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COE 540 – Computer Networks
Term 112
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Lecture Contents

1. The channel allocation problem
2. Multiple access protocols
3. Ethernet
4. Wireless LANs
5. Broadband Wireless
6. Bluetooth, RFID
7. Data link layer switching

These slides are based on the Tanenbaum's textbook and original author slide

Medium Access Control (MAC)

- Data link layer typically divided into
  - Logical link control (LLC), and
  - Medium access control (MAC)
- MAC determined how to access the medium and transmit the information
  - Point-to-point link – MAC is simple
  - Shared media - ?
- The central theme of the chapter is how to allocate a single broadcast channel among competing users.

The Channel Allocation Problem – Static Allocation

- Traffic:
  - Bursty – data (variable/random intensity)
  - Non-bursty – constant arrival rate (bits, frames, etc.)
- FDM – an example of static allocation scheme
  - System bandwidth B Hz is divided equally between N users – each user has B/N Hz
  - Excellent for non-bursty traffic but VERY poor for highly bursty traffic.
  - Hard capacity limit – if more than N users want to access the channel → blocked
- Same arguments apply for time division multiplexing (TDM) as well

The Channel Allocation Problem – Static Allocation (2)

- Assume total capacity = C b/s, frames arrive with λ frames/sec and have average length of 1/μ bits, then the mean time delay T is given by

$$T = \frac{1}{\mu C - \lambda}$$

- The above formula is valid for an M/M/1 queue setting
- Now, divide the total capacity in to N sub-channels (FDM or TDM) and let the frame arrivals per sub-channel to be λ/N. The mean time delay now, T_N, is given by

$$T_N = \frac{1}{\mu(C/N) - \lambda/N} = \frac{N}{\mu C - \lambda} = N\,T$$

- It is clear than TN is N times the original T – This is referred to by the scaling effect for M/M/1 queues; refer to queueing slides.

- Conclusion – Static allocation is very bad for bursty traffic
  - No need to reserve the channel for the entire duration of the bursty traffic session

Dynamic Channel Allocation - Assumptions

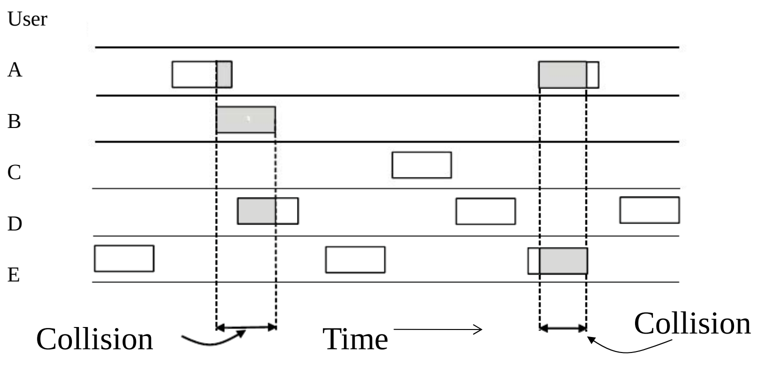
- Independent traffic – N independent sources (e.g. computers, telephones, users)
  - Average number of arrivals during Δt is equal to λ Δt.
  - Once a frame is generated, the source is blocked till the frame has been successfully transmitted
  - Poisson model – mathematically tractable.
- Single channel – only a single channel is available for all communications
- Observable collisions
- Continuous or slotted time
- Carrier sense versus no carrier sense

Multiple Access Protocols – Pure ALOHA

- Two versions
  - Pure ALOHA
  - Slotted ALOHA
- Pure ALOHA – users transmit whenever they have data to be sent
- Assumptions:
  - Group of N terminals send frames to a central computer
  - Correctly received frames are acknowledged on the downlink channel
  - Frames not acknowledged (i.e. were not received or not correctly received) are scheduled for retransmission
  - Two or more frame overlapping in time are said to be collided
- ALOHA is a contention system

Multiple Access Protocols – Pure ALOHA (2)

- PURE ALOHA = Start of transmission for frames can be at *any* point in time
- Example below – 5 terminals transmitting frames whenever the frames are ready to be sent
  - Observe the two collision events



Multiple Access Protocols – Slotted ALOHA (3)

- Slotted ALOHA = Start of transmission for frames can be only at slot border
- Time axis is divided into equal slot periods equal to the frame time
  - Frames arriving in one slot can be transmitted at the beginning of the next slot

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Throughput of Pure/Slotted ALOHA (4)

- Throughput – fraction of transmitted frames that are correctly received per frame time.
- Assume new frames generation follow Poisson distribution – average of N frames per frame time
  - Note the channel can handle at most 1 frame per frame time
  - For reasonable throughput we expect 0 < N < 1.
- Further assume that old and new frames generated follow Poisson distribution – average of G frames per frame time
  - Clearly G >= N
- Throughput, S, is the fraction of G that do NOT collide

S = G Prob [no transmissions from the rest of the population in the vulnerable period]
= G P0

where G – frames per frame time represent the average load injected into the system

Throughput of Pure/Slotted ALOHA (5)

- Vulnerable period for pure ALOHA is of length equal to TWO frame time
- Vulnerable period for Slotted ALOHA is of length equal to ONE frame time
- Prob of k frames generated during a given frame time in which G frames are expected is given by the Poisson distribution:

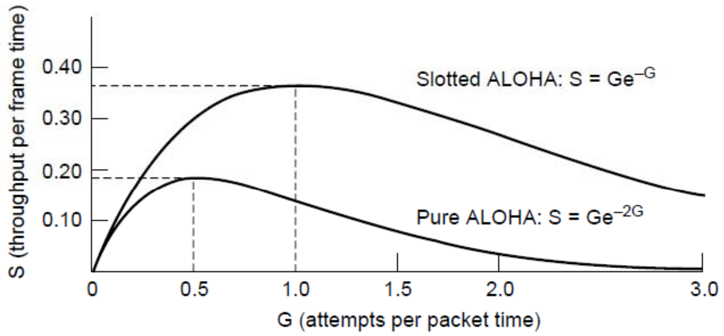
$$Pk = \frac{G^{k}\, e^{-G}}{k!}$$

- Therefore, P0 is equal to

$$P0 = (2G)^{0}\, e^{-(2G)} / 0! = e^{-2G} \leftarrow \text{Pure ALOHA}$$
$$= (1G)^{0}\, e^{-(1G)} / 0! = e^{-G} \leftarrow \text{Slotted ALOHA}$$

Throughput of Pure/Slotted ALOHA (6)

- Throughput versus offered traffic



Throughput of Pure/Slotted ALOHA (7)

- Throughput peak at G*
  - G* = 0.5 attempt per packet time for pure ALOHA
  - G* = 1.0 attempt per packet time for slotted ALOHA
- For G > G* ➔ collisions increase exponentially ➔ throughput approaches zero
- Proof (Slotted ALOHA case)

  Probability of success = P0 = e^{-G}

  Prob of failure = 1 – P0 = 1 – e^{-G}

  Consider the random variable (RV) k defined as then number of transmission for packet until it is success ➔ k is a geometric RV – refer to discrete RVs material

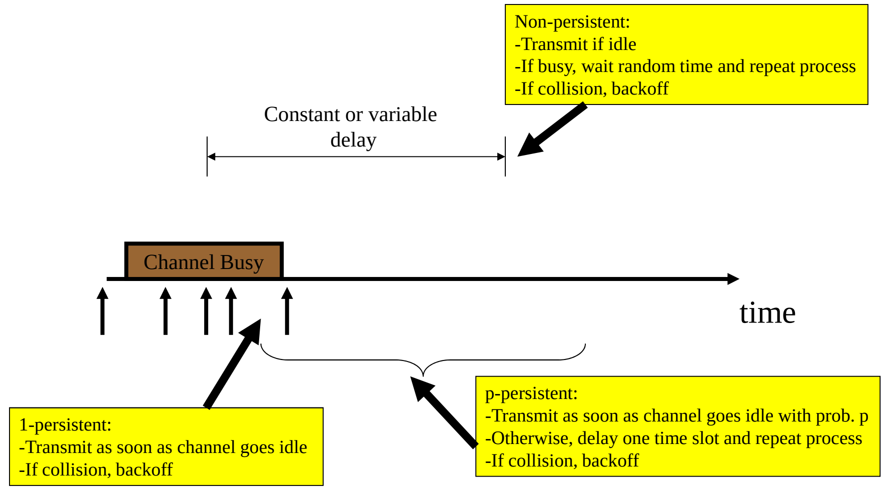
$$P_k = e^{-G}\left(1-e^{-G}\right)^{k-1} \quad \text{for} \quad k = 1,\ 2,\ \cdots$$

The expected number of transmission can be computed as

$$E = \sum_{k=1}^{\infty} kP_k = \sum_{k=1}^{\infty} ke^{-G}\left(1-e^{-G}\right)^{k-1} = e^{G}$$

Exponential increase with load

Carrier Sense Multiple Access Protocols



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

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

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

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

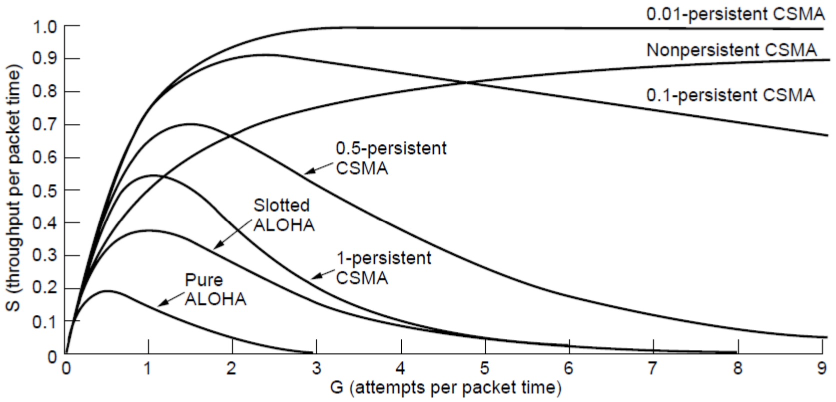
- Slotted 1-Persistent CSMA

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

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

Throughput of CSMA Protocols – cont’d

- Comparison of the channel utilization versus load for various random access protocols

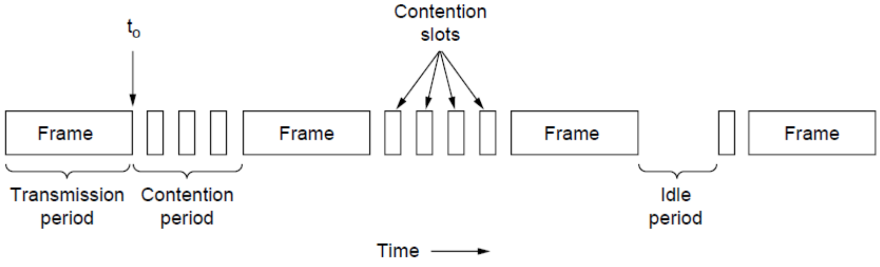


CSMA with Collision Detection

- Persistent and nonpersistent CSMA protocols are an improvement over ALOHA protocols. Why?
- An added improvement is CSMA with collision detection – CSMA/CD; the basis for the classical Ethernet LAN
- CSMA/CD model:
  - At t0 a station has finished transmission
  - Stations may attempt to transmit during the contention period
  - If collision
    - Abort transmission
    - Wait for a random time
    - Retry

CSMA with Collision Detection (2)

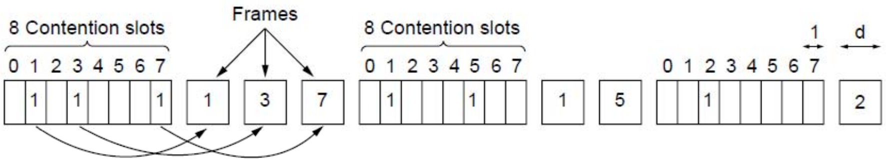
- CSMA/CD can be in contention, transmission, or idle state



- If two stations begin transmitting at t0 – How long does it take them to detect the collision?
- A station cannot be sure that it has seized the channel until it has transmitted for 2τ without detecting a collision
  - τ is the signal propagation time for the full cable length

Collision-Free Protocols – Bit-Map Protocol

- For N stations we have N contention slots
  - There is not real contention here – ith slot is dedicated for ith station.
  - If station i has data to send, then it transmits a bit 1 in its contention slot
- When the N contention slots are complete, all stations (assuming all are listening) have a map of traffic to be sent from all stations
- Refer to the figure.



- Example for N = 8; stations 1, 3, and 7 have traffic to send for the first round
- A form of reservation protocol
- Length of contention slot = 1 unit, length of data frame = d units

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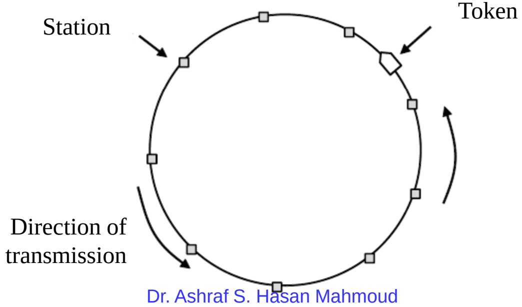
Bit-Map Protocol (2)

- Mean access delay – low load case:
  - Low numbered stations (such as 0 or 1) – N/2 + N = 1.5 N
  - High numbered stations (such as N-1 and N) – N/2
  - Average = 1.5 N + 0.5 N = N for all terminals
- Mean access delay – high load case
  - Queueing time + (N-1)d + N
- Channel efficiency
  - Low load – d/(d + N)
  - High load – Nd/(Nd + N) = d/(d + 1)

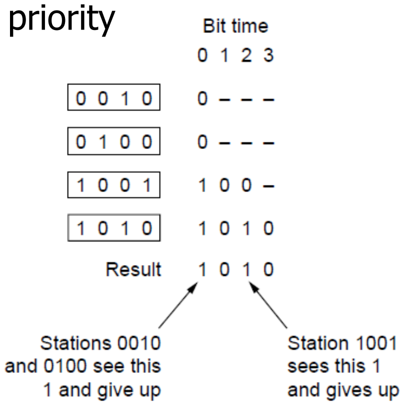
Token Passing

- Token = permission to send
- Topology determines the order of transmission/permissions
- Frames transmitted in the direction of the token
- Source of destination of frame must remove frame transmission from ring
- Performance –
- IEEE802.5
- Fiber Distributed Data Interface (FDDI)
- Resilient Packet Ring (RPR) – IEEE802.17 ~ 2000's metropolitan area rings used by ISPs



Binary Count Down

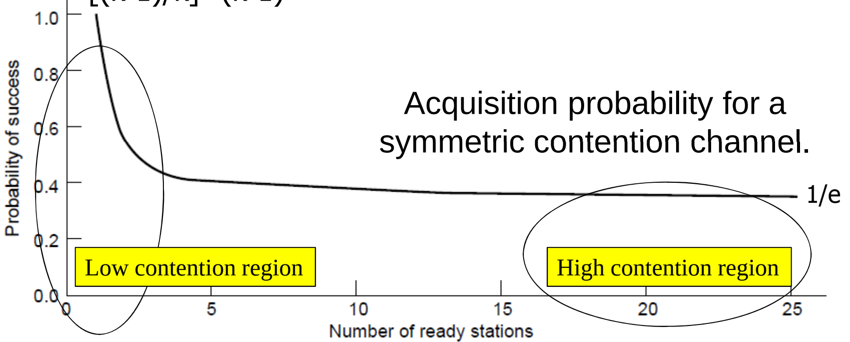
- Basic bit-map and token rings suffer from overhead of 1 bit per station
  - Does not scale well
- Transmit addresses in binary form
- Higher address have higher priority
- Channel efficiency d/(d+log2N)
  - May be as high as 100%



The binary countdown protocol. A dash indicates silence.

Limited-Contention Protocols

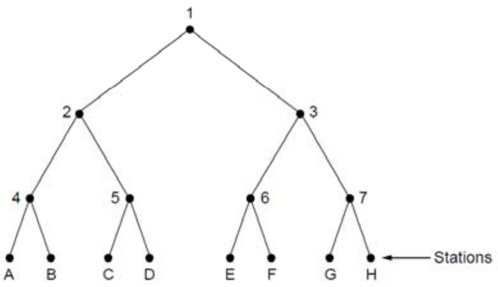
- Combination of contention and collision-free protocols
- Station attempts to acquire channel with prob. p – may be different for different terminals
  - Prob. 1- p to defer transmission
- Prob. of success – Binomial distribution = $kp(1-p)^{(k-1)}$
- To maximize prob. of success p = 1/k ➔ Prob. of success = $[(k-1)/k]^{(k-1)}$



Acquisition probability for a symmetric contention channel.

Adaptive Tree Walk

- Stations are represented by the leaves of the binary tree.
- Rules:
  - Slot 0 (first contention slot following a successful frame transmission) – all terminals are permitted to attempt
  - If collision, during slot 1, only stations falling under node 2 are permitted to compete
    - If one of them acquires the channel, then subsequent slot (slot 2) is reserved for stations under node 3
    - If collision (i.e. 2 or more stations under node 2 want to Tx), only stations under node 4 are allowed to compete for slot 2
    - Etc.
- Enhancements – when load is heavy no need to dedicate slot 0 for node 1
  - Same can be argued for nodes 2 and 3 since many terminals want to transmit!
  - Where to start the search?

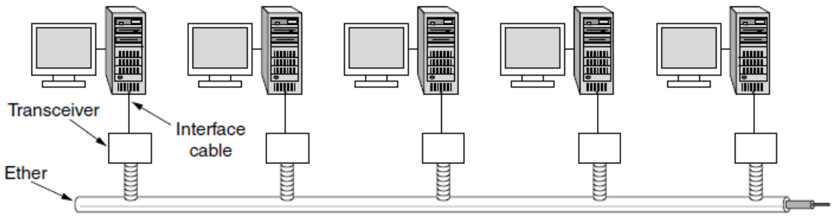


Adaptive Tree Walk – cont'd

- Assume q terminals on average want to send – distributed uniformly in the tree
- Level i of binary tree has 2^{-i} fraction of terminals ➔number of terminals with traffic under node i is equal to $2^{-i}q$
- For optimality, we should start the search at the level where the expected number of contending stations is equal to 1 ➔i = log2(q)

Ethernet

- De facto LAN standard
- Classical versus switched Ethernet
- Relation to IEEE802.3
- Classical Ethernet physical layer
  - 1978 – 10 Mb/s Ethernet (DIX standard)
  - Coaxial cable (thick versus thin) – BNC connectors
  - Repeaters connecting multiple segments – max 2.5 km with 4 repeaters at most



Ethernet – MAC Sublayer

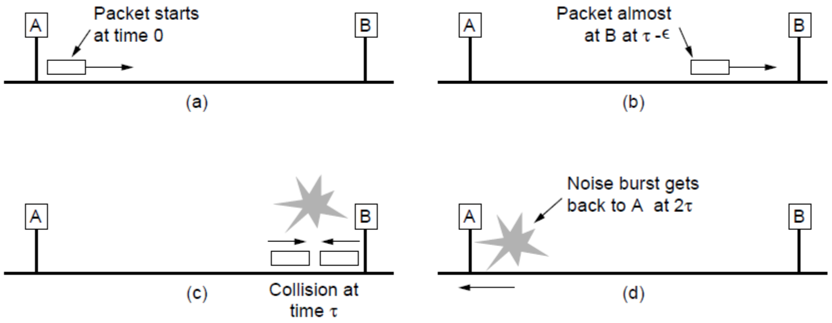
- Preamble – 8 bytes; each byte 10101010 with the exception of the last byte in which the last 2 bits are set to 11
  - Last byte is called SOF for IEEE802.3
- Machester encoding – 10 MHz
- Type/Length fields
  - Max frame length – 1500 bytes of data
  - Min frame length – 64 bytes (with padding if needed)
- 32-bit CRC - checksum

Bytes	8	6	6	2	0-1500	0-46	4
(a)	Preamble	Destination address	Source address	Type	Data	Pad	Check-sum
(b)	Preamble SOF	Destination address	Source address	Length	Data	Pad	Check-sum

Frame formats. (a) Ethernet (DIX). (b) IEEE 802.3.

Ethernet – MAC Sublayer (2)

- Ethernet slot time = 2xTprop
- Min frame length is longer than the slot time



Collision detection can take as long as 2τ.

CSMA/CD with Binary Exponential Backoff

- After the ith collision, a random number between 0 and 2k – 1 is chosen where k = min(i, 10)

F – frame length
B – link rate
L – cable length
c – signal propagation speed
e – contention slots per frame

Ethernet Performance

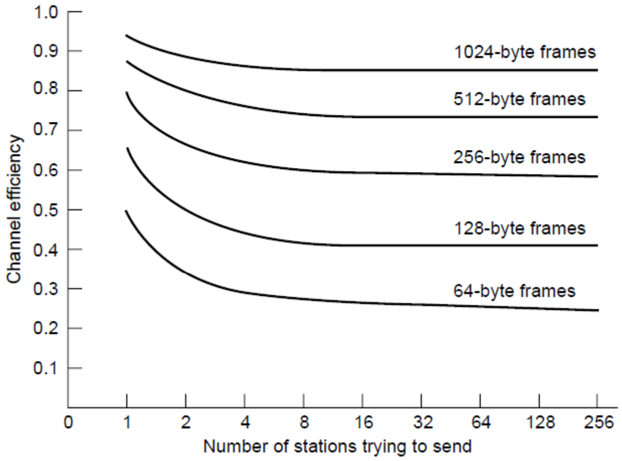
- Let P be mean frame time, 2τ be the slot duration
- Mean number of slots per contention = A^{-1} = e where A = e^{-1}
- Therefore, mean contention interval is 2τ/A ➔ Efficiency is calculated as

$$\text{Channel Efficiency} = \frac{P}{P + 2\tau/A}$$

$$\text{Channel Efficiency} = \frac{1}{1 + 2BLe/(cF)}$$

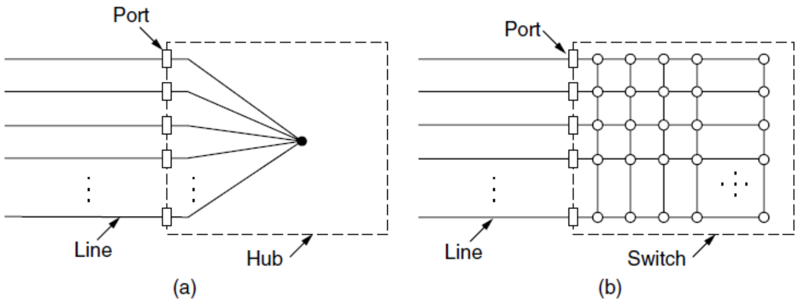
Ethernet Performance (2)

- Efficiency of Ethernet at 10 Mb/s with 512-bit time slot



Switched Ethernet

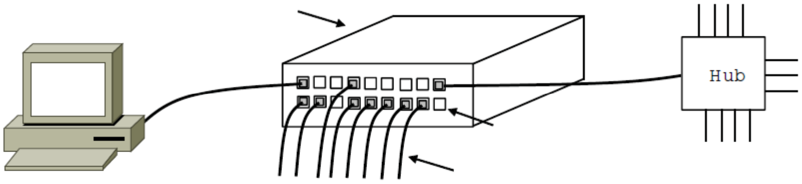
- For fast 100 Mb/s Ethernet
- High-speed backplane that connects all ports
  - Proprietary algorithm



(a) Hub. (b) Switch.

Switched Ethernet (2)

- Collision domain
- Concentration ports
- Promiscuous mode – Security benefits



An Ethernet switch.

Fast Ethernet

- IEEE802.3u (June 1995) – amendment to the existing IEEE802.3
- Identical frame format and procedural rules to 10 Mb/s Ethernet
- 100BaseTX
  - Uses 4B/5B encoding – 125 MHz signal to provide 100 Mb/s
  - Full duplex – can send 100 Mb/s on one twisted pair and receive at 100 Mb/s on another pair
- 100BaseFX – two strands of multimode fiber (one per direction)
- Supports switches and hubs

Name	Cable	Max. segment	Advantages
100Base-T4	Twisted pair	100 m	Uses category 3 UTP
100Base-TX	Twisted pair	100 m	Full duplex at 100 Mbps (Cat 5 UTP)
100Base-FX	Fiber optics	2000 m	Full duplex at 100 Mbps; long runs

Original fast Ethernet cabling

Gigabit Ethernet

- Two MAC extensions: (1) carrier extension and (2) frame bursting
- 8B/10B
- Jumbo frames

Name	Cable	Max. segment	Advantages
1000Base-SX	Fiber optics	550 m	Multimode fiber (50, 62.5 microns)
1000Base-LX	Fiber optics	5000 m	Single (10 µ) or multimode (50, 62.5 µ)
1000Base-CX	2 Pairs of STP	25 m	Shielded twisted pair
1000Base-T	4 Pairs of UTP	100 m	Standard category 5 UTP

Gigabit Ethernet cabling

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10 Gigabit Ethernet

- Full duplex mode only
- CSMA/CD is not part of the design
- Fiber options: 64B/66B code
- 10GBase-CX4: 4 pairs of twinaxial copper wiring – each pair 8B/10B coding provides 3.125 Gsymbol/sec
- 10GBase-T: 800 Msymbols/sec (16 different voltage levels) – LDPC coding

Name	Cable	Max. segment	Advantages
10GBase-SR	Fiber optics	Up to 300 m	Multimode fiber (0.85µ)
10GBase-LR	Fiber optics	10 km	Single-mode fiber (1.3µ)
10GBase-ER	Fiber optics	40 km	Single-mode fiber (1.5µ)
10GBase-CX4	4 Pairs of twinax	15 m	Twinaxial copper
10GBase-T	4 Pairs of UTP	100 m	Category 6a UTP

10 Gigabit Ethernet cabling

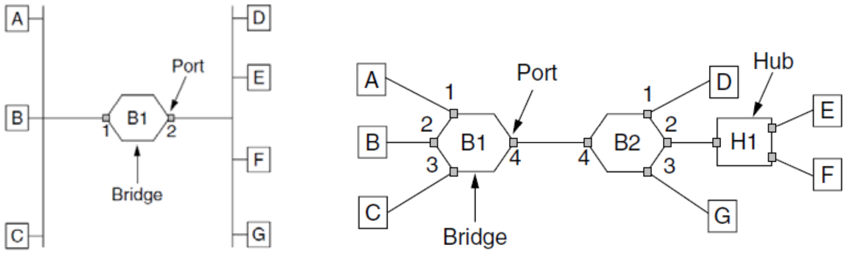
100 Gigabit Ethernet

- 2007 an effort to standardize 40 Gb/s and 100 Gb/s Ethernet
- Completed in June 2010 and March 2011

100 Gigabit Ethernet cabling

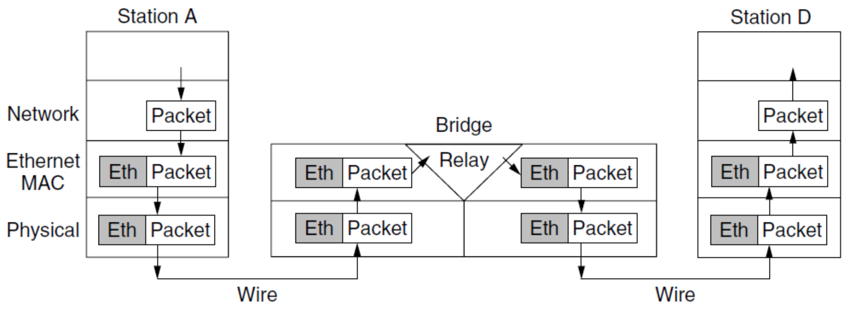
Data Link Switching – The Use of Bridges

- Learning bridges
- Backward learning
- Cut-through switching



The Use of Bridges – cont’d

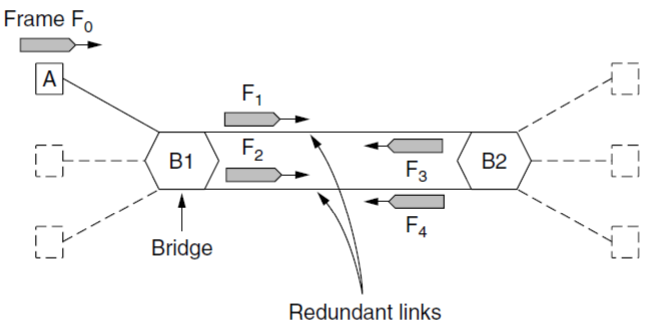
- Protocol stacks



Protocol processing at a bridge.

Spanning Tree Bridges

- X



Bridges with two parallel links

Spanning Tree Bridges – cont’d

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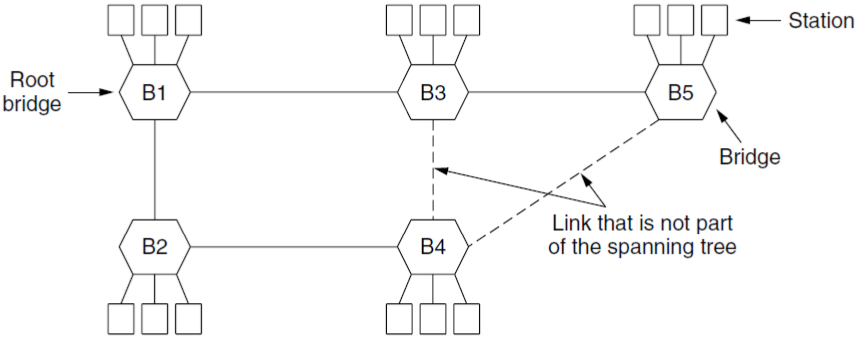
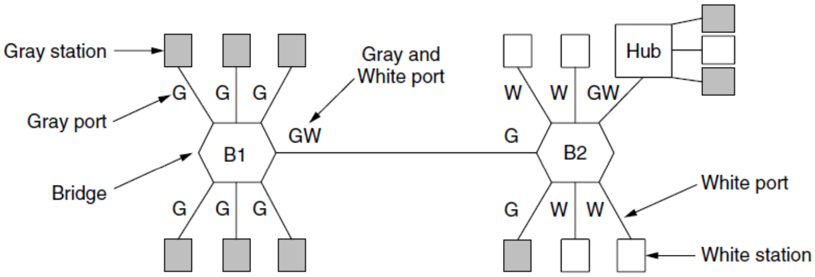


A spanning tree connecting five bridges. The dotted lines are links that are not part of the spanning tree.

Virtual LANs

- X



Two VLANs, gray and white, on a bridged LAN.