Chapter 7. Packet-Switched Networks

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Introduction

Context

This unit continues the treatment of the technology of networks commenced in the previous unit.

Introduction

Many countries have introduced packet-switched networks as their national data networks. The broad principles of packet switching are explained, beginning from the idea that a packet-switched network divides the messages it must convey into standard chunks, known as packets, so that it handles only this standard item. Packet-switched networks have, in general, a mesh structure, so that there are many ways to traverse it from a sending computer to a destination computer. For this reason, it is necessary to select from the many possibilities a route for each packet. The way in which a route is determined with the aid of routing tables is explained.

In fact, a route is just the concatenation of a series of point-to-point links, and we already know how to send data reliably over each point-to-point link. The network software needed for a packet-switched network can, therefore, be constructed by adding a routing layer, known as the Network Layer, (to decide which link to take next) above the Data Link and Physical layers.

The interaction between the network hardware and software can be illustrated by linking the contributions of the network, in transporting the packets, and of the packets, in carrying the information necessary to route them. After introducing the Transport Layer as the layer responsible for, at one end, dividing messages into packets, and, at the other end, putting packets back together to make messages, the packets can also be seen to carry the information necessary for message re-assembly.

The two basic styles of packet switching, datagram and virtual circuit, are distinguished. The claim that the Internet is a packet-switched network, which is something of a simplification, is clarified and justified.

Objectives

At the end of this module, you should be able to:

- explain the principles of packet switching;
- understand the methods used for routing;
- justify the claim that the Internet is a packet-switched network.

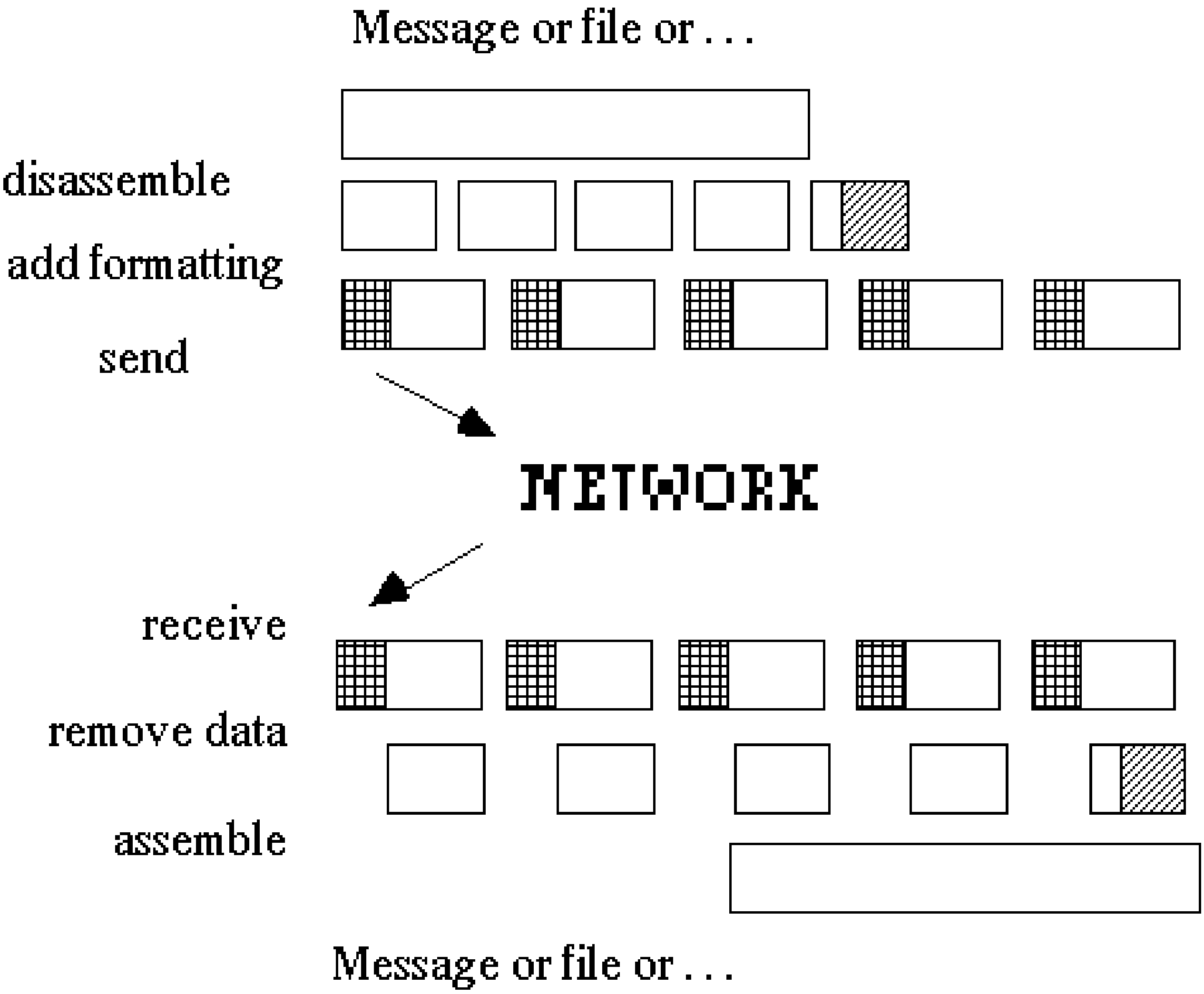
Content

In parallel with this unit, you should read the relevant parts of you textbooks.

Introduction

Packet switching is the technology employed by many wide-area networks, including public data networks and the Internet. We begin the unit by exploring the way that packet-switched networks operate.

A packet-switched network carries nothing but packets. A packet has a fixed length and a fixed format. No matter whether an e-mail is being sent, a file transferred or a multi-media presentation is being transmitted, they are all first divided into packets. The network then delivers packets to their destination, treating all the packets it handles in essentially the same way. The broad idea of packet switching, then, can be illustrated as follows:



The message or file to be transmitted is divided into equal length chunks (disassembled). It will rarely divide exactly into whole number of chunks but, as in the diagram, is likely to give a number of chunks (in this case four) with a bit left over. The remaining bit is padded to make it up to the standard length. The padding takes the form of a conventionally agreed filling pattern. Each chunk becomes the pay load for a packet, and has extra items added to it in an agreed format to create a packet. The extra items provide the information necessary to deliver the packet and reconstruct the message at the destination.

A typical minimal format for a packet is:

source address	destination address	message number	packet number	last packet?	data chunk	parity bits

The reason for giving a frame such a format will be explained and discussed later on, but the destination address, for example, is obviously needed to be able to deliver the packet.

When the sending computer is directly connected to the destination computer, it can pass the packets directly to it. In general, though, this is not the case. Packet-switched networks are large, and have a mesh structure, which means that most pairs of computers are not directly connected. To communicate with each other, they must pass their packets to an intermediate computer which, in turn, may pass them to another intermediate computer, and so on until the packets reach their destination.

The network delivers each packet in this 'store-and-forward' fashion, which is so called because each computer in the chain from the sender up to the recipient first stores a packet and then forwards it to a neighbouring intermediate computer. At the destination the data is removed from each packet, and the data chunks are concatenated to assemble the message or file.

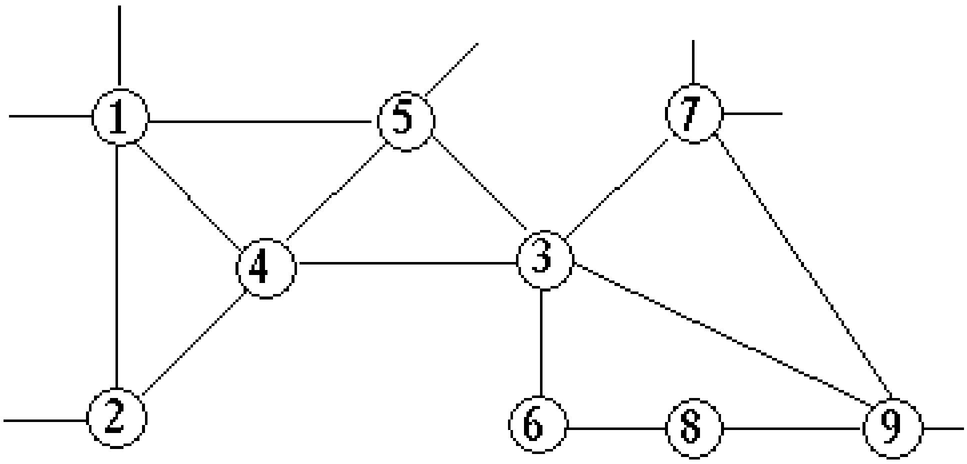
To Do

Do Review Questions 1 and 2.

Routing

At this point, it begins to become apparent that what happens on a packet-switched network is rather more complicated than what happens on a LAN. A LAN has a single channel, while a packet-switched network has a mesh of interconnections. Frames are broadcast on a LAN, while a packet is stored and forwarded through one path in a mesh. But a mesh, in general provides a number of routes between any two computers attached to it. This means that it is necessary to select the specific route for a packet from the various routes that the network can provide. The problem of selecting a route is usually solved by giving each computer in a packet-switched network the capability not only to store and forward packets, but also to decide where to forward them.

The next diagram shows part of a 'store-and-forward' network. It also gives the addresses of the computers in the network. In this context, let us consider the problem of sending packets from computer 1 to computer 9.



There are several routes between these two computers, and one of them will have to be chosen for each packet. Some routes may be better than others. Some parts of a route may be more vulnerable than others.

To Do

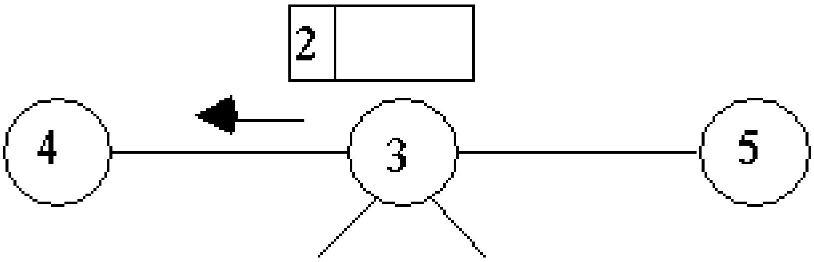
Do Review Questions 3, 4 and 5.

An addressed packet is routed through such a network with the aid of routing tables. All the computers in the network have a routing table, and each uses its table to determine where next to send the packets that come to it. A routing table contains addresses and takes the form:

Destination	Send To
1	5
2	4

Destination	Send To
...	...

If this were part of the routing table for computer 3 in the network illustrated above, then a message addressed to computer 2 would be forwarded as shown.



To Do

Do Review Questions 6 and 7.

So, a packet is passed to its destination by a sequence of store-and-forward actions. The computer that is storing a packet uses its routing table to determine which of its neighbours to forward the packet to. This means that no single computer is aware of the complete route, while every computer along the route is aware of the next hop along the route. In this way, routing is a distributed activity in that it takes place as a result of the combined efforts of all the computers along the route.

To Do

Do Review Question 8.

Variations on Routing with Tables

The idea of a routing table can be elaborated to give forms of routing that are more robust or adaptable. A more robust style of routing can be achieved with tables that provide a second choice of route in case the first choice is busy or faulty. In this case, the routing tables take the form:

Destination	Send To	Send To
	(1st choice)	(2nd choice)
1	5	4
2	4	5
...	...	...

Routing that adapts to the state of the network can be achieved with routing tables that assume the same form as those first described:

Destination	Send To
1	5
2	4
...	...

but which, rather than having fixed entries in the right-hand column, have entries that change according to the state of the network. A network can give much the same level of performance to all its users if traffic is spread evenly across it rather than accumulating in a few parts (to cause traffic jams there) while other parts are unused. Traffic can be spread evenly if the routing tables can be made to adapt to the state of the network and route new packets away from the busier parts and into the less busy parts.

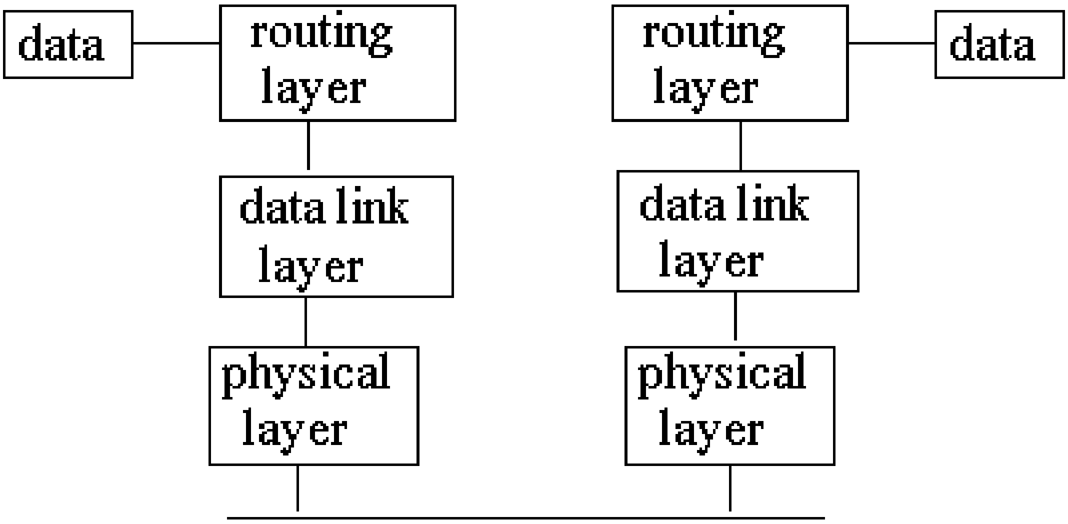
To Do

Do Review Questions 9, 10 and 11.

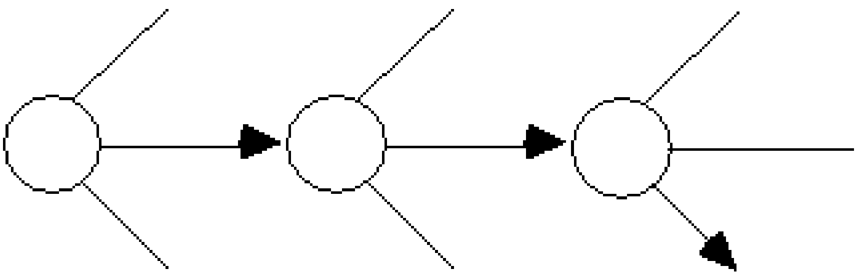
Carry out Activity 1.

Routing Software

The process of routing a packet through a network can be seen as the selection and use of a series of point-to-point links that make up a route from its source to its destination. We already have the ability to send packets reliably over a single link: adding a routing capability to that allows packets to be routed across a network. The structure of the communication software needed at each computer to achieve this is:

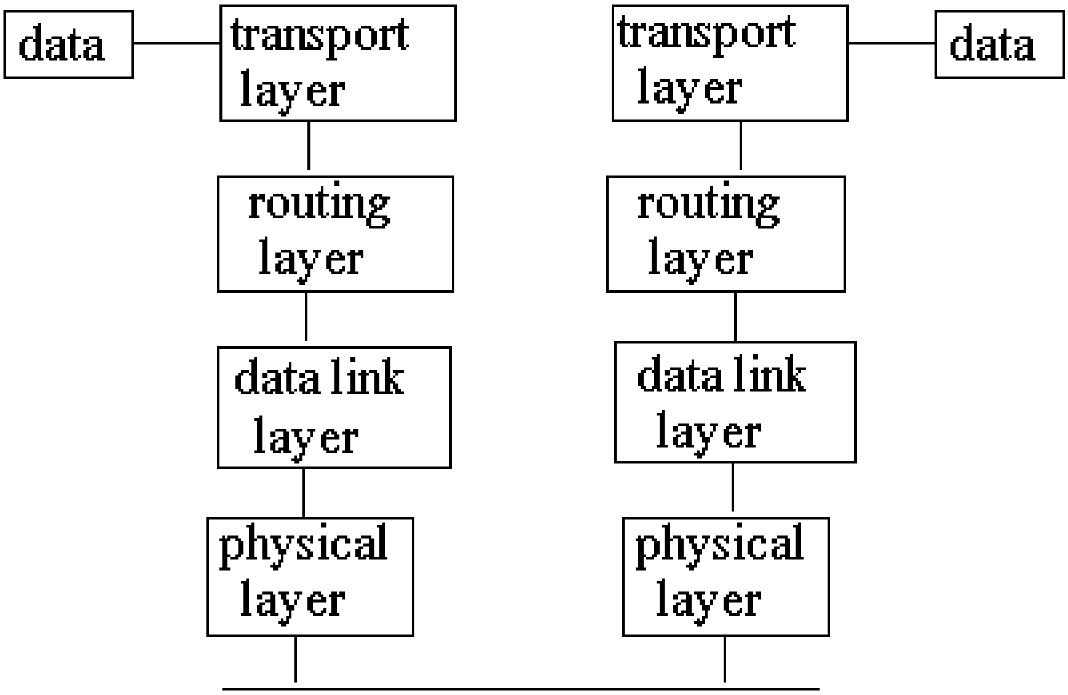


The routing, or network, layer is realised by a procedure that decides which link to use next by looking it up the routing table. The routing layer at the successive computers chooses the successive links, as shown in the diagram. After the link has been selected, the data link and physical layers of the forwarding computer ensure the reliable exchange of data over that link.



Delivering Messages

With the ability to deliver packets reliably, it is a simple matter to be able to deliver complete messages correctly. A so-called transport layer is added to divide messages into packets at the sending computer and to put them together to recover messages at the receiving computer. The structure of the software at each computer is now:



To Do

Do Review Question 12.

Styles of Packet Switching

In fact, there are two distinct styles of packet switching. In one, the packets of a message can make their way independently through the network to their destination. (Packets that can proceed independently through a network are known as datagrams.) In the other, a route is established between the source and destination computers before any packets are sent , and then all the packets of a message are piped along this route. (A route established prior to packet transmission is called a virtual circuit.)

A format for a datagram (repeated for convenience) is:

Source Address	Destination Address	Message Number	Packet Number	Last Packet?	Information	Parity Bits

The fields of a datagram are devised to ensure that it carries with it sufficient information for its own delivery and incorporation in the reconstructed message.

To Do

Do Review Question 13.

A format for packets that use virtual circuits is:

vc id.	last packet?	information	parity bits

Because the virtual circuit is set up within the network prior to the transmission of any information-bearing packets, the virtual circuit identifier (vc id.) allows each computer along the route to identify the next computer. The last packet identifier indicates the end of the transmission of the message.

To Do

Do Review Questions 14 and 15.

The two styles of packet switching can be compared in this way:

	overhead	speed
virtual circuit	low	slow
datagram	high	fast

To Do

Carry out Activity 2.

The Internet

The Internet is essentially a packet-switched network, supporting both virtual circuit and datagram transmission. But:

- packets do not have a fixed length, although they have a maximum length.
- the format of the packets is complex. The fields indicated above are included along with a number of others, most of which are to deal with somewhat obscure and rare circumstances (see Halsall for the details).
- routing is done not with fixed tables, but with tables that adapt to the state of the network with the aim of avoiding any localised congestion.

At this stage, we have enough knowledge of the technical aspects of the Internet to understand the following high-level view of its operation. It can be considered as one large packet-switched network into which a large number of computers of different types, running various applications, can insert the packets into which their messages have been divided. Once they have been inserted, the packets are all treated equally, and the network does its best to deliver each and every one as quickly as it can.

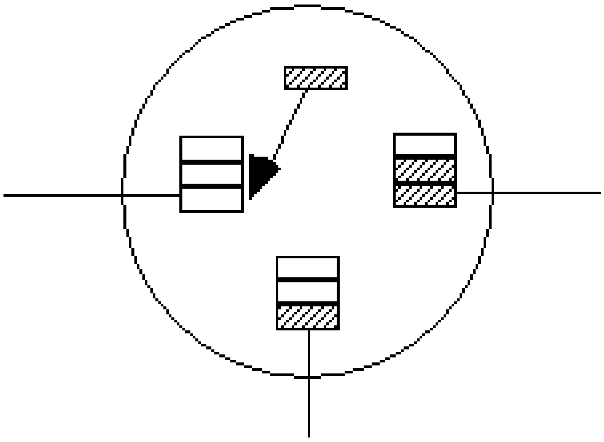
To Do

Carry out Activity 3.

Activities

Activity 1 - Routing Methods

An early method of routing was called 'hot potato' routing because each store-and-forward node in a network got rid of packets it was required to pass on as quickly a possible, as if each one was a hot potato. They did this by routing the current packet along the link for which the queue of waiting packets was the shortest. The diagram shows a node with a new packet to pass on. There are three routes from the node: one has two packets waiting in its queue, another has one, while the third has none. The packet is routed along the link with the fewest packets in its queue, in this case, the link with no queued packets.



Another method used routing by 'flooding', in which a store-and-forward node with a packet to send simply retransmitted the packet on all its outgoing routes, thereby flooding the network with copies of the packet.

Examine the behaviour of these routing methods, and compare them with routing by means of routing tables. Do these methods have any redeeming features? Why is the concept of 'packet lifetime' particularly important with routing by flooding? Is it also relevant to hot potato routing?

You can find a discussion of this activity at the end of the chapter.

Activity 2 - Datagrams and Virtual Circuits

Carry out a comparison of the effectiveness of datagrams and virtual circuits for message transmission by selecting a specific message and analysing the differences in its treatment by these two methods of delivery.

You can find a discussion of this activity at the end of the chapter.

Activity 3 - Internet Characteristics

Accepting the view that the Internet accepts packets in an undifferentiated way and does its best to deliver each one, so that their transmission is also undifferentiated, why is it difficult for the Internet to offer different qualities of service to different users, and any guarantee of security to its users?

You can find a discussion of this activity at the end of the chapter.

Review Questions

Review Question 1

In the context of a store-and-forward network, where communication takes place by repeatedly storing any item to be communicated at one computer and forwarding to the next one along the route, what are the differences in the storage requirement at each computer when:

1. complete messages or files are sent, and

2. when packets are sent?

You can find an answer/comment for this review question at the end of the chapter.

Review Question 2

One computer has a message of length 4 kbits to send to another computer. It will be routed via two intermediate nodes. The signalling rate on all the links is 1 kbit/s. How long will it take to deliver the message if it is sent as a single message?

Now consider the situation when the sending computer has 4 packets each of length 1 kbit to send down the same path. How long will it take to deliver them?

Thirdly, suppose the sending computer is attached to a packet-switching network with sufficient connectivity to provide four separate paths to the destination, each with two intermediate computers. How long will it take to deliver the four 1 kbit packets?

In all three cases, assume that nothing else is being sent, and that the time an intermediate computer holds a communicated item is negligible.

You can find an answer/comment for this review question at the end of the chapter.

Review Question 3

How many routes are there from computer 1 to computer 9? (Take a route to consist of a sequence of computers with no repetitions.)

You can find an answer/comment for this review question at the end of the chapter.

Review Question 4

What is the length of the shortest route and of the longest route?

You can find an answer/comment for this review question at the end of the chapter.

Review Question 5

Is there a computer in this mesh that is crucial in that if it fails there is no way to 'work around' it?

You can find an answer/comment for this review question at the end of the chapter.

Review Question 6

For the part of the network illustrated, complete the routing table for computer 3.

You can find an answer/comment for this review question at the end of the chapter.

Review Question 7

In general, what entries appear in the left-hand column of a routing table? What entries appear in the right-hand column?

You can find an answer/comment for this review question at the end of the chapter.

Review Question 8

Packets sent from computer 1 to computer 9 are to take the route 1539. Devise routing table for computers 1 and 5 which, along with the routing table given above for computer 3, will ensure that packets take this route.

You can find an answer/comment for this review question at the end of the chapter.

Review Question 9

Trace the sequence of actions that occurs in sending a packet from computer 1 to computer 9 using the routing tables devised in answer to the previous questions.

You can find an answer/comment for this review question at the end of the chapter.

Review Question 10

Complete the routing table for computer 3 with second choice routes.

You can find an answer/comment for this review question at the end of the chapter.

Review Question 11

How could the information needed to maintain routing tables that adapted to the state of the network be obtained?

You can find an answer/comment for this review question at the end of the chapter.

Review Question 12

A data stream is to be sent across a packet-switched network. Let us suppose the data is read from a CD at the sending computer and is to be played at once on its reception at the destination computer. The data is sent at a rate of 352 kbits per second. The packets carry 32 kbits.

At what rate must the computers exchange packets?

What is the effect if a packet is lost?

What condition must packet deliveries meet if the listener is not to complain?

You can find an answer/comment for this review question at the end of the chapter.

Review Question 13

On the diagram at the beginning of this unit, showing the idea of packet switching, indicate the protocol layers associated with the message, packet and network elements.

You can find an answer/comment for this review question at the end of the chapter.

Review Question 14

Explain the need for and role of each of the elements of the formatted datagram in ensuring message exchange.

You can find an answer/comment for this review question at the end of the chapter.

Review Question 15

Why are fields for a message number and a packet number not needed with virtual circuit transmissions?

You can find an answer/comment for this review question at the end of the chapter.

Discussion Topics

1. Discuss the reasons for using packet switching as a communications technology, as opposed to, say, message switching and circuit switching. At the same time, you could draw out the reasons for the success of packet switching as a communications technology.

2. Different variants of packet switching use different lengths for the packets. The Internet, for example, uses rather long packets, while ATM uses very short ones. By considering the advantages and disadvantages of both long and short packets, can you determine whether there might be an optimum length for packets?

3. One of the factors involved in any determination of an optimum packet length is the current state of the technology. The use of short packets calls for the use of more computation than the use of long packets by requiring more packets to be created, formatted and reassembled. On the other hand, short packets allow for more effective use of the communication network by providing more opportunities for parallel transmission of packets and more chance of being able to fill any gaps that occur in other transmissions.

   Explore the ways in which relative changes between computer and communication technologies, as manifested in properties such as speed, cost and capacity, affect the design of ideal computer networks.

Answers and Comments

Activity 1

Hot potato routing keeps all the packets in the network on the move, and it spreads them evenly around the network, there by spreading the traffic load evenly. There is, though, no guarantee that packets are moved towards their destination.

With routing by flooding, when a packet is sent, all the routes in the network are exercised by a copy of the packet. This means that the best route (no matter what 'best' may mean) is also exercised. The price for this is a network clogged up with copies of the packet. The network could be 'cleaned up' if packets were allowed only a certain life time within the network. As long as the time they were allowed was long enough to ensure their delivery, both optimum delivery and an automatically cleaned up network could be ensured.

Limiting the life time of packets using hot potato routing would also prevent their wandering aimlessly within the network for ever, but if they were terminated without being delivered, their senders ought to be notified accordingly.

Activity 2

Review Question 2 covers the ideas relevant to speed of transmission. The diagrams showing the formats provide the information needed concerning overheads. The table comparing the styles of packet switching provides a framework for the comparison.

Activity 3

Since the treatment of packets is undifferentiated, the quality of service, which relates to aspects of the delivery of packets, cannot be differentiated, no matter who sends a packet.

Similarly, the network is making its best effort to deliver the packet. It is not concerned with security, and if its best delivery effort involves the use of an insecure site, that is how it will be.

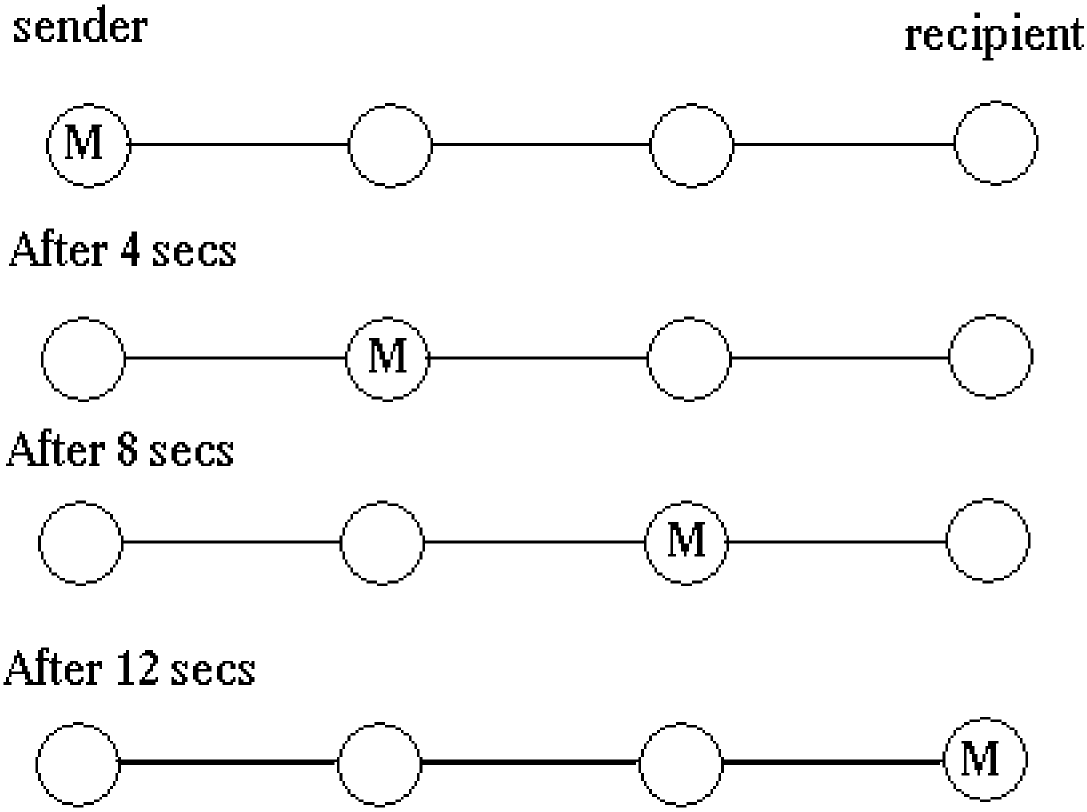
Exercise 1

Review Question 1

The difficulty in sending complete messages and files is that you don't know how long they may be. This means that you don't know how much storage to allocate for store-and-forward communication. No matter how much storage you allocate, sooner or later a message that is too large will arrive, and the attempt to communicate it will fail. By contrast, the length for packets is fixed, so that exactly how much storage is needed is known, and communication will never fail through lack of storage space. Further, the storage allocated to packets will be used to capacity each time a packet is handled, with no unused surplus, as there inevitably will be when complete messages are handled.

Review Question 2

The complete message takes 12 seconds.



Review Question 3

Eighteen. They are: 1539, 15379, 153689, 1439, 14379, 143689, 15439, 154379, 1543689, 14539, 145379, 1453689, 12439, 124379, 1243689, 124539, 1245379, 12453689.

Review Question 4

The length of the shortest route is 3 hops (shared by 1539 and 1439). The length of the longest route is 7 hops (12453689).

Review Question 5

Yes. Computer 3 is a bottleneck. If it fails, communication between 1 and 9 is no longer possible. In fact, its failure would partition the network into two parts.

Review Question 6

destination	send to
1	5
2	4
4	4
5	5
6	6
7	7
8	6
9	9

Review Question 7

The left-hand column of a computer's routing table contains the addresses of the other computers in the network. The right hand column contains the addresses of neighbours of the computer

Review Question 8

The routing table for computer 1 could be:

destination	send to
2	2
3	4
4	4
5	5
6	4
7	4
8	4
9	5

and that for computer 5:

destination	send to
1	1
2	4
3	3
4	4
6	3
7	3
8	3
9	3

Review Question 9

Computer 1 has a packet addressed to computer 9. It looks up its routing table to find that the packet must be forwarded to computer 4. When it has done this, computer 4 has a packet addressed to computer 9. It looks up its routing table to find that the packet must be forwarded to computer 3. When it has done this, computer 3 has a packet addressed to computer 9. It looks up its routing table to find that the packet must be forwarded to computer 9. When it has done this, computer 9 has a packet addressed to it, and the packet has been delivered.

Review Question 10

Destination	Sent to (1st Choice)	Send to (2nd Choice)
1	5	4
2	4	5
4	4	5
5	5	4
6	6	9
7	7	9
8	6	9
9	9	7

Review Question 11

Essentially, by monitoring the network. Monitoring activities can provide the information needed to construct a view of the overall state of the network so as to be able to determine, for example, where there are any traffic jams and where there is no traffic.

Review Question 12

The network must deliver 11 packets per second between sender and recipient. A lost packet will cause a gap of one-eleventh of a second in the music. A packet must arrive not more than one-eleventh of a second after the starting time for playing its predecessor.

Review Question 13

A file or a message is passed to the Transport layer which divides it into packets and passes them to the network layer. The Network layer decides how packets will be routed across the network.

Review Question 14

Source address is needed for acknowledgements and retransmissions. Destination address is needed for delivery. Message number is needed to identify which packets belong to which message. Packet number is needed to order the packets within a message when it is assembled. The last packet identifier is needed as an indicator that all parts of the message have been received. Parity bits are needed for error control.

Review Question 15

A virtual circuit is established for transmission of a message, and so the virtual circuit identifier also acts as a message identifier. Packets are sent in order, cannot overtake each other and, so, are received in order.