Datalink layer: Broadcast networks (most LANs)

- key issue: how to determine which node can use the shared channel at any given time
    - when 2 or more nodes want to transmit at the same time, they are said to ***contend*** for the channel
    - if 2 or more nodes transmit at the same time, the usual assumption is that all the transmissions ***collide*** and are destroyed $\Rightarrow$ no transmission is successful

- 3 basic ***contention resolution*** strategies:
    - divide the channel into **independent sub-channels**, one for each transmission (e.g. using TDM or FDM) – turns the channel into a set of point-to-point links

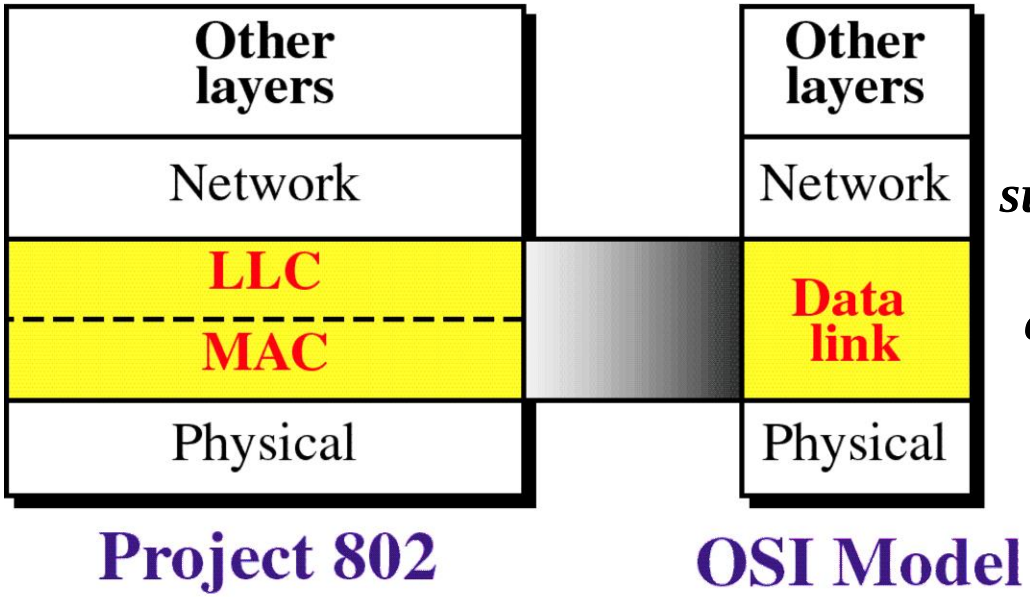
    - **collision resolution:** allow nodes to start transmitting whenever they like, but nodes check for collisions; if a collision is detected, each node involved waits a ***random*** amount of time *(why?)*, and starts transmitting again
        - improvement – active nodes listen before/while transmitting; if collision detected, stop transmitting immediately, then wait random amount of time…

    - **reservations:** a node must obtain the ***token*** (giving permission to transmit) before transmitting; when finished, node releases the token to its neighbour
        - modification – token doesn’t have to be passed from neighbour to neighbour, as long as all nodes get (maybe unequal) chances to transmit

Datalink layer: Broadcast networks (cont.)

• HDLC not suitable for broadcast (or ***multi-access***) channels

• in 1985, the IEEE started Project 802 to define standards for broadcast LANs to enable communications between equipment from different vendors



LLC: Logical Link Control sublayer (non-architecture-specific, common to all broadcast LANs; concerned with logical addresses, control information, and data). Standardised by 802.2 protocol.

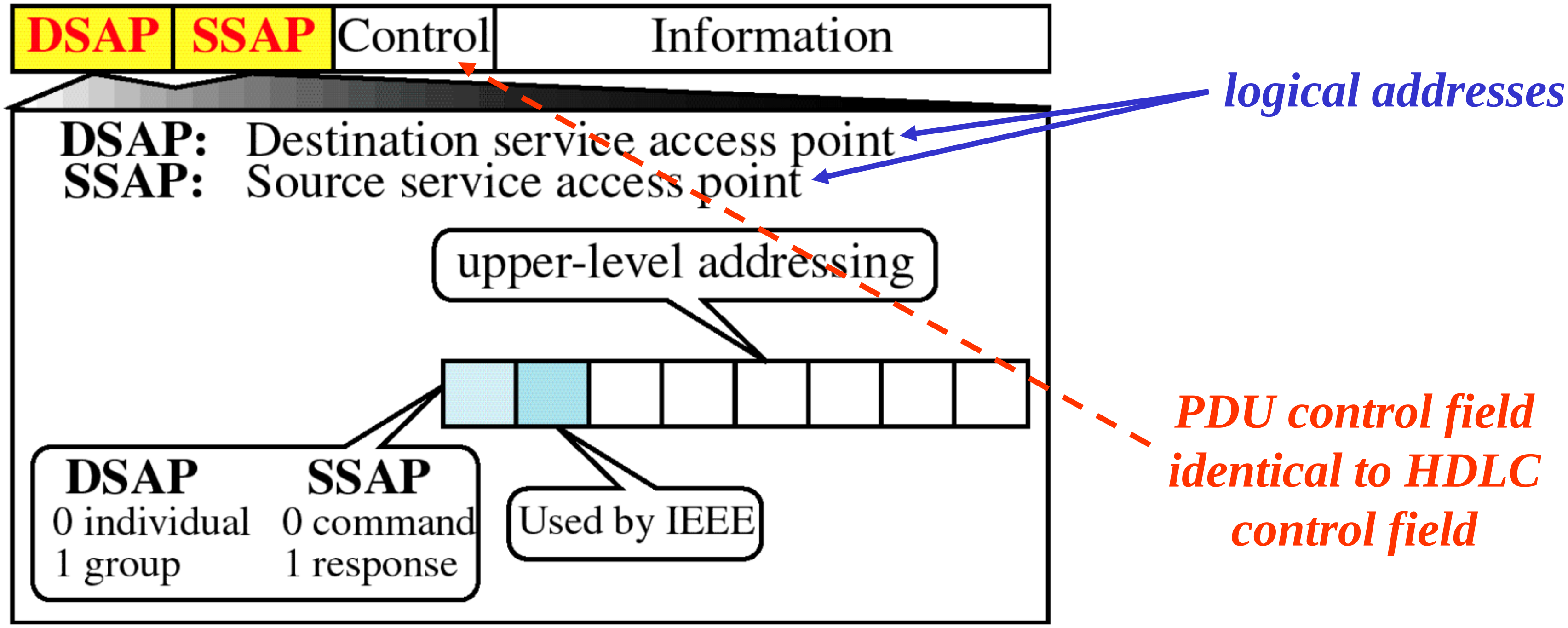
• MAC: Medium Access Control sublayer

• MAC protocol is specific to the LAN technology being used

- • e.g. 802.3 (CSMA/CD), 802.4 (Token Bus), 802.5 (Token Ring), …
- • resolves contention for the channel - specifies flags, error control schemes, physical addresses

Datalink layer: Broadcast networks (cont.)

• data unit at LLC sublayer is called a PDU (Protocol Data Unit)



• PDU has no flag fields, no CRC/checksum, and no physical (machine) addresses - these are supplied by the MAC sublayer

Datalink layer: Ethernet

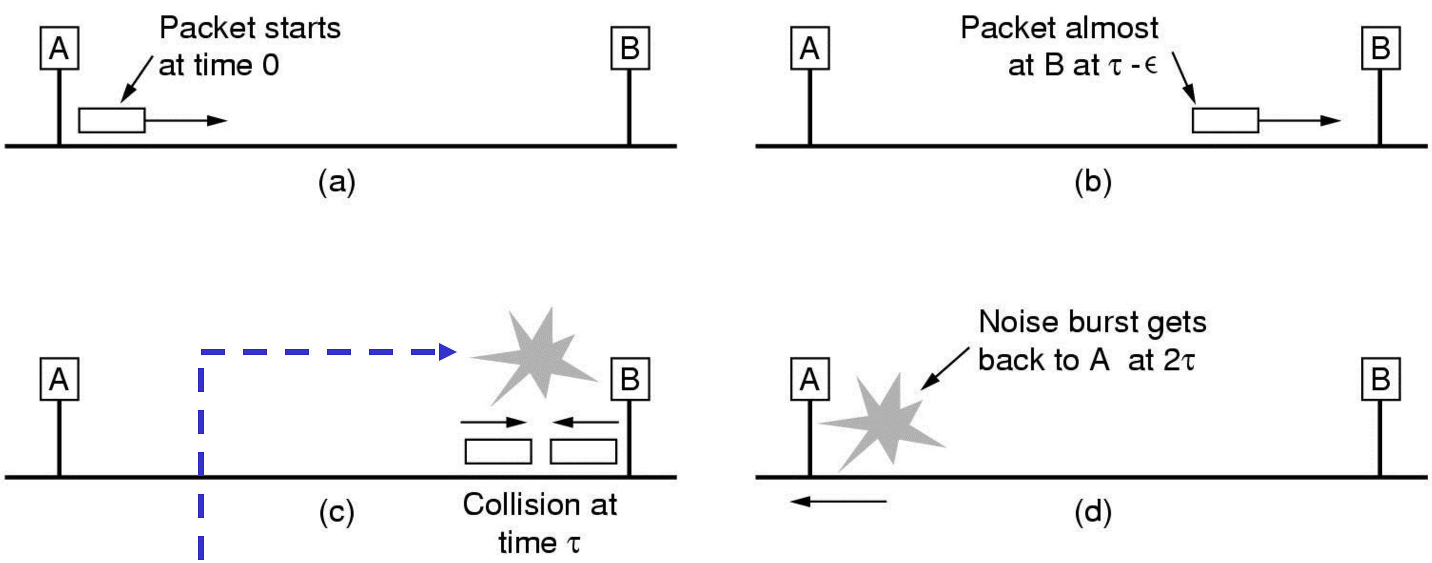
• mid-70s: Xerox PARC developed first Ethernet to connect 100 computers on a 1 km cable; subsequently developed by Xerox, DEC, and Intel
• Ethernet is slightly different to IEEE 802.3
• channel access method: CSMA/CD (Carrier Sense Multiple Access with Collision Detection) - try to reduce the ***likelihood*** and ***effects*** of a collision

> • CSMA: a node wishing to transmit must first **listen** to the channel (e.g. by measuring the channel's voltage level). If the channel is busy, some other node is transmitting and our node must wait until it detects that the channel is idle. When the channel is determined to be idle, our node can transmit.
>
> • CD: during transmission, our node listens to the channel and if another transmission is detected (e.g. higher voltage level than expected for one transmission), all nodes involved in the collision stop transmitting immediately. Each node then computes a **randomly-sized** time interval, waits for that amount of time, and begins the transmission attempt again.

• basic problem with CSMA/CD is that, theoretically, a node wishing to transmit may ***never*** be able to (Maximum Medium Access Time, MMAT = ∞): even with random waiting times, the node's transmission attempts may collide every time!

Datalink layer: collisions in CSMA/CD / Ethernet

• even with Carrier Sensing before transmission, collisions can still occur because it takes non-zero time for signal to propagate along the channel
• if the propagation time along the length of the channel is denoted by τ, can show that the ***worst-case collision detection time*** is (approximately) 2τ



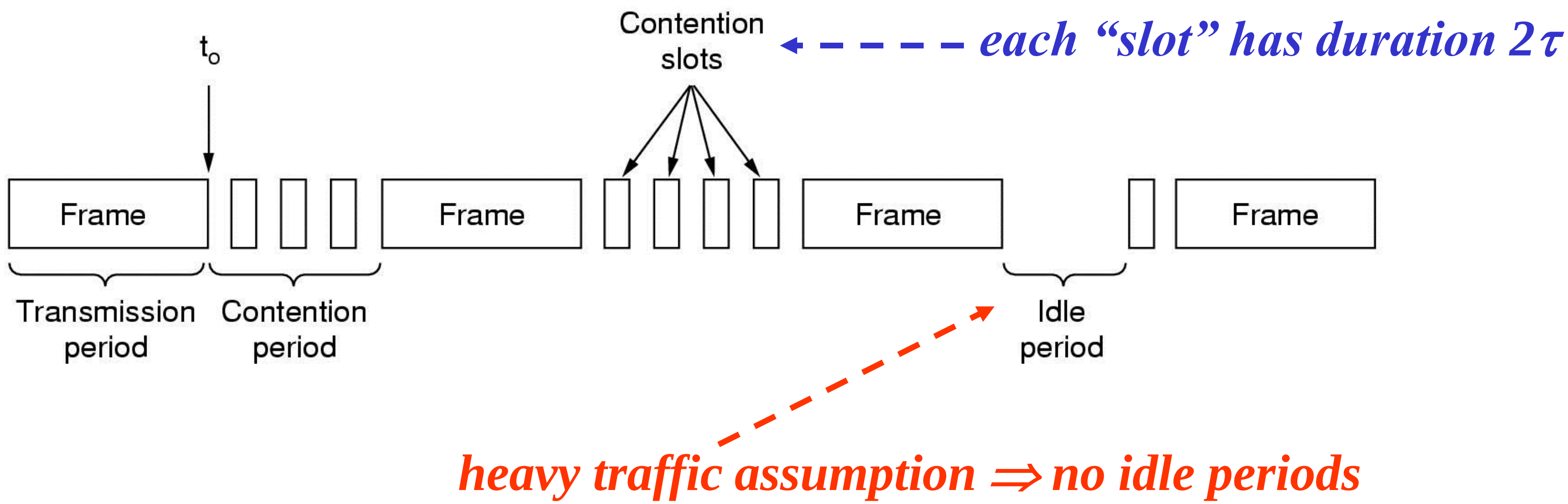
noise burst generated by node B to warn all other nodes about collision

• this shows why there is a **<u>minimum frame length</u>** in CSMA/CD systems: all frames must take more than 2τ to transmit *("pad" information field, if necessary)*

Datalink layer: performance of CSMA/CD / Ethernet

• main complication is the analysis of the randomisation algorithm each node uses to determine how long it should wait after detecting a collision before attempting to transmit again

- algorithm used is called BEB (Binary Exponential Backoff)
- basic idea of BEB: the more collisions this transmission attempt has been involved in so far, the longer it may have to wait before attempting again
- can show that in heavy traffic conditions, BEB results in an ***average contention period*** of $w = (2\tau) \times e$ seconds, or approximately $w = 5.4\tau$



Datalink layer: performance of CSMA/CD / Ethernet (cont.)

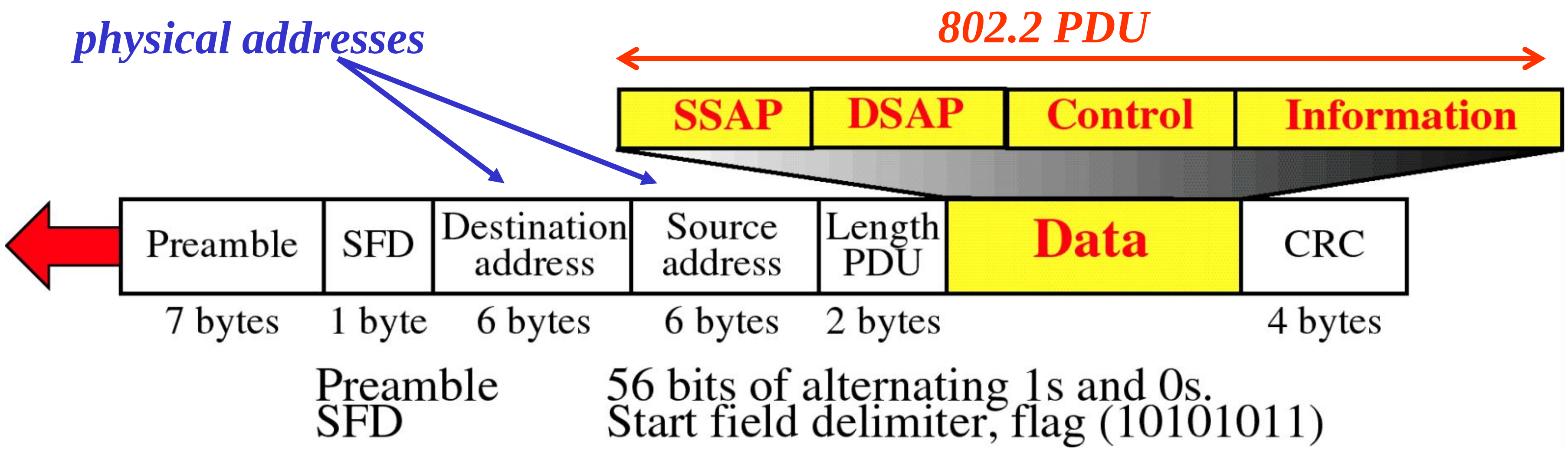
- efficiency = *(TRANSF) / (TRANSF + w) = 1 / (1 + [w/TRANSF])*
  - but τ = channel propagation delay = PROP, and $w = 5.4\tau$
  - therefore efficiency = *1 / (1 + 5.4×[PROP/TRANSF])*
  - therefore throughput = efficiency/TRANSF = *1 / (TRANSF + 5.4×PROP)*

- allows us to see the effects on efficiency and throughput when some system characteristic(s) are changed. Examples:

- what if ***length of the channel is increased*** (everything else held constant) ?
  - then PROP increases (since PROP = (length of channel)/(signal propagation speed in channel)), so ***both efficiency and throughput decrease***

- what if ***channel bandwidth is decreased*** (everything else held constant) ?
  - then TRANSF increases (since TRANSF = (length of Frame)/(channel bandwidth), so ***efficiency increases*** (?!?!) but ***throughput decreases***
    - remember that efficiency only measures the fraction of time spent doing "useful work", in this case transmitting Frames – if it takes longer to transmit Frames and the propagation delay is held constant (meaning the collision detection time is held constant), then a larger fraction of the time is spent actually transmitting Frames!

Datalink layer: CSMA/CD / Ethernet Frame



Preamble is to allow Receiver to synchronise with incoming transmission.

SFD is the start flag in Ethernet.

Node physical address: 6 bytes, encoded on node's Network Interface Card (NIC). Each NIC ever made has a *unique* 6-byte address.

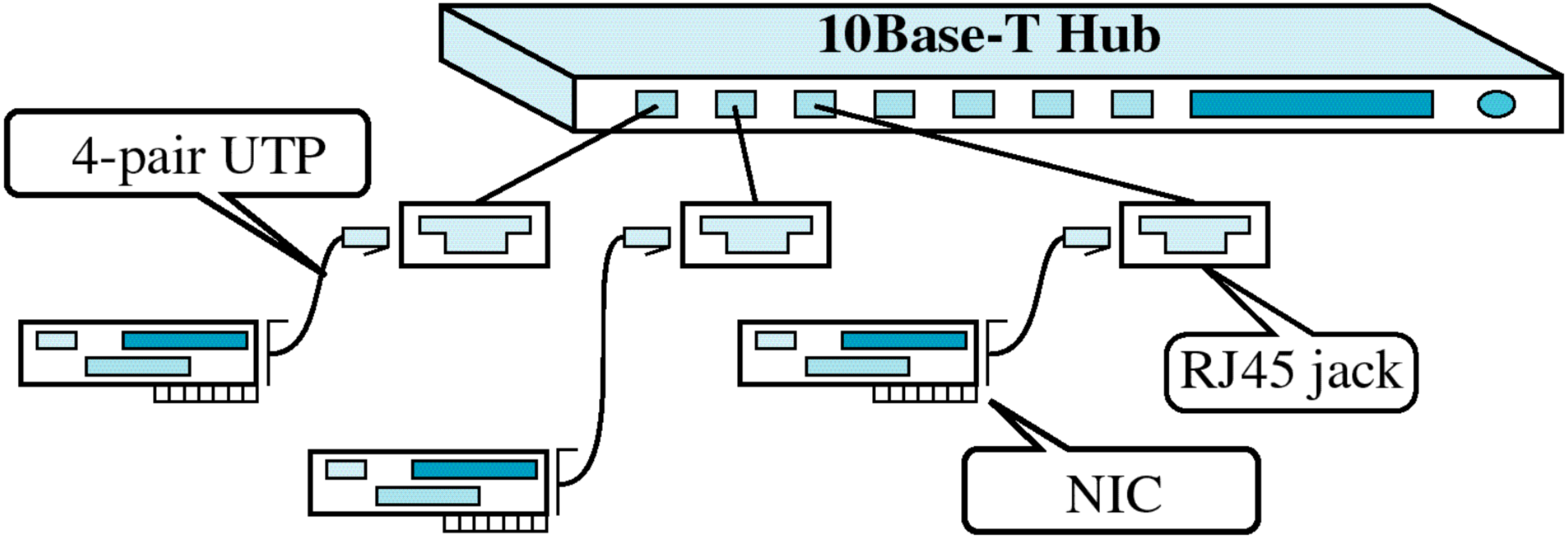
Maximum length of Data field = 1500 bytes.

Note: no provision for ACK/NAK - must be implemented at a higher layer ⇒ Ethernet is an *unreliable* medium.

Datalink layer: Ethernet Implementations (3)

<u>10BaseT:</u> 10 Mbps, Baseband (digital encoding), twisted pair wiring,
maximum length hub-to-node = 100 metres

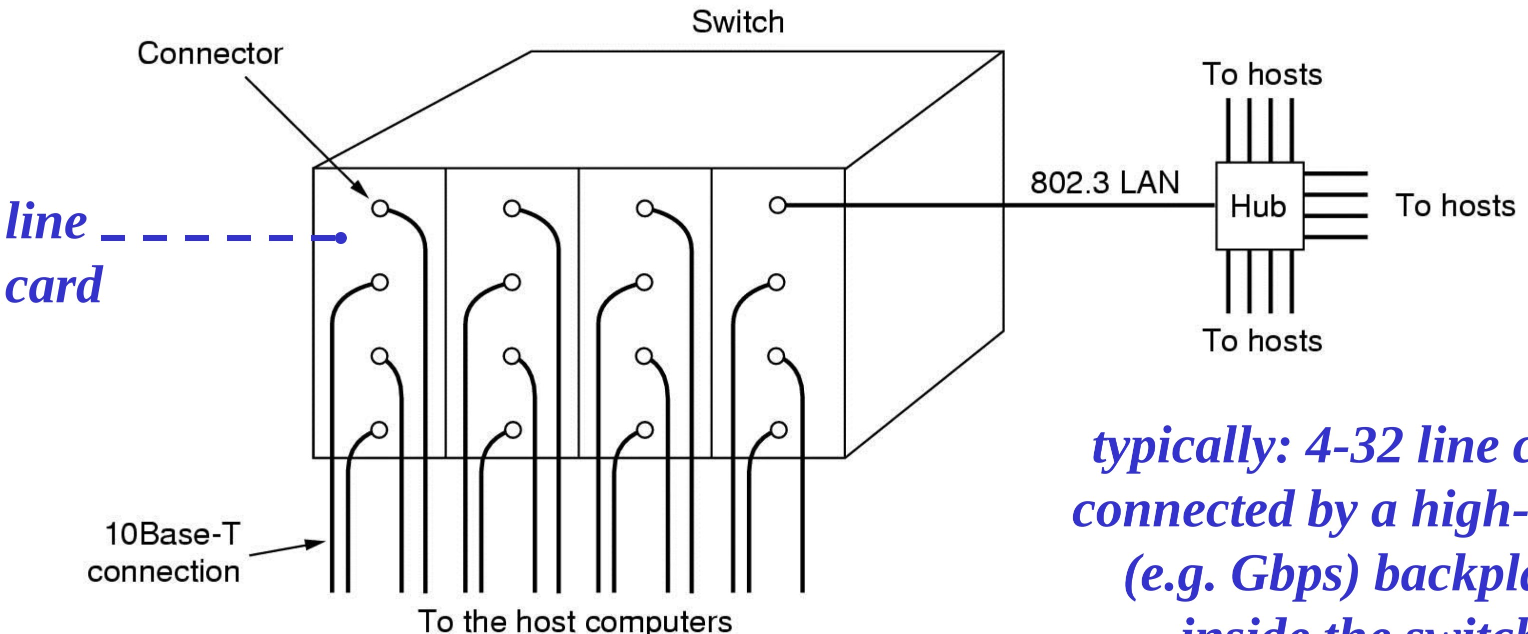
100BASE-TX,and 1000BASE-T move to 100Mbps and 1Gbps



logically still a bus topology, although physical topology is a star

Datalink layer: Ethernet Implementations (4)

<u>Switched Ethernet:</u> replace hub with a *switch*



typically: 4-32 line cards connected by a high-speed (e.g. Gbps) backplane inside the switch

hub: when a node sends a Frame to the hub, it is sent out on all other hub interfaces ⇒ only one node can transmit at a time.

Switched Ethernet: when a node sends a Frame to the switch, it is sent out only on the interface for the destination node ⇒ switch can forward more than one Frame at a time.

Datalink layer: CSMA/CD Advantages & Disadvantages

+ low ***average*** access time under light loading conditions
+ easy to move/upgrade/change nodes, due to distributed channel access protocol
+ graceful performance degradation as number of nodes increases
+ the most popular LAN technology, with a huge installed base

– substantial analogue component: collision detection circuitry
– minimum valid frame length is inefficient if data is short (e.g. 1 character)
– priorities not supported $\Rightarrow$ difficult to support (e.g.) real-time traffic
– channel access time unpredictable
– as load increases: access time increases, and is theoretically unbounded

• the potential problems with Ethernet led to the development of some alternative technologies in the early 80s

  • IBM chose a ***ring topology*** for office automation applications – led to the Token Ring (802.5) standard

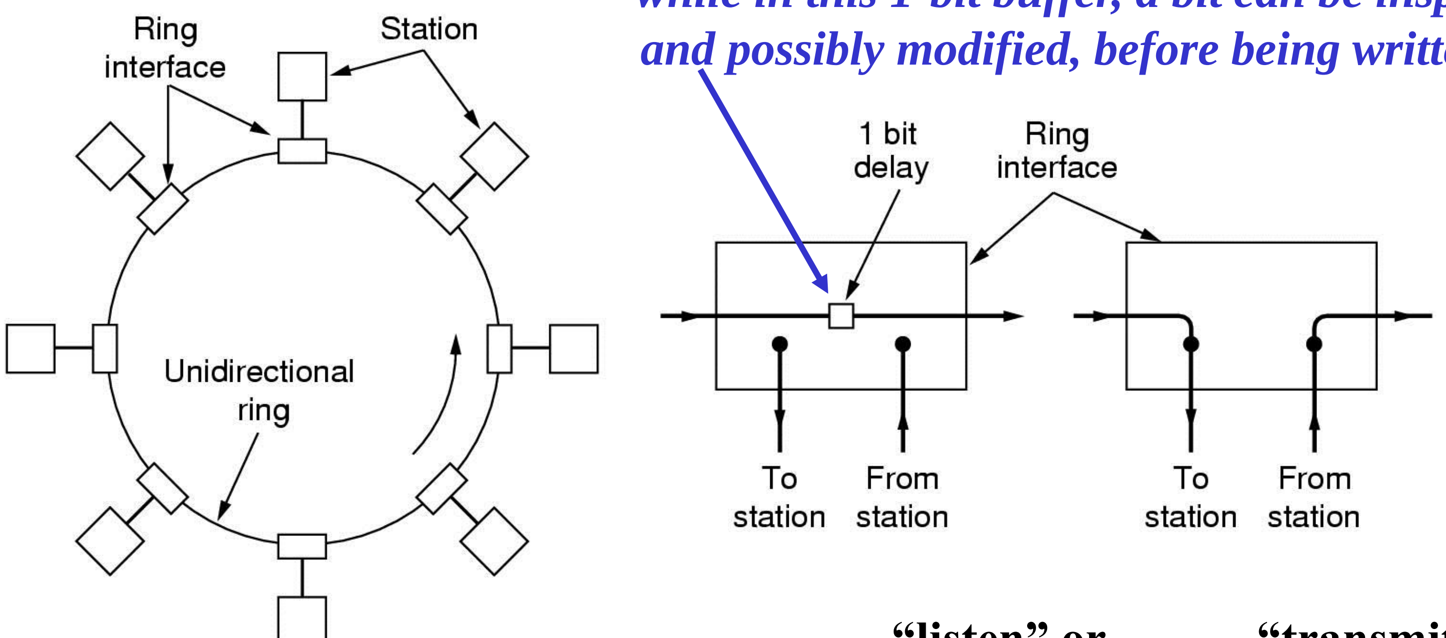
  • General Motors, and others interested in factory automation, chose a ***bus topology*** as a good match to layout of assembly lines – led to the Token Bus (802.4) standard

• key point in both of these cases: the Maximum Medium Access Time (MMAT) is **bounded**, assuming the network is working correctly

Datalink layer: Token Ring networks (802.5)

- "ring" is actually a set of point-to-point links that form a circle
  - ring is (logically) unidirectional
- token = special frame that is passed from one node to the next
  - a node may only transmit Frame(s) when it has the token
- when a node receives the token, it removes it from the ring and transmits one Frame, then puts the token back on the ring (i.e. transmits it to next node)
  - "removing the token" means changing it into the start of a data Frame…

while in this 1-bit buffer, a bit can be inspected, and possibly modified, before being written out



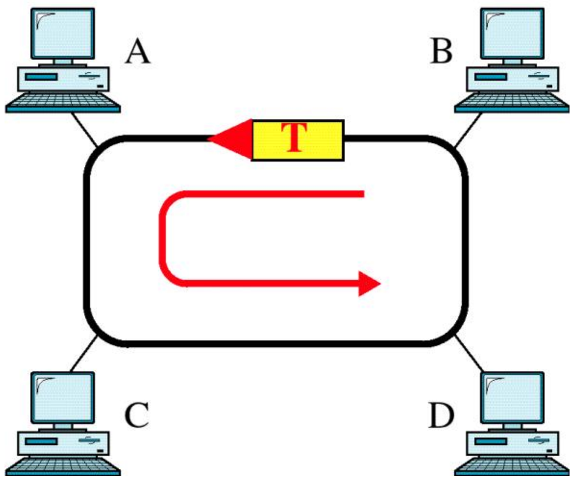
(a)

(b) **"listen" or "wait" mode**

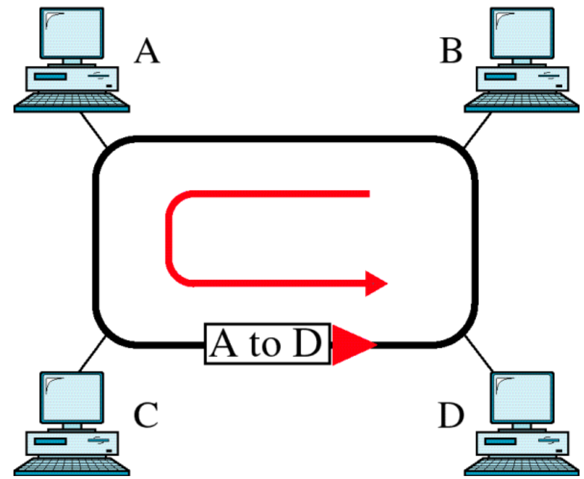
(c) **"transmit" mode**

Datalink layer: Token Ring – token passing

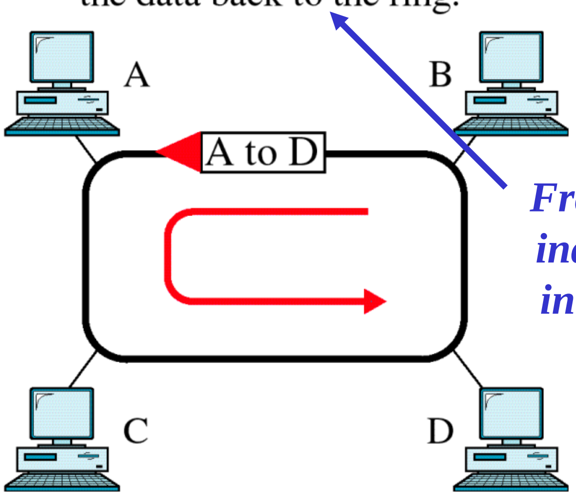
1. Token is traveling along the ring.



2. Station A captures the token and sends its data to D.

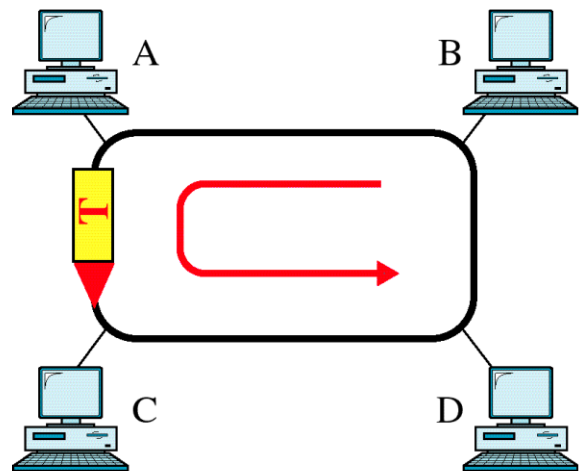


3. Station D copies the frame and sends the data back to the ring.

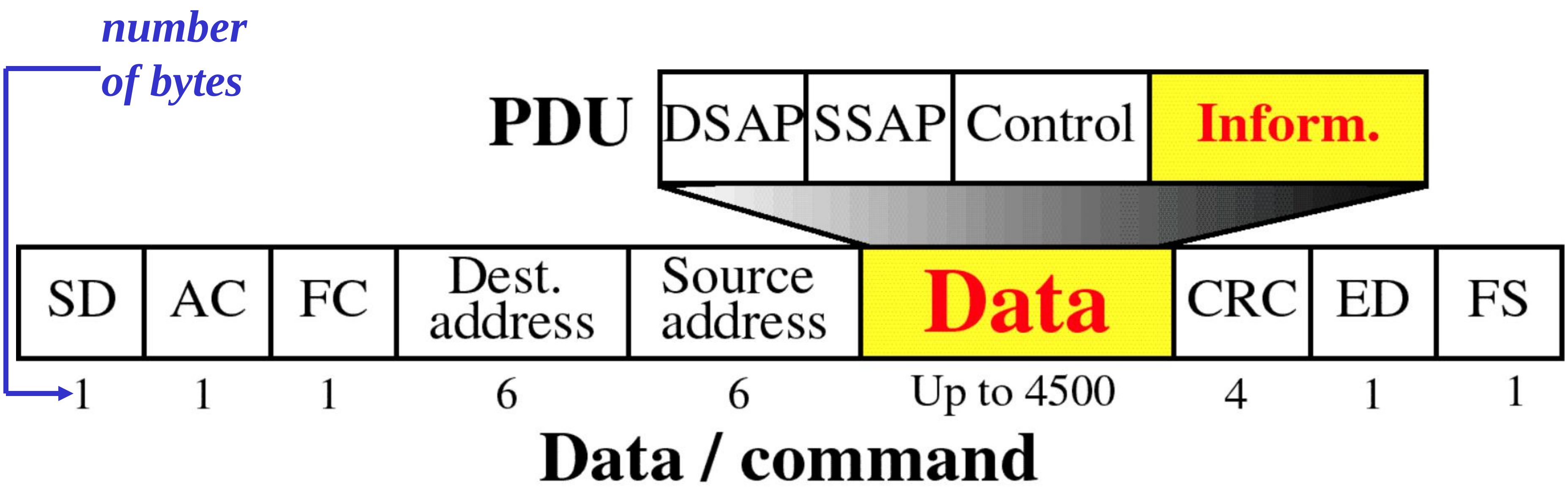


Frame now carries indication that the intended Receiver copied it

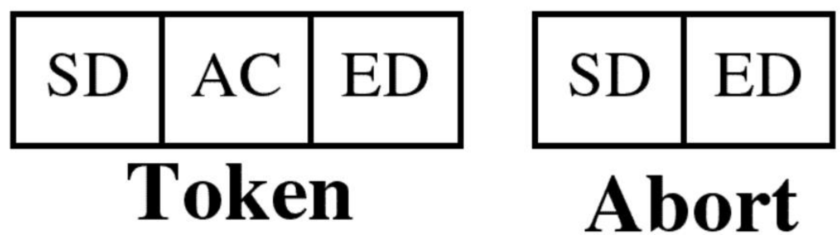
4. Station A receives the frame and releases the token.



Datalink layer: Token Ring Frame formats



SD Start delimiter (flag)
AC Access control (priority)
FC Frame control (frame type)
ED End delimiter (flag)
FS Frame status



used to indicate (1) Receiver address recognised, and (2) Frame copied by Receiver

Datalink layer: Token Ring Performance Analysis

• assume heavy traffic: all nodes always have Frames to transmit

• a complete cycle consists of each node waiting for the token, transmitting one Frame when they get the token, and then releasing the token

• cycle time = N×[TRANSF + TRANST + PROP] + PROP, where

- N = number of nodes
- TRANSF = Frame transmission time
- TRANST = token transmission time
- PROP = ring latency = propagation delay around the ring

sum of propagation delays as token circulates around ring

• useful time within a cycle = N×TRANSF

• therefore efficiency = (useful time)/(cycle time) = … ***(you can plug in)***

• approximation: if TRANST << TRANSF and N >> 1, then approximately efficiency ≈ 1/(1+a), where a = PROP/TRANSF

- note that if a is negligible (in other words, PROP << TRANSF), then the efficiency is approximately 100%

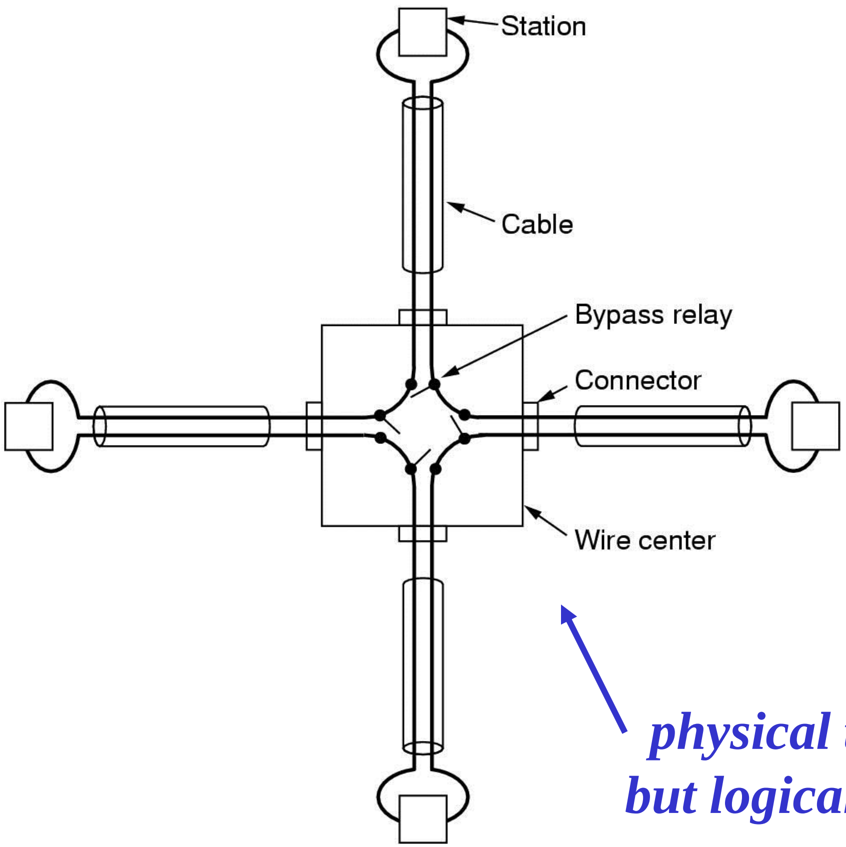
• can find throughput = efficiency/TRANSF …

Datalink layer: Token Ring Performance Analysis (cont.)

- what is the worst-case access time for a Frame which is ready for transmission ? *(Note: ignore **queueing delay** within a node)*
  - MMAT occurs when the node has just started transmitting the last Frame allowed by the token: then newly-ready Frame will have to wait while token circulates around ring, with every node transmitting a Frame
- MMAT = cycle time = N×[TRANSF + TRANST + PROP] + PROP
  - so worst-case access time is known and finite
- modification permitted in IEEE 802.5 standard: when a node receives the token, it is allowed to transmit for up to THT seconds before releasing the token (THT = Token Holding Time)
  - typically THT >> TRANSF, so several Frames may be transmitted every time the token is captured
  - efficiency ≈ 1/(1+b), where b = PROP/THT
  - MMAT = [TRANSF + TRANST + PROP] + (N-1)×[THT + TRANST + PROP] + PROP, which as before is known and finite

Datalink layer: Token Ring Implementation

• problem with ring topology: if there is a break in the cable between 2 nodes, or if a node crashes, the ring is broken
• solution: wire centre – if a cable breaks or a node crashes, appropriate relay closes and faulty section of ring is bypassed

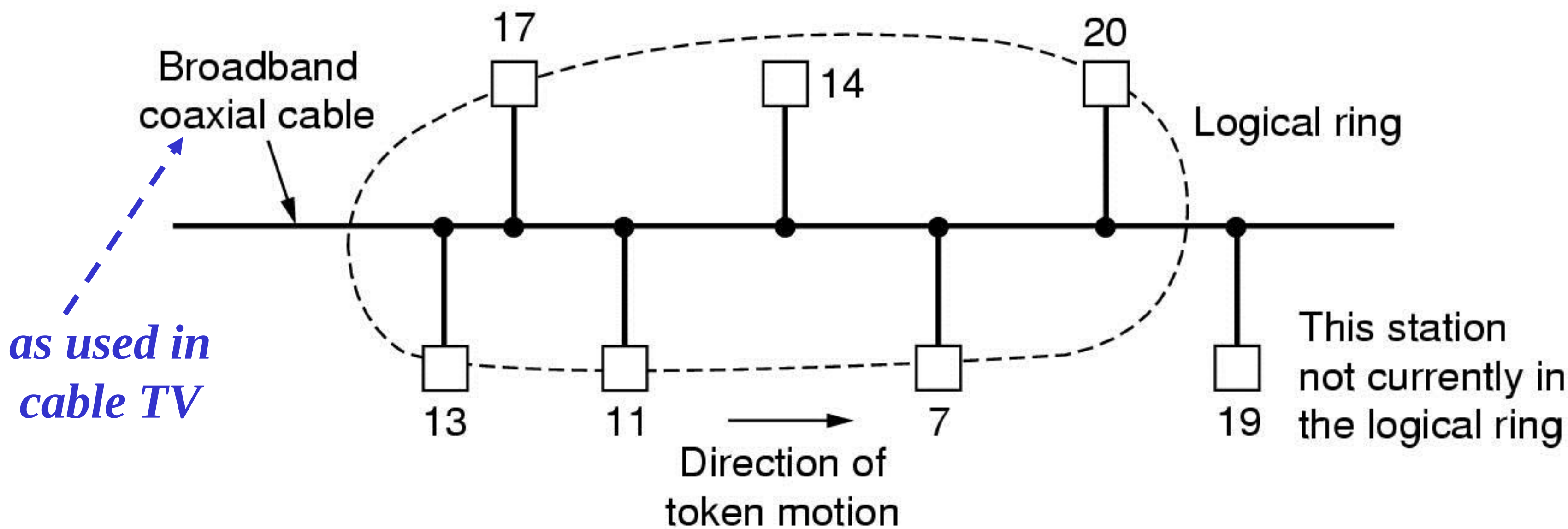


802.5 standard specifies:
- **4 or 16 Mbps**
- **THT = 10 millisec**
- **priority levels**
- **automatic ring maintenance (1 node designated as the ring monitor; every node is capable of doing this)**

physical topology is a star, but logical topology is a ring

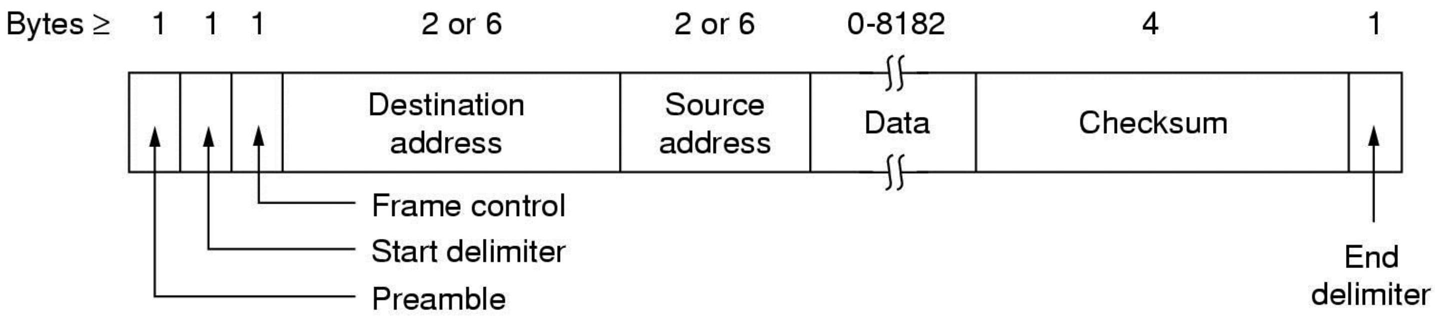
Datalink layer: Token Bus networks (802.4)

- physically a bus, but logically a token-passing ring
  - each node in the logical ring knows physical address of its successor and its predecessor
  - each node connected to the bus (whether it is in the logical ring or not) receives each Frame – but discards Frames not addressed to it



the physical ordering of nodes on the bus is irrelevant to the operation of the token bus protocol, though it has an impact on performance

Datalink layer: Token Bus Frame Format



Preamble: to synchronise Receiver to incoming signal, as in Ethernet.

Frame Control: indicates data or control Frame; for data Frames, also indicates Frame's priority level. Can also carry indication that Receiver must ACK or NAK the Frame.

Addresses: same as in Ethernet protocol.

802.4 standard specifies:
- **1, 5, or 10 Mbps**
- **THT operation *(similar to Token Ring)***
- **different physical layer to Ethernet *(allows symbols other than 0 or 1)***
- **distributed automatic logical ring maintenance *(no centralised monitor)***
- **supports priorities: can be configured to provide a guaranteed fraction of the bandwidth to highest-priority traffic *(e.g. real-time traffic)***

Datalink layer: Fibre Distributed Data Interface (FDDI)

• standardised by ANSI and ITU-T, originally as a high-speed alternative to Ethernet and Token Ring LANs since FDDI runs at 100 Mbps

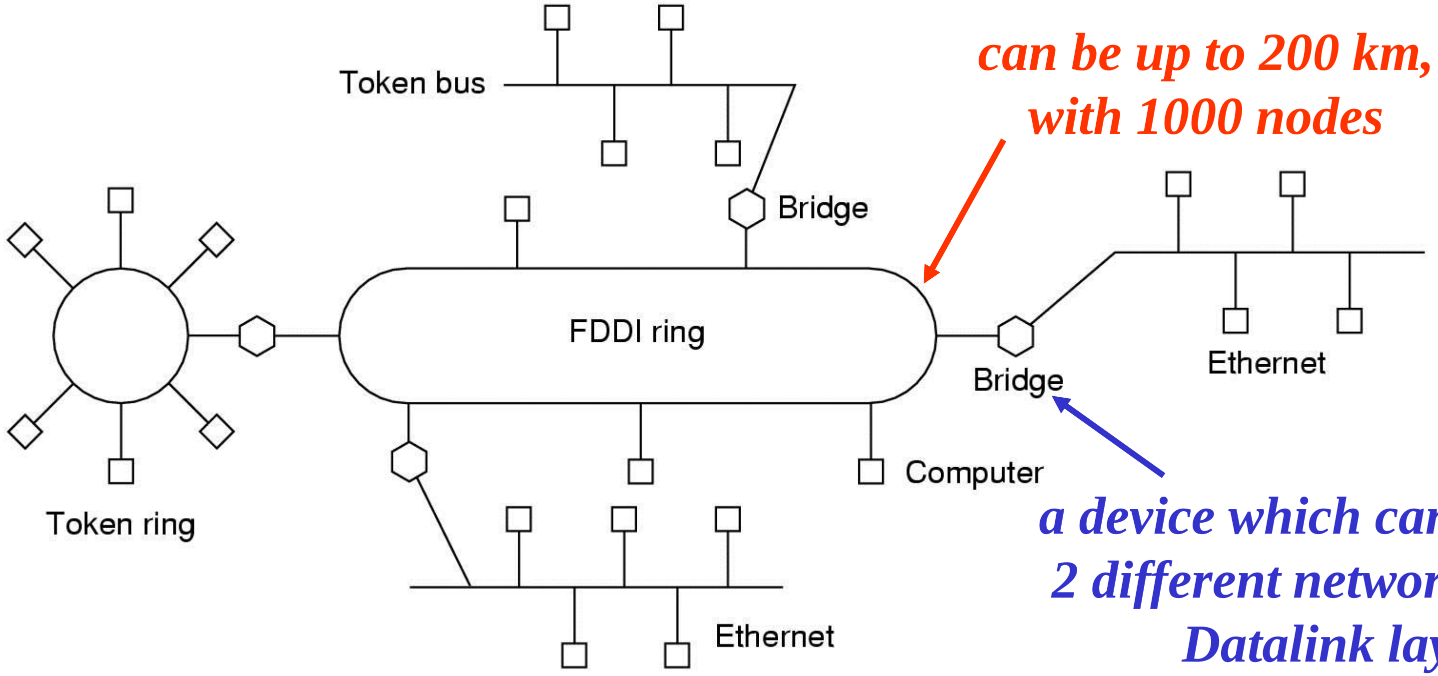
  • copper-wire version now available: CDDI

• access method is token-passing, limited by time

  • supports 2 kinds of traffic: real-time and non-real-time

  • real-time traffic sent first when token received

• now mostly used as a backbone to connect other LANs of various types



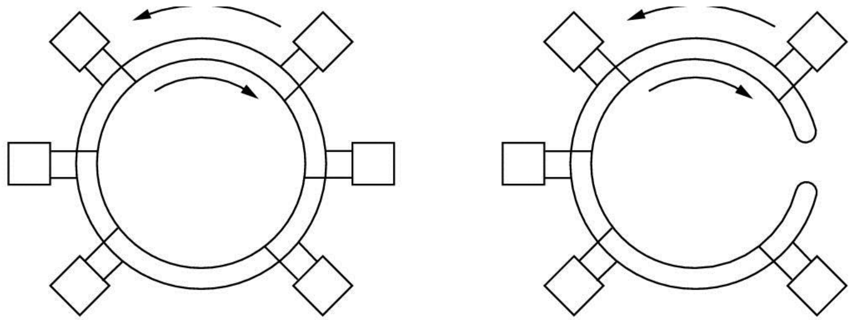
can be up to 200 km, with 1000 nodes

a device which can connect 2 different networks at the Datalink layer

Datalink layer: FDDI (cont.)

- FDDI implemented as a dual ring
  - usually, all transmissions on ***primary*** ring; other ***(secondary)*** ring used only for backup when some part of the primary ring fails

difference with Token Ring: in FDDI, node releases token immediately after Frame transmission



(a) **normal operation** (b) **ring failure**

- Frame format similar to IEEE 802.5:

SD	FC	ED
1	1	1

Token

SD	Start delimiter (flag)
FC	Frame control (frame type)
ED	End delimiter (flag)
CRC	Cyclic redundancy check
FS	Frame status

LLC Data unit

DSAP	SSAP	Control	**Inform.**

number of bytes →

SD	FC	Dest. address	Source address	**Data**	CRC	ED	FS
1	1	6	6	0-4500	4	0.5	1.5

Data