Chapter 6

Network Layer

The local area networks that we studied in the last three chapters have limited geographic coverage and limited scalability interms of number of stations. These limitations are due to their inherent technology that is based on broadcast type of communication . It is possible to engineer data network that can span cities, countries and continents such that networks are called Wide Area Networks (WANs). A wide area network consists of collection of network nodes which provides resources for interconnection of the end – systems. The technology used in these networks does not have distance or scalability limitations.

6. 1. Switched Data Networks

A switched data network consists of an interconnected collection of nodes. The interconnecting link between two nodes is called trunk (Fig. 6.1) . Data units are transmitted fro source to destinatio by routed through these nodes. For example, data units from end systems 4A intended for 6F are sent to the exit node 6. Each end system is identified by a unique address to facilitate routing of the data units, usually the address of an end system also contains identification of the node to which the end system is attached.

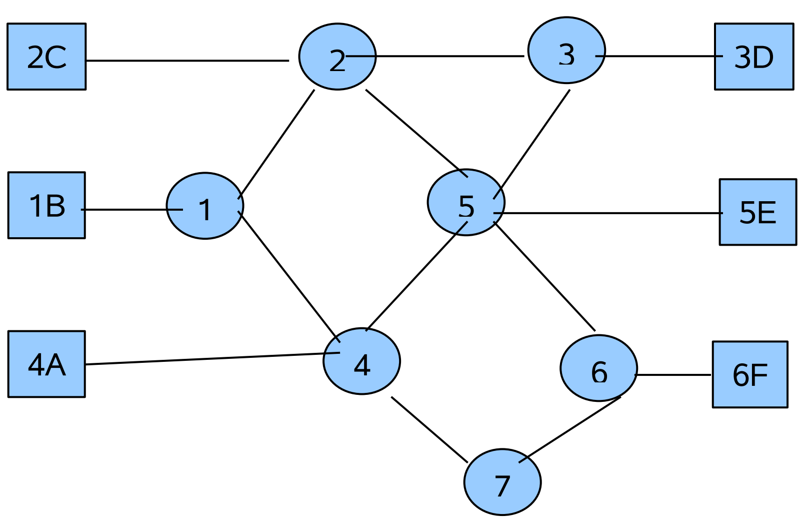


Fig. 6.1 Switched data networks

Two major networking requirements that drive use of switch network are flexible topology and resource sharing.

Flexible Topology:

Switching enables delivering of information presented at one access node of the network to a varity of destination which can be selected by the users. Thus, switching provides a flexible interconnection topology.

Resource Sharing:

The network resources are available to all users the network. As and when required the services of the network, the resources are allocated to it.

6.1.2. Types of Switched Data Network

There are two techinques for switching data units at the nodes:

- Circuit Switching
- Store – and – Forward Switching

Circuit – Switching is used primarly for voice communication but it can be used for data networks. The data network on the other hand are based on store – and – forward switching . VOATM(Voice – Over – ATM) and VOIP (Voice – Over – IP) are new techonology that enabe even to voice signals to be carried on store – and – forward networks.

6. 2. Circuit Switching

The circuit switched data network cosnsists of circuit switching nodes interconnected by trunk circuits. The circuit switching nodes carry out interconnection of the incoming trunk circuits and outgoing trunk circuts to establish an end – to – end transmission path, called connection. All the data units are sent on the established connection. The connection is released by the ed system after availing the network srvices. As an examplee of the circuit switched is ISDN service of the telephone network.

Service features of the circuite switched data networks are as summarized below:

- There are connection establishment, data transfer and connection release phases, Fig 6.2
- There is connection setup delay (10 second and more on long distance or international calls) that increases with traffic
- Distination address is specified only during connection setup phase
- One circuit per one user
- Data delivery delay is constant irrespective of traffic, delivery delay is minial, only the propagation delay(about 5msec per 1000Km)
- Data rates at source and destination are the same .
- There is no error control mechanism within the network.

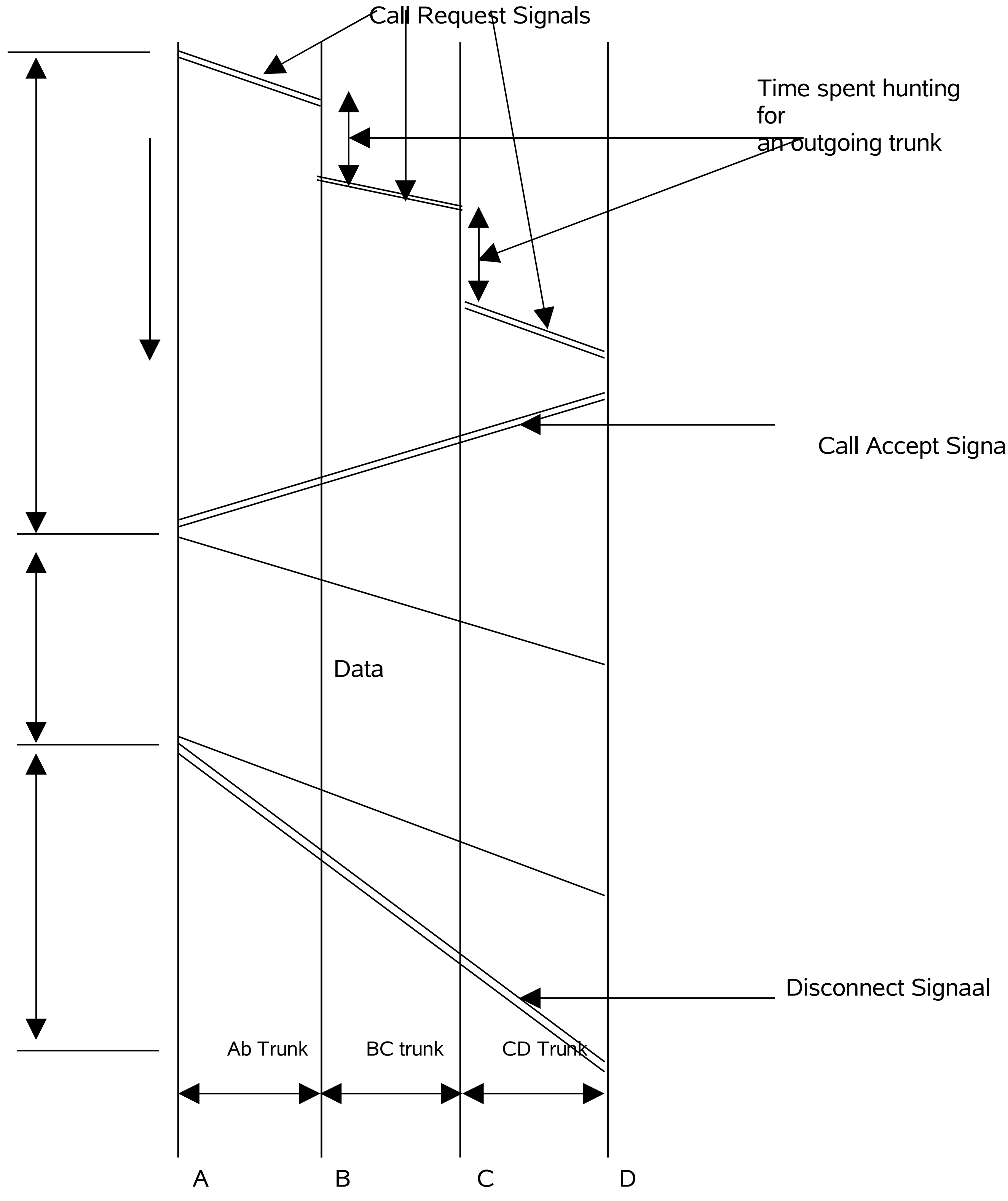


Fig. 6.2 Timing of events in Circuit Switching

6.3. Store – and – Forward data networks

In Store – and – Forward switching data unit is accepted by the network node, stored, put in queue, and when its turn comes it is forwarded to the next node. There are two types of basic techinques that can be used in the store – and – forward data networks

- Message Switched network
- Packet Switeched network

In message switched network the data unit is full message and it is switched at the network nodes. In packet switched network, the data unit is small chunk of data bytes, called data packets or simply packets. The message to be trasmitted is divided into packets by the end system and these packets are switched through the network.

6.3.1 Message Switching

A message switched network consists of store – and – forward nodes interconnected by trunks. Each node is equiped with secondary storage device wherein all incoming messages are temporarly stores for onward transmission. A message along with the source and destination addresses is sent from node to node till it reaches its destination.

Fig. 6.3. shows a message switched newoork consisting of four nodes. When end systen A wants to send a message to end system B, it sends the message along with the source and destination address to node 1.

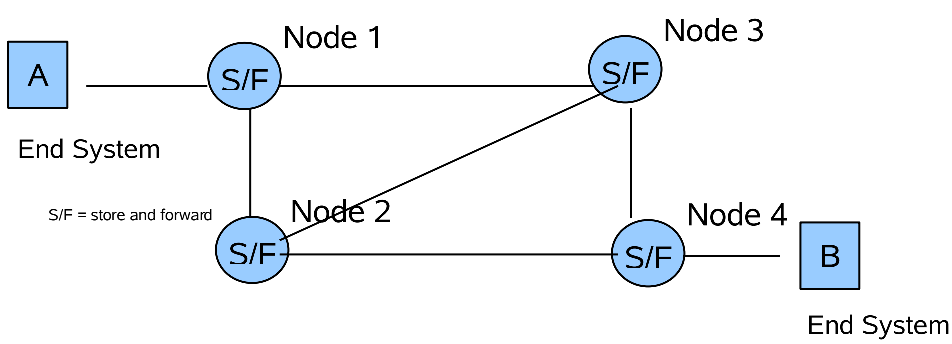


Fig. 6.3. Message Switched Network

A forwarding table is maintained at each node. It containes entries indicating destination and the corresponding outgoing ports from the node. Node 1 consults its forwarding table for the outgoing port to the destination B ans puts the message in queue of Node 2. When the message is received at Node2, it is again put in a queue of message awaiting transmission to Node 4. When Node 4 receives the message, it delivers it to the destination.

The basic features of Store – and – Forward Message Switching are as follows:

- Since the message is stored in a bulk buffer (secondary storage) at each stage of transmission, each node – to – node transfer is independent operation. The trunks can operate at different data transmission rates. Even the source and destination end systems can operate at different transmission rates.
- Each message carries destination and source addresses and is treated as an independent entity by the the networks.

Delivery Delay

Message delivery time is the sum of the following components, Fig. 6.4.

1. Propagation delay of the link
2. Processing time delay taken by each node
3. Message retransmission time at each node
4. Queueing (waiting) time at each node

The main service features of the message switched network are summarized as follows:

- One circuit for multiple users
- There are no connection establishment and release phases
- Full source and destination addresses are specifies on each message
- Delivery time is significant and random
- Delivery delay increases with traffic
- Needs large strage device
- High bit error rate due to message length
- Data rates at the source and destination need not be the same
- Provides unidirectional message transmission

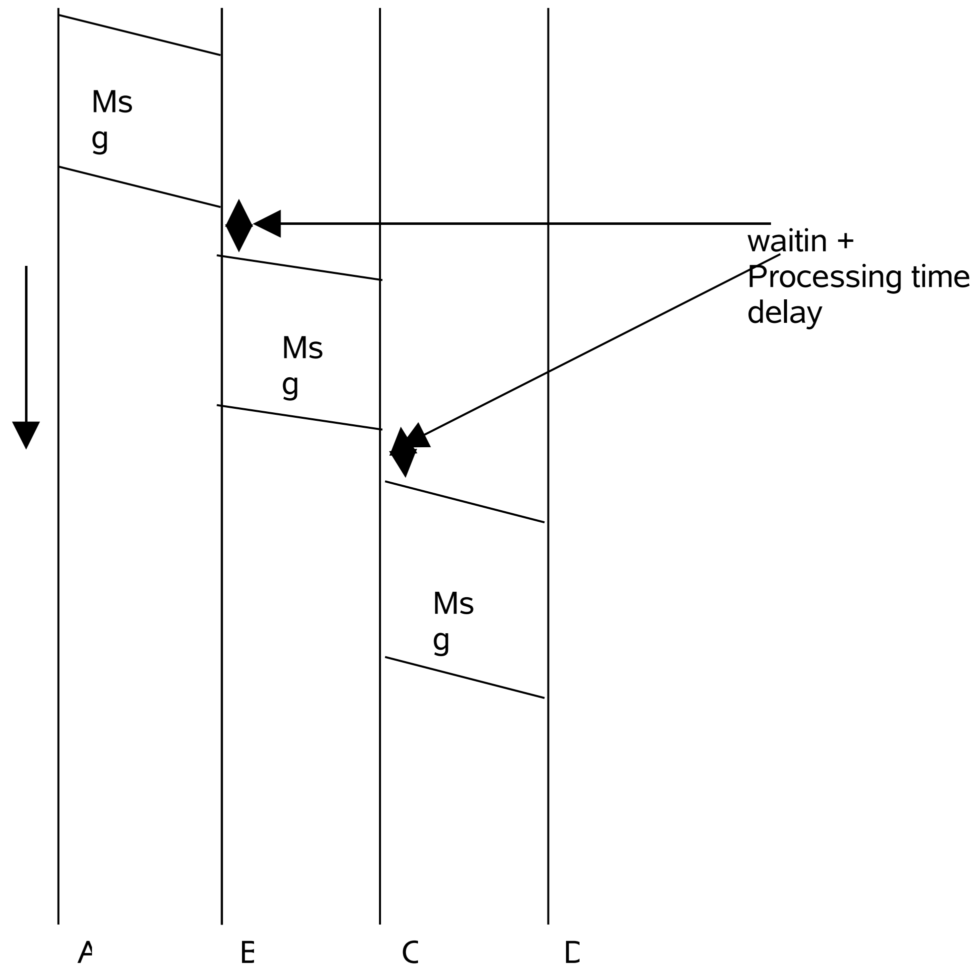


Fig. 6.4. Delivery delay in Message Switched Networks

6.3.2. Packet Switching

- In message switching there is significant delivery delay because a message is retransmitted by a node to the next only after it has been completely received
- In m essage switched network , each node should have a large size storage device (secondary storage device) to store the message which have large size.
- Also due to the large size of the messages the bit error rate is relatively high
- Also the message retransmission time from node to node until the message arrives at its destination, has a significant contribution in the large delivery delay time.

All the above disadvantages of the message switched network can be overcome by dividing the message into smaller packets and then transmitting each packet as an independent entity, Fig. 6.5.

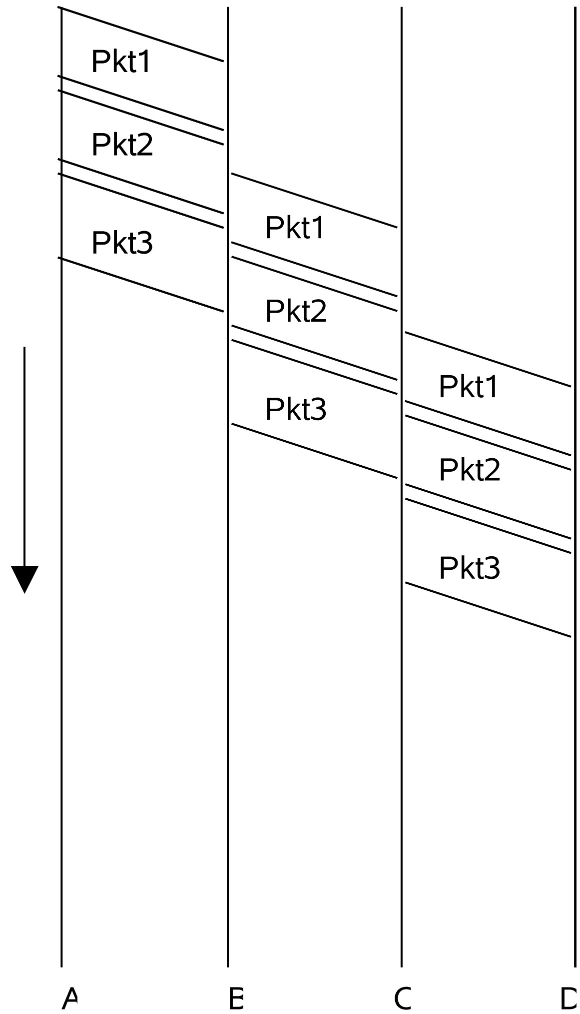


Fig. 6.5. Timing of events in Packet Switching network

The reduction in delivery time is on two accounts:

- Reduced processing time in the nodes
- Reduced total retransmission time of the message due to pipelining effect.

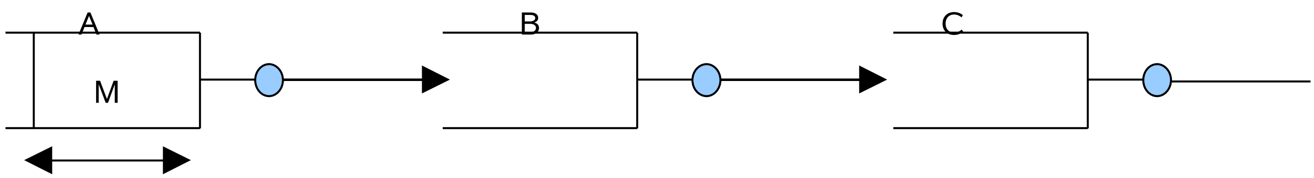
The processing time of the packet switching node is less than the message switching node because the packets are stored in the primary memory (RAM) of the nodes insteade of the secondary memory. Access time of primary memory is much less than the access time of secondary memory.

Packets are transmittes as soon as they become available for transmission. It is nor necessary to wait for all packets that comprise a message. Conversion of messages into packets and vice versa is usually done by the end systems themseves. All the data networks today are based on packet switching technology

Pipelining Effect

For understanding the pipelining effect, let us assume thaat we have a message of length L-bit at node A. This message is transmitted to node C through node B. First we shall compute the total retransmission time using message switching techinque and secondly we shall caculate the total retransmission time using packet switching techinque:

Message Switching:

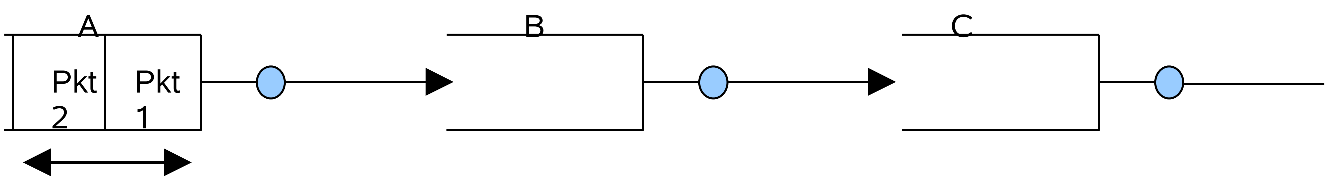


Total retransmission time from A to C, T_{AC}

$$T_{AC} = T_{AB} + T_{BC} = L/\mu + L/\mu = 2L/\mu \text{ sec}$$

Packet Switching:

Now the message is divided into two packets , each one has length of L/2



Here to calculate T_{AC}, we have three phases

- Phase One:

  T_{pkt1}, A $\rightarrow$B $= L/2\mu$ sec

- Phase Two:

  T_{pkt1}, B $\rightarrow$C $= T_{pkt2}$, A $\rightarrow$B $= L/2\mu$ sec

- Phase Three

  T_{pkt2}, B $\rightarrow$C $= L/2\mu$ sec

  $T_{AC} = L/2\mu + L/2\mu + L/2\mu = 3L/2\mu$ sec

From the above we notice that , the total retransmission time in case of packet switching is less than that of the message switching. This is called pipelining effect.

Note that if the orginal message is divided in to a large number of packets, there will be no significant improvement in the total retransmission time and the retransmission time in packet switching will become more than the retransmission time for message switching. This is due to the the fact that source and destination address must be added to each packet and consequencly this will increas the total retransmission time.

Basic Operation

A packet switched network consists of interconnected packet switching nodes (Fig. 6.6). The packect switching nodes are based on the store – and – forward technology.

The end system sends data packets containing addressing information in their header to entry node. The packet swtched node uses the addressing information to determine the outgoing port and puts the packet in the queue for further transmission. The addressing information in the header depends on the type of the packet switxhing approach deployed, datagram or virtual circuit. Addressing information may not be the physsical address of the end system (e.g 1A, 2B, 3C and 4D)

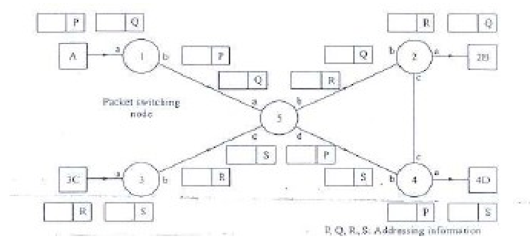


Fig. 6.6. Packet Switched Network

Note that:

- Statistical multipleying of data packets is carried out on all the circuits, i.e. packets belonging to different sources ans meant for different destinations share the same link.
- An end station can have several simultaneous data communication sessions with different end systems

6.4. Types of Packet Switched Data Networks

Packet switched data networks can be of two types:

- Datagram switching
- Virtual Circuit packet switching

6.4.1. Datagram Switched Network

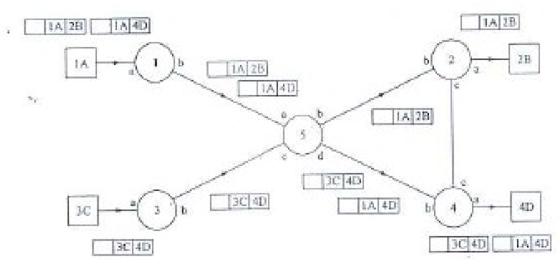
In datagram switched network, each data packet is an independent entity. It carries source and destination addresses in the header. The packet switching odes are store – and – forward nodes and they route the data packets to the destination based ob the address on the packets.

In the datagram approach, eacj packet switxhing node maintains a forwarding table that indicates the port through which an end system can be reached. When a data packet, carrying the destination address is received by a node , the node consults its forwarding table to determine the outgoing port towards the the destination address and puts the packet in the queue at that port. The process is repeated at each node till the packet reaches the destination. All the datagram packets are individually routed across the network by the nodes to their destinations. The nodes are threfore called routers.

Fig. 6.7 represents the operation in somedetails.

Consider that end system 1A has two packets to be sent to end systems 2B and 4D

- End system 1A sends the two packets, addressed to end system s 2 B and 4D, to node 1
- Node 1 forwards the packets through port **b** after consulting its forwarding table
- The packets are received by node 5. Node 5 consults its forwarding table and forwards the packet addressed to 4D through port **d** of node 5. The second packet addressed to 2B is forwarded to port **b** of node 5
- Node 2 recieves the packet through port **b** and forwards it through port **a** to the destination 2B
- Node 4 receives the packet though port **b** and forwards it though port **a** to the destination 4D



Forwarding table at node 1

To	O/G port
1A	a
2B	b
3C	b
4D	b

Forwarding table at node 2

To	O/G port
1A	b
2B	a
3C	b
4D	c

Forwarding table at node 3

To	O/G port
1A	b
2B	b
3C	a
4D	b

Forwarding table at node 4

To	O/G port
1A	b
2B	c
3C	b
4D	a

Forwarding table at node 5

To	O/G port
1A	a
2B	b
3C	c
4D	d

O/G port: Outgoing port

Fig. 6.7. Routing of Datagrams

Since the network layer consists of very large number of nodes, the forwarding tables tend to be big. It is quite possible to divide the network into several doains so that the nodes belonging to one domain are required to maintain forwarding table for nodes within their domain. Inter – domain traffic is routed through specific nodes. If new node is added to a domain, the forwarding tables in that domain only will need to be updated.

Routing of Datagrams

Creating and maintaining forwarding table is very important task in datagram switching

- The forwarding tables must be consistent
- The forwarding tables must reflect the current topology of the network.
- There should not be endless routing loops
- If a link of a node is down, alternate routes need be defines immediately

Before we proceed further, we need to distingudh the two interpretations of the term “routing”. Routing is commonly interpreted as the process of deciding and forwarding a packet along a route. In data networks, routing refers the process of creation and maintaining forwarding tables. The act of switching packets from one port to another is simply switching or forwarding but not routing. Routing protocol is the protocol for learning the network topology and updating network topology changes in the forwarding tables. Exaple of ng protocols are RIP, OSPF and BGP.

The network layer protocols of layer 3, on the other hand, define format of the user data packets and the process of their exchange. Examples of the network layer protocols are X – 25 and Internet Protocol (IP).

There are two approaches for creating and maintainig of the forwarding tables

- Static routing
- Dynamic routing

Static Routing

In static routing, the forwarding tables are preconfigured at the time of creation of the network or when a new node is added to the network. The network administrator updates the forwarding tables periodically or as and when required. E.g. When a link or node is down or when congestion arises in some part of the network. A simplified routing table is shown in table 6.1. It corresponds to node 5 of Fig.6.7.

Incoming port	Destination	Outgoing port
a	1A	x
a	2B	b
a	4D	d
a	3C	c
b	1A	a
b	2B	x
b	4D	x
b	3C	c
c	1A	a
c	2B	b
c	4D	d
c	3C	x
d	1A	a
d	2B	x
d	4D	x
d	3C	c

x: Do not forward

Table 6.1

Dynamic Routing

In static routing, the forwarding tables become outdated very son and need frequent updates. As the size of the network grows their maintainance becomes a very cumbersome process. Dynamic routing addresis these issues by automatically creating and updating the forwarding tabes. In dymamic routing, the exchange routing information using protocols called routing protocols. A routing protocol enables determination of network topology and creation of forwarding tables that indicate the best paths to the destination.

The routing protocols used in packet switched datanetworks are based on two fundamental algorithsms

- Distance Vector Algorithsm
- Link State Algorithsm

Both the algorithsms enable the nodes to fide global routing information, i.e. next hop to reach every destination in the network by shortest path. Nodes accoplish this by exchange of routing information with other nodes.

Features of Datagrams:

- There is no end – to – end connection setup. There is only data transfer
- All packets carry source and destination addresses
- There is finite and fluctuating delay in delivery of packets
- There can be packet loss due to errors and discarded packets
- The packets may be received out of sequence
- Datagram service is not reliable in the sense that there is no acknowledgment for the received packets

6.4.2. Virtual Circuit Packet Switching

In the vitual circuit approach, a virtual connection is established through the network and all the data packets are transported on the virtual connection. Unlike the datagram approach , the nodes do not make the routing decisions for each packet. It is made once for all the packets at the time of establishing of virtual connection.

To understand how the virtual connections are setup and released between two end systms, consider a five node packet switching network with end system 1A, 2B, 3C and 4D as shown in Fig. 6.8. Suppose end system 1A has some data packets to send to end system 4D. Virtual circuit packet switching has three phases , connection establishment phase, data transfer phase, and connection release phase. End system 1A must go through these phases.

Connection establishment phase:

It takes place as follows

- End system 1A send CONNECT REQUEST packet to node 1 specifying the destination address 4D and source address 1A. The CONNECT REQUEST packet also specifies a connection identifier (N1) that is later used for identifying the packets meant for the particular destination. Thus the CONNECT REQUEST is essentially : " Connect 1A to 4D. Logical channel identifier is N1."

  End system keeps record of this connection (destination address and identifier N1) in its connection table, where it maintains records of all the active connections

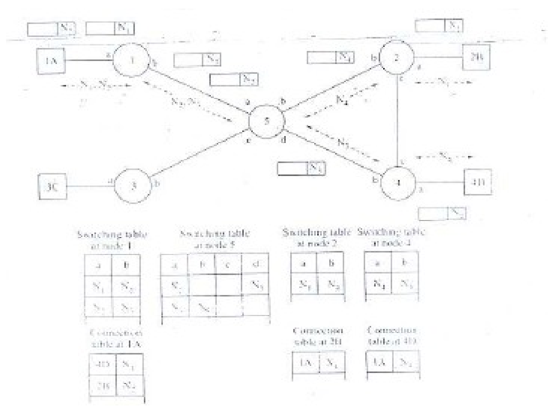


Fig. 6.8. Virtual Circuit Packet Switching

- On receipt of the CONNECT REQUEST packet node 1 examines the destination address specified in the packet and works out the outgoing link towards the destination using its routing table. Node1 selects a " free" identifier N2 for this link to node 5. Node 1 then sends a modified CONNECT REQUEST packet to node 5: " Connect 1A to 4D. Logical channel identifier is N2."

  All the future data packets of the connection being established shall bear n2 while traversing the link between node 1 and node 5. Node 1 maintains switching table in which it maintaines records relating the logical channel identifier and respective ports.(Fig. 6.8.). It makes new entry in the switching table for the new identifiers N1 and N2.
- On receipt of this packet node 5 works out the further route and forwards the packet to node 4 using another identifier N3. Node 5 also updates its switching table
- On receipt of the packet node 4 forwards it to its destination, 4D. It does so using other identifier N4
- If 4D decides to accept the call, it returns an ACCEPTANCE packet to node 4, it uses the identifier node 4 already used for this link of the connection. There is no need to specify the addresses now. The logical identifier N4 suffices

- Node 4 sends this ACCEPTANCE packet to node 5 using identifier N3.
- Node 5 forwards this packet to node 1 using identifier N2
- On receipt of the ACCEPTANCE packet, node 1 forwards the packet to 1A confirming establishment of the connection to the destination. The confirmation bears the identifier N1.

Thus in connection establishment phase, a virtual path to the destination is finalized and confirmation is received from the destination. The connection is virtual in the sense that a record relating the identifiers and ports has been created in switching tables of each intervening node.(Fig. 6.8) The end system maintains   connection table which contains the address of the end system at the other end of the connection and the respective connection identifiers.

Data Transfer Phase:

After connection is established, 1A can send its data packets to 4D . Each data packet bears the identifeier N1. 4D uses the identifier N4 on its packets for 1A. Destination addess is not needed in data packets. When a network node receives a data packet to the port as idicated there in. It also gives to the packets a new identifier as indicated in the switching table. The data packets bear sequence numbers. Flow control and acknowledgment mechanisms can be readily implemented.

Connection release phase

The vertical connection is released when 1A sends a CLEAR REQUEST packet.This packet also bears the connection identifier N1. End system 4D.Confirms connection release by sending CLEAR CONFIRMATION.With the exchange of this packets, the respective entries in the connection and switching tables are erased.

It may be noted that an end system can operate several connections simultaneously by using different connection identifiers. This is illustrated in Fig.(6.8). 1A is operating two connections,one to end station 2B and the other to end station 4D.

Ex 6.1 Figure 6.9. shows six nodes of a virtual circuit packet switching network. The switching tables maintained at nodes Q and R are shown. Determine the various connections with their paths working on the network.

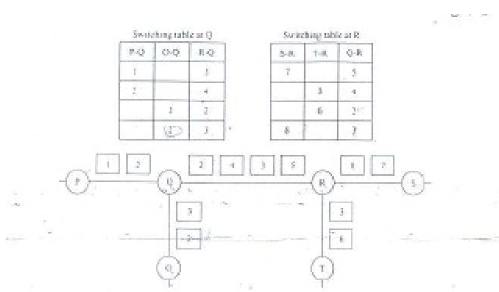


Fig. 6.9 Example 6.1

solution:

Node P has two connections,one to node S and the other to node T

-P-(1)-Q-(5)-R-(7)-S

-P-(1)-Q-(4)-R-(3)-T

Node O also has two connections, one to node S and the other to node T.

-O-(3)-Q-(2)-R-(6)-T

-O-(2)-Q-(3)-R-(8)-S

The features of virtual circuit packet switching:

- There are three phases-connection establishement,data transfer,and connection rlease.
- source and destination addresses are indicated only during establishement phase. Routing tables are also required during connection establishement phase.
- All packets carry logical channel identifeiers.
- swithching tables are used for forwarding the packets during data transfer phase. switching is based on logical channel identifeiers.
- All data packets take the same path. Therefore, the delivery delay is almost constant. Minor variations can be there due to retransmission of packets between two nodes if there is an error.
- There is no packet loss due to errors. Packets are never discarded.
- There is delivery confirmation for each packet in form of acknowledgment. Virtual circuit service is, therefore relable.
- one circuit per multiple users.
- As the packets folow the same route,their sequence is retained across the network.
- At the time of connection set-up, the nodes allocate some buffer resourses for temporary storage of the packet. by specifying maximum flow control window size based on the buffer size, it is possible to avoid deadlocks.

6.5 Purpose of network Layer

The layered architecture of packet switching data network helps in identifying the functions carried out by each layer.

Consider that there are two end systems A and B connected to switched data network. Let us examine the layered architecture of the end to end path taken by a data packet.

6.5.1 The end – system to access node link

The end system can be connected to the access node on a point to point dedicated physical link or through a local area network. Fig. 6.10.

Point to point connection is usualy through a pair of modems (Fig 6.10.a). The data link layer protocols are HDLC or PPP

It is also possible that the end system is connected through a local area network (Fig. 6.10. b). The interface of the access node that connects to the LAN has LAN interface with MAC and LLC sublayers. The LLC sublayer provides connectionless service to the network layer

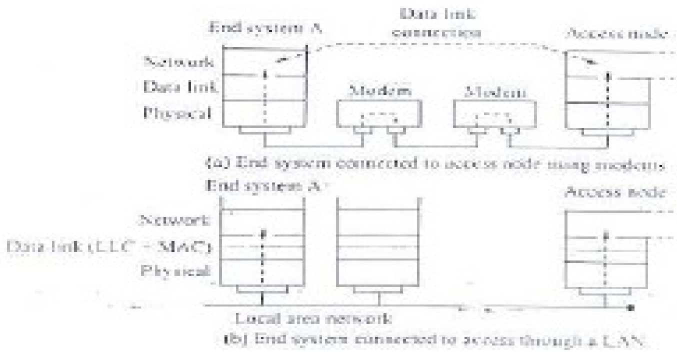


Fig. 6.10 End system to Acess node data link connection

6.5.2 Node-to- Node Link

The nodes of packet switched data network have multiple ports. All the ports have associated physical and data link layers (Fig.6.11). The Data link layers of various ports in a node provide service to a common network layer. HDLC or PPP data link protocols are used between adjcent nodes. The data links between adjacent nodes take care of errors introduced in the physical connection between the two nodes.

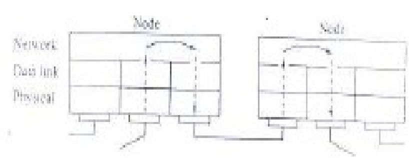


Fig. 6.11 Node-to-node data link connection

6.5.3. End system-to-End system Layered Network Architecture

The end- to- end transport of data packets is achieved by routing the data packets through series of data links across the networks(Fig.6.12). As each nodes is connected to several other nodes, there is need to decide the data link to be chosen at each nod16e for further transport of the data units.

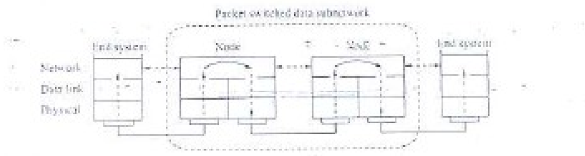


Fig. 6.12 End system -to- end system layered architecture

This routing decision is taken by the net work layer of the nodes. The forward tables (and switching tables in virtual circuit routing) maintained at each node indicate the next data link through which a data packet is to be forwarded to the next node.

In virtual circuit packet switching the virtual path through the net work is established on per call basis. The net work layer of access node to establish the end- to- end virtual connection,exchange data packets, and for rleasing the connection. In datagram routing, the network layer of and end system generates data packets that carry the destination and source addresses. The net work layer of the nodes route the data packets of their destinations.

Thus, the over all purpose of the network layer is to route the data packets from one end system to the destination by transporting these data packets over a series of data links. The mechanisms- deployed for their transport can be connection-oriented or confirmationless.

6.6 Network service

The network layer provides service to the transport layer (Fig.6.13). Note that the transport layer resides in the end systems only. The highest layer in the network nodes is the network layer.

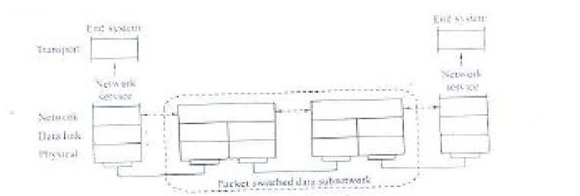


Fig. 6.13 Network Service.

Network services can be of two types:

- Connection – oriented Network services (CONS)
- Connectionless network sevices (CLNS)
  (i.e The IP protocol of TCP/IP suite)

6.6.1. Basic features of Network Services

- The network layer masks the dissimilarities of various networks. Therefore, transport layer is relieved from all concerns regarding hoe various networks are to be used
- Network services is transparent, i.e. it does not restrict the content, format or coding of user data
- When requested the network layer establishes, maintains and releases connection between transport entities.
- Unrecoverable errors are notified to the transport enties

6.7. Functions of the Network Layer

Funytions are activities that are carried out by a layer to provide the required service. The network layer carries out its functions by adding a header in the form of protocol control information(PCI) to the N – SDUs. The N – SDUs so formed are transported over the data links. The header contains all the required informaaation necessary to perform the functions. Some of the functions carried out by the network layer are listed out below:

- Network Connection:

  On receipt of the connect request network layer establishes end – to – end connection. It makes use of the poit – to – poit data link connections between the nodes of the network

- Routing and Forwarding:

  The network layer of the nodes forwards the N – SDUs to the next node. Forwarding decision is made at each node based on routing function which generates forwarding table at each node.

- Multiplexing:

  Inorder to optimize the use of data link connections, the network layer may multiplex several network connections on one data link connection.

- Segmentation and Blocking:

  Segmenting and blocking of N – SDUs is done by the network layer to get the N -SDU of the required size. The delimiters of the N – SDUs are preserved during operations

- Error Detection and Recovery:

  Error detections functions are used to ckeck that the quality of the network service is maintained

- Other Functions:

  The network layer also carries out flow control to ensure that the network nodes are note congested.