COMPUTER NETWORKS

UNIT - 3

CONTENTS

- **Network Layer: Design issues**
- **Routing algorithms: The Optimality Principle, Shortest Path Algorithm, Flooding, Distance Vector Routing, Link State Routing, OSPF, BGP.**
- **Congestion Control Algorithms**
- **Quality of Service**
- **Internetworking**
- **The Network layer in the Internet - The IP Version 4 Protocol, Fragmentation and IP Addresses, CIDR Notation, IP Version 6, Internet Control Protocols.**
- **Basics of IP Support Protocols (ARP/RARP, DHCP, ICMP)**
- **Network Address Translation (NAT)**

Previous Layers

- The purpose of the physical layer is to transport a raw bit stream from one machine to another.
- The main task of the data link layer is to transform a raw transmission faculty into a line that appears free of undetected transmission errors to the network layer.

- This layer is concerned with getting packets from the source all the way to the destination.
- Getting to the destination may require making many hops at intermediate routers along the way.
- Thus, the network layer is the lowest layer that deals with end-to-end transmission.
- To achieve its goals, the network layer must know about the topology of the communication subset (i.e., the set of all routers) and choose appropriate paths through it.
- It must also take care to choose routes to avoid overloading some of the communication lines and routers while leaving others idle.

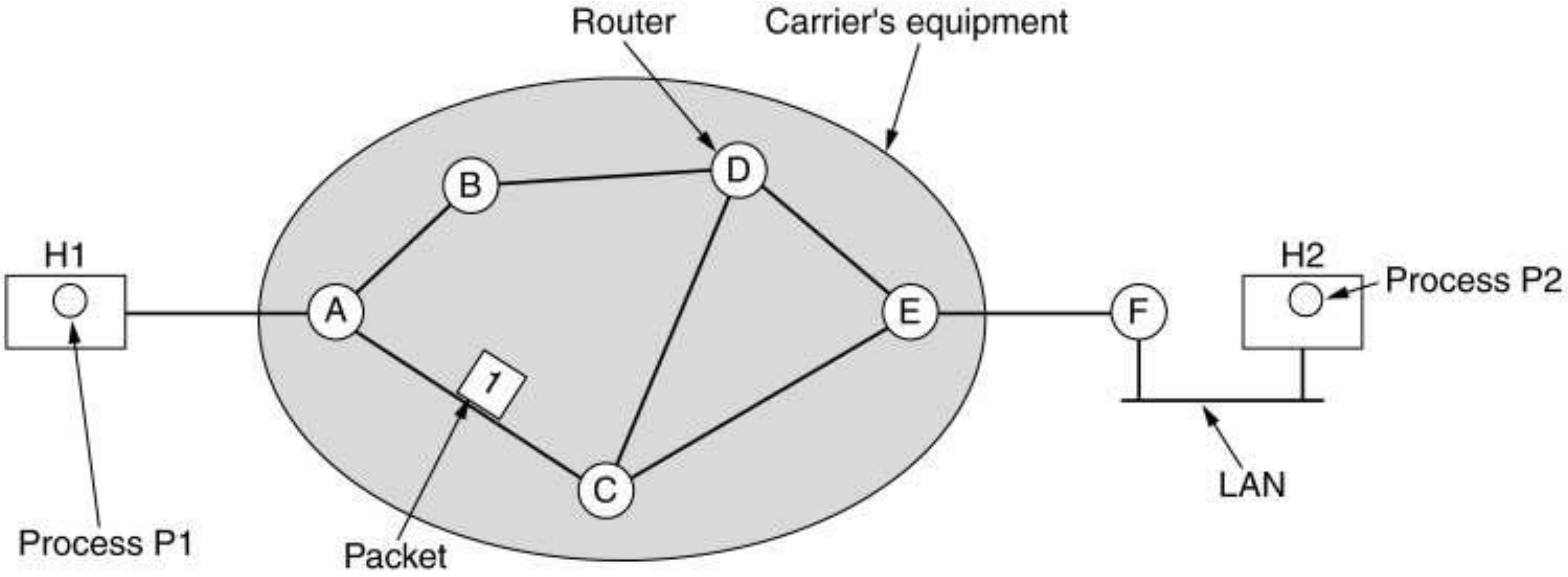
- Finally, when the source and destination are in different networks, new problems occur. It is up to the network layer to deal with them.
- In this chapter we will study all these issues and illustrate them, primarily using the Internet and its network layer protocol, IP, although wireless networks will also be addressed.

NETWORK LAYER DESIGN ISSUES

- In the following sections we will provide an introduction to some of the issues that the designers of the network layer must grapple with.
- These issues include the service provided to the transport layer and the internal design of the subnet.
  - ✓ Store-and-Forward Packet Switching
  - ✓ Services Provided to the Transport Layer
  - ✓ Implementation of Connectionless Service
  - ✓ Implementation of Connection-Oriented Service
  - ✓ Comparison of Virtual-Circuit and Datagram Subnets

Store-and-Forward Packet Switching

- Let us restate the context in which the network layer protocols operate.



The environment of the network layer protocols.

Store-and-Forward Packet Switching

- A host with a packet to send transmits it to the nearest router, either on its own LAN or over a point-to-point link to the carrier.
- The packet is stored there until it has fully arrived so the checksum can be verified.
- Then it is forwarded to the next router along the path until it reaches the destination host, where it is delivered.
- This mechanism is store-and-forward packet switching, as we have seen in previous chapters.

Services Provided to the Transport Layer

- The network layer provides services to the transport layer at the network layer/transport layer interface.
- An important question is what kind of services the network layer provides to the transport layer.
- The network layer services have been designed with the following goals in mind.
  a. The services should be independent of the outer technology.
  b. The transport layer should be shielded from the number, type, and topology of the routers present.
  c. The network addresses made available to the transport layer should use a uniform numbering plan, even across LANs and WANs.

Services Provided to the Transport Layer

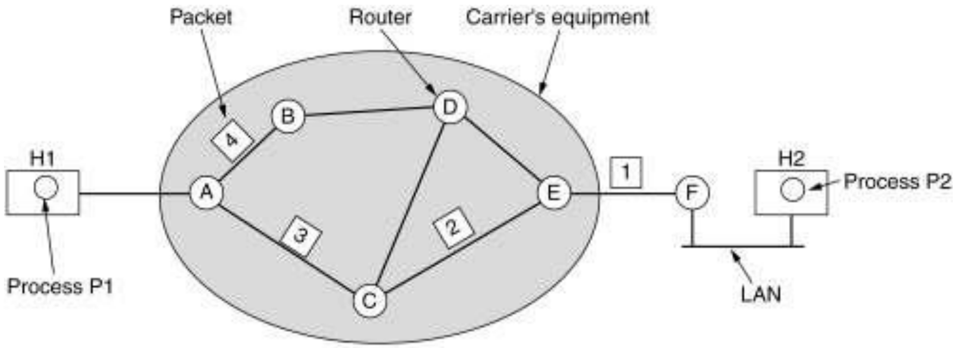
- The discussion centers on whether the network layer should provide connection oriented service or connectionless service.
- Internet community's opinion: the routers' job is moving packets around and nothing else. The subnet is inherently unreliable. Therefore, the hosts should accept the fact that the network is unreliable and do error control and flow control themselves.
- This viewpoint leads quickly to the conclusion that the network service should be connectionless, with primitives SEND PACKET and RECEIVE PACKET.
- Furthermore, each packet must carry the full destination address, because each packet sent is carried independently of its predecessors, if any.

Services Provided to the Transport Layer

- Telephone companies' opinion: the subnet should provide a reliable, connection oriented service.
- In this view, quality of service is the dominant factor, and without connections in the subnet, quality of service is very difficult to achieve, especially for real-time traffic such as voice and video.
- The Internet offers connectionless network layer service.
- ATM networks offer connection-oriented network-layer service.
- However, it is interesting to note that as quality-of-service guarantees are becoming more and more important, the Internet is evolving.

Implementation of Connectionless Service

- If connectionless service is offered, packets are injected into the subnet individually and routed independently of each other.
- In this context, the packets are frequently called datagrams and the subnet is called a datagram subnet.



Dest.	A's table initially (Line)	A's table later (Line)	C's table (Line)	E's table (Line)
A	–	–	A	C
B	B	B	A	D
C	C	C	–	C
D	B	B	D	D
E	C	B	E	–
F	C	B	E	F

Dest. Line

Routing within a diagram subnet.

Implementation of Connectionless Service

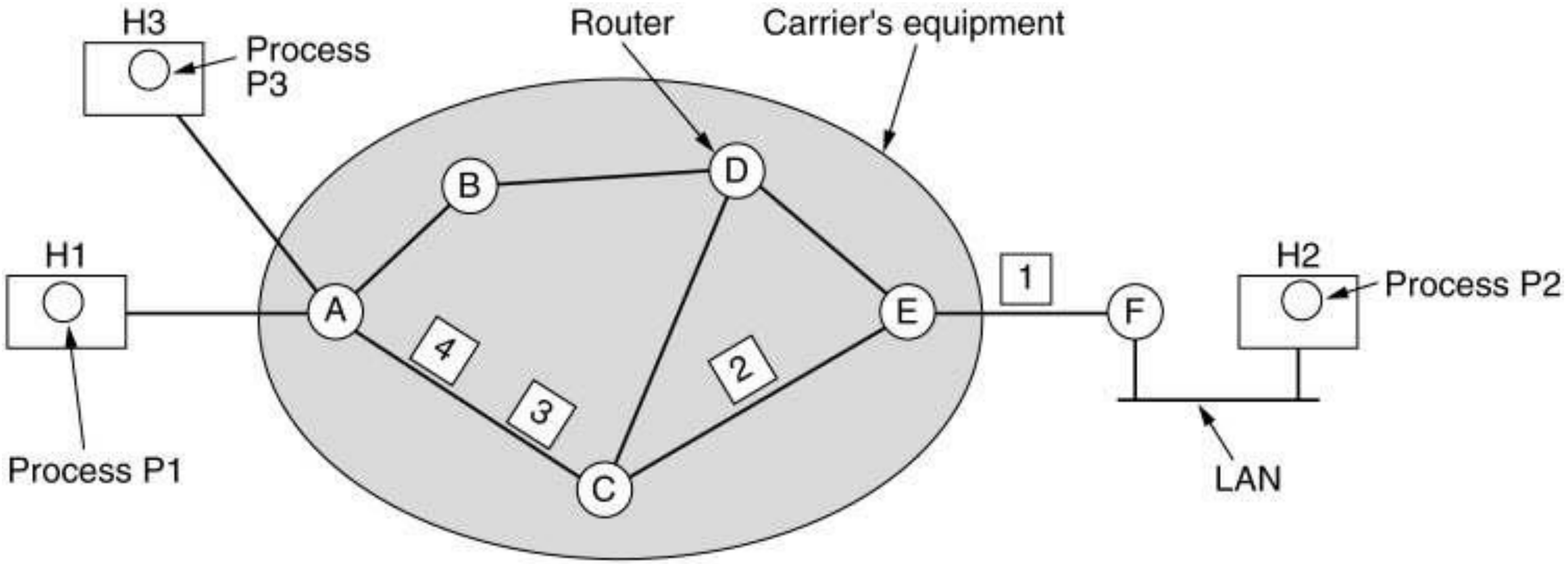
Routers

- When a packet comes into a router, the frame header and trailer are stripped off and the packet located in the frame's payload field is passed to the routing software. This software uses the packet header to choose an output line.
- Each router has an internal table telling it where to send packets for each possible destination.
- The algorithm that manages the tables and makes the routing decisions is called the routing algorithm. Routing algorithms are one of the main things we will study in this chapter.

Implementation of Connection-Oriented Service

- If connection-oriented service is used, a path from the source router to the destination router must be established before any data packets can be sent.
- This connection is called a VC (virtual circuit), in analogy with the physical circuits set up by the telephone system, and the subnet is called a virtual-circuit subnet.
- When a connection is established, a route from the source machine to the destination machine is chosen as part of the connection setup and stored in tables inside the routers.
- When the connection is released, the virtual circuit is also terminated.
- With connection-oriented service, each packet carries an identifier telling which virtual circuit it belongs to.

Implementation of Connection-Oriented Service



A's table

In		Out	
H1	1	C	1
H3	1	C	2

C's table

A	1	E	1
A	2	E	2

E's table

C	1	F	1
C	2	F	2

Routing within a virtual-circuit subnet.

Comparison of Virtual-Circuit and Datagram Subnets

- Both virtual circuits and datagrams have their supporters and their detractors.
- One trade-off is between router memory space and bandwidth. VC allow packets to contain circuit numbers instead of full destination addresses. If the packets tend to be fairly short, a full destination address in every packet may represent a significant amount of overhead and hence, wasted bandwidth.
- Another trade-off is setup time versus address parsing time.
- Using VC requires a setup phase, which takes time and consumes resources.
- VC have some advantages in guaranteeing quality of service and avoiding congestion within the subnet because resources can be reserved in advance, when the connection is established.

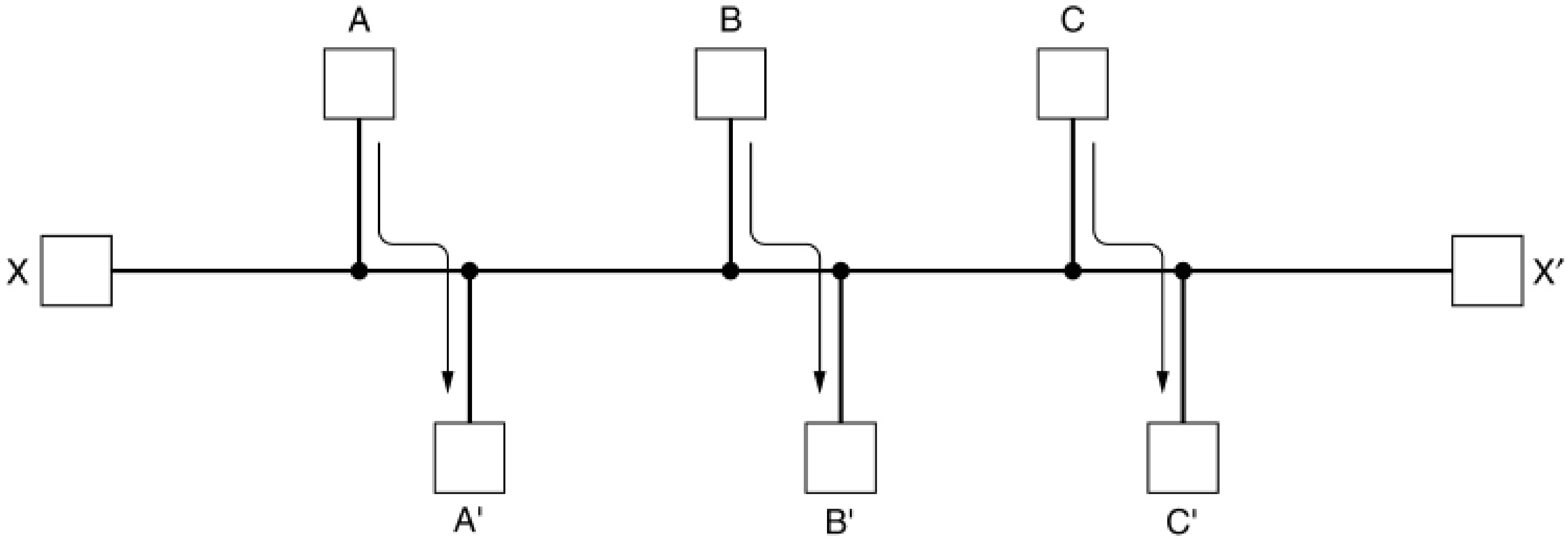
Comparison of Virtual-Circuit and Datagram Subnets

Issue	Datagram subnet	Virtual-circuit subnet
Circuit setup	Not needed	Required
Addressing	Each packet contains the full source and destination address	Each packet contains a short VC number
State information	Routers do not hold state information about connections	Each VC requires router table space per connection
Routing	Each packet is routed independently	Route chosen when VC is set up; all packets follow it
Effect of router failures	None, except for packets lost during the crash	All VCs that passed through the failed router are terminated
Quality of service	Difficult	Easy if enough resources can be allocated in advance for each VC
Congestion control	Difficult	Easy if enough resources can be allocated in advance for each VC

- The main function of NL (Network Layer) is routing packets from the source machine to the destination machine.
- The algorithms that choose the routes and the data structures that they use are a major area of network layer design.
- The routing algorithm is that part of the NL software responsible for deciding which output line an incoming packet should be transmitted on.
- There are two processes inside router:
  a. One of them handles each packet as it arrives, looking up the outgoing line to use for it in the routing table. This process is forwarding.
  b. The other process is responsible for filling in and updating the routing tables. That is where the routing algorithm comes into play. This process is routing.

- Regardless of whether routes are chosen independently for each packet or only when new connections are established, certain properties are desirable in a routing algorithm:
  - ✓ Correctness
  - ✓ Simplicity
  - ✓ Robustness
  - ✓ Stability
  - ✓ fairness, and
  - ✓ optimality.

- Correctness and simplicity hardly require components.
- Robustness: the routing algorithm should be able to cope with changes in topology and traffic without requiring all jobs in all hosts to be aborted and the network to be rebooted every time some router crashes.
- Stability is also an important goal for the routing algorithm. A stable algorithm reaches equilibrium and stays there.
- Fairness and optimality may sound obvious – surely no reasonable person would oppose them – but as it turn out, they are often contradictory goals.



Conflict between fairness and optimality.

ROUTING ALGORITHMS

- Routing algorithms can be grouped into two major classes: nonadaptive and adaptive.
- Nonadaptive algorithm do not base their routing decisions on measurements or estimates of the current traffic and topology. Instead, the choice of the route to use to get from I to J is computed in advance, off line, and downloaded to the routers when the network is booted. This procedure is sometimes called static routing.
- Adaptive algorithm, in contrast, change their routing decisions to reflect changes in the topology, and usually the traffic as well.
- Adaptive algorithms differ in where they get their information (e.g., locally, from adjacent routers, or from all routers), when they change the routes (e.g., every GT sec, when the load changes or when the topology changes), and what metric is used for optimization (e.g., distance, number of hops, or estimated transit time). This procedure is called dynamic routing.

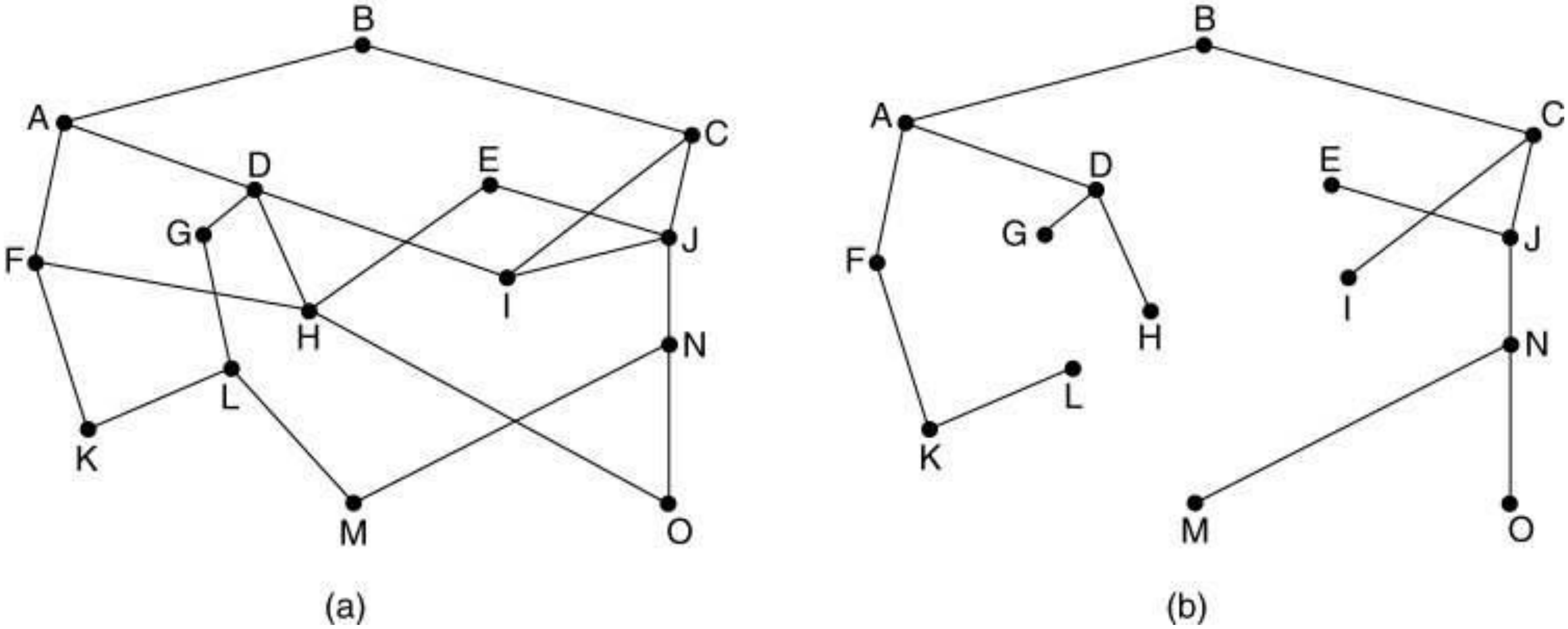
ROUTING ALGORITHMS

- The Optimality Principle
- Shortest Path Routing
- Flooding
- Distance Vector Routing
- Link State Routing
- Hierarchical Routing
- Broadcast Routing
- Multicast Routing

The Optimality Principle

- One can make a general statement about optimal routes without regard to network topology or traffic.
- This statement is known as the optimality principle.
- It states that if router J is on the optimal path from router I to router K, then the optimal path from J to K also falls along the same route.
- As a direct consequence of the optimality principle, we can see that the set of optimal routes from all sources to a given destination form a tree rooted at the destination.
- Such a tree is called a sink tree.
- The goal of all routing algorithms is to discover and use the sink trees for all routers

The Optimality Principle



(a) A subnet. (b) A sink tree for router B.

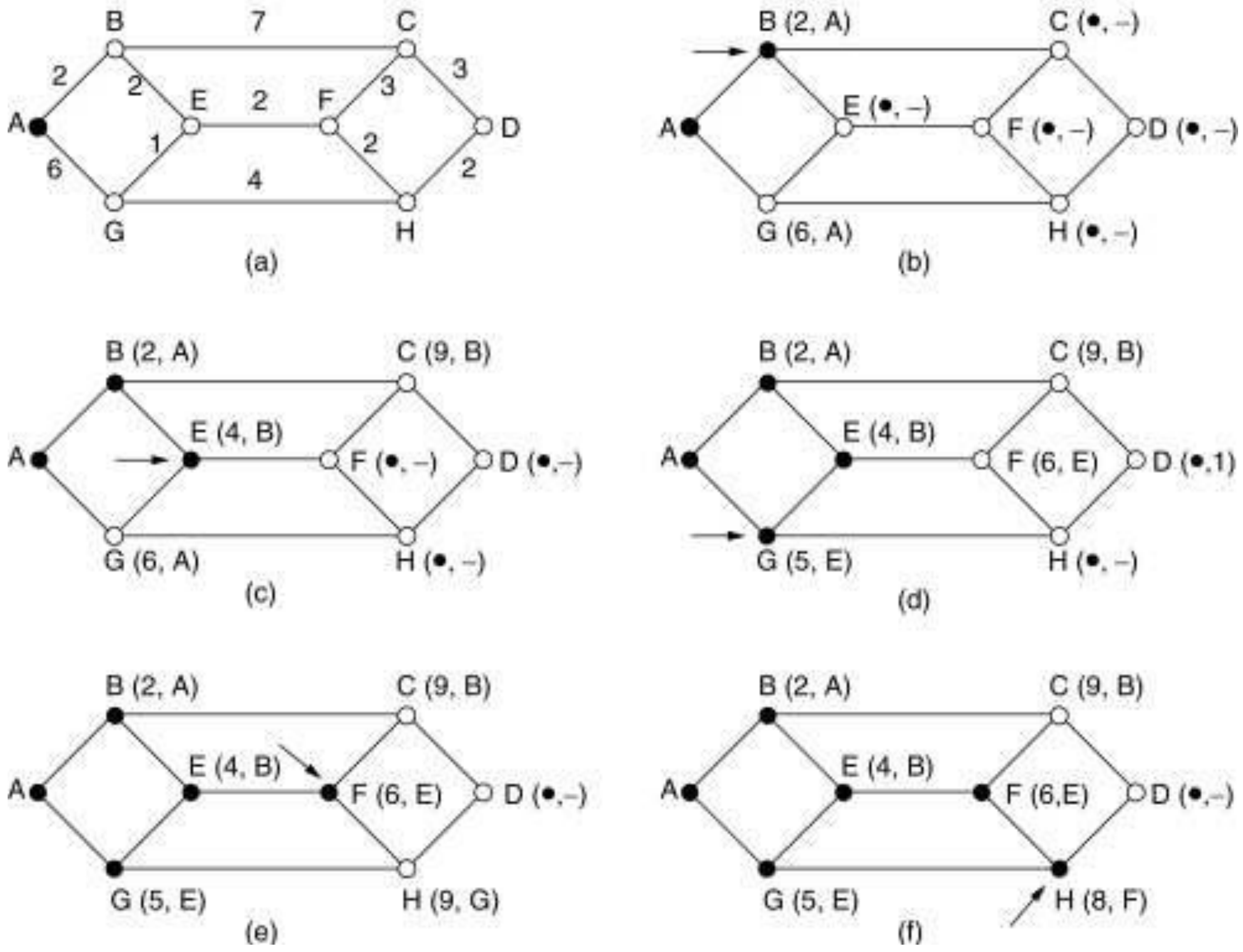
Shortest Path Routing

- The idea is to build a graph of the subnet, with each node of the graph representing a router and each arc of the graph representing a communication line or link.
- To choose a route between a given pair of routers, the algorithm just finds the shortest path between them on the graph.
- Many algorithms are proposed based on this technique, Dijkstra algorithm is one of the widely popular shortest path routing algorithm. Dijkstra algorithm is also based on greedy approach as is also known as the least cost path approach.

Shortest Path Routing

- The working of Dijkstra algorithm is as follows:
  1. Select the source node as the start node (S).
  2. Mark the direct neighbor nodes as tentative nodes (Initially all the nodes are considered as tentative nodes).
  3. Choose the node from tentative nodes list with lowest cost from the source node and mark it as permanent nodes and make it as source node.
  4. If, the destination node is covered or there is no more nodes in the tentative list(i.e. no more nodes to be explored) then stop, otherwise go to step number 2.

Shortest Path Routing



The first 5 steps used in computing the shortest path from A to D.
The arrows indicate the working node.

Shortest Path Routing

- Many other metrics besides hops and physical distance are also possible.
- For example, each arc could be labeled with the mean queuing and transmission delay for some standard test packet as determined by hourly test runs.
- With this graph labeling, the shortest path is the fastest path rather than the path with the fewest arcs or kilometers.
- In the general case, the labels on the arcs could be computed as a function of the distance, bandwidth, average traffic, communication cost, mean queue length, measured delay, and other factors.
- By changing the weighting function, the algorithm would then compute the “shortest” path measured according to any one of a number of criteria or to a combination of criteria.

Flooding

- Another static algorithm is flooding, in which every incoming packet is sent out on every outgoing line except the one it arrived on.
- Flooding obviously generates vast numbers of duplicate packets, in fact, an infinite number unless some measures are taken to damp the process.
- One such measure is to have a hop counter contained in the header of each packet, which is decremented at each hop, with the packet being discarded when the counter reaches zero.
- Ideally, the hop counter should be initialized to the length of the path from source to destination.

Flooding

- A variation of flooding that is slightly more practical is selective flooding.
- In this algorithm the routers do not send every incoming packet out on every line, only on those lines that are going approximately in the right direction.
- Flooding is not practical in most applications.

Advantages

- It is very simple to setup and implement, since a router may know only its neighbours.
- It is extremely robust. Even in case of malfunctioning of a large number routers, the packets find a way to reach the destination.
- All nodes which are directly or indirectly connected are visited. So, there are no chances for any node to be left out. This is a main criteria in case of broadcast messages.
- The shortest path is always chosen by flooding.

Disadvantages

- Flooding tends to create an infinite number of duplicate data packets, unless some measures are adopted to damp packet generation.
- It is wasteful if a single destination needs the packet, since it delivers the data packet to all nodes irrespective of the destination.
- The network may be clogged with unwanted and duplicate data packets. This may hamper delivery of other data packets.