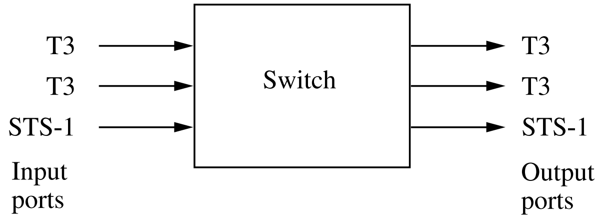
Switching and Forwarding

- Outline
  - Store-and-Forward Switches
  - Bridges and Extended LANs
  - Cell Switching
  - Segmentation and Reassembly

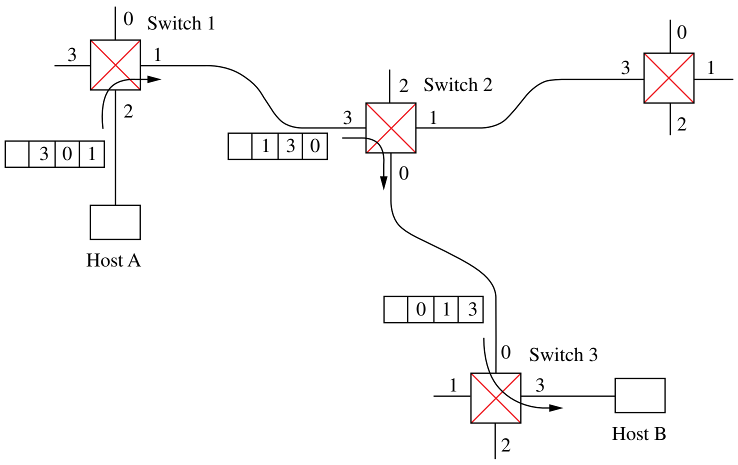
Scalable Networks

- Switch
  - forwards packets from input port to output port
  - port selected based on address in packet header



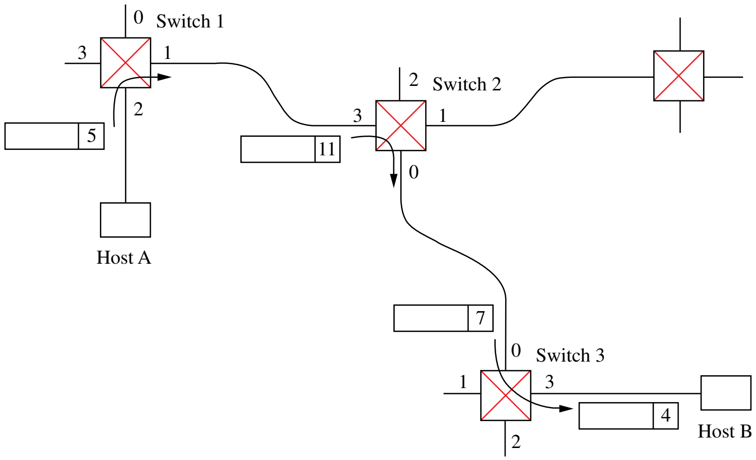
- Advantages
  - cover large geographic area (tolerate latency)
  - support large numbers of hosts (scalable bandwidth)

Source Routing



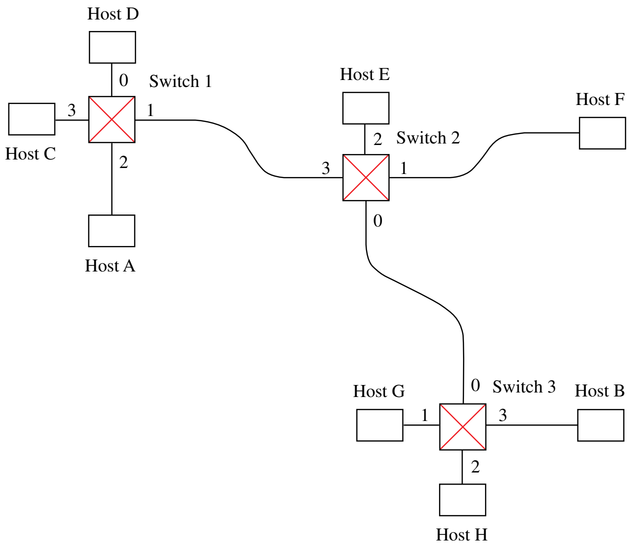
Virtual Circuit Switching

- Explicit connection setup (and tear-down) phase
- Subsequent packets follow same circuit
- Analogy: phone call
- Sometimes called *connection-oriented* model
- Each switch maintains a VC table.



Datagram Switching

- No connection setup phase
- Each packet forwarded independently
- Analogy: postal system
- Sometimes called *connectionless* model
- Each switch maintains a forwarding (routing) table



Virtual Circuit versus Datagram

Virtual Circuit Model:

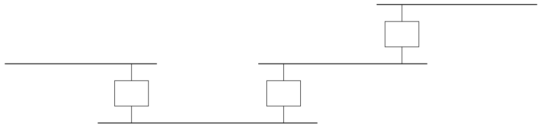
- Typically wait full RTT for connection setup before sending first data packet.
- While the connection request contains the full address for destination, each data packet contains only a small identifier, making the per-packet header overhead small.
- If a switch or a link in a connection fails, the connection is broken and a new one needs to be established.
- Connection setup provides an opportunity to reserve resources.

Datagram Model:

- There is no round trip time delay waiting for connection setup; a host can send data as soon as it is ready.
- Source host has no way of knowing if the network is capable of delivering a packet or if the destination host is even up.
- Since packets are treated independently, it is possible to route around link and node failures.
- Since every packet must carry the full address of the destination, the overhead per packet is higher than for the connection-oriented model.

Bridges and Extended LANs

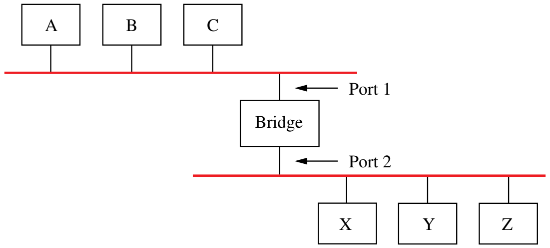
- LANs have physical limitations (e.g., 2500m Ethernet)
- Connect two or more LANs with a *bridge*
  - accept and forward strategy
  - level 2 connection (does not add packet header)



- Ethernet Switch = Bridge on Steroids

Learning Bridges

- Do not forward when unnecessary



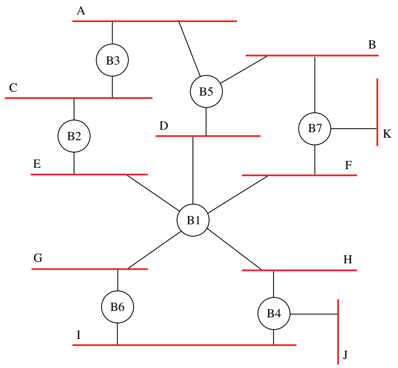
- Maintain forwarding table

Host	Port
A	1
B	1
C	1
X	2
Y	2
Z	2

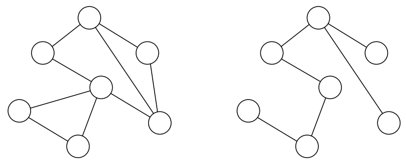
- Learn table entries based on source address
- Table is an optimization; need not be complete
- Always forward broadcast frames

Spanning Tree Algorithm

- Problem: loops



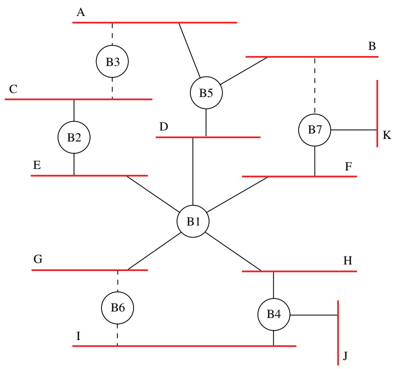
- Bridges run a distributed spanning tree algorithm
  - select which bridges actively forward frames
  - developed by Radia Perlman at DEC
  - now IEEE 802.1 specification



(a) (b)

Algorithm Overview

- Each bridge has a unique id (e.g., B1, B2, B3)
- Select bridge with smallest id as root
- Select bridge on each LAN that is closest to the root as that LAN's designated bridge (use id to break ties)
- Each bridge forwards frames over each LAN for which it is the designated bridge

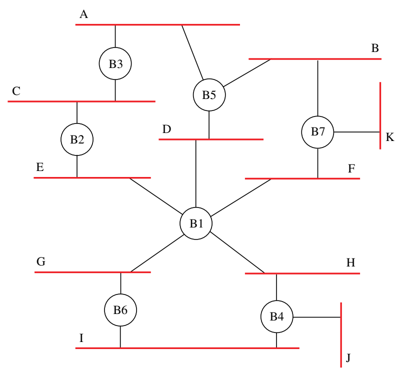


Algorithm Detail

- Bridges exchange configuration messages
  - id for bridge sending the message
  - id for what the sending bridge believes to be root bridge
  - distance (hops) from sending bridge to root bridge
- Each bridge records current best configuration message for each port
- Initially, each bridge believes it is the root
- When learn not root, stop generating configuration message
  - in steady state, only root generates configuration messages
- When learn not designated bridge, stop forwarding configuration messages
  - in steady state, only designated bridges forward configuration messages
- Root bridge continues to send configuration messages periodically
- If any given bridge does not receive configuration message after a period of time, starts generating configuration messages claiming to be to be the root

Broadcast and Multicast

- Forward all broadcast/multicast frames (current practice)
- Learn when no group members downstream
- Accomplished by having each member of group G send a frame to bridge multicast address with G in source field



Limitations of Bridges

- Do not scale
  - spanning tree algorithm does not scale
  - broadcast does not scale
- Do not accommodate heterogeneity
- Caution: beware of transparency

Cell Switching (ATM)

- Connection-oriented packet-switched network
- Used in both WAN and LAN settings
- Signalling (connection setup) Protocol: Q.2931
- Specified by ATM Forum
- Packets are called *cells*: 5-byte header + 48-byte payload
- Commonly transmitted over SONET (but not necessarily)

Variable vs Fixed-Length Packets

- No Optimal Length
  - if small: high header-to-data overhead
  - if large: low utilization for small messages
- Fixed-Length Easier to Switch in Hardware
  - simpler
  - enables parallelism

Big vs Small Packets

- Small Improves Queue Behavior
  - finer-grained pre-emption point for scheduling link
    - maximum packet = 4KB
    - link speed = 100Mbps
    - transmission time = $4096 \times 8/100 = 327.68\mu s$
    - high priority packet may sit in the queue $327.68\mu s$
    - in contrast, $53 \times 8/100 = 4.24\mu s$ for ATM
  - near cut-through behavior
    - two 4KB packets arrive at same time
    - link idle for $327.68\mu s$ while both arrive
    - at end of $327.68\mu s$, still have 8KB to transmit
    - in contrast, can transmit first cell after $4.24\mu s$
    - at end of $327.68\mu s$, just over 4KB left in queue
- Small Improves Latency (for voice)
  - voice digitally encoded at 64Kbps (8-bit samples at 8KHz)
  - need full cell's worth of samples before sending cell
  - example: 1000-byte cells implies 125ms per cell (too long)
  - smaller latency implies no need for echo cancellors
- ATM Compromise: 48 bytes = (32+64)/2

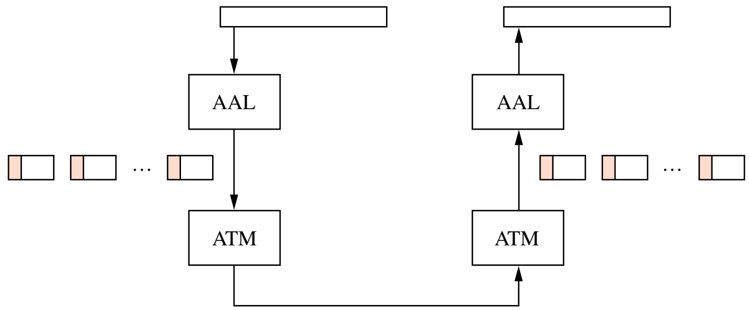
Cell Format

- User-Network Interface (UNI)

4	8	16	3	1	8	384 (48 bytes)
GFC	VPI	VCI	Type	CLP	HEC (CRC-8)	Payload

  - host-to-switch format
  - GFC: Generic Flow Control (still being defined)
  - VCI: Virtual Circuit Identifier
  - VPI: Virtual Path Identifier
  - Type: management, congestion control, AAL5 (later)
  - CLP: Cell Loss Priority
  - HEC: Header Error Check (CRC-8)
- Network-Network Interface (NNI)
  - switch-to-switch format
  - GFC becomes part of VPI field

Segmentation and Reassembly



- ATM Adaptation Layer (AAL)
  - AAL 1 and 2 designed for applications that need guaranteed rate (e.g., voice, video)
  - AAL 3/4 designed for packet data
  - AAL 5 is an alternative standard for packet data

AAL 3/4

- Convergence Sublayer Protocol Data Unit (CS-PDU)

8	8	16	< 64 KB	8	0−24	8	16
CPI	Btag	BASize	User data	Pad	0	Etag	Len

  - CPI: common part indicator (version field)
  - Btag/Etag: beginning and ending tag
  - BAsize: hint on amount of buffer space to allocate
  - Length: size of whole PDU
- Cell Format

40	2	4	10	352 (44 bytes)	6	10
ATM header	Type	SEQ	MID	Payload	Length	CRC-10

  - Type
    - ∗ BOM: beginning of message
    - ∗ COM: continuation of message
    - ∗ EOM: end of message
  - SEQ: sequence number
  - MID: message id
  - Length: number of bytes of PDU in this cell

AAL5

- CS-PDU Format

< 64 KB	0–47 bytes	16	16	32
Data	Pad	Reserved	Len	CRC-32

  - pad so trailer always falls at end of ATM cell
  - Length: size of PDU (data only)
  - CRC-32 (detects missing or misordered cells)
- Cell Format
  - end-of-PDU bit in Type field of ATM header