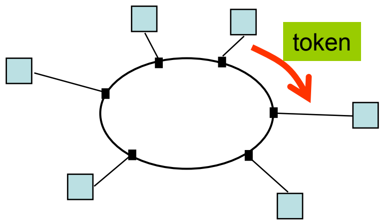
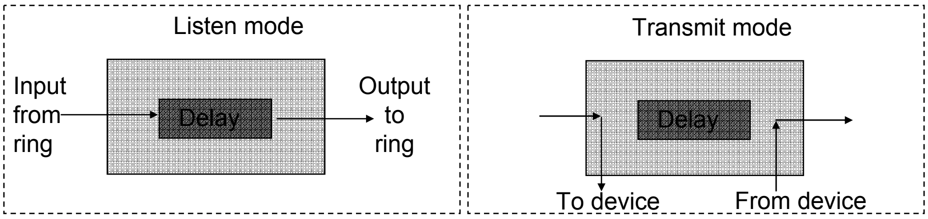
6.3.3 Token-Passing Rings



Free Token = Poll

Frame Delimiter is Token
Free = 01111110
Busy = 01111111

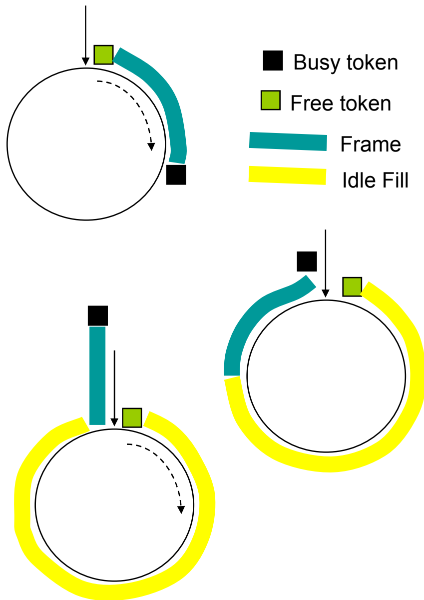


Ready station looks for free token
Flips bit to change free token to busy

Ready station inserts its frames
Reinserts free token when done

Methods of Token Reinsertion

- Multi-token operation
  - Free token transmitted immediately after last bit of data frame
  - High throughput
- Single-token operation
  - Free token inserted after last bit of the busy token is received back
  - Transmission time at least ring latency
  - Only one token in the ring. Simplify the recovery from errors in the token
- Single-Frame operation
  - Free token inserted after transmitting station has received last bit of its frame
  - Allow the station to check the return frame for errors before giving out the control of the token



Token Ring Throughput

- Definition
  - τ': ring latency (time required for bit to circulate ring)
  - X: maximum frame transmission time allowed per station
- *Multi-token operation*
  - Assume network is fully loaded, and all M stations transmit for X seconds upon the reception of a free token
  - This is a polling system with limited service time:

$$\rho_{\max} = \frac{MX}{\tau' + MX} = \frac{1}{1 + \tau'/MX} = \frac{1}{1 + a'/M}$$

$$a' = \frac{\tau'}{X} \text{ is the normalized ring latency}$$

Token Ring Throughput

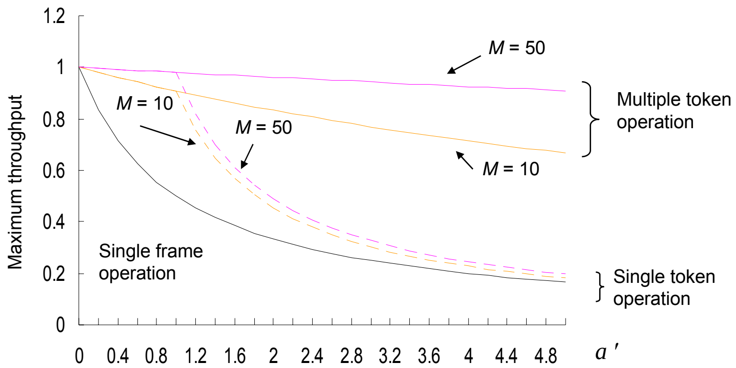
- *Single-frame operation*
  - Effective frame transmission time is maximum of X and τ', therefore

$$\rho_{\max} = \frac{MX}{\tau' + M\max\{(X, \tau'\}} = \frac{1}{\max\{1, a'\} + a'/M}$$

- *Single-token operation*
  - Effective frame transmission time is X+ τ', therefore

$$\rho_{\max} = \frac{MX}{\tau' + M(X + \tau')} = \frac{1}{1 + a'(1 + 1/M)}$$

Token Reinsertion Efficiency Comparison



- a <<1, any token reinsertion strategy acceptable
- $a \approx 1$, single token reinsertion strategy acceptable
- a >1, multitoken reinsertion strategy necessary

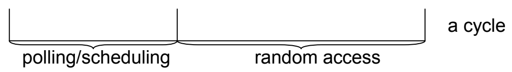
6.3.4 Comparison of Scheduling Approaches

- Read by yourself

6.3.5 Comparison of Random Access and Scheduling MACS

- Scheduling:
  1. methodical orderly access to the medium
  2. less variability in the delays.
- Random Access:
  1. uncoordinated unordered access to the medium
  2. can provide small delays when load is light
- Multimode MAC: combine scheduling with random access

  Cycles:



used in 802.11 wireless LAN

6.4 Channelization

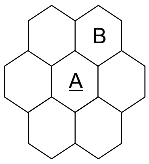
MAC scheme: user traffic is bursty, e.g. data traffic

Channelization: stations generate a steady stream of information, e.g digital voice

- 3 schemes:
  - FDMA: frequency-division multiple access (Fig 6.27)
  - TDMA: time-division multiple access (Fig 6.28)
  - CDMA: code-division multiple access (Fig 6.31)

6.4.4 Channelization in Telephone Cellular Networks

1. AMPS (Advanced Mobile Phone System) and IS54/IS136
   - Developed in US, first-Generation (1G), FDMA
   - 50 MHZ bandwidth/2 service providers = 25MHZ/Service provider
   - A single voice signal: 30kHz channel
     - $\frac{25\times10^6}{2\times30\times10^3}$ =416 two-way channels
     - 21 channels are used for control purpose
     - AMPS: frequency reuse factor is 7



   - Cell A and B can't use a same channel at the same time due to interference
   - On average, cell A can use $\frac{416-21}{7}$ channels

6.4.4 Channelization in Telephone Cellular Networks (continue)

- Spectrum efficiency: number of calls/MHz/Cell that can be supported

AMPS: $\frac{416-21}{7\times25}$ = *2.26 calls/cell/MHz*

- IS54 (Interim Standard-54) D-AMPS 2G
  - A hybrid channelization technique (TDMA/FDMA)
  - a 30 kHz channel is divided into 3 TDMA channels
  - digital voice is compressed to 13kbps (carried In 1 TDMA channel)

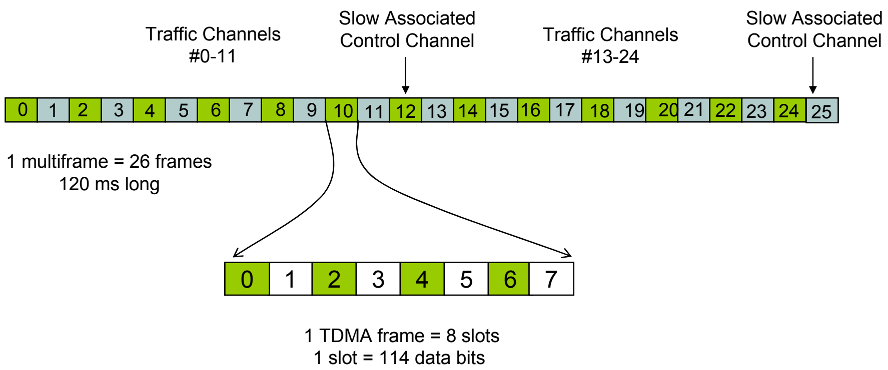
  Total 3x416=1248 channels. 21 channels for control purpose

  Spectrum efficiency IS-54: $\frac{1248-21}{7\times25}$ = *7 calls/cell/MHZ*

  IS136 is a revision of IS-54 (text messaging, CSD)

6.4.4 Channelization in Telephone Cellular Networks (continue)

- GSM (Global System for Mobile Communications)
  - A European Standard
  - A hybrid TDMA/FDMA system
  - 50 MHz: 25MHz forward channel (base station to mobile)
    25MHz reverse channel (mobile to base station)
  - $\frac{25MHZ}{200KHZ}$ = *124 one-way carriers* (FDMA)
  - Carrier signal: *120ms* multiframes (TDMA)
  - 1 multiframe = 26 frames
  - 2 frames for control purpose. 24 for digital voice traffic



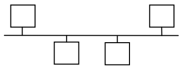
6.4.4 channelization in Telephone Cellular Networks (continue)

– 1 frame → 8 slots. 1 slot (1 channel) → 114 data bits
  $\Rightarrow$ bit rate/channel $= \frac{24\ slots/multiframe \times 114\ bits/slot}{120\ ms/multiframe}$ = 22,800 bps
  caries 13 kbps digital voice + error-correction bits
– frequency reuse factor 3 or 4
  Spectrum efficiency of GSM
  $= \frac{124 \times 8}{3 \times 50}$ =6.61 calls/cell/MHz
– GPRS is an enhancement of GSM to data services (Internet)

6.4.4 Channelization in Telephone Cellular Networks (continue)

- IS-95
  – based on spread spectrum communication (CDMA)
  – CDMA can operate with a frequency reuse factor of 1
  – 12.1 calls/cell/MHz < spectrum efficiency of IS95 < 45.1
- 1G: AMPS
  2G: IS54 GSM IS95
  2.5G: GSM/GPRS (circuit switch + packet switch)
  3G: W-CDMA, CDMA2000 (circuit switch + packet switch)
  4G: packet switching only?

Local Area Networks (LAN)
6.7 Ethernet and IEEE 802.3



bus topology

- Network Interface Card (NIC) or LAN adapter card
  - each NIC card is assigned a unique MAC or physical address
  - *6* bytes: e.g., 00-09-bB-A6-BC-A1 a unicast address
  - Multicast address: a group of stations, if first bit of the address is *1*
  - broadcast address: all *1s*
- CSMA-CD with 1-presistent
- Minimum frame length or mini-slot (L_{min})
  - Need $2t_{prop}$ to detect a collision
  - $\frac{L_{min}}{R} \geq 2t_{prop}$
  - *R=10 Mbps*, *d=2500m* (with four repeaters) $\Rightarrow$ *51.2 μs*.
    $L_{min} \approx 512$ *bits = 64 bytes*

6.7 Ethernet and IEEE 802.3

- Frame structure

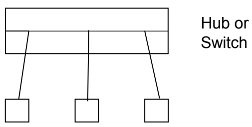
	Dest	Src	Info	FCS

32 bit CRC

- 10 base 5 — Thick coaxial cable — 500 m
- 10 base 2 — thin coax — 185 m

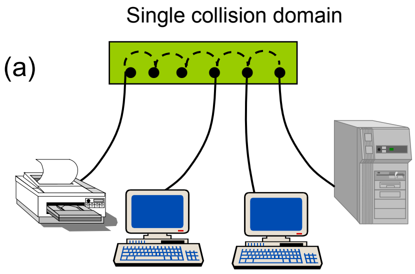
(10 base 5 and 10 base 2: bus topology)

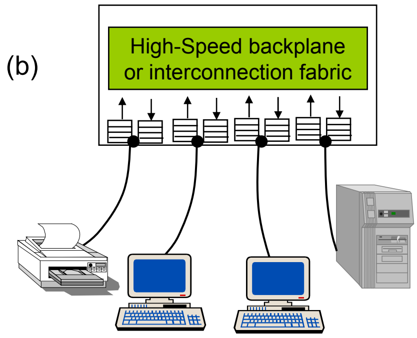
- 10 BaseT: unshielded twisted pairs (UTP) 100m



Star Topology

Ethernet Hubs & Switches



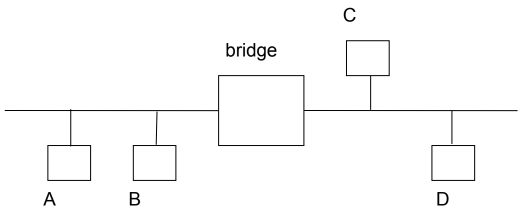


Twisted Pair Cheap
Easy to work with
Reliable
Star-topology CSMA-CD

Twisted Pair Cheap
Bridging increases scalability
Separate collision domains
Full duplex operation

6.7 Ethernet and IEEE 802.3

- Switch: multi-port bridge



- Collision domain: A, B in same collision domain
  A, C in the different collision domains
- Full-duplex, half-duplex
  - If each port of a switch has only a single station attached and full-duplex: no collision (no need CSMA-CD)

6.7 Ethernet and IEEE 802.3

- Fast Ethernet (100 Mbps)
  - *R: 10 Mbps → 100 Mbps*
    - To keep $\frac{L_{\min}}{R} \geq 2t_{prop}$: (1) L_{min}: *64 → 640* or (2) *d: 2500m → 250m*
  - only hub (star) topology.
  - *100* BaseTX: UTP5 *100m* full-duplex
  - One pair of wires: transmission, one pair: reception
- Gigabit Ethernet
  - L_{min}: *64bytes → 512 bytes*
  - CSMA-CD reaches the limits of efficient operation
  - operates primarily in a switched mode
- *10* Gigabit Ethernet
  - full-duplex, point-to-point
  - CSMA-CD disabled
  - Optical fibers

6.11 LAN Bridges and Ethernet Switches

- Several ways to interconnect networks
  1. physical layer: repeater
  2. MAC or data link layer: bridge
  3. network layer: router
  4. higher layer: gateway
- Repeater: range extension as long as the maximum distance is not exceeded
  - LAN can only handle up to some maximum level of traffic
  - Collision domain is the entire network (when connected with repeaters)
- Bridge: segment the entire network into multiple collision domains

  $\begin{cases}\text{transparent bridge: Ethernet} \\ \text{source routing bridge: Token-ring}\end{cases}$

6.11.1 Transparent Bridges

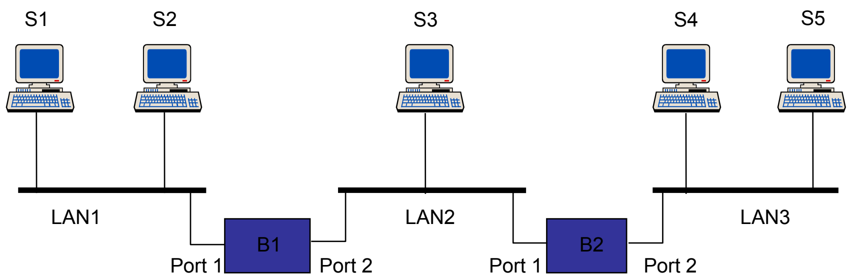
- Transparent: station are unaware of the presence of bridges
- Ethernet switches are simply multi-port transparent bridges

- Bridge Learning:
  - The bridge maintains a forwarding table

MAC	Port

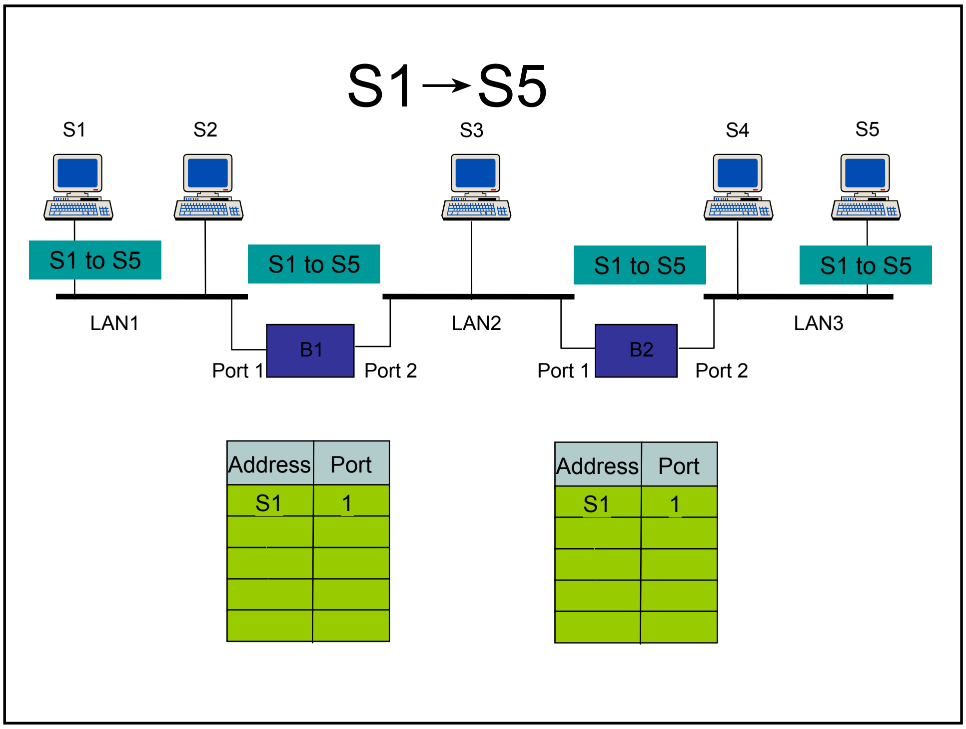
  - When a bridge receives a frame, if the source address (MAC) is not in the table, it is added to the table with the port number
  - If the dest address is in the table, the frame is forwarded to the port indicated in the table, however, if the port is the same one on which the frame was received frame will not be forwarded (filtering)
  - If not "flood" to all ports except the one on which the frame was received

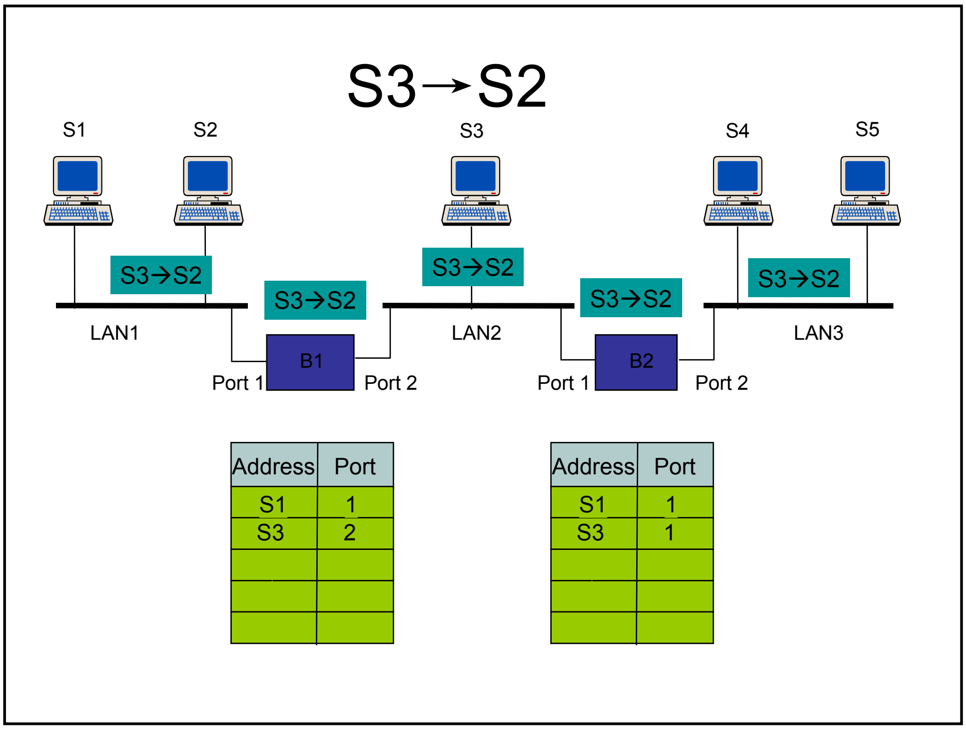
    Example: see Fig 6.81 to 6.85
  - Aging: when an entry is added to the table, it is given a timer. Each time a frame is received from a station, the corresponding entry is "refreshed". The timer is decreased periodically when the value reaches 0, the entry is erased.
  - When a frame is received and the port number in the entry is different from the port number on which the frame was received., the entry is updated with the new port number



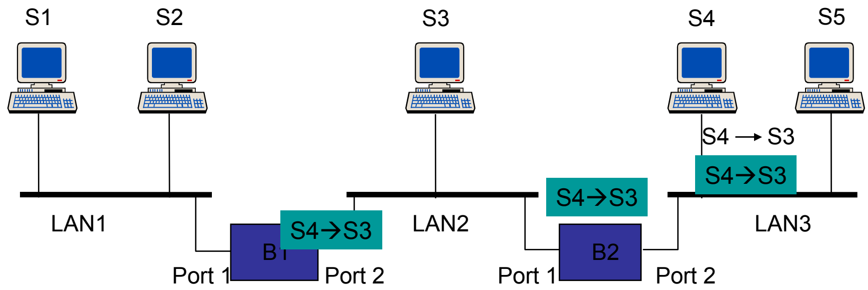
Address	Port

Address	Port


S1→S5
S1
S2
S3
S4
S5
S1 to S5
S1 to S5
S1 to S5
S1 to S5
LAN1
LAN2
LAN3
B1
B2
Port 1
Port 2
Port 1
Port 2
Address Port
S1 1
Address Port
S1 1


S3→S2
S1
S2
S3
S4
S5
S3→S2
S3→S2
S3→S2
S3→S2
S3→S2
LAN1
LAN2
LAN3
B1
B2
Port 1
Port 2
Port 1
Port 2
Address Port
S1 1
S3 2
Address Port
S1 1
S3 1

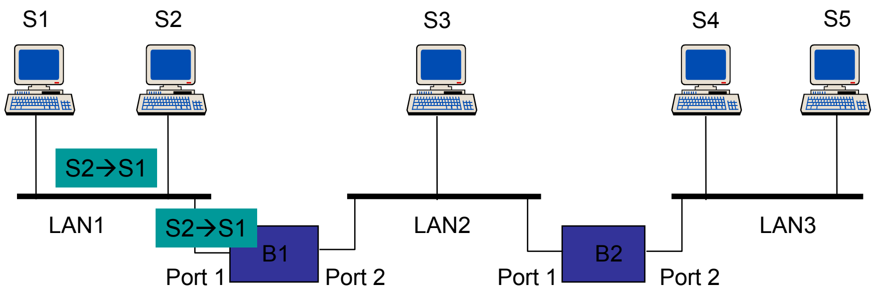
S4→S3



Address	Port
S1	1
S3	2
S4	2

Address	Port
S1	1
S3	1
S4	2

S2→S1

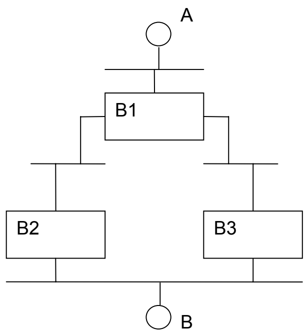


Address	Port
S1	1
S3	2
S4	2
S2	1

Address	Port
S1	1
S3	1
S4	2

6.11.1 Transparent Bridges (continue)

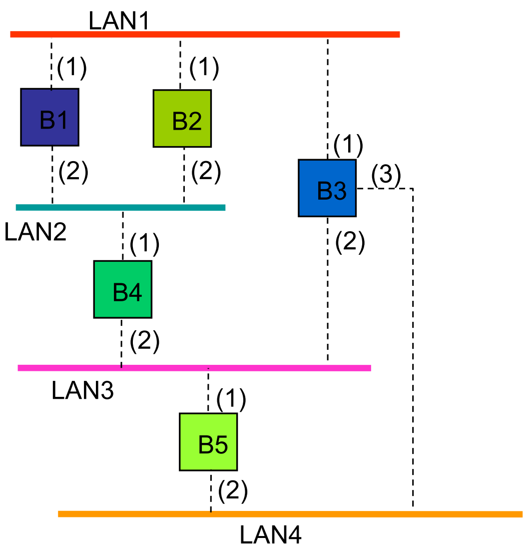
- Broadcast storm: when there are loops in the network.

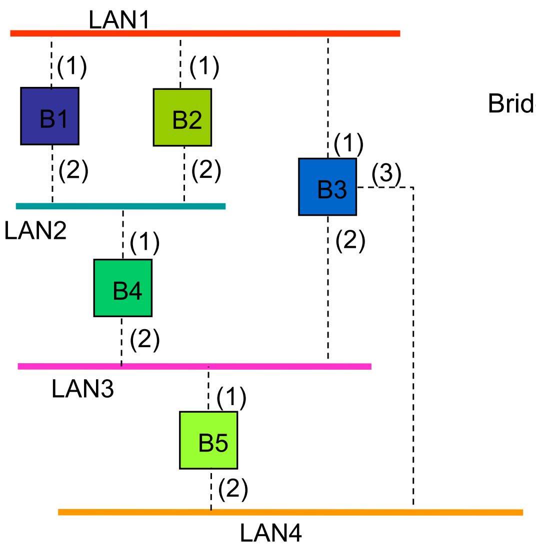


– B1, B2, B3 have no entry for B
– A send a packet to B
– B1 broadcast to → B2 → B3 → B1 → B2 → B3 ……

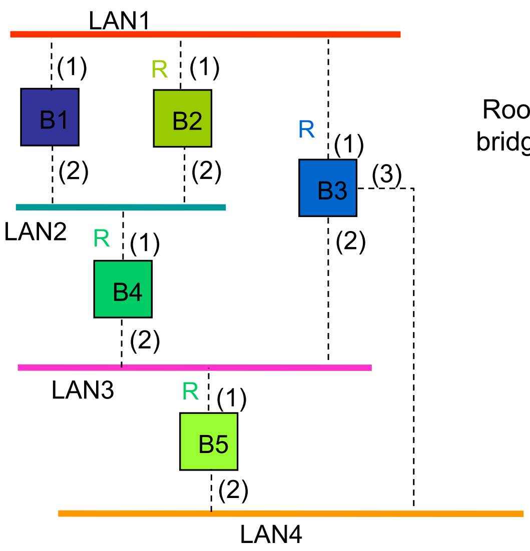
6.11.1 Transparent Bridges (continue)

- Spanning Tree Algorithm: disable certain bridges to remove loops
  - Each bridge has a unique bridge ID
  - Each port within a bridge has a unique port ID.
  1. select a root bridge: the one with the lowest bridge ID
  2. Determine root port for each bridge except the root bridge.
     - Root port: the one with the least-cost path to the root bridge
     - Cost: is assigned to each LAN
     - Path cost: is the sum of the costs along the path.
     - In case of tie, choose the one with the lowest port ID
  3. Select a designated bridge for each LAN
     - the bridge that offers the least-lost path to the root bridge
     - In case of tie, choose the one with the lowest bridge ID.
  4. All root ports and designated ports are in “forwarding” state other ports are in “blocking” state (disabled). See Fig 6.86, 6.87 for an example.

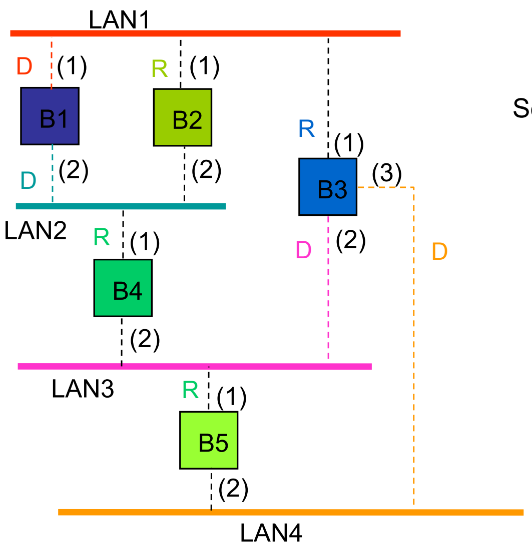




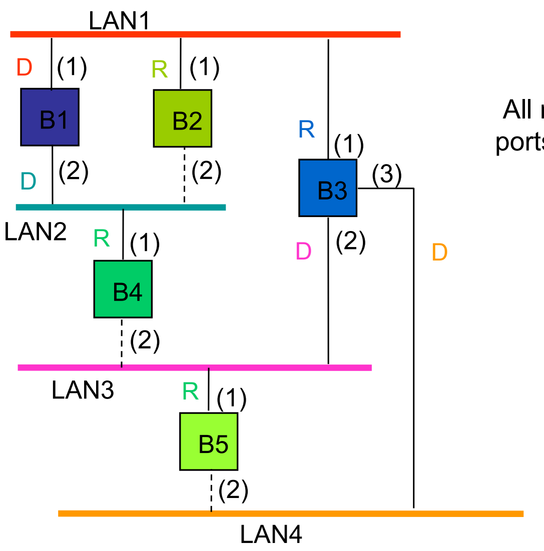
Bridge 1 selected as root bridge



Root port selected for every bridge except the root bridge

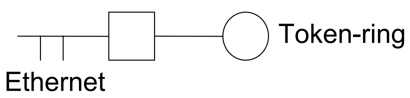


Select designated bridge for each LAN



All root ports & designated ports put in forwarding state

6.11.3 Mixed-Media Bridges



- MAC address
- Maximum frame size
- Transmission rate

6.11.4 Virtual LANs

- Physical association between a station and a LAN is not flexible
- Virtual LAN: logical partition of stations
  See Fig 6.92
- Port-based VLAN
- Tagged VLAN