Unit-IV
Switching and Routing

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Network Layer

- The network layer is responsible for the source-to-destination delivery of a packet, possibly across multiple networks (links).
- Whereas the data link layer oversees the delivery of the packet between two systems on the same network (links), the network layer ensures that each packet gets from its point of origin to its final destination.
- **The network layer is responsible for the delivery of individual packets from the source to the destination host.**
- The network layer adds a header that includes the **logical addresses** of the sender and receiver to the packet corning from the upper layer. If a packet travels through the Internet, we need this addressing system to help distinguish the source and destination.
- When independent networks or links are connected together to create an internetwork, routers or switches route packets to their final destination. One of the functions of the network layer is to provide a **routing** mechanism.

Functions of Network Layer

Network layer is majorly focused on getting packets from the source to the destination, routing error handling and congestion control. Before learning about design issues in the network layer, let's learn about it's various functions.

- **Logical Addressing:** Maintains the address at the frame header of both source and destination and performs addressing to detect various devices in network.
- **Packetizing:** This is performed by Internet Protocol. The network layer converts the packets from its upper layer.
- **Routing:** It is the most important functionality. The network layer chooses the most relevant and best path for the data transmission from source to destination.
- **Inter-networking:** It works to deliver a logical connection across multiple devices.

Network Layer Design Issues

The network layer comes with some design issues they are described as follows:

1. **Store and Forward packet switching:** The host sends the packet to the nearest router. This packet is stored there until it has fully arrived once the link is fully processed by verifying the checksum then it is forwarded to the next router till it reaches the destination. This mechanism is called "Store and Forward packet switching."
2. **Services provided to Transport Layer:** Through the network/transport layer interface, the network layer transfers it's services to the transport layer. Based on the connections there are 2 types of services provided:
   - **Connectionless –** The routing and insertion of packets into subnet is done individually. No added setup is required.
   - **Connection-Oriented –** Subnet must offer reliable service and all the packets must be transmitted over a single route.

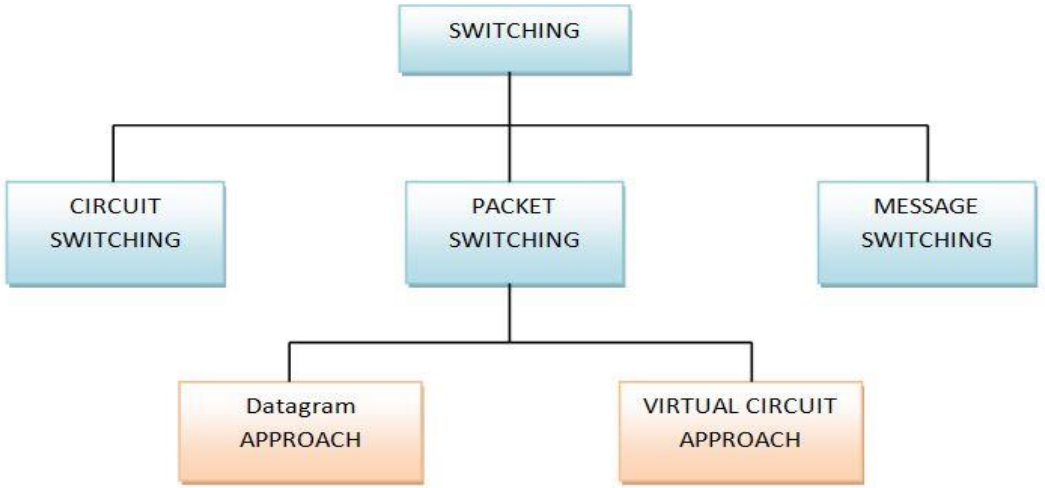
3. **Implementation of Connectionless Service:** Packet are termed as “datagrams” and corresponding subnet as “datagram subnets”. When the message size that has to be transmitted is 4 times the size of the packet, then the network layer divides into 4 packets and transmits each packet to router via. a few protocol. Each data packet has destination address and is routed independently irrespective of the packets.
4. **Implementation of Connection Oriented service:** To use a connection-oriented service, first we establishes a connection, use it and then release it. In connection-oriented services, the data packets are delivered to the receiver in the same order in which they have been sent by the sender. It can be done in either two ways :
   - **Circuit Switched Connection:** A dedicated physical path or a circuit is established between the communicating nodes and then data stream is transferred.
   - **Virtual Circuit Switched Connection:** The data stream is transferred over a packet switched network, in such a way that it seems to the user that there is a dedicated path from the sender to the receiver. A virtual path is established here. While, other connections may also be using the same path.

Switching

- A computer network consists of a large number or computers and interconnecting devices. Passage of a message from a source to a destination involves many decisions.
- When a message reaches a connecting device, a decision needs to be made to select one of the output ports through which the packet needs to be sent out.
- The connecting device acts as a switch that connects one port to another port and data movement between the devices is called switching.

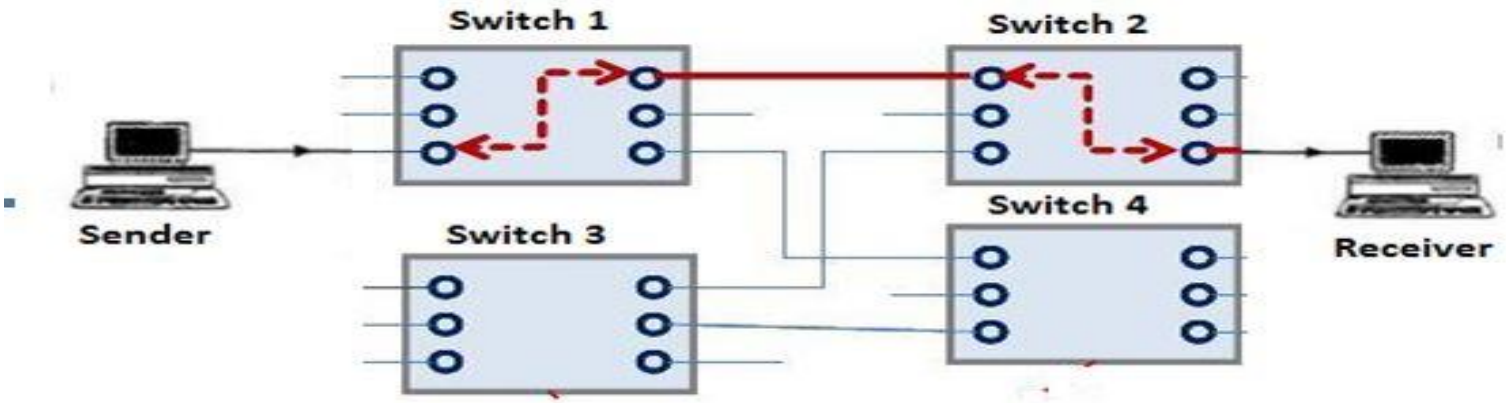
Switched Networks

- A switched network consists of a series of interlinked nodes called switches. Switched are hardware and software devices capable of creating temporary circuit between two or more devices.
- Classification of switched networks:
  - Circuit Switching
  - Packet Switching
  - Message Switching



CIRCUIT SWITCHING

- In circuit switching a dedicated physical connection is established between sender and receiver.
- A circuit-switched network is made of a set of switches connected by physical links.
- The dedicated path established between sender and receiver is maintained for entire duration of conversation.
- Circuit switching takes place at the physical layer.



Phases of Circuit Switching

- **Phase I: Setup**

  Before starting communication, the stations must make a reservation for the resources to be used for communication. The resources, such as channels, switch, input output ports must be dedicatedly allotted during entire communication

- **Phase II: Data transfer**

  Once circuit is established between sender are receiver continuous data (not packets) flows between sender and receiver there may be no data in between.

- **Phase III: Circuit tear down**

  When any one of the parties needs to disconnect, a signal is sent to each switch to release the resources.

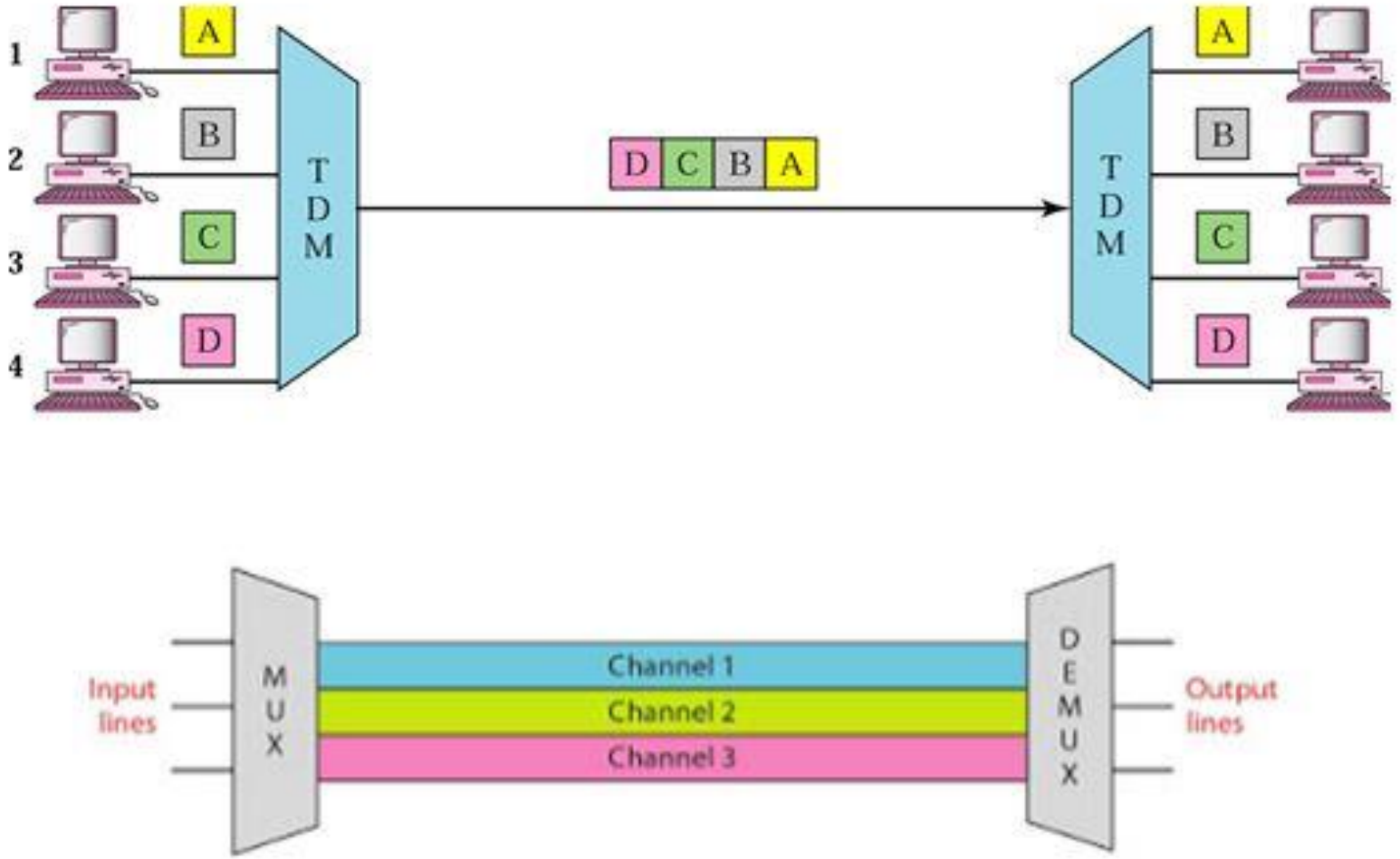
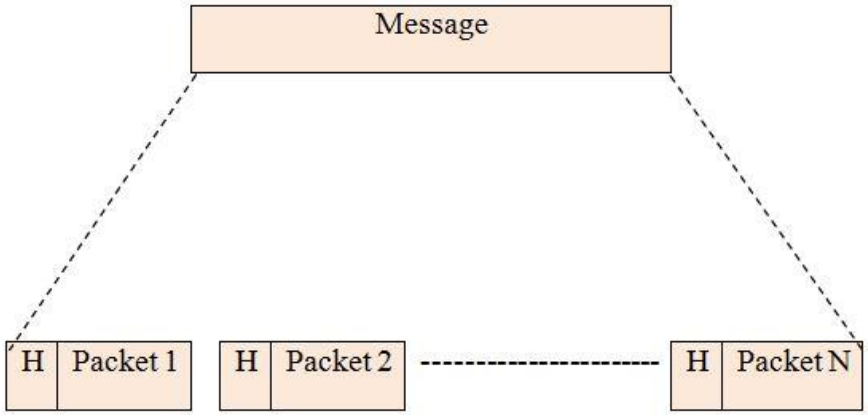


Fig TDM and FDM

- **Advantage of Circuit Switching**
  - Dedicated path or circuit between sender and receiver provides a guaranteed data rate.
  - Once circuit is established data can be transmitted without any delay.
  - Method is suitable for long continuous transmission.
- **Disadvantages of Circuit Switching**
  - As the connection is dedicated it cannot be used to transmit any other data even if channel is free.
  - It is inefficient in terms of utilization of system resources .
  - Dedicated channels consume more bandwidth.
  - Not efficient for long distance communication.
- **Telephone networks** are the best example of circuit switched networks.

PACKET SWITCHING

- Adopted in 1970 for long distance communication.
- In packet switching message is broken up into packets of fixed or variable size.
- Each of the packets contain header with the information of sender, receiver and other control information.
- No resources are dedicatedly allocated before the transfer of packets. Resources are allocated on demand on first come first server bases.
- These networks are also called as store and forward networks as at each node stores the packet briefly and route it according to the information stores in header.



Advantages of Packet Switching

- Line efficiency increases as node to node link can be shared by many packets over time.
- As the routing is done on packet basis, intermediate nodes do not have to wait for the entire message, hence transmission is fast.
- Buffer requirement at the nodes is small as packets are small.
- More effective for real time bursty data.
- Packets are accepted even when network is busy.
- Priorities can be used.
- Switching nodes can route the packets as and when required.

Disadvantages of Packet Switching

- Packets may be lost while routing.
- Sequence number increases the overhead.
- Header information is repeated for all the packets.

Approaches in Packet Switching

There are two different approaches in packet switching:

- **Datagram packet switching**

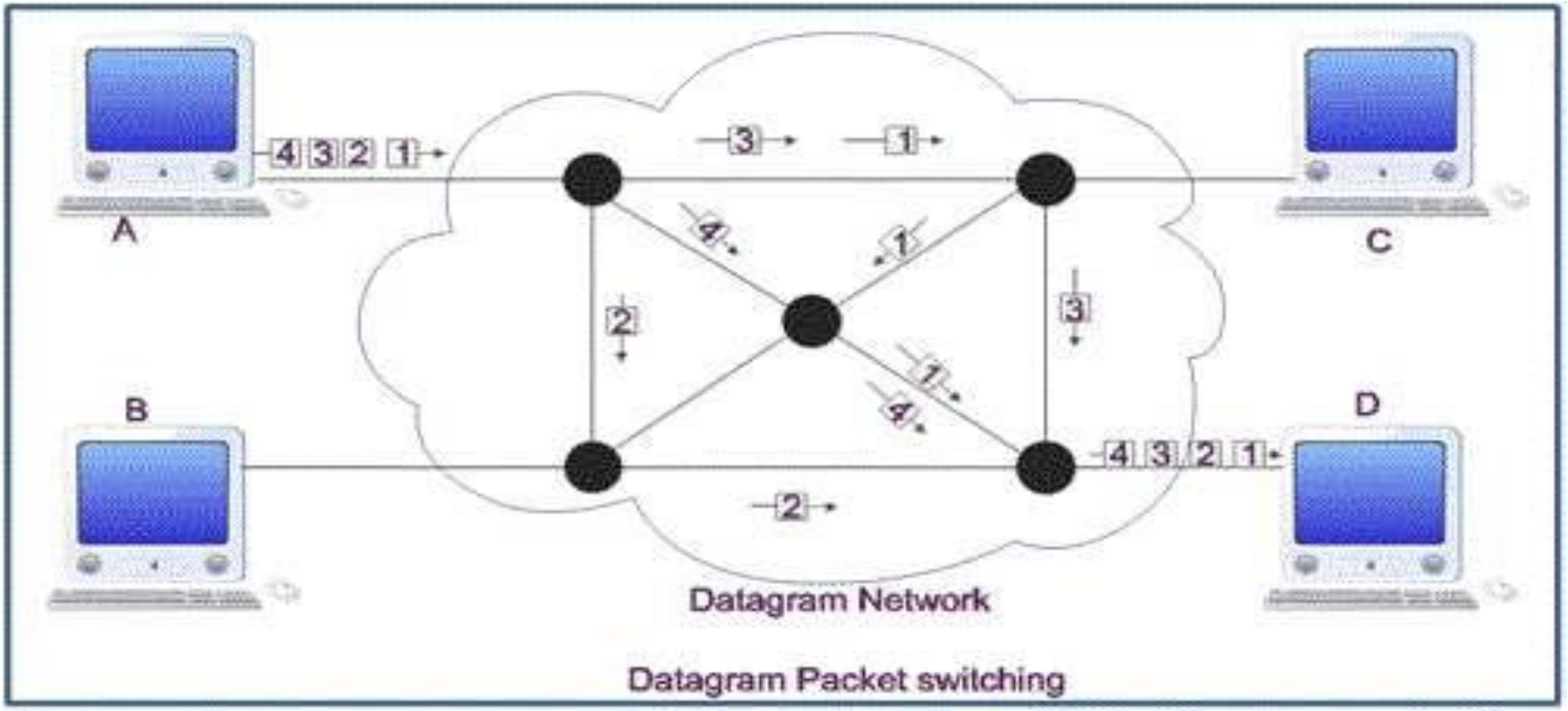
  In this approach, message is divided into stream of packets of fixed or variable size. Each packet is separately addressed (contains header with sender and receiver address)

- **Virtual Circuit Packet Switching**

  A virtual-circuit network is a cross between a circuit-switched network and a datagram network.

DATAGRAM NETWORKS

- In a datagram network, each packet is treated independently of all others.
- Even if a packet is part of a multipacket transmission, the network treats it as though it existed alone.
- Packets in this approach are referred to as datagrams.
- Datagram switching is normally done at the network layer.
- The datagram networks are sometimes referred to as connectionless networks. The term *connectionless here means that the switch (packet switch) does not keep information* about the connection state.
- There are no setup or teardown phases. Each packet is treated the same by a switch regardless of its source or destination.



Datagram Packet switching

Figure show how a datagram approach is used to deliver four packets from station A to station D. All the four packets belong to same message but they may travel via different paths to reach the destination *i.e.* station D.

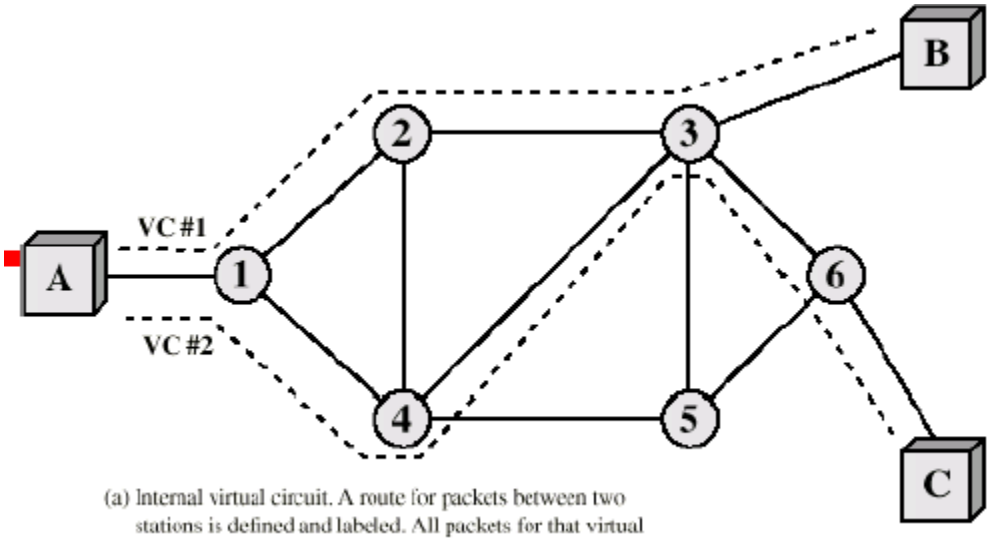
Switching in the Internet is done by using the datagram approach to packet switching at the network layer.

VIRTUAL-CIRCUIT NETWORKS

A virtual-circuit network is a cross between a circuit-switched network and a datagram network. It has some characteristics of both.

- As in a circuit-switched network, there are setup and teardown phases in addition to the data transfer phase.
- Resources can be allocated during the setup phase, as in a circuit-switched network, or on demand, as in a datagram network.
- As in a datagram network, data are packetized and each packet carries an address in the header.
- As in a circuit-switched network, all packets follow the same path established during the connection.
- A virtual-circuit network is normally implemented in the data link layer, while a circuit-switched network is implemented in the physical layer and a datagram network in the network layer.

- Before the data transfer begins, the source and destination identify a suitable path for the virtual circuit.
- All intermediate nodes between the two points put an entry of the routing in their routing table for the call.
- Additional parameters, such as the maximum packet size, are also exchanged between the source and the destination during call setup.
- The virtual circuit is cleared after the data transfer is completed.



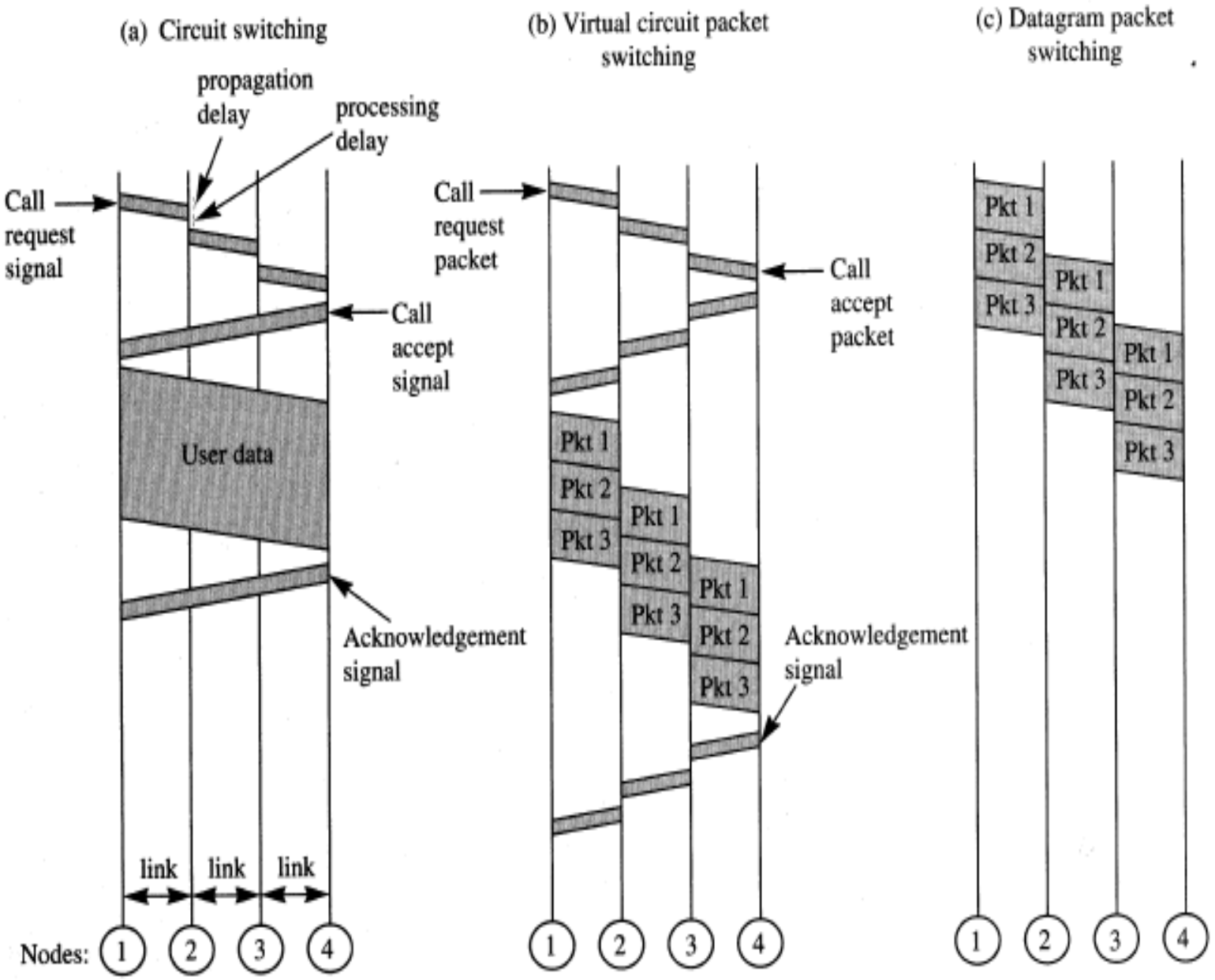
(a) Internal virtual circuit. A route for packets between two stations is defined and labeled. All packets for that virtual circuit follow the same route and arrive in the same sequence.

Advantages of virtual circuit switching

- Packets are delivered in order, since they all take the same route;
- The overhead in the packets is smaller, since there is no need for each packet to contain the full address;
- The connection is more reliable, network resources are allocated at call setup so that even during times of congestion, provided that a call has been setup, the subsequent packets should get through;
- Billing is easier, since billing records need only be generated per call and not per packet.

Disadvantages of a virtual circuit switched network

- The switching equipment needs to be more powerful, since each switch needs to store details of all the calls that are passing through it and to allocate capacity for any traffic that each call could generate;
- Resilience to the loss of a trunk is more difficult, since if there is a failure all the calls must be dynamically reestablished over a different route.


(a) Circuit switching
propagation delay
processing delay
Call request signal
Call accept signal
User data
Acknowledgement signal
link
link
link
Nodes:
1
2
3
4
(b) Virtual circuit packet switching
Call request packet
Call accept packet
Acknowledgement signal
Pkt 1
Pkt 2
Pkt 3
(c) Datagram packet switching

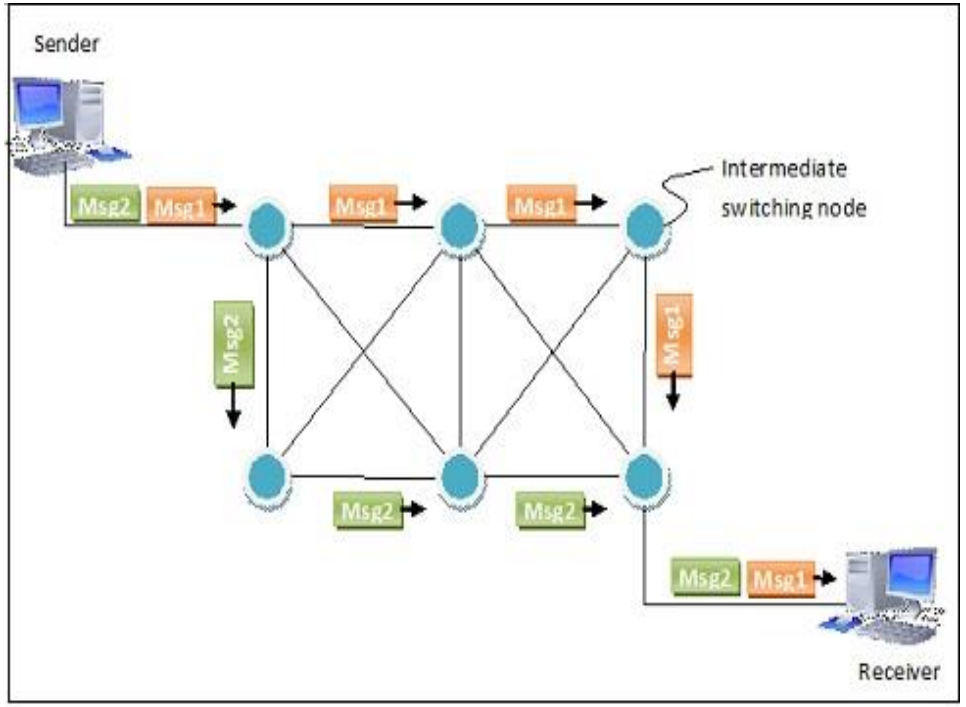
SNo.	Parameter	Circuit Switched	Packet Switched Network
1	Path or route	A path is created between two points by setting the switches	A virtual circuit or route is created between two points.
2	Type of link	The links that make a path are dedicated and cannot be used by other connections.	In virtual circuit the links are shared by other connections.
3	Store and forward approach	Not used	Each node may store incoming packets and forward them later.
4	Bandwidth	Required bandwidth is reserved in advance so it is fixed.	Bandwidth can be acquired or released as it is needed. So it is dynamic.
5	Bandwidth wasted	Unused bandwidth on allocated circuit is wasted.	Unused bandwidth can be used by other circuits.
6	Route followed	Always same route is followed.	May or may not be same.
7	Setup phase	Is required	Not required
8	Time of congestion	More probability is at the time or setup phase.	Congestion can occur on every packet.
9	Applications	Telephonic network.	Internet.
10	Layer for implementation	Implemented at physical layer	A virtual circuit is implemented at data link layer and data gram network at network layer.

Message Switching

- In message switching, end users communicate by sending and receiving *messages* that included the entire data to be shared. Messages are the smallest individual unit.
- Also, the sender and receiver are not directly connected. There are a number of intermediate nodes transfer data and ensure that the message reaches its destination.
- Message switched data networks are hence called hop-by-hop systems.

- Message switching treats each message as an individual unit. Before sending the message, the sender node adds the destination address to the message. It is then delivered entirely to the next intermediate switching node.
- The intermediate node stores the message in its entirety, checks for transmission errors, inspects the destination address and then delivers it to the next node. The process continues till the message reaches the destination.

In the switching node, the incoming message is not discarded if the required outgoing circuit is busy. Instead, it is stored in a queue for that route and retransmitted when the required route is available. This is called store and forward network.



Advantages

- Sharing of communication channels ensures better bandwidth usage.
- It reduces network congestion due to store and forward method. Any switching node can store the messages till the network is available.
- Broadcasting messages requires much less bandwidth than circuit switching.
- Messages of unlimited sizes can be sent.
- It does not have to deal with out of order packets or lost packets as in packet switching.

Disadvantages

- In order to store many messages of unlimited sizes, each intermediate switching node requires large storage capacity.
- Store and forward method introduces delay at each switching node. This renders it unsuitable for real time applications.

SNo.	Parameter	Message Switching	Circuit Switching	Packet Switching
1	Multiplexing Technique			
2	Addressing Scheme	Geographical	Hierarchical Number plan	Hierarchical address space
3	Data type	Digital data	Analog and digital data	Digital Data
4	End terminal	Telegraph	Telephone	Computer
5	Routing	Manual	Route selected during setup	Each packet follows independent routing techniques
6	Application	Telegraph network	Telephone network for real time transfer of voice signals	Internet for datagram and reliable stream service between computers.

Routing

- Routing is the act of moving information across an inter-network from a source to a destination.
- It's also referred to as the process of choosing a path over which to send the packets.

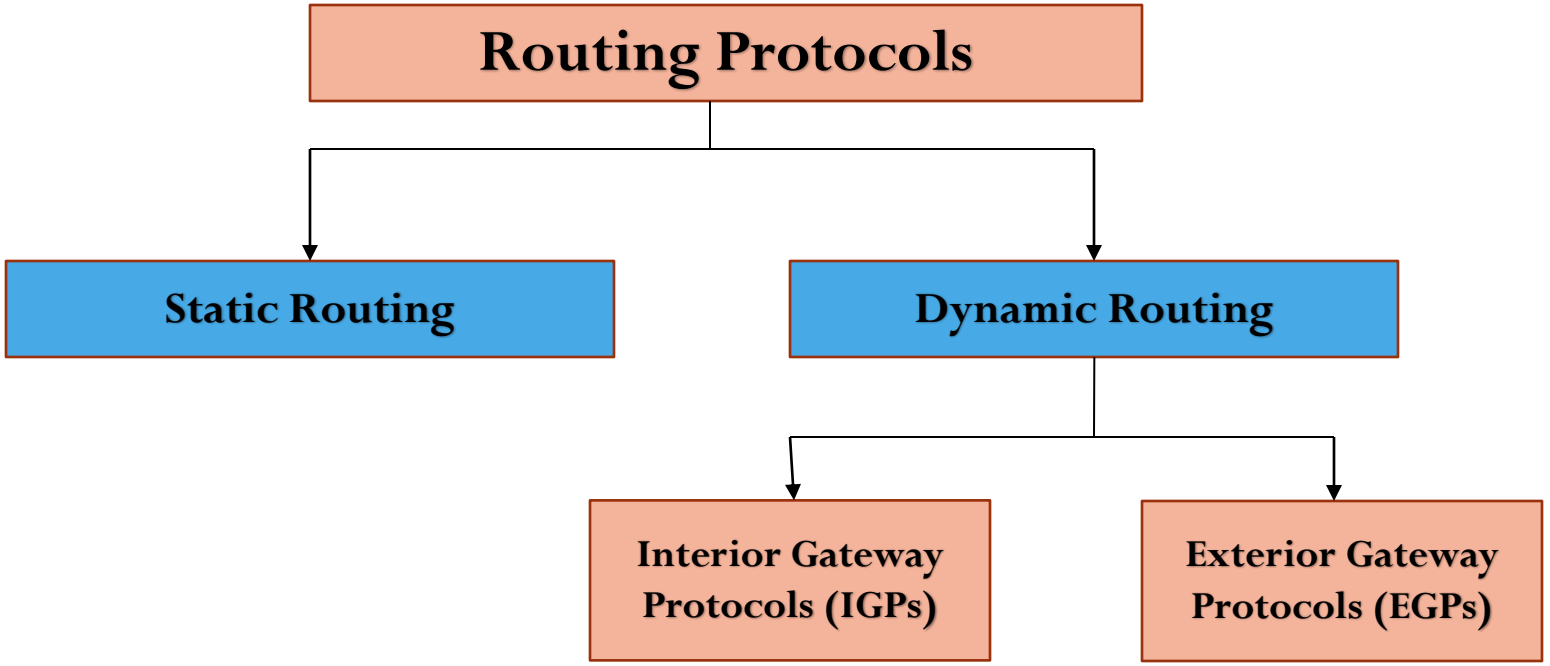
Classification of Routing:

- Static versus Dynamic
- Single-path versus multi-path
- Intra-domain versus inter-domain
- Flat versus hierarchical.
- Link-state versus distance vector
- Host-intelligent versus router-intelligent.

Routing algorithm Metric:

Various metrics of routing algorithm are:

- Path length
- Delay
- Bandwidth
- Load
- Communication cost
- Reliability


Routing Protocols
Static Routing
Dynamic Routing
Interior Gateway Protocols (IGPs)
Exterior Gateway Protocols (EGPs)

Static Routing Protocols

Static routing ,when an administrator manually assigns the path from source to destination network. It provides more security to network. The main drawback of static routing is that when a link fail in the internetwork all the network goes down. This is feasible in small networks, but not in large networks.

Advantages

- No overhead on router CPU.
- No bandwidth usage between links.
- Security (only administrator add routes.)

Disadvantages

- Administrator must really understand internetwork & how each router is connected.
- Not practical on large networks as it is time intensive.
- Administrator must update all routers.

Dynamic Routing Protocols

Dynamic routing is the process in which routing tables are automatically updates by routing table

*Dynamically discover & maintains routes.

*Calculate routes

*Distributing routing updates to other routers in the network

Advantages

-less work in maintaining the configuration when adding & deleting networks.

-protocols automatically react to the topology changes.

-configuration is less-prone.

-More scalable.

Disadvantages

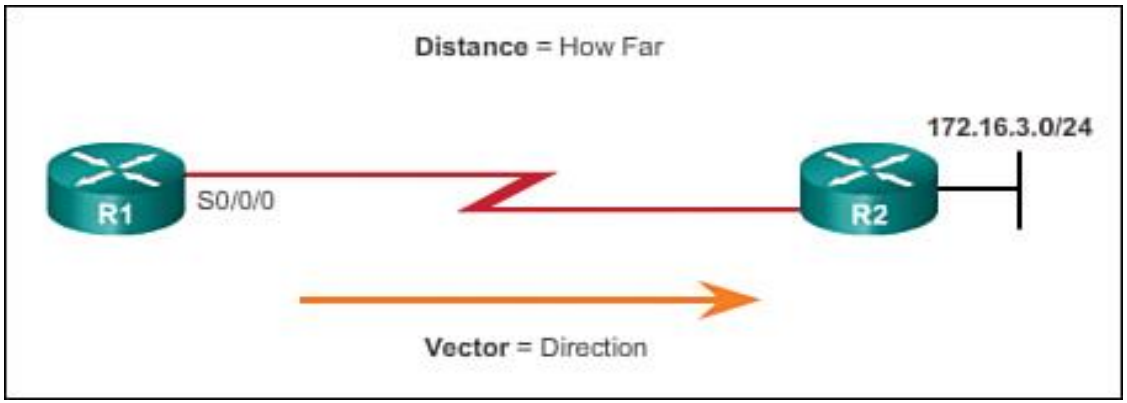
-Routers resource are used.

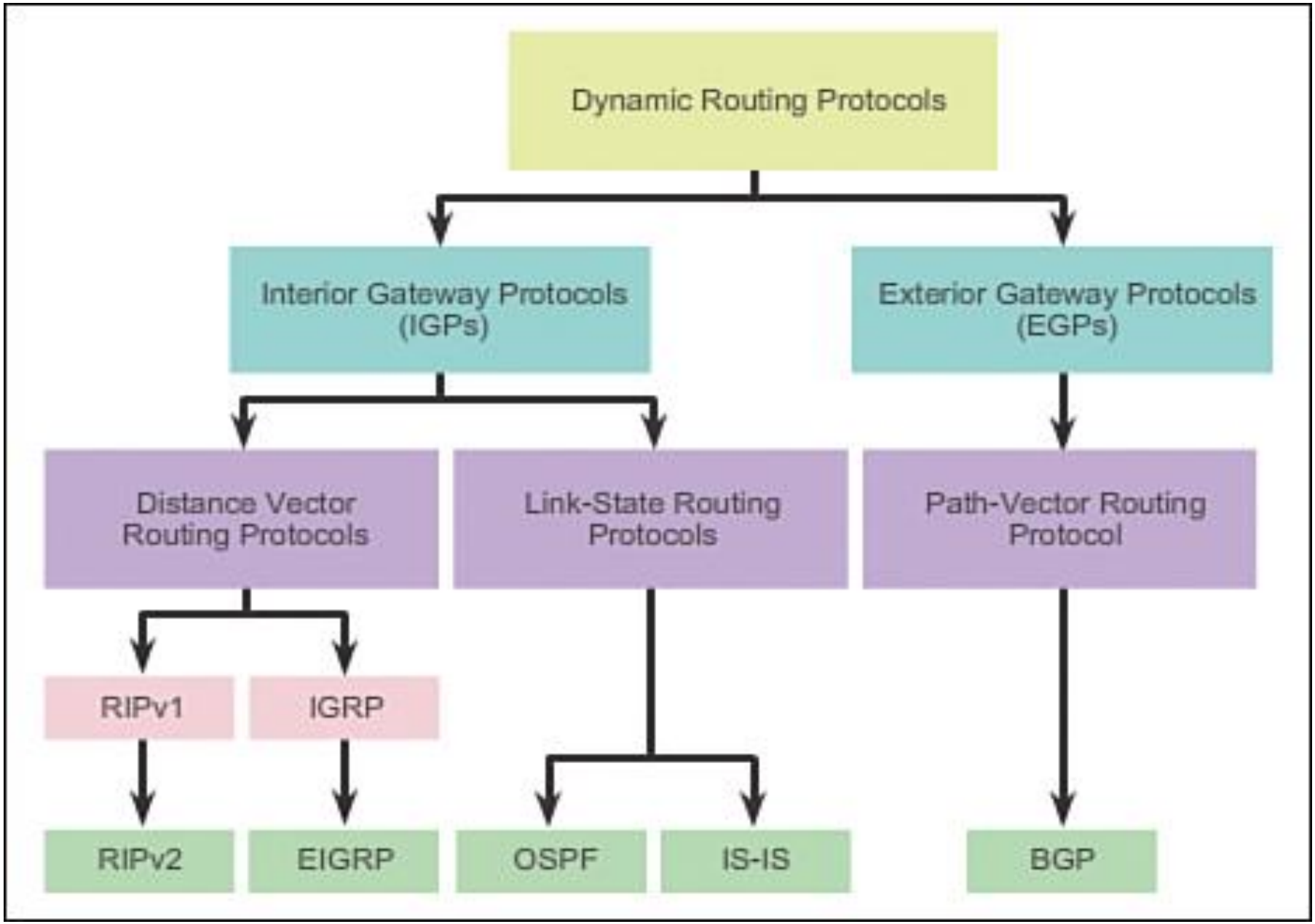
-More administrator knowledge is required for configuration

Distance Vector Routing Protocols

Distance vector means that routes are advertised by providing two characteristics:

- **Distance**: Identifies how far it is to the destination network and is based on a metric such as the hop count, cost, bandwidth, delay, and more
- **Vector**: Specifies the direction of the next-hop router or exit interface to reach the destination

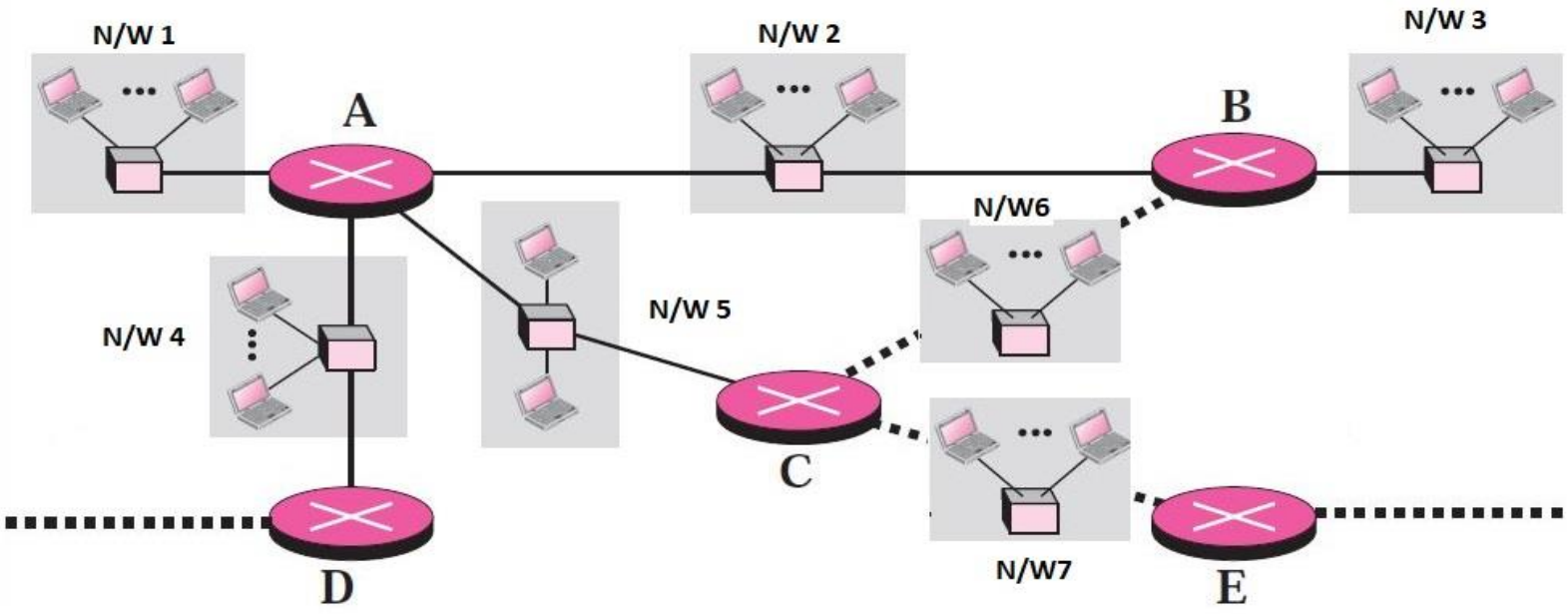



Dynamic Routing Protocols
Interior Gateway Protocols (IGPs)
Exterior Gateway Protocols (EGPs)
Distance Vector Routing Protocols
Link-State Routing Protocols
Path-Vector Routing Protocol
RIPv1
IGRP
RIPv2
EIGRP
OSPF
IS-IS
BGP

Distance Vector Routing or Bellman Ford Algorithm is a type of algorithm used by routing protocols to learn routes on an interconnected network. Routing protocols that use distance-vector routing protocols include:

1. Routing Information Protocol RIP.
2. Cisco's Internet Gateway Routing Protocol IGRP.
3. Apple's Routing Table Maintenance Protocol RTMP.

- In distance vector routing when a router is booted it maintains a routing table advertising vector of distance and direction. Direction is represented by next hop address, whereas Distance uses metrics such as hop count.
- After every fixed period of time router exchanges its routing table with its neighbouring router and we get a new merged table.



When Routers are booted Routers gathers information from attached networks and maintains following routing tables:

Router A		
Destination	Cost	Next
Network1	1	-
Network2	1	-
Network4	1	-
Network5	1	-

Router B		
Destination	Cost	Next
Network2	1	-
Network3	1	-
Network6	1	-

Router C		
Destination	Cost	Next
Network5	1	-
Network6	1	-
Network7	1	-

Router D		
Destination	Cost	Next
Network4	1	-

Router E		
Destination	Cost	Next
Network7	1	-

After a fixed period of time routing tables of the neighbouring tables are shared:

- Router A swaps its information with Router B , Router C and Router D.
- Router B swaps its information with Router A and Router C
- Router C swaps its information with Router A, Router B and Router E
- Router D swaps its information with Router A
- Router E swaps its information with Router C

Router A		
Destination	Cost	Next
Network1	1	-
Network2	1	-
Network3	2	B
Network4	1	-
Network5	1	-
Network6	2	C
Network7	2	C

Router B		
Destination	Cost	Next
Network1	2	A
Network2	1	-
Network3	1	-
Network4	2	A
Network5	2	C
Network6	1	-
Network7	2	C

Router C		
Destination	Cost	Next
Network1	2	A
Network2	2	A
Network3	2	B
Network4	2	A
Network5	1	-
Network6	1	-
Network7	1	-

Router D		
Destination	Cost	Next
Network1	2	A
Network2	2	A
Network4	1	-
Network5	2	A

Router E		
Destination	Cost	Next
Network5	2	C
Network6	2	C
Network7	1	

After a fixed period of time updated routing tables of the neighbouring tables are shared:

- Router A swaps its information with Router B , Router C and Router D.
- Router B swaps its information with Router A and Router C
- Router C swaps its information with Router A, Router B and Router E
- Router D swaps its information with Router A
- Router E swaps its information with Router C

Router A

Destination	Cost	Next
Network1	1	-
Network2	1	-
Network3	2	B
Network4	1	-
Network5	1	-
Network6	2	C
Network7	2	C

Router B

Destination	Cost	Next
Network1	2	A
Network2	1	-
Network3	1	-
Network4	2	B
Network5	2	C
Network6	1	-
Network7	2	C

Router C

Destination	Cost	Next
Network1	2	A
Network2	2	A
Network3	2	B
Network4	2	A
Network5	1	-
Network6	1	-
Network7	1	-

Router D

Destination	Cost	Next
Network1	2	A
Network2	2	A
Network3	3	A
Network4	1	
Network5	2	A
Network6	3	A
Network7	3	A

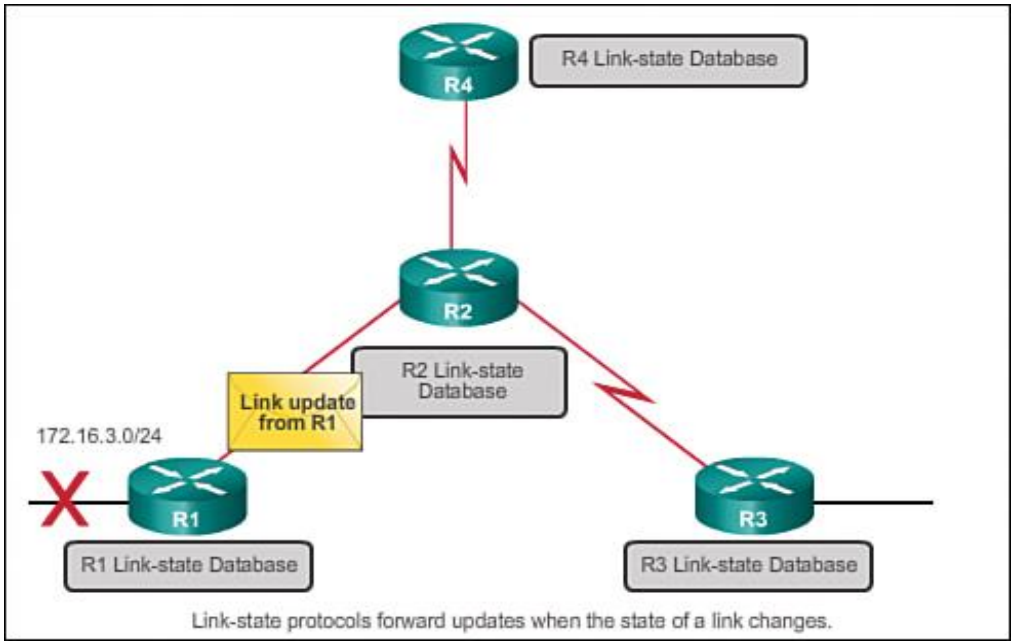
Router E

Destination	Cost	Next
Network1	3	C
Network2	3	C
Network3	3	C
Network4	3	C
Network5	2	C
Network6	2	C
Network7	1	-

- **Note: See example of Bellman Ford Algorithm.**

Link-State Routing Protocols

- Router configured with a ***link-state routing protocol*** can create a complete view or topology of the network.
- This is done by gathering information from all of the other routers.
- Link-state update is only sent when there is a change in the topology



Link-state protocols work best in situations where:

- The network design is hierarchical, usually occurring in large networks.
- Fast convergence of the network is crucial.
- The administrators have good knowledge of the implemented link-state routing protocol

There are two link-state IPv4 IGPs:

- **OSPF**: Popular standards-based routing protocol
- **IS-IS**: Popular in provider networks

Open Shortest Path First (OSPF)

- Open Shortest Path First (OSPF) is another Interior Gateway Protocol. OSPF was created because the Routing Information Protocol (RIP) was increasingly incapable of serving large inter-networks.
- OSPF is based on the Shortest Path First algorithm, which is also referred to as the Dijkstra's algorithm.
- OSPF is a link-state routing protocol as it sends state of all other routers.
- This protocol is open, which means anyone can implement it without paying license fees.
- It supports both IPv4 and IPv6 routed protocols.
- There are certain disadvantages of OSPF also, it requires extra CPU process to run SPF algorithm, it requires more RAM and is more complex to setup and hard to troubleshoot.

Link State of can be measured using following metrics:

- Measuring link utilization
- Number of hops (hop count)
- Speed of the path
- Packet loss (router congestion/conditions)
- Latency (delay)
- Path reliability
- Path bandwidth
- Throughput
- Load on link
- MTU maximum transmission unit

Note: See the pdf file for the numerical example of Djkstra algorithm