LESSON 3: CIRCUIT SWITCHING AND MANUAL SWITCHING

Objective

To provide a detailed understanding of the concepts, principles and issues associated with Circuit switching, and Manual switching.

Introduction

According to Pecar "Circuit switching is a process that establishes connections on demand and permits exclusive use of those connections until they are released." In this module we will cover the highlights of that process including:

- The analog voice waveform that you, the calling party, input to the system,
- Conversion of that analog signal to it's digital equivalent known as a voice channel or voice circuit,
- Sharing (multiplexing) of a single transmission medium by multiple voice channels over great distances,
- Switching of the voice channels along various network paths so that connections to the correct called parties can be made, and
- Conversion of the digital voice channel back to an analog waveform that is understandable to the called party.

Circuit Switching

Circuit switching is entirely analogous to the telephonic switching. In circuit switching, an electrical path is established between the source and the destination before any data transfer takes place. The electrical path may be realised by using any media such as physical wires or coaxial cables or radio links or satellite links. It remains dedicated to the communicating pair for the entire duration of the transmission irrespective of whether data is actually transferred or not. No other potential user can use the path even if it is idle. The connection is released only when specifically signaled so by either of the communicating entities. Data transmission using PSTN connection is a typical example of a circuit switched data transfer.

We can illustrate the principle of circuit switching by a diagram given in Fig. 3.1. When host computer H_1 wants to transfer data to the host computer H_6, a connection request is made to the switching node N_1. This node (N_1) selects a suitable neighbouring node through which the desired connection may be established, say in this case node N_5.

Node N_5 in turn, selects a suitable onward path and so on until an electrical path is established between HI and Ho. The path selection is generally based on a routing algorithm that may take into account the network traffic, path length etc. Once a path is established Data transfer begins.

Data transfer in circuit switched network involves three explicit phases.

1. Connection Establishment
2. Data transmission
3. Connection Release

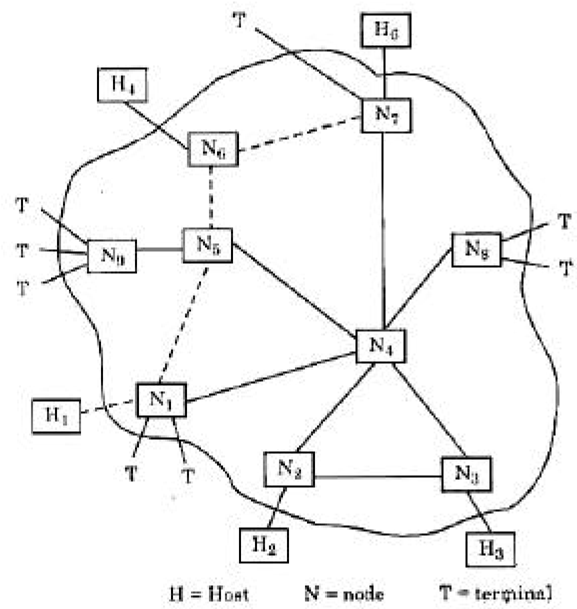

Fig.3.1 Illustration of circuit switched network

1. Therefore, total time taken for data transfer in a circuit switched network depends upon three components. It is given by

$$T_{cs} = T_e + T_t + T_r \qquad \ldots\ldots\ldots\ldots\text{Eq.1}$$

Where, T_e = time for connection establishment

T_t = time for data transmission

T_r = time for path release.

Signal propagation time also contributes to the data transfer time. However, ignore the propagation delays for the present, as they are comparatively small.

T_e depends upon the number oh-witching nodes in the path between the source and destination hosts. Each node except last one selects the route as per the routing algorithm and this involves a certain amount of processing a switching time in each node,

Accordingly, establishment time T_e may be expressed as

$$T_e = (N - 1)\, T_m \qquad \ldots\ldots\ldots\ldots\ldots\ldots\text{Eq.2}$$

Where,

N = Number of switching nodes in the path

T_m = Average route selection time in each node for a given network load

Data transmission time T_t is expressed as

$Tt = M/R$ ……………….Eq.3

Where,

M= Message length in bits

R = Data rate in pits/sec

Connection release time (T_r) is also dependent upon the number of switching nodes in the path. Connection release is generally initiated by a release signal, which propagates from the other. On receiving connection release signal each node in the circuit performs certain house keeping operations such as making entries in routing tables.

T_r may be expressed as

$T_r = N\ T_h$ …………..Eq.4

Where,

T_h = time taken by a node to make housekeeping entries.

Therefore, we have

$T_{cs} = (N - 1)\ T_m + M/R + N\ T_h$ …………….Eq.5

Propagation time is dependent upon the electrical distance between the source and the medium of transmission. The free space propagation speed is approximately equal to, the velocity of electromagnetic (EM) waves in vacuum. The speed in typical coaxial cables is of the order of 200 m /µsec.

While the propagation time one way may be determined by knowing the distance and medium properties, the number of times the propagation time needs to be counted for each data transfer phase depends on the actual protocols used in each phase.

For example, in a simple protocol for connection establishment phase, successful connection is indicated by a signal sent from the destination-switching node to the source-switching node. In this case, twice the propagation time T_p would figure in connection establishment time T_e. Now we assume that no acknowledgement during data transmission and connection release phases, only one T_p needs to be accounted for in each T_t and T_r. Therefore, eq.5 can be written as

$T_{cs} = (N - 1)\ T_m + M/R + N\ T_h + 4T_p$ ……….Eq.6

Where, T_p = One-way Propagation time

Example 1: A Circuit -Switched Network connection involves 5 switching nodes. Each node takes 2 seconds and 0.2 seconds for establishing and releasing connections, respectively. If the data transfer rate is 2400 bits/second, find the data transfer time for a. message that is 300 bytes long.

Solution:

Neglecting the propagation delay time, data transfer time for a message is given by,

$$T_{cs} = (N - 1)\ T_m + M/R + NT_h + 4T_p$$
$$= (N - 1)\ T_m + M/R + N\ T_h \text{, since } T_p = 0$$
$$= (5 - 1) * 2 + (300*8) / 2400 + 5 * 0.2$$
$$= 10.0 \text{ second}$$

In this example, 9 seconds out of total time 10 seconds are spent on connection establishment and release and the actual data transfer lasts for only 1 second.

Circuit switching technique is insufficient for small messages where the total data transfer time is dominated by the path establishment time. Consequently circuit switching is prepared where large volume data transfer in involved. Connection **establishment time T_e** is often a function of load on the network. As the load increases, each of the concerned node may have to look for a number of alternative routes before one is chosen. The paths chosen may, in general have a large number of nodes than when the network is highly loaded. Consequently, the path set up time Te increases with load. Connection release and data transmission times are not significantly affected by the load. Fig. 3.2 shows the variation of different times with respect to load. Blocking occurs when the network is fully loaded (as indicated by the local value P). Circuit switching has certain disadvantages for transmitting data traffic. The path set up time is typically of the order of 20-30 second or more. This set up time turns out to be an excessive overhead for bursty computer traffic which typically lasts for a few seconds or less.

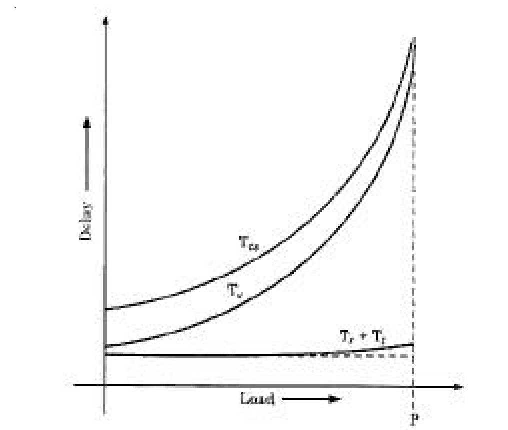

Fig. 3.2 Variations of delay time components in circuit switching.

The entire line quality is affected if there is one bad link in the circuit. In fact such type of problem faced in many PSTN circuit switched connections. The intensity of traffic in PSTNs is carried by high quality coaxial or microwave or satellite links whereas the subscriber end links are of poor quality. Therefore, entire circuit is of poor quality although the major portion (95% or more) of the circuit uses high quality links. This problem is called 'Last Mile' problem. Similarly, the speed of operation of' the circuit is limited by the slowest link in the circuit. This leads to poor utilization of high capacity lines. In circuit switched connection. The required bandwidth is statically allocated and the unused bandwidth is wasted, the network provides no error control facilities, which are to be handled by the end systems.

Manual switching system

In the older days, manual switching systems were used. With the advent of automatic switching systems, the manual exchanges have almost gone out of use. Now a days operator assistance is required on a routine basis, only to connect the incoming calls at a private automatic branch exchange (PABX) to the required expansion numbers. Even this operator assistance will cease to exist with the large scale introduction of what is known as Direct Inward dialling (DID) facility. The organization of manual exchanges could help in understanding many of the principles of a telecommunication switching system. We can classify early switching systems into two categories Local battery exchanges (LB), and central battery exchanges (CB).

We already know that a microphone requires to be energized in order to produce electrical signals corresponding to the speech waveform. In the very early switching systems the microphone was energized using a battery at the subscriber end. After some time, a battery located at the exchange was used.

Accordingly, we can classify early switching systems into two categories: These are local battery (LB) exchanges and central battery (CB) exchanges. Now we shall discuss these exchanges.

Local battery exchanges:

In this system, dry cells were used in subscriber sets to power the microphone, but these systems having limited power output. Therefore, these cannot be used for signaling over long lines to the exchanges. Hence, LB subscriber sets were provided with a magnet generator. In this system subscriber needed to rotate a handle to generate the required a.c. supply to operate indicators at the telephone exchange. The use of magneto generator leads to the alternative nomenclature magneto exchange for LB systems. The necessity to replace dry cells frequently and cumbersome method of rotating the magneto generator leads to the development of central battery (CB) exchanges.

Central battery exchanges:

In CB exchanges, subscriber set is energized from a powerful central battery at the exchange. Almost all the present day telephone exchanges are CB systems. But in future, systems can be used to LB structures if low cost reliable power supplies for the subscriber premises become available. Fig. 3.3 shows a simple CB system operated by a human being. This system consists of one or more switchboards manned by operators. The subscriber lines are terminated on jacks mounted on, the switchboard. One jack is used for one subscriber. Associated with each jack is a light indicator to draw the attention of the operator. When a subscriber lifts the hand set, the off-hook switch is closed. Therefore, it causes a current that flows through the hand set and the lamp relay coil.

The lamp relay operates and the indicator corresponding to the subscriber lights up. The operator establishes contact with the subscriber by connecting the head set to the subscriber line via the head set key and a plug-ended cord pair. A plug-ended cord pair has two cords. These cords are connected internally and terminated with a plug each at the external ends. The plugs mate with the jacks. For making contact, a cord is plugged into the subscriber jack and the key corresponding to the chosen cord is thrown in position to connect the headset. On being told the number required by the subscriber the operator verifies whether the called party is free or not. If the called party is free then operator sends out the ringing current to the called subscriber using a plug-ended cord pair. The ringing circuit at the subscriber end is usually a bell. The bell is shown in Fig.3.3.

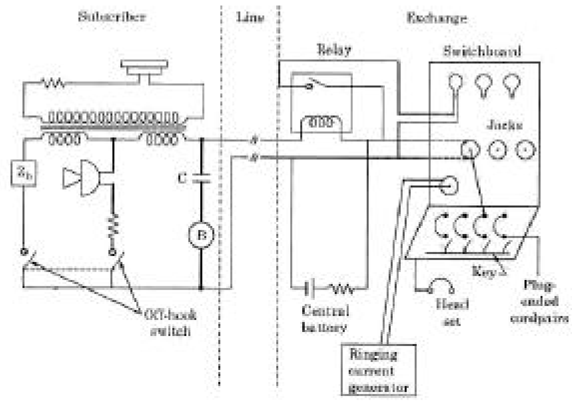

Fig.3.3 Manned Central Battery (CB) Switching System or exchange

There is a capacitor C in series with bell B. They remain connected to the circuit always. The capacitor allows the alternating ringing current from the exchange to pass through the bell but prevents the loop direct current. If the called party is busy, the calling subscriber is told about the same. When the called party answers, his indicator lamp lights up. The operator then establishes a connection between the calling and the called party by plugging in the cord pair to the called party jack. In a manual switching system or exchange, the operator has full control of a connection. In manual switching system, operator enables the signalling systems, performs switching and, releases a connection after a conversation.

If there are 200 subscribers terminated on a switchboard, there can be a maximum of 100 simultaneous calls. We require 100 plug-ended cord pairs on a switchboard to support 100 simultaneous calls. But a single operator cannot handle 100 calls simultaneously. It will be a rare case that all the subscribers would want to talk simultaneously. Now we, are assuming that only 20 subscribers (10 calls) will use the system simultaneously, the switchboard needs to be provided with only 10 plug-ended cord pairs. If more than 20 users or subscribers want to talk at the same time, the operator will not have plug-ended cords for establishing the connection and users are blocked. The users are also blocked if the operator is not able to handle more than a certain number of calls simultaneously, even though free plug-ended cord pairs are available.

When the number of subscribers increases, multiple switchboards and operators are required to handle the traffic.

Subscriber's switchboards are of two types. These are single termination and multi termination switchboards. The terms nonmultiple and multiple are sometimes used to denote single termination and multi termination schemes, respectively.

In the single termination scheme, a subscriber is terminated on only one board, whereas in the multi termination scheme, a subscriber is terminated on more than one switchboard. In the single termination board, subscribers are split into groups and connected to different switchboards. Each switchboard is handled by separate operator. When a user wants to make a call to another in the same group, operator concerned establishes the call. If a subscriber wishes to call another subscriber in another group then transfer lines are provided between the boards. These are shown in Fig.3.4.

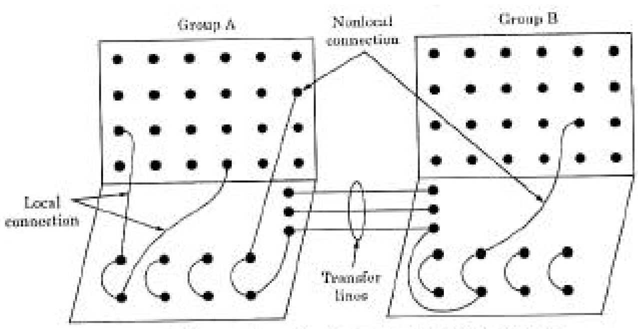

Fig.3.4 Illustration of single termination boards with transfer jacks

The number of transfer lines is determined by using the knowledge of the estimated intergroup traffic. Here, we can note that an intergroup call requires the services of two operators manning the respective groups.

The maximum number of simultaneous calls within a group is limited by the number of plug-ended cord pairs in the group or the number of simultaneous calls that can be handled by the operator, whichever is smaller. The number of simultaneous calls between the groups is limited by the number of transfer lines. There is a serious disadvantage in single termination system that as many, operators as there are switchboards are always required irrespective of the peak or lean traffic period. During lean traffic period, the average number of simultaneous calls is much less than that during the peak traffic period. Two operators are required to establish every intergroup call. Consequently even a small number of intergroup calls among the switchboards demands that all boards be manned.

In the multi termination switchboard scheme, we can avoid the need of two operators per call. Here, every subscriber is terminated on all the switchboards. It is shown in Fig. 3.4. Such an arrangement has the advantage that a single operator can establish a call between any two subscribers connected to the system. The number of operators needed on duty at any time is now determined by the number of simultaneous calls estimated during the period.

This system has two drawbacks:

1. The total number of connections in the system increases considerably, thereby reducing the reliability of the system.
2. Termination of all the subscribers in all the switchboards. Such that the terminations are easily accessible to the operators, poses human engineering problems. The switchboard height becomes large, and the operator does not have easy access to the numbers at the top of the switchboard.

The problem is somewhat reduced by terminating half the number of subscribers in alternate switchboards in a cyclic manner and letting an operator have access to one half of the adjacent boards on the left and right. The scheme for two operator positions is shown in Fig.3.6. The termination of various subscribers on the switchboards is done as per the following order.

Subscriber Nos.	Operator Board	Right/left Top/Bottom
0-99	1	Left-top
100-199	1	Right-top
200-299	2	Left-top
300-399	2	Right-top
400-499	1	Left-bottom
500-599	1	Right-bottom
600-699	2	Left-bottom
700-799	2	Right-bottom

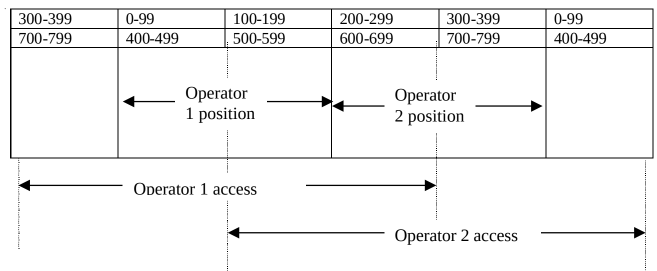

Fig. 3.5 Illustration of a practical multitermination board scheme with cyclic assignment of numbers

In addition, the numbers terminated on the right half of operator (2) panel, 300-399 and 700-799, are terminated on the half panel on the left side of the operator (1).

Similarly, the numbers terminated on the left half of operator (1) panel, 0-99 and 400-499, are terminated on the half panel on the right side of the operator (2).

Operator (1) gets access to numbers 200-299 and 700-799 from the left hand side half-panel and to numbers 200-299 and 600-699 from the half-panel of the operator (2). In similar fashion, operator (2) gets access to numbers 100-199 and 500-599 from the left and to numbers 0-99 and 400-499 from the right. It can be noted here that we require one unmanned half-panel at either end of the switchboard row. Thus, in an 8-operator switchboard, there are nine logical switchboards. As the number of subscribers increases (typically to a thousand or more) manual switching becomes more and more difficult and a method of automatic switching, signalling and control is inevitable.

Fig.3.6 Multi-termination Boards

Circuit Switching Vs. Message Switching

In our introduction to the idea of a computer network based on switching, we have emphasized the similarities between the techniques used in the telephone network and in a switched computer network. There are, however, major differences in the way such networks operate. In this and the next section we will discuss three distinct approaches to switching — circuit switching, message switching and packet switching — and examine their relative advantages.

Our discussion of switching techniques may appear to be focused on a very obscure technical detail of the operation of communications networks. There are two facts that may help maintain your interest as you make your way through this material. First, as mentioned above, there are several individuals who are credited with (or claim for themselves) the distinction of "inventing the Internet" based on what might be deemed THE key technical invention that makes the Internet possible. One of these individuals is Leonard Kleinrock. Kleinrock's claim is based principally on the fact that he was the first to publish a description of the switching technique used in the Internet, packet switching.

The second fact provides an explanation for the first. How is it that a switching technique could be so essential that its inventor could be considered the inventor of the Internet. As we will see, any of the three switching techniques described in the next two sections could be used to build a computer network. What is so special about packet switching? The answer is an economic one. While packet switching does not make anything totally new possible, it does make it possible to do an old thing, transmit information, more efficiently and therefore less expensively - MUCH less expensively. To make the point clearer, consider an earlier invention with a similar effect. Gutenberg is credited with inventing the printing press. This isn't quite accurate. Printing presses were already in use. What Guttenberg added was the idea of reusable, moveable type. In any case, one thing Guttenberg definitely didn't invent was the book. Monks had been producing books by hand for centuries. All Gutenberg did was make it much less expensive to make books. That is, like packet switching, his invention made it possible to do an old thing, transmit information, more efficiently and less expensively. Few, however, would argue that his contribution was a small one. We argue that packet switching may be a contribution of comparable significance. Therefore, we will ask you to devote some effort to appreciating its advantages.

Consider the functioning of an early phone system in which connections were made manually by human switchboard operators. For the sake of simplicity, assume that a call is made between two phones connected to the same exchange. Before the call is made, there is no direct electrical connection between the calling phone and the phone which is being called. Each phone is connected to the switchboard in the central exchange, but they are not directly connected to one another. The caller contacts the operator and asks to be connected. The operator takes a wire that is connected to the caller's phone on one end and has a jack on the other end and plugs it into a socket which is connected to the wire leading to the called party's phone. At this point, there is a physical path of wires capable of conducting electric current between the two phones. As the parties converse, this path carries the varying electric current encoding their voices back and forth without further intervention from the operator.

A physical path capable of conducting electrical current is called a circuit. Accordingly, the task performed by an operator in a phone system is called circuit switching. In the modern phone system, the task remains the same even though it is accomplished automatically. When a call is made, the result of the process of handling the call is either the establishment of a path that can carry continuous stream of audio signals between the two phones or a busy signal if such a connection is not possible. The path may not be easily described as a wire. It may include fiber optic cables on which the audio signal is multiplexed with hundreds or thousands of other signals. All components of the path, however, provide functionality equivalent to a dedicated wire in that the signal that emerges on the receiving phone's local loops is identical to that which would be delivered by a physical path or simple wires. Once a connection has been established, the call proceeds without the involvement of the switching system.

In computer networks, an alternate approach to switching is possible. Just as it is easier to appreciate circuit switching by imagining the behavior of a turn of the century telephone operator than by imagining the operation of a modern digital telephone switching center, it is easier to understand the technique used in computer networks by imagining how it might have been used in a much older network, the telegraph system.

We have already discussed the Morse code system used to encode messages. While this system seems incredibly primitive by today's standards, the introduction of the telegraph revolutionized communication in the 19th century to a degree equal to or more likely exceeding the impact of the Internet. Before the telegraph, the fastest means of sending a message cross continent took days and communications across the ocean took even longer. With the telegraph, instant communications became possible. In its day, Western Union was as powerful and profitable a corporation as AT&T was for most of the 20th century.

As with computer networks and the phone system, the telegraph was not very interesting by itself. Two telegraph instruments at the end of a wire did not constitute a communications system. Like the phone system and the Internet, the importance of the telegraph rested on the establishment of a network of telegraph links that spanned the whole country. Also, like the phone system and Internet, it was not practical to construct a telegraph network with direct connections between every telegraph office in every town and city in the country. Instead, the telegraph network relied on a network of connections between telegraph offices that provided paths of several links between any two offices and on the ability of telegraph offices to act as intermediate switching centers between offices that were not directly connected.

Imagine you are part of a start-up company providing telegraph service along the east coast of the United States. You have established offices in Philadelphia, New York and Boston with plans of providing delivery service between those cities. Customers in each city will bring messages for delivery to your office. You will send the message electrically to your office in the destination city where it will be typed and hand delivered to the designated recipient.

Given the expense of installing cable, your company would probably not install three lines providing direct connections between all three cities. A more economical approach would be to install a line between New York and Philadelphia and another line between New York and Boston. Then, when someone wants to send a message from Boston to Philadelphia, they will do so by sending the message through New

York. The interesting question is exactly how to have the New York office to fulfill its role as a "switch" between Philadelphia and Boston.

There are two distinct ways that the staff and facilities in the New York office could handle message from Boston to Philadelphia. To make things concrete, let's imagine how things might be done in New York. In the New York office in addition to your squad of messenger boys, you might have three employees: a) Bob who sends and receives message from Boston, b) Phil who sends and receives messages from Philadelphia, and c) Ned who mans the front desk, taking messages from customers and giving them to Bob or Phil for transmission depending on their destination.

When the Boston office needs to send a message to Philadelphia, they will have to start by sending some message to Bob through the line to New York. The first approach would be to have them send a message telling Bob that they need to be connected to the Philadelphia line as a phone customer might ask an operator to make a connection. In this case, Bob would have to first check to see if Phil was busy sending or receiving a message. If so, he would send a message back to Boston telling them they have to wait. Once the line to Philadelphia became idle, Bob would tell Phil that Boston needed to use the line. Then they would physically connect the line from Boston to the line from Philadelphia and sit back and wait until the Boston office finished sending its message. At that point, they would disconnect the lines and return to normal. This procedure is just the telegraph equivalent of circuit switching.

There is an alternative approach which requires no physical connection of the lines from Boston and Philadelphia. The simplicity of this alternate message depends on two simple practices that would be fairly standard in the operation of a telegraph office. First, think about what Ned, the front desk operator does as customers give him messages. Depending on each message's destination, he simply give the message to be sent to either Bob or Phil. Bob or Phil may be busy sending or receiving a message when this happens. If so, the new messages simply get placed in a stack awaiting transmission. Second, note that whenever a message is sent, the information transmitted must include the address to which the message should be delivered. If this information were not included, the receiving office would not be able to dispatch a messenger to deliver the telegram.

Now, suppose that the operator in Boston simply sends all outgoing message, whether destined to New York or Philadelphia out on the New York line. Bob, the operator in New York can decide what to do with them after they arrive by examining the destination addresses. If a message arrives from Boston destined for an address in New York, Bob will simply give the message to Ned at the front desk who will assign it to one of the delivery boys. If Bob receives a message destined for Philadelphia, he can simply add it to Phil's pile of message awaiting transmission to Philadelphia in the same way Ned places messages from New York to Philadelphia on Phil's pile. Eventually, Phil will transmit all the messages, whether from Boston or New York, to Philadelphia as desired.

This approach is very different from physically connecting the line from Boston to the line from Philadelphia. There is never a physical, electrical connection all the way from Boston to Philadelphia in this scheme. Nevertheless, message will get delivered from Boston to Philadelphia. The New York office is still functioning as a switching center. In this case, however, the technique employed is refereed to as message switching rather than circuit switching.

Message switching would not be at all acceptable for use within the phone system. Imagine if when you made a call you actually only talked directly to an operator who repeated everything you said to the person to whom you really wanted to talk and also told you everything they wanted to say to you. Telephone calls would be a very different experience. On the other hand, we have tried to show that message switching works quite naturally in the context of a telegraph system. There is no loss of "personal touch" when messages are finally delivered. The tasks required of the employees in the telegraph office are actually simplified. They only need to know how to send and receive message and to determine for each message on which line it should be sent. They no longer need to know how to physically connect lines.

Just as it is a natural approach in the context of a telegraph system, message switching fits in well in a computer network. Again, there is no loss of "personal touch" as long as the intended sequence of 0's and 1's gets delivered to its intended destination. To participate in any computer network, computers have to be designed so that they can send and receive messages. This is true even for the computer on the periphery of the network that are not even serving as switches of any kind. Given a computer that knows how to send and receive messages, it is fairly simple to program the machine to forward messages from an incoming network connection to an outgoing connection to achieve message switching. In fact, as we will see, a close cousin of message switching called packet switching is used in the Internet and most other computer networks.

Compared to circuit switching, message switching simplifies the process of sharing communication lines. Suppose for a moment that our telegraph office used circuit switching. Recall that in this case when the Boston office requests a connection through New York to Philadelphia, the New York operator has to check to see if the line from New York to Philadelphia is free. If a message is currently being sent or received on the New York to Philadelphia line, the Boston office will have to wait until the Philadelphia line becomes free before beginning its transmission. This is a waste of resources. For the waiting period, the Boston to New York line will remain idle even though the Boston office may have other messages that need to be sent directly to New York. Basically, either lines will have to be wasted or some complex procedures will have to be followed to minimize waiting time.

With message switching all the available lines in the system are used to their fullest. If a message that needs to be sent out on a given line arrives while that line is busy, it just is added to the collection of messages waiting to be sent out on that line later. Messages wait for lines, but lines are not left idle waiting for connections to other lines.

Notes