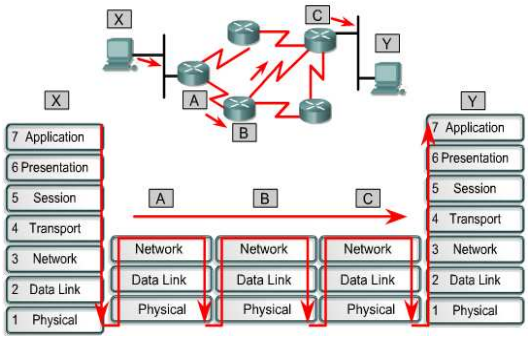
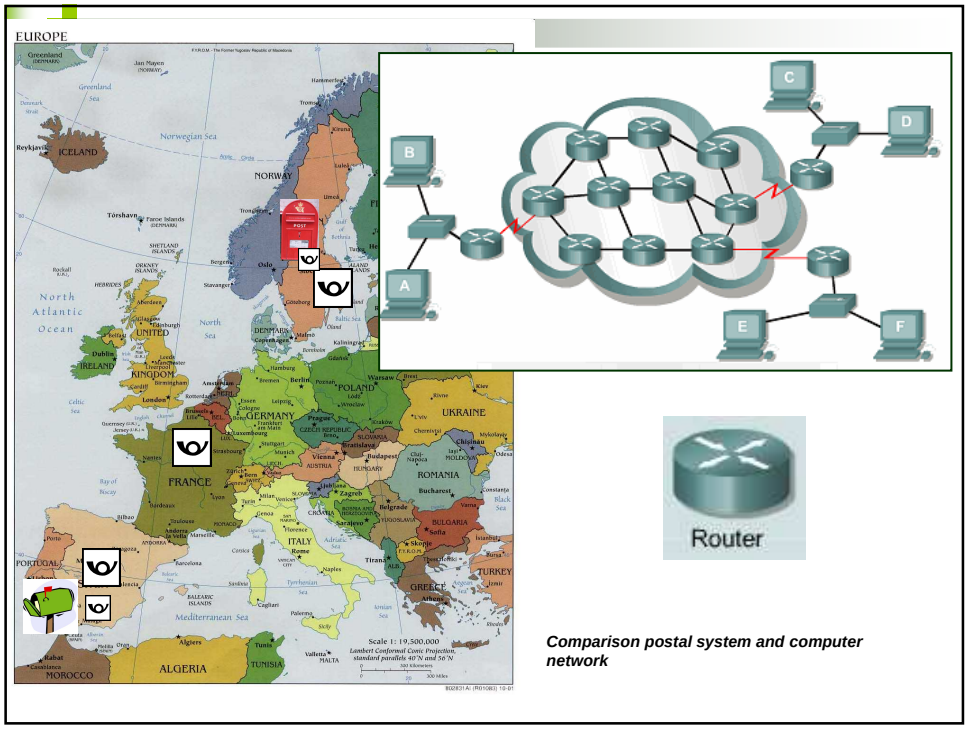
Data communication I

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		00000110		00110011
Binary	200	.	114	.	6	.	51
	number	dot	number	dot	number	dot	number

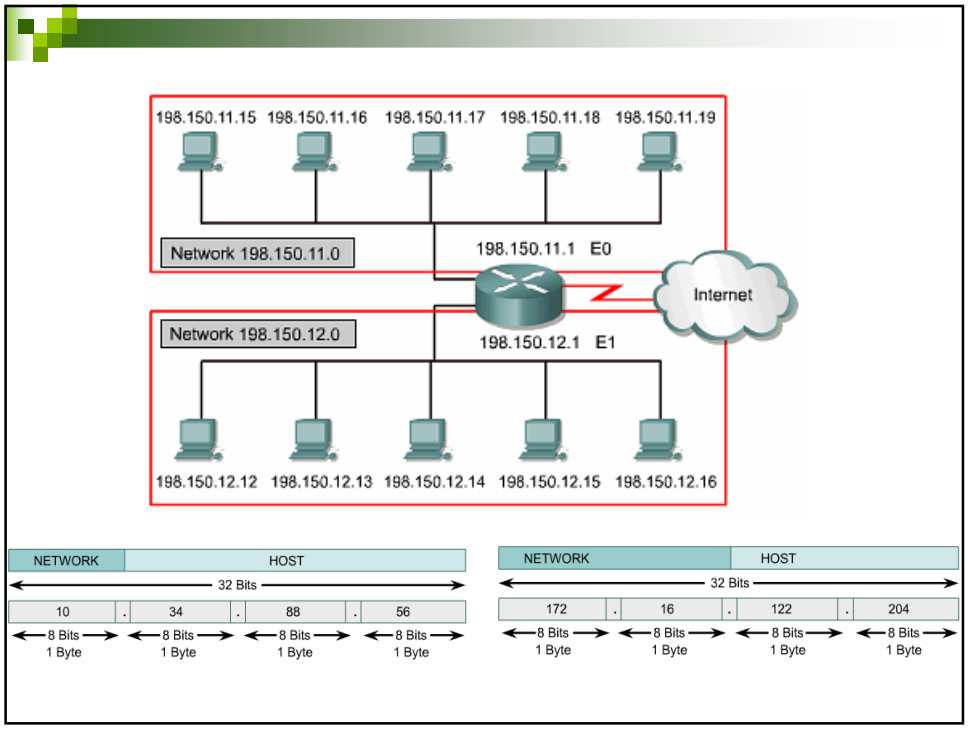
IP-address in binary and dotted decimal form

- 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	
11001001.01110001.11010001.11011100.11001001	
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

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

Node 2 Directory

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

Node 3 Directory

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

Node 4 Directory

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

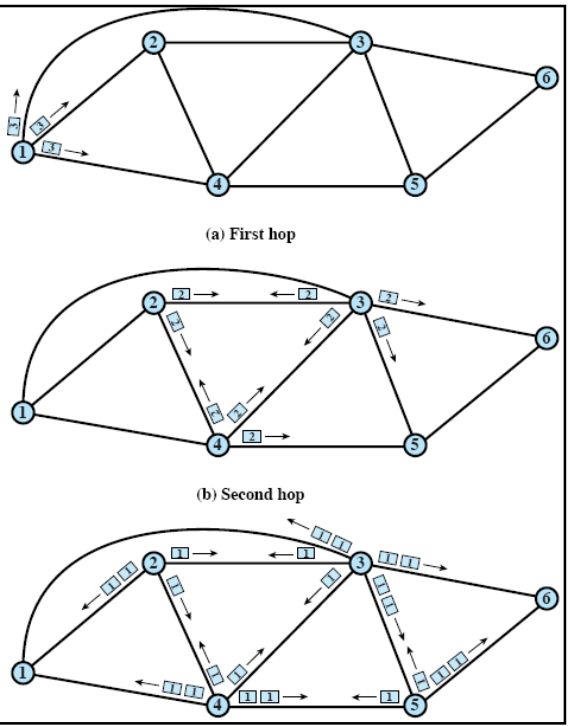
Node 5 Directory

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

Node 6 Directory

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

Example of flooding with a hop count of 3

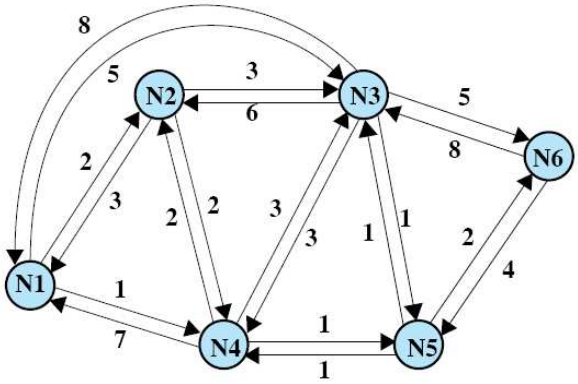


Routing protocols

- 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)	• 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

Routing table

- Present in each router
- Fixed entries or updated dynamically

Destination	*Distance*	*Next hop*
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

Destination	*Distance*	*Next hop*
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

Destination	*Distance*
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

Destination	*Distance*	*Next hop*	*Note*
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

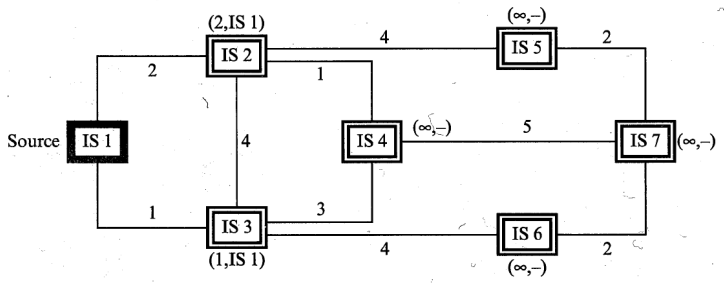
Link-State	Open Shortest Path First (OSPF) Intermediate-System to Intermediate-System (IS-IS)	• Uses shortest path • Updates are event triggered • Sends link-state packets to all network routers • Has common view of network • Fast to converge • Not as susceptible to routing loops • Harder to configure • Requires more memory and processing power than distance vector • Consumes less bandwidth than distance vector

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

→Dijkstra’s Algorithm

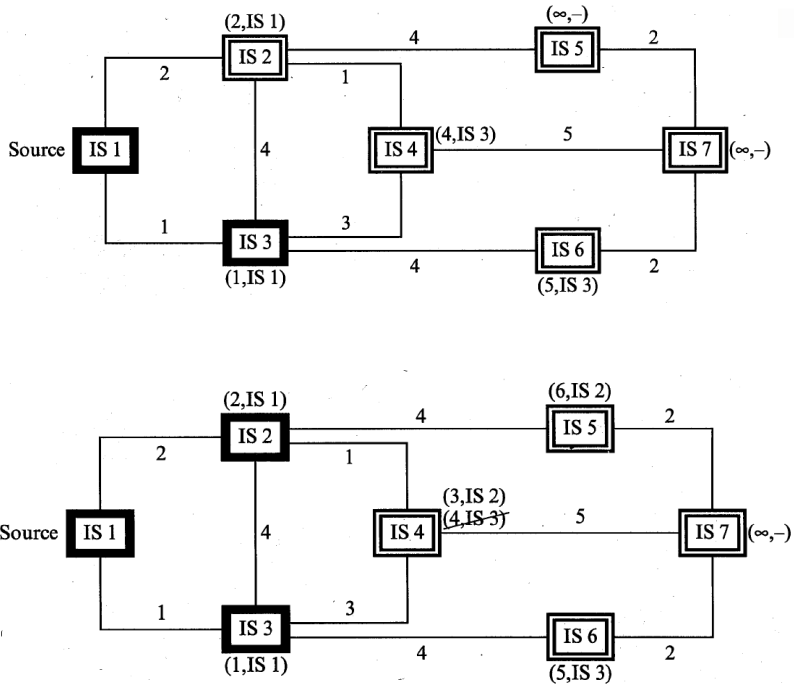
- Find shortest (least cost) path from a given source router to all other routers in the network
- Algorithm proceeds in stages away from the source router where the shortest (least cost) path is determined at each stage
- Each router uses Dijkstra’s algorithm to obtain a complete view of the network

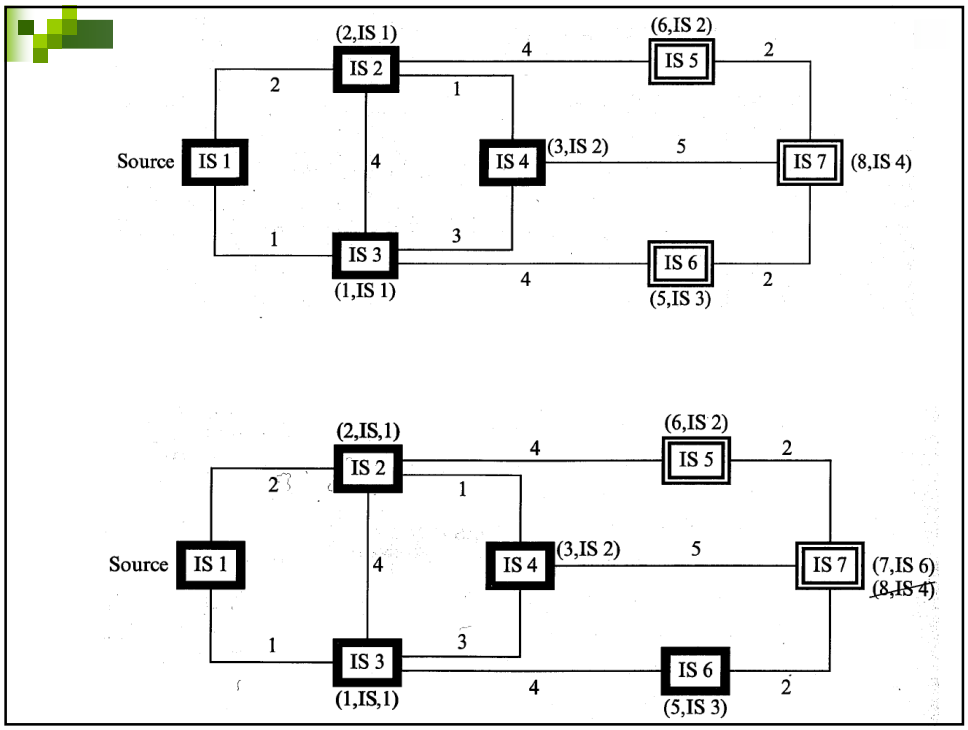
Dijkstra's Algorithm

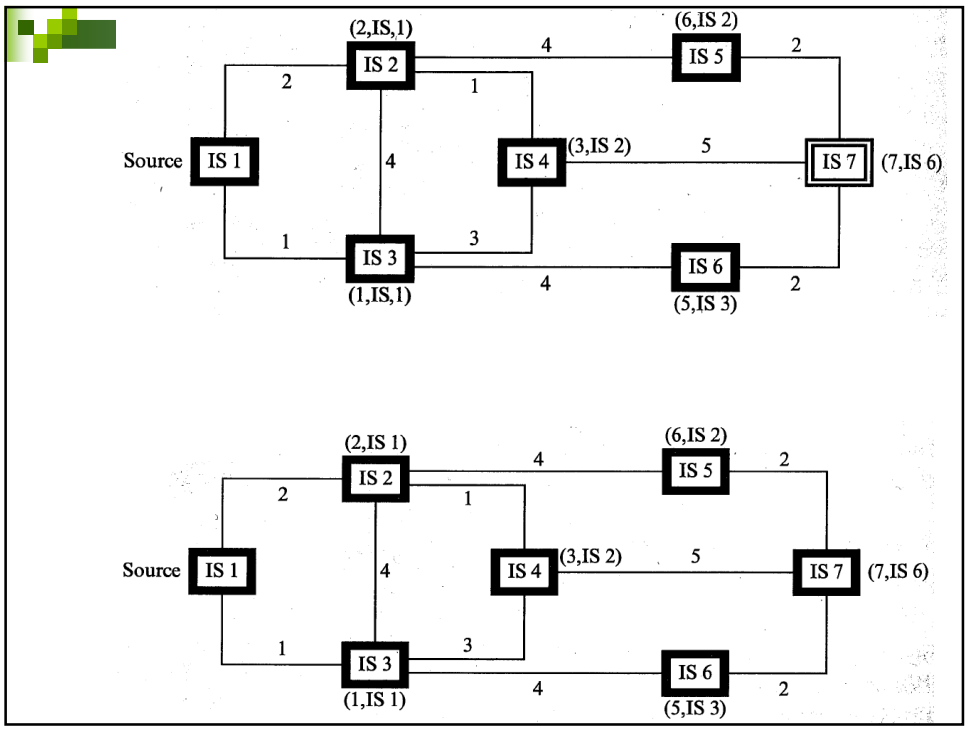


IS = Intermediate System
(=router)

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




(2,IS 1)
IS 2
(6,IS 2)
IS 5
4
2
2
1
Source
IS 1
4
IS 4
(3,IS 2)
5
IS 7
(8,IS 4)
1
3
IS 3
IS 6
(1,IS 1)
4
2
(5,IS 3)
(2,IS,1)
IS 2
(6,IS 2)
IS 5
4
2
2
1
Source
IS 1
4
IS 4
(3,IS 2)
5
IS 7
(7,IS 6)
(8,IS 4)
1
3
IS 3
IS 6
(1,IS,1)
4
2
(5,IS 3)


(2,IS,1)
IS 2
(6,IS 2)
IS 5
4
2
2
1
Source
IS 1
4
IS 4
(3,IS 2)
5
IS 7
(7,IS 6)
1
3
IS 3
IS 6
(1,IS,1)
4
2
(5,IS 3)
(2,IS 1)
IS 2
(6,IS 2)
IS 5
4
2
2
1
Source
IS 1
4
IS 4
(3,IS 2)
5
IS 7
(7,IS 6)
1
3
IS 3
IS 6
(1,IS 1)
4
2
(5,IS 3)

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