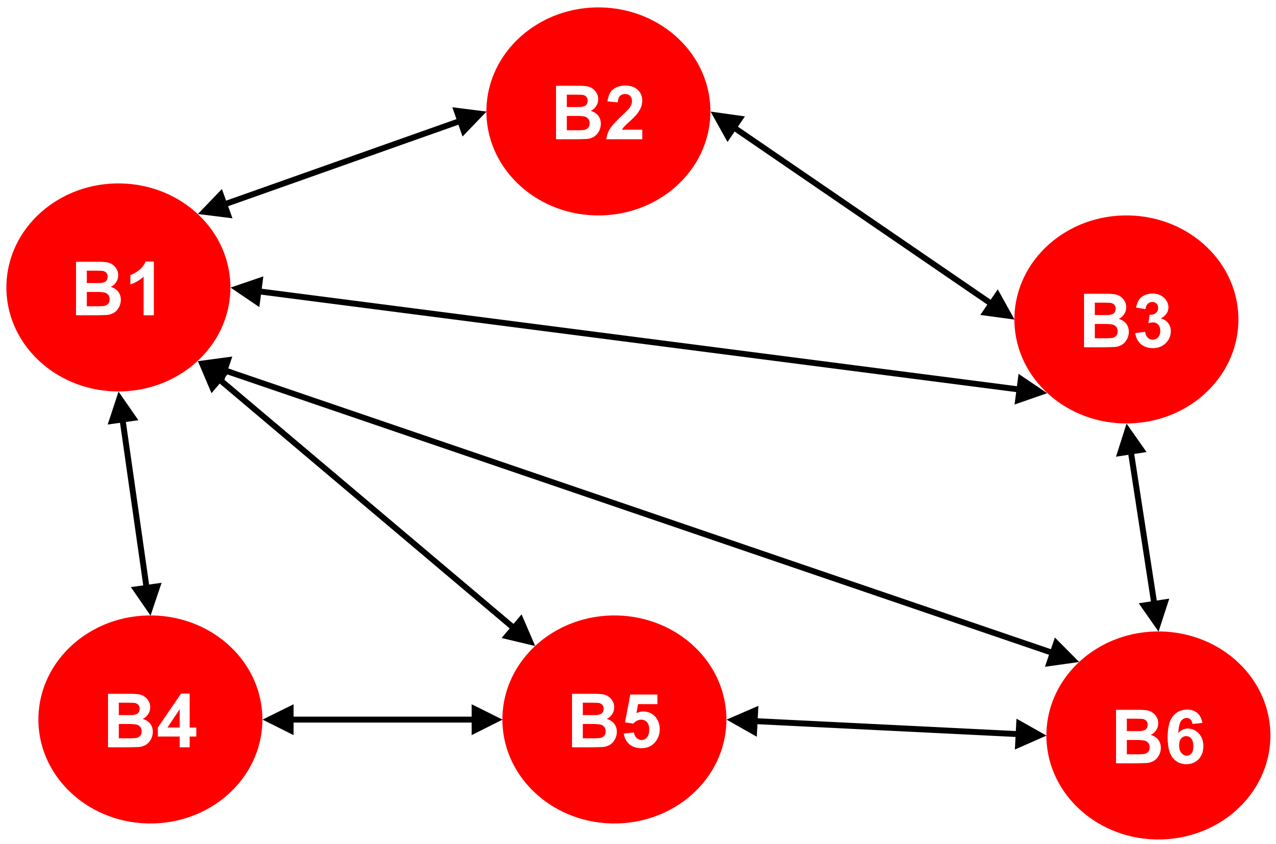
HWP2 – Application level query routing

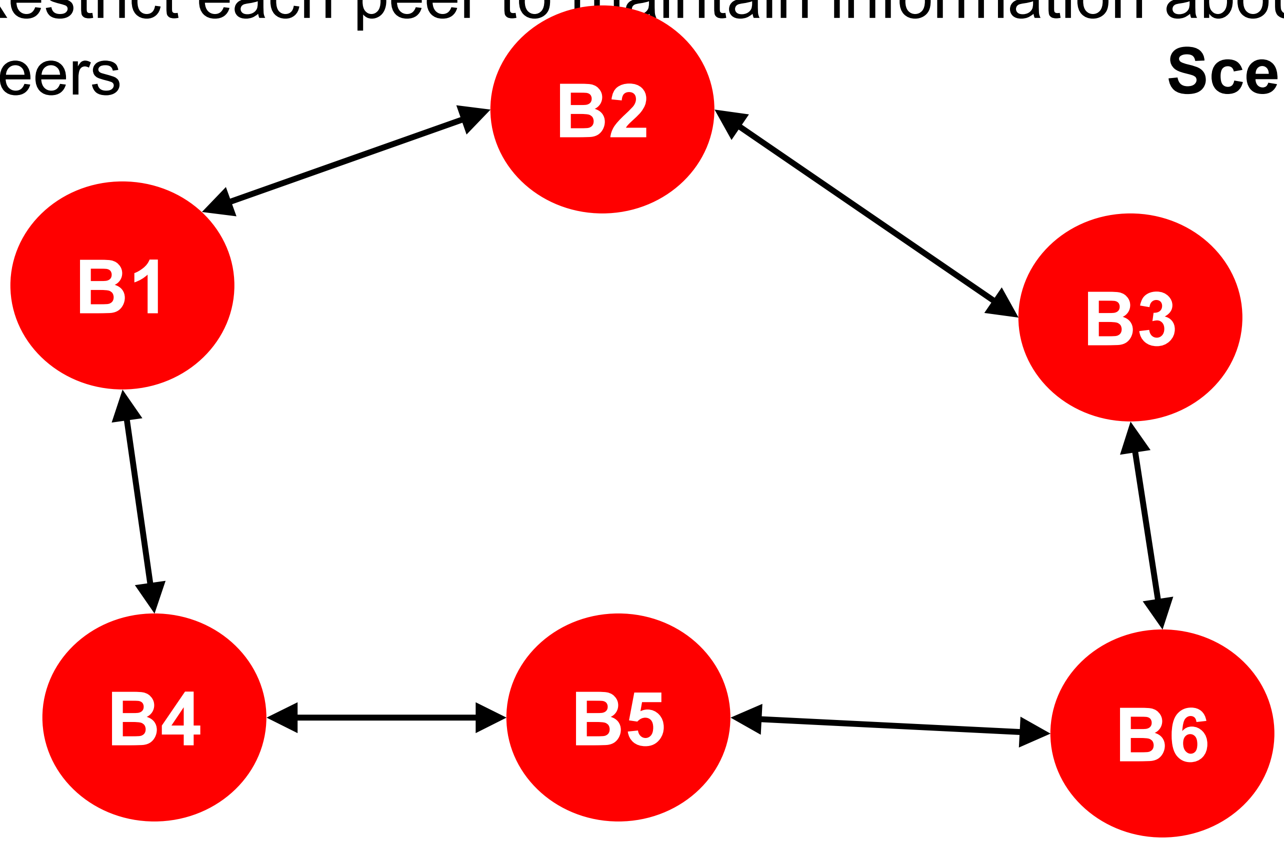
HWP1 – Each peer knows about every other beacon



HWP2 – Query routing

- searchget(searchkey, hopcount)
- Rget(host, port, key)
  - Restrict each peer to maintain information about two other peers

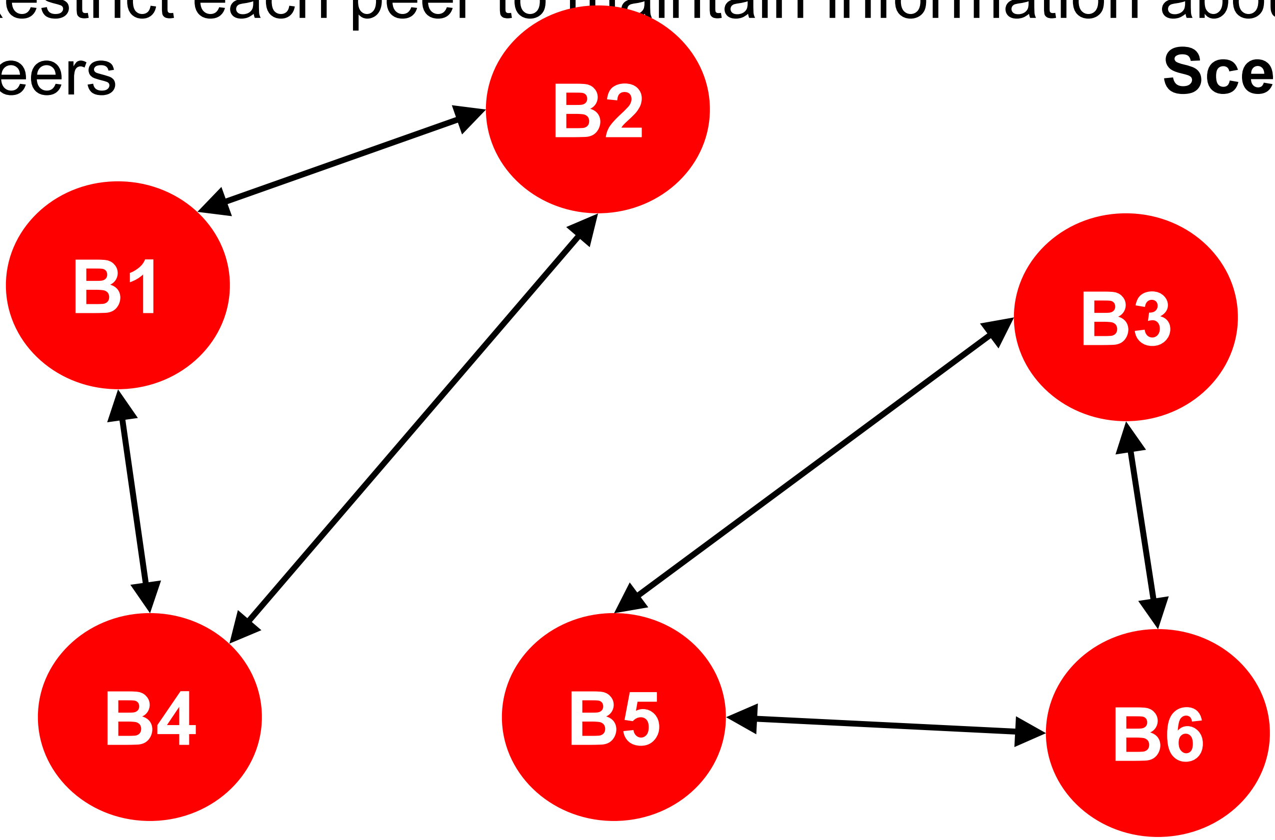
Scenario: 1



HWP2 – Distributed search

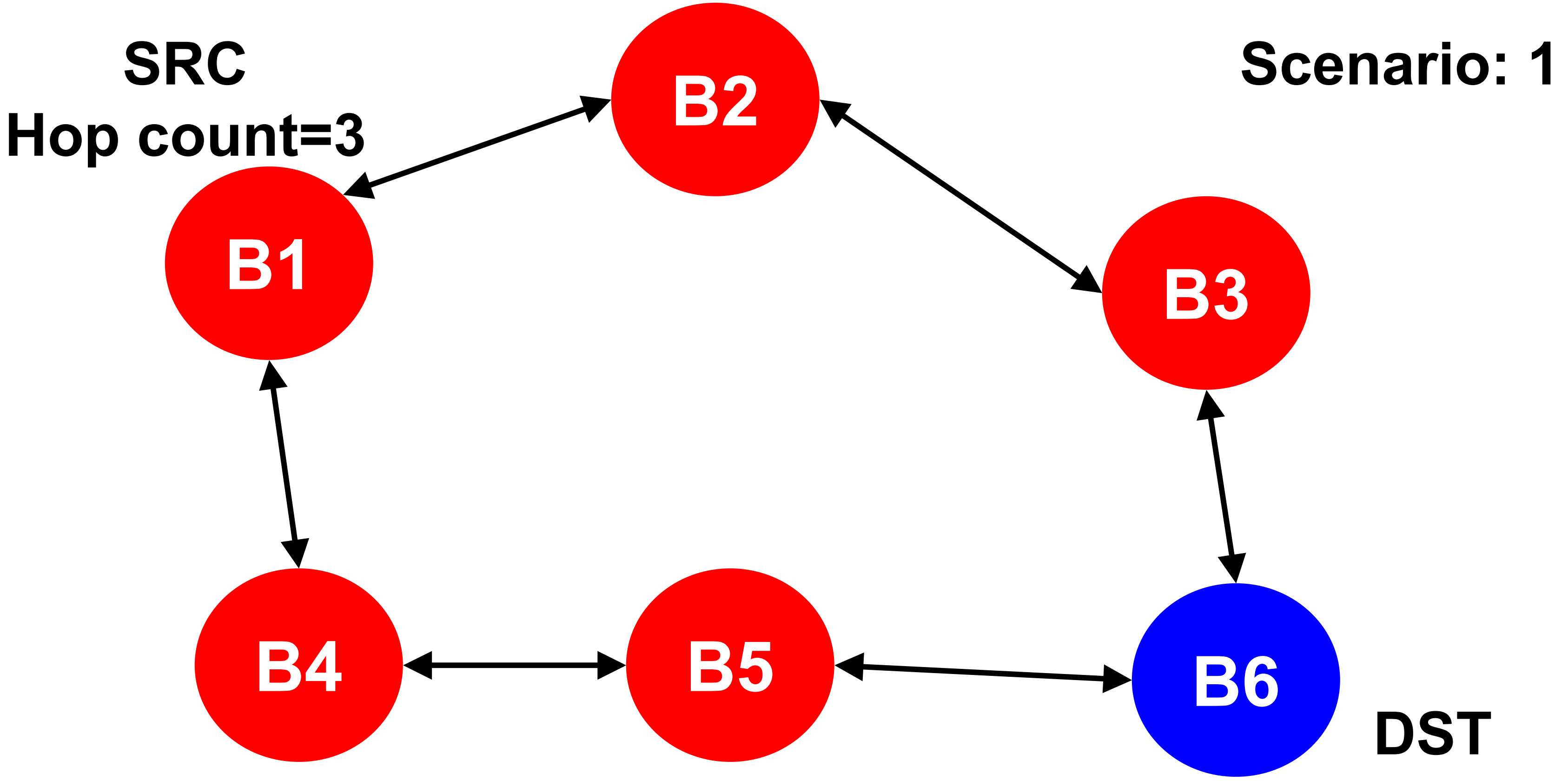
- searchget(searchkey, hopcount)
- Rget(host, port, key)
  - Restrict each peer to maintain information about two other peers

Scenario: 2



HWP2 – Distributed search

- searchget(searchkey, hopcount)
- Rget(host, port, key)



HWP2 – Distributed search

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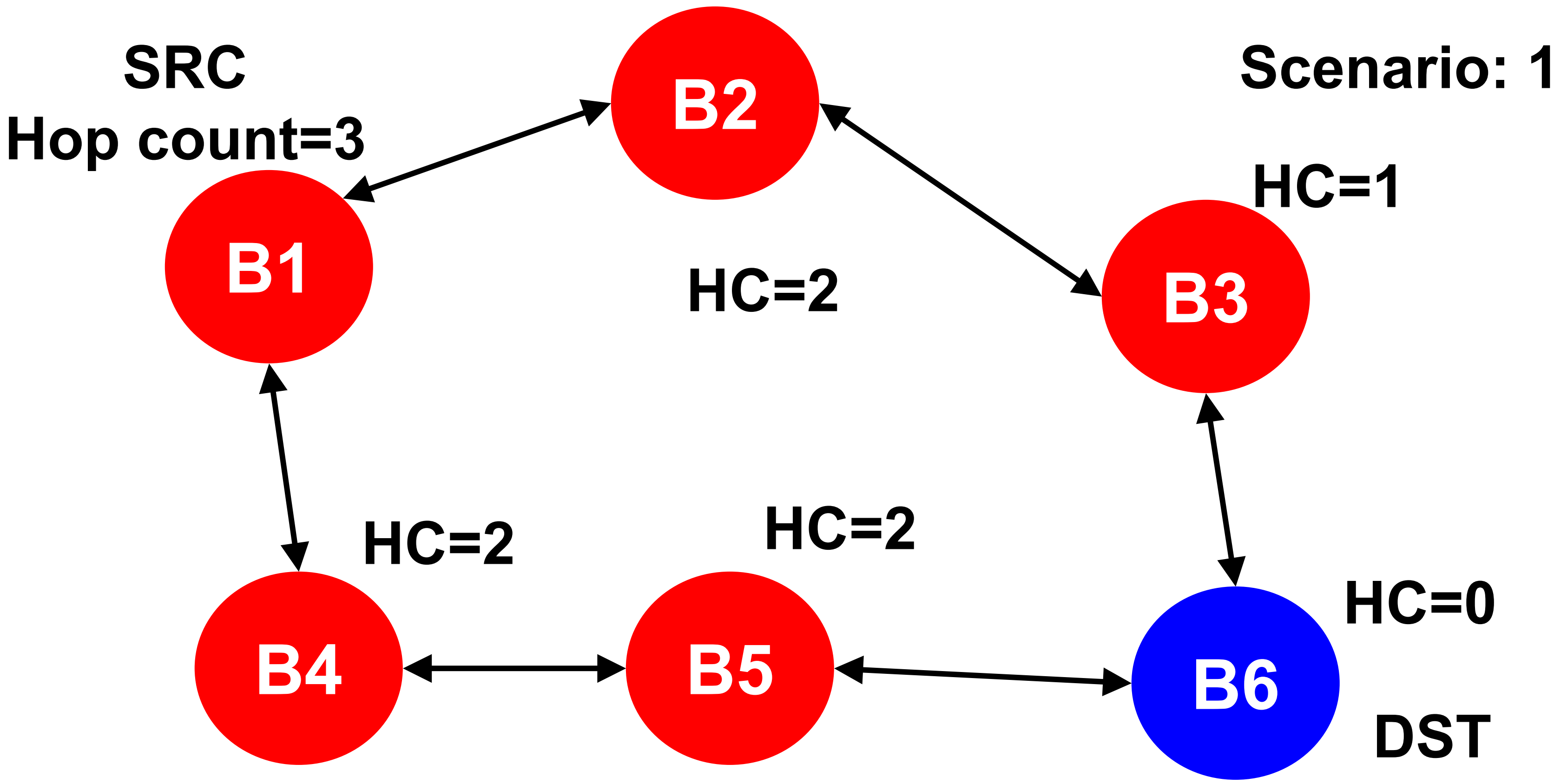
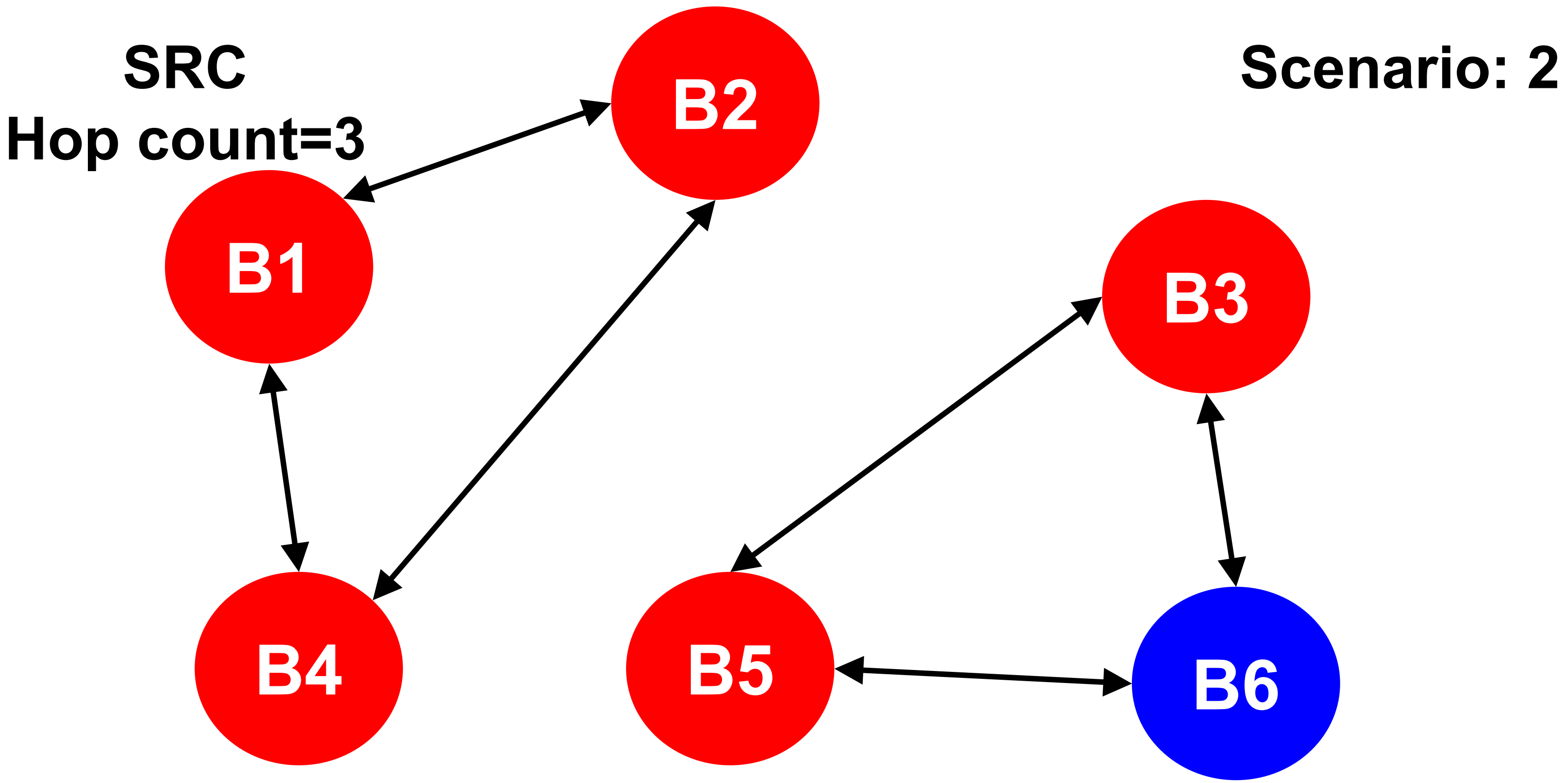


HWP2 – Distributed search

- searchget(searchkey, hopcount)
- Rget(host, port, key)



- Searchget
  - You will use controlled flooding to search for key
- Rget
  - You will use routing technologies

Reference HWP1 solution

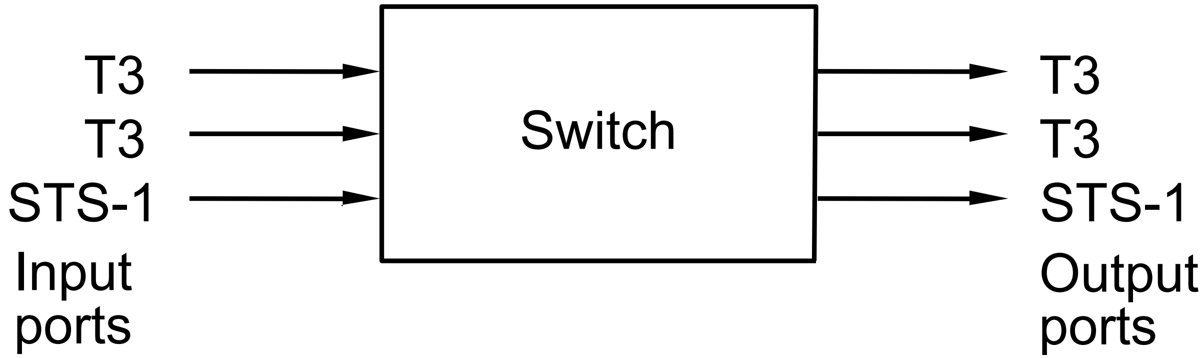
- C source code will be available in the course web page (home works section)
- Four threads
  - locatePeersSend
    - Continously sends identification every BEAT seconds on multicast port
    - Garbage collects clients that you haven't heard in 3*BEAT seconds
  - locatePeersRecv
    - Receives multicast packets and adds to internal table
    - Sends ACK back – useful for RTT calculation
  - RTT
    - Receives ACK packets – compute RTT
  - serviceRequest
    - Services telnet clients for tuple service

Switching and Forwarding

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

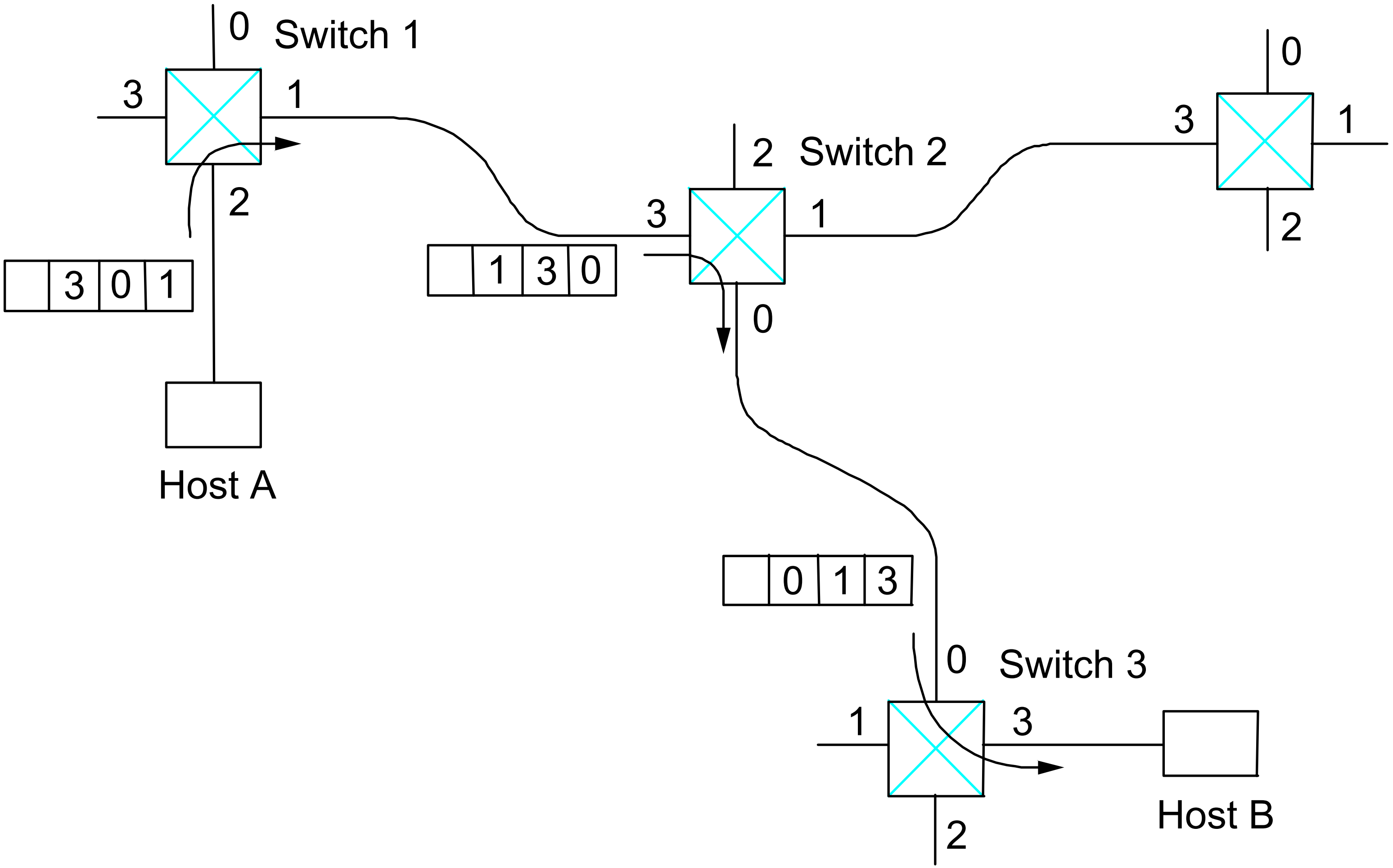
Scalable Networks

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



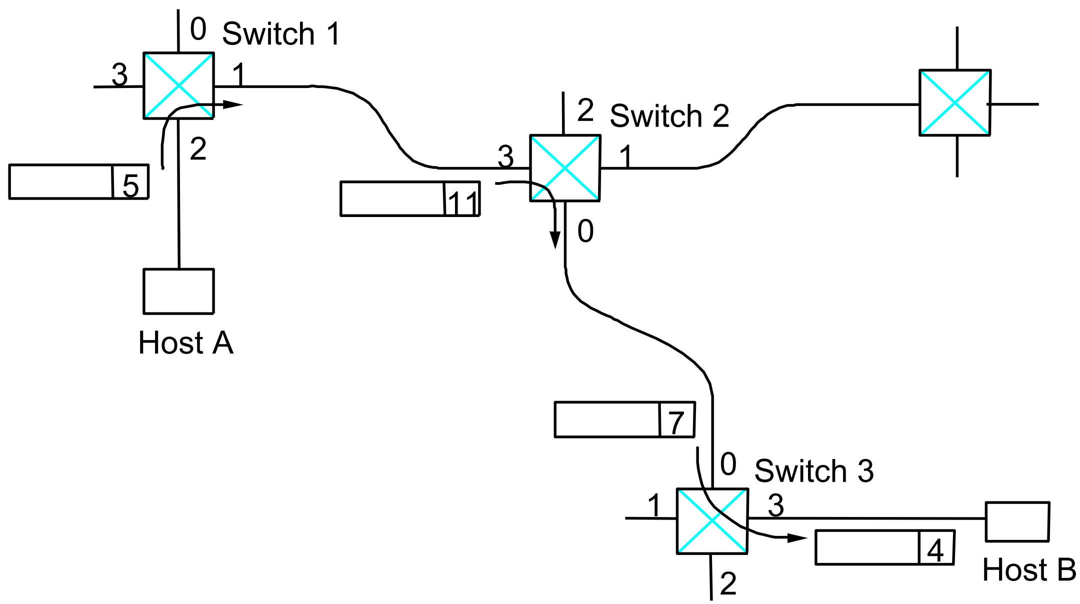
- Advantages
  - cover large geographic area (tolerate latency)
  - support large numbers of hosts (scalable bandwidth)

Source Routing



Virtual Circuit Switching

- Explicit connection setup (and tear-down) phase
- Subsequence packets follow same circuit
- Sometimes called connection-oriented model



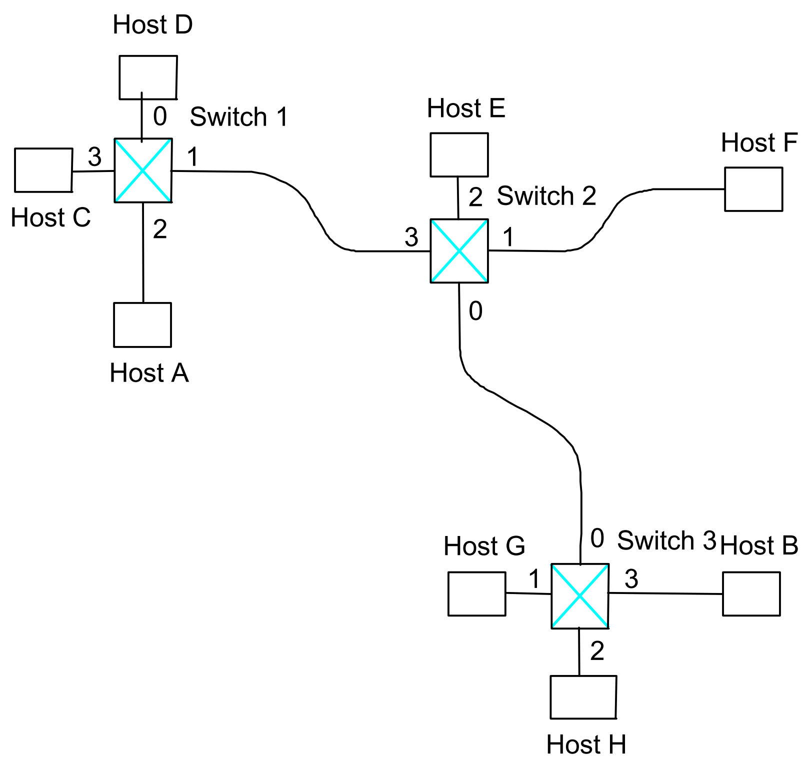
- Analogy: phone call

- Each switch maintains a VC table

Datagram Switching

- No connection setup phase
- Each packet forwarded independently
- Sometimes called connectionless model

  - Analogy: postal system
  - Each switch maintains a forwarding (routing) table



Virtual Circuit Model

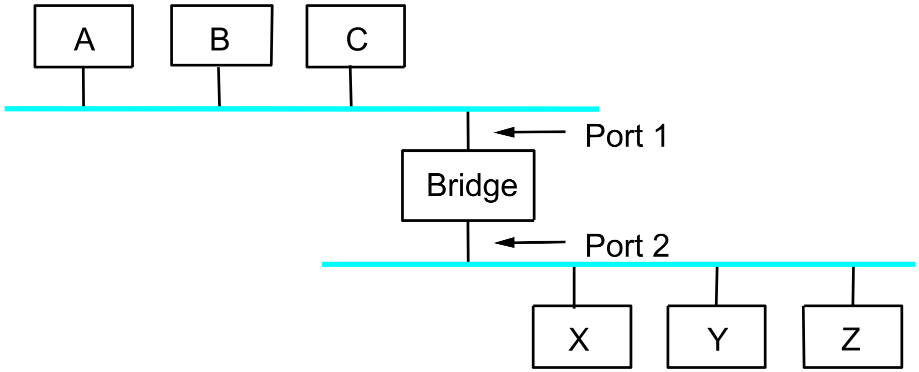
- Typically wait full RTT for connection setup before sending first data packet.
- While the connection request contains the full address for destination, each data packet contains only a small identifier, making the per-packet header overhead small.
- If a switch or a link in a connection fails, the 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 waitint 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

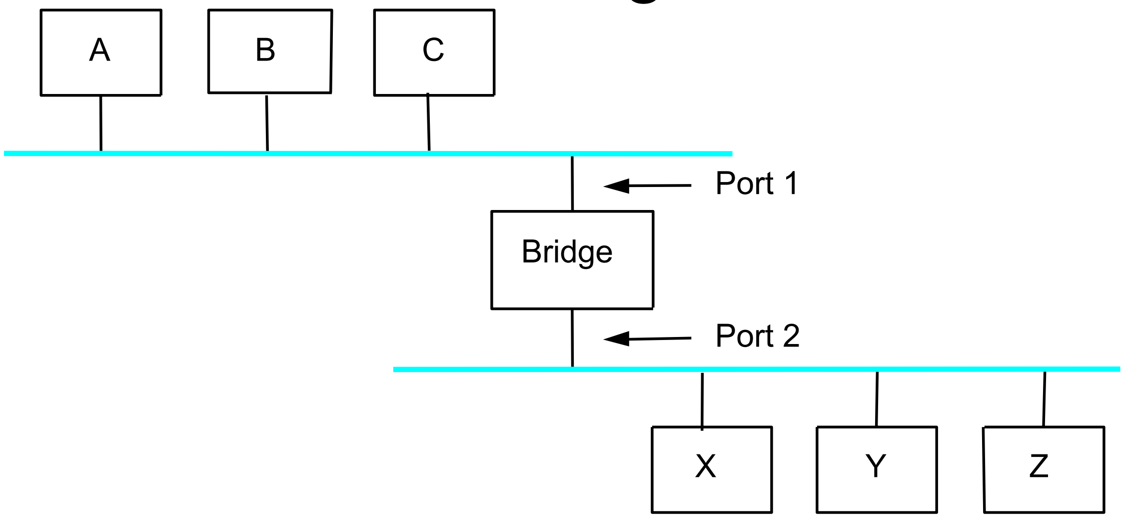
- LANs have physical limitations (e.g., 2500m)
- Connect two or more LANs with a bridge
  - accept and forward strategy
  - level 2 connection (does not add packet header)



- Ethernet Switch = Bridge on Steroids

Learning Bridges

- Do not forward when unnecessary
- Maintain forwarding table

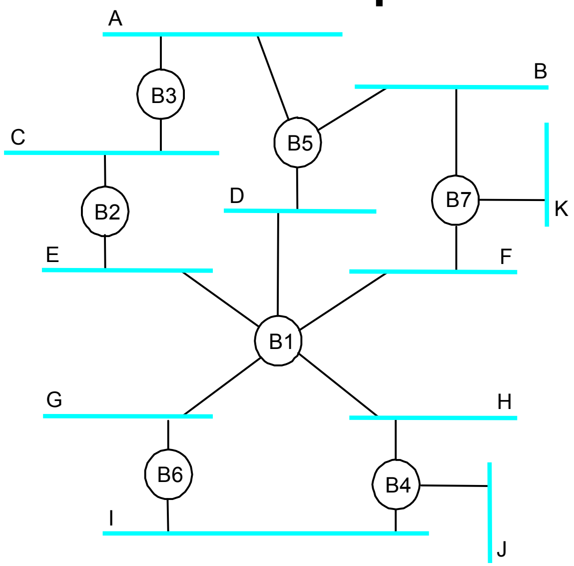


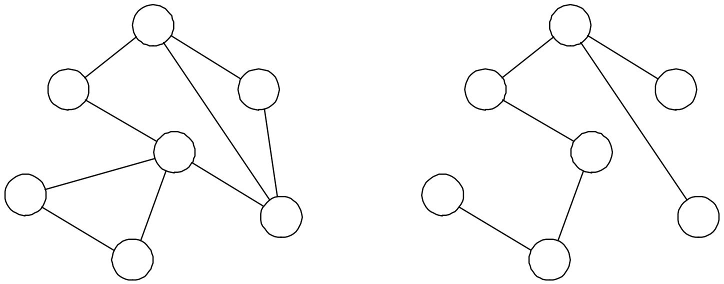
Host	Port
A	1
B	1
C	1
X	2
Y	2
Z	2

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

Spanning Tree Algorithm

- Problem: loops



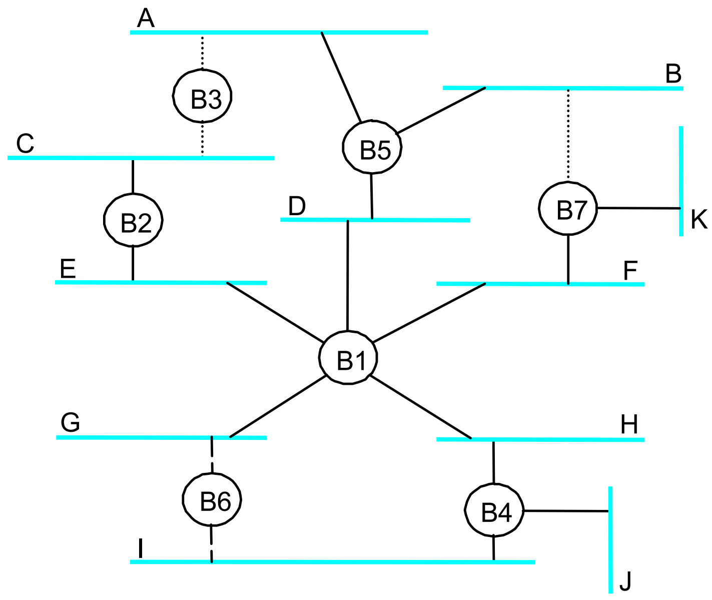


- Bridges run a distributed spanning tree algorithm
  – select which bridges actively forward
  – developed by Radia Perlman
  – now IEEE 802.1 specification

Algorithm Overview

- Each bridge has unique id (e.g., B1, B2, B3)
- Select bridge with smallest id as root
- Select bridge on each LAN closest to root as designated bridge (use id to break ties)

  - Each bridge forwards frames over each LAN for which it is the designated bridge



Algorithm Details

- 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

Algorithm Detail (cont)

- When learn not root, stop generating config messages
  - in steady state, only root generates configuration messages
- When learn not designated bridge, stop forwarding config messages
  - in steady state, only designated bridges forward config messages
- Root continues to periodically send config messages
- If any bridge does not receive config message after a period of time, it starts generating config messages claiming 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
- Signaling (connection setup) Protocol: Q.2931
- Specified by ATM forum
- Packets are called cells
  - 5-byte header + 48-byte payload
- Commonly transmitted over SONET
  - other physical layers possible

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 x 8/100 = 327.68us
    - high priority packet may sit in the queue 327.68us
    - in contrast, 53 x 8/100 = 4.24us for ATM
  - near cut-through behavior
    - two 4KB packets arrive at same time
    - link idle for 327.68us while both arrive
    - at end of 327.68us, still have 8KB to transmit
    - in contrast, can transmit first cell after 4.24us
    - at end of 327.68us, just over 4KB left in queue

Big vs Small (cont)

- 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)

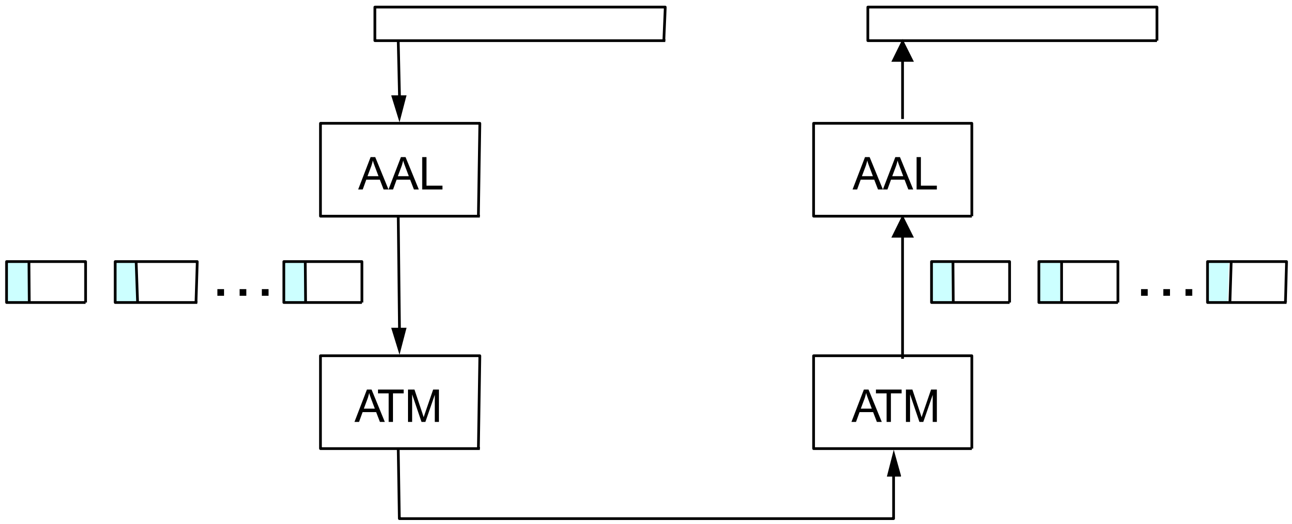
4	8	16	3	1	8	384 (48 bytes)
GFC	VPI	VCI	Type	CLP	HEC (CRC-8)	Payload

  - 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)
  - CLPL 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	0– 24	8	8	16
CPI	Btag	BASize	User data	Pad	0	Etag	Len

  – CPI: commerce 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

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

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

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

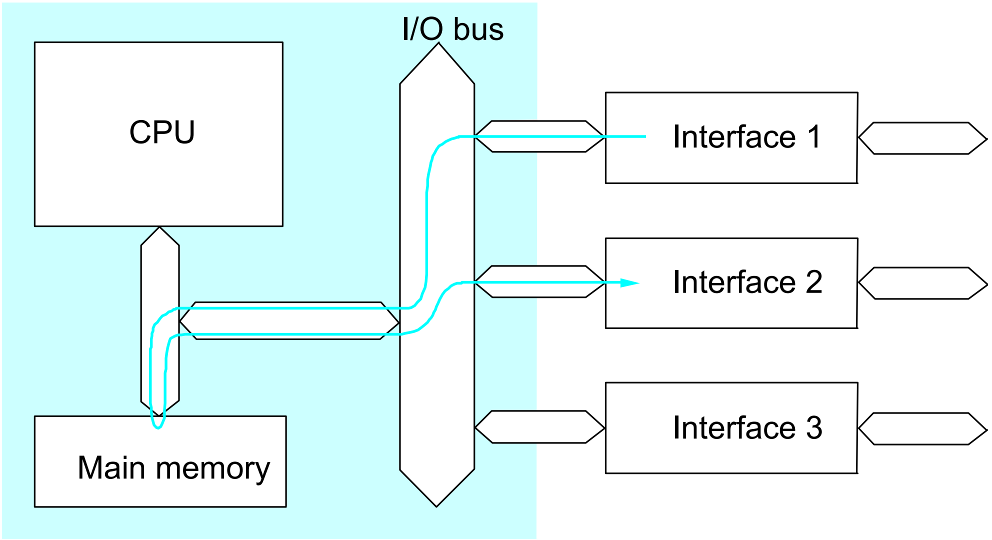
Router Construction

- Outline
  - Switched Fabrics
  - IP Routers
  - Extensible (Active) Routers

Workstation-Based

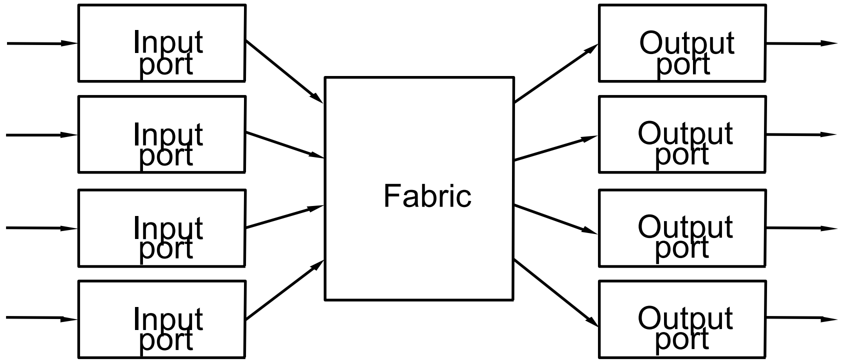
- Aggregate bandwidth
  - 1/2 of the I/O bus bandwidth
  - capacity shared among all hosts connected to switch
  - example: 800Mbps bus can support 8 T3 ports

- Packets-per-second
  - must be able to switch small packets
  - 100,000 packets-per-second is achievable
  - e.g., 64-byte packets implies 51.2Mbps



Switching Hardware

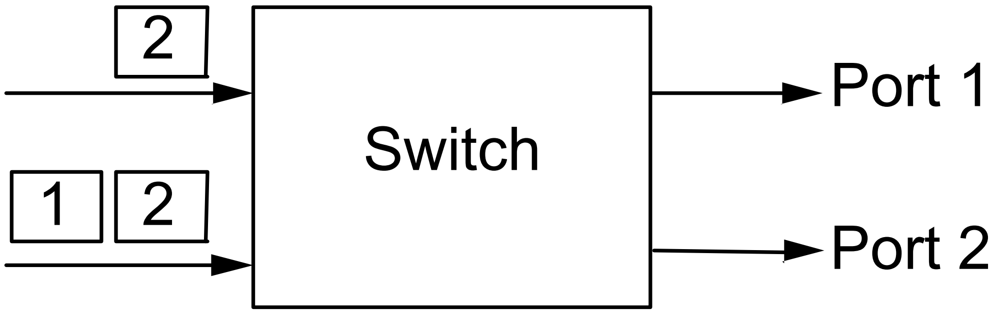
- Design Goals
  - throughput (depends on traffic model)
  - scalability (a function of n)



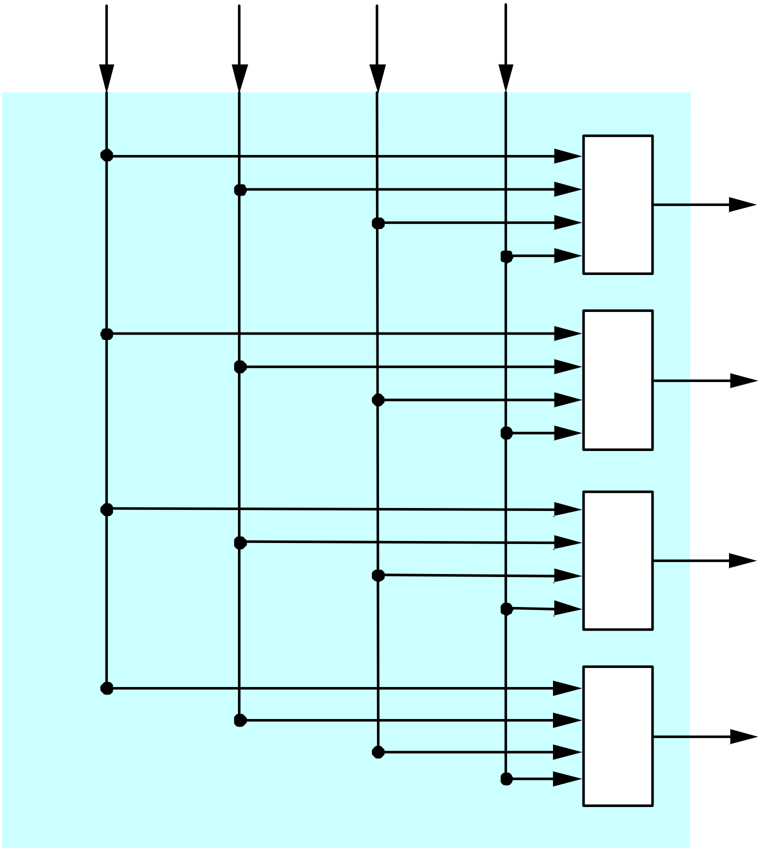
- Ports
  - circuit management (e.g., map VCIs, route datagrams)
  - buffering (input and/or output)
- Fabric
  - as simple as possible
  - sometimes do buffering (internal)

Buffering

- Wherever contention is possible
  - input port (contend for fabric)
  - internal (contend for output port)
  - output port (contend for link)
- Head-of-Line Blocking
  - input buffering

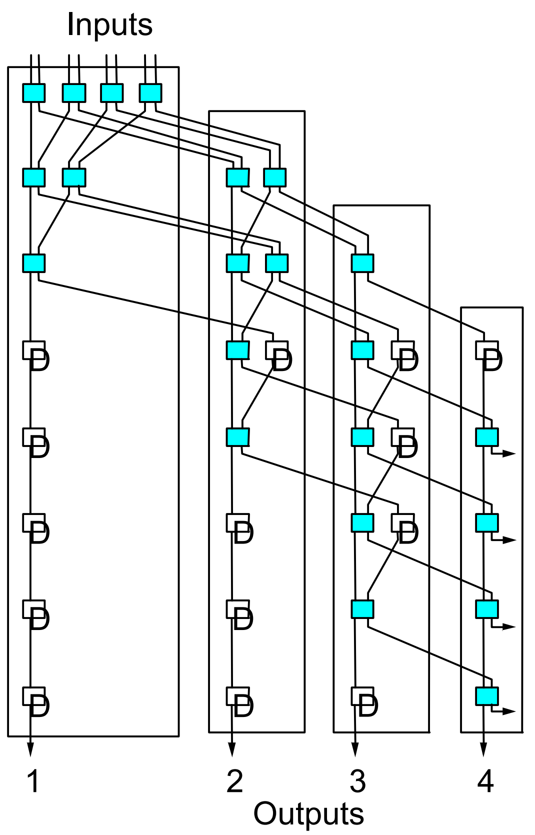


Crossbar Switches



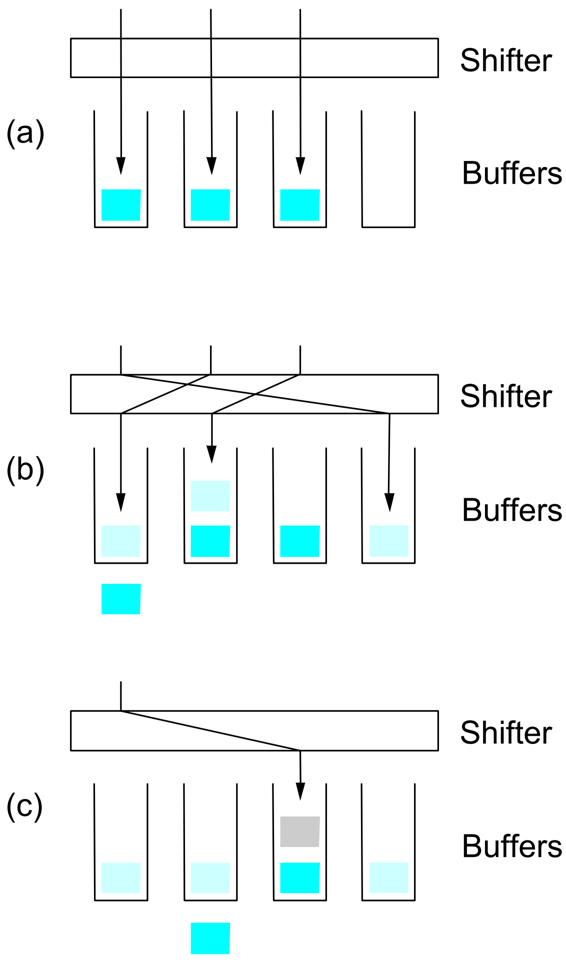
Knockout Switch

- Example crossbar
- Concentrator
  - select l of n packets
- Complexity: n2



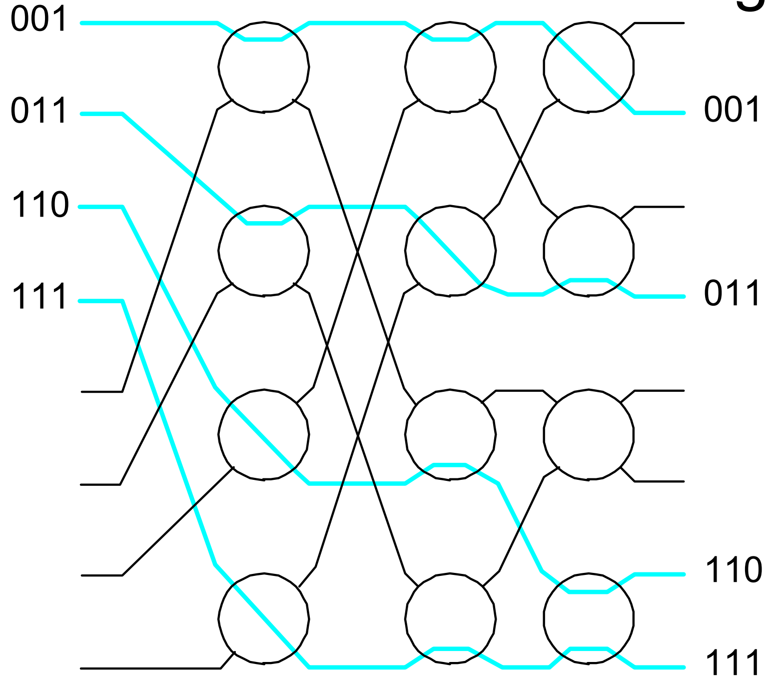
Knockout Switch (cont)

- Output Buffer



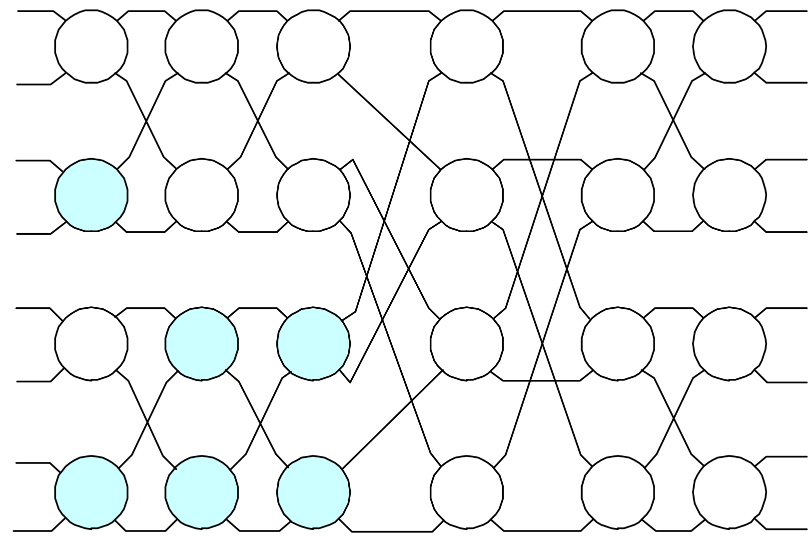
Self-Routing Fabrics

- Banyan Network
  - constructed from simple 2 x 2 switching elements
  - self-routing header attached to each packet
  - elements arranged to route based on this header
  - no collisions if input packets sorted into ascending order
  - complexity: n log2 n



Self-Routing Fabrics (cont)

- Batcher Network
  - switching elements sort two numbers
    - some elements sort into ascending (clear)
    - some elements sort into descending (shaded)
  - elements arranged to implement merge sort
  - complexity: n log22 n

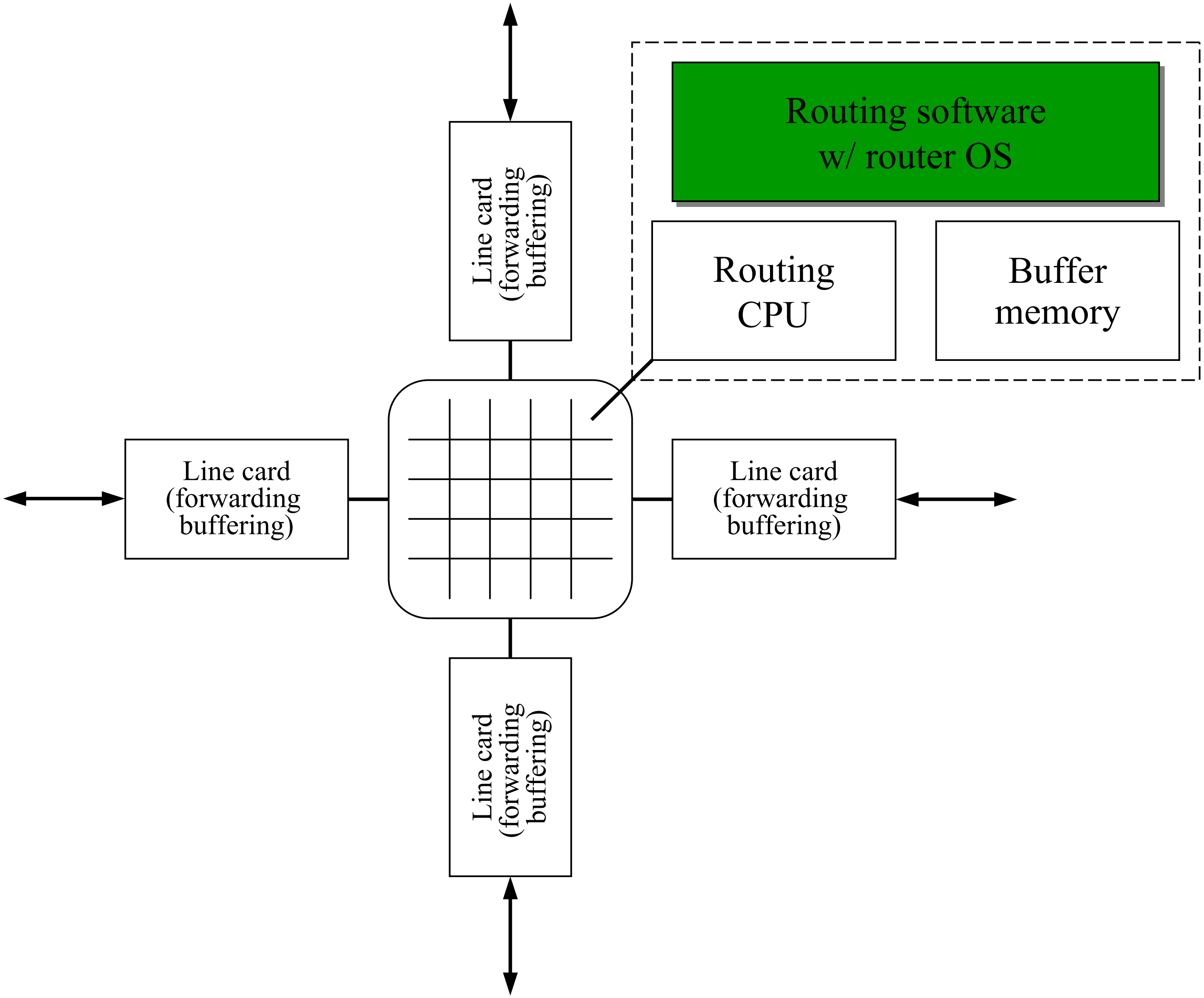


- Common Design: Batcher-Banyan Switch

High-Speed IP Router

- Switch (possibly ATM)
- Line Cards + Forwarding Engines
  - link interface
  - router lookup (input)
  - common IP path (input)
  - packet queue (output)
- Network Processor
  - routing protocol(s)
  - exceptional cases

High-Speed Router



Alternative Design