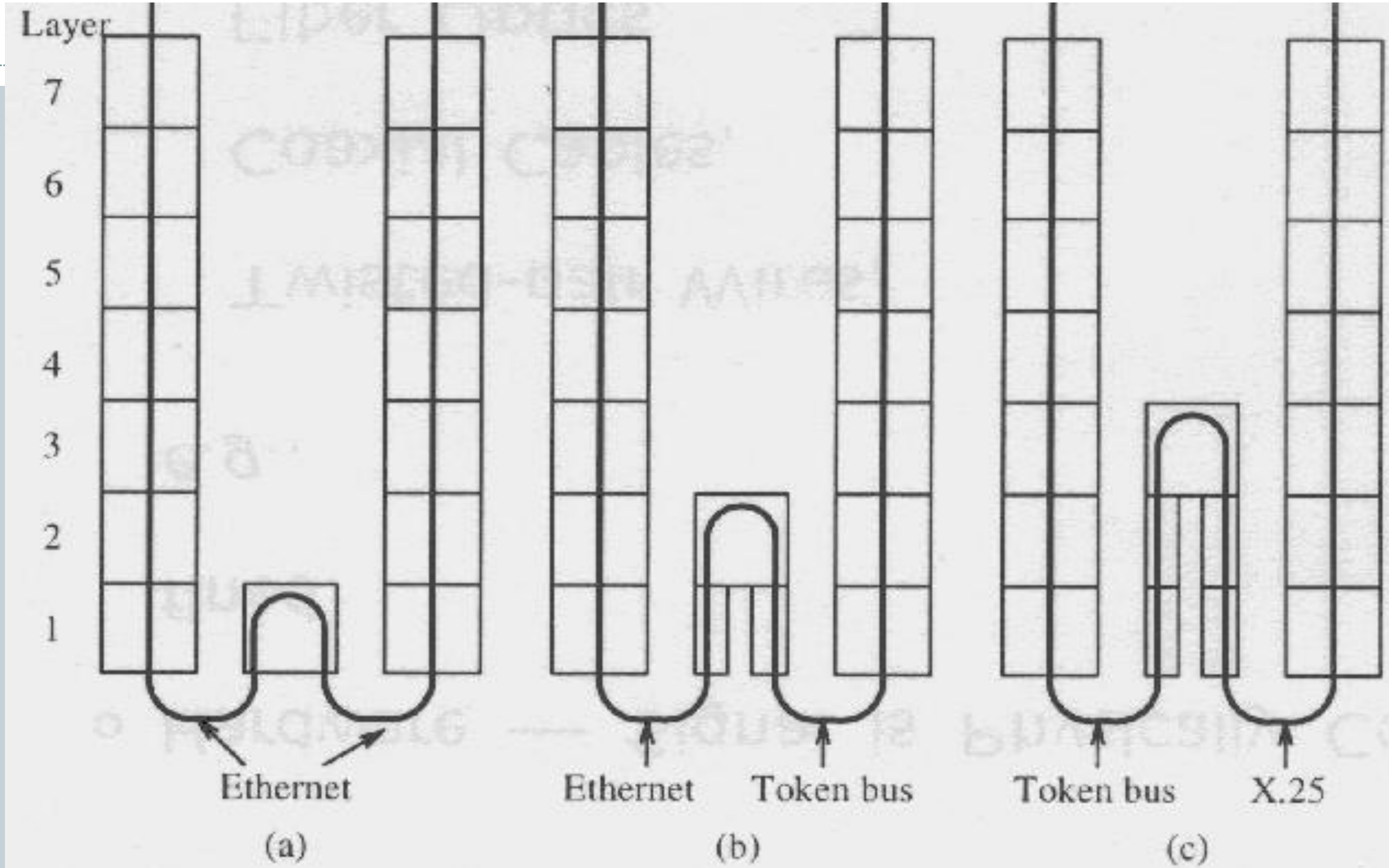
WAN Technologies and Routing

- The objective of this unit is to introduce:
  - Packet switching network
  - Physical addressing in a WAN
  - Hierarchical address and routing
  - WAN architecture and capacity
  - Routing in a WAN
  - Route computation
  - Shortest path computation
  - Examples of WAN Technologies: ARPANET, X.25, ISDN, Frame Relay, SMDS, ATM

Introduction

- LANs can be extended using repeaters, bridges,..
- LANs Can not be extended to handle arbitrarily many computers (*size*) and sites (*distance*) :
  - Distance limitations even with extensions
  - Broadcast is a problem
  - CSMA/CD limitations
- Other technologies are needed for larger networks

Network Devices



(a) A repeater (b) A bridge (c) A router

Characterizations of Networks

- *Local Area Network (LAN)* for a lab, building, campus (few kms)
- *Metropolitan Area Network (MAN)* for a single city (10s kms)
- *Wide Area network (WAN)* for a country, continent (100-1000 kms)
- Internet (internetwork) which is a collection of interconnected networks by routers running TCP/IP suite (planet: > 500K hosts, 500 nets)
- Subnet: a collection of routers and communication lines owned by a network provider such as AOL,..

Differences Between LAN and WAN

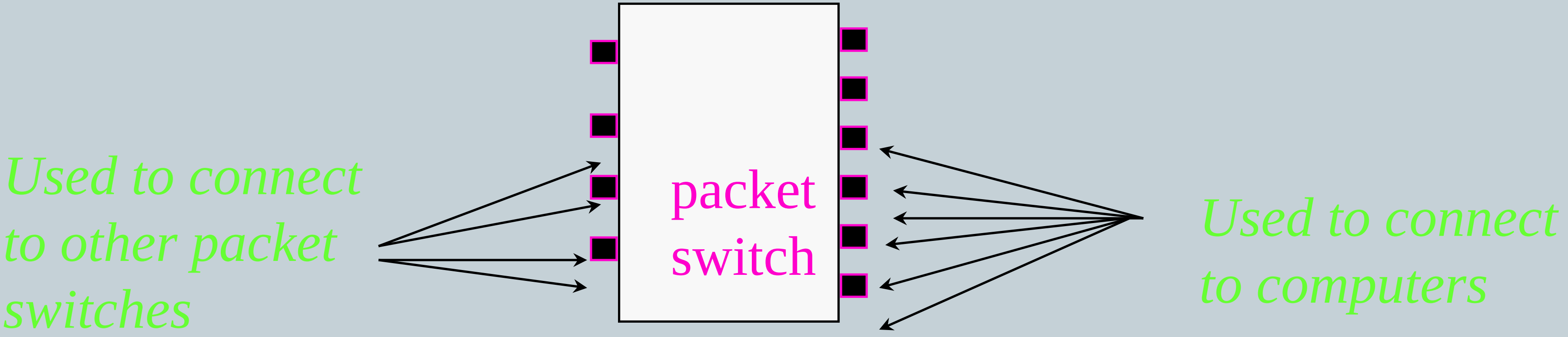
- The key issue is *scalability*:
  - WAN is able to grow as needed to connect many sites across large distances
  - LAN can be extended across large distances using satellite bridge but cannot accommodate large no of computers
- LAN protocols such as: CSMA/CD and token passing can’t be used for large network
- Reliability issues: WAN has multiples links
- Management & security issues
- Applications

Packet Switches

- To span long distances or many computers, network must replace shared medium with packet switches
  - Each switch moves an entire packet from one connection to another
  - Packet switching is a dedicated computer with network interfaces, memory and software to implement packet routing

Connections to Packet Switches

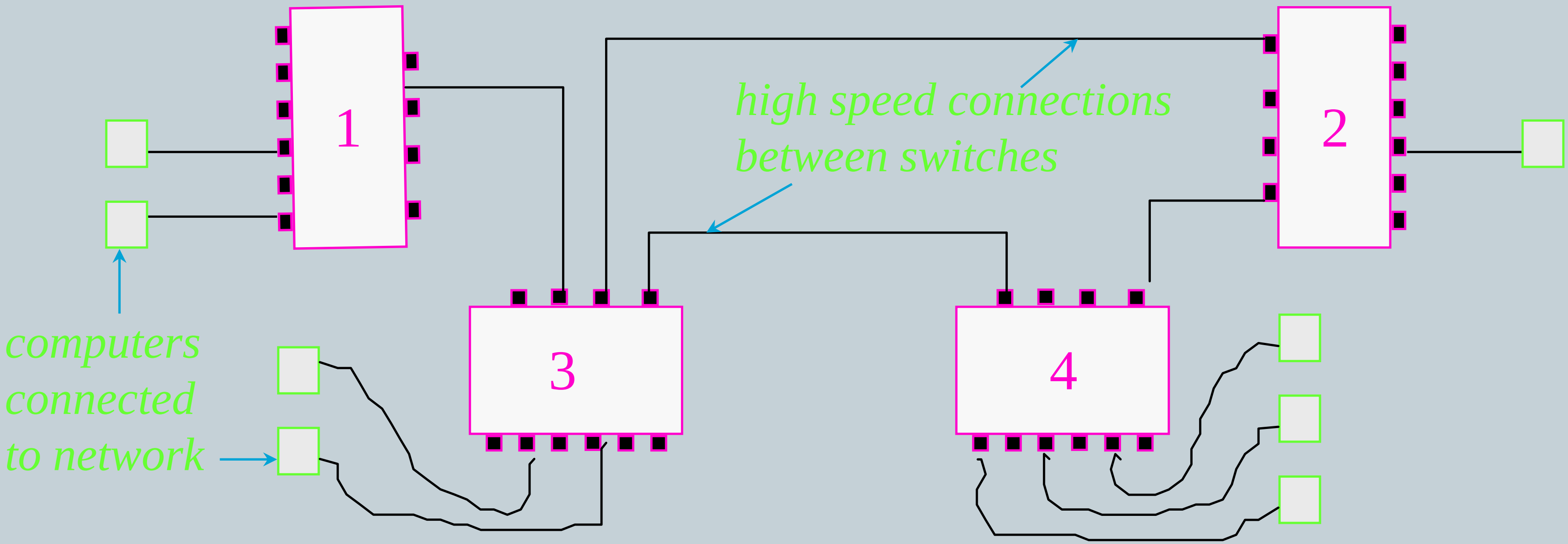
- Packets switches connect to:
  - Computers using lower speed connections
  - Other packet switches using high speed connections



- Packet switch is a basic building block in WAN
- Therefore, packet switches linked together to form WAN

Forming a WAN

- Each switch may connect to one or more other switches and one or more computers



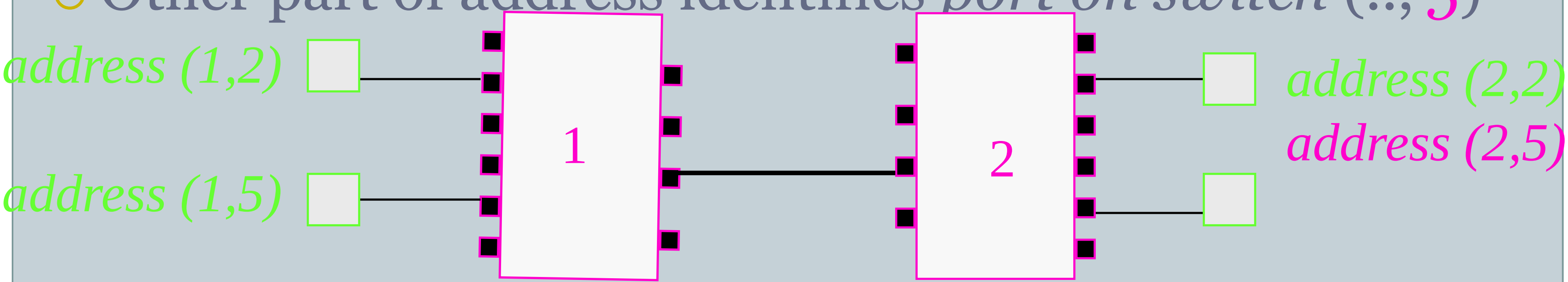
- WANs need not be symmetric or have regular connections

Store and Forward

- Data delivery from one computer to another is accomplished through store-and-forward technology
  - Packet switch stores incoming packet and forwards the packet to another switch or a computer
- Packet switch has internal memory
  - Can hold packet (in queue)if outgoing connection is busy

Physical Addressing in a WAN

- Similar to LAN
  - Data transmitted in packets (equivalent to frames)
  - Each packet has format with header
  - Packet header includes destination and source addresses
- Many WANs use 2-part hierarchical addressing for efficiency
  - One part of address identifies the *destination switch* (**2**,..)
  - Other part of address identifies *port on switch* (.., ***5***)

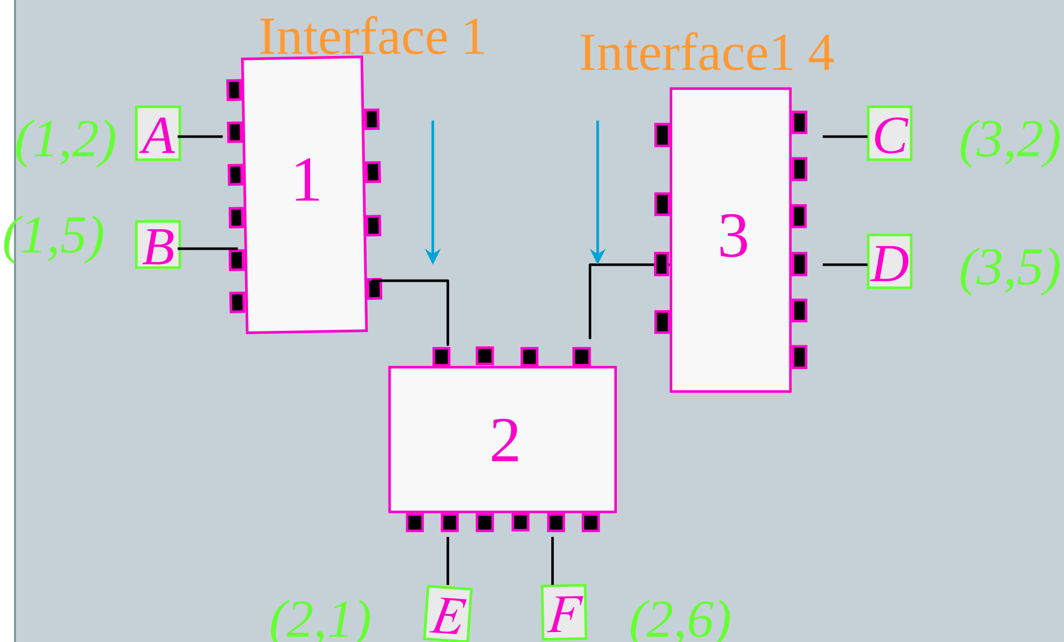


Next-Hop Forwarding

- Packet switch must choose outgoing connection for forwarding based on the *destination address* in packet:
  - If destination is a local computer, packet switch delivers to the local computer port
  - If destination is attached to another switch, this packet switch forwards to the *next hop* through connection to another switch

Choosing Next Hop

- Packet switch doesn't keep complete information about all possible destination just keeps next hops information
- So, for each coming packet, packet switch looks up destination in the table and forwards through connection to the appropriate next hop



DESTINATION	NEXT HOP
(1,2)	interface 1
(1,5)	interface 1
(3,2)	interface 4
(3,5)	interface 4
(2,1)	computer E
(2,6)	computer F

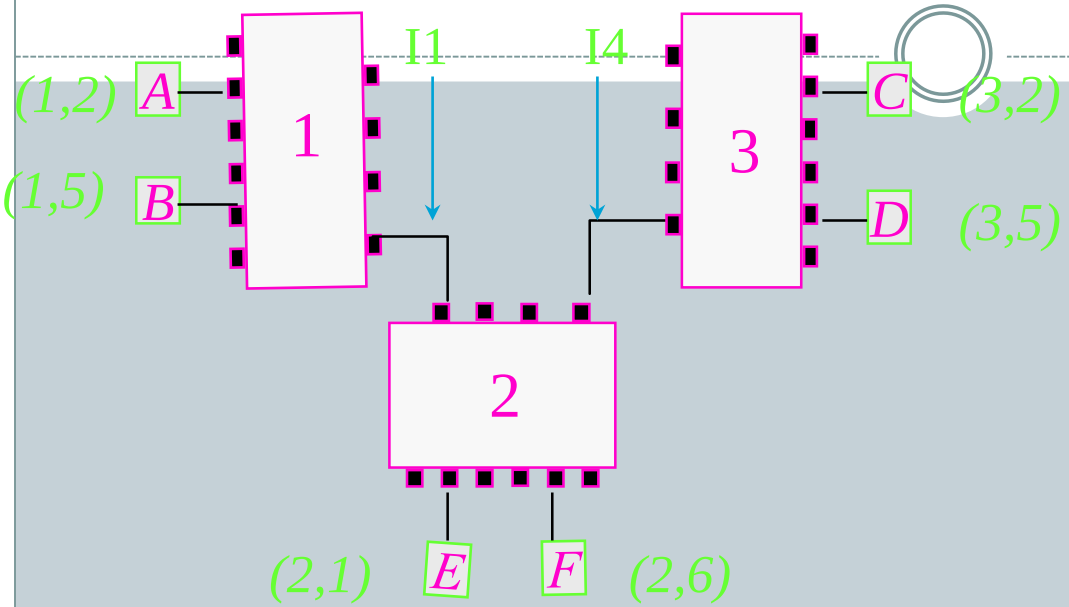
Source Independence

- Source independence: next hop to destination does not depend on the source of the packet
- Allows fast and efficient routing
- Packet switch need not have complete information, just next hop
  - Reduces total information
  - Increases dynamic robustness: network can continue to function even if topology changes without notifying entire network

Hierarchical Address and Routing

- Routing is the process of forwarding
- Information is kept in a routing table
- Note that many entries have same next hop
- In particular, all destinations on same switch have same next hop
- Thus, routing table can be collapsed by including switch no only: (**1**,1), (**1**,2), (**1**,3)   (**1**,*)
- Using 1-part of a 2-part hierarchical address will:
  - Reduce computation time to forward packets
  - reduce the entire routing table

Routing Table For Switch 2



DESTINATION	NEXT HOP
(1,2)	interface 1
(1,5)	interface 1
(3,2)	interface 4
(3,5)	interface 4
(2,1)	computer E
(2,6)	computer F

DESTINATON	NEXT HOP
(1, anything)	interface 1
(3, anything)	interface 4
(2, anything)	local computer

WAN Architecture and Capacity

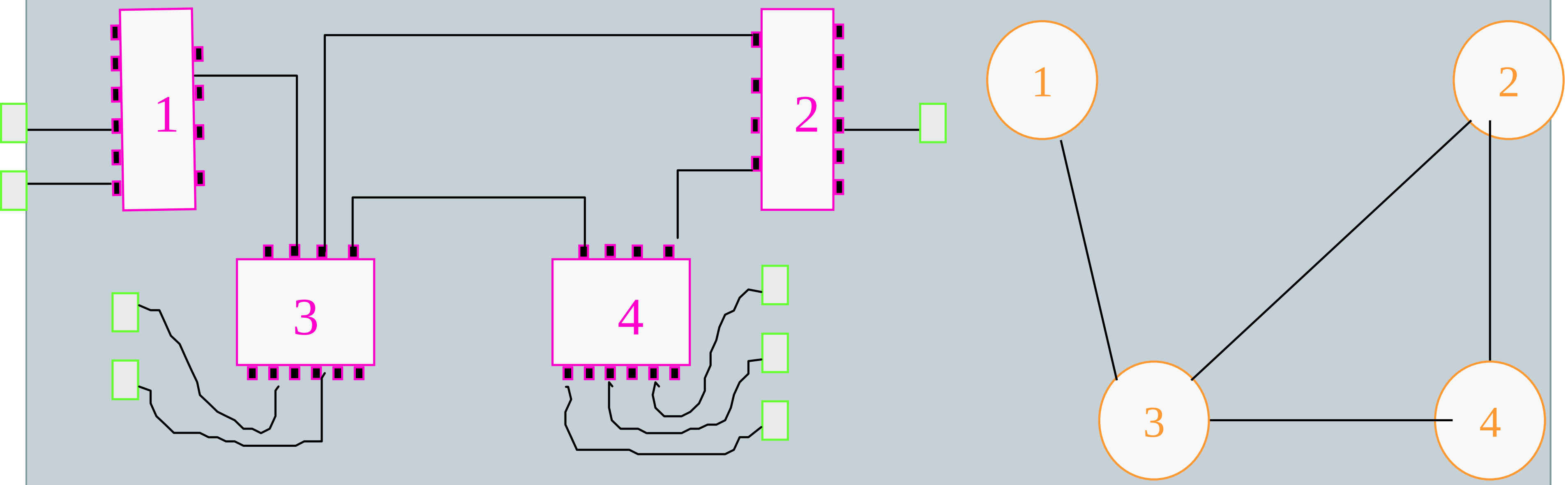
- More computers means more traffic
- Can add capacity to WAN by adding more links and packet switches
- Packet switches need not have computers attached
  - Interior switch: no attached computers
  - Exterior switch: attached computers

Routing in a WAN

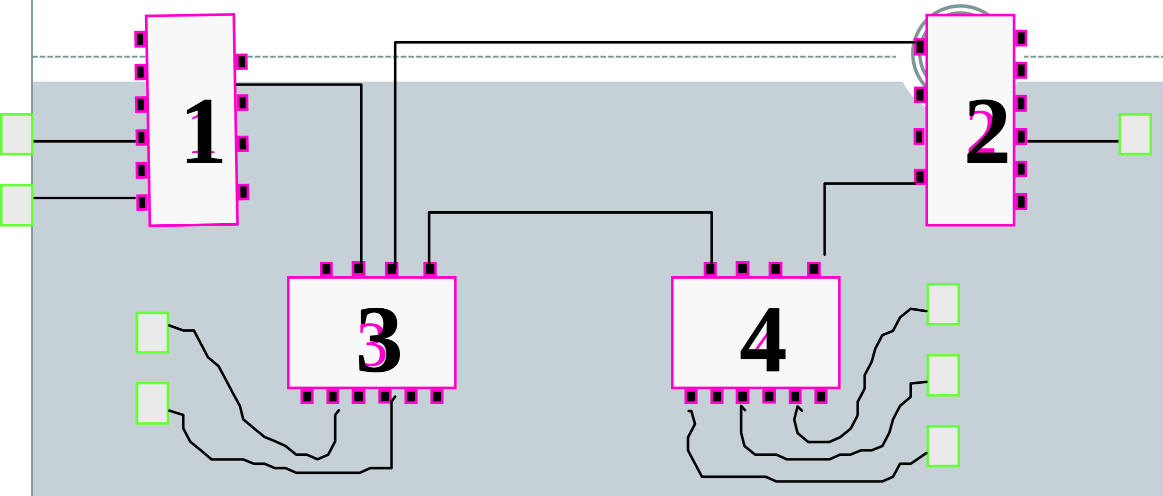
- Both interior and exterior switches must:
  - Forward packets
  - Need routing tables
- Must have:
  - *Universal routing*: next hop for each possible destination
  - *Optimal routes*: next hop in table must be on shortest path to destination

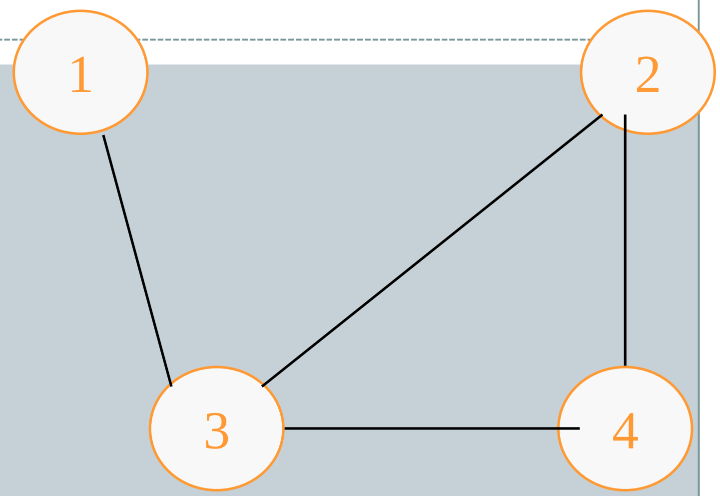
Modeling a WAN

- Use a graph:
  - *Nodes* model *switches*
  - *Edges* model *direct connections* between switches
- Captures essence of network, ignoring attached computers



Routing in a WAN





destin-ation	next hop
1	-
2	(1,3)
3	(1,3)
4	(1,3)

node 1

destin-ation	next hop
1	(2,3)
2	-
3	(2,3)
4	(2,4)

node 2

destin-ation	next hop
1	(3,1)
2	(3,2)
3	-
4	(3,4)

node 3

destin-ation	next hop
1	(4,3)
2	(4,2)
3	(4,3)
4	-

node 4

Route Computation With a Graph

- Can represent routing table with edges:

node 1

destin-ation	next hop
1	-
2	(1,3)
3	(1,3)
4	(1,3)

node 2

destin-ation	next hop
1	(2,3)
2	-
3	(2,3)
4	(2,4)

node 3

destin-ation	next hop
1	(3,1)
2	(3,2)
3	-
4	(3,4)

node 4

destin-ation	next hop
1	(4,3)
2	(4,2)
3	(4,3)
4	-

- Graph algorithms can be applied to find routes

Redundant Routing Information

- Notice duplication of information in routing table for node 1:

destin-ation	next hop
1	-
2	*(1,3)*
3	*(1,3)*
4	*(1,3)*

node 1

destin-ation	next hop
1	(2,3)
2	-
3	(2,3)
4	(2,4)

node 2

destin-ation	next hop
1	(3,1)
2	(3,2)
3	-
4	(3,4)

node 3

destin-ation	next hop
1	(4,3)
2	(4,2)
3	(4,3)
4	-

node 4

- Switch 1 has only one outgoing connection; all traffic must traverse that connection

destin-ation	next hop
1	-
2	*(1,3)*
3	*(1,3)*
4	*(1,3)*

node 1

destin-ation	next hop
1	-
*	(1,3)

node 1

destin-ation	next hop
1	(2,3)
2	-
3	(2,3)
4	(2,4)

node 2

destin-ation	next hop
2	-
4	(2,4)
*	(2,3)

node 2

destin-ation	next hop
1	(3,1)
2	(3,2)
3	-
4	(3,4)

node 3

destin-ation	next hop
1	(3,1)
2	(3,2)
3	-
4	(3,4)

node 3

destin-ation	next hop
1	(4,3)
2	(4,2)
3	(4,3)
4	-

node 4

destin-ation	next hop
2	(4,2)
4	-
*	(4,3)

node 4

Default Routes

- Can collapse routing table entries with a default route
- If destination does not have an explicit routing table entry, use the default route:
- Use of default route is optional (see node 3)

destin-ation	next hop
1	-
*	(1,3)

node 1

destin-ation	next hop
2	-
4	(2,4)
*	(2,3)

node 2

destin-ation	next hop
1	(3,1)
2	(3,2)
3	-
4	(3,4)

node 3

destin-ation	next hop
2	(4,2)
4	-
*	(4,3)

node 4

Building Routing Tables

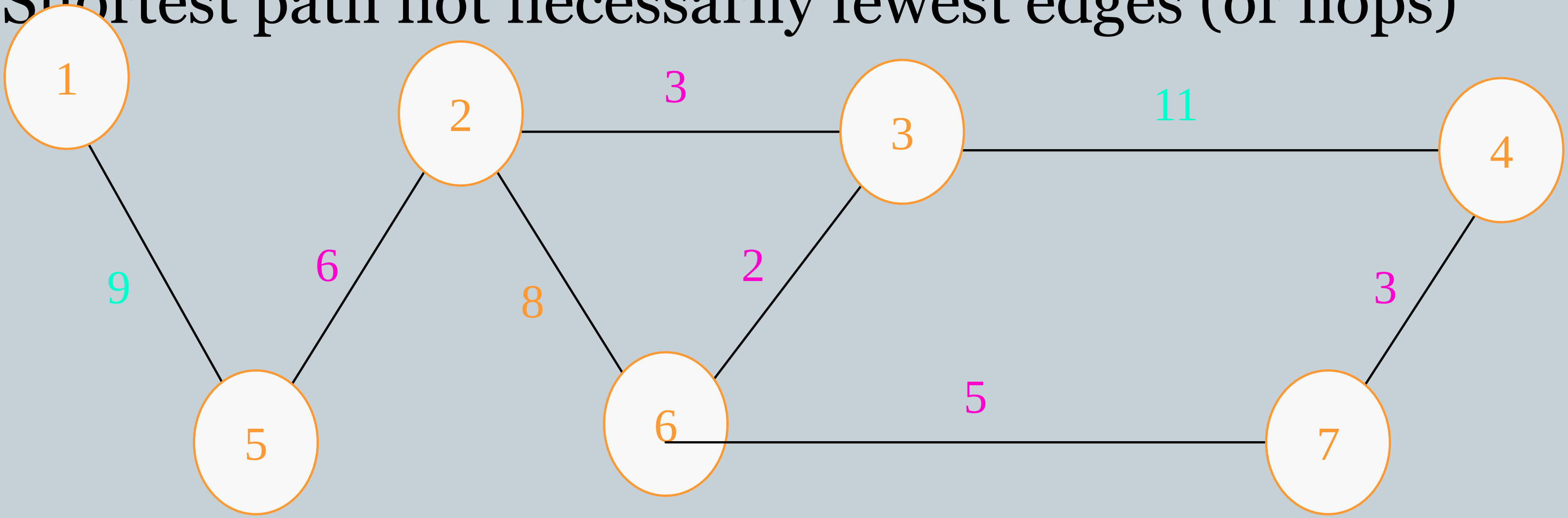
- How to enter information into routing tables:
  - Manual entry: initialization file
  - Dynamically: through runtime interface
- How to compute routing table information:
  - Static routing: build routing table at boot time
    - It is simpler; low overhead; doesn't accommodate changes to network topology
  - Dynamic routing: allow periodic updates
    - requires additional protocol(s); monitor traffic; modify routes as a result of network failures

Computation of Shortest Path in a Graph

- Assume graph representation of network at each node
- Use Djikstra's algorithm to compute shortest path from each node to every other node
- Extract next-hop information from resulting path information
- Insert next-hop information into routing tables

Weighted Graph

- Djikstra's algorithm can accommodate weights on edges (link) in the graph
- Shortest path is the path with lowest total weight (sum of weights of all edges)
- Shortest path not necessarily fewest edges (or hops)

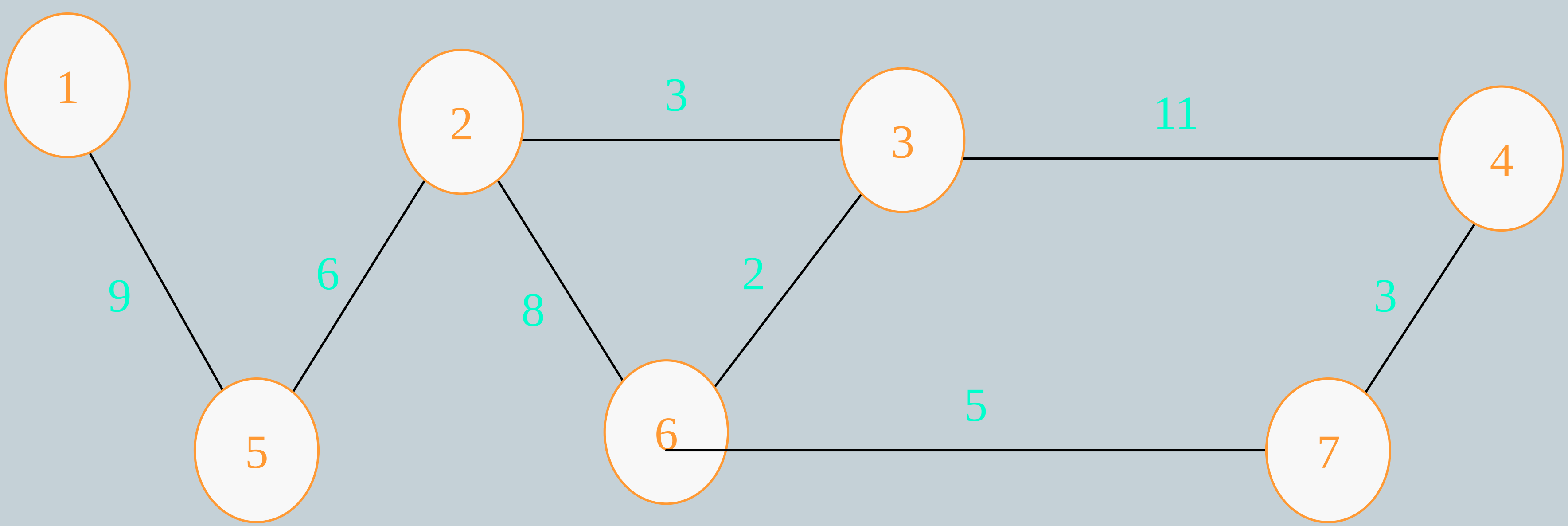


Synopsis of Djikstra's Algorithm

- Keep data structure with list of nodes and weights of paths to those nodes
- Use infinity to represent a node in the set S of nodes for which a path has not yet been computed
- At each iteration, find a node in S, compute the path to that node, and delete the node from S

Distance Metrics

- Weights on graph edges reflect "cost" of traversing edge
  - Time
  - Dollars
  - Hop count (weight == 1)
- Resulting shortest path may not have fewest hops



Dynamic Route Computation

- **Dynamic routing**, also called **adaptive routing**, describes the capability of a system, through which routes are characterized by their destination, to alter the path that the route takes through the system in response to a change in conditions
- Network topology may change dynamically
  - Switches may be added
  - Connections may fail
  - Costs for connections may change
- Switches must update routing tables based on topology changes

Distributed Route Computation

- Each packet switch computes its routing table locally
- Send result to neighboring packet switches
- Pass information about network topology between nodes
- Update information periodically in case of failures

Vector-distance Algorithm

- Local information is next-hop routing table and distance from each switch
- Switches periodically broadcast routing information (*destination*, *distance*)
- Other switches update routing table based on received information

Vector-Distance Algorithm (Continued)

- Wait for next update message
- Iterate through entries in message
- If entry has shorter path to destination:
  - Insert source as the next hop to destination
  - Record distance as distance from next hop to destination PLUS distance from this switch to next hop

Link-state Routing (Shortest Path First)

- Separates network topology from route computation
- Switches send link-state information about local connections
- Each switch builds own routing tables
- Uses link-state information to update global topology
- Runs Djikstra's algorithm

Comparison

- Vector-distance algorithm
  - Very simple to implement
  - May have convergence problems
  - Used in RIP (Routing Inf. Protocol)
- Link-state algorithm
  - Much more complex
  - Switches perform independent computations
  - Used in OSPF (Open Shortest Pass First)

Examples of WAN Technologies: ARPANET

- Was the first large-scale store-forward packet-switched network in 1960s
- Funded by Advanced Research Projects Agency (ARPA), an organization of the DOD to be used in battlefield conditions that uses 56Kbps leased lines
- Left a legacy of concepts, algorithms, and terminology which lead to Internet with TCP/IP Software
- Interconnected NSFNET and ARPANET

The CCITT X.25 Standard

- Standard set by ITU (International Telecom Union) which was originally CCITT (Consultative Committee for International Telegraphy & Telephony) in 1970s
- It is connection-oriented & supports both switched virtual circuits & permanent ones
- It was revised for computer communications in 1980, ‘84, 88, 92, and 93
- Provides an interface between public packet networks & their customers
- X.25 comprises the first 3 layers: physical layer, the data link layer & the network layer
- It is probably the most widely used protocol standard in Europe

Integrated Service Digital Network (ISDN)

- Integrates phone service with WAN service
- Digital signal over phone line transmits digitized voice and/or data
- Basic Rate Interface (BRI) provides 144Kbps
  - B channel (Bearer) provides 64Kbps data transmission
  - D channel (Delta) used for control (16Kbps)
  - BRI includes 2 B channels and 1 D channel
- Audio digitized using pulse code modulation (PCM)
- BISDN provides 3 channels with 150 MPbs

Frame Relay

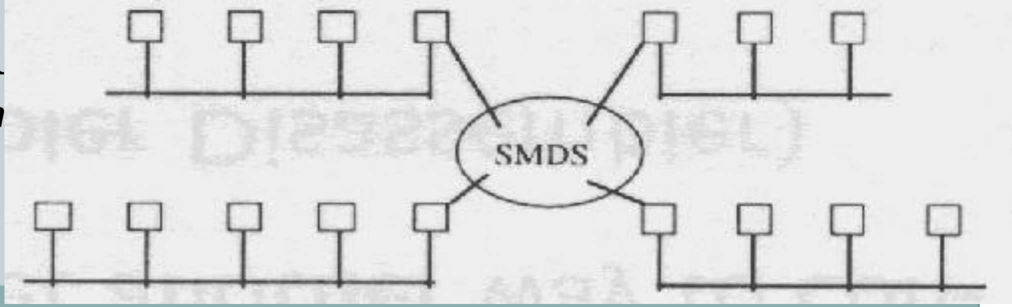
- A significant advance over traditional PS & X.25
  - eliminate much of the overhead imposed on the end user systems and PS network to move bits at reasonable speed at a low cost
  - No hop-by-hop flow control & error control; only end-to end
- Connection-based service; must contract with telco for circuit between two endpoints (as virtual leased line)
- Typically 56Kbps, 1.5, 2Mbps; can run to 100Mbps

Frame Relay

- Variable size packets (Frames) may be up to 1600 bytes
- Lower delay & higher throughput, since internal processing is reduced, as is the protocol functionality at the user-network interface
- Call control signaling is on a separate logical connection from user data
- Multiplexing & switching of logical connections take place in layer 2

SMDS: Switched Multi-megabit Data Service

- Known as Connectionless Broadband Data Service (*CBDS*) in Europe
- SMDS used to connect LANs
- SMDS is designed to handle bursty traffic (1.5-100Mbps)
- SMDS service: simple connectionless packet service
- It is a Connectionless data service public network
- Any SMDS station can sen
on the same SMDS "cloud"



ATM: Asynchronous Transfer Mode

- A cell-switching technology designed to provide:
  - Universal information carrier for voice, video, & data
  - Low jitters (variance in delivery time) and high capacity
  - Small & fixed size cells: 48 octets data & 5 octets header
- Connection-oriented
- Can connect multiple ATM switches into a network
- Example services: video on demand, live TV from many sources, full motion multimedia E-mail, CD-quality music, high-speed data transport, LAN interconnection

ATM

- Normal speed for ATM networks is 155 Mbps, 622 Mbps, and future gigabit speed
- The ATM Forum: an international group that guides the future of ATM

Other Store-and Forward PS Networks

- Networks differ in routing, flow control, addressing, and in the way these functions are organized
- IBM's *System Networks Architecture (SNA)* started in 1974
- Digital Equipment's *DECnet* in 1975
- Siemens' *TRANDATA* in 1978
- Distributed Queue and Dual Bus (DQDB) is a MAN standard consists of two unidirectional buses (cables) to which all computers are connected

Summary

- WAN can span arbitrary distances and interconnect arbitrarily many computers
- Uses packet switches and point-to-point connections
- Packets switches use store-and-forward and routing tables to deliver packets to destination
- WANs use hierarchical addressing
- Graph algorithms can be used to compute routing tables
- Many LAN technologies exist

Comparison of Networking Services

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Issue	DQDB	SMDS	X.25	Frame relay	ATM
Connection oriented	Yes	No	Yes	Yes	Yes
Normal speed(Mbps)	45	45	.064	2	155
Switched	No	Yes	Yes	No	Yes
Fixed-size payload	Yes	No	No	No	Yes
Max payload	44	9188	128	1600	48
Permanent VCs	No	No	Yes	Yes	No
Multicasting	No	Yes	No	No	Yes