King Fahd University of Petroleum & Minerals Computer Engineering Dept

COE 541 – Design and Analysis of Local Area Networks

Term 051

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Carrier Sense Multiple Access with Collision Detection

- Random access or contention based protocol
- CSMA/CD
- IEEE802.3
- Ethernet
- One of the most popular protocols
- Similar to IEEE802.11 Wireless LAN MAC protocol (known as CSMA/CA)

ALOHA and Slotted ALOHA

- Precursors
- ALOHA:
  - A group of terminals that transmit at well – if multiple transmission overlap ➔ collision – packet needs retransmission
  - Successful transmission (i.e. no collision) ➔ throughput
  - Maximum throughput ~ 16%
- Slotted ALOHA
  - Time access is slotted (i.e divided into equal length slots)
  - Stations need to synchronize with a common clock
  - Maximum throughput ~ 36%

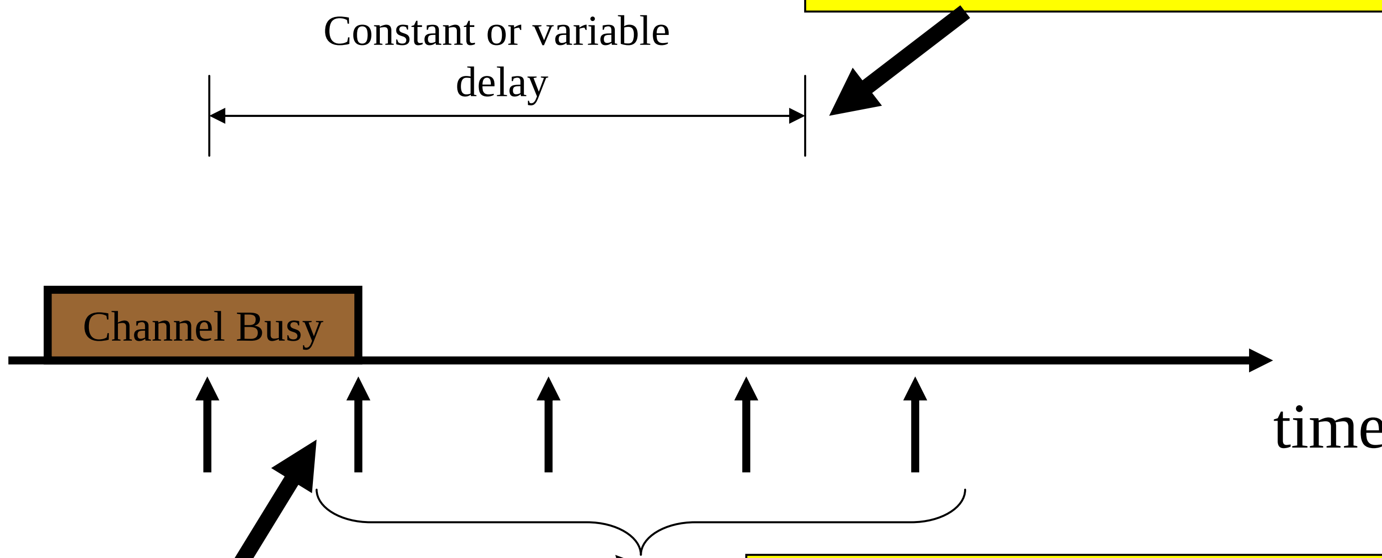
Basic Idea of CSMA/CD

- If medium is idle transmit
- If medium is busy, defer transmission
- data transmit time is much less than propagation time
- If collision occurs it is detected after a short period from the beginning of the data transmit
- Therefore, CSMA has a potentially high throughput compared to ALOHA

CSMA/CD Persistence

What to do if the medium is found BUSY?

(1) Non-persistent:
-Transmit if idle
-If busy, wait random time and repeat process
-If collision, backoff



(2) 1-persistent:
-Transmit as soon as channel goes idle
-If collision, backoff

(3) p-persistent:
-Transmit as soon as channel goes idle with prob. p
-Otherwise, delay one time slot and repeat process
-If collision, backoff

Throughput of CSMA Protocols

- Unslotted Nonpersistent CSMA

$$S = \frac{Ge^{-aG}}{G(1+2a) + e^{-aG}}$$

- Slotted Nonpersistent CSMA

$$S = \frac{aGe^{-aG}}{1 - e^{-aG} + a}$$

- Unslotted 1-Persistent CSMA

$$S = \frac{G\left[1 + G + aG\left(1 + G + aG/2\right)\right]e^{-G(1+2a)}}{G(1+2a) - \left(1 - e^{-aG}\right) + (1 + aG)e^{-G(1+a)}}$$

- Slotted 1-Persistent CSMA

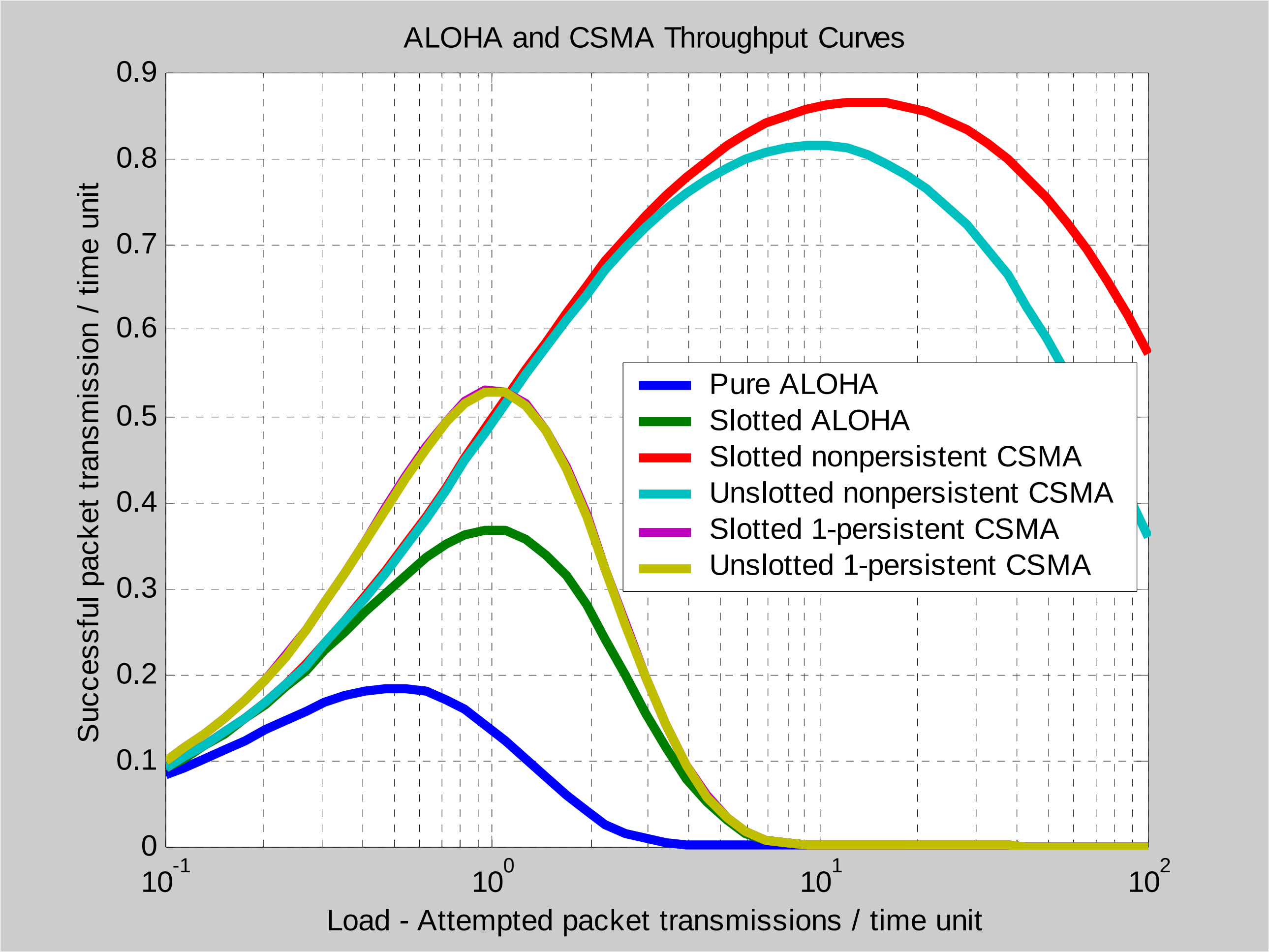
$$S = \frac{G\left[1 + a - e^{-aG}\right]e^{-G(1+a)}}{(1+a)\left(1 - e^{-aG}\right) + ae^{-G(1+a)}}$$

$a = T_{prop}/T_p$
T_{prop} = propagation delay
T_p = packet/frame transmission time

Throughput Figures for CSMA Protocols – cont'd

- For a = 0.01

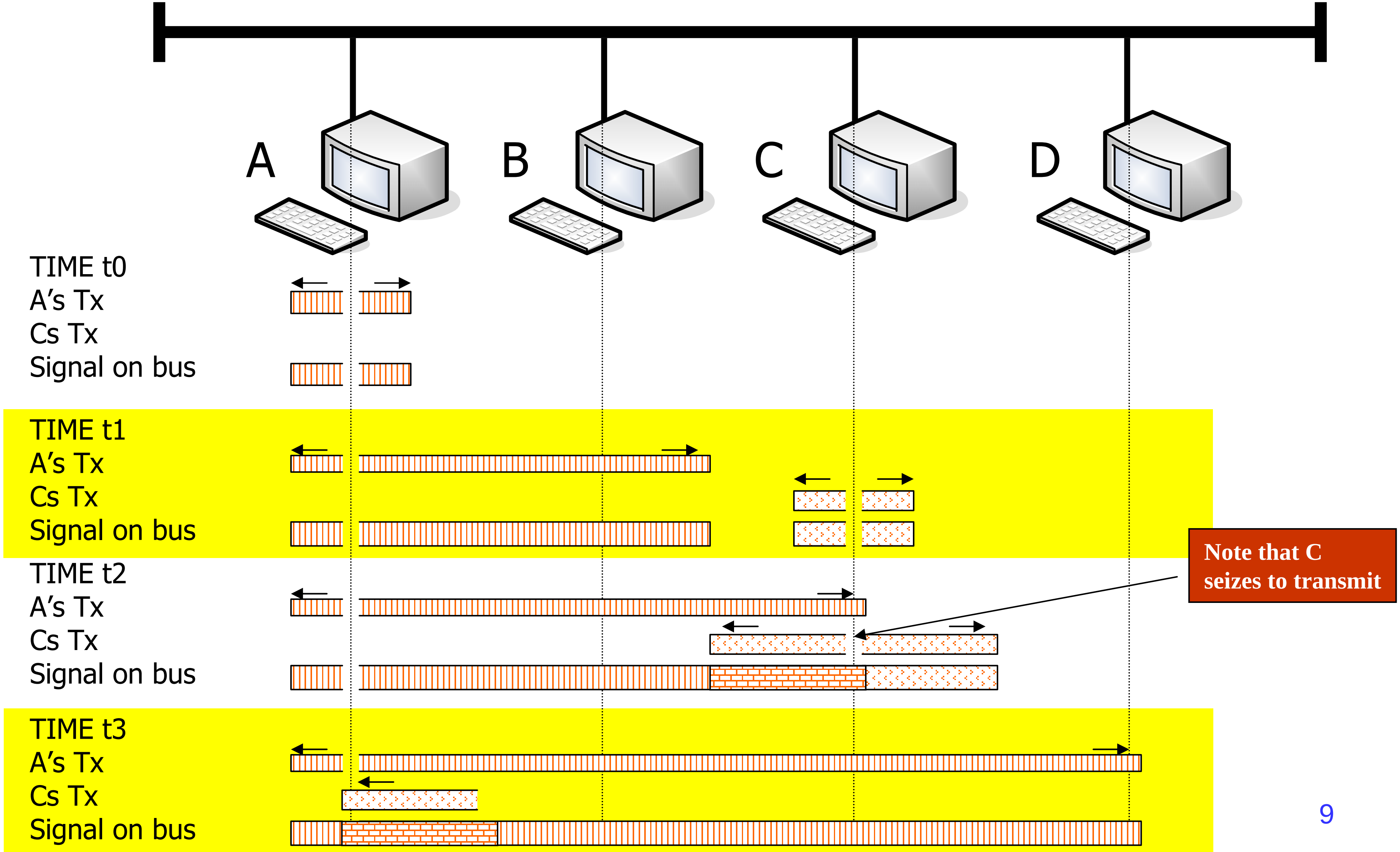
- How does the performance look like for a ~ 1? What about a >> 1?



CSMA/CD Access Rules

1. If medium is idle transmit, otherwise goto step 2
2. If medium is busy, continue to listen until channel is idle; then transmit immediately
3. If a collision occurs during transmission, transmit a brief jamming signal
4. Wait a random amount of time then attempt to transmit again (goto step 1)

CSMA/CD Example

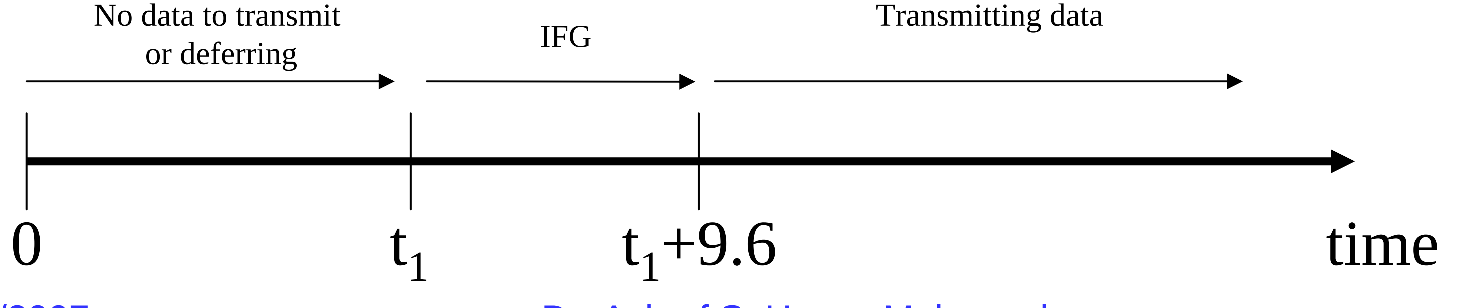


CSMA/CD Access Rules

- The 1-persistant algorithm is used for CSMA/CD (IEEE802.3)
- The backoff mechanism is necessary for the operation and stability of CDMA/CD
- Only 16 unsuccessful attempts are allowed – abort is issued

CSMA/CD Operation – No Collision

- When station has data to transmit
  - MAC layer monitors channel (Carrier Sense signal from PLS)
  - When channel idle – defer for Inter-Frame Gap (IFG)
    - IFG – a fixed gap of 9.6 μsec (for 10Base-T)
  - When IFG expires – station can transmit using PLS signalling function



With 1-persistent

Binary Exponential Back-off

- For a terminal that have collided n (n=1, ...,15) successive times (station aborts if the 16th collision occur):
  - Choose a random number K from set {0, 1, 2, ..., 2^m-1}, where m = min(10,n) – uniform distribution
  - Wait for K time slots – slot time = 512 bits or 51.2 μsec
  - E.g. after first collision – terminal waits either 0 or 1 time slot – after 2nd collision – terminal waits either 0, 1, 2, or 3 time slots, and so on

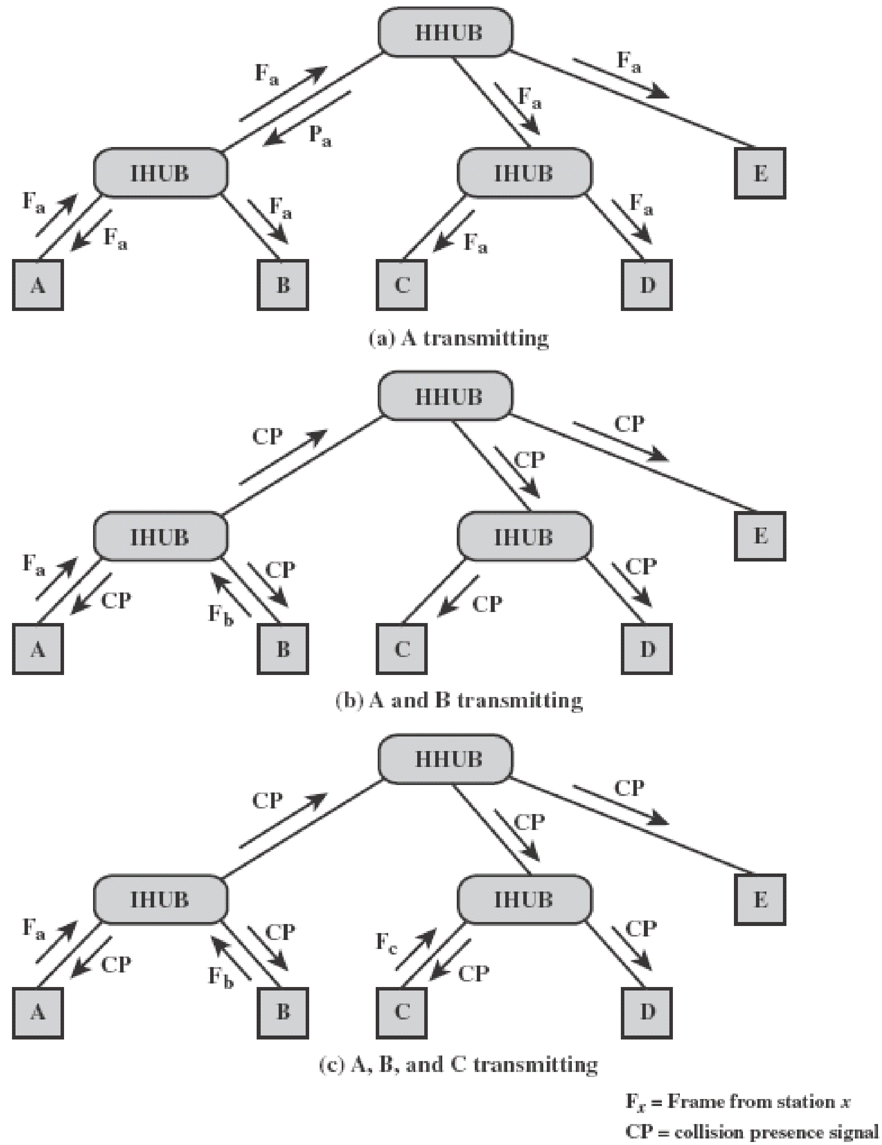
Carrier Sense and Collision Detection

- Baseband carrier Sense – for Manchester encoding of digital signal, there must be a signal transition every bit time
- The absence of transition = no carrier

- Baseband collision detection – multiple transmissions on the shared line cause higher voltages (current)
  - Rule: if voltage/current is higher than that generated by transceiver, then assume collision
    - What if the two colliding stations are far apart – the overall signal may be still below (due to attenuation) that of one station
    - Need to limit cable length (~ 500 meter)

Operation of a Two-Level Star Topology with CSMA/CD

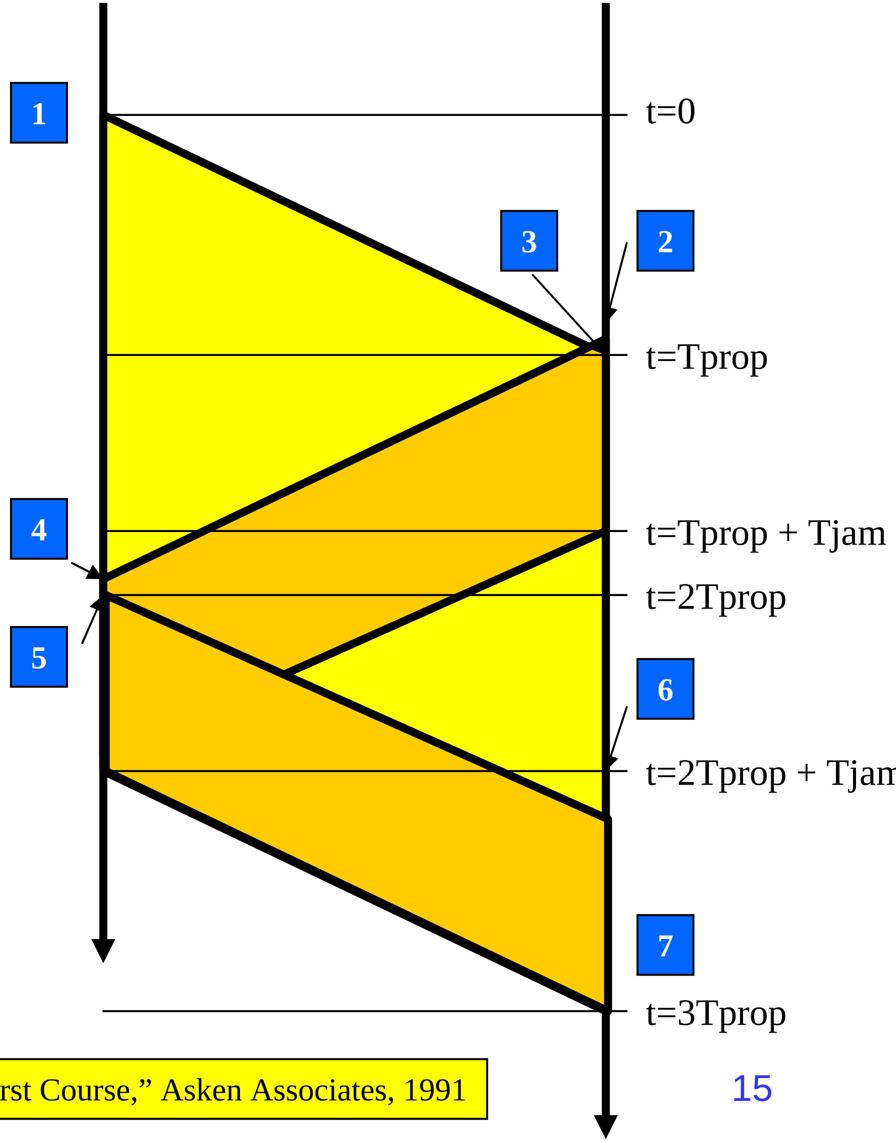
- If a repeater detects a collision on either cable, it must transmit a jamming signal on the other side



CSMA with Collision Detection (CSMA/CD) – Timing Diagram

Collision Scenario

1. A starts transmitting
2. B starts transmitting
3. A's transmission reaches B
   - B detects collision and transmits a jamming signal
4. B's transmission reaches A
5. A detects collision and transmits a jamming signal
6. The jamming signal transmission is complete – A stops
   - All stations on bus are aware of collision
7. A's jamming signal reaches B – Channel is clear after 3Tprop +Tjam



Based on Figure 5.9 of Jean Walrand, "Communication Networks: A First Course," Asken Associates, 1991

CSMA/CD – Timing Diagram – cont'd

- CSMA/CD is a "polite version" of ALOHA
  - (Listen before talk rule)
  - ALOHA is designed for long propagation links – carrier sensing is inefficient – collisions will be detected long after packets are transmitted
- A Node detect collision while transmitting when its transceiver measures excessive voltage/current on the cable
- The maximum collision detection time equals twice the propagation time
- The minimum packet length allowed has to exceed the collision detection window + the longest jamming pattern (32 to 48 bits)

CDMA/CD – Performance

- Time slot = 2 X Tprop
- The time which guarantees that all terminals know (receives the jamming signal) of the collision
- By 3 X Tprop – the channel is clear

- Efficiency of CSMA/CD ≈ 1/(1+3a)
  where a = Tprop/Tframe

CDMA/CD – Performance – cont'd

Proof:

Prob[1 terminal transmits] = β = $Np(1-p)^{N-1}$

This probability is maximized if p = 1/N

For large N ➔ Prob[1 terminal transmits] = $\beta \approx 0.4$

Let A be number of time slots waisted till a successful tx goes through, therefore A = βX0 + (1- β)X(1+A)

➔ A = 1.5

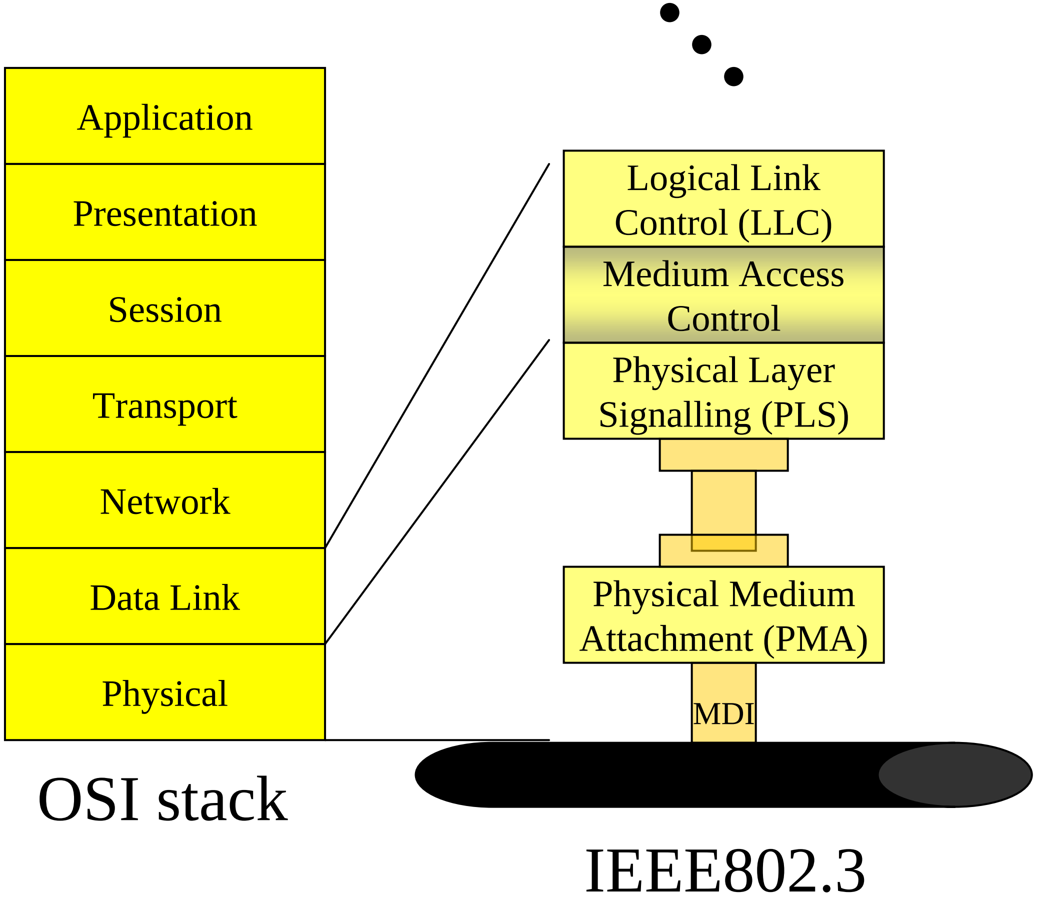
Therefore Efficiency = Tframe/(Tframe + 1.5X2*Tprop), or

= 1/(1+3a)

Actual performance is closer to = 1/(1+5a)

Medium Access Control

- MAC: is a medium independent facility built up the medium-dependent physical layer
- Two main functions:
  - Data encapsulation (framing, addressing, error detection), and
  - Media access (media allocation and contention resolution)



Medium Access Control Frame Structure

Payload (Information + Padding)

Preamble (7)	SFD (1)	Dest Address (2/6)	Src Address (2/6)	Length/Type (2/6)	Information (variable)	Padding (variable)	FCS (4)

Minimum frame size of 64 Octets, Maximum of 1518 Octets (Dest Address through FCS)

- Frame transmitted from left-to-right, with each field (except FCS) transmitted LSB first
- Preamble: pattern of 101010… - for synchronization
- SFD (Start of Frame Delimiter): 10101011

Medium Access Control Frame Structure – cont'd

- Destination Address – most implementations use 6 bytes
  - I/G – bit (unicast, multicast, broadcast)
  - U/L bit (locally administered addresses versus universally administered addresses – the 2^{nd} type is the dominant
  - Of the form: XX-YY-ZZ-ab-cd-ef
    - Organization Unique Identifier (OUI): XX-YY-ZZ
    - A unique identifier (assigned at the time of manufacturing): ab-cd-ef
    - Use the command "ipconfig /all" to know the MAC address of your network card!
- Source Address – to identify the source station

Medium Access Control Frame Structure – cont'd

- Length/Type
  - IEEE802.3 – length of information field – range: 0000_{16} (zero bytes) to $05DC_{16}$ (1500 bytes)
  - Ethernet – EtherType code to indicate the type or protocol of the information (0600 Xerox NS IDP, 0800 Internet Protocol, 0806 ARP, etc.)
  - EtherType codes CAN NOT be confused for frame lengths – Why?
- Information and Padding
  - Padding (mostly 0s) is added to make the length of the information field 46 octets
- FCS: the following generator polynomial is used: $X^{32}+X^{26}+X^{23}+X^{22}+X^{16}+X^{12}+X^{11}+X^{10}+X^{8}+X^{7}+X^{5}+X^{4}+X^{2}+X+1$
  - Based on all fields except preamble, SFD, and FCS

IEEE802.3 Parameterized Values

- slotTime:
- interFrameGap:
- attemptLimit:
- backoffLimit:
- jamSize:
- maxFrameSize:
- minFrameSize:
- burstLimit:

IEEE802.3 Parameterized Values – cont'd

- Baseband

Parameter	10-Mb/s Value	100-Mb/s Value	1000-Mb/s Value
slotTime	512 bit times	512 bit times	4096 bit times
interFrameGap	9.6 µsec	0.96 µsec	0.096 µsec
attemptLimit	16	16	16
backoffLimit	10	10	10
jamSize	32 bits	32 bits	32 bits
maxFrameSize	1518 octets	1518 octets	1518 octets
minFrameSize	64 octets	64 octets	64 octets
burstLimit	NA	NA	8192 octets

10 Mb/s Ethernet

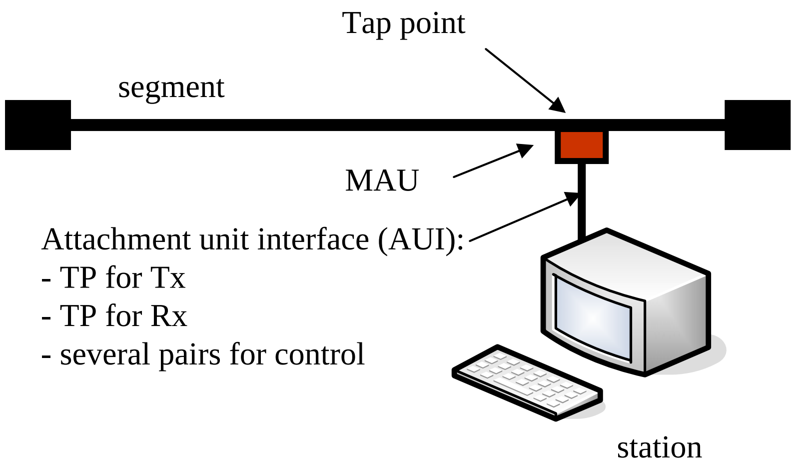
- Various implementations: 10BASE5, 10BASE2, 10BASE-T, 10BROAD36, 10BASE-F

IEEE802.3 10-Mb/s Physical Layer Medium Alternatives

	10BASE5	**10BASE2**	**10BASE-T**	**10BASE-FP**
Transmission medium	Coaxial cable (50 Ω)	Coaxial cable (50 Ω)	UTP	850-nm optical fiber pair
Signaling Technique	Baseband (Manchester)	Baseband (Manchester)	Baseband (Manchester)	Manchester/on-off
Topology	Bus	Bus	Star	Star
Maximum segment length (m)	500	185	100	500
Nodes per segment	100	30	-	33
Cable diameter	10 mm	5 mm	0.4 ~ 0.6 mm	62.5/125 μm

Medium Access Unit (MAU)

- MUA performs:
  - Transmit signals on the medium
  - Receive signals from the medium
  - Recognize presences of signal on the medium
  - Recognize a collision
- MAU could be physically integrated with the 802.3 logic

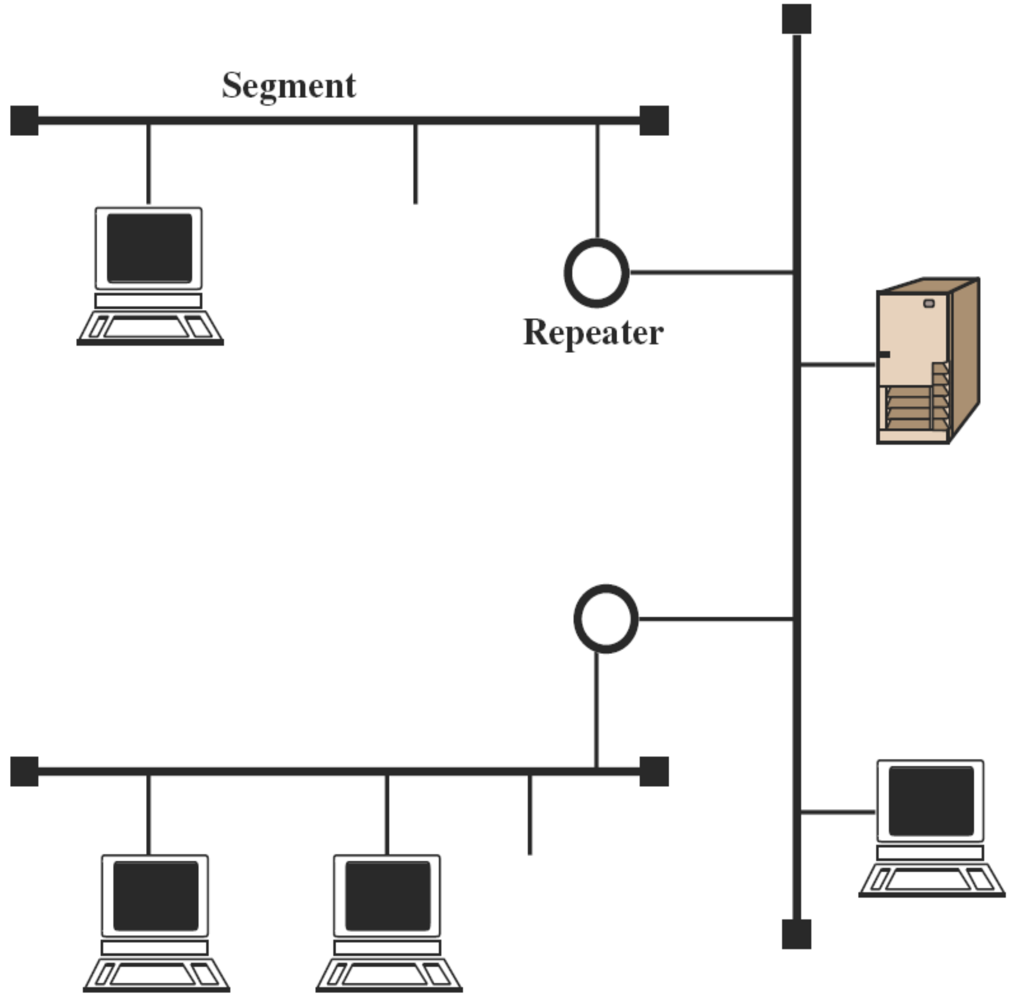


10Base5 Medium Specification

- The original 1985 IEEE/ANSI 802.3 (Ethernet) standard
- 50-Ω coaxial cable – special purpose cable used for baseband bus LANs
  - Much better performance compared to the 75-Ω more common CATV cable
- 10 Mb/s – Manchester encoding
- Maximum length of cable segment is 500 m
  - Length of network can be extended using repeaters
  - Standard allows a maximum of 4 repeaters between any two stations → effective length of the medium = 2.5 km
- Repeater: Two MAUs connecting two segments

10Base5 Medium Specification

- Figure depicts 3 segments and 2 repeaters



10Base2 Medium Specification

- Lower cost version of 10Base5 for PCs
- Uses thinner and more flexible cable (50-Ω coaxial cable) – simpler electronics
- 10 Mb/s – Manchester encoding
- It is possible to mix 10Base5 and 10Base2 segments in the same network
  - Restriction: 10Base2 segment CAN NOT be used to bridge two 10Base5 segments

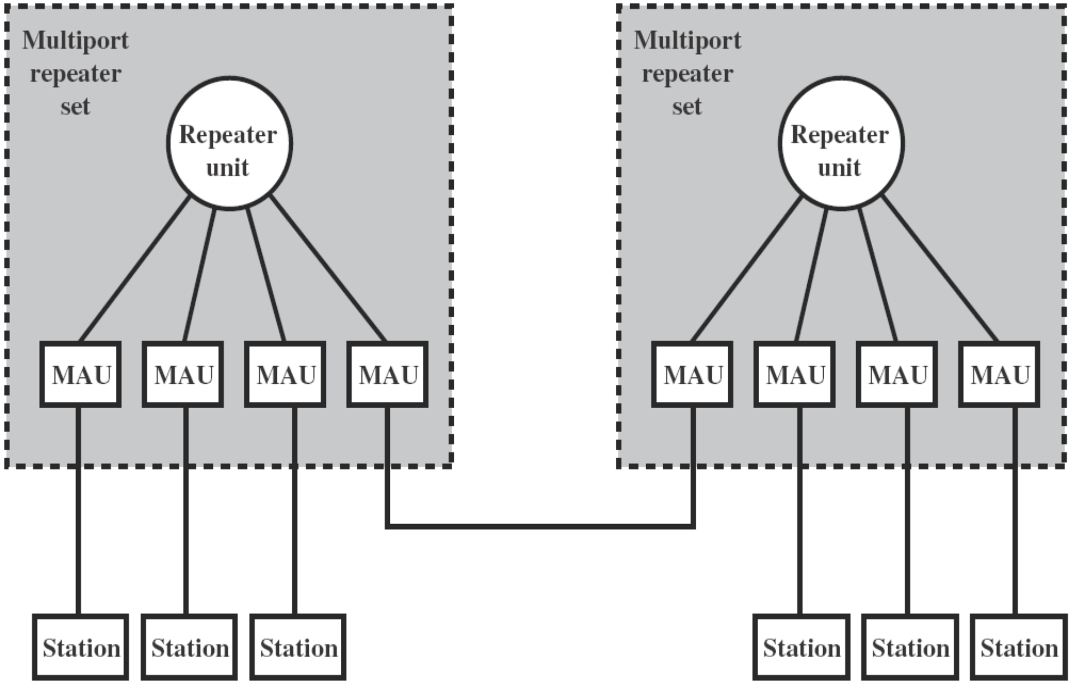
10Base-T Medium Specification

- Unshielded twisted pair (UTP)
- Defines a star-shaped topology
  - Central node = multiport repeater – accepts input on any one line and repeats it on all other lines
- Link: two UTPs
- 10 Mb/s – Manchester encoding
- Length – limited to 100 m
  - Alternatively a fiber can be used → length = 500 m
- Through the use of repeaters, 10Base-T system can be mixed with 10Base2 and 10Base5 systems
- The maximum transmission path permitted between any two stations is 5 segments and 4 repeaters
- The maximum number of coaxial cable segments in a path is 3

10Base-T – Multiport Repeater

- Multiport repeater makes no distinction between a station and another repeater
- Function in the same manner as an ordinary repeater for 10Base5 and 10Base2

- Functions:
  1. A valid signal appearing on any input is repeated on all other links
  2. If two inputs occur (collision), a collision enforcement signal is transmitted on all links
  3. If a collision enforcement signal is detected on any input, it is repeated on all other links

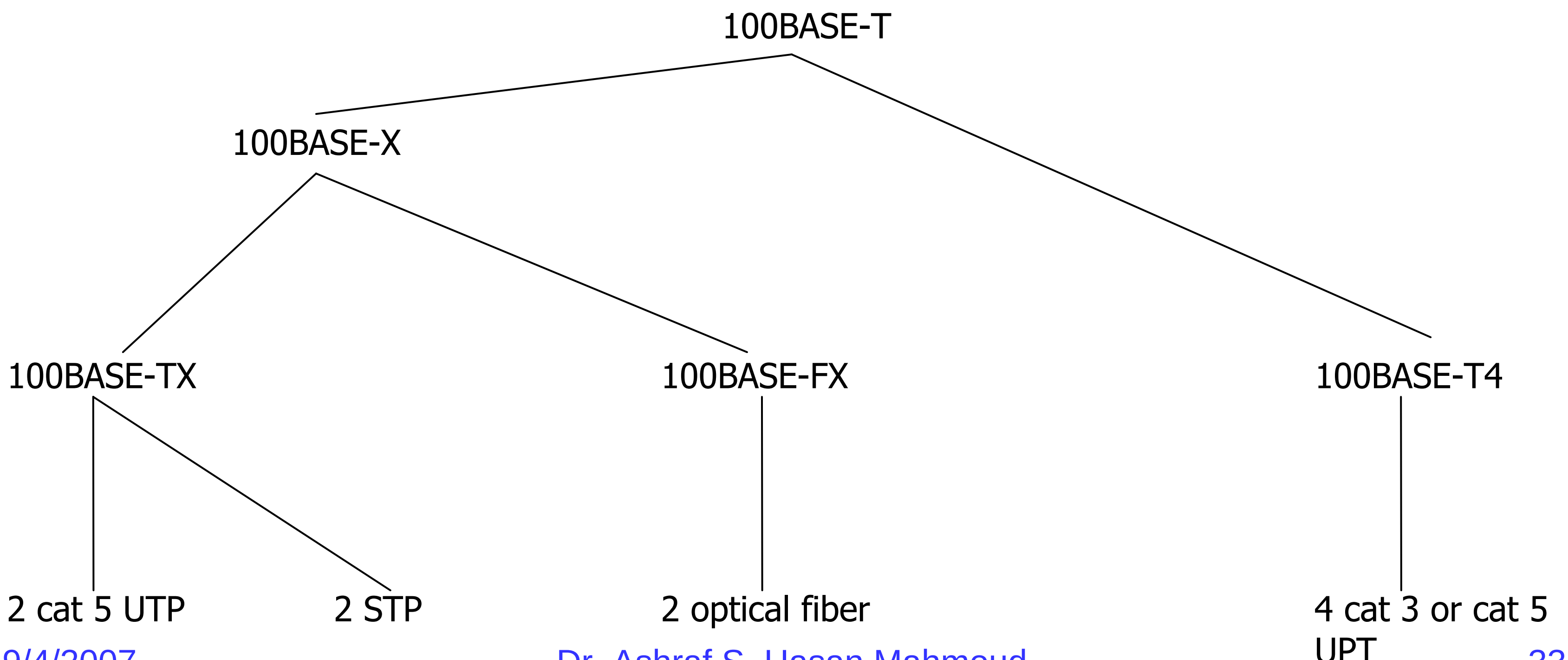


10Base-F Medium Specification

- Added to IEEE 802.3 in 1993
- Use optical fiber
- Three items included:
  - 10Base-FP (passive): passive star topology for interconnecting stations and repeaters with up to 1 km per segment
  - 10Base-FL (link): defines point-to-point that can be used to connect stations or repeaters at up to 2 km
  - 10Base-FB (backbone): Defines a point-to-point link that can be used to connect repeaters at up to 2 km
- Each link = 2 fibers (tx and rx)
- Signal: electrical (Manchester) 10 Mb/s ➔ optical 20 M light pulses on the fiber

100 Mb/s Ethernet

- Fast Ethernet
- IEEE 802.3 100Base-T options (refer to figure)
  - All share same MAC



100 Mb/s Ethernet – cont'd

- All 100Base-T options use **star topology** like 10Base-T

IEEE802.3 100BASE-T Physical Layer Medium Alternatives

	100BASE-TX		100BASE-FX	100BASE-T4
Transmission medium	2 pair, STP	2 pair, Cat 5 UTP	2 optical fibers	4 pair, Cat 3, 4, or 5 UTP
Signaling Technique	MLT-3	MLT-3	4B5B, NRZI	8B6T, NRZ
Maximum segment length (m)	100	100	100	100
Network span	200 m	200 m	400 m	200 m

100BASE-X

- Unidirectional 100 Mb/s data is transmitted over a single link (TP or fiber)
- Two distinct physical media: 100Base-TX (STP or UPT) and 100Base-FX (optical fiber)

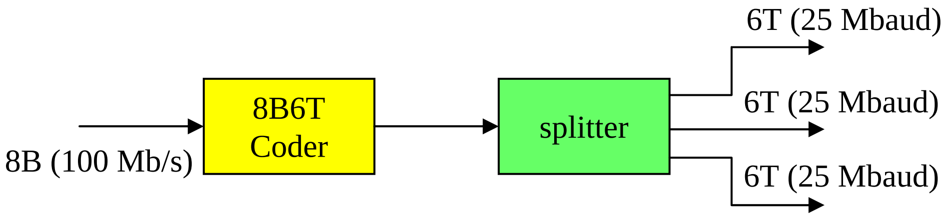
100BASE-T4

- 100 Mb/s over low quality Cat 3 cable
  - Cat 3 – voice grade twisted pair; available in most installations
  - Cat 5 is optional
- Communication is split over three parallel streams (each 33.3 Mb/s)
  - Data transmitted over pairs D1, D3 and D4
  - Data received over pairs D2, D3 and D4
  - Collision is detected over pair D2
- Uses 8B6T data encoding
- Typically operates in a star-wire topology

8B6T Transmission Scheme

- A translation table from 8 bits (1 byte) to 6T code
- Two criteria:
  - Synchronization (i.e. maximum number of transitions)
  - DC balance (zero mean signal)
- A portion of the 8B6T table is shown

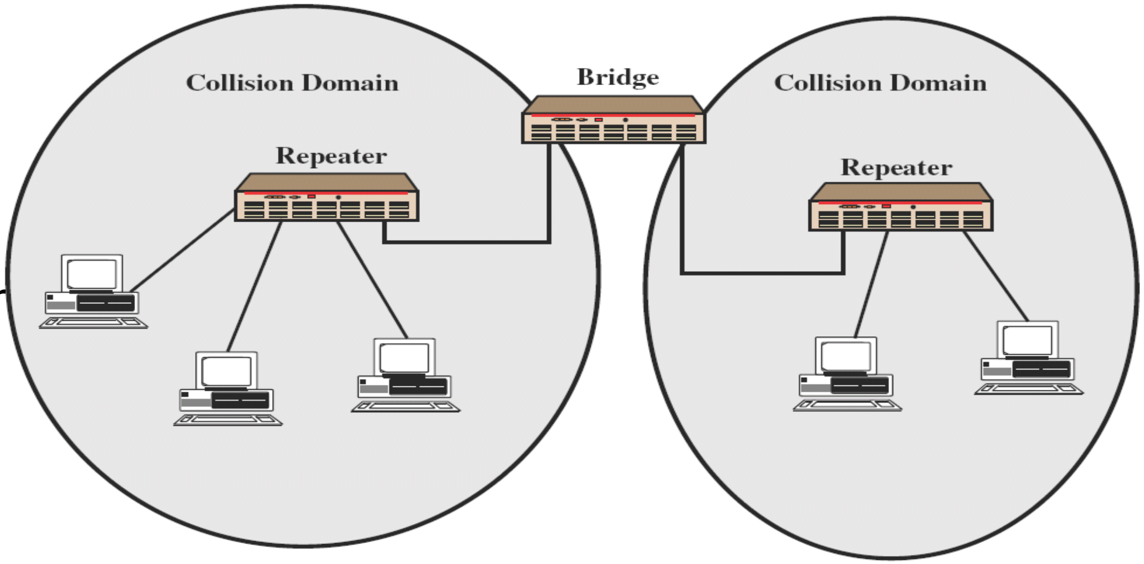
Data octet	6T code group	Data octet	6T code group	Data octet	6T code group	Data octet	6T code group
00	+−00+−	10	+0+−−0	20	00−++−	30	+−00−+
01	0+−+−0	11	++0−0−	21	−−+00+	31	0+−−+0
02	+−0+−0	12	+0+−0−	22	++−0+−	32	+−0−+0
03	−0++−0	13	0++−0−	23	++−0−+	33	−0+−+0
04	−0+0+−	14	0++−−0	24	00+0−+	34	−0+0−+
05	0+−−0+	15	++00−−	25	00+0+−	35	0+−+0−
06	+−0−0+	16	+0+0−−	26	00−00+	36	+−0+0−
07	−0+−0+	17	0++0−−	27	−−+++−	37	−0++0−
08	−+00+−	18	0+−0+−	28	−0−++0	38	−+00−+
09	0−++−0	19	0+−0−+	29	−−0+0+	39	0−+−+0
0A	−+0+−0	1A	0+−++−	2A	−0−+0+	3A	−+0−+0
0B	+0−+−0	1B	0+−00+	2B	0−−+0+	3B	+0−−+0
0C	+0−0+−	1C	0−+00+	2C	0−−++0	3C	+0−0−+
0D	0−+−0+	1D	0−+++−	2D	−−00++	3D	0−++0−
0E	−+0−0+	1E	0−+0−+	2E	−0−0++	3E	−+0+0−
0F	+0−−0+	1F	0−+0+−	2F	0−−0++	3F	+0−+0−



Collision Domains

- Multiport repeater function:
  - A valid signal appearing on any signal input is repeated on all output links
  - If two inputs occur at the same time, a jam signal is transmitted on all links
- Collision domain: defines a single CSMA/CD network

- 100BASE-T defines two repeaters
  - Class I: handles different phyiscal media (i.e. 100Base-T4 and 100Base-Tx)
  - Class II: limited to one physical media
- A bridge function in a store-and-forward manner ➔ separation of collision domains

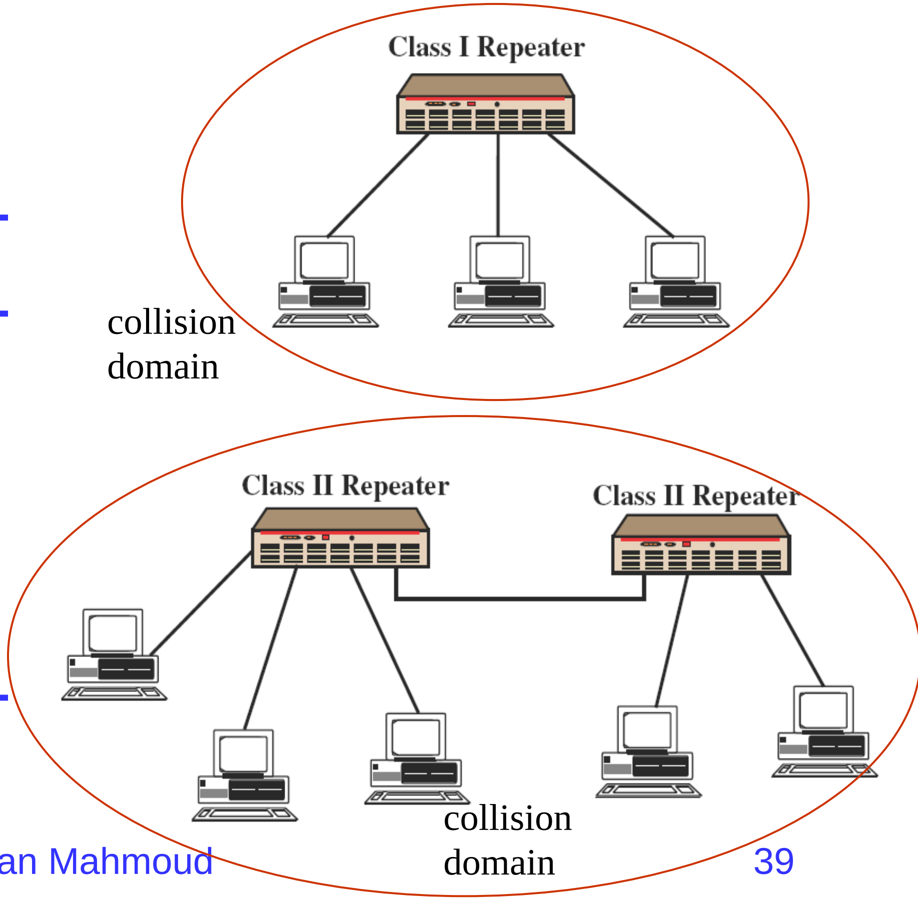


Collision Domains (2)

- Repeater makes no distinction between a station and another repeater
- Table list the allowable distances for various collision domains

Maximum Collision Domains (meters)

Repeater Type	Copper	Copper and Fiber	Fiber
Station-to-station	100	N/A	400
1 Class I repeater	200	230	240
1 Class II repeater	200	285	318
2 Class II repeater	205 (200 Cat 3)	212	226



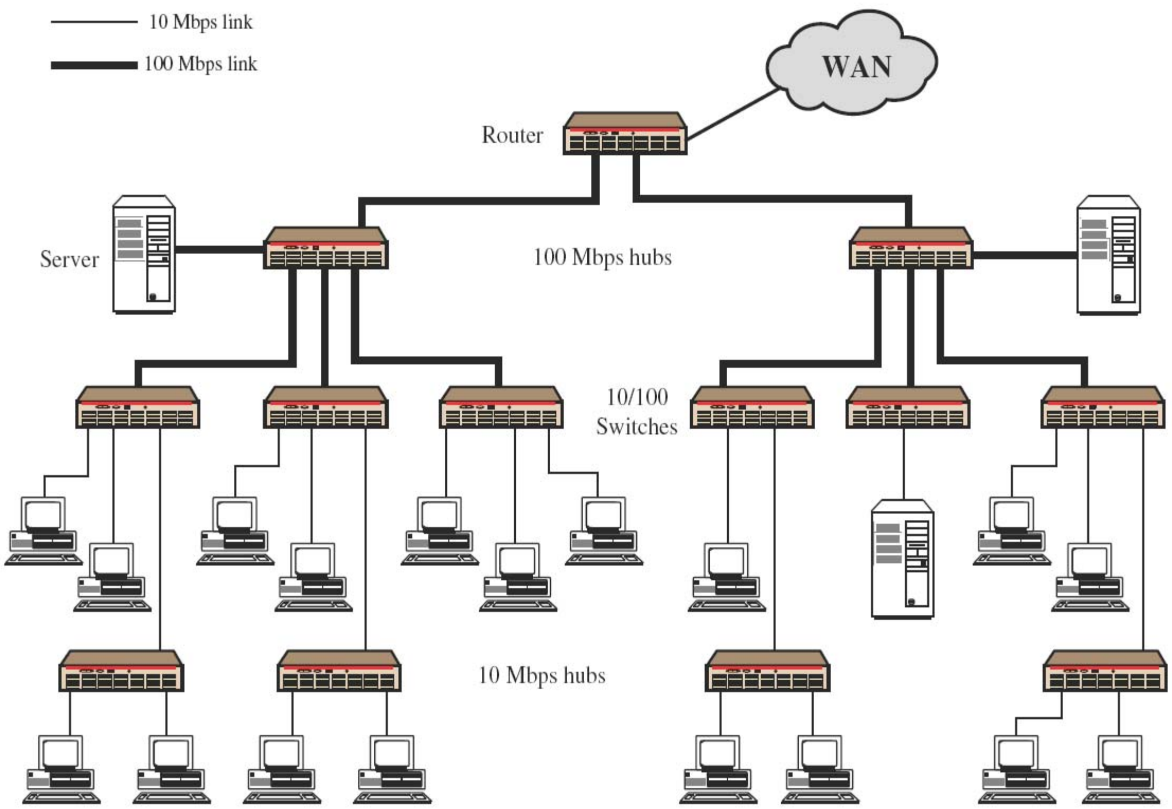
Full Duplex Operation

- Traditional Ethernet operates in half duplex mode
  - A station either transmits OR receives a frame – but not both at the same time
- When 100Base-T runs in full duplex mode, the theoretical transfer rate is 200 Mb/s!
- When using the full duplex mode:
  - The LAN card should support full duplex operation
  - Can not have simple multiport repeaters on the LAN – we need a switch!
  - No need for CSMA/CD – no collisions can occur
- MAC-level flow control is introduced between station and switch – "pause frames"
  - Avoid losing frames due to buffer overflow at the switch

Mixed Configuration

- Fast Ethernet supports a mixture of existing 10 Mb/s LANs and newer 100-Mb/s

- 10 Mb/s hubs – support 10Base-T
- 10/100 LAN switch – supports 10Base-T and 100Base-T
- High capacity workstations and servers can be connected to the LAN switches directly



Auto-negotiation

- Option in the 100Base-T standard
- Two connecting devices can exchange info about their capability
- Minimum – indicate whether it operates at 10 Mb/s or 100 Mb/s
- Used by the LAN switch
- Stations that does not support auto-negotiation are not affected

Giga Bit Ethernet

- Defines a new medium and transmission specifications (called MAC extension) – while retaining the same CSMA/CD found in 10Base-T networks
- Typical deployment scenario