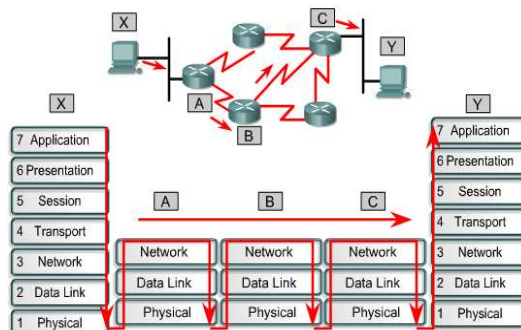


Data communication I

Lecture 7 – Routing

Routing

- Layer 3 – network layer
- Router makes choice about the best path through a network
 - Based on fairness, stability, efficiency, simplicity etc.



Comparison postal system and computer network

IP-addresses

Decimal	11001000	01110010	00001110	00110011
Binary	200	114	6	51
	number	dot	number	dot
			number	dot
				number

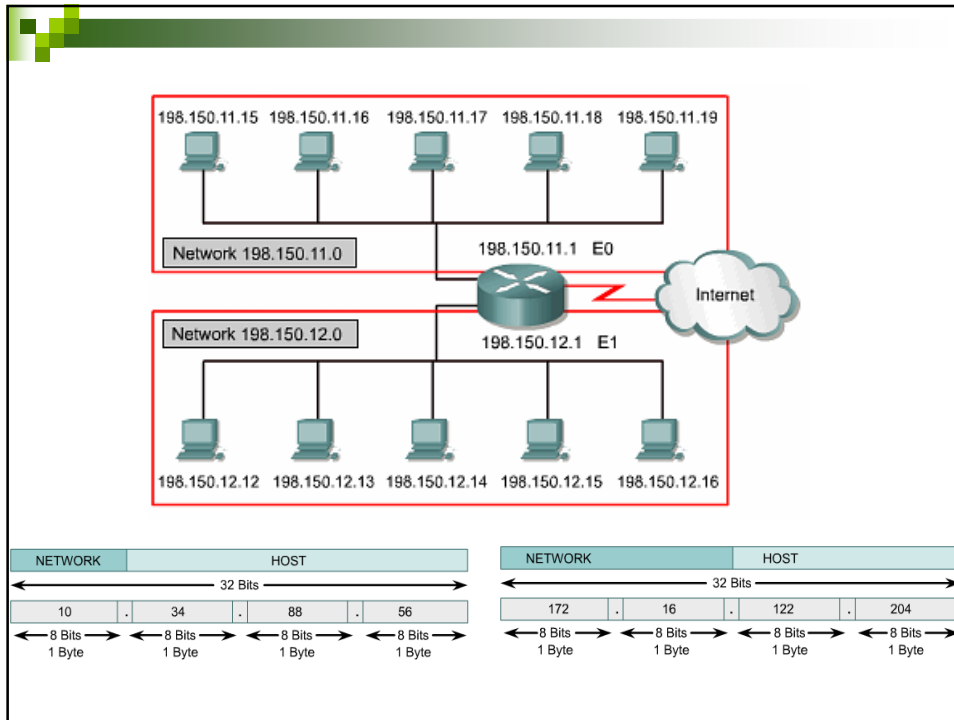
IP-address in binary and dotted decimal form

- IP-addresses are used to identify a network and a specific host on that network
- Soon switch between IPv4 and IPv6 addresses (due to limited number of IPv4 addresses)

Internet Protocol Version 4 (IPv4)	4 octets
11010001.11011100.11001001.01110001	
209.156.201.113	
4,294,467,295 IP addresses	

Internet Protocol Version 6 (IPv6)	16 octets
11010001.11011100.11001001.01110001.11010001.11011100	
110011001.01110001.11010001.11011100.11001001	
01110001.11010001.11011100.11001001.01110001	
A524:72D3:2C80:DD02:0029:EC7A:002B:EA73	
3.4 x 10 ³⁸ IP addresses	

Address space in IPv4 and IPv6



When and where are routing decisions made?

- Depends on switching strategy used
 - Packet switching with datagrams
 - Each packet is routed individually
 - Decision is made at the router when a packet arrives
 - Packet switching with virtual circuit
 - Decision is made before the virtual circuit is established
 - Each packet is then routed the same way

Routing strategies

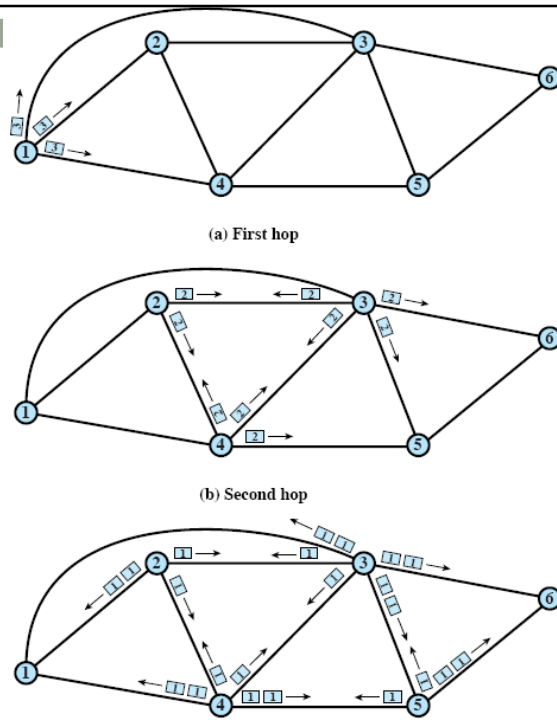
- How does the router get the necessary information for the routing decision?
 - Static/fixed routing
 - Static routes entered by a network administrator
 - Not automatically adaptable to changes in the network
 - Flooding
 - A router sends out a packet on all connected ports except the one the packet came through
 - Duplicate packets are discarded
 - Maximum hop count limits the flooding
 - All possible paths are tried and thereby automatically even the optimal one
 - Random routing
 - An incoming packet is sent out on one, randomly chosen port
 - Dynamic routing
 - **routing protocol** is used to dynamically adapt to changes

Example of static routing tables in each router

Node 1 Directory		Node 2 Directory		Node 3 Directory	
Destination	Next Node	Destination	Next Node	Destination	Next Node
2	2	1	1	1	5
3	4	3	3	2	5
4	4	4	4	4	5
5	4	5	4	5	5
6	4	6	4	6	5

Node 4 Directory		Node 5 Directory		Node 6 Directory	
Destination	Next Node	Destination	Next Node	Destination	Next Node
1	2	1	4	1	5
2	2	2	4	2	5
3	5	3	3	3	5
5	5	4	4	4	5
6	5	6	6	5	5

Example of flooding with a hop count of 3



Routing protocols

- Dynamic routing is based on common routing protocols to continuously adapt to changes in the network
- Variety of known routing algorithms
 - What criterion (metric) is used to determine the best path between two nodes?
 - Minimum number of hops
 - Delay
 - Throughput
 - "Cost"
 - What protocol is used to collect the necessary information to find this best path?
 - Distributed or centralized solution?

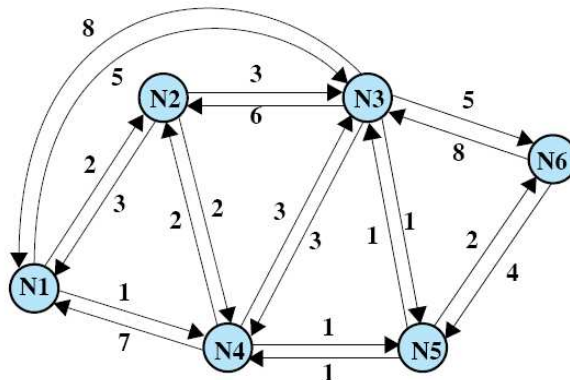
Adaptive routing

■ Advantages

- Improves performance
- No manual updates needed (as compared to fixed routing)
- Network is not flooded with (potentially unnecessary) packets (as compared to flooding)
- There is no random factor determining the best path but a qualified decision is possible

■ Drawbacks

- Routing decision more complex
- Extensive overhead to keep routers up to date with the current network situation
- It takes time for network changes to propagate to all affected routers in the network



■ Network with link cost in each direction

- Link cost could be related to monetary cost, delay, data rates etc.
- The shortest path is not necessarily the fastest, most reliable, cheapest etc.

Adaptive routing

- "Least cost" routing
 - Minimize number of hops, cost, delay etc.
 - Most popular routing strategies in packet switched networks
 - Two types of routing strategies:
 - Link-state routing
 - Based on Dijkstra's algorithm
 - Distance vector routing
 - Based on the Bellman-Ford algorithm

Distance vector vs link state

- Distance vector routing

Distance Vector	RIP v1 and RIP v2 Interior Gateway Routing Protocol (IGRP)	<ul style="list-style-type: none">• Copies routing table to neighbors• Updates frequently• RIP v1 and RIP v2 use hop count as metric• Views the network from the perspective of the neighbors• Slow to converge• Susceptible to routing loops• Easy to configure and administer• Consumes a lot of bandwidth
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Routing table

- Present in each router
- Fixed entries or updated dynamically

<i>Destination</i>	<i>Distance</i>	<i>Next hop</i>
Net 2	3	Router D
Net 7	1	Direct
Net 8	1	Direct
Net 12	8	Router D
Net 18	2	Router C
Net 23	5	Router B

Routing table in Router A

<i>Destination</i>	<i>Distance</i>	<i>Next hop</i>
Net 2	3	Router D
Net 7	1	Direct
Net 8	1	Direct
Net 12	8	Router D
Net 18	2	Router C
Net 23	5	Router B

Routing update *from* Router B

<i>Destination</i>	<i>Distance</i>
Net 2	1
Net 5	14
Net 8	2
Net 12	7
Net 18	2
Net 23	10

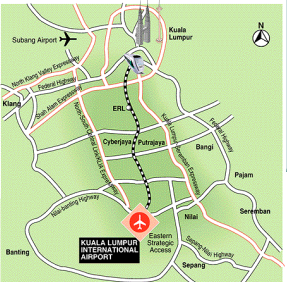
Routing table in Router A after updating

<i>Destination</i>	<i>Distance</i>	<i>Next hop</i>	<i>Note</i>
Net 2	2	Router B	Lower cost via Router B
Net 5	15	Router B	New destination
Net 7	1	Direct	
Net 8	1	Direct	
Net 12	8	Router D	
Net 18	2	Router C	
Net 23	11	Router B	Changed cost

Distance vector vs link state

■ Link state

Link-State	Open Shortest Path First (OSPF) Intermediate-System to Intermediate-System (IS-IS)	<ul style="list-style-type: none">• Uses shortest path• Updates are event triggered• Sends link-state packets to all network routers• Has common view of network• Fast to converge• Not as susceptible to routing loops• Harder to configure• Requires more memory and processing power than distance vector• Consumes less bandwidth than distance vector
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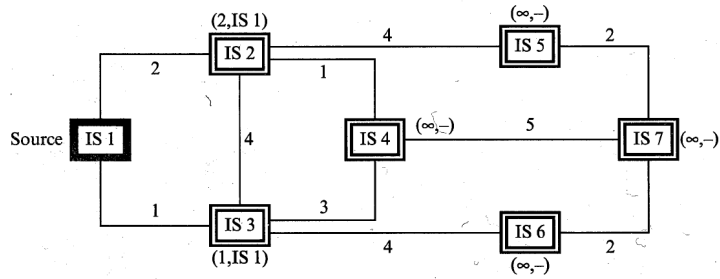


How does a "link state" router obtain its up-to-date view of the network?

→ Dijkstra's Algorithm

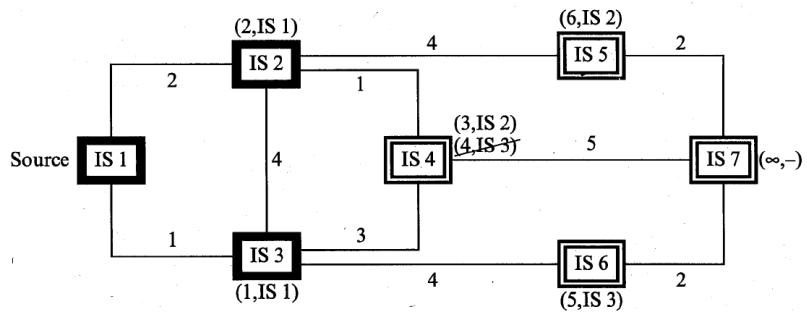
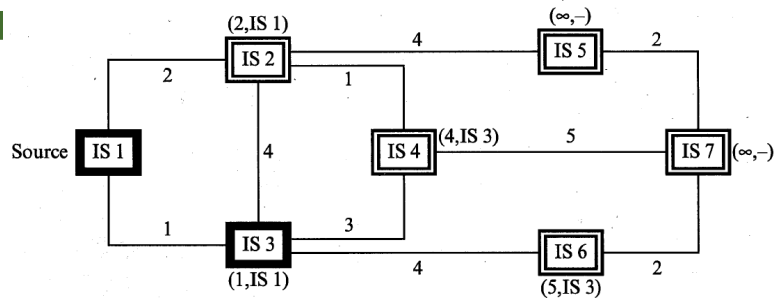
- Find shortest (least cost) path from a given source router to all other routers in the network
- Algorithm proceeds in stages away from the source router where the shortest (least cost) path is determined at each stage
- Each router uses Dijkstra's algorithm to obtain a complete view of the network

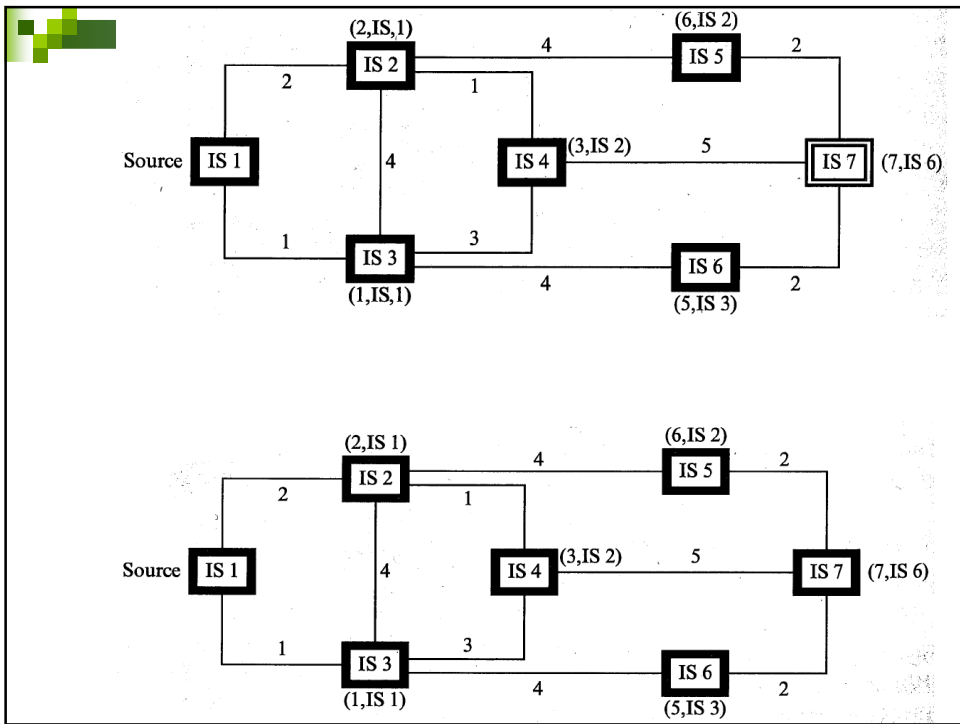
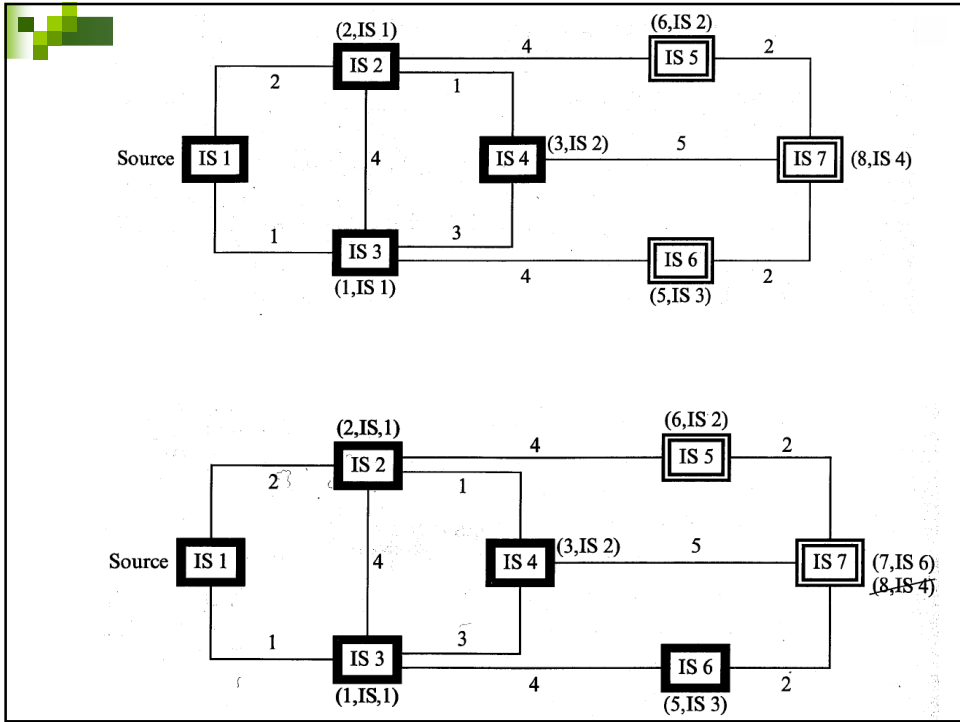
Dijkstra's Algorithm



IS = Intermediate System
(=router)

F. Halsall, *Data Communications, Computer Networks and Open Systems (4th ed.)*, Addison-Wesley, 1996.







Key terms

- Routing protocol
- IP-address
- IPv4 vs IPv6 addresses
- Network part vs host part in an IP address
- Static/fixed routing
- Flooding
- Random routing
- Adaptive/dynamic routing
- Metric
- Link state routing
- Distance vector routing
- Routing table
- Bellman Ford algorithm
- Dijkstra's algorithm