior When Colliding

Behavior

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

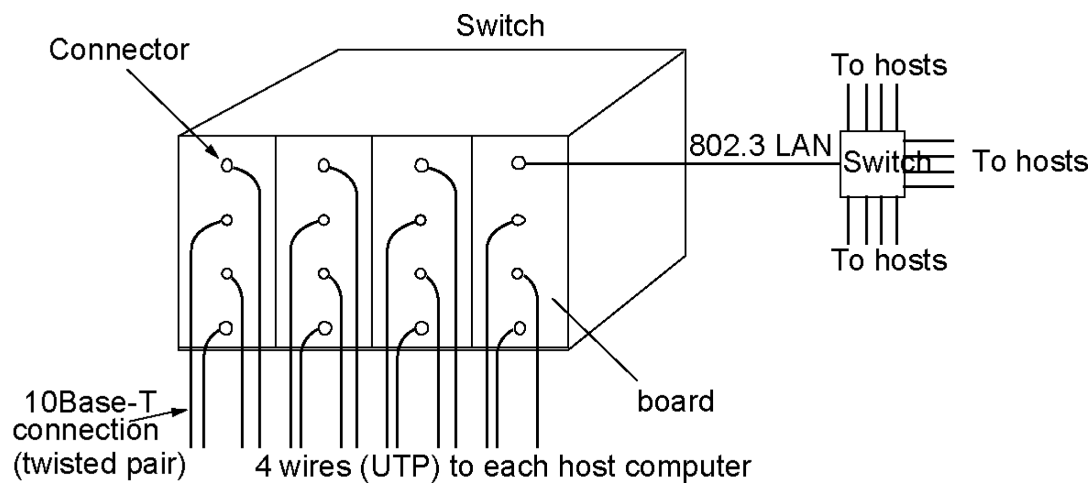


6.6 802.3: Switched LANs

Increasing the throughput by

- higher data rates than 10Base-T
- 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 (if not located) only then: at a different location

collision domain

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

6.7 802.3: Conclusion CSMA / CD

Properties

+ most widely spread
+ stations connect without shutting down the network
+ practically no waiting period during low workload

- analog components for collision recognition
- minimum frame size (64 bytes)
- not deterministic (no maximum waiting period)
- no prioritizing
- when load increases, collisions also increase

→ poor throughput at high load

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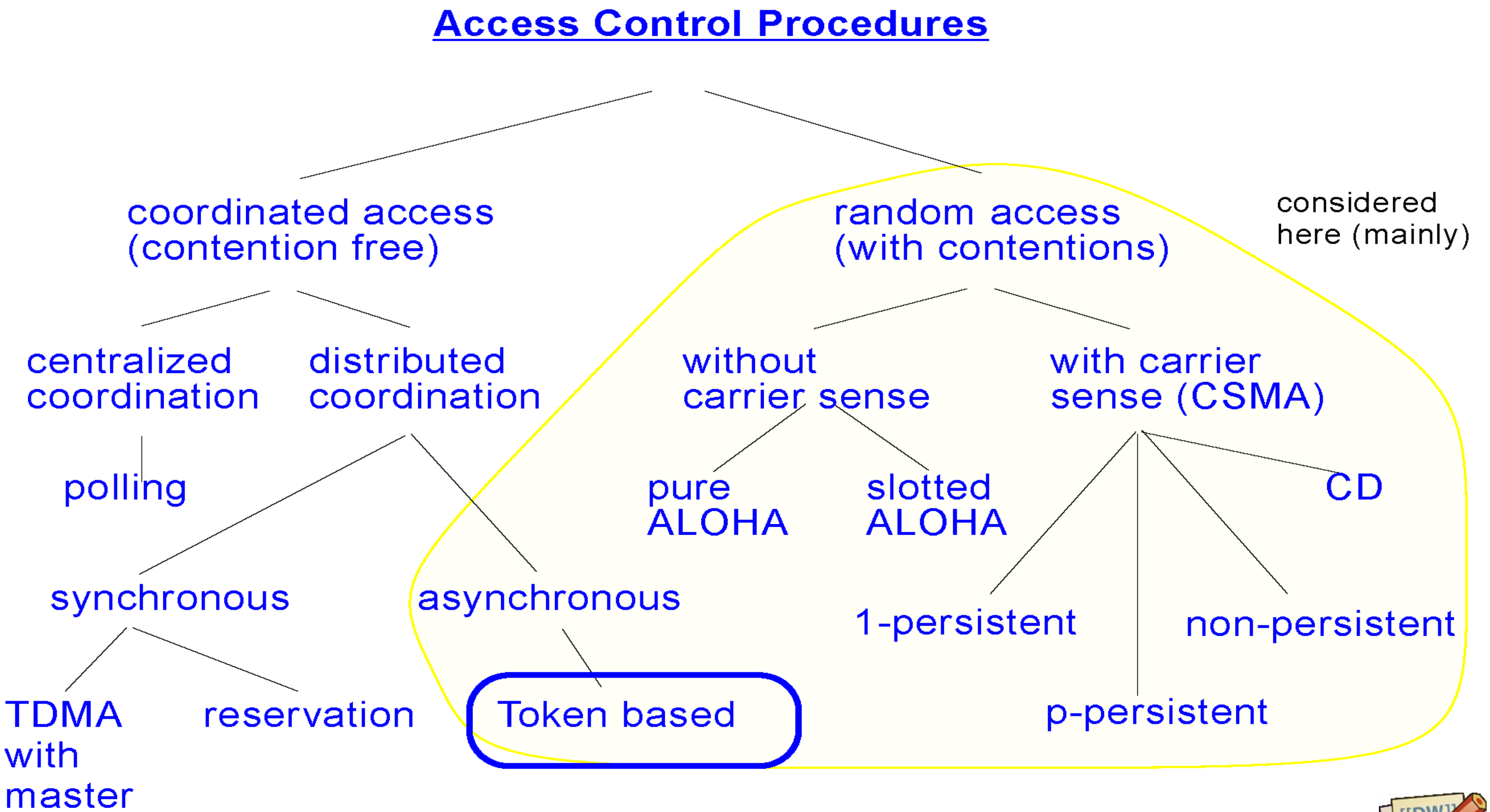
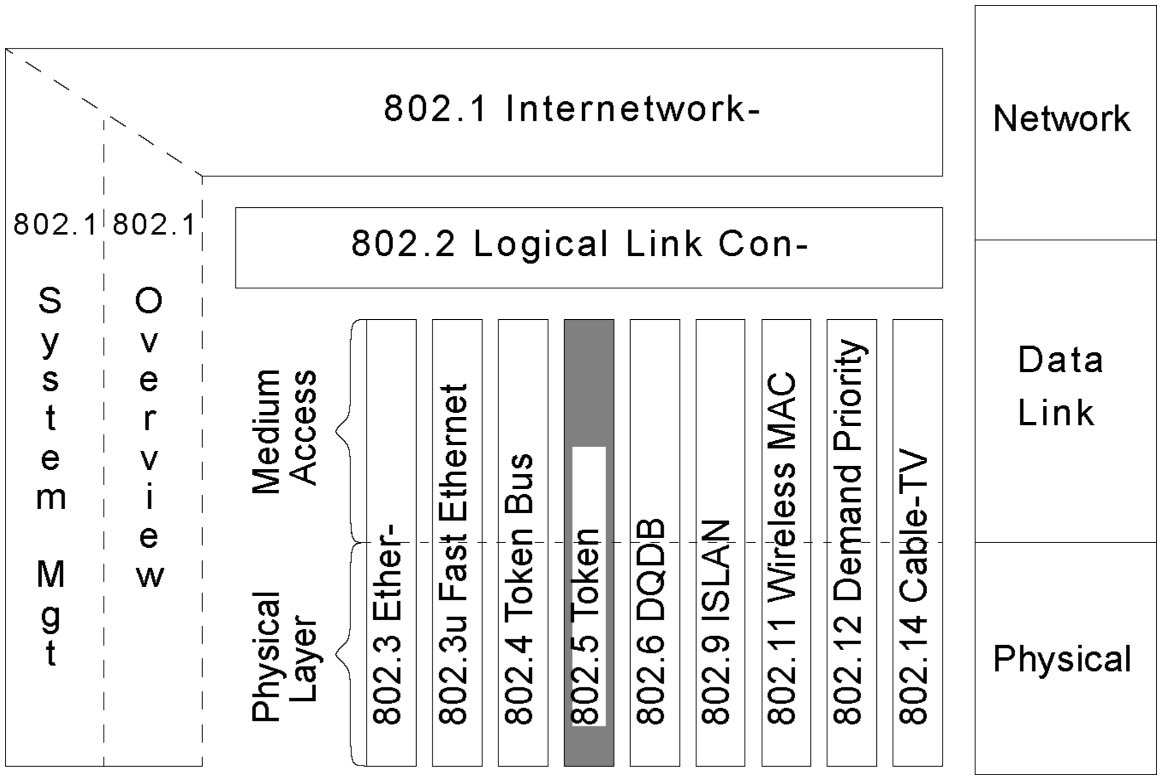


IEEE 802.5: Token Ring



History

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

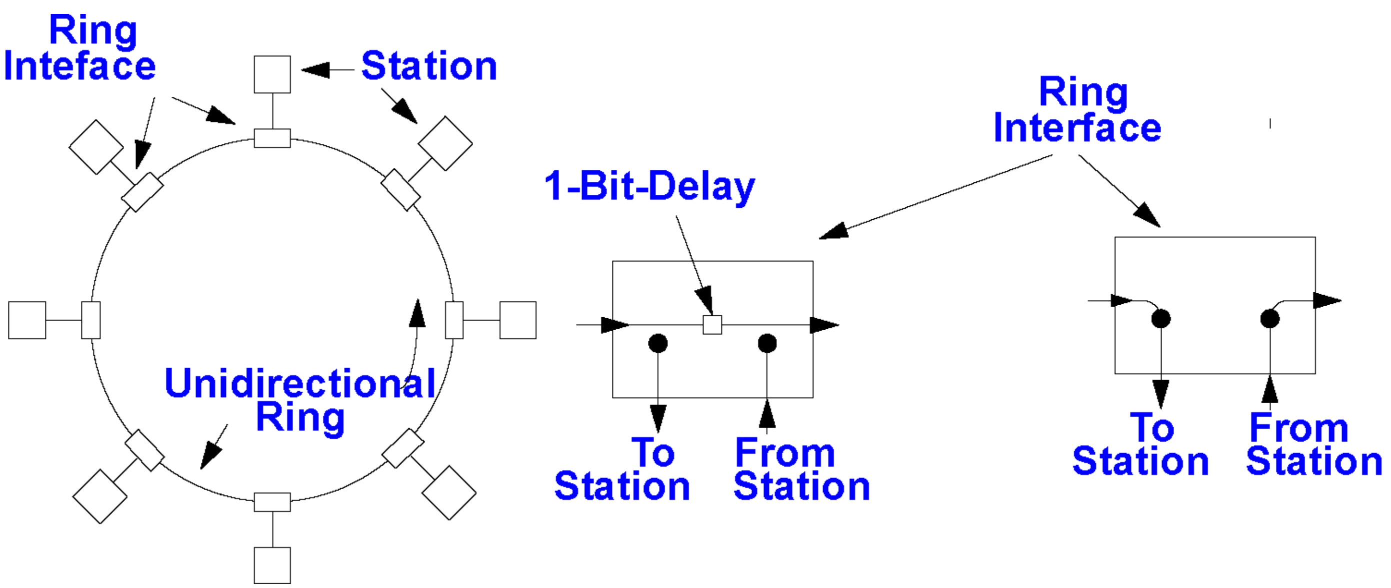
7.1 802.5: Ring Topology

Ring

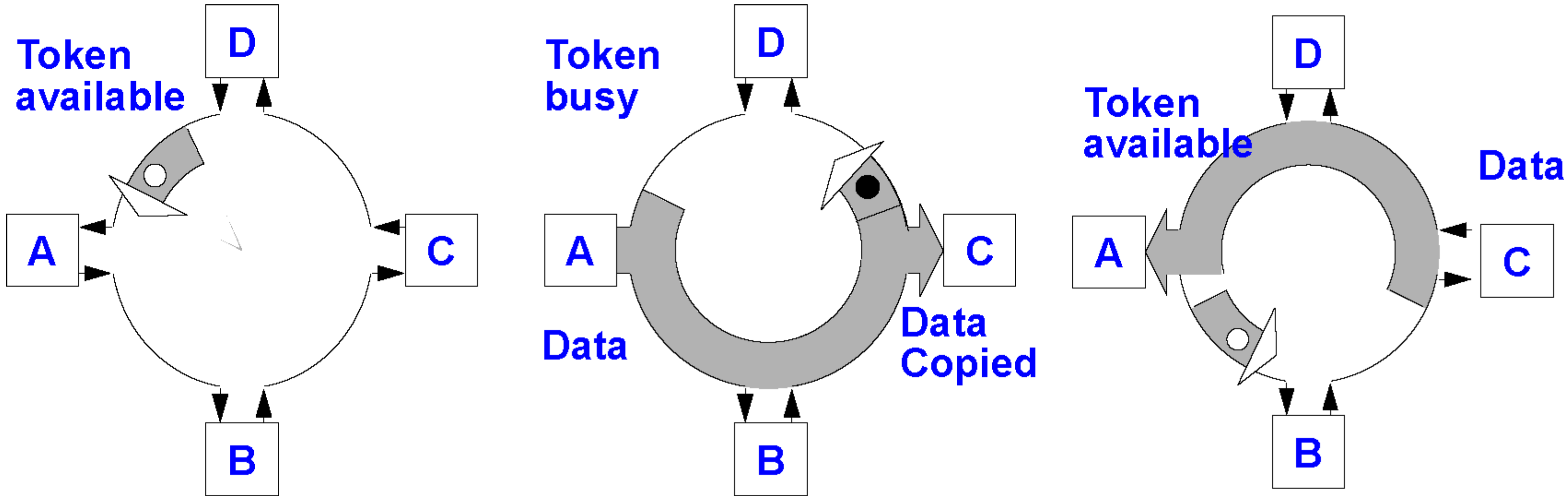
- not really a broadcast medium, but
  - a multitude of point-to-point lines

Station

- copies information bit by bit from one line to the next (active station)



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

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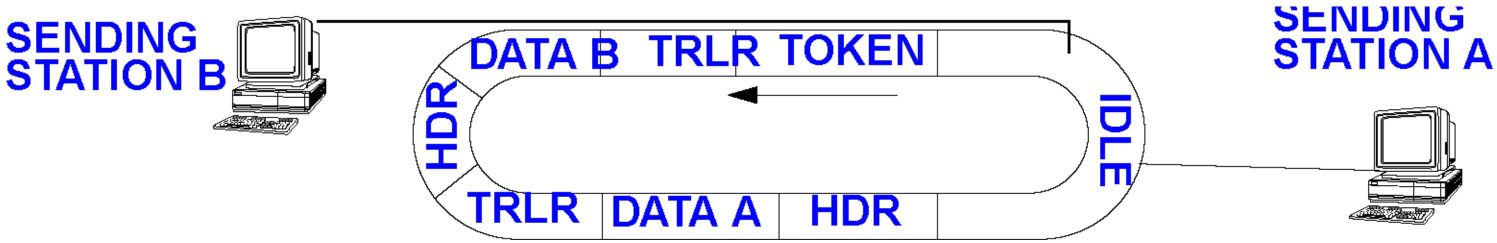
Token Ring behavior optimized for increased data rate

- at lower data rate
  - always data “on the line”, i.e. “long bits”
- at higher data rate
  - frames occupy minor part of the ring (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:
    removes token
    appends its data to frame
    appends (free) token
```

Application

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

802.5: Token and Frames

Typical (measured) values:

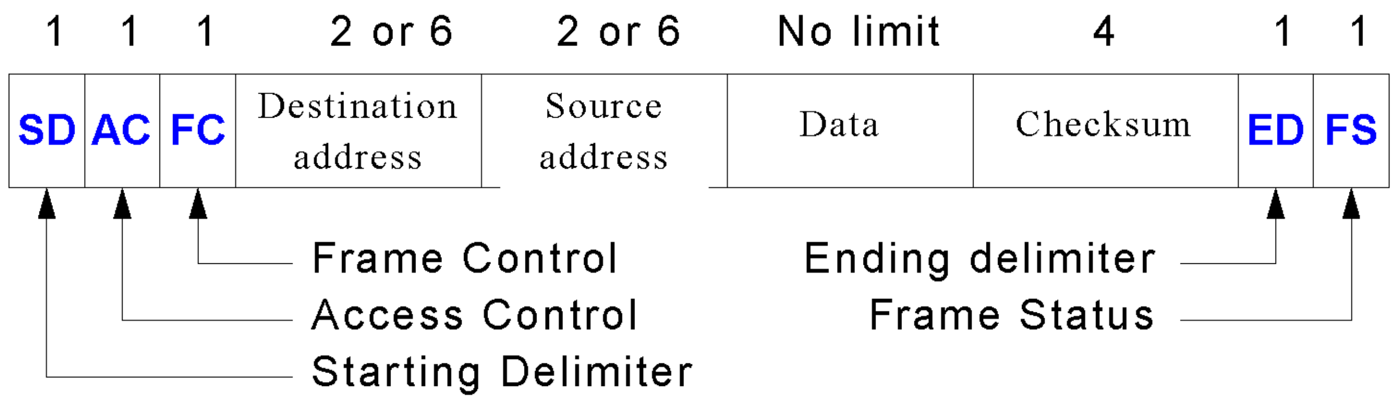
- token circulates 20 times
- frame circulates once with e.g. 256 byte

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": change T=0 → T := 1

7.3 802.5: 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, optic fiber (as FDDI)
- increased transmission rates:
  - 16 Mbps
  - (as Early Token Release, IBM product)

Additional condition:

- Frame with 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
(no. of bits on the ring)
    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...

802.5: Calculations, also Ring Bit Number

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Solution: artificial delay at each station

Calculation:

D = delay / station [bit]

N = number of connected stations

Ring circulation time

$$U = L/V + N \bullet D/K$$

Ring bit number

$$R = U \bullet K$$

$$= L \bullet K/V + N \bullet D$$

with

P_{max} = max. packet length [bit]

P_T = token length [bit]

T = transport time for token to adjacent node

U = ring circulation time

K = transmission capacity

N = number of stations

Example:

L = 1 000 m; K = 4 Mbps; N = 50; D = 1 :

→ R = 70 bit

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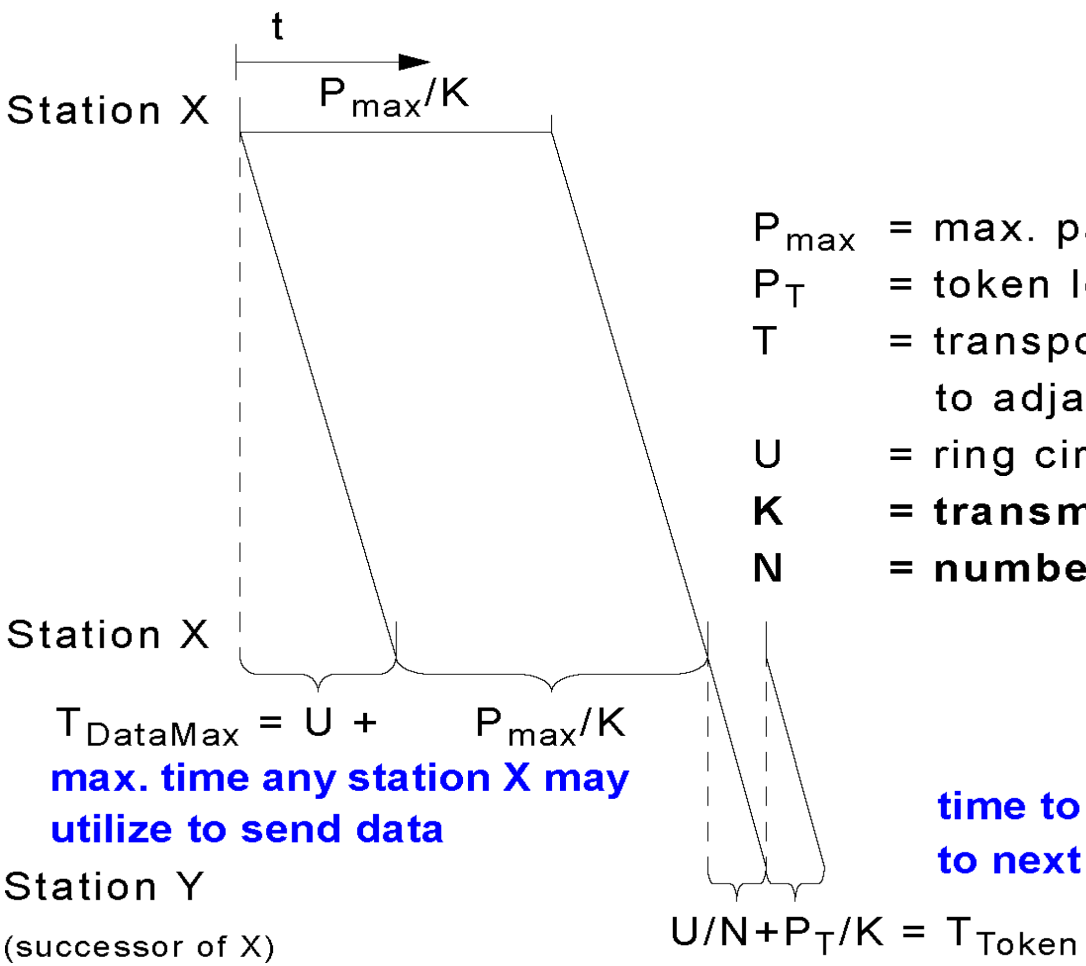
802.5: Maximum Waiting Period

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

- i.e. all stations want to send with the max. amount of allowed time



P_{max} = max. packet length [bit]
P_T = token length [bit]
T = transport time for token to adjacent node
U = ring circulation time
K = transmission capacity
N = number of stations

802.5: Maximum Waiting Period

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

$= (N-1)(P_{max}/K + U) + N(P_T/K + U/N)$

$= (N-1)(P_{max}/K + U) + NP_T/K + U$

$= (N-1)(P_{max}/K + U) + U$

Note: $NP_T/K = 0$ for $P_T \ll P_{max}$

7.5 802.5: 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

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:**	**recognizing 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 $P \le N$
    - can reserve next token with priority N ($R := N$), if $R \le N$

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

Station C = Receiver of Station B:
- receives data and
- releases token with previous priority

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 RESETS 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

Comments:

- these bits (Frame Status) are not included in checksum, because
  - this field is changed by a lot of stations
  - then too time-consuming to always re-calculate

→ duplicate included because of increased 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

7.6 802.5: Summary Token Ring

Properties

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

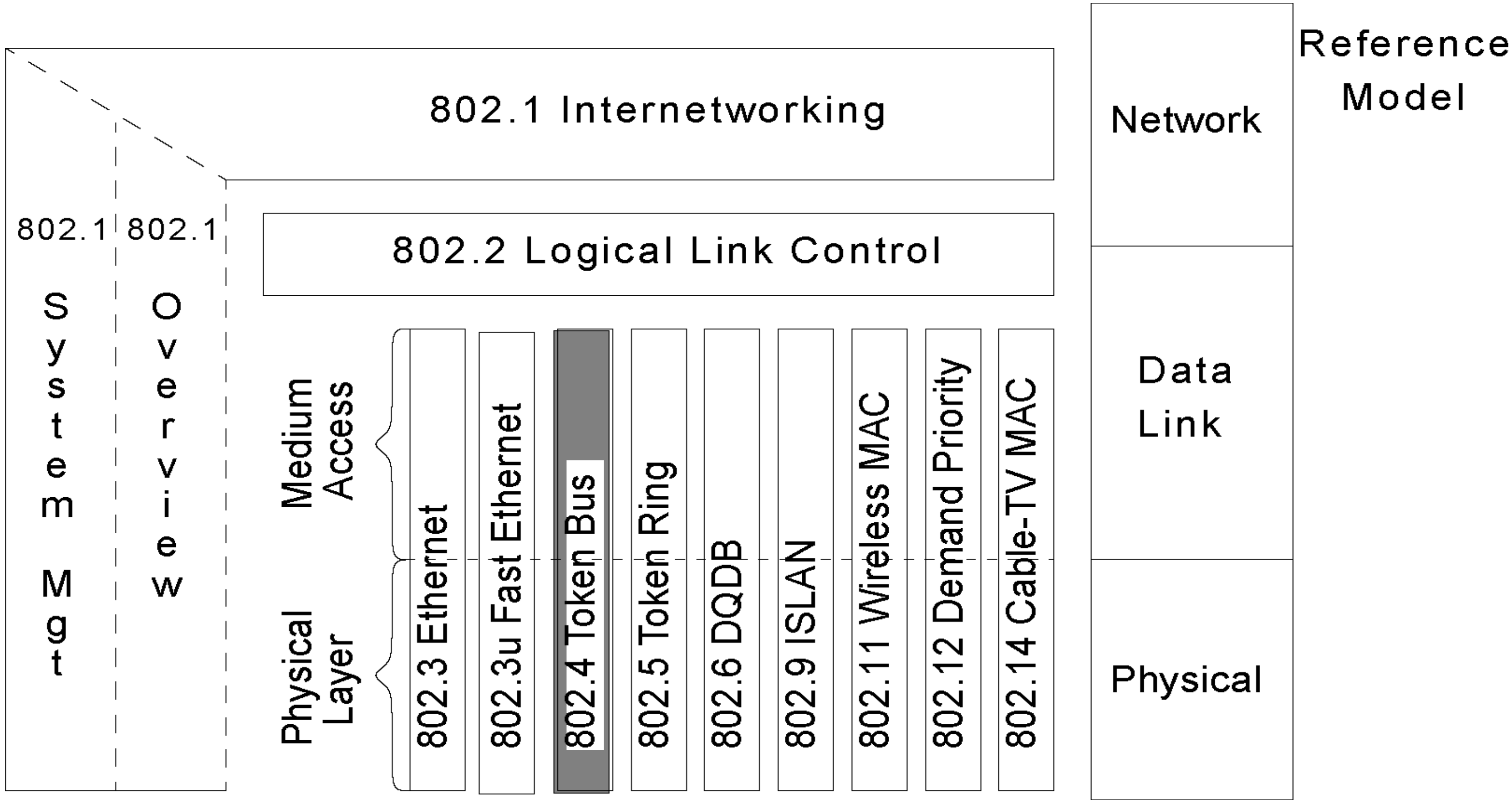
- central monitor
- delays because of waiting for token

7.7 Comparison of 802.3 and 802.5

	802.3: CSMA / CD
+	cost efficient
+	most widely spread
+	connecting stations without shutting down the network
+	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

7.8 IEEE 802.4: Token Bus



HISTORY:

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