DATA COMMUNICATON NETWORKS

PACKET SWITCHING NETWORK

by

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Aim and Objectives

- To understand the packet switching network packet switching network topology in data communication.
- To analyze the different Packet Switching techniques.
- To enrich the idea of various types of routers.
- To acquire knowledge about ATM.

Pre-MCQ Test

[1] What is the main function of the transport layer?

a) Node to node delivery.
b) End to end message delivery.
c) Synchronization.
d) Routing table.

[2] As the data packets moves from the lower to the upper layers, headers are ______________

a) added.
b) subtracted.
c) rearranged.
d) modified.

[3] Which of the following frame types is specified in the 802.5 standard?

a) Token.
b) abort.
c) data/command.
d) all of the above.

[4] Which LAN has the highest data rate?

a) 10base5.
b) 10base-T.
c) Twisted pair token ring.
d) FDDI.

[5] In framing, there is no need for defining the boundaries of frames in

a) fixed size.
b) variable size.
c) standard.
d) none of these.

Theory Contents

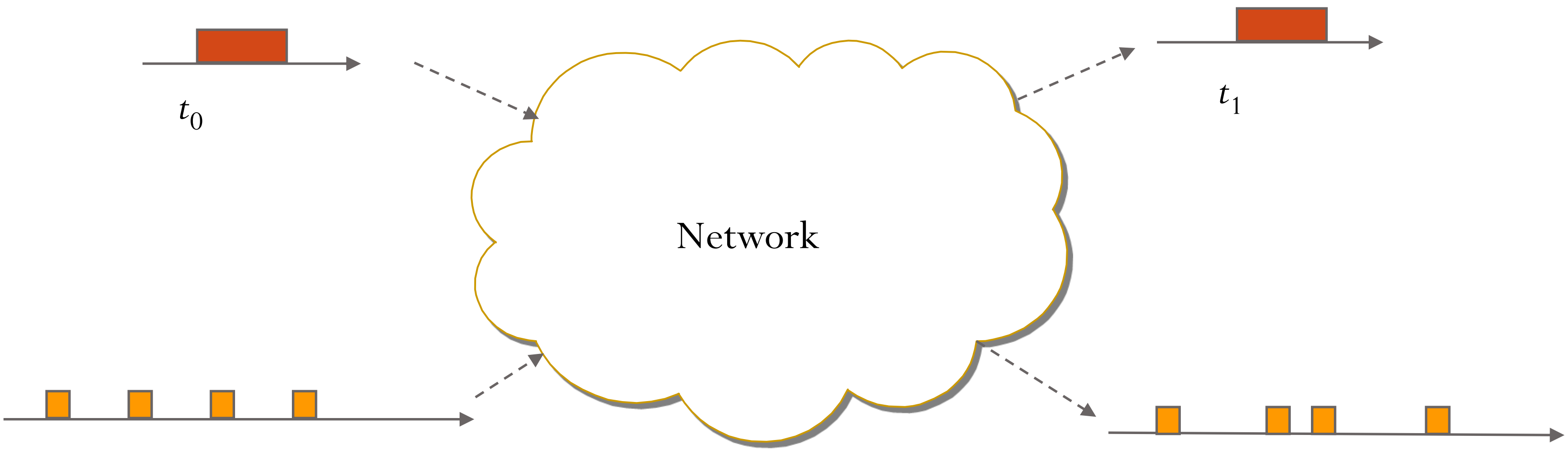
- Packet Switching
- Network Service
- Network Layer Functions
- LAN Concentration
- The Switching Function
- Connectionless Packet Switching
- Virtual Circuit Packet Switching
- Self-Routing Switches
- Routing in Packet Networks
- Creating the Routing Tables
- Routing in Virtual-Circuit Packet Networks
- Routing Tables in Datagram Packet Networks
- Hierarchical Routing
- Specialized Routing

- Shortest Path Routing
  - Routing Metrics
  - Distance Vector
  - MPLS & ATM
  - Bellman-Ford Algorithm
  - Link-State Algorithm
  - Dijkstra's Algorithm
  - Examples
- Asynchronous Transfer Mode (ATM)
  - ATM Networking
  - ATM: Attributes of TDM & Packet Switching
  - ATM Switching
  - ATM Virtual Connections

Network Layer

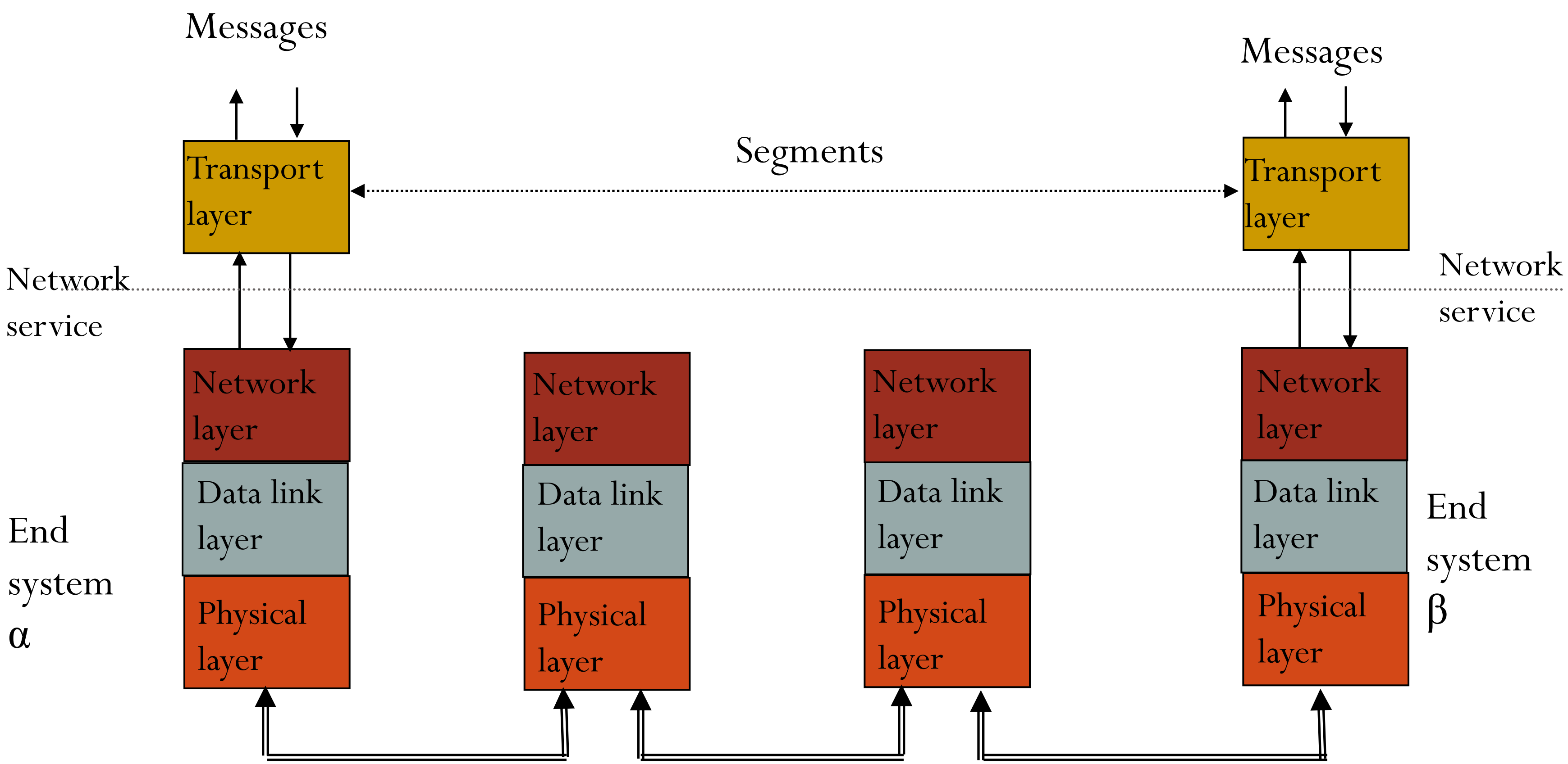
- Network Layer: the most complex layer
  - Requires the coordinated actions of multiple, geographically distributed network elements (switches & routers)
  - Must be able to deal with very large scales
    - Billions of users (people & communicating devices)
  - Biggest Challenges
    - Addressing: where should information be directed to?
    - Routing: what path should be used to get information there?

Packet Switching



- Transfer of information as payload in data packets
- Packets undergo random delays & possible loss
- Different applications impose differing requirements on the transfer of information

Network Service



- Network layer can offer a variety of services to transport layer
- Connection-oriented service or connectionless service
- Best-effort or delay/loss guarantees

Network Service vs. Operation

Network Service

- Connectionless
  - Datagram Transfer
- Connection-Oriented
  - Reliable and possibly constant bit rate transfer

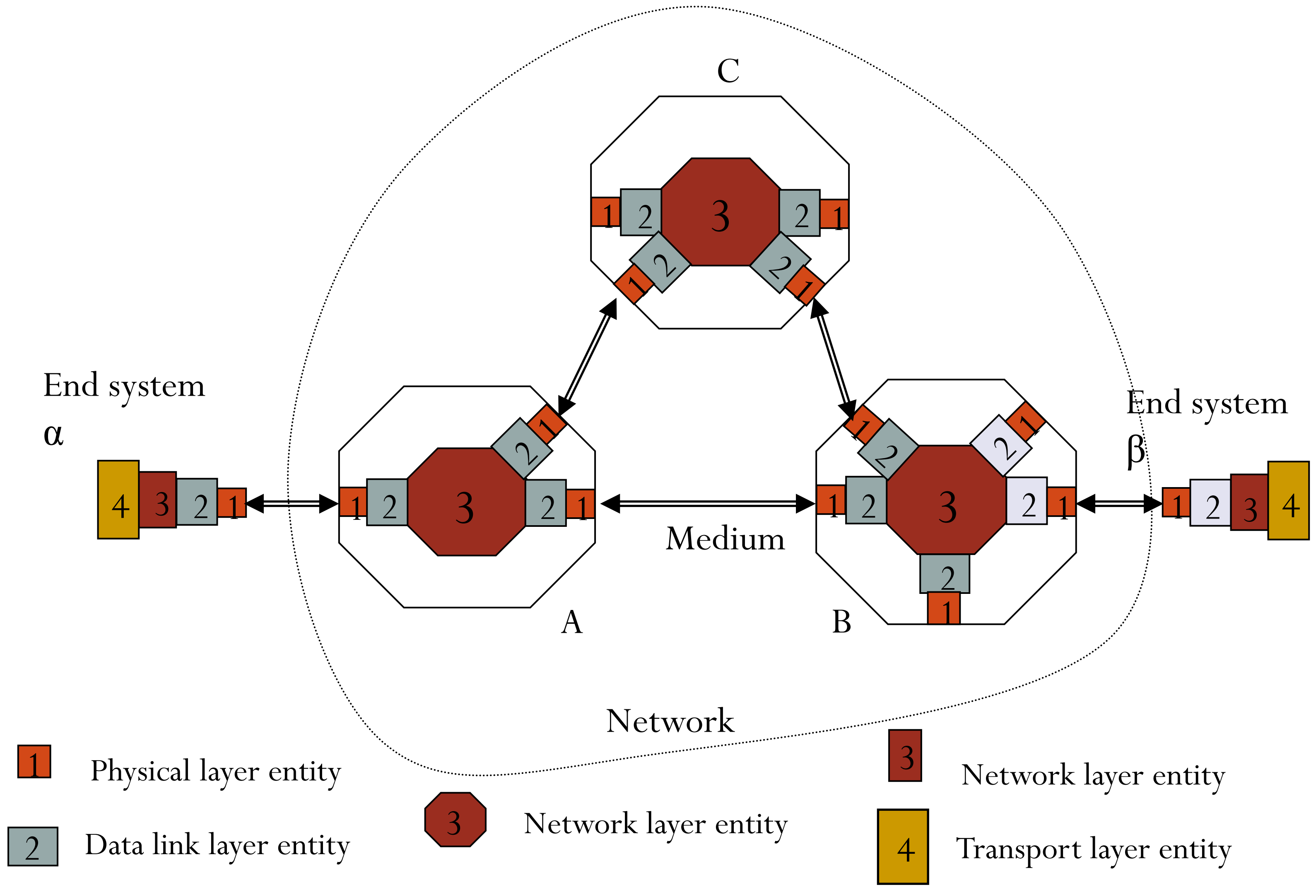
Internal Network Operation

- Connectionless
  - IP
- Connection-Oriented
  - Telephone connection
  - ATM

Various combinations are possible

- Connection-oriented service over Connectionless operation
- Connectionless service over Connection-Oriented operation
- Context & requirements determine what makes sense

Complexity at the Edge or in the Core?



The End-to-End Argument for System Design

- An end-to-end function is best implemented at a higher level than at a lower level
  - End-to-end service requires all intermediate components to work properly
  - Higher-level better positioned to ensure correct operation
- Example: stream transfer service
  - Establishing an explicit connection for each stream across network requires all network elements (NEs) to be aware of connection; All NEs have to be involved in re-establishment of connections in case of network fault
  - In connectionless network operation, NEs do not deal with each explicit connection and hence are much simpler in design

Network Layer Functions

Essential

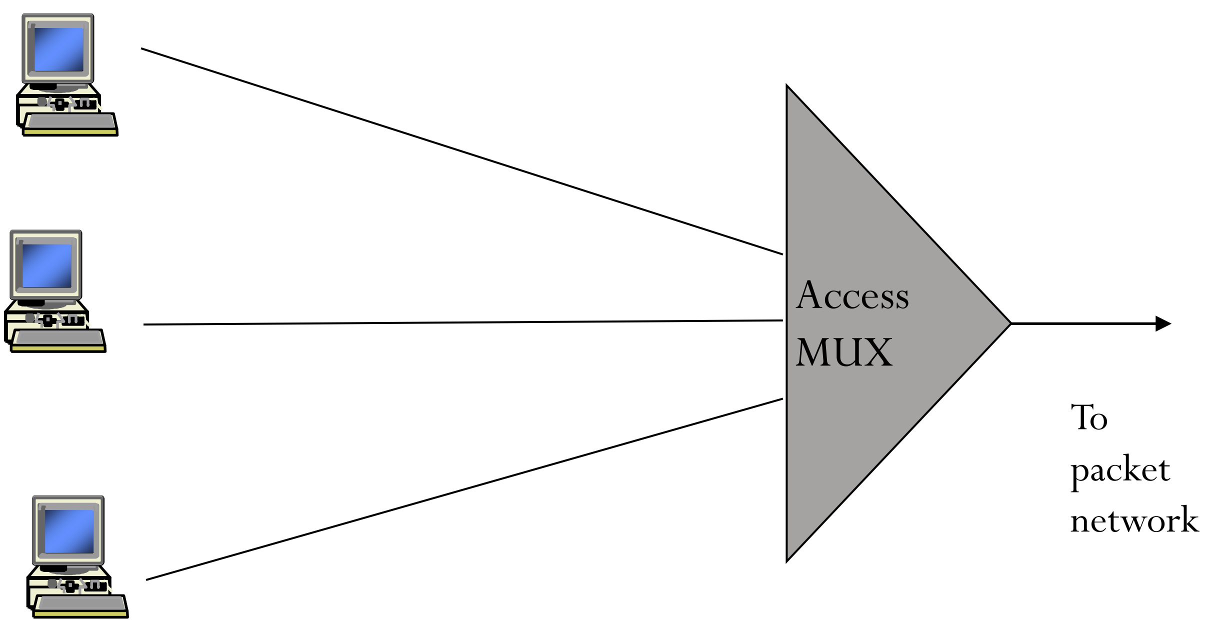
- **Routing**: mechanisms for determining the set of best paths for routing packets requires the collaboration of network elements
- **Forwarding**: transfer of packets from NE inputs to outputs
- **Priority & Scheduling**: determining order of packet transmission in each NE

Optional: congestion control, segmentation & reassembly, security

End-to-End Packet Network

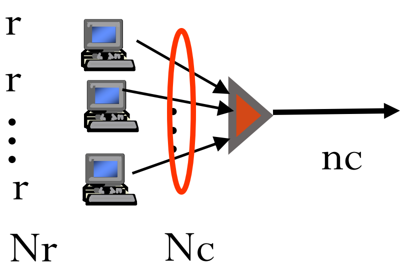
- Packet networks very different than telephone networks
- Individual packet streams are highly bursty
  - Statistical multiplexing is used to concentrate streams
- User demand can undergo dramatic change
  - Peer-to-peer applications stimulated huge growth in traffic volumes
- Internet structure highly decentralized
  - Paths traversed by packets can go through many networks controlled by different organizations
  - No single entity responsible for end-to-end service

Access Multiplexing



- Packet traffic from users multiplexed at access to network into aggregated streams
- DSL traffic multiplexed at DSL Access Mux
- Cable modem traffic multiplexed at Cable Modem Termination System

Oversubscription

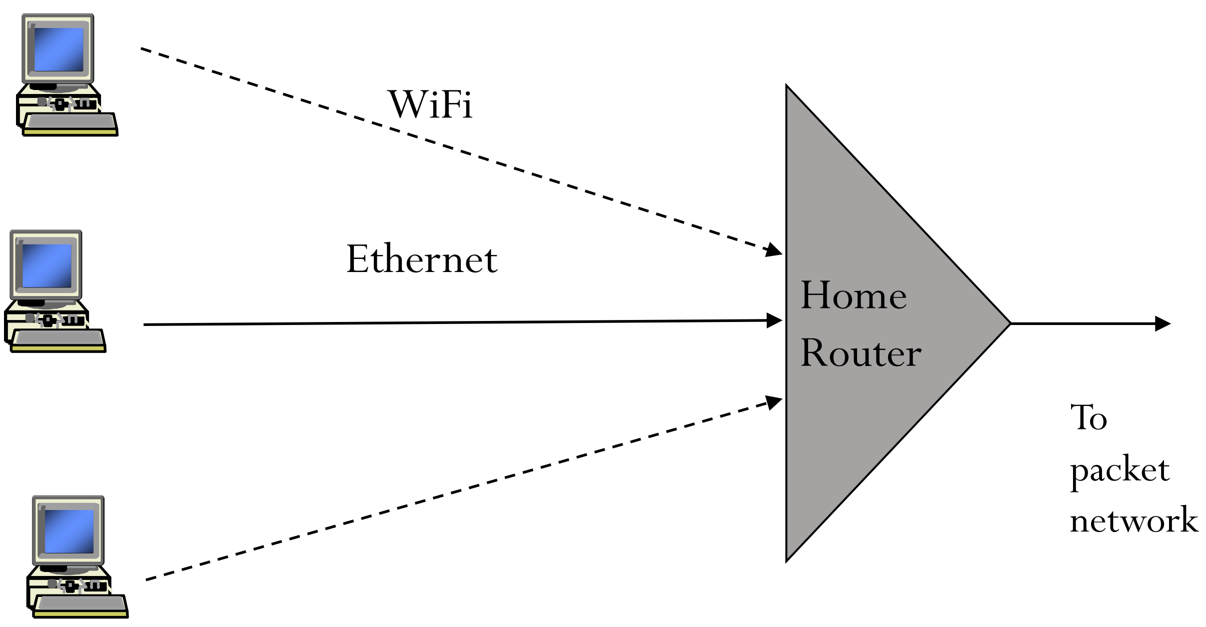


- Access Multiplexer
  - N subscribers connected @ c bps to mux
  - Each subscriber active r/c of time
  - Mux has C=nc bps to network
  - Oversubscription rate: N/n
  - Find n so that at most 1% overflow probability

Feasible oversubscription rate increases with size

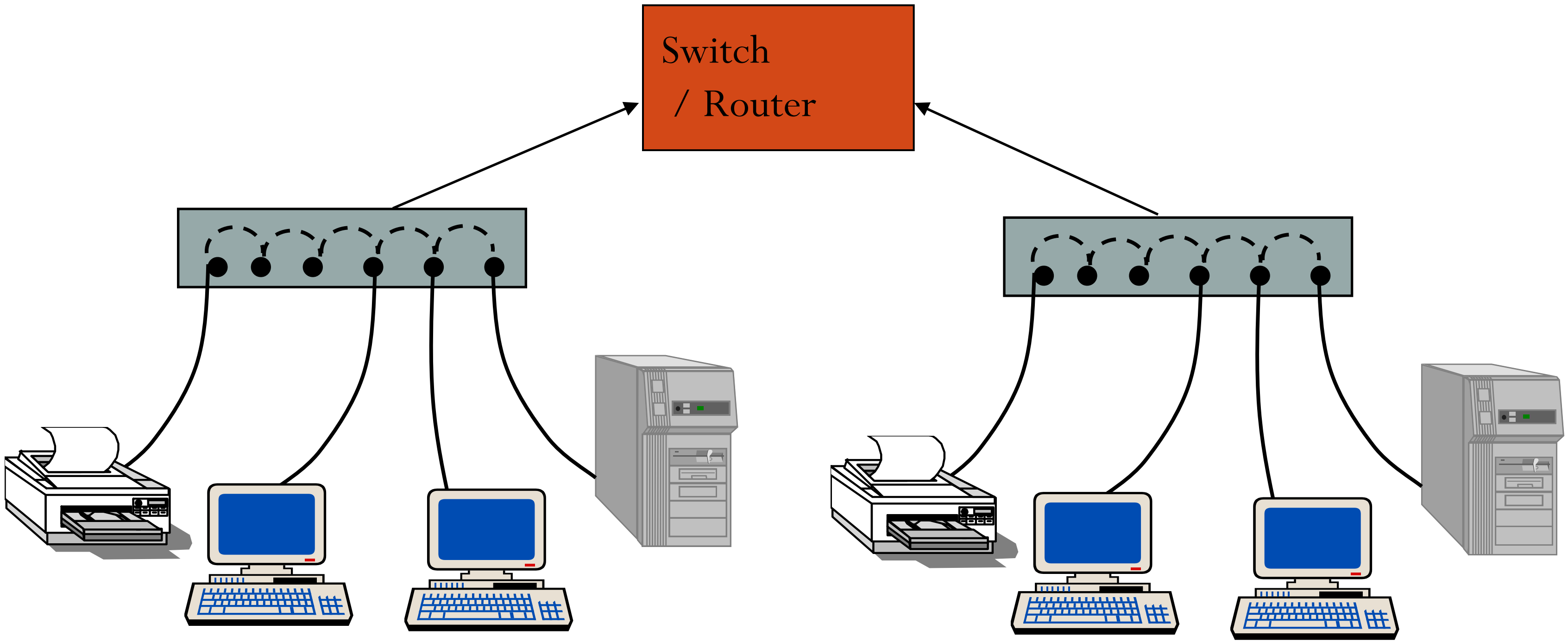
N	r/c	n	N/n	
10	0.01	1	10	10 extremely lightly loaded users
10	0.05	3	3.3	10 very lightly loaded user
10	0.1	4	2.5	10 lightly loaded users
20	0.1	6	3.3	20 lightly loaded users
40	0.1	9	4.4	40 lightly loaded users
100	0.1	18	5.5	100 lightly loaded users

Home LANs



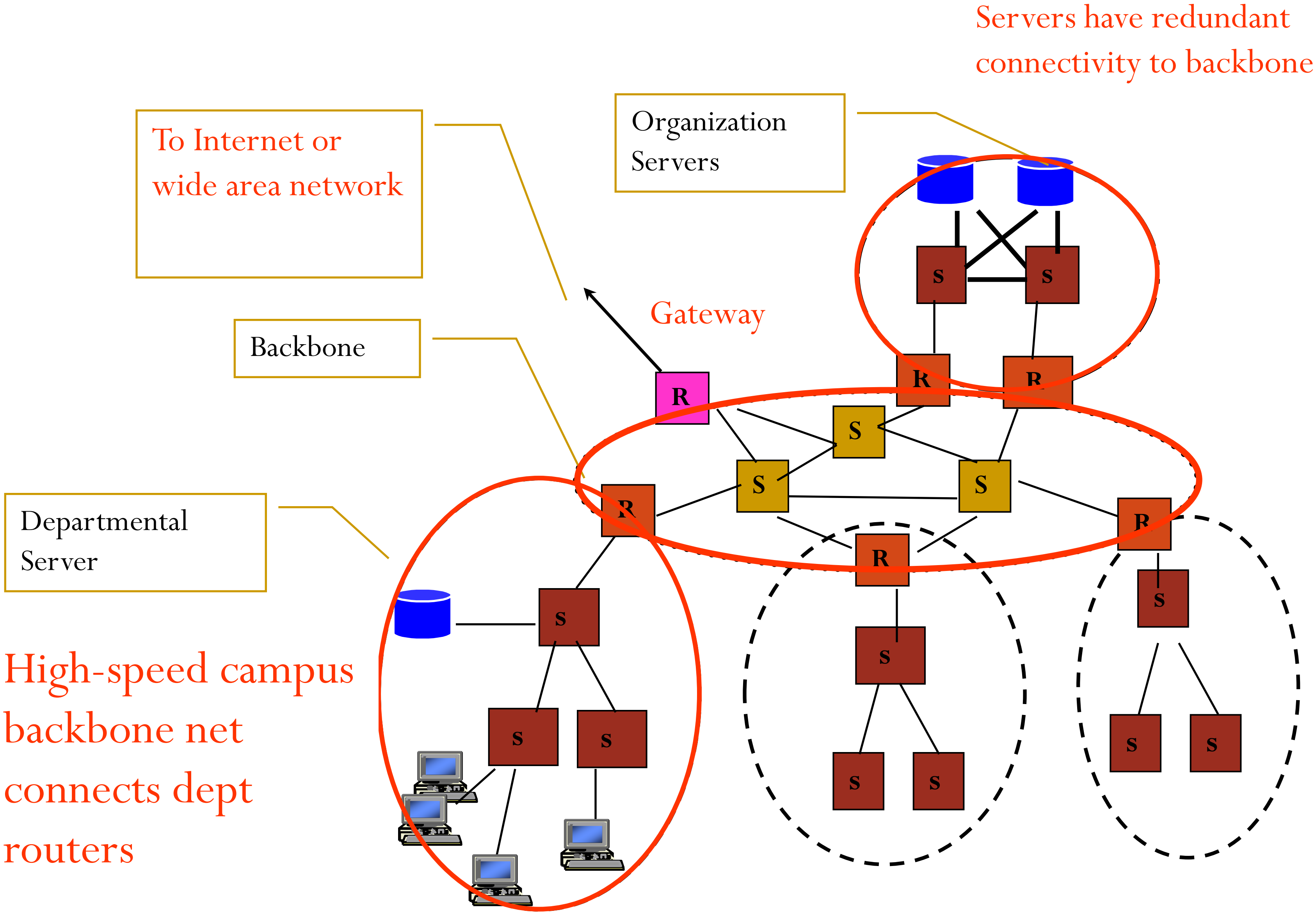
- Home Router
  - LAN Access using Ethernet or WiFi (IEEE 802.11)
  - Private IP addresses in Home (192.168.0.x) using Network Address Translation (NAT)
  - Single global IP address from ISP issued using Dynamic Host Configuration Protocol (DHCP)

LAN Concentration

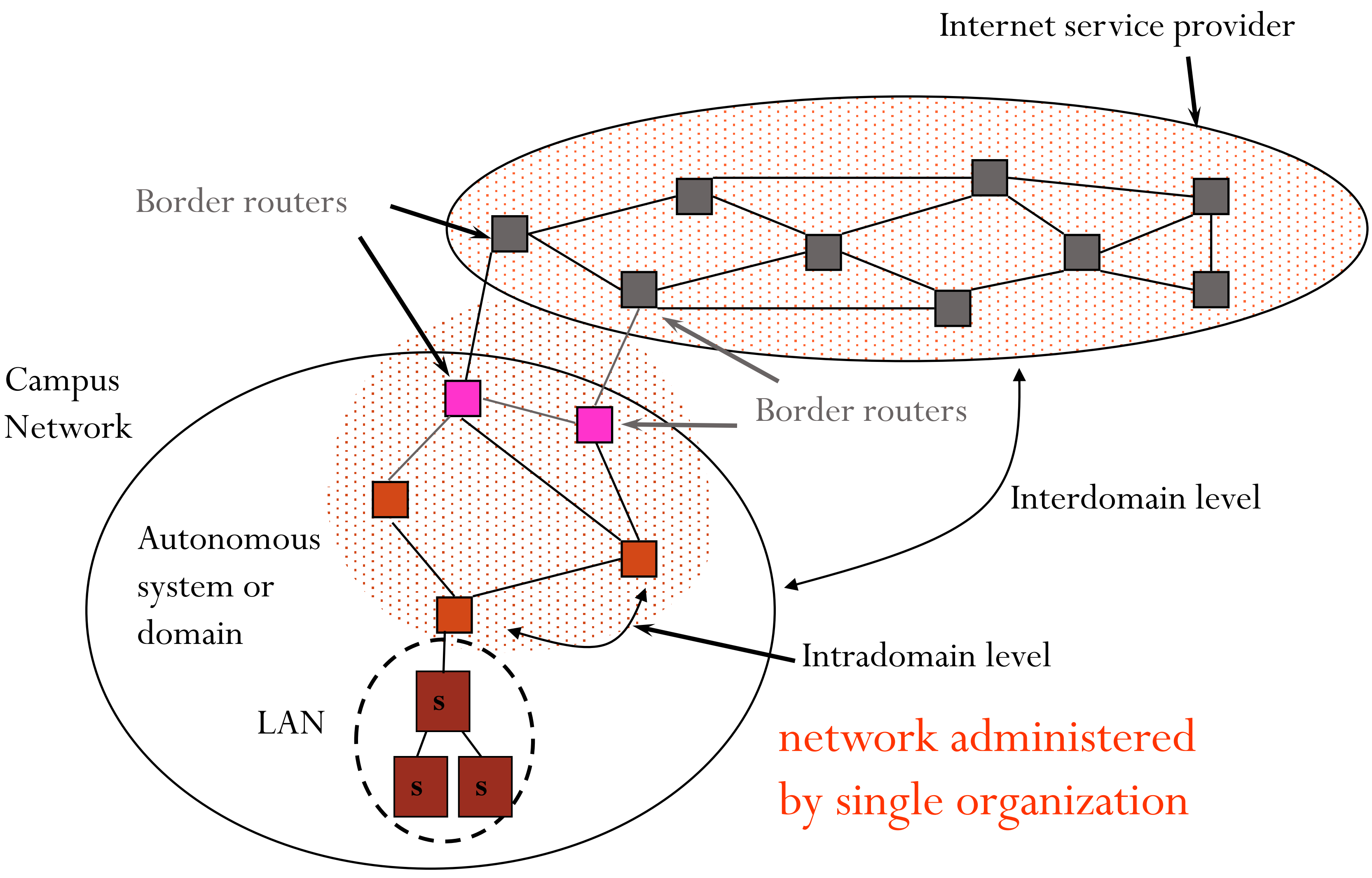


- LAN Hubs and switches in the access network also aggregate packet streams that flows into switches and routers

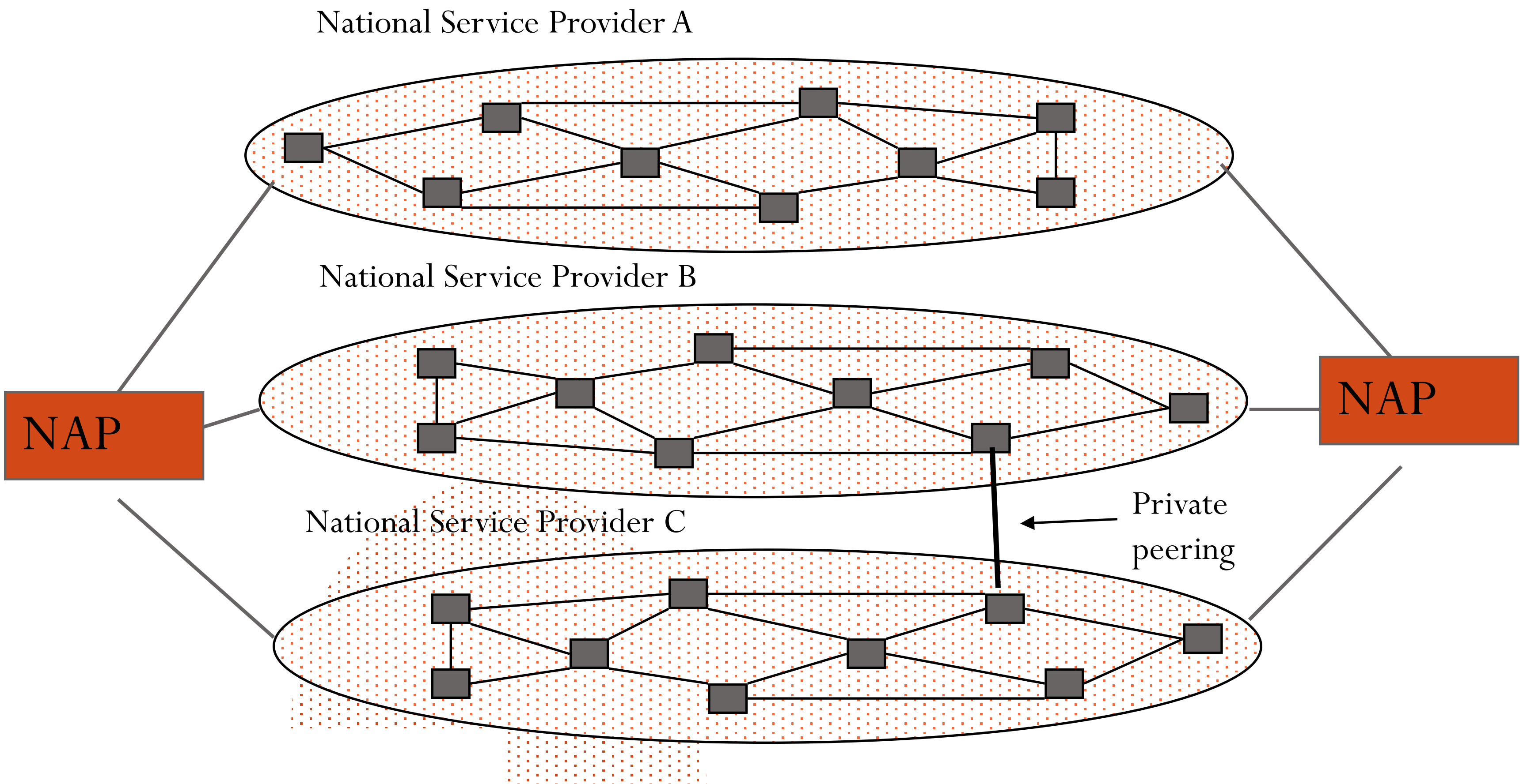
Campus Network



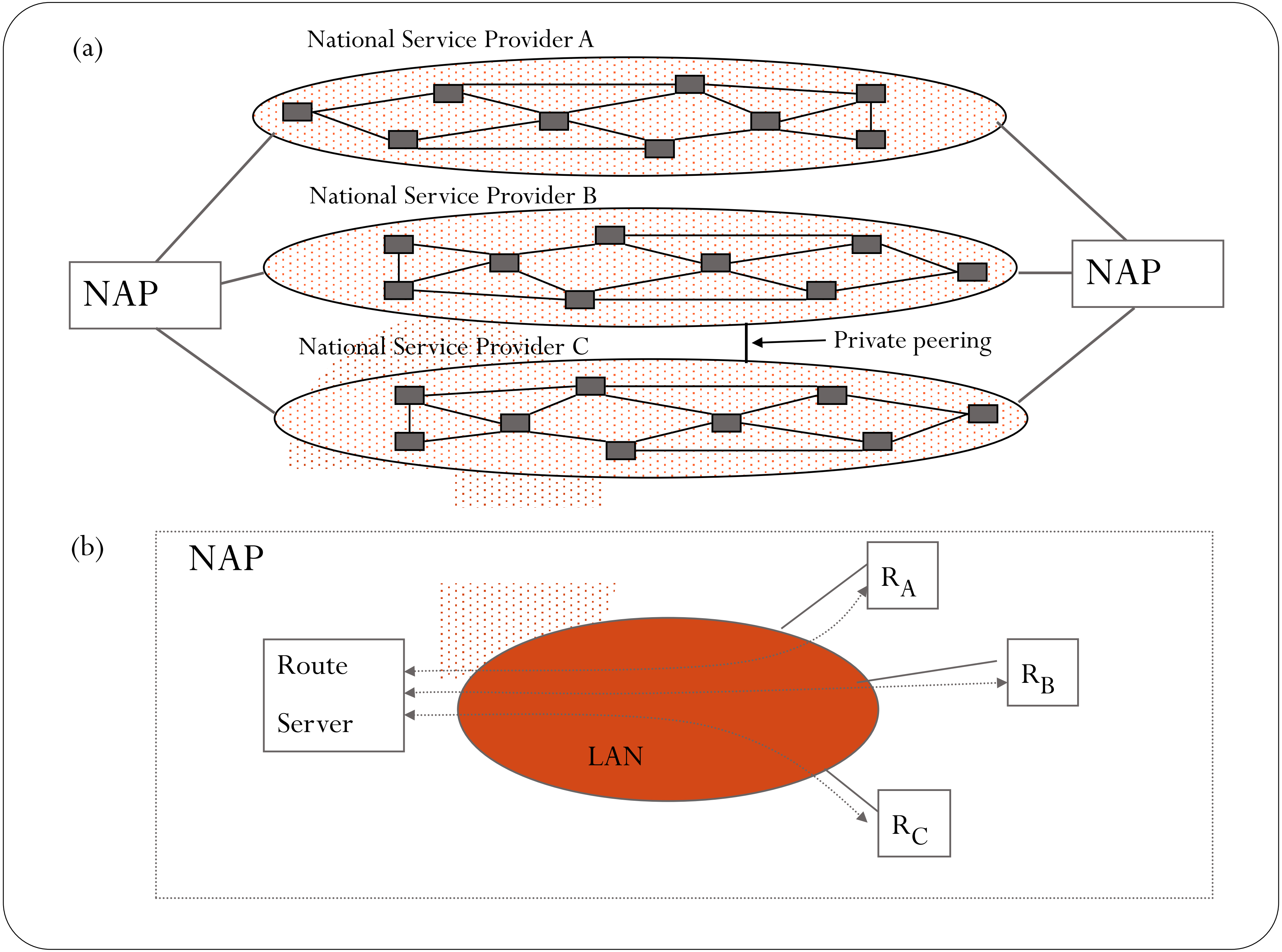
Connecting to Internet Service Provider



Internet Backbone



- Network Access Points: set up during original commercialization of Internet to facilitate exchange of traffic
- Private Peering Points: two-party inter-ISP agreements to exchange traffic


(a)
National Service Provider A
National Service Provider B
National Service Provider C
NAP
NAP
Private peering
(b)
NAP
Route
Server
LAN
R_A
R_B
R_C

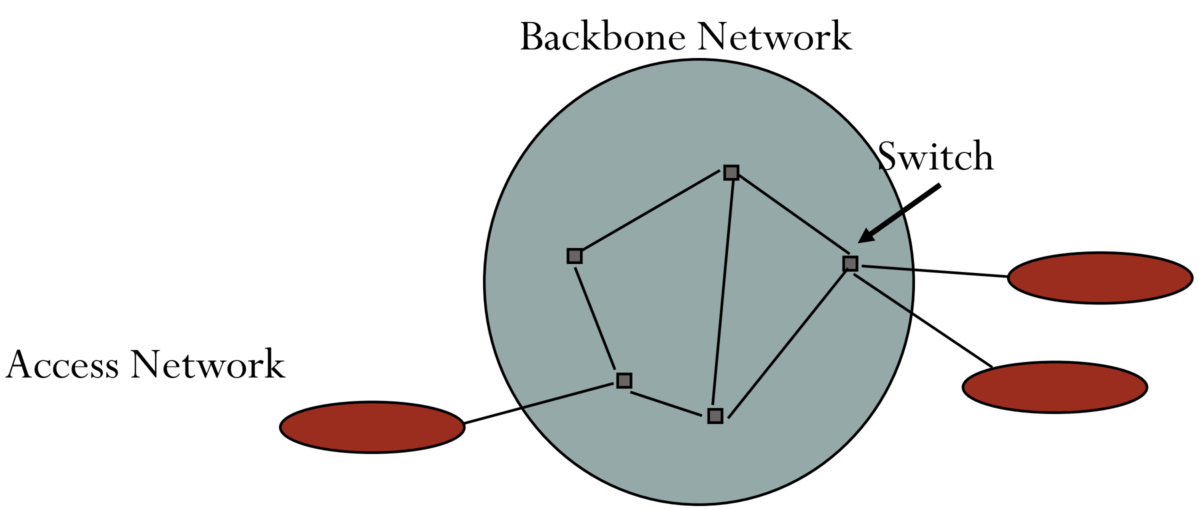
Key Role of Routing

How to get packet from here to there?

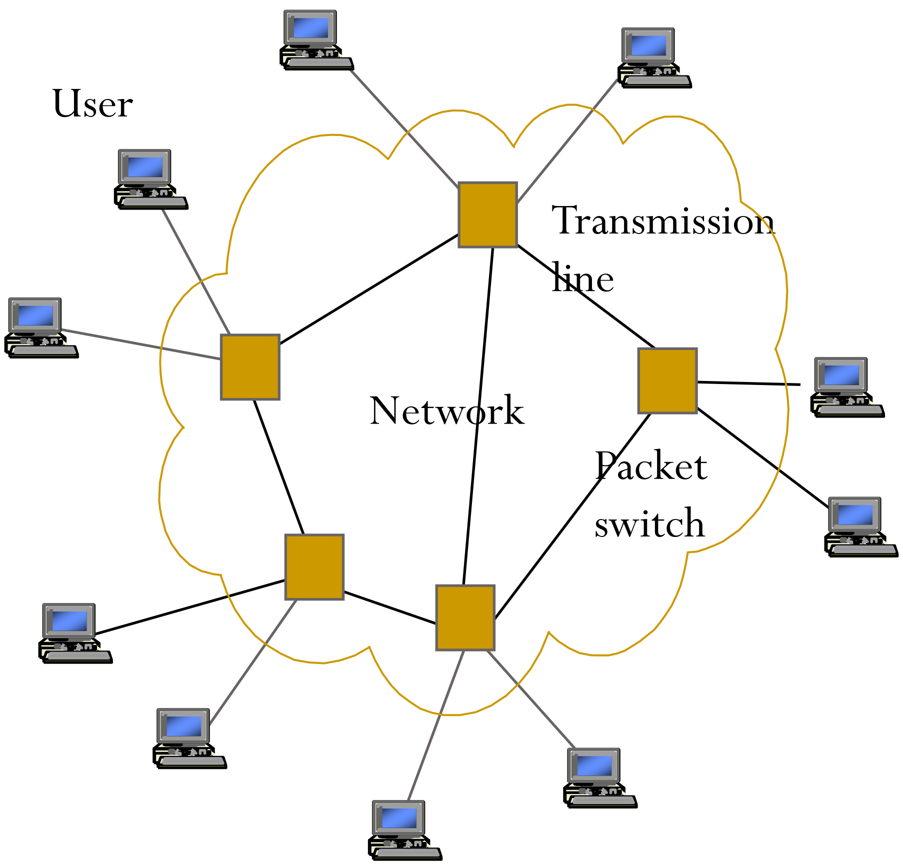
- Decentralized nature of Internet makes routing a major challenge
  - Interior gateway protocols (IGPs) are used to determine routes within a domain
  - Exterior gateway protocols (EGPs) are used to determine routes across domains
  - Routes must be consistent & produce stable flows
- Scalability required to accommodate growth
  - Hierarchical structure of IP addresses essential to keeping size of routing tables manageable

The Switching Function

- Dynamic interconnection of inputs to outputs
- Enables dynamic sharing of transmission resource
- Two fundamental approaches:
  - Connectionless
  - Connection-Oriented: Call setup control, Connection control



Packet Switching Network



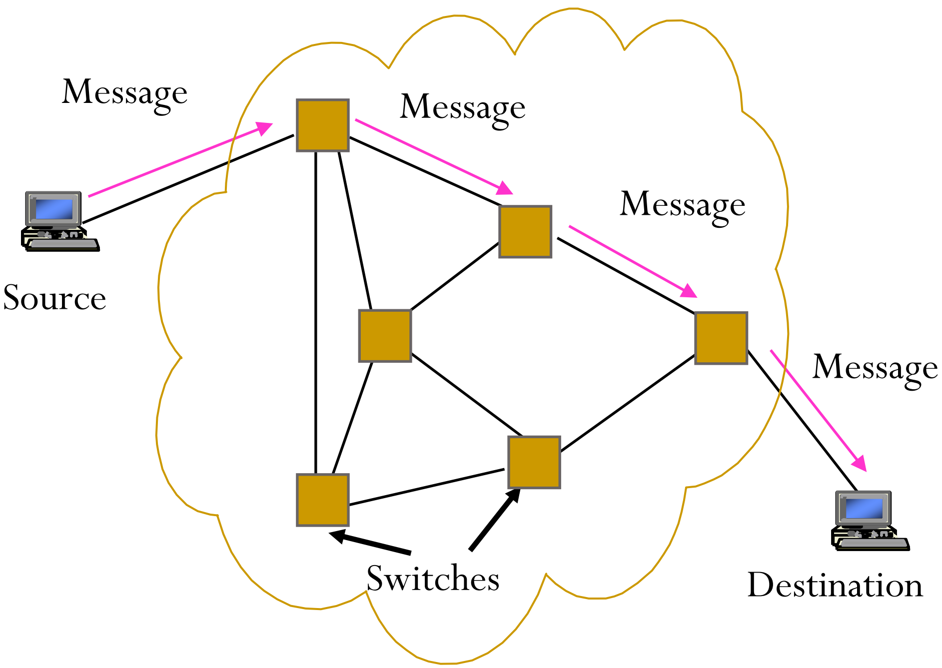
Packet switching network

- Transfers packets between users
- Transmission lines + packet switches (routers)
- Origin in message switching

Two modes of operation:

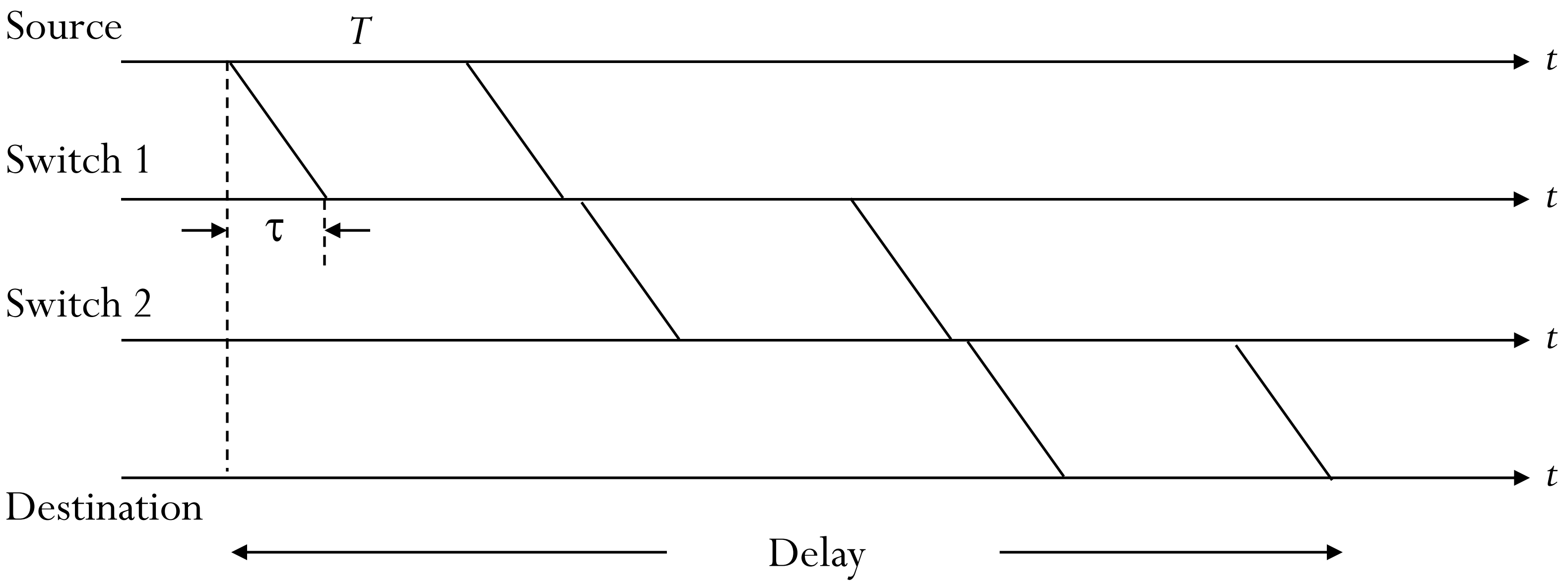
- Connectionless
- Virtual Circuit

Message Switching



- Message switching invented for telegraphy
- Entire messages multiplexed onto shared lines, stored & forwarded
- Headers for source & destination addresses
- Routing at message switches
- Connectionless

Message Switching Delay

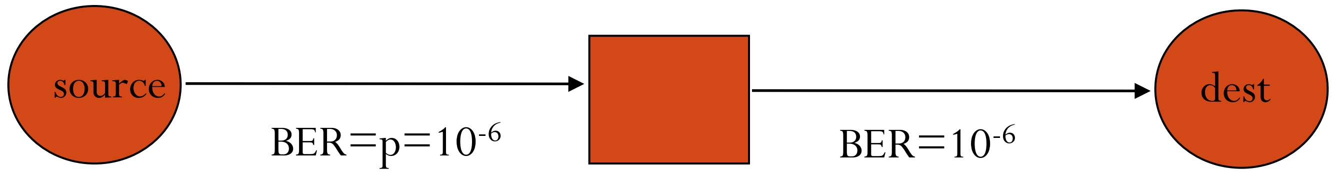


Minimum delay = $3\tau + 3T$

Additional queueing delays possible at each link

Long Messages vs. Packets

1 Mbit message



How many bits need to be transmitted to deliver message?

- Approach 1: send 1 Mbit message
- Probability message arrives correctly

$$P_c = (1-10^{-6})^{10^6} \approx e^{-10^6 10^{-6}} = e^{-1} \approx 1/3$$

- On average it takes about 3 transmissions/hop
- Total # bits transmitted ≈ 6 Mbits

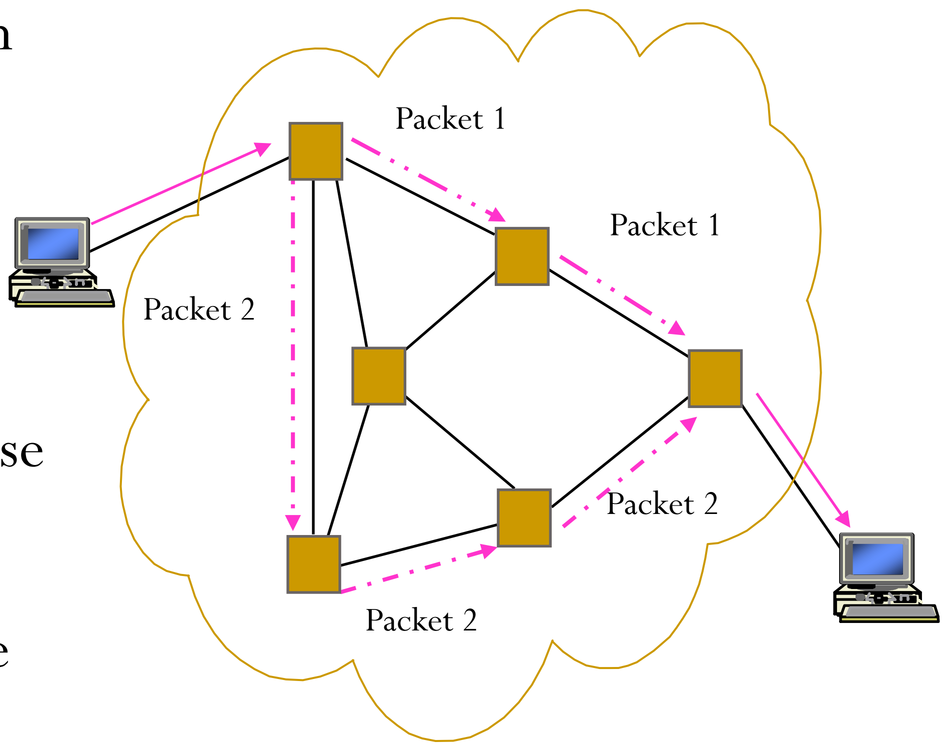
- Approach 2: send 10 100-kbit packets
- Probability packet arrives correctly

$$P_c' = (1-10^{-6})^{10^5} \approx e^{-10^5 10^{-6}} = e^{-0.1} \approx 0.9$$

- On average it takes about 1.1 transmissions/hop
- Total # bits transmitted ≈ 2.2 Mbits

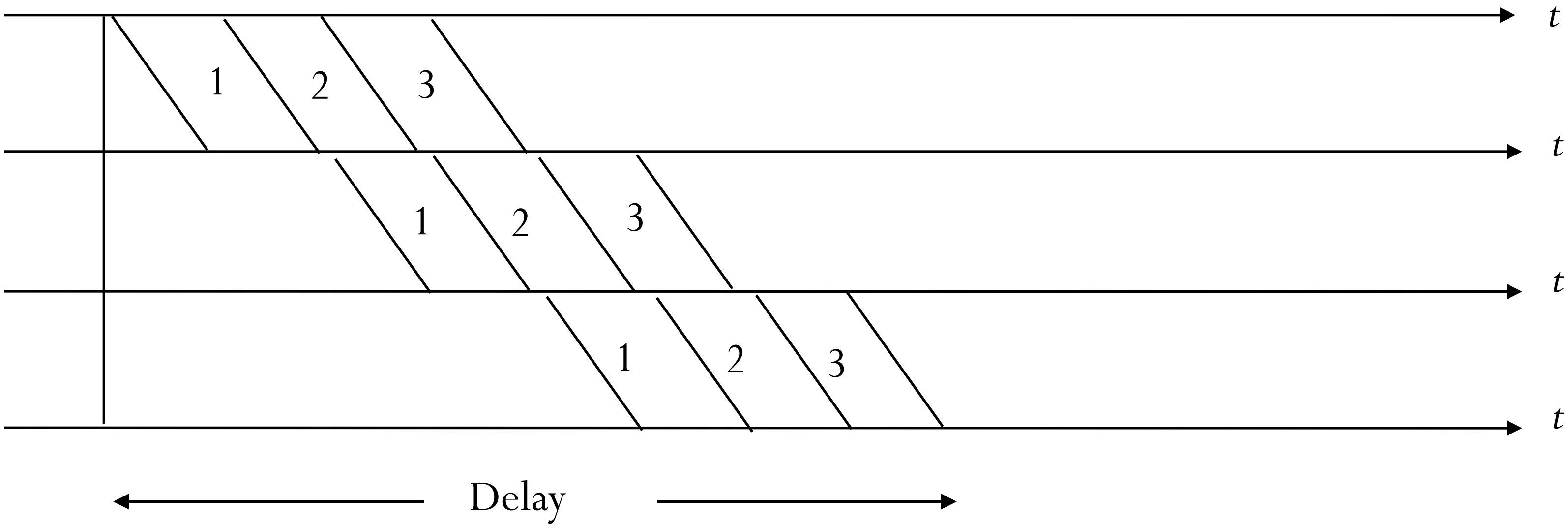
Packet Switching - Datagram

- Messages broken into smaller units (packets)
- Source & destination addresses in packet header
- Connectionless, packets routed independently (datagram)
- Packet may arrive out of order
- Pipelining of packets across network can reduce delay, increase throughput
- Lower delay that message switching, suitable for interactive traffic



Packet Switching Delay

Assume three packets corresponding to one message traverse same path

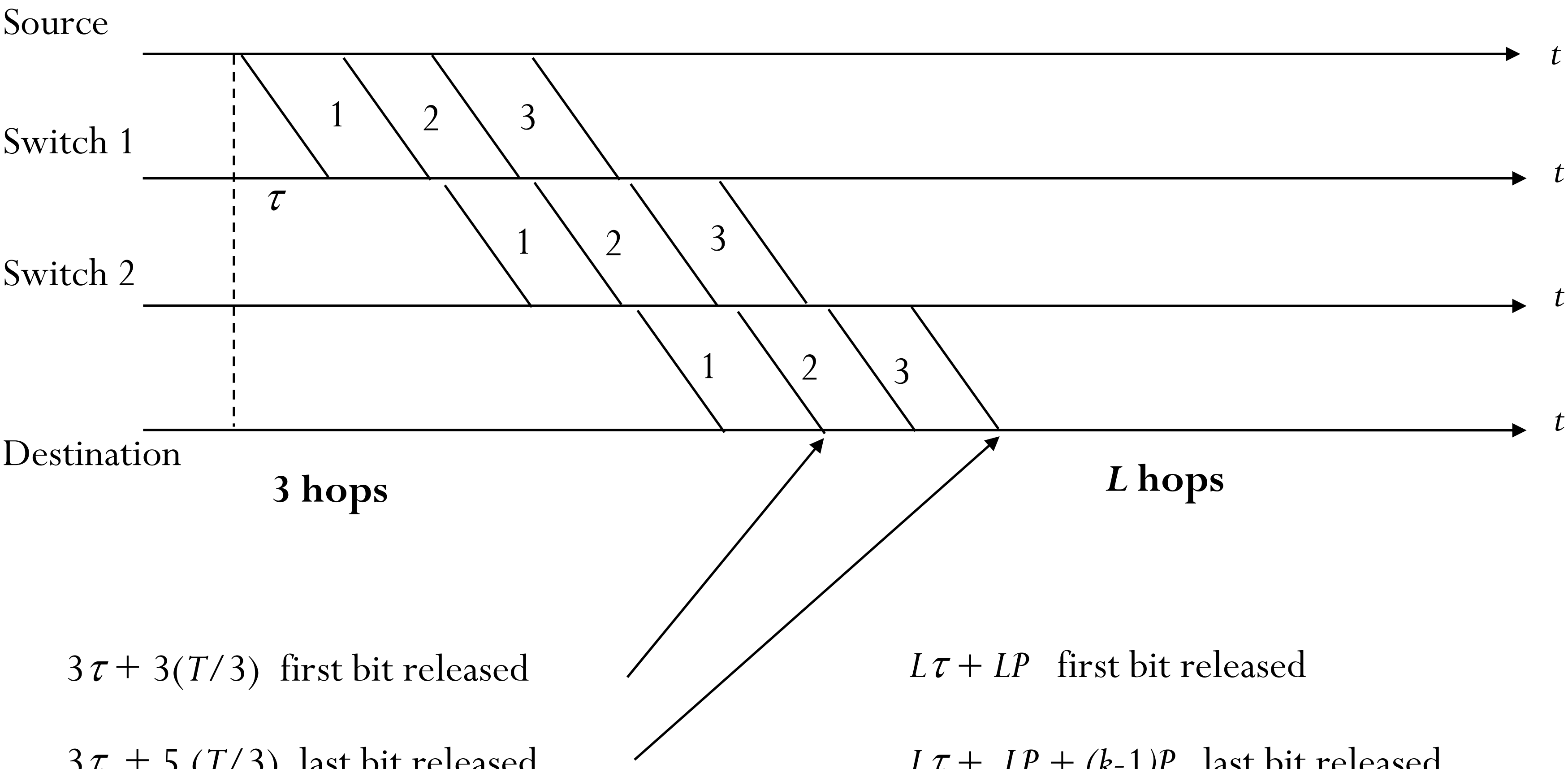


Minimum Delay $= 3\tau + 5(T/3)$ (single path assumed)

Additional queueing delays possible at each link

Packet pipelining enables message to arrive sooner

Delay for k-Packet Message over L Hops



$3\tau + 3(T/3)$ first bit released

$3\tau + 5(T/3)$ last bit released

$L\tau + LP$ first bit released

$L\tau + LP + (k-1)P$ last bit released

where $T = kP$

Routing Tables in Datagram Networks

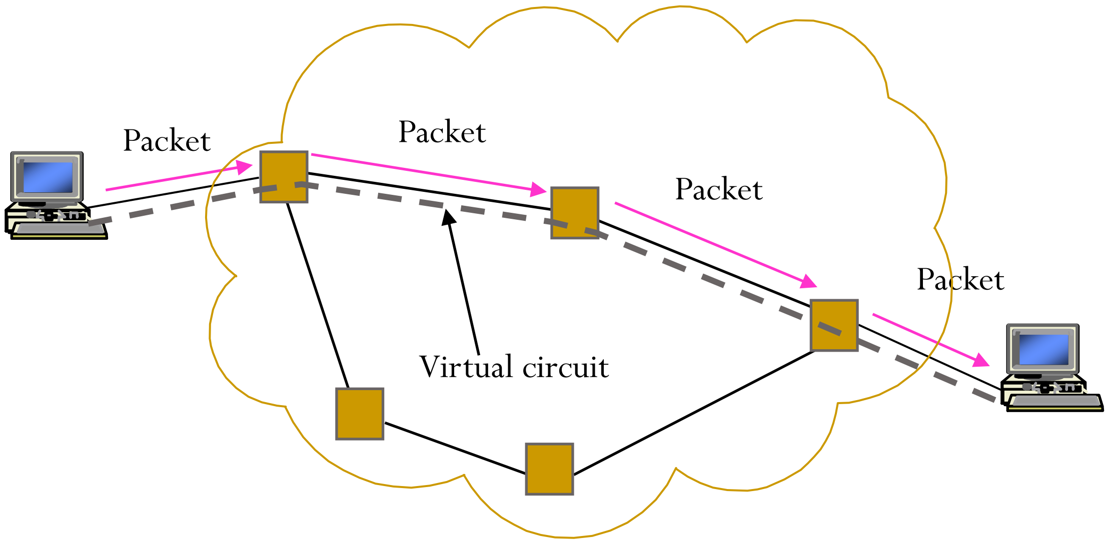
Destination address	Output port
0785	7
1345	12
1566	6
2458	12

- Route determined by table lookup
- Routing decision involves finding next hop in route to given destination
- Routing table has an entry for each destination specifying output port that leads to next hop
- Size of table becomes impractical for very large number of destinations

Example: Internet Routing

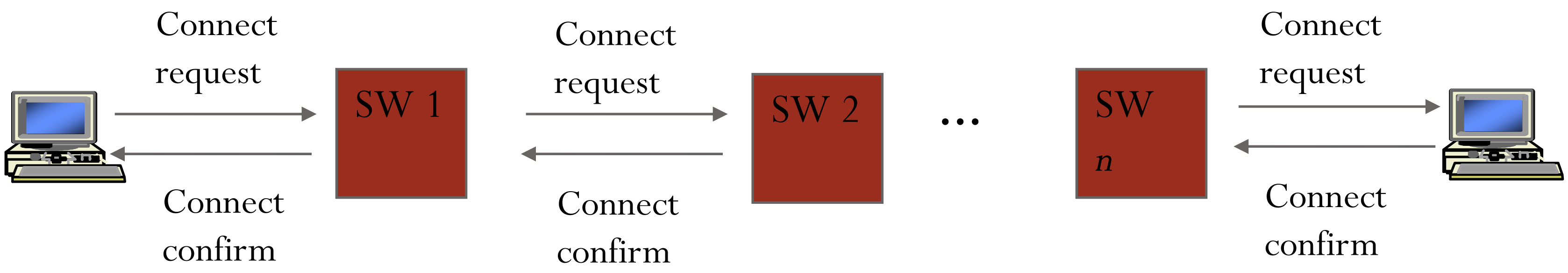
- Internet protocol uses datagram packet switching *across networks*
  - Networks are treated as data links
- Hosts have two-port IP address:
  - Network address + Host address
- Routers do table lookup on network address
  - This reduces size of routing table
- In addition, network addresses are assigned so that they can also be aggregated

Packet Switching – Virtual Circuit



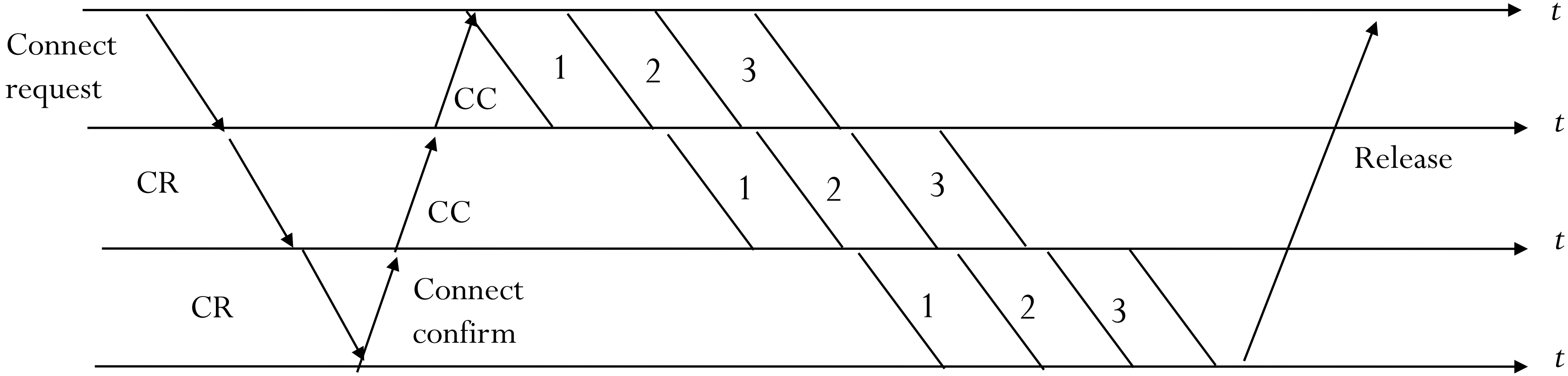
- Call set-up phase sets ups pointers in fixed path along network
- All packets for a connection follow the same path
- Abbreviated header identifies connection on each link
- Packets queue for transmission
- Variable bit rates possible, negotiated during call set-up
- Delays variable, cannot be less than circuit switching

Connection Setup



- Signaling messages propagate as route is selected
- Signaling messages identify connection and setup tables in switches
- Typically a connection is identified by a local tag, Virtual Circuit Identifier (VCI)
- Each switch only needs to know how to relate an incoming tag in one input to an outgoing tag in the corresponding output
- Once tables are setup, packets can flow along path

Connection Setup Delay



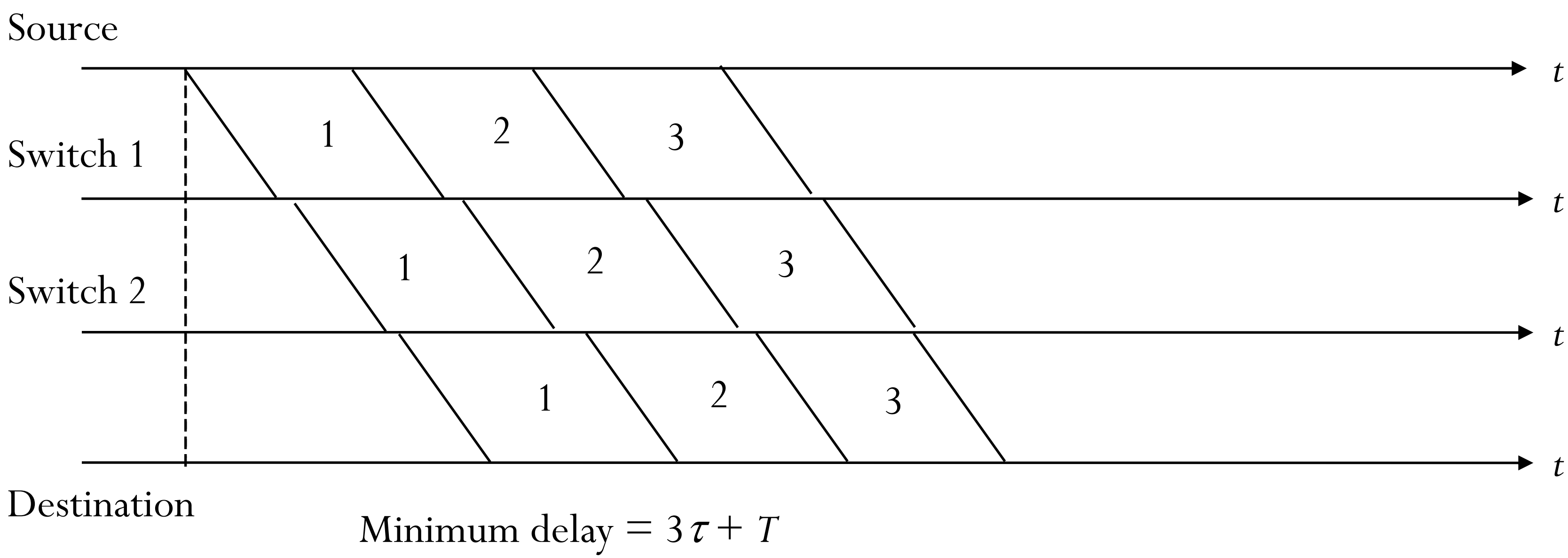
- Connection setup delay is incurred before any packet can be transferred
- Delay is acceptable for sustained transfer of large number of packets
- This delay may be unacceptably high if only a few packets are being transferred

Virtual Circuit Forwarding Tables

Input VCI	Output port	Output VCI
12	13	44
15	15	23
27	13	16
58	7	34

- Each input port of packet switch has a forwarding table
- Lookup entry for VCI of incoming packet
- Determine output port (next hop) and insert VCI for next link
- Very high speeds are possible
- Table can also include priority or other information about how packet should be treated

Cut-Through switching



- Some networks perform error checking on header only, so packet can be forwarded as soon as header is received & processed
- Delays reduced further with cut-through switching

Example: ATM Networks

- All information mapped into short fixed-length packets called *cells*
- Connections set up across network
  - Virtual circuits established across networks
  - Tables setup at ATM switches
- Several types of network services offered
  - Constant bit rate connections
  - Variable bit rate connections

Message vs. Packet Minimum Delay

- Message:

$$L\,\tau + L\,T \qquad = L\,\tau + (L-1)\,T + T$$

- Packet

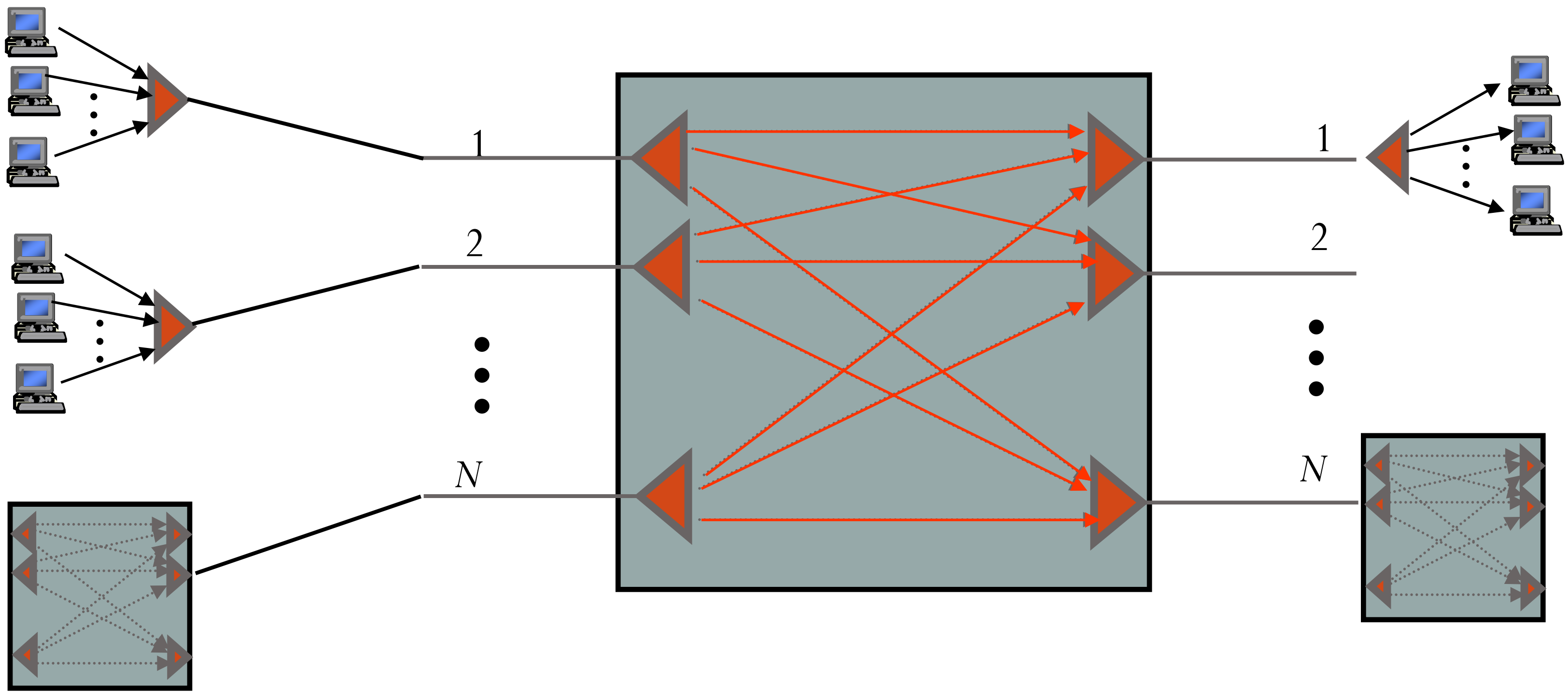
$$L\,\tau + L\,P + (k-1)\,P \qquad = L\,\tau + (L-1)\,P + T$$

- Cut-Through Packet (Immediate forwarding after header)

$$= L\,\tau + T$$

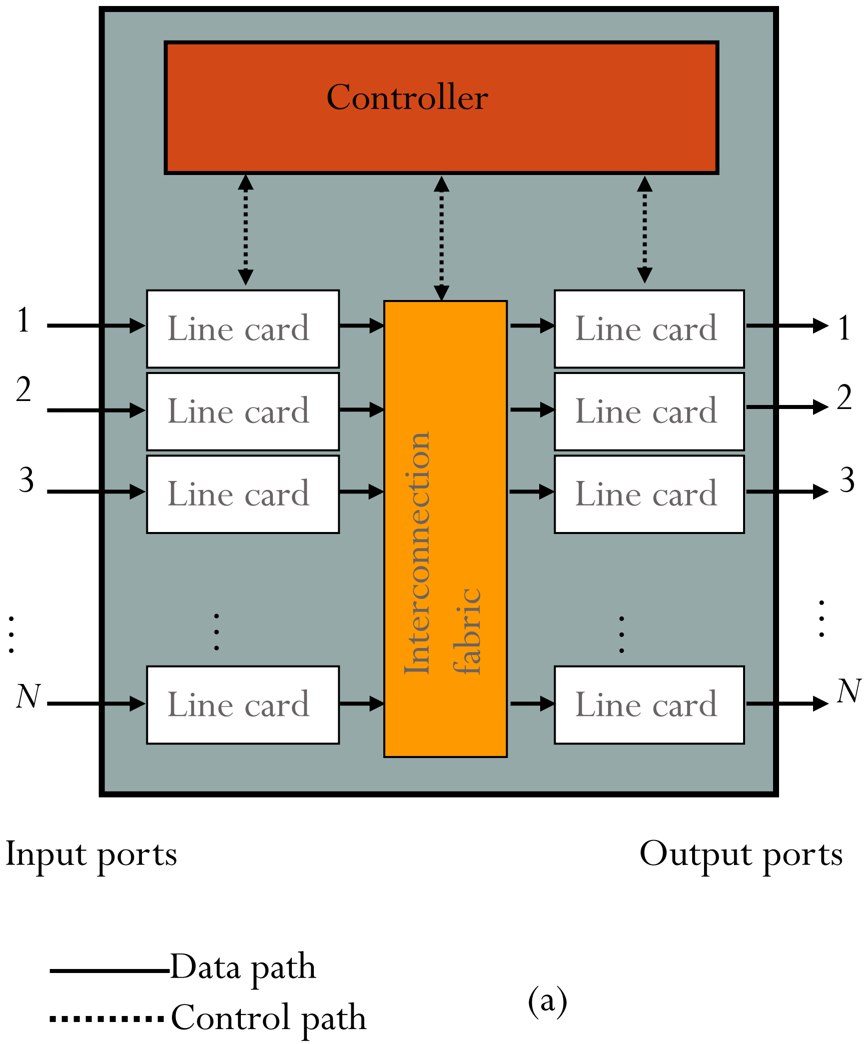
Above neglect header processing delays

Packet Switch: Intersection where Traffic Flows Meet



- Inputs contain multiplexed flows from access muxs & other packet switches
- Flows demultiplexed at input, routed and/or forwarded to output ports
- Packets buffered, prioritized, and multiplexed on output lines

Generic Packet Switch

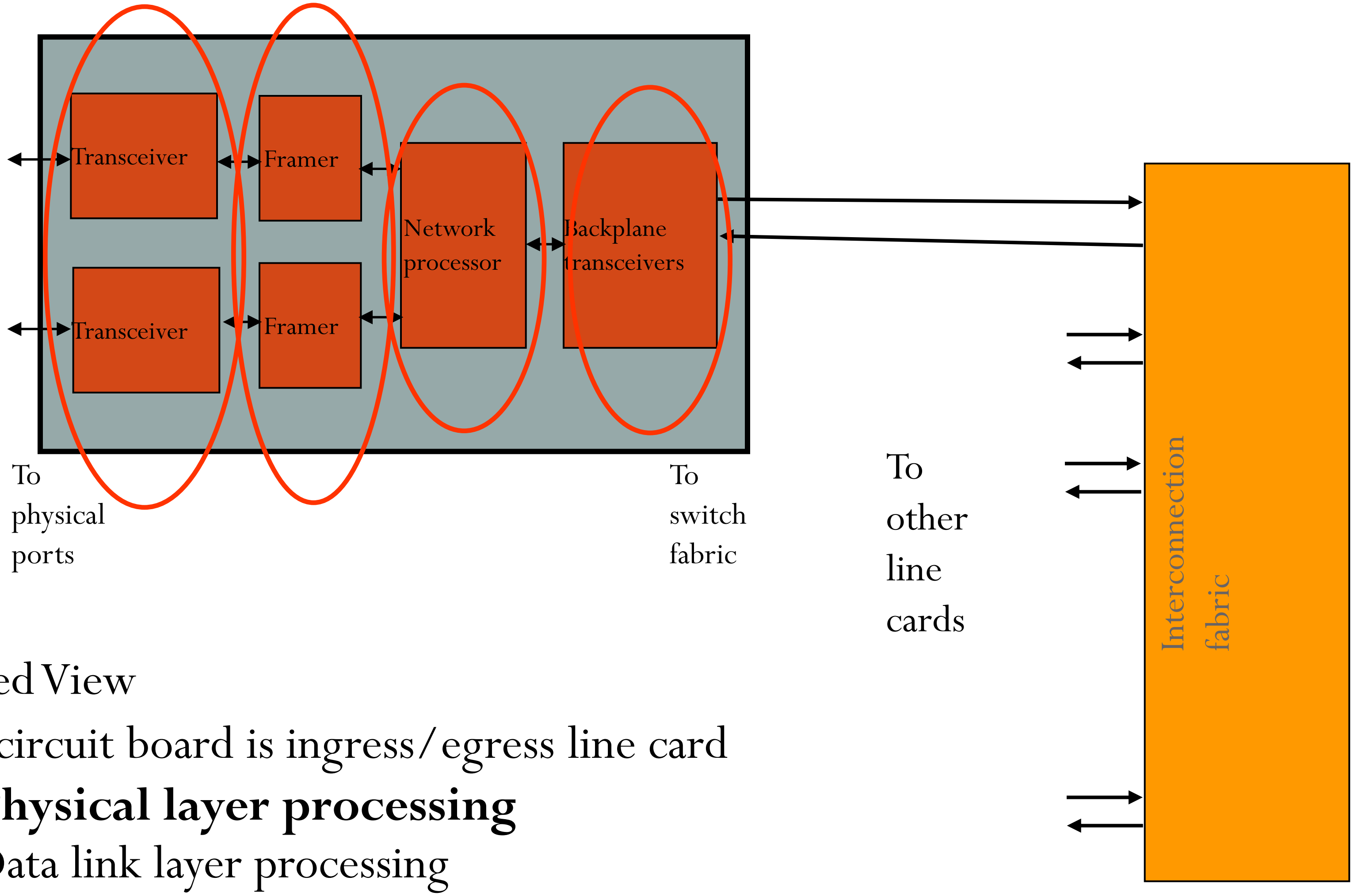


(a)

"Unfolded" View of Switch

- Ingress Line Cards
  - Header processing
  - Demultiplexing
  - Routing in large switches
- Controller
  - Routing in small switches
  - Signalling & resource allocation
- Interconnection Fabric
  - Transfer packets between line cards
- Egress Line Cards
  - Scheduling & priority
  - Multiplexing

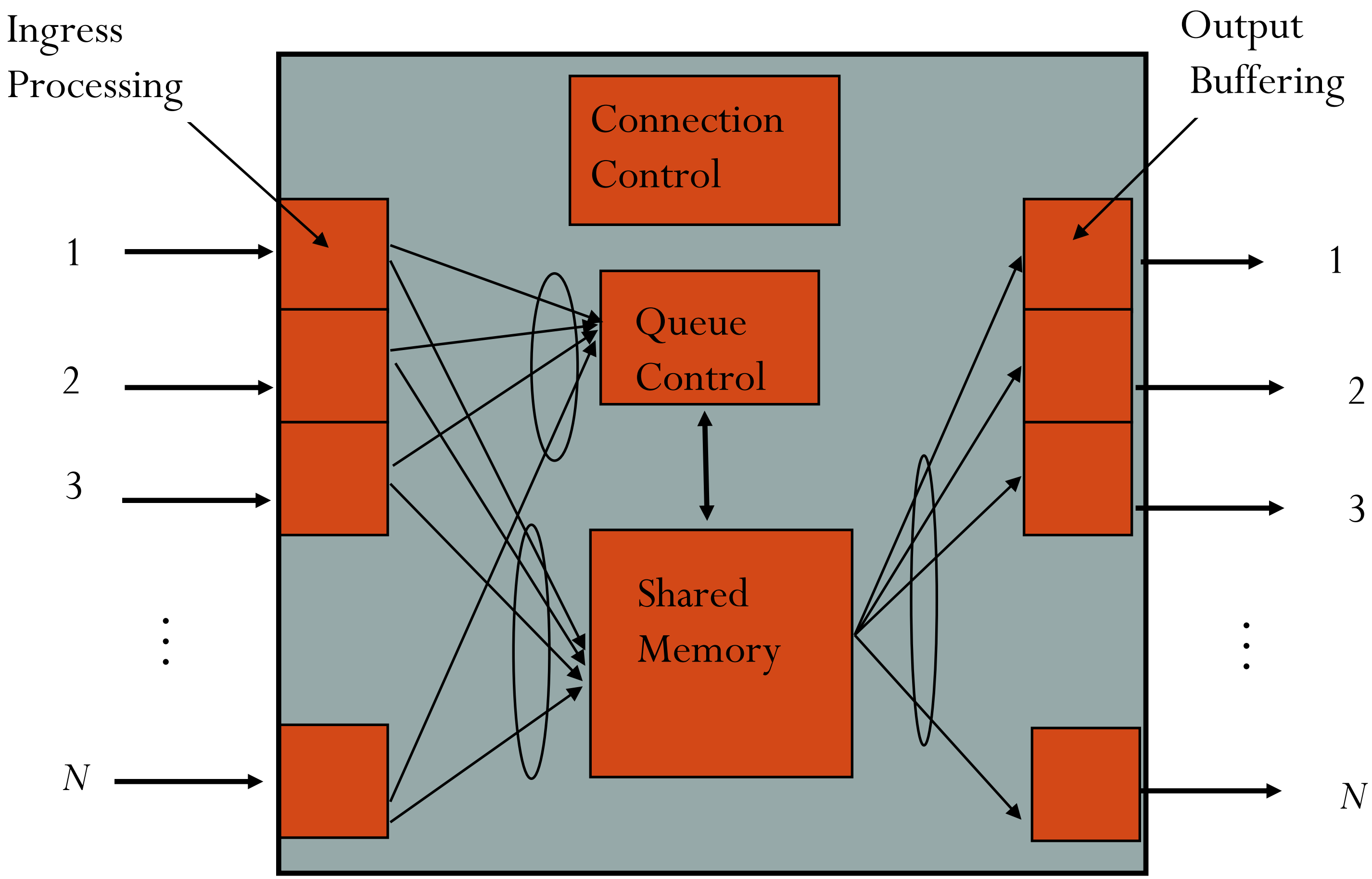
Line Cards



Folded View

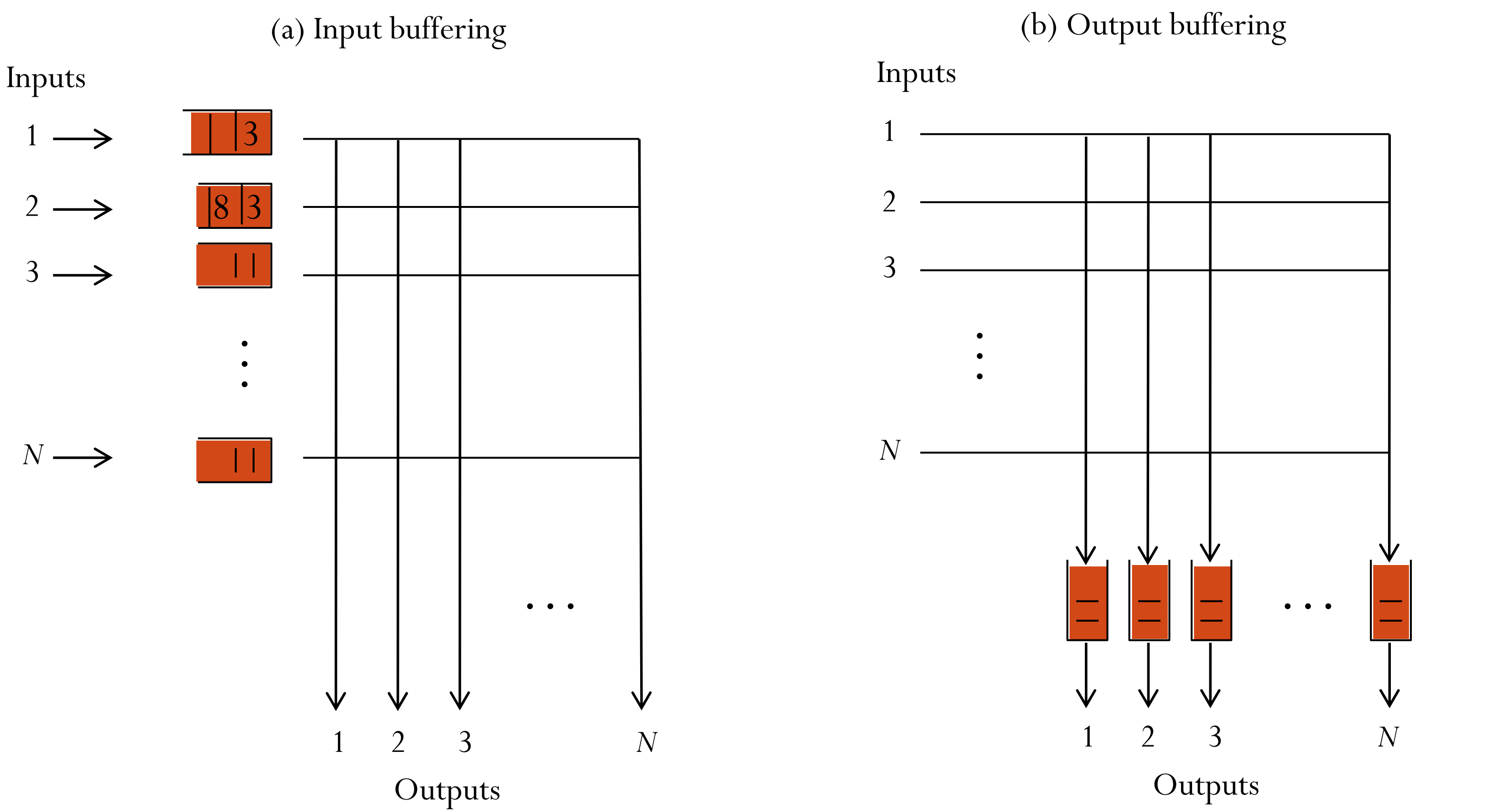
- 1 circuit board is ingress/egress line card
- **Physical layer processing**
- Data link layer processing
- Network header processing
- Physical layer across fabric + framing

Shared Memory Packet Switch



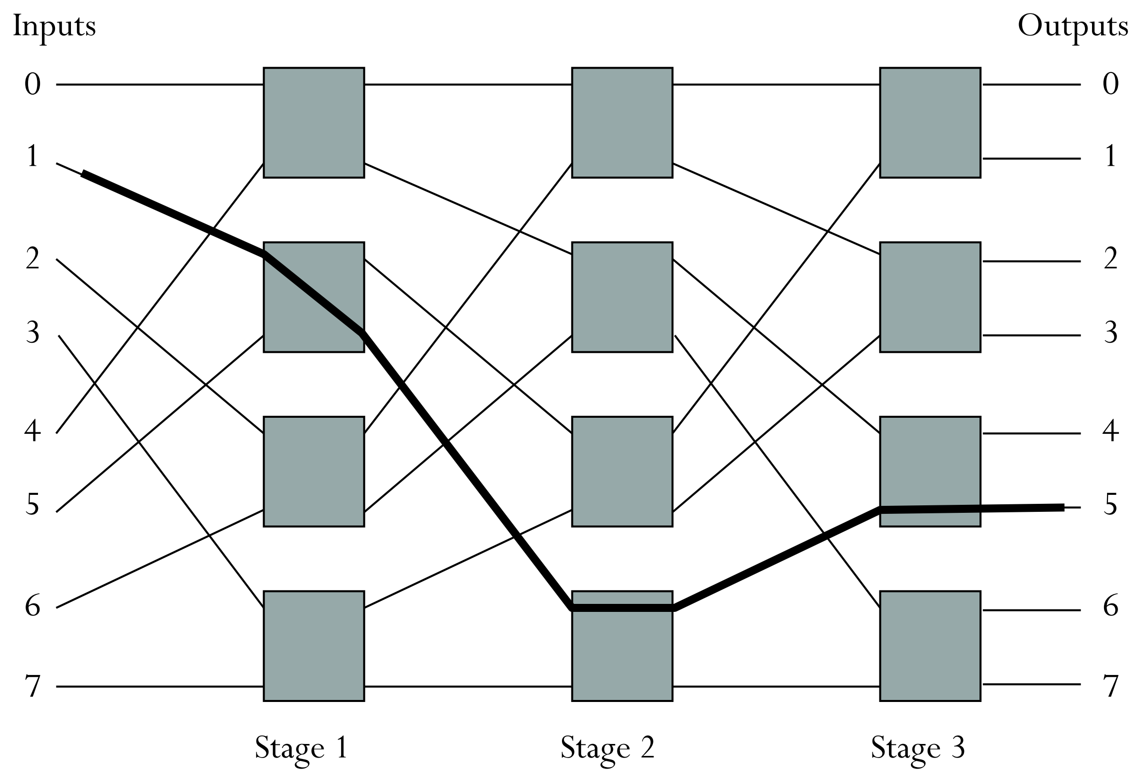
Small switches can be built by reading/writing into shared memory

Crossbar Switches



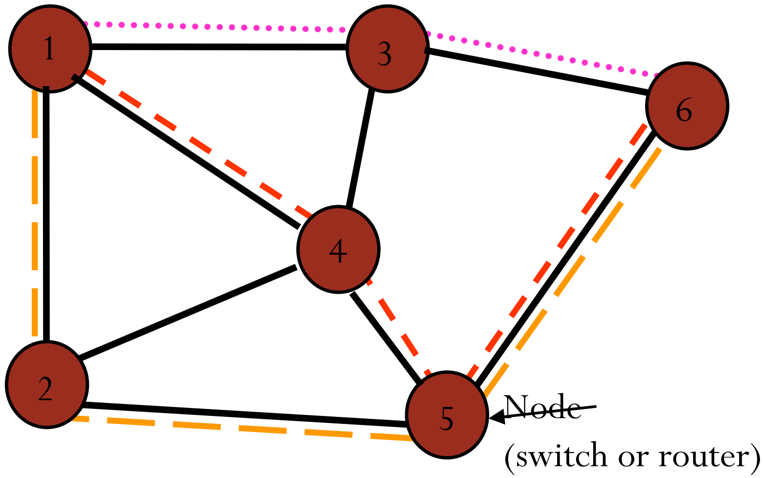
- Large switches built from crossbar & multistage space switches
- Requires centralized controller/scheduler (who sends to whom when)
- Can buffer at input, output, or both (performance vs complexity)

Self-Routing Switches



- Self-routing switches do not require controller
- Output port number determines route
- 101 → (1) lower port, (2) upper port, (3) lower port

Routing in Packet Networks

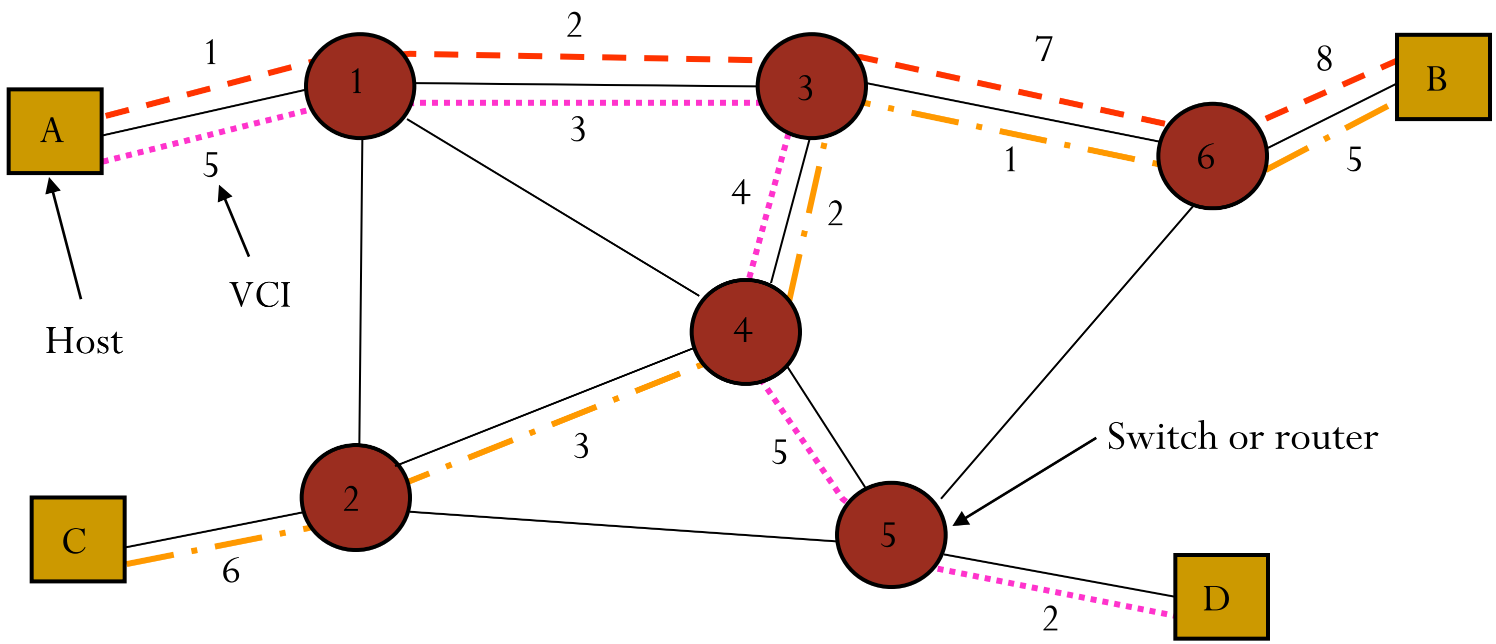


- Three possible (loopfree) routes from 1 to 6:
  - 1-3-6, 1-4-5-6, 1-2-5-6
- Which is "best"?
  - Min delay? Min hop? Max bandwidth? Min cost? Max reliability?

Creating the Routing Tables

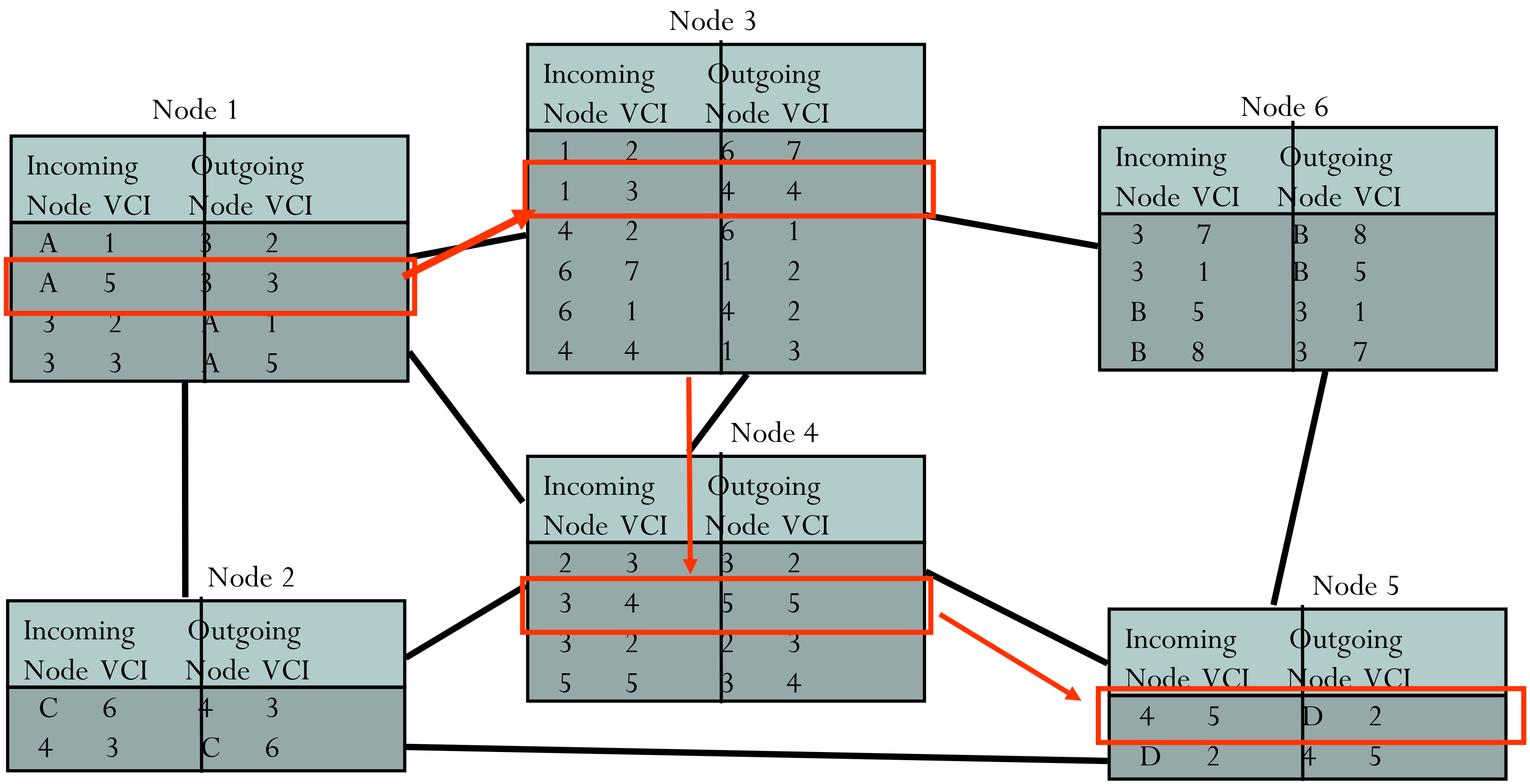
- Need information on state of links
  - Link up/down; congested; delay or other metrics
- Need to distribute link state information using a routing protocol
  - What information is exchanged? How often?
  - Exchange with neighbors; Broadcast or flood
- Need to compute routes based on information
  - Single metric; multiple metrics
  - Single route; alternate routes

Routing in Virtual-Circuit Packet Networks



- Route determined during connection setup
- Tables in switches implement forwarding that realizes selected route

Routing Tables in VC Packet Networks



- Example: VCI from A to D
  - From A & VCI 5 → 3 & VCI 3 → 4 & VCI 4
  - → 5 & VCI 5 → D & VCI 2

Routing Tables in Datagram Packet Networks

Node 1

Destination	Next node
2	2
3	3
4	4
5	2
6	3

Node 2

Destination	Next node
1	1
3	1
4	4
5	5
6	5

Node 3

Destination	Next node
1	1
2	4
4	4
5	6
6	6

Node 4

Destination	Next node
1	1
2	2
3	3
5	5
6	3

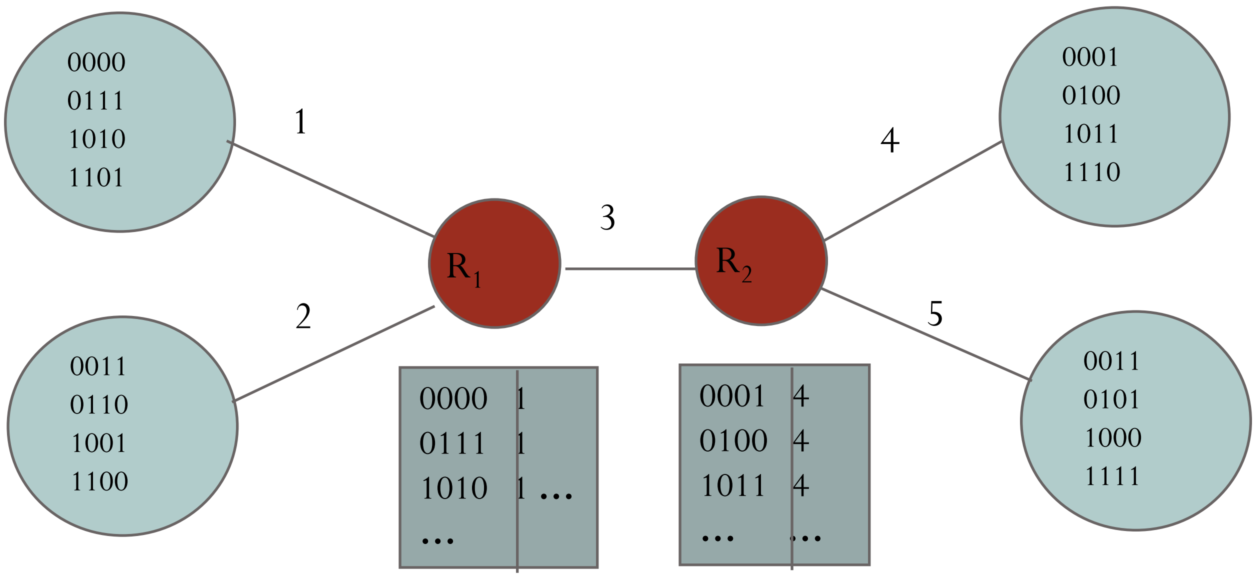
Node 5

Destination	Next node
1	4
2	2
3	4
4	4
6	6

Node 6

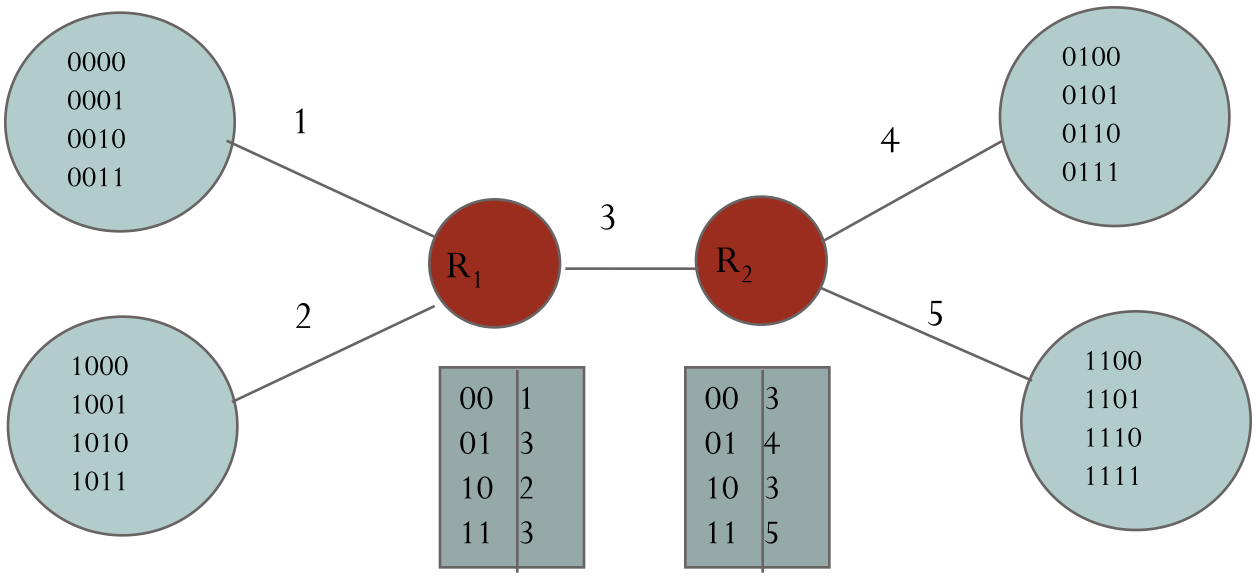
Destination	Next node
1	3
2	5
3	3
4	3
5	5

Non-Hierarchical Addresses and Routing



- No relationship between addresses & routing proximity
- Routing tables require 16 entries each

Hierarchical Addresses and Routing



- Prefix indicates network where host is attached
- Routing tables require 4 entries each

Specialized Routing

- Flooding
  - Useful in starting up network
  - Useful in propagating information to all nodes
- Deflection Routing
  - Fixed, preset routing procedure
  - No route synthesis

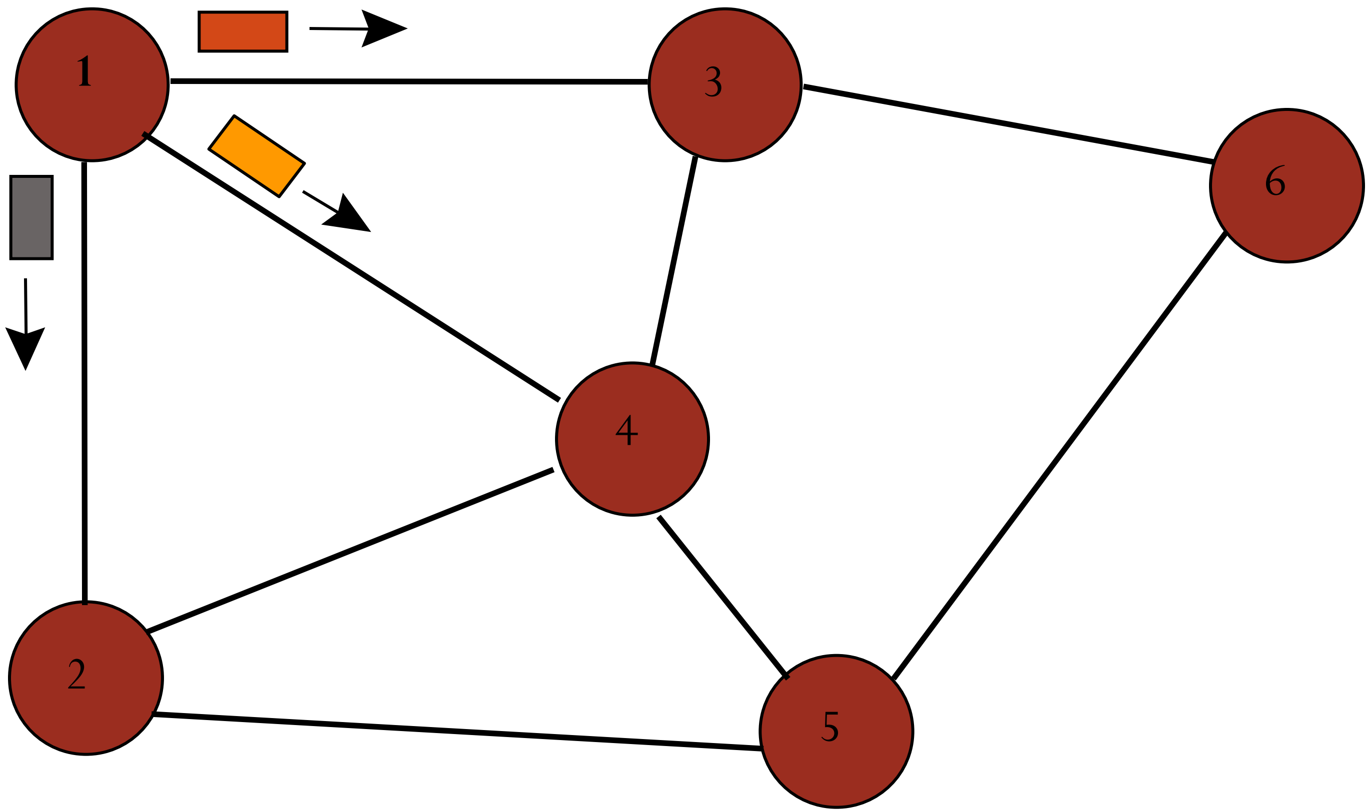
Flooding

Send a packet to all nodes in a network

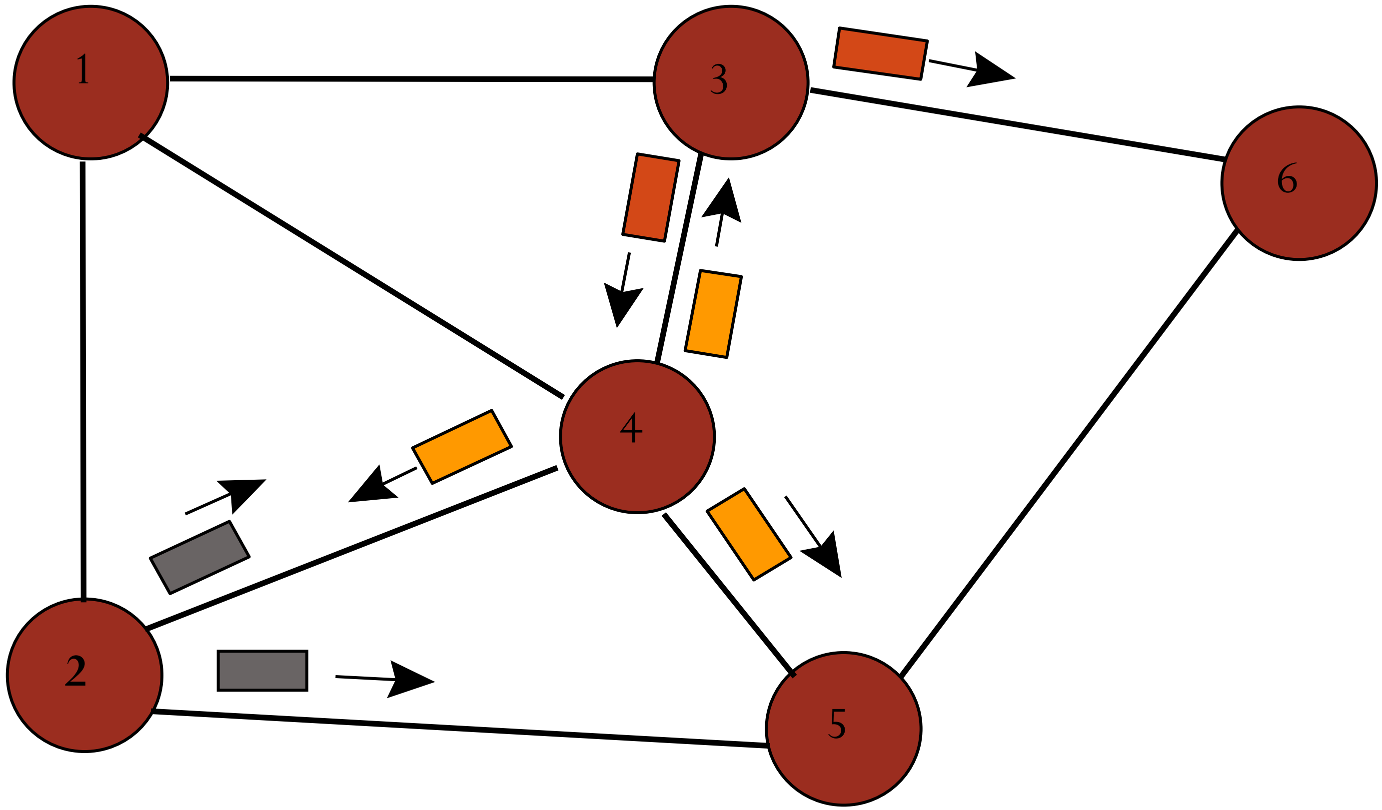
- No routing tables available
- Need to broadcast packet to all nodes (e.g. to propagate link state information)

Approach

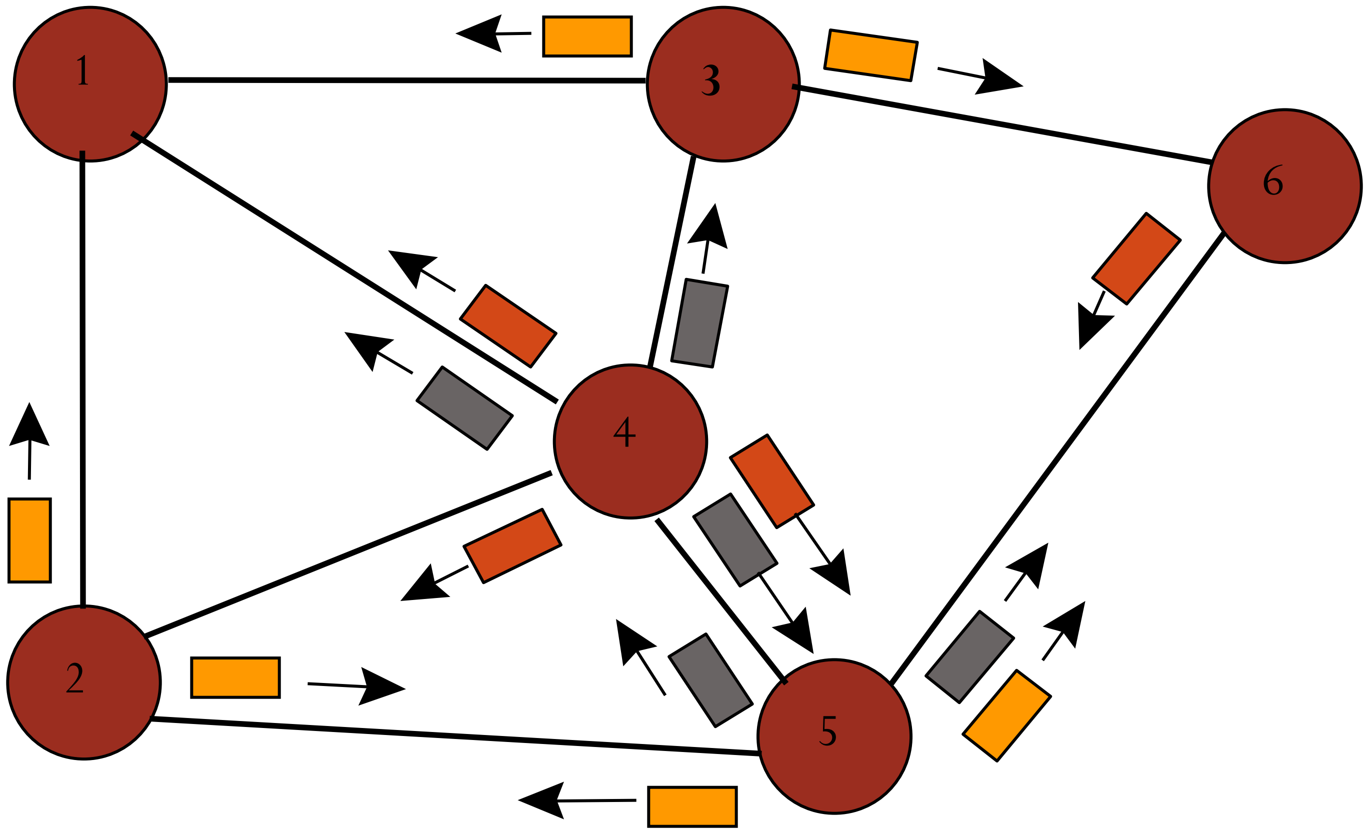
- Send packet on all ports except one where it arrived
- Exponential growth in packet transmissions



Flooding is initiated from Node 1: Hop 1 transmissions



Flooding is initiated from Node 1: Hop 2 transmissions



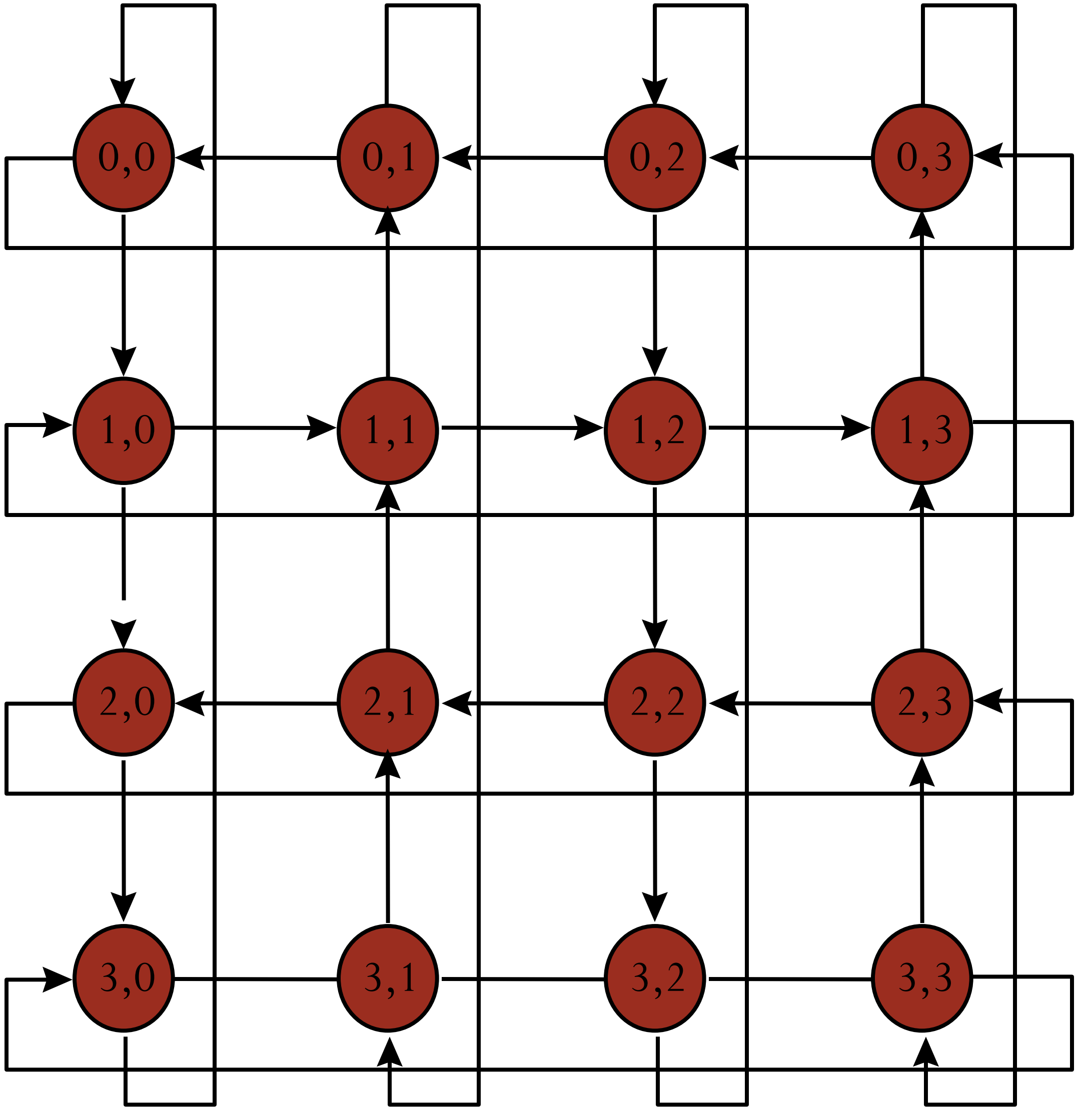
Flooding is initiated from Node 1: Hop 3 transmissions

Limited Flooding

- Time-to-Live field in each packet limits number of hops to certain diameter
- Each switch adds its ID before flooding; discards repeats
- Source puts sequence number in each packet; switches records source address and sequence number and discards repeats

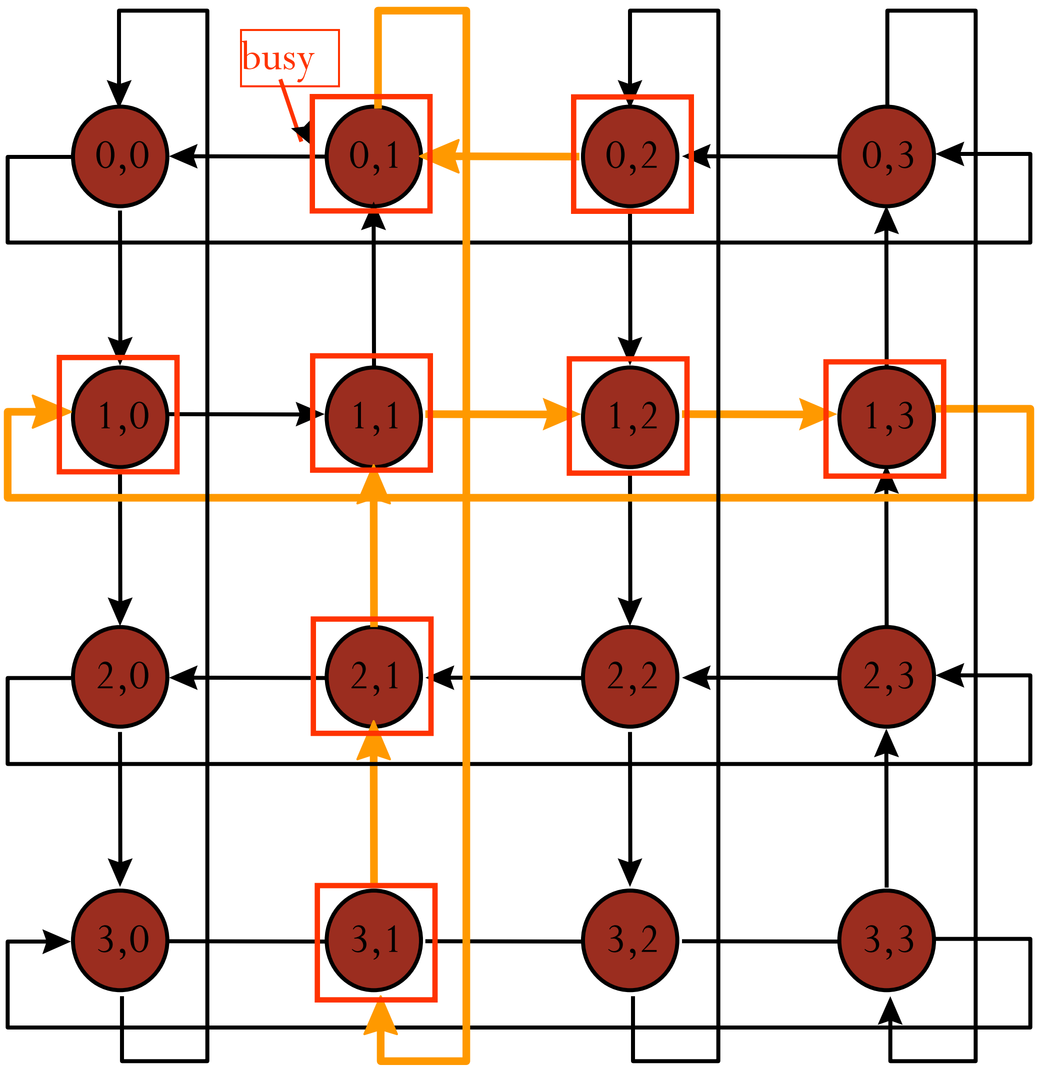
Deflection Routing

- Network nodes forward packets to preferred port
- If preferred port busy, deflect packet to another port
- Works well with regular topologies
  - Manhattan street network
  - Rectangular array of nodes
  - Nodes designated (i,j)
  - Rows alternate as one-way streets
  - Columns alternate as one-way avenues
- Bufferless operation is possible
  - Proposed for optical packet networks
  - All-optical buffering currently not viable



Tunnel from last column to first column or vice versa

Example: Node (0,2)→(1,0)



Shortest Path Routing

- Many possible paths connect any given source and to any given destination
- Routing involves the selection of the path to be used to accomplish a given transfer
- Typically it is possible to attach a cost or distance to a link connecting two nodes
- Routing can then be posed as a shortest path problem

Routing Metrics

Means for measuring desirability of a path

- Path Length = sum of costs or distances
- Possible metrics
  - Hop count: rough measure of resources used
  - Reliability: link availability; BER
  - Delay: sum of delays along path; complex & dynamic
  - Bandwidth: "available capacity" in a path
  - Load: Link & router utilization along path
  - Cost: $$$

Shortest Path Approaches

Distance Vector Protocols

- Neighbors exchange list of distances to destinations
- Best next-hop determined for each destination
- Ford-Fulkerson (distributed) shortest path algorithm

Link State Protocols

- Link state information flooded to all routers
- Routers have complete topology information
- Shortest path (& hence next hop) calculated
- Dijkstra (centralized) shortest path algorithm

Distance Vector

Do you know the way to San Jose?

San Jose 294

San Jose 392

San Jose 596

San Jose 250

Distance Vector

Local Signpost

- Direction
- Distance

Routing Table

For each destination list:

- Next Node
- Distance

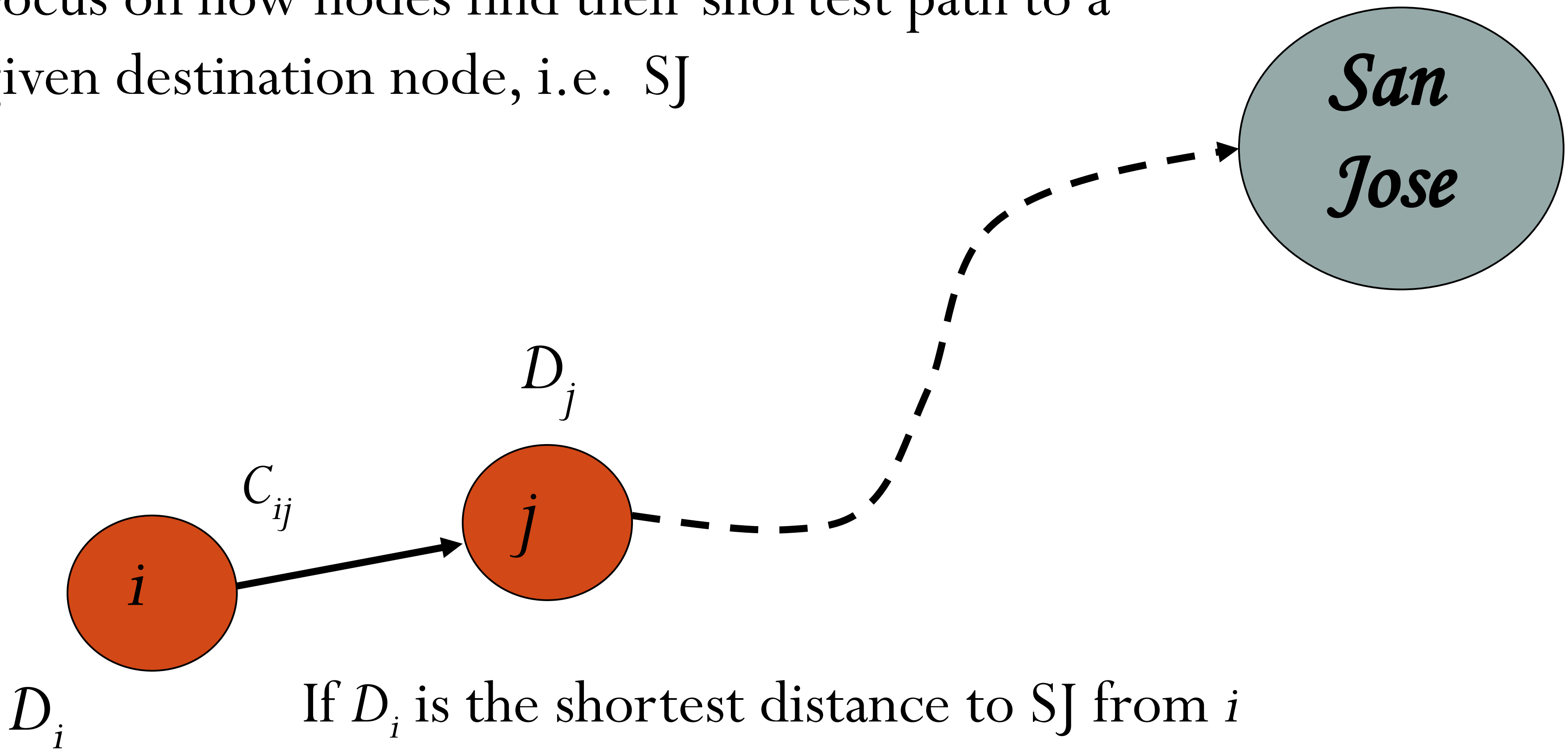
dest	next	dist

Table Synthesis

- Neighbors exchange table entries
- Determine current best next hop
- Inform neighbors
  - Periodically
  - After changes

Shortest Path to SJ

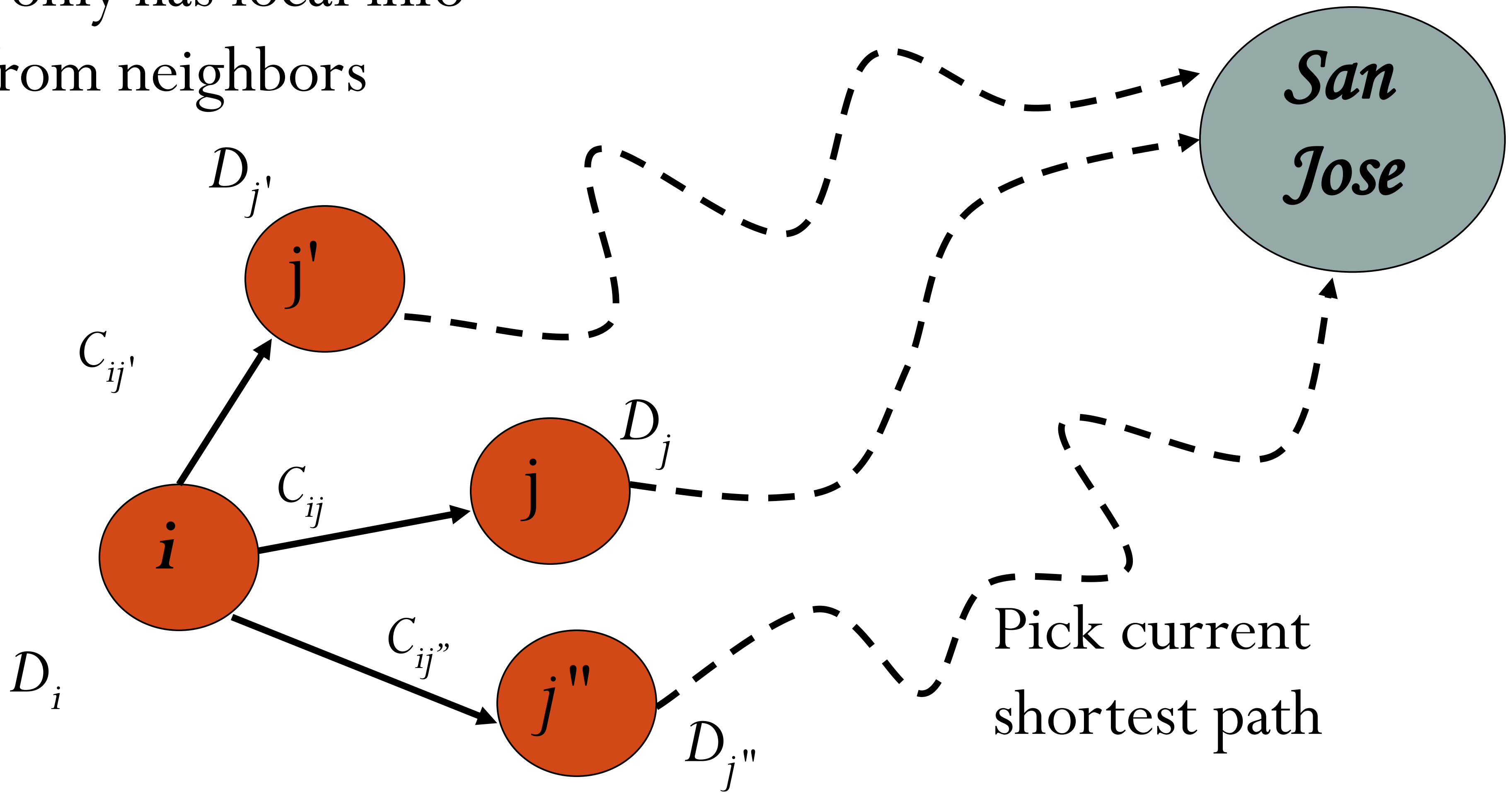
Focus on how nodes find their shortest path to a given destination node, i.e. SJ



If D_i is the shortest distance to SJ from i and if j is a neighbor on the shortest path, then $D_i = C_{ij} + D_j$

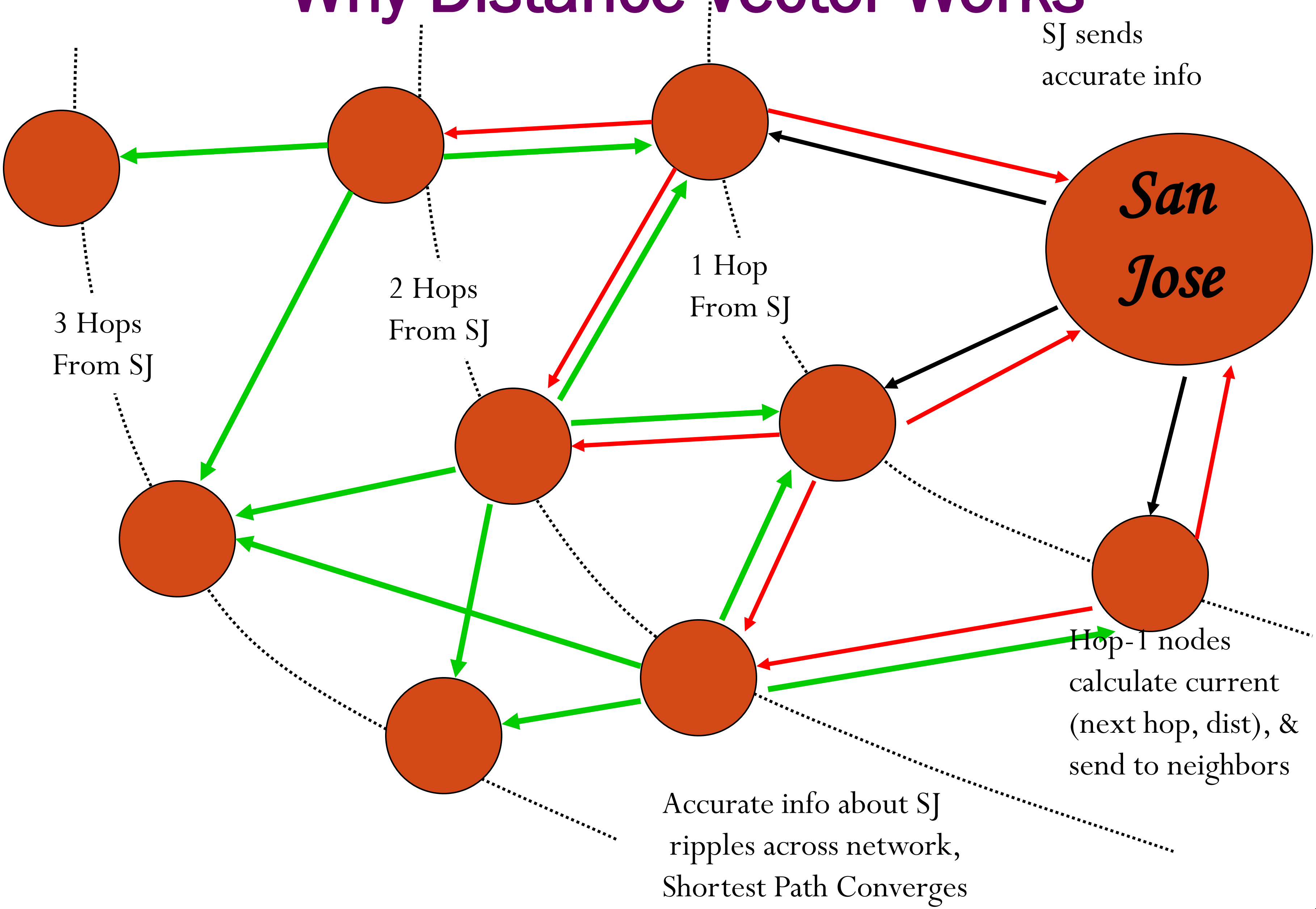
But we don't know the shortest paths

i only has local info from neighbors



Pick current shortest path

Why Distance Vector Works



Bellman-Ford Algorithm

- *Consider computations for one destination d*
- *Initialization*
  - Each node table has 1 row for destination d
  - Distance of node d to itself is zero: $D_d = 0$
  - Distance of other node j to d is infinite: $D_j = \infty$, for $j \neq d$
  - Next hop node $n_j = -1$ to indicate not yet defined for $j \neq d$
- *Send Step*
  - Send new distance vector to immediate neighbors across local link
- *Receive Step*
  - At node j, find the next hop that gives the minimum distance to d,
    - $Min_j \{ C_{ij} + D_j \}$
    - Replace old $(n_j, D_j(d))$ by new $(n_j^*, D_j^*(d))$ if new next node or distance
  - Go to send step

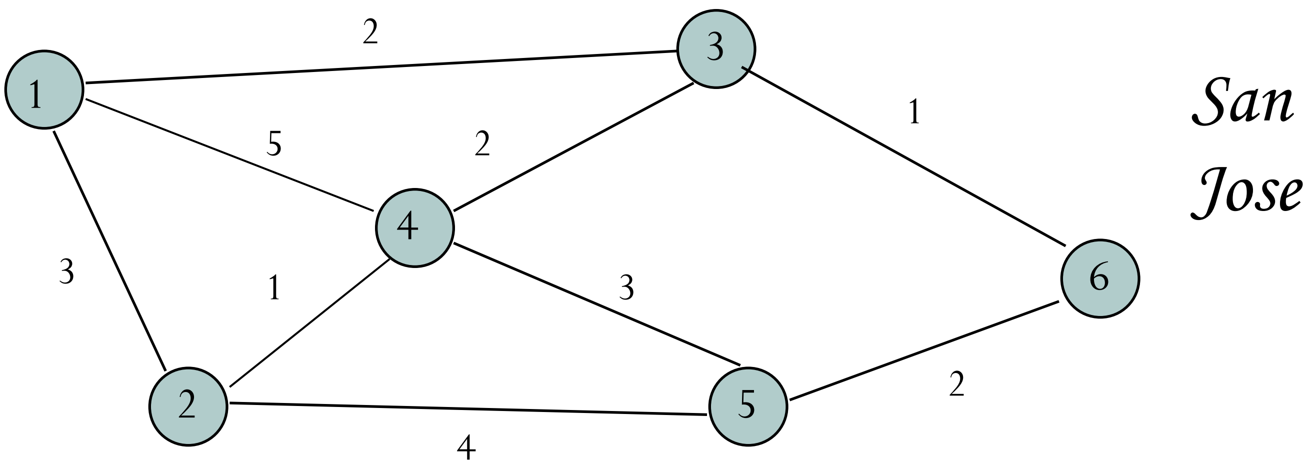
Bellman-Ford Algorithm

- *Now consider parallel computations* *for all destinations* *d*
- *Initialization*
  - Each node has 1 row for each destination *d*
  - Distance of node *d* to itself is zero: $D_d(d)=0$
  - Distance of other node *j* to *d* is infinite: $D_j(d)= \propto$, for $j \neq d$
  - Next node n_j = -1 since not yet defined
- *Send Step*
  - Send new distance vector to immediate neighbors across local link
- *Receive Step*
  - For each destination *d*, find the next hop that gives the minimum distance to *d*,
    - $Min_j \{ C_{ij} + D_j(d) \}$
    - Replace old $(n_j, D_i(d))$ by new $(n_j^*, D_j^*(d))$ if new next node or distance found
  - Go to send step

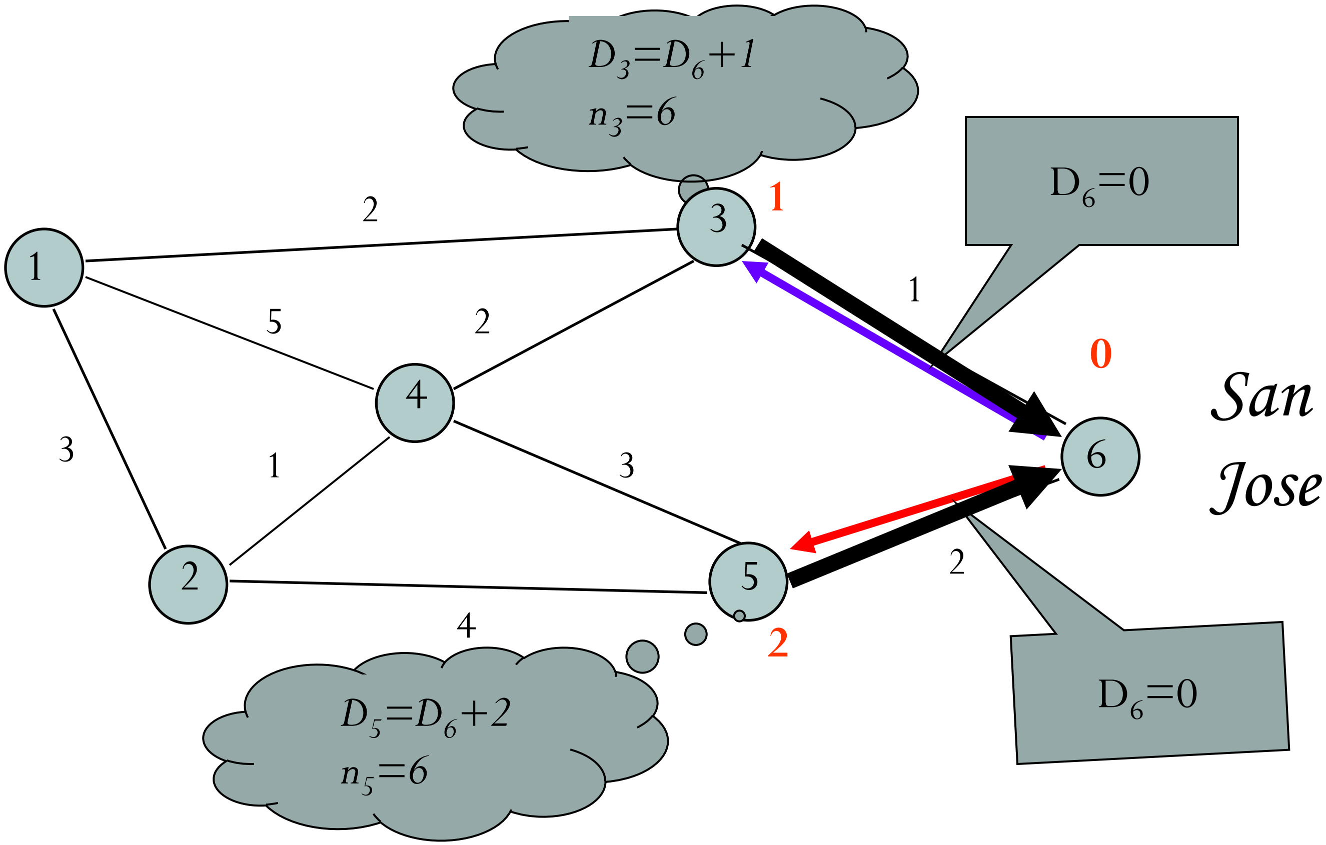
Iteration	Node 1	Node 2	Node 3	Node 4	Node 5
Initial	(-1, ∞)	(-1, ∞)	(-1, ∞)	(-1, ∞)	(-1, ∞)
1					
2					
3					

Table entry @ node 1 for dest SJ

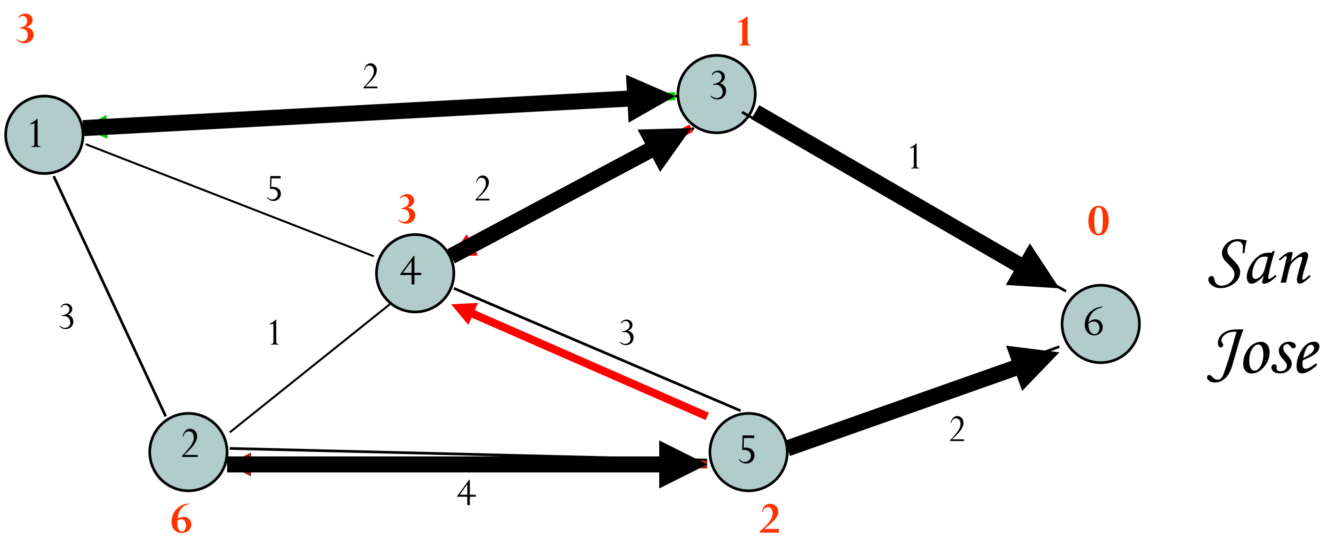
Table entry @ node 3 for dest SJ



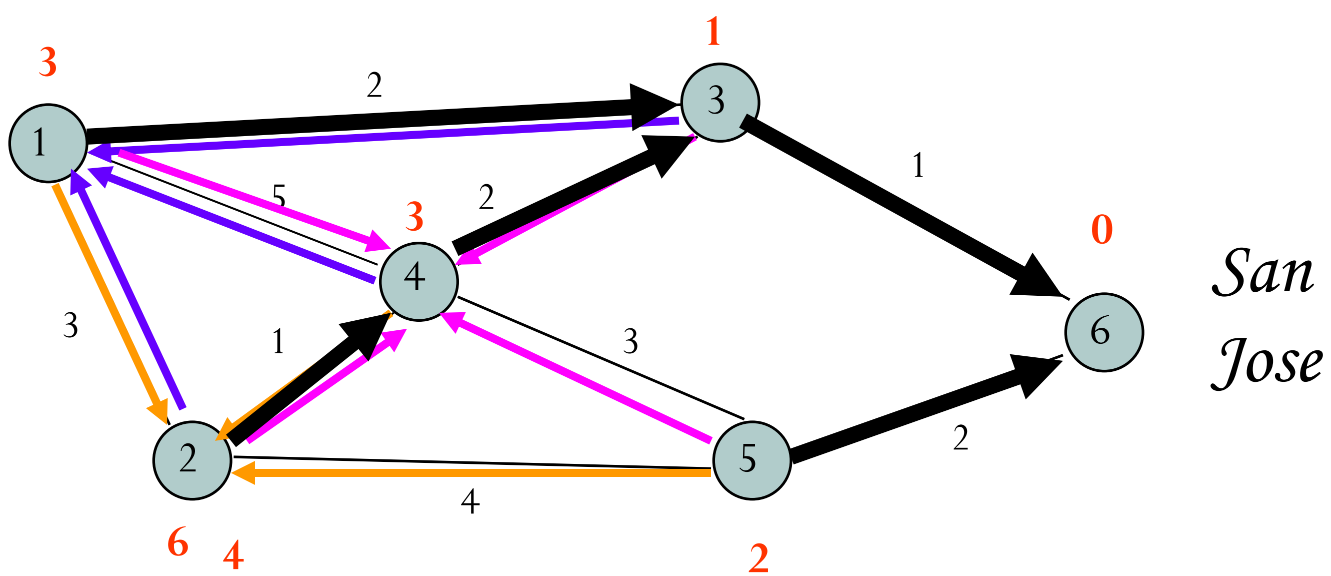
Iteration	Node 1	Node 2	Node 3	Node 4	Node 5
Initial	(-1, ∞)	(-1, ∞)	(-1, ∞)	(-1, ∞)	(-1, ∞)
1	(-1, ∞)	(-1, ∞)	(6,1)	(-1, ∞)	(6,2)
2					
3					



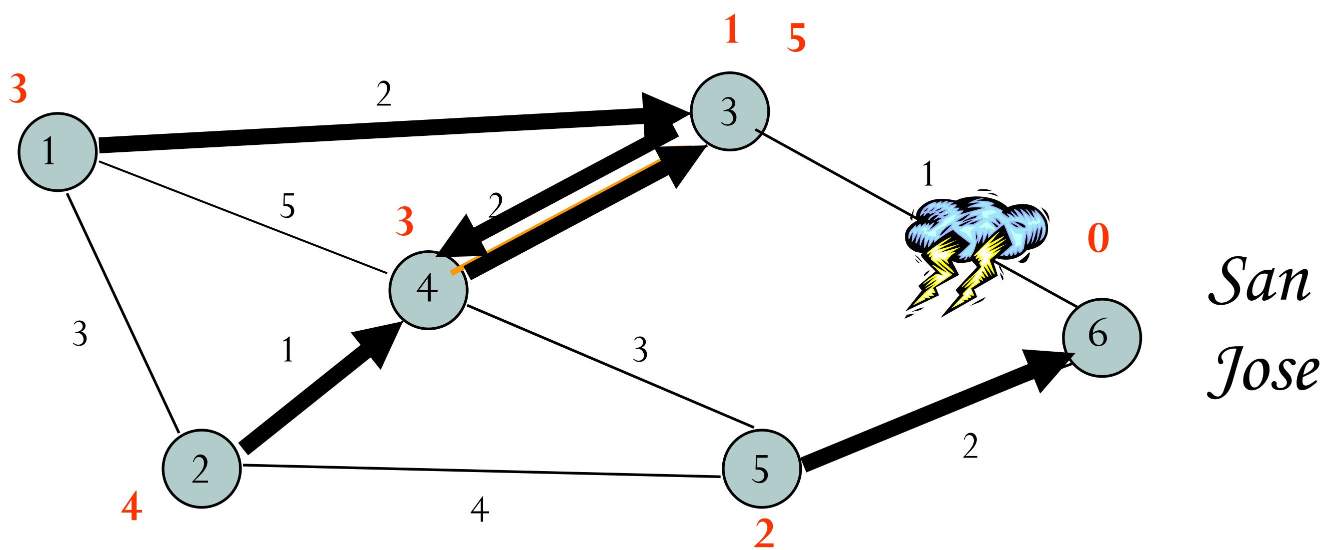
Iteration	Node 1	Node 2	Node 3	Node 4	Node 5
Initial	(-1, ∞)	(-1, ∞)	(-1, ∞)	(-1, ∞)	(-1, ∞)
1	(-1, ∞)	(-1, ∞)	(6, 1)	(-1, ∞)	(6,2)
2	(3,3)	(5,6)	(6, 1)	(3,3)	(6,2)
3					



Iteration	Node 1	Node 2	Node 3	Node 4	Node 5
Initial	(-1, ∞)	(-1, ∞)	(-1, ∞)	(-1, ∞)	(-1, ∞)
1	(-1, ∞)	(-1, ∞)	(6, 1)	(-1, ∞)	(6,2)
2	(3,3)	(5,6)	(6, 1)	(3,3)	(6,2)
3	(3,3)	(4,4)	(6, 1)	(3,3)	(6,2)

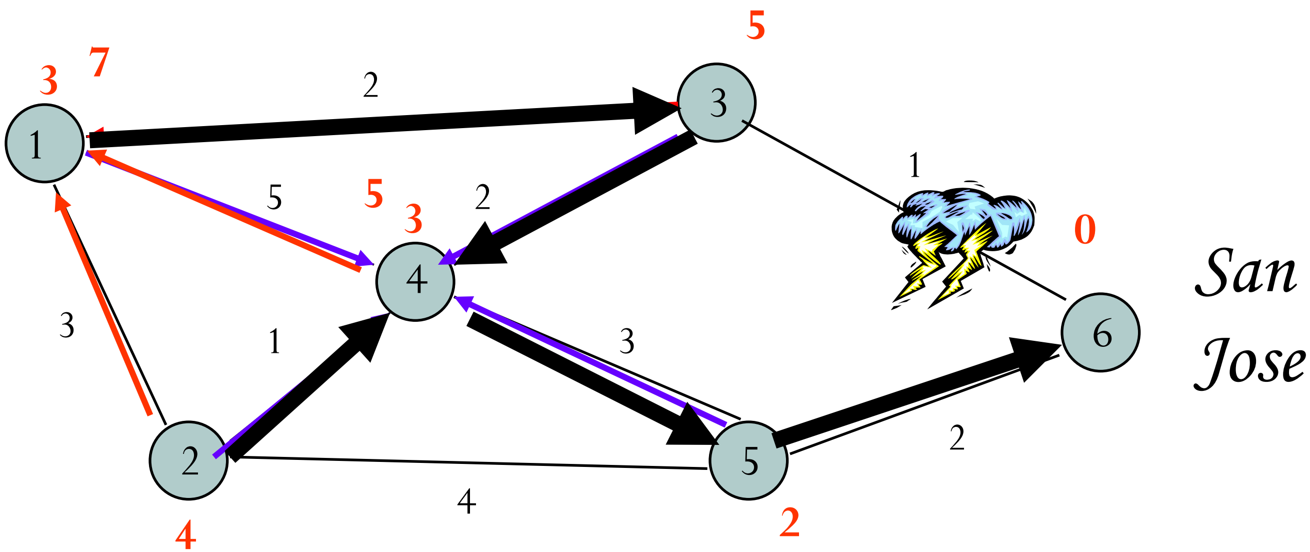


Iteration	Node 1	Node 2	Node 3	Node 4	Node 5
Initial	(3,3)	(4,4)	(6, 1)	(3,3)	(6,2)
1	(3,3)	(4,4)	(4, 5)	(3,3)	(6,2)
2					
3					



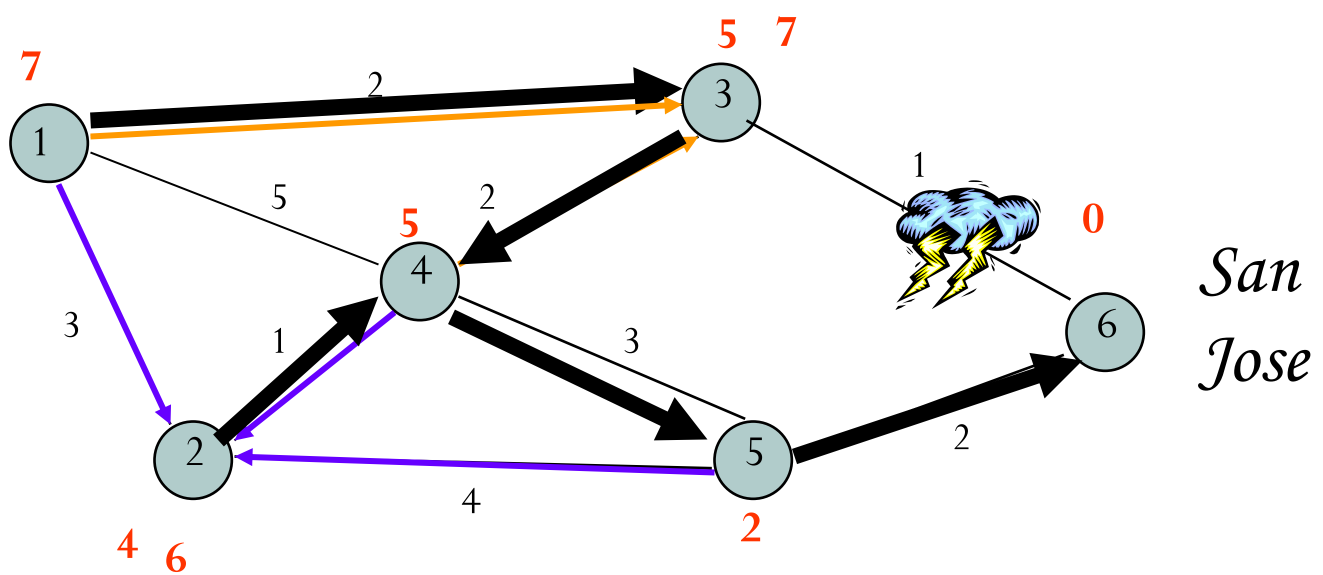
Network disconnected; Loop created between nodes 3 and 4

Iteration	Node 1	Node 2	Node 3	Node 4	Node 5
Initial	(3,3)	(4,4)	(6, 1)	(3,3)	(6,2)
1	(3,3)	(4,4)	(4, 5)	(3,3)	(6,2)
2	(3,7)	(4,4)	(4, 5)	(5,5)	(6,2)
3					



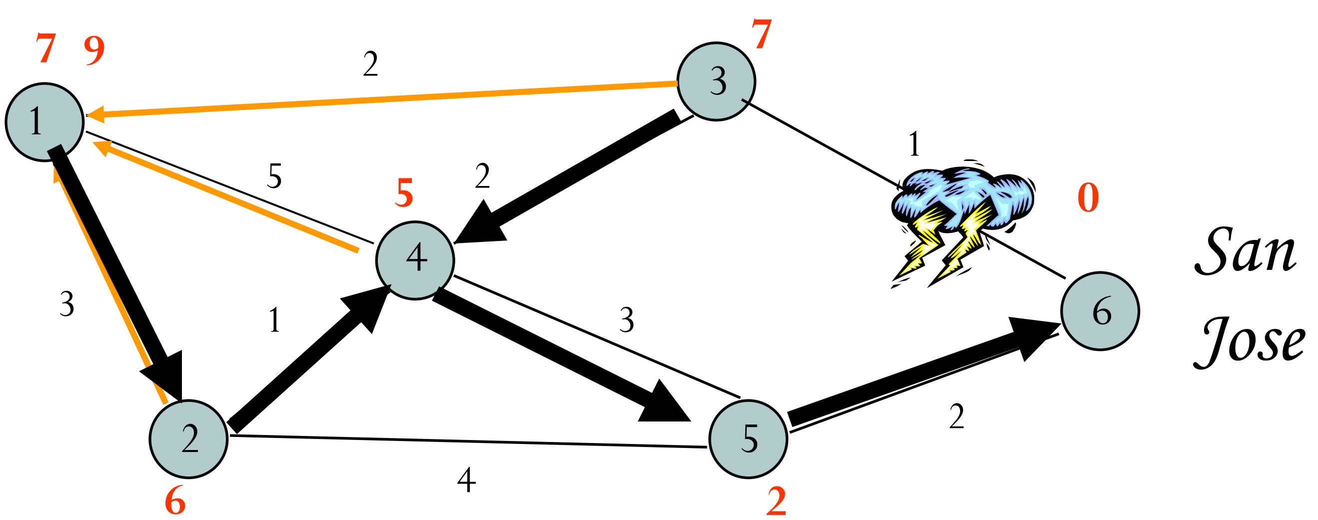
Node 4 could have chosen 2 as next node because of tie

Iteration	Node 1	Node 2	Node 3	Node 4	Node 5
Initial	(3,3)	(4,4)	(6, 1)	(3,3)	(6,2)
1	(3,3)	(4,4)	(4, 5)	(3,3)	(6,2)
2	(3,7)	(4,4)	(4, 5)	(5,5)	(6,2)
3	(3,7)	(4,6)	(4, 7)	(5,5)	(6,2)



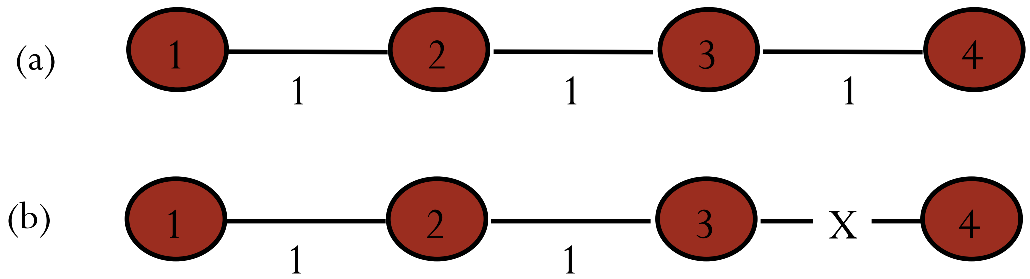
Node 2 could have chosen 5 as next node because of tie

Iteration	Node 1	Node 2	Node 3	Node 4	Node 5
1	(3,3)	(4,4)	(4, 5)	(3,3)	(6,2)
2	(3,7)	(4,4)	(4, 5)	(2,5)	(6,2)
3	(3,7)	(4,6)	(4, 7)	(5,5)	(6,2)
4	(2,9)	(4,6)	(4, 7)	(5,5)	(6,2)



Node 1 could have chose 3 as next node because of tie

Counting to Infinity Problem



Nodes believe best path is through each other
(Destination is node 4)

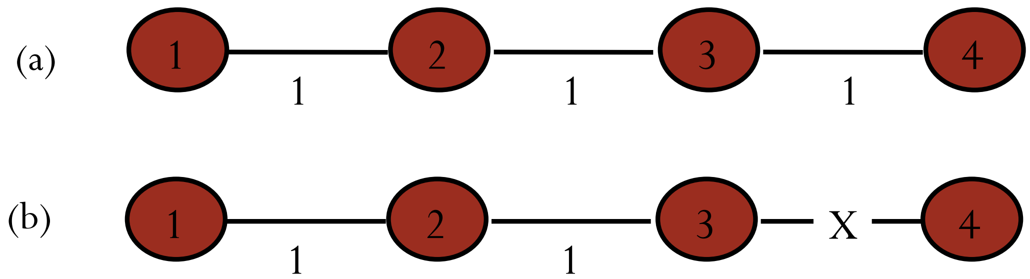
Update	Node 1	Node 2	Node 3
Before break	(2,3)	(3,2)	(4, 1)
After break	(2,3)	(3,2)	(2,3)
1	(2,3)	(3,4)	(2,3)
2	(2,5)	(3,4)	(2,5)
3	(2,5)	(3,6)	(2,5)
4	(2,7)	(3,6)	(2,7)
5	(2,7)	(3,8)	(2,7)
…	…	…	…

Problem: Bad News Travels Slowly

Remedies

- Split Horizon
  - Do not report route to a destination to the neighbor from which route was learned
- Poisoned Reverse
  - Report route to a destination to the neighbor from which route was learned, but with infinite distance
  - Breaks erroneous direct loops immediately
  - Does not work on some indirect loops

Split Horizon with Poison Reverse



Nodes believe best path is through each other

Update	Node 1	Node 2	Node 3	
Before break	(2, 3)	(3, 2)	(4, 1)	
After break	(2, 3)	(3, 2)	(-1, ∞)	Node 2 advertizes its route to 4 to node 3 as having distance infinity; node 3 finds there is no route to 4
1	(2, 3)	(-1, ∞)	(-1, ∞)	Node 1 advertizes its route to 4 to node 2 as having distance infinity; node 2 finds there is no route to 4
2	(-1, ∞)	(-1, ∞)	(-1, ∞)	Node 1 finds there is no route to 4

Link-State Algorithm

- Basic idea: two step procedure
  - Each source node gets a map of all nodes and link metrics (link state) of the entire network
  - Find the shortest path on the map from the source node to all destination nodes
- Broadcast of link-state information
  - Every node *i* in the network broadcasts to every other node in the network:
    - ID's of its neighbors: $\mathcal{N}_i$=set of neighbors of i
    - Distances to its neighbors: $\{C_{ij} \mid j \in N_i\}$
  - Flooding is a popular method of broadcasting packets

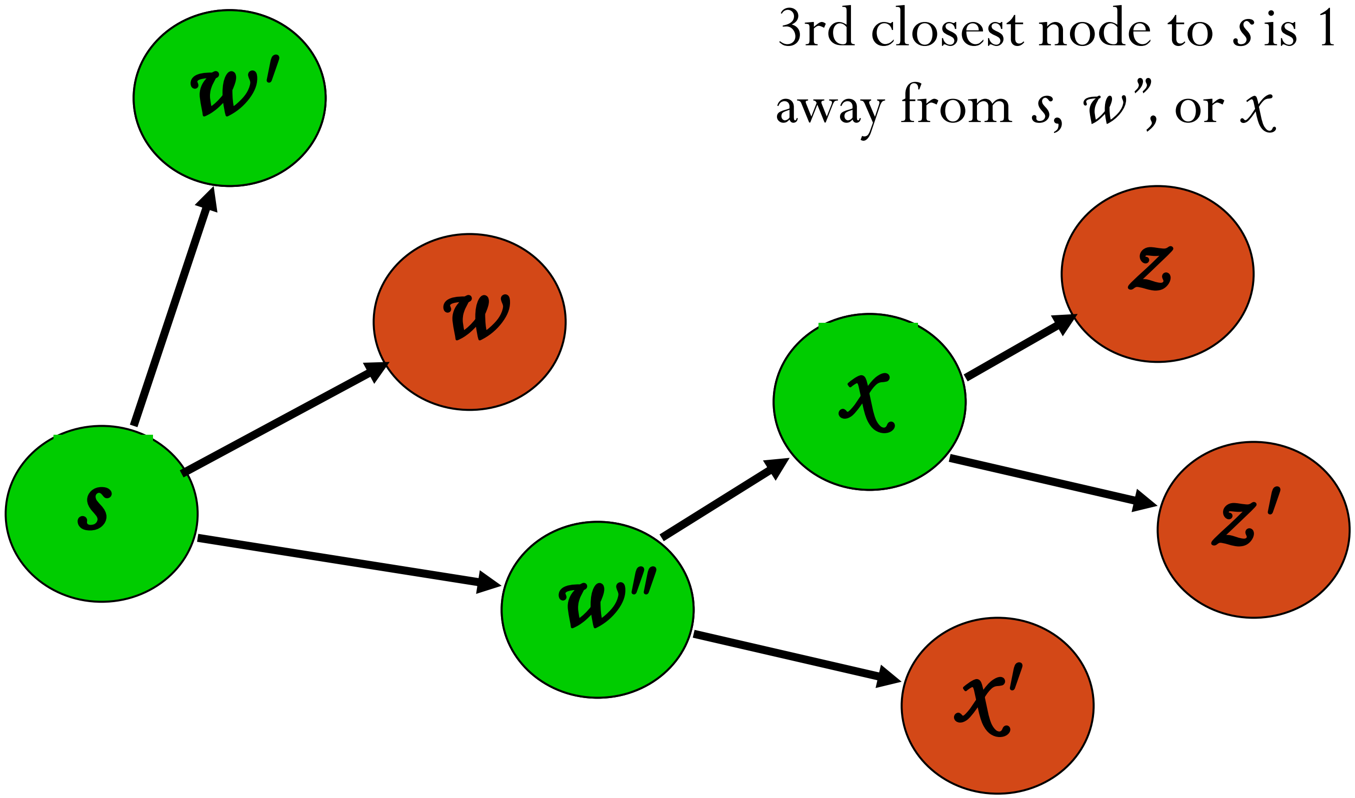
Dijkstra's Algorithm: Finding shortest paths in order

Find shortest paths from source s to all other destinations

Closest node to s is 1 hop away

2nd closest node to s is 1 hop away from s or w''

3rd closest node to s is 1 hop away from s, w'', or x

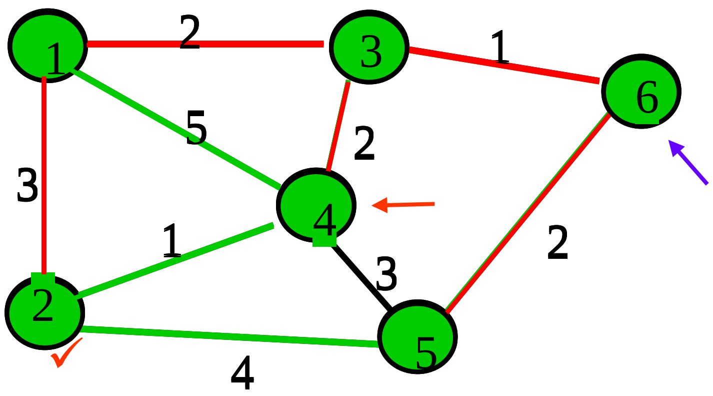


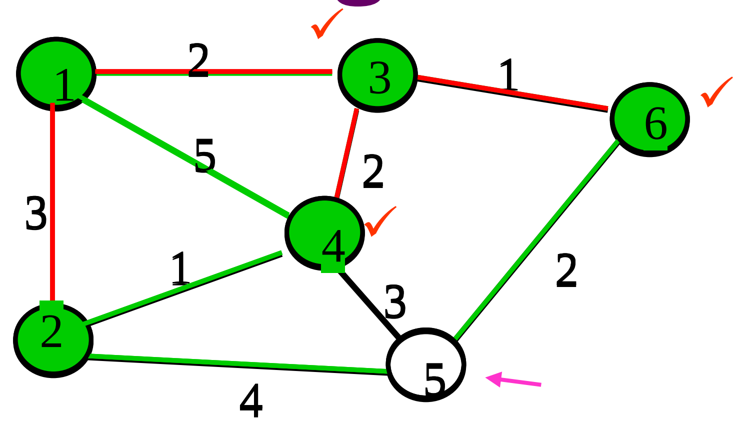
Dijkstra's algorithm

- N: set of nodes for which shortest path already found
- Initialization: (*Start with source node s)*
  - $N = \{s\}$, $D_s = 0$, "*s* is distance zero from itself"
  - $D_j = C_{sj}$ for all $j \neq s$, distances of directly-connected neighbors
- Step A: (*Find next closest node i*)
  - Find $i \notin N$ such that
  - $D_i = \min Dj$ for $j \notin N$
  - Add i to N
  - If N contains all the nodes, stop
- Step B: (*update minimum costs)*
  - For each node $j \notin N$
  - $D_j = \min (D_j, D_i + C_{ij})$
  - Go to Step A

Minimum distance from s to *j through node* ***i*** *in N*

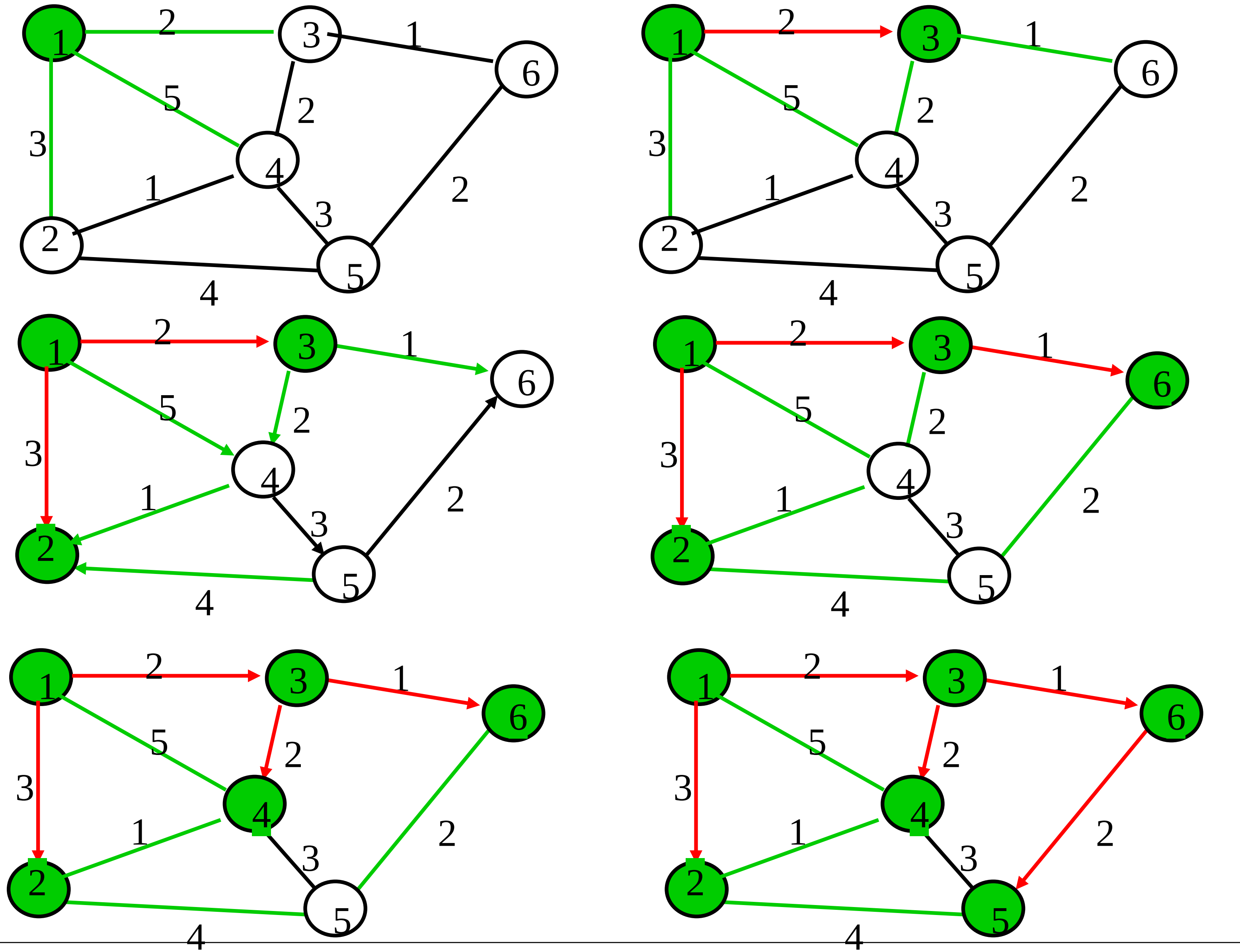
Execution of Dijkstra's algorithm





Iteration	**N**	D_2	D_3	D_4	D_5	D_6
Initial	{1}	3	2 ✓	5	∝	∝
1	{1,3}	3 ✓	2	4	∝	3
2	{1,2,3}	3	2	4	7	3 ✓
3	{1,2,3,6}	3	2	4 ✓	5	3
4	{1,2,3,4,6}	3	2	4	5 ✓	3
5	{1,2,3,4,5,6}	3	2	4	5	3

Shortest Paths in Dijkstra’s Algorithm



Reaction to Failure

- If a link fails,
  - Router sets link distance to infinity & floods the network with an update packet
  - All routers immediately update their link database & recalculate their shortest paths
  - Recovery very quick
- But watch out for old update messages
  - Add time stamp or sequence # to each update message
  - Check whether each received update message is new
  - If new, add it to database and broadcast
  - If older, send update message on arriving link

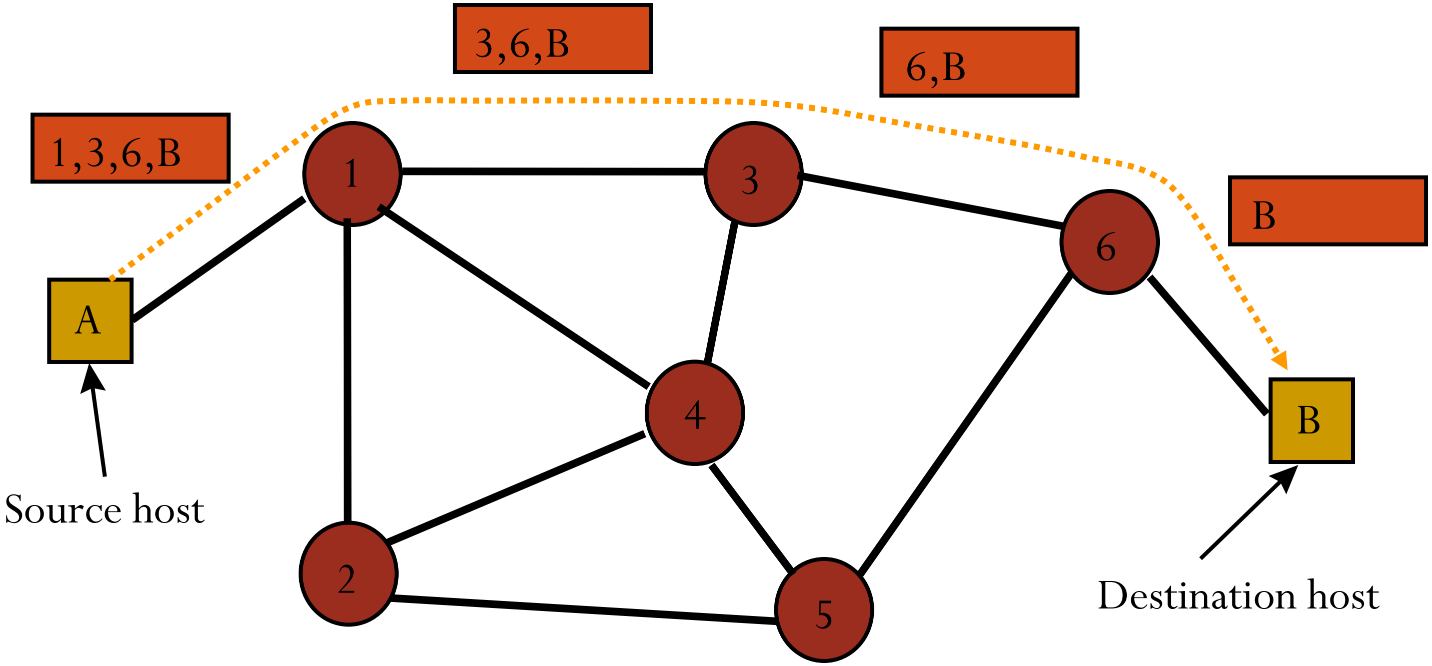
Why is Link State Better?

- Fast, loopless convergence
- Support for precise metrics, and multiple metrics if necessary (throughput, delay, cost, reliability)
- Support for multiple paths to a destination
  - algorithm can be modified to find best two paths

Source Routing

- Source host selects path that is to be followed by a packet
  - Strict: sequence of nodes in path inserted into header
  - Loose: subsequence of nodes in path specified
- Intermediate switches read next-hop address and remove address
- Source host needs link state information or access to a route server
- Source routing allows the host to control the paths that its information traverses in the network
- Potentially the means for customers to select what service providers they use

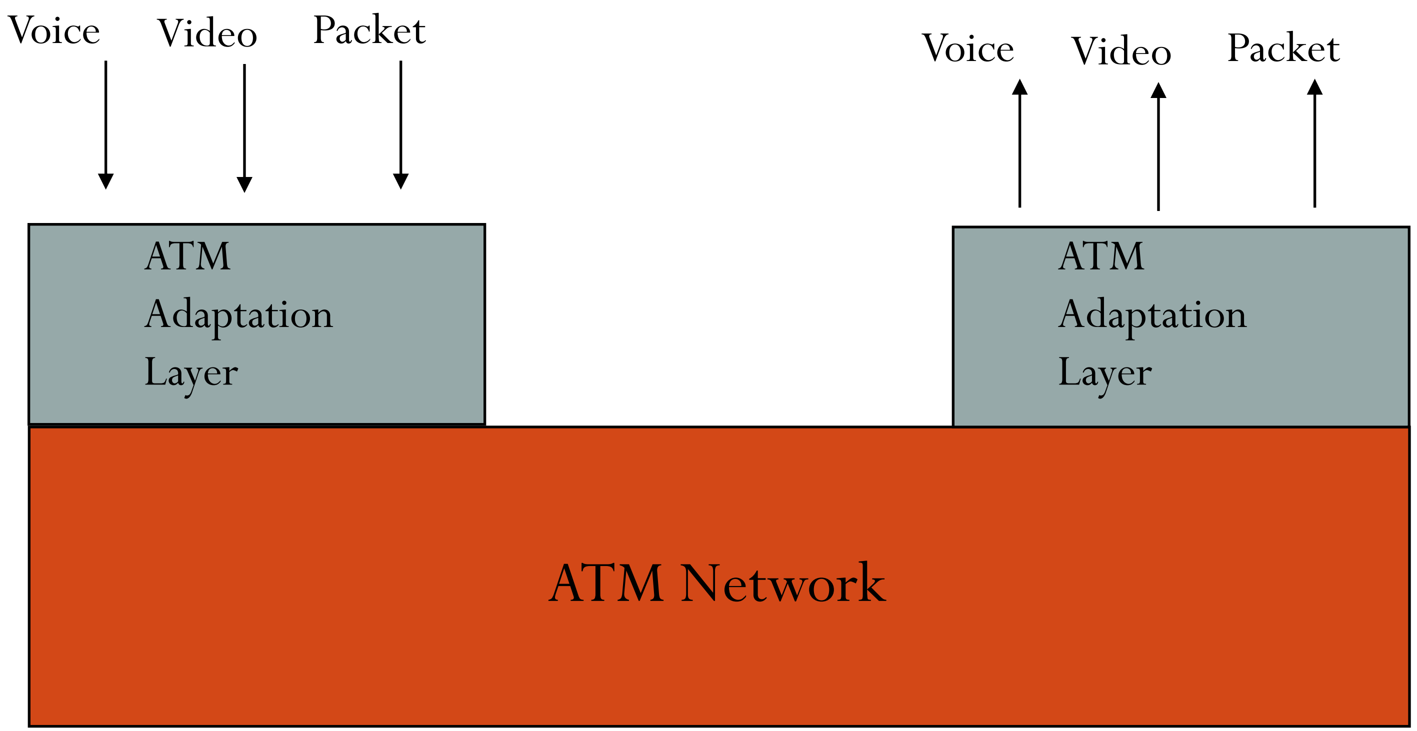
Example



Asynchronous Transfer Mode (ATM)

- Packet multiplexing and switching
  - Fixed-length packets: “cells”
  - Connection-oriented
  - Rich Quality of Service support
- Conceived as end-to-end
  - Supporting wide range of services
    - Real time voice and video
    - Circuit emulation for digital transport
    - Data traffic with bandwidth guarantees

ATM Networking



- End-to-end information transport using cells
- 53-byte cell provide low delay and fine multiplexing granularity

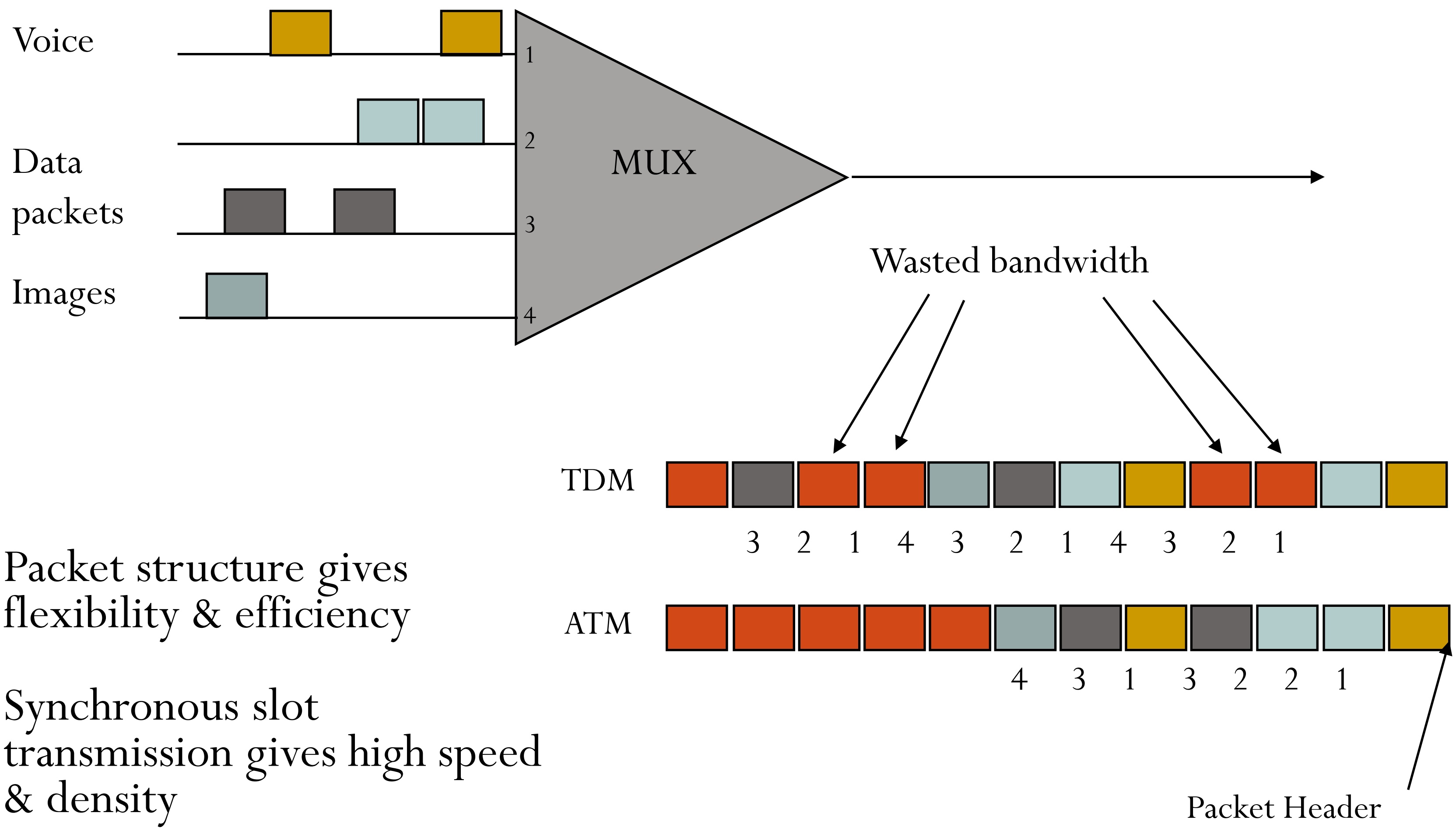
Support for many services through ATM Adaptation Layer

TDM vs. Packet Multiplexing

	Variable bit rate	Delay	Burst traffic	Processing
TDM	Multirate only	Low, fixed ✓	Inefficient	Minimal, very high speed
Packet	Easily handled ✓	Variable	Efficient ✓	Header & packet processing required*

*In mid-1980s, packet processing mainly in software and hence slow; By late 1990s, very high speed packet processing possible

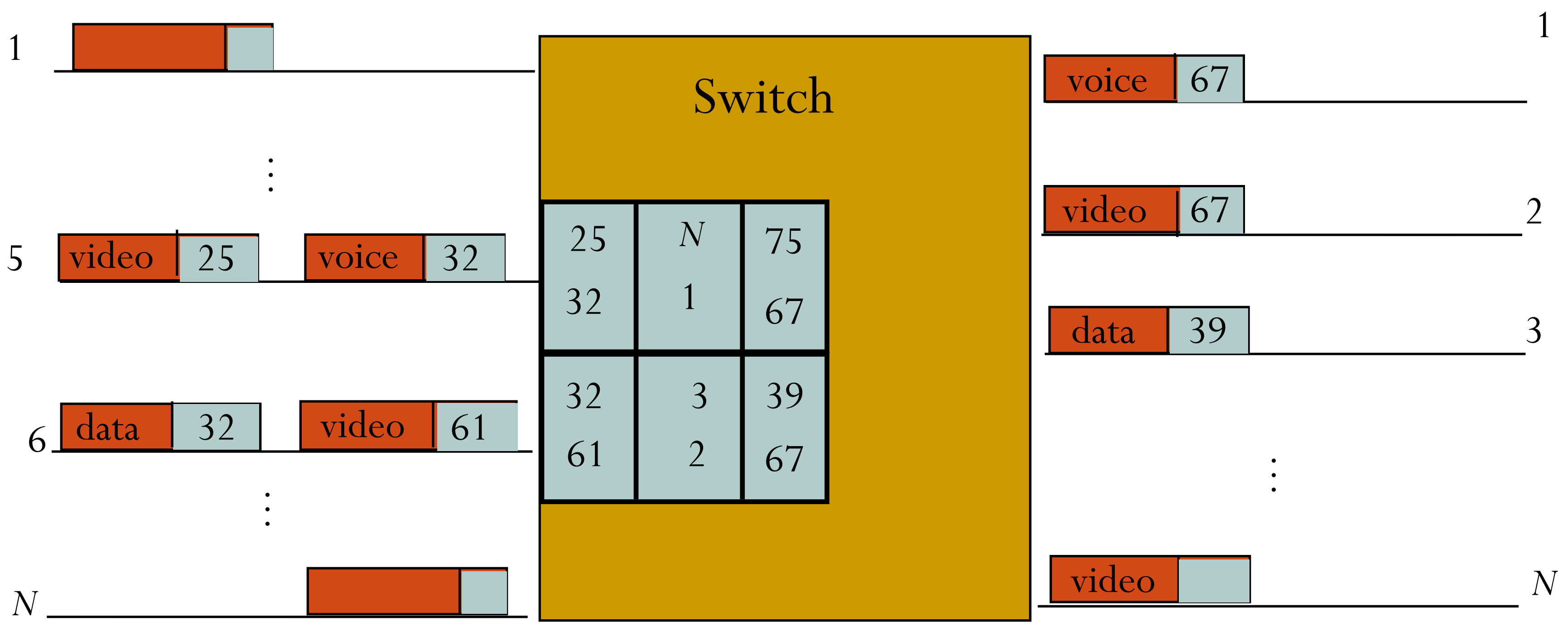
ATM: Attributes of TDM & Packet Switching



- Packet structure gives flexibility & efficiency
- Synchronous slot transmission gives high speed & density

ATM Switching

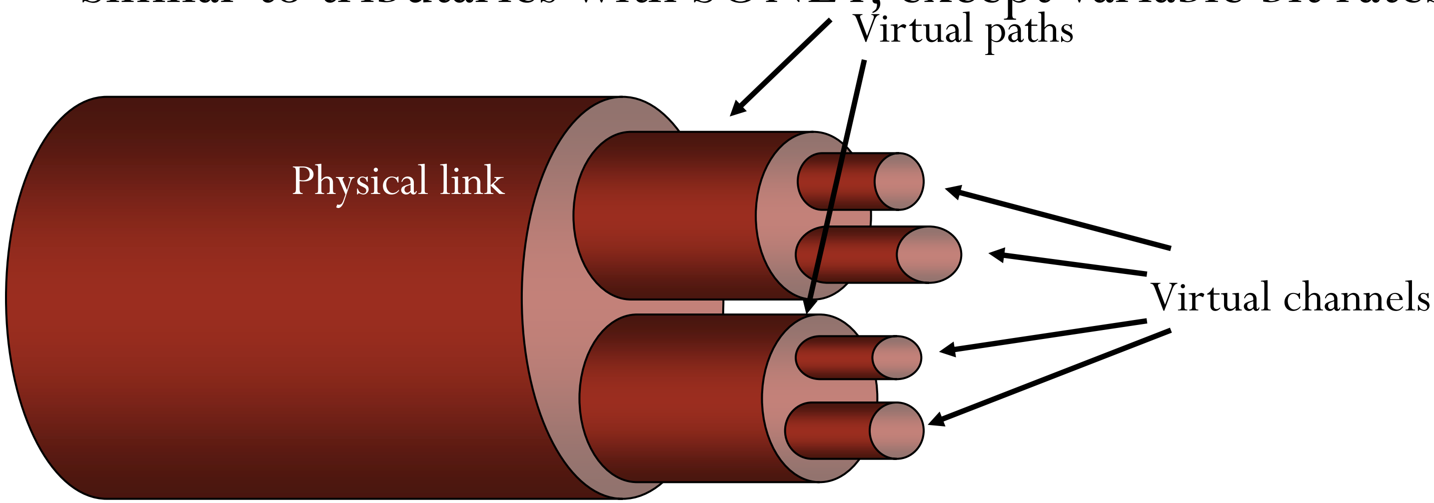
Switch carries out table translation and routing



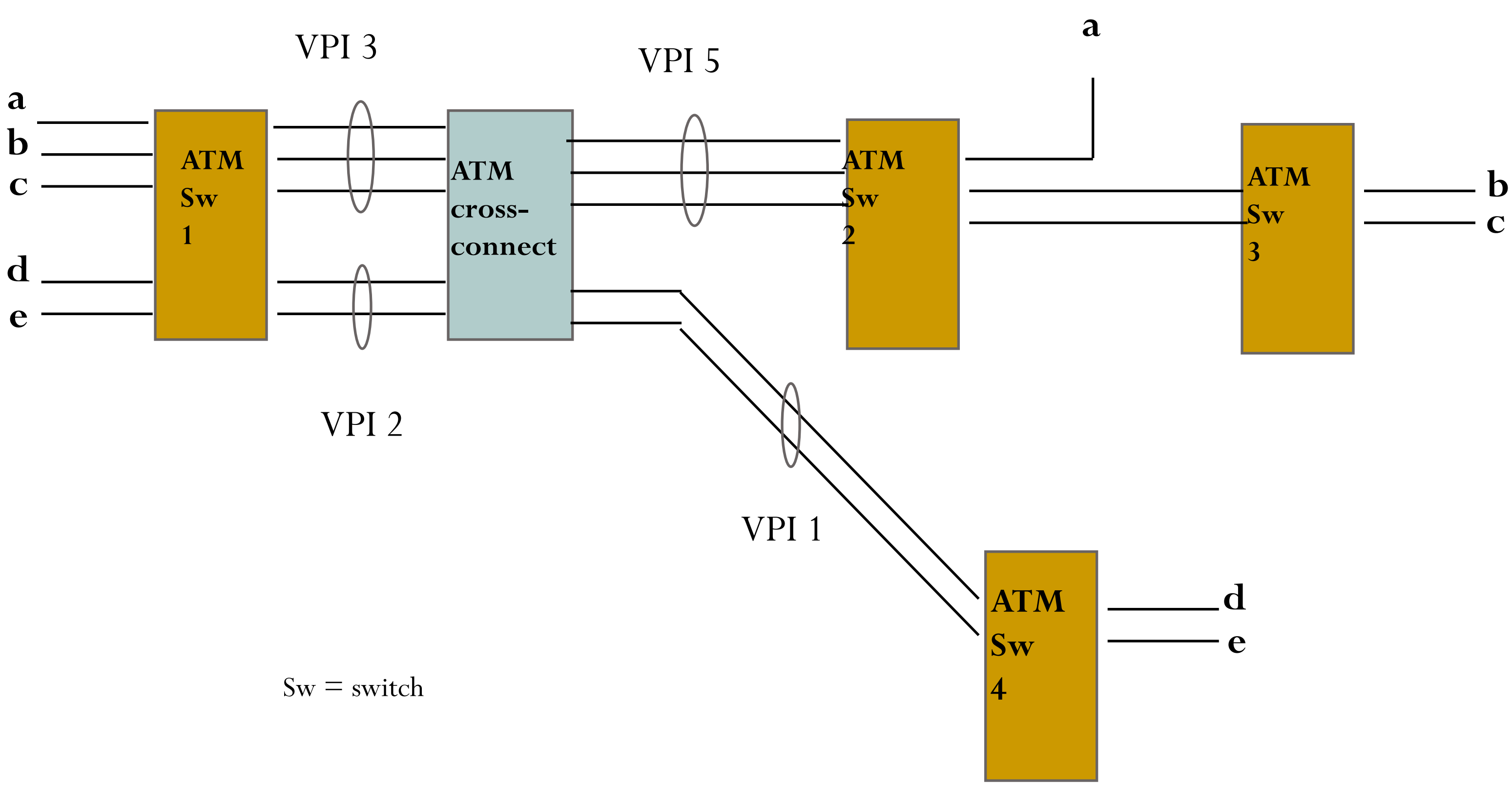
ATM switches can be implemented using shared memory, shared backplanes, or self-routing multi-stage fabrics

ATM Virtual Connections

- Virtual connections setup across network
- Connections identified by locally-defined tags
- ATM Header contains virtual connection information:
  - 8-bit Virtual Path Identifier
  - 16-bit Virtual Channel Identifier
- Powerful traffic grooming capabilities
  - Multiple VCs can be bundled within a VP
  - Similar to tributaries with SONET, except variable bit rates possible



VPI/VCI switching & multiplexing



- Connections a,b,c bundled into VP at switch 1
  - Crossconnect switches VP without looking at VCIs
  - VP unbundled at switch 2; VC switching thereafter
- VPI/VCI structure allows creation virtual networks

MPLS & ATM

- ATM initially touted as more scalable than packet switching
- ATM envisioned speeds of 150-600 Mbps
- Advances in optical transmission proved ATM to be the less scalable: @ 10 Gbps
  - Segmentation & reassembly of messages & streams into 48-byte cell payloads difficult & inefficient
  - Header must be processed every 53 bytes vs. 500 bytes on average for packets
  - Delay due to 1250 byte packet at 10 Gbps = 1 μsec; delay due to 53 byte cell @ 150 Mbps ≈ 3 μsec
- MPLS chauses tags to transfer packets across virtual circuits in Internet

Applications

Post MCQ Test

[1] In forwarding the full IP address of a destination is given in the routing table as

a) next hop.

b) network specific.

c) host specific.

d) default.

[2] ATM uses ______________ as a transmission medium.

a) twisted-pair cable

b) coaxial cable

c) fiber-optic cable

d) all of the above

[3] The end product of the SAR is a data packet that is___________

(a) variable in length.

(b) 48 bytes long .

(c) 44 to 48 bytes long.

(d) > 48 bytes long.

[4] In a _________ switch, both the VPI and the VCI can change.

a) VP

b) VPC

c) VPI

d) VCI

[5] To create a neighborhood relationship ,a router running BGP sends an message

a) Open.

b) Update.

c) Keep alive.

d) None of these.

[6] The value of the window size is determined by

(a) The sender.

(b) The receiver.

(c) Both the sender and receiver.

(d) None of the above.

[7] Which of the following does UDP guarantee?

a) Flow control.

b) Connection-oriented delivery.

c) Error control.

d) None of the above.

[8] The task of moving the packet from the input queue to the output queue in a router is done by

a) Input and output ports.

b) Routing processor.

c) Switching fabrics.

d) None of the above.

[9] The use of hierarchy in routing tables can __________ the size of the routing tables

(a) Reduce.

(b) Increase.

(c) Both reduce and increase.

(d) None of the above.

[10] If a segment carries data along with an acknowledgment this is called as

a) Back packing.

b) Piggy backing.

c) Piggy packing.

d) None of the above.

Conclusion

- In this unit, the packet switching networks from several perspectives were examined.
- The service is connection oriented or connectionless which does not imply that the internal operation uses the same mode.
- There are two approaches to operating packet networks : Virtual circuits and datagram where the Internet and ATM networks were presented as examples.
- The several approaches to selecting routes across a network and different types of routing tables that are involved in this process were explained.
- The shortest path algorithms and their use in synthesizing routing tables.
- ATM networks were introduced as an example of connection oriented networks.

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2. Communication Networks by Alberto Leon Garcia, Indra Widjaja, II edn, TMGH
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5. Computer Networks by Andrew Tanenbaum, 3e, PHI

Assignment

[1] Name the ATM layers and their functions.

[2] Explain why the distance in hops from your ISP to a NAP is very important. What happens if a NAP becomes congested.

[3] Explain how a network that operates internally with virtual circuits can provide connectionless service.

[4] Discuss the different methods of error detection in each of the AAL types.

[5] Compare and contrast a VP switch and a VPC switch.

[6] Explain how a network that operates internally with virtual circuits can provide connectionless service. Comment on the delay performance of the service. Can you identify inefficiencies in this approach.

[7] Apply the end to end argument to the question of how to control the delay jitter that is incurred in traversing a multi hop network.

[8] Compare the operation of the layer 3 entities in the end systems and in the routers inside the network.

[9] Explain the difference between the leaky bucket traffic shaper and the token bucket traffic shaper.

[10] Discuss the implementation complexity of the random early detection algorithm.

ANY QUERIES?

Email to maarchaname@gmail.com

THANK YOU