Computer Networks

Wenzhong Li

Nanjing University

Chapter 2. Direct Link Networks

- Link Service and Framing
- Error Detection and Reliable Transmission
- HDLC, PPP, and SONET
- Token Ring
- Ethernet
- Bridges and Layer-2 switch
- Wireless Networks
- Network Performance

Bridges and Layer-2 switch

Bridges and Layer-2 switch

- Ability to expand beyond single LAN
- Provide interconnection to other LANs/WANs

Bridge is used (later Layer-2 switch)

- Connects LANs, usually more than two LANs
- Identical protocols for physical and MAC layers

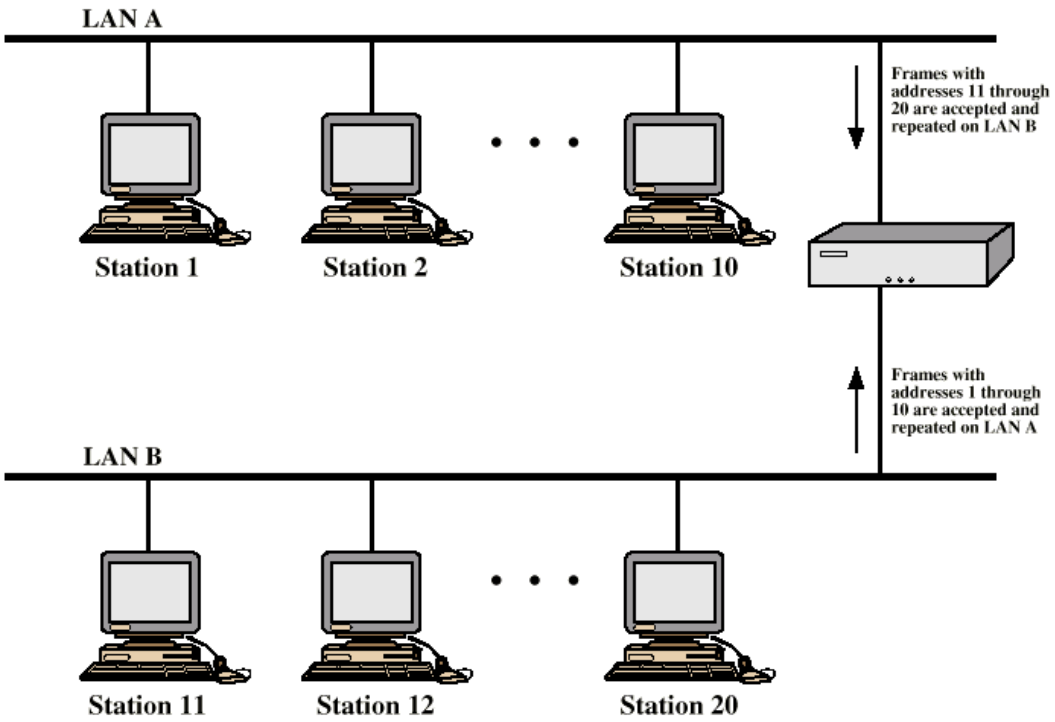
- Store, forward LAN frames
- Exact bitwise copy of frame

- Switch (route) functions needed

Requirements of a Bridge

- Store and Forward
  - Read frames transmitted on one LAN, Examine frames' MAC address, selectively store those address to other LANs
  - Using MAC protocol of second LAN, retransmit each frame
- Transparent
  - Stations are unaware of presence of bridges
- Plug-and-play, self-learning
  - Bridges do not need to be configured

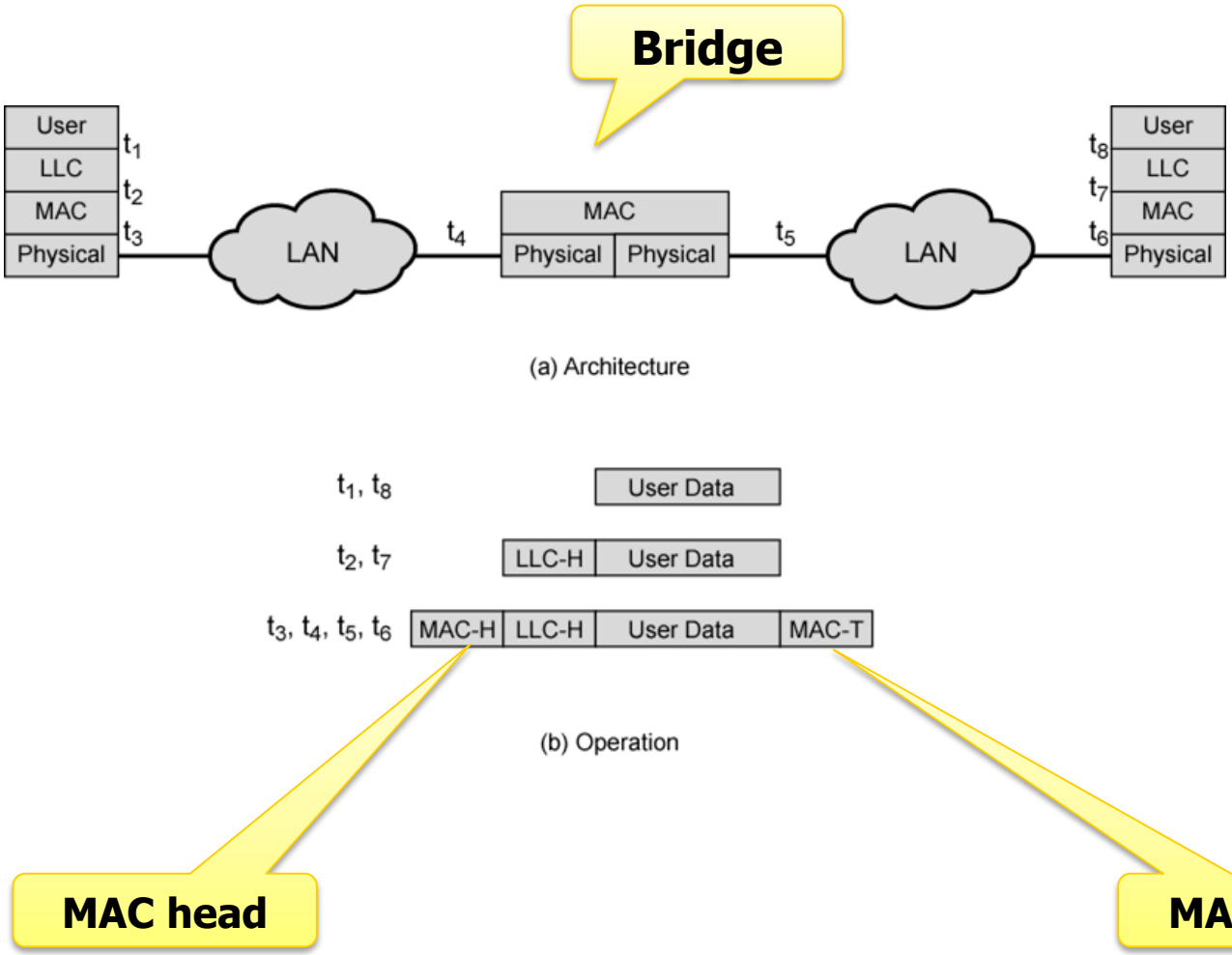
Bridge Operation



Bridge Protocol Architecture

- IEEE 802.1D, MAC level
  - Use MAC address for switching
- Bridge does not need LLC layer
  - Relaying MAC frames
- Can pass frame over external WAN or links
  - Capture LAN frame, encapsulate it
  - Forward it across WAN (Wide Area Network) link
  - Remove encapsulation and forward over LAN link

A Simple Connection of LANs

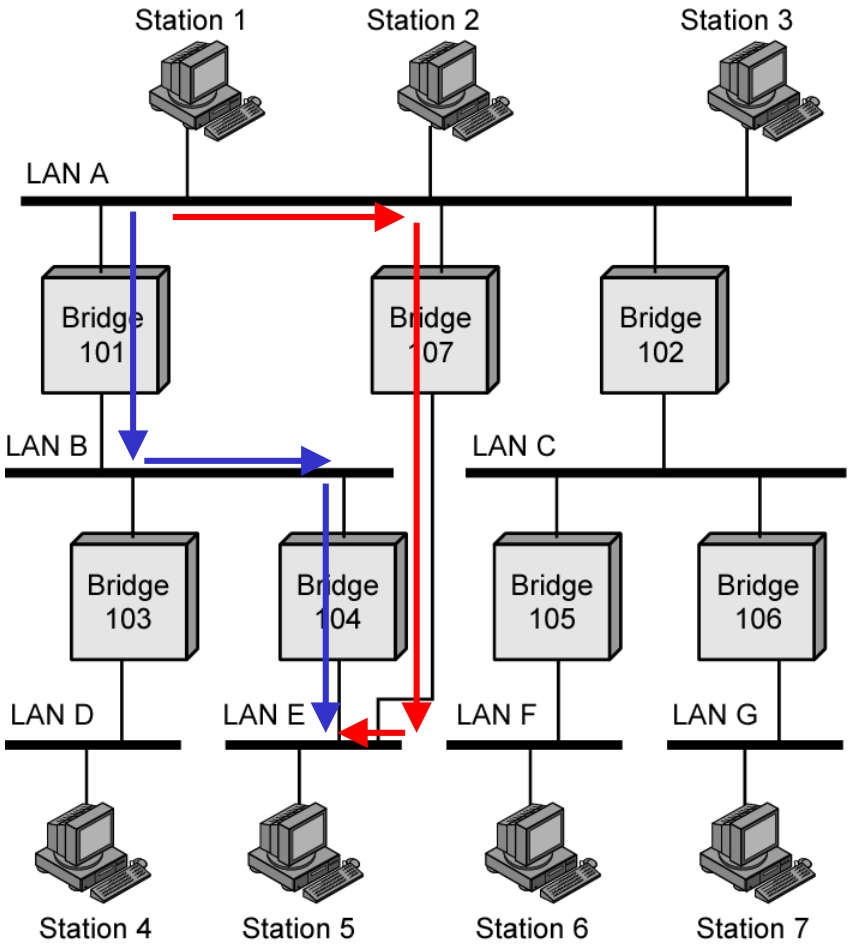


Routing for Bridges

- Complex LANs configuration cause alternative routes
- Bridge must decide (Switching)
  - Whether to forward frame
  - Which LAN to forward frame on
  - **A forward table is needed**
- Fixed routing for each source-destination pair of LANs
  - Done in configuration
  - Station cannot be moved
  - **Fixed routing is impracticable**

Bridges and LANs with Alternative Routes

1→ 5



Mechanisms of a Bridge

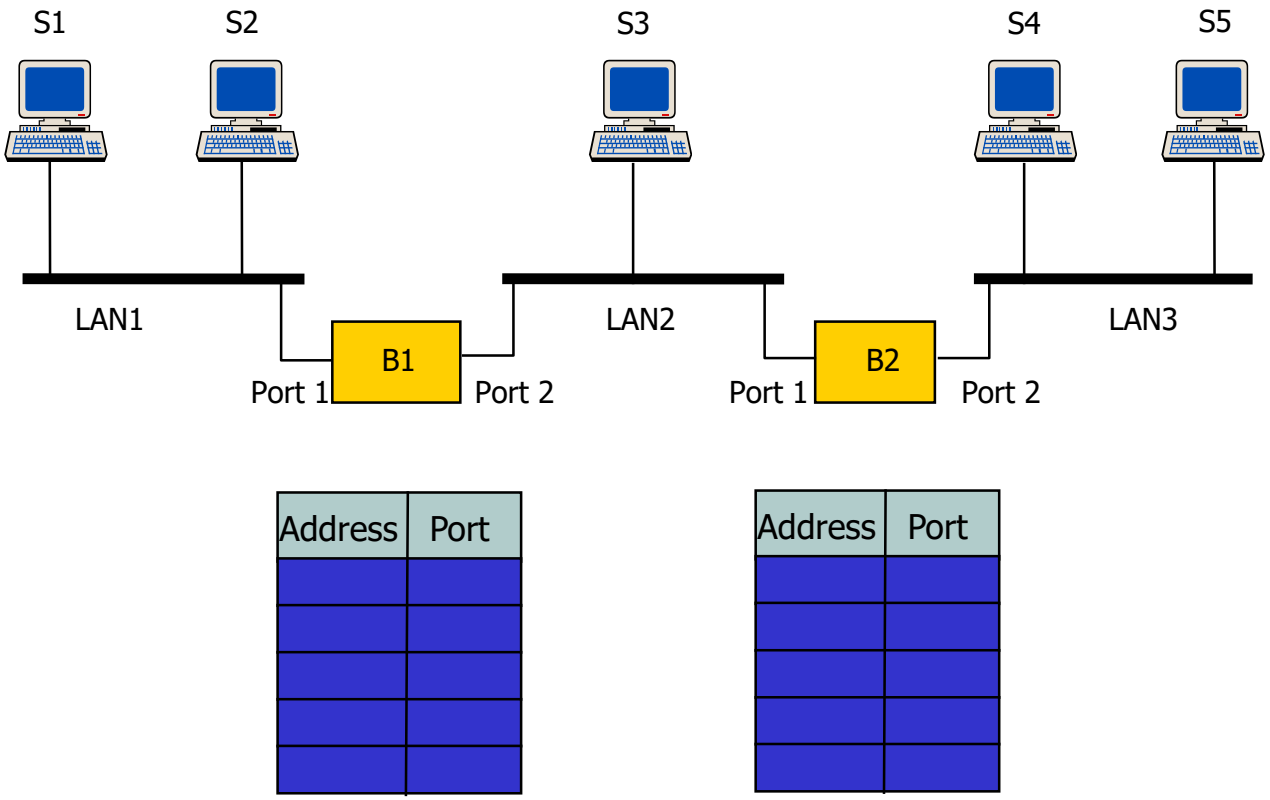
- Objectives
  - Bridge automatically develops switching table
  - Automatically update in response to changes
- Mechanisms
  - Transparent bridge: 802.1D
    - Frame forwarding
    - Address learning
    - Loop resolution: spanning tree
  - Source Routing Bridges： connecting Token Ring

Frame forwarding

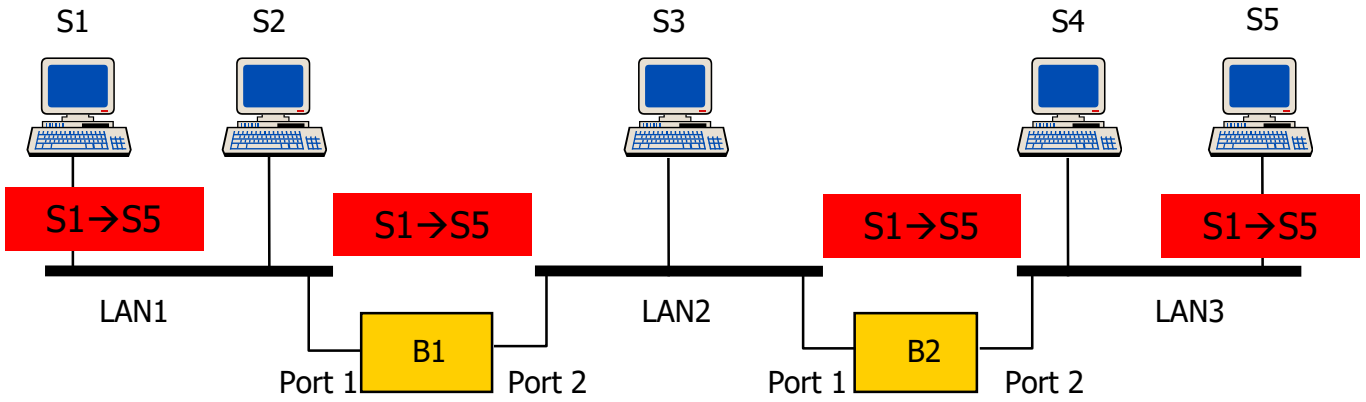
- Maintain **forwarding database** for each port
  - <Mac Address, Port, Timestamp>: station addresses reached through each port
- For a frame arriving on port X
  - Search forwarding database to see if dest MAC address is listed for any port:
  - If address not found, forward to all ports (flooding) except X
  - If address listed for port X, drop it
  - If address listed for port Y, check port Y for Blocking or Forwarding state, transmit if Forwarding state
  - Blocking used to form a tree

Address Learning

- Forwarding database can be learned
- When frame arrives at port X, it has come from the LAN attached to port X
- Use the source address to update forwarding database for port X to include that address
- Timer on each entry in database, Entry deleted when timer is off
- Each time frame arrives, source address checked against forwarding database


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

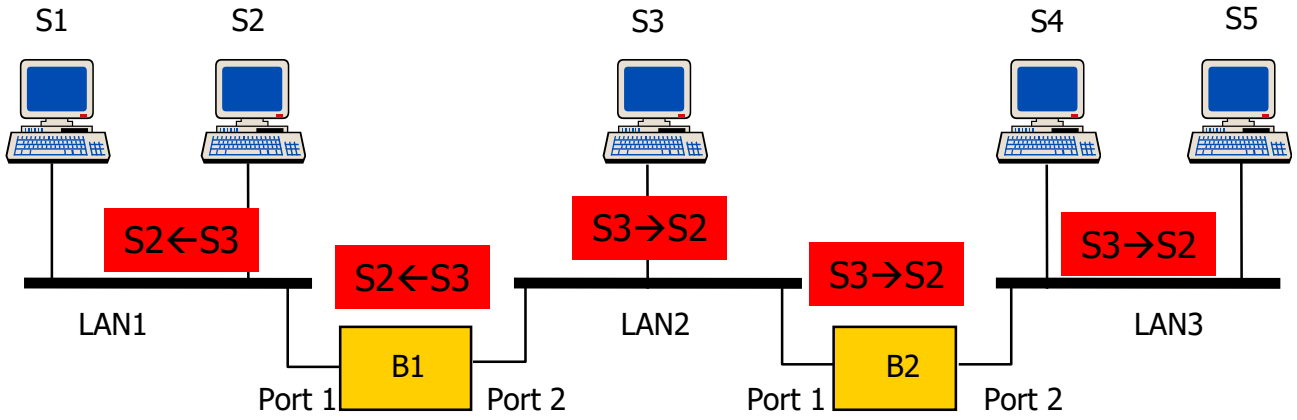
S1→S5



Address	Port
S1	1

Address	Port
S1	1

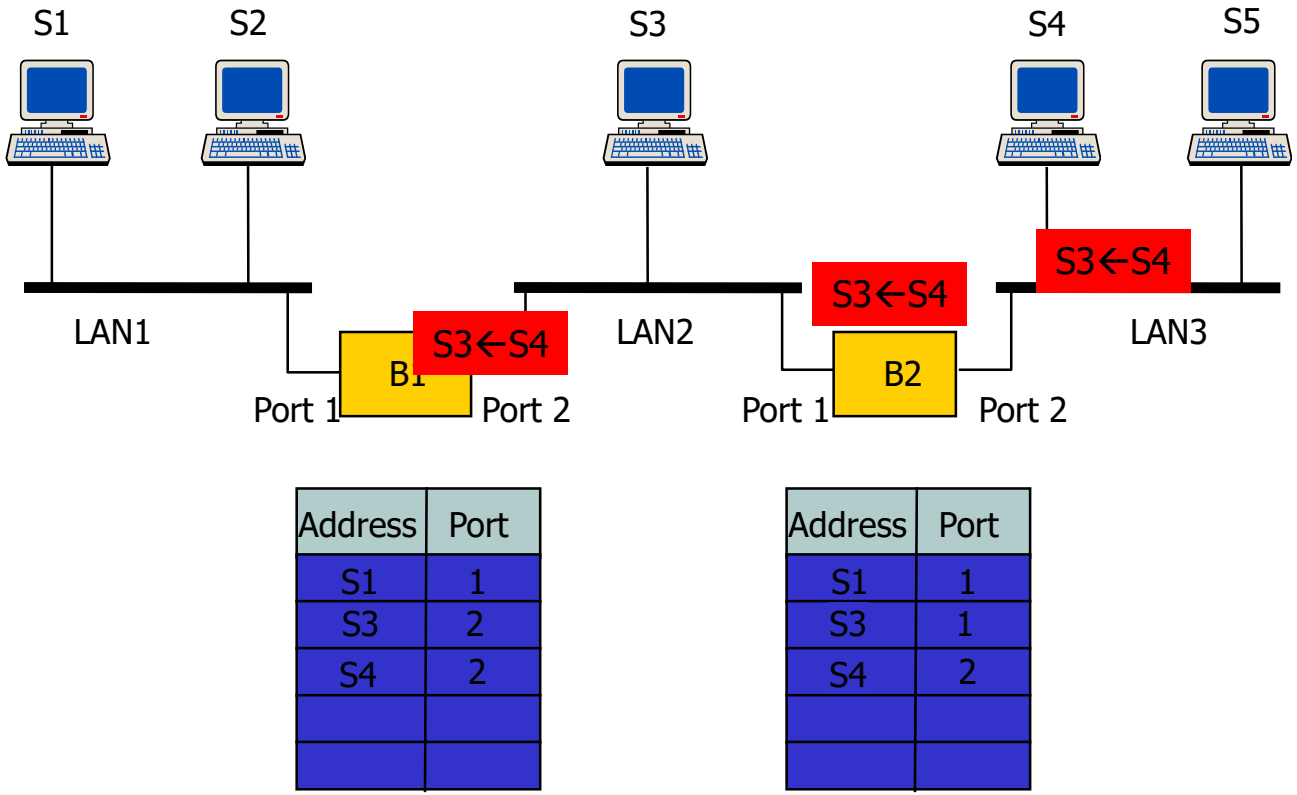
S3→S2



Address	Port
S1	1
S3	2

Address	Port
S1	1
S3	1

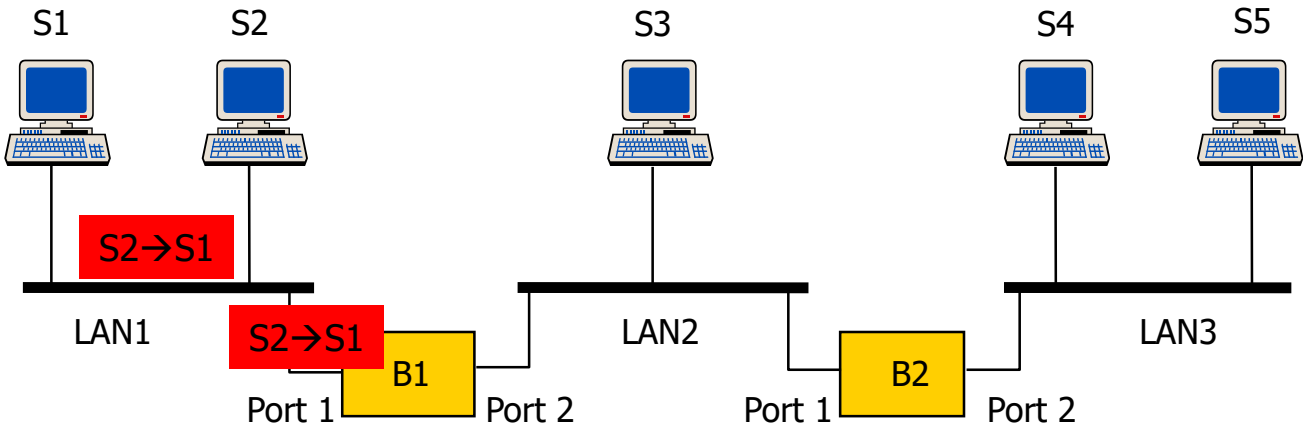
S4→S3



Address	Port
S1	1
S3	2
S4	2

Address	Port
S1	1
S3	1
S4	2

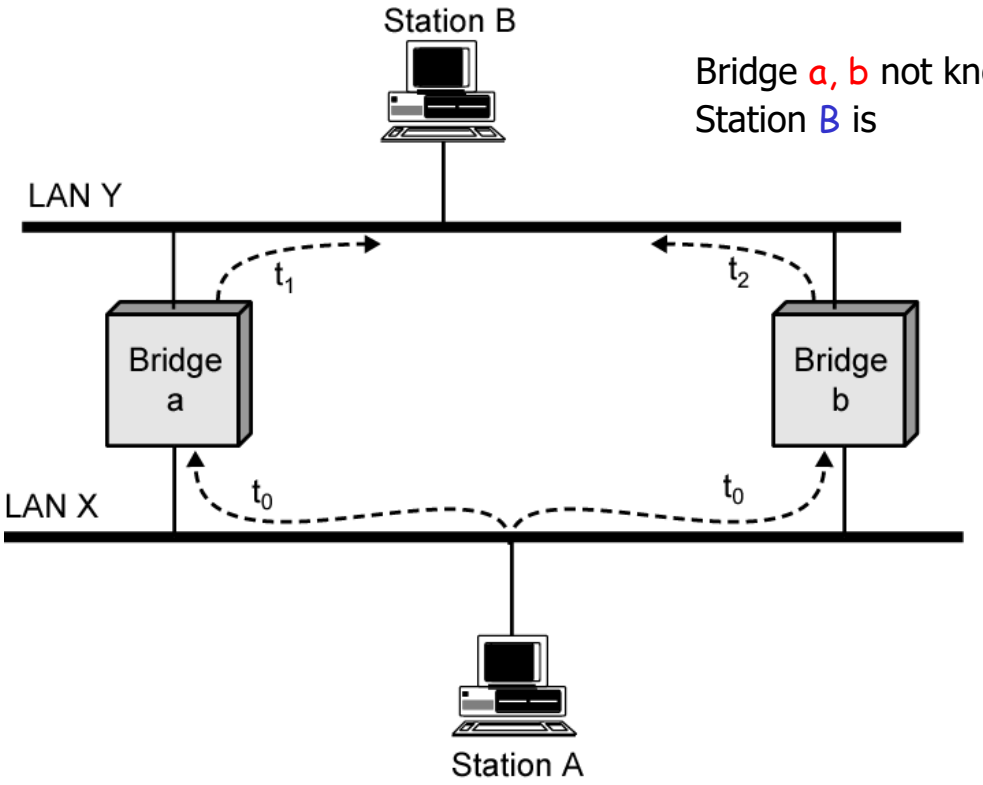
S2→S1



Address	Port
S1	1
S3	2
S4	2
S2	1

Address	Port
S1	1
S3	1
S4	2

Loop of Bridges



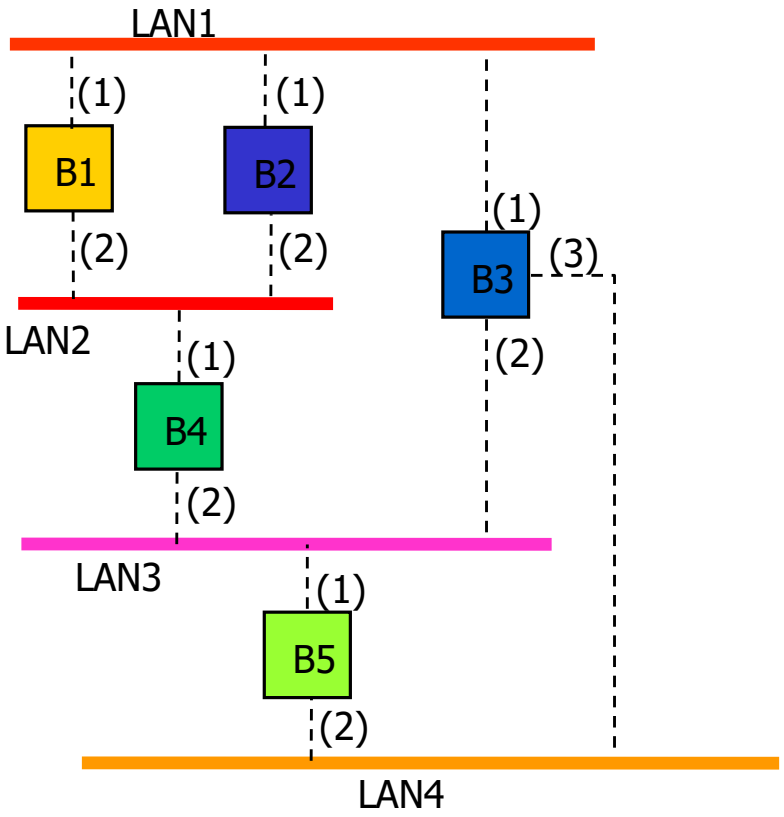
Bridge a, b not know where Station B is

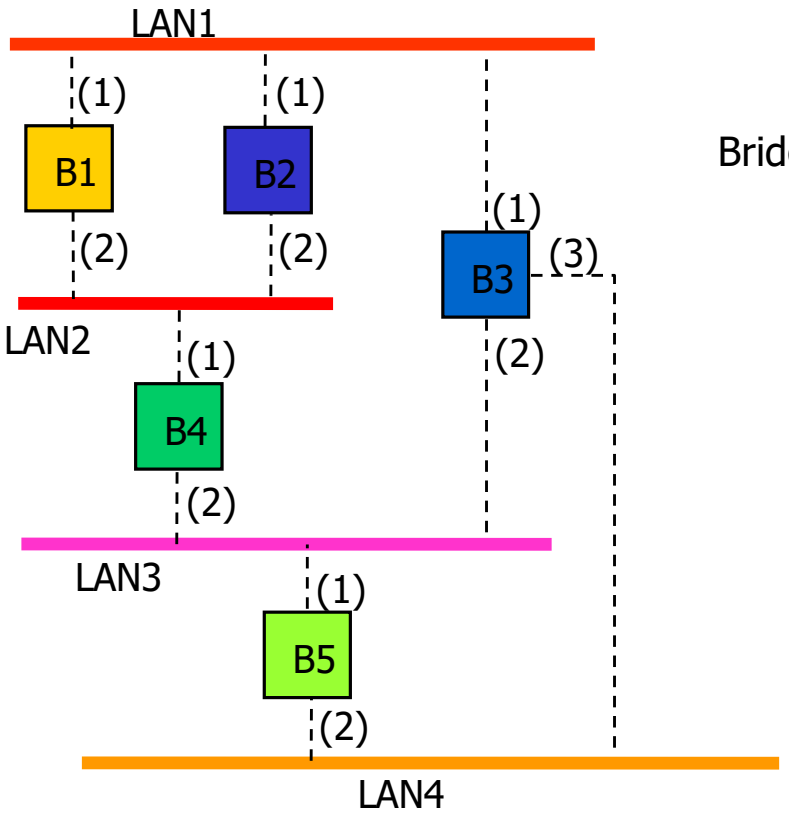
Spanning Tree

- Address learning works for tree layout
  - i.e. no closed loops
- Spanning tree
  - A tree that maintains connectivity but contains no loops for any connected graph
- Each bridge assigned unique identifier
- Exchange between bridges to establish spanning tree

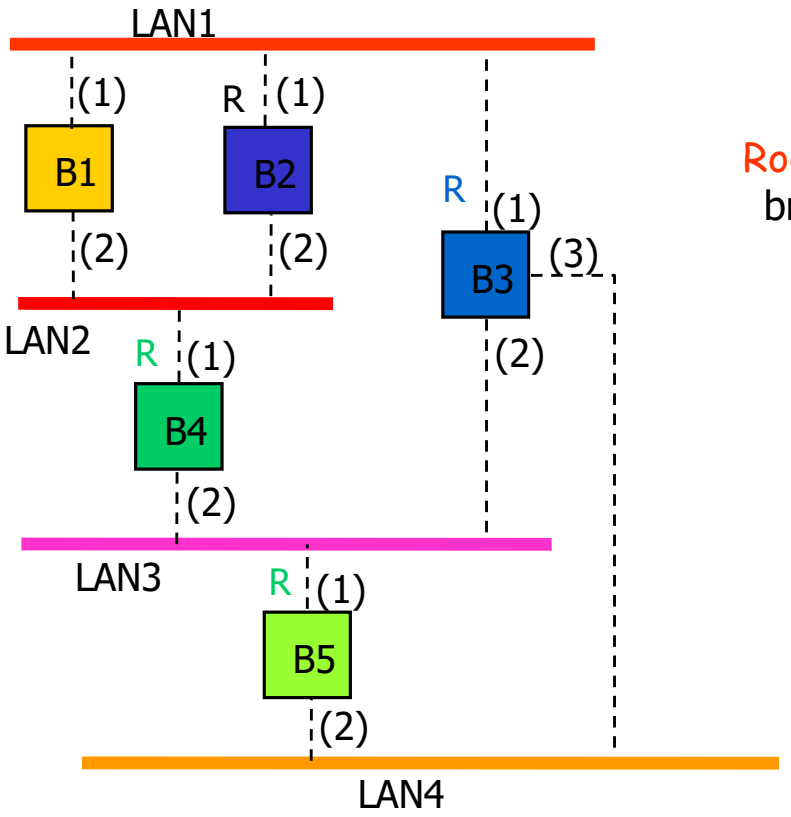
The Algorithm

- Select a root bridge among all the bridges
  - Root bridge = the lowest bridge ID
- Determine the root port for each bridge except the root bridge
  - Root port = port with the least-cost path to the root bridge
- Select a designated bridge for each LAN
  - Designated bridge = bridge with the least-cost path from the LAN to the root bridge
- Designated port connects the LAN with the designated bridge
- All root ports and all designated ports are placed into a forwarding state
- The other ports are placed into a blocking state

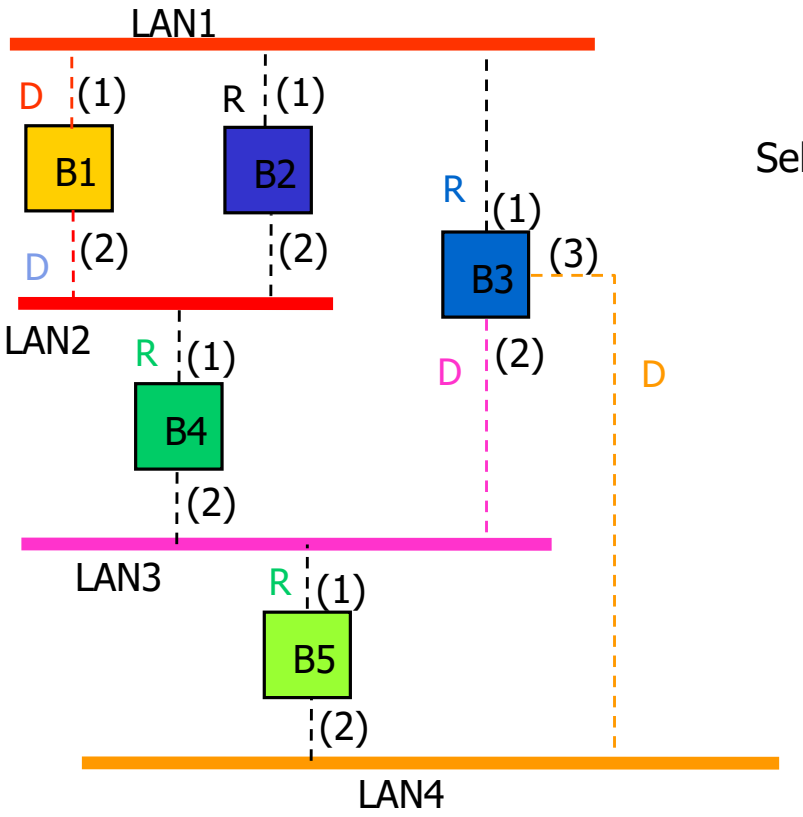

LAN1
(1)
(1)
B1
B2
(1)
(2)
(2)
B3
(3)
LAN2
(1)
(2)
B4
(2)
LAN3
(1)
B5
(2)
LAN4



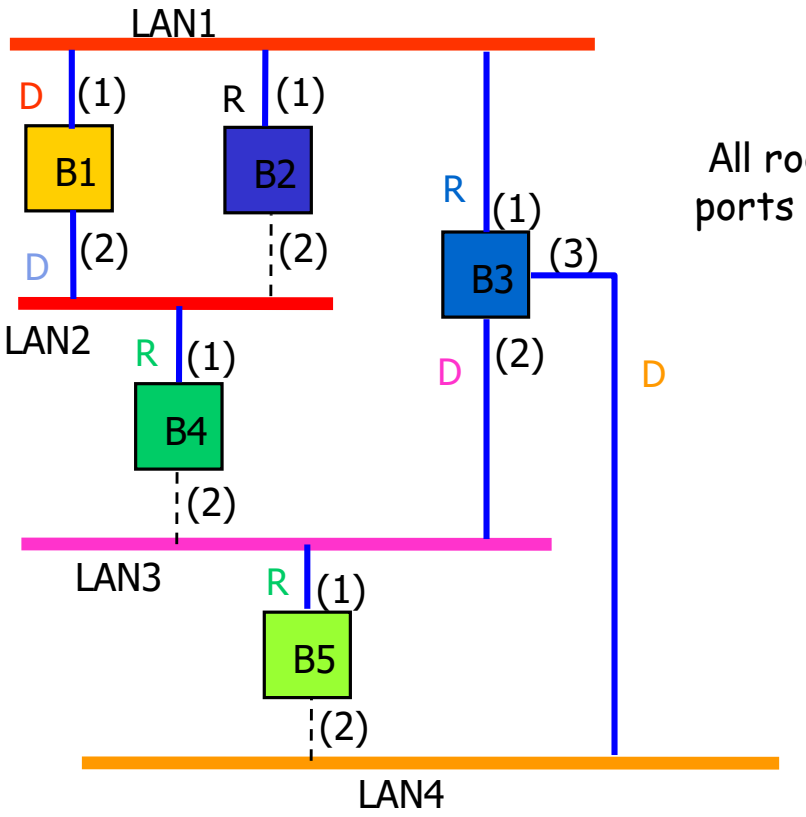
Bridge 1 selected as root bridge



Root port selected for every bridge except root bridge



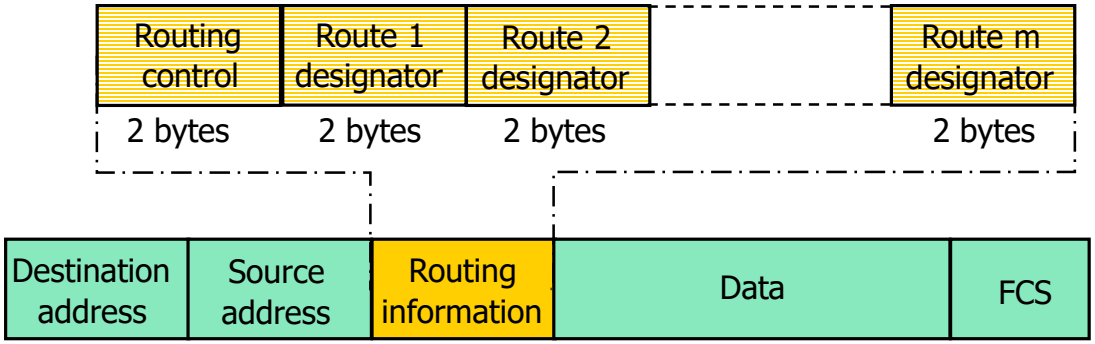
Select designated bridge for each LAN



All root ports & designated ports put in forwarding state

Source Routing Bridges

- To interconnect IEEE 802.5 token rings
- The source station determines route to destination
- Routing information inserted in frame



Route Discovery

- For a destination each station broadcasts a single-route broadcast frame
- The frame visits every LAN once & eventually reaches destination

- Destination sends all-routes broadcast frame which generates all routes back to source
- Source collects routes & picks best

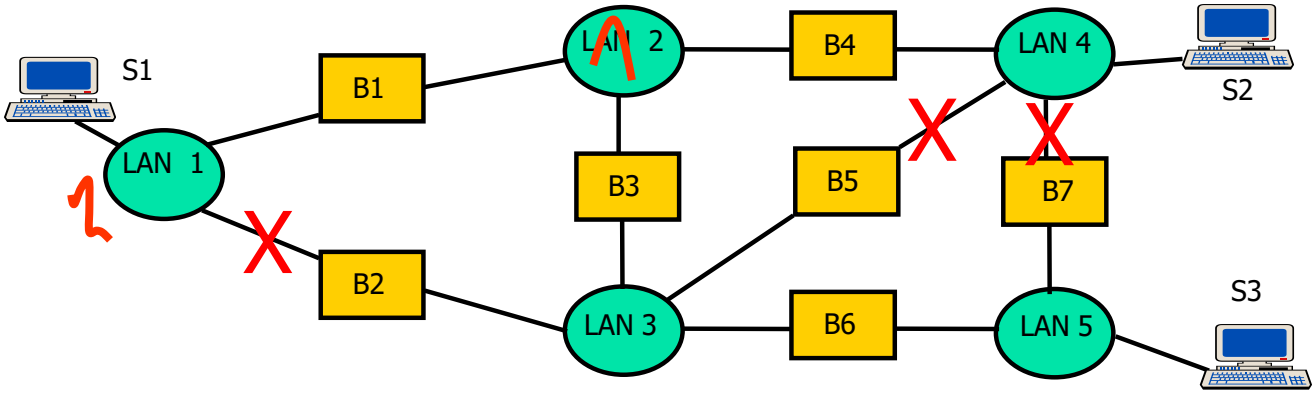
Detailed Route Discovery (Source)

- Bridges must be configured to form a spanning tree
- Source sends single-route frame without route designator field
- Bridges in first LAN add <incoming LAN #, bridge #, outgoing LAN #> into frame & forwards
- Each subsequent bridge attaches <bridge #, outgoing LAN #>
- Eventually, one single-route frame arrives at destination

Detailed Route Discovery (Destination)

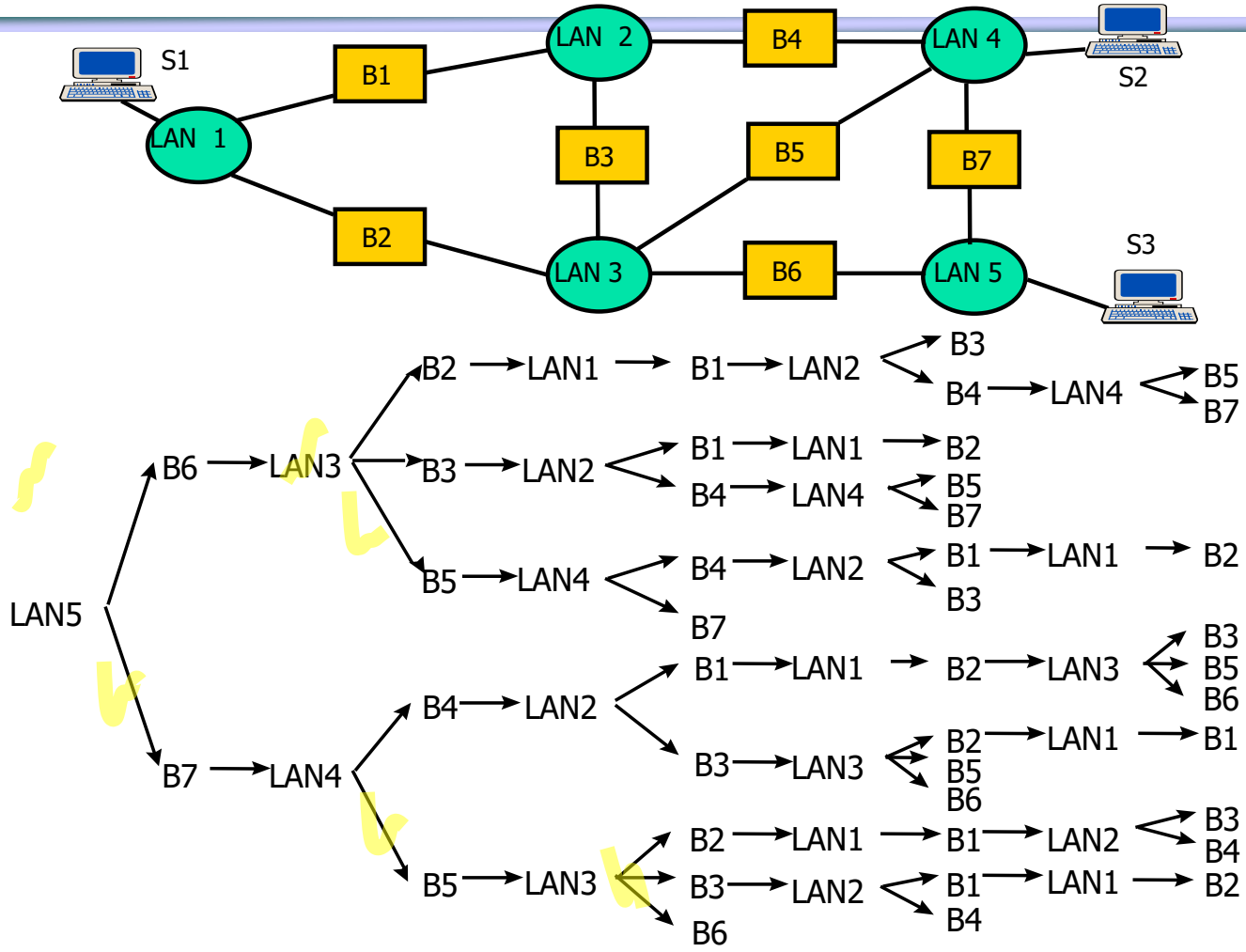
- When destination receives single-route broadcast frame it responds with all-routes broadcast frame
- Bridge at first hop inserts <incoming LAN #, bridge #, outgoing LAN #> and forwards
- Subsequent bridges insert <bridge #, outgoing LAN #> and forward
- Before forwarding, bridge checks to see if outgoing LAN already in designator field
- Source eventually receives all routes to destination station

Find Routes from S1 to S3



LAN1 → B1 → LAN2 → B3 → LAN3 → B6 → LAN5

LAN1 → B1 → LAN2 → B4 → LAN4


S1
LAN 1
B1
B2
LAN 2
LAN 3
B3
B4
B5
B6
B7
LAN 4
LAN 5
S2
S3
LAN5
B6
B7
LAN3
LAN4
B2
B3
B5
B4
LAN1
LAN2
LAN4
LAN2
LAN3
LAN1
LAN3
LAN2
LAN1
LAN2
LAN1
LAN3
LAN2
LAN1
LAN4
LAN1
LAN3
LAN2
LAN1
LAN4
LAN3
LAN2
LAN1

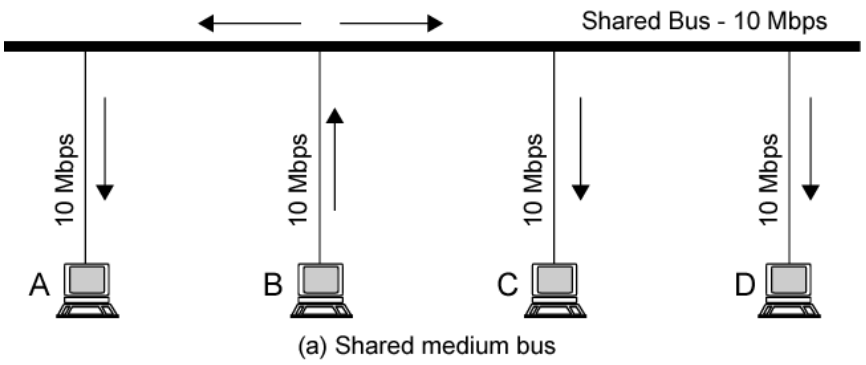
Types of devices for interconnecting LANs

- Hubs: physical repeaters
- Bridges：connecting LANs (forwarding + address learning)
- Layer 2 switches: connecting Hosts or LANs (bridge functions + collision free)
- Layer 3 switches: involving router functions

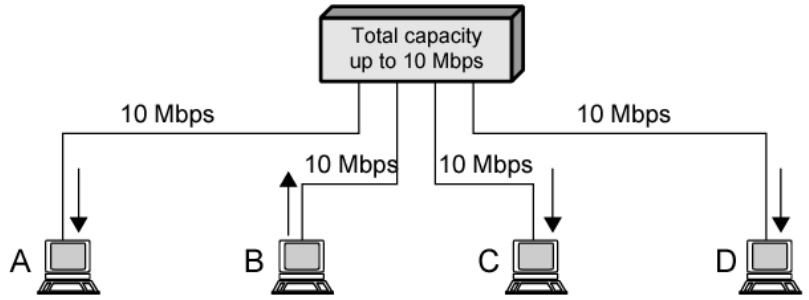
Hubs

- Active central element of star layout
- Each station connected to hub by two lines
  - Transmit and receive
- Hub acts as a repeater
  - When a station transmits, hub repeats signal on outgoing line to all other stations
- Physically star, logically bus
  - Transmission from any station received by all other stations
  - If two stations transmit at the same time, collision

Shared Medium Bus and Hub



(a) Shared medium bus



(b) Shared medium hub

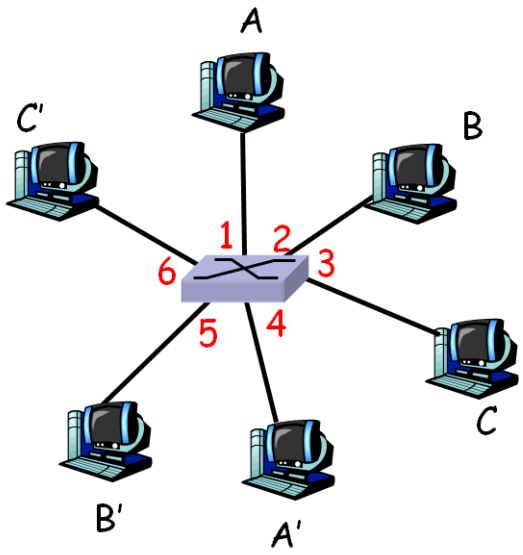
Layer 2 Switch：Requirement

- Link-layer device: takes an active role
  - Store, forward Ethernet frames
  - Examine incoming frame's MAC address, selectively forward frame to one-or-more outgoing links when frame is to be forwarded on segment, uses CSMA/CD to access segment
- Transparent
  - Hosts are unaware of presence of switches
- Plug-and-play, self-learning
  - Switches do not need to be configured
- Switch vs. Bridge
  - Bridge: connect LANs (normally 2-4 ports)
  - Switch: connect multiple hosts/subnets (a lot of ports, can achieve collision-free transmission)

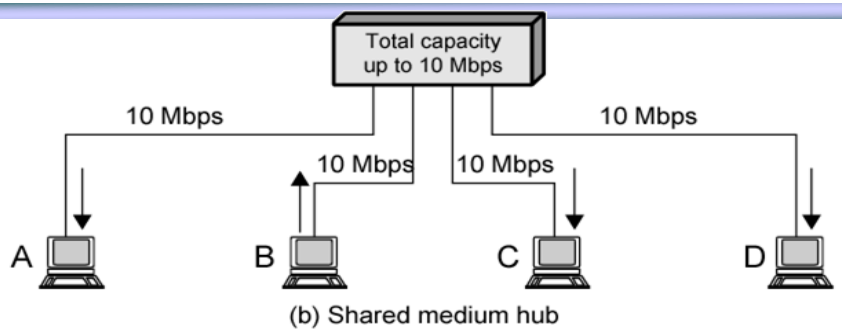
Switch: multiple simultaneous transmissions

- Stations have dedicated, direct connection to switch
- Switches buffer and forward frames
- Ethernet protocol used on *each* incoming link, but no collisions; full duplex
  - each link is its own collision domain
- *switching:* A-to-A' and B-to-B' can transmit simultaneously, without collisions

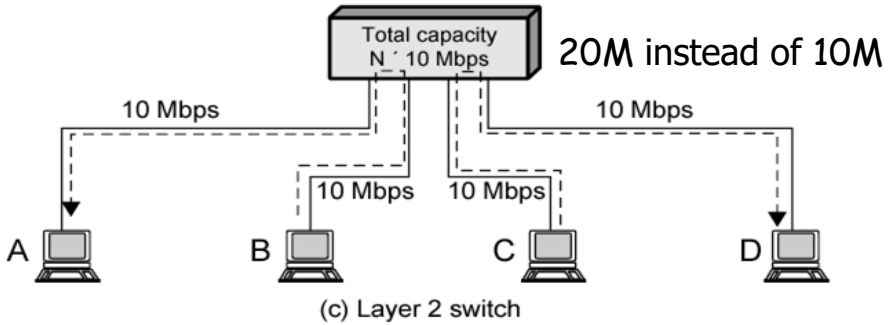
- Multiplying capacity of LANs
  - Each port/link forms a LAN segment (no collisions)
  - More than one station transmitting at a time



Shared Medium Hub and Layer 2 Switch

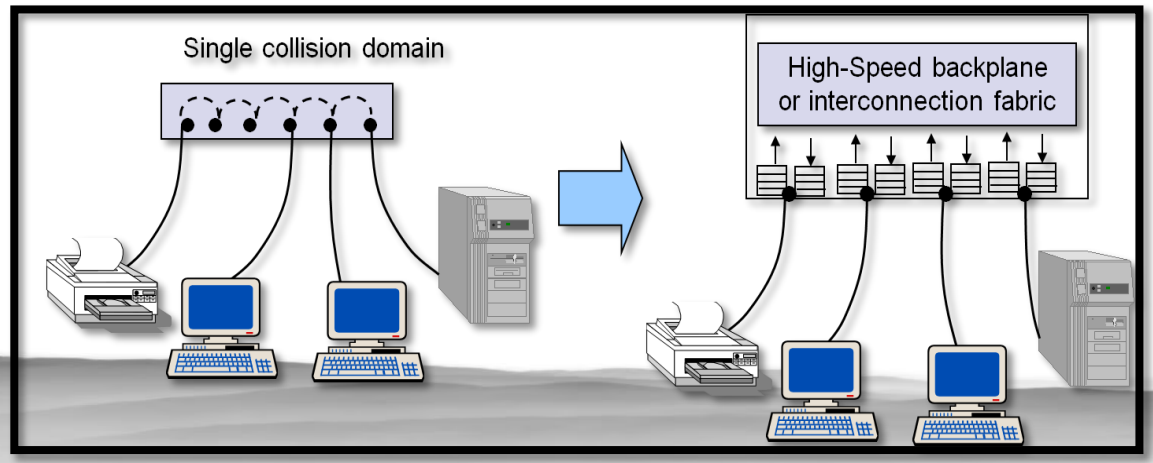


(b) Shared medium hub



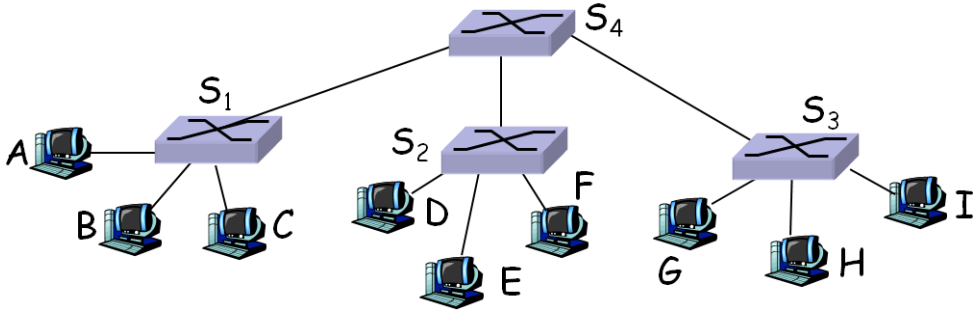
20M instead of 10M

(c) Layer 2 switch



Layer 2 Switch Benefits

- No change to attached stations to convert bus/hub LAN to switched LAN
  - For Ethernet LAN, each station uses Ethernet MAC protocol
- Station has dedicated capacity equal to original LAN
  - Assuming switch has sufficient capacity to keep up with all stations
- Layer 2 switch scales easily
  - New layer 2 switch added to accommodate additional stations



Types of Layer 2 Switch

- Store-and-forward switch
  - Accepts frame on input line
  - Buffers and routes it to appropriate output line
  - Adds delay between sender and receiver while boosts integrity of network
- Cut-through switch (直通式交换)
  - Takes advantage of dest address appearing at beginning of frame
  - Begins repeating frame onto output line as soon as it recognizes dest address
  - Highest possible throughput
  - Risk of propagating bad frames: unable to check *CRC* prior to retransmission

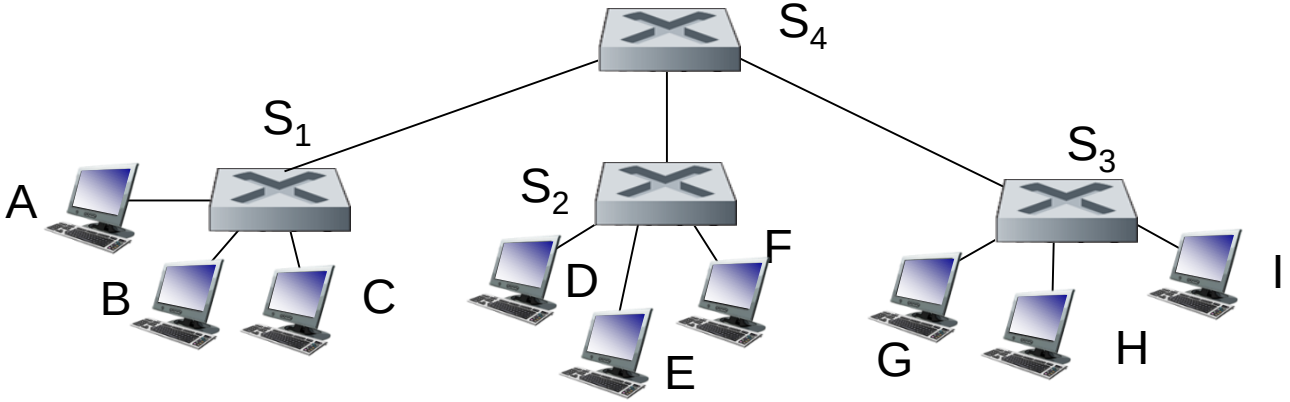
Switch: frame filtering/forwarding

when frame received at switch:

1. record incoming link, MAC address of sending host
2. index switch table using MAC destination address
3. if entry found for destination
   then {
   if destination on segment from which frame arrived
   then drop frame
   else forward frame on interface indicated by entry
   }
   else flood /* forward on all interfaces except arriving interface */

Interconnecting switches

- switches can be connected together

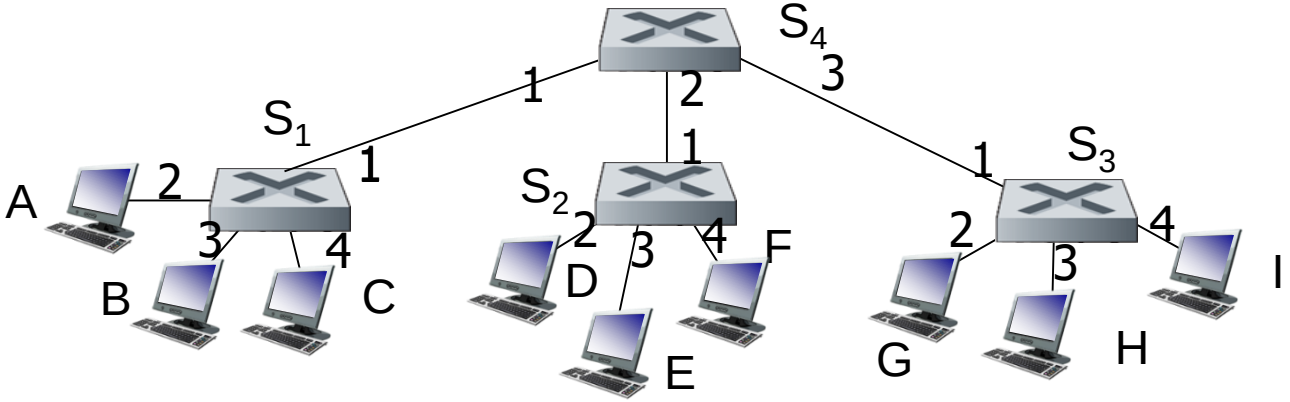


Q: sending from A to G - how does S_1 know to forward frame destined to F via S_4 and S_3?

- A: self learning! (works exactly the same as in single-switch case!)

Self-learning multi-switch example

Suppose C sends frame to I, I responds to C



- Q: show switch tables and packet forwarding in S_1, S_2, S_3, S_4 (assuming they are empty in the beginning)

Layer 3 Switches

- As number of stations grows, layer 2 switches reveal inadequacies
  - Broadcast overload
  - Lack of multiple paths
- Layer 3 switch
  - Implement packet-forwarding (IP) logic of a router in hardware
  - Interconnecting similar LANs, as in layer 2 switches

Broadcast Overload

- Set of stations and LANs connected by layer 2 switches builds singular physical net
- All nodes share common MAC broadcast address

- Broadcast frame delivered to all stations attached to LANs connected by layer 2 switches
- Under broadcast, layer 2 switches become hubs

- IP causes many broadcasts under daily work, e.g. ARP, DHCP, IGMP

Lack of Multiple Paths

- Layer 2 switches uses spanning tree for routing (switching)
- Dictate no closed loops: only one path between any two stations
- Limits both performance and reliability

Solution:

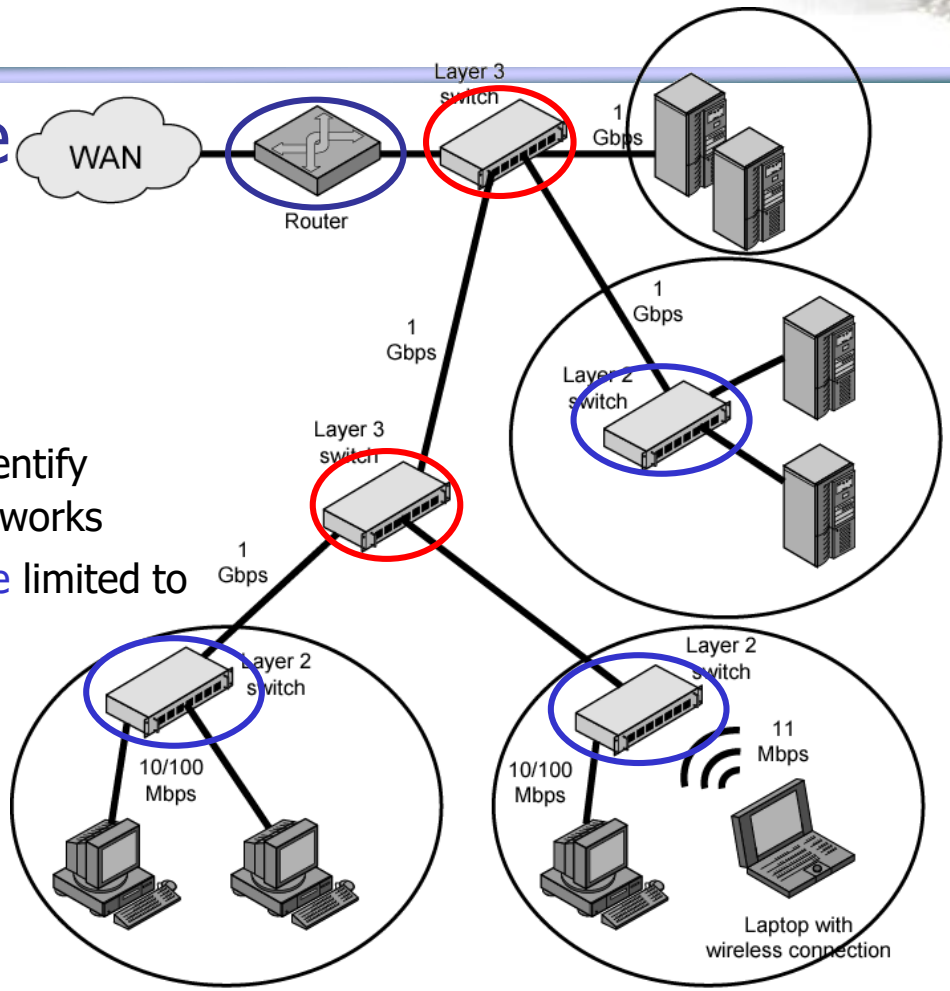
- Break up LANs into sub-networks connected by switches using router functions (layer 3 switch)
- MAC broadcast frames limited to single sub-network
- Allow use of multiple paths between sub-networks

Two Categories of Layer 3 Switches

- Packet by packet
  - Operates in same way as traditional router
  - Order of magnitude increase in performance compared to software-based router
- Flow-based switch tries to enhance performance by identifying flows of IP packets
  - Same source and destination
  - Done by using a special flow label in packet header
  - Once flow is identified, predefined route can be established

Typical Large LANs in an Organization

- Circles in diagram identify separate LAN subnetworks
- MAC broadcast frame limited to its subnetwork



VLANs（Virtual Local Area Network）

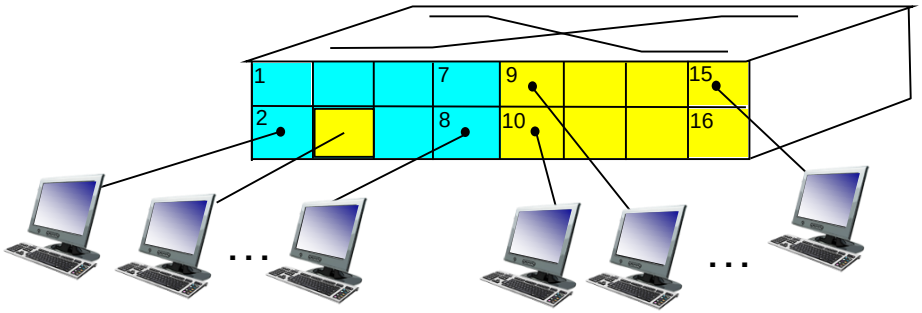
consider:

- CS user moves office to EE, but wants connect to CS switch?

Virtual Local Area Network

switch(es) supporting VLAN capabilities can be configured to define multiple ***virtual*** LANS over single physical LAN infrastructure.

port-based VLAN: switch ports grouped (by switch management software) so that *single* physical switch operates as multiple virtual switches



Summary

- Bridge and Layer 2 Switch
  - 概念
  - 转发表
  - 地址学习
  - 生成树算法
  - 路由发现机制
- 比较：Bridge, hub, Layer 2 Switch, Layer 3 Switch (Router)

Homework

- 第5章：P23, P24, P25, P26