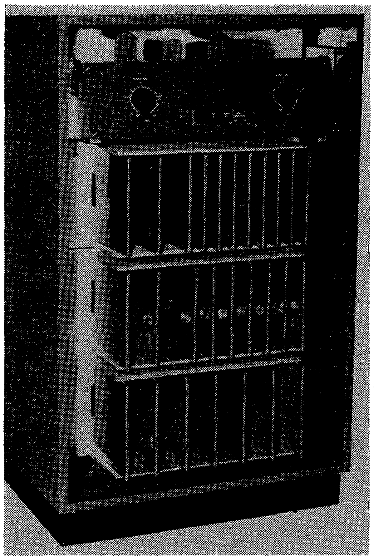

Fig. 4.

pacity is 72 characters. The punch operation is started when sufficient data has been stored in the memory to assure that the punch will not overtake the incoming information even if it is running at its fastest tolerance of 107 cards per minute.

An 80-bit storage register assembles a full row from the memory. The punched card is reproduced row by row. If the parity checks indicate an error, the punched card is offset in the stacker.

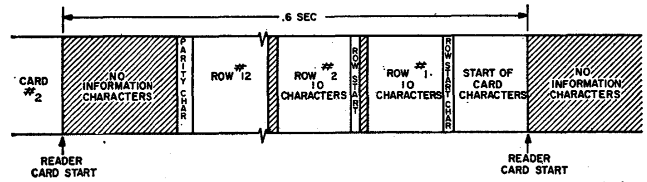

Fig. 5.

The converter is completely transistorized including the punch-magnet drivers. Construction is modular and consists of printed-circuit cards many of which are identical. A complete transmit and receive terminal is contained in a 5-½ foot cabinet.

Conclusions

Reliable communication between digital computers and on-line use of business machines utilizing wire-line and radio facilities can be accomplished with efficient data-transmission systems and special-purpose converters.

Economic considerations, clarifications of use requirements, lack of common language, format and data-rate standardization, incompatability of equipments and operational inexperience are some of the limiting factors.

The Kineplex data-transmission system provides a common signaling method for use with a variety of existing and future input devices which want to take advantage of available voice channels.

The Kinecard converter increases the speed of transmission of punched-card data to the usual operating speed of punching machines thereby permitting on-line use.

Communication Switching Systems as Real-Time Computers

A. E. JOEL†

Introduction—The Nature of Communication Service

AUTOMATIC communication switching systems were the first practical and mass-produced data processing systems. Initially, they were designed with electromechanical elements, such as selector switches and relays. However, as will be covered in more detail in another paper,[1] electronic data processing techniques are rapidly being applied to these systems.

Not only were automatic communication systems the first mass-produced data processing systems, they were also the first "real-time" computers. What makes them "real-time" computers? They must serve on demand of the customers "quickly when wanted" and "all of the time." A service request by a communications customer is a perishable commodity and the longer the delay in serving, the more likely the chance that the request will be withdrawn. Therefore, in communication switching the time between a service request and its fulfillment must be kept small, if we are to provide the service for which we are granted public franchise and to capitalize to the maximum extent by making the supply of service approach the demand as

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[1] R. W. Ketchledge, "An introduction to the Bell System's first electronic switching office," this issue, p. 204.

closely as possible. Public reaction to inability to serve is an important factor in providing service when requested.

If service cannot be offered when requested, there is either abandonment or delay. The amount of delay, in this case, may determine whether the system is truly real time or not. Real time is relative. A one-second delay on a call which lasts for 180 seconds is not excessive. Perhaps a 10-second delay is excessive on a short distance call but not on a longer distance call.

Equipment failures are inevitable in a system which must serve "all the time." Even with only one source demanding service on request, duplicate or multiple facilities are provided to greatly reduce the chance of expected failure to serve on demand. Improved maintenance facilities and device reliability also reduce outage time of equipment which has failed and thereby reduce the amount of multiple facilities required to maintain service.

In the telephone business we also speak of service orders when someone requests telephone service, that is, installation of an instrument. In so-called "common carrier" type of communication system, the service must be offered to all who desire it. The ability to add new telephones on demand imposes many problems on this real-time system, since in "real time" there is a limit to the number of telephones and calls therefrom which a system may serve with a given amount of equipment. Each new telephone served will require additional equipment capacity in this real-time system.

Therefore, we have many sources of demand. Each source originates requests more or less at random and independent of others, but over a long period of time patterns do exist which influence the engineering of these systems. Another paper[2] covers these traffic aspects in considerably more detail. Each new source also becomes a "sink" since communication traffic is usually two-way and, therefore, facilities to interconnect all sources must be provided. One of the differences between a communications system and a computer using the same data processing techniques is this necessity for interconnecting sources as well as processing data for each. Many of the real-time computers have a plurality of sources, but these sources seldom need to be interconnected or interrelated directly through the computer.

Signaling

In recent years we have tended to separate the switching problem into two parts and deal with each separately. These two parts are: 1) the receipt and recording of service requests and the control of the establishment of the desired connections, and 2) the arrangement of switching devices to permit any desired pattern of interconnection. The first part is a digital data processing problem. Thinking of a communication switching system as a real-time system brings traffic and other aspects which have long been with us in this industry to the attention of those designing complex digital computers. The second part of the system is an inherent characteristic of most communication switching systems and will not be dealt with here.[3] The analogy between telephone switching systems and computers has been covered previously[4,5] and will be assumed as background for this paper.

The devices with which these problems were first solved were several orders of magnitude slower than those presently being employed in digital computers or contemplated for electronic switching. The earlier and most familiar dial telephone systems, such as the step-by-step system, combine these two parts inexorably. Nevertheless, their study in the light of the new electronic techniques teaches us many things about the nature of the real time problem. For one thing, the speed of the devices in the central office was fast enough to keep up with the maximum rate at which human beings could spontaneously actuate call devices, such as dials and keysets, to place information directly into the system.

Assuming each channel receives information from only one person, the rate at which information enters the system is thus limited by his sending rate. Common carrier systems usually involve very large numbers of sources; there are at present some 62,000,000 telephones in the United States. To select one of a large number in a single operation would require a very large calling device, such as a dial with 62,000,000 holes, and tremendous dexterity on the part of the user. It would also require complex or time-consuming signal generating and receiving equipment. Considerable time might also be required to select the desired telephone. A practical way to accomplish a selection among a large number is to use a sequence of digits to sift through all the possibilities. This means that several digits must be sent and a compromise made as to the number base of the system, the complexity of the calling device for encoding the signal, and the number of digits to be transmitted. It is well known that the base 10 has become universal because it is most readily used by the public and the number of digits, up to recently, have not been excessive. The calling device is simple—a 10-hole dial or 10-button keyset.

Here human engineering comes into the picture. Obviously, the base 10 is used because it is best known. However, one of the early methods was to use the first letters of central office names arranged in base 10 as a mnemonic aid. Recent psychological studies indicate that such an aid may not be as useful and helpful as we once believed. In any event, such aids should not be ignored since they may provide better service by reducing dialing errors. Reduction of dialing errors allows the equipment to operate

[2] J. A. Bader, "Traffic aspects of communications switching systems," this issue, p. 208.

[3] C. Y. Lee, "Analysis of switching networks," *Bell Sys. Tech. J.*, vol. 34, pp. 1287-1315; November, 1955.

[4] W. D. Lewis, "Electronic computers and telephone switching," *Bell Labs. Rec.*, vol. 32, pp. 321-325; September, 1954.

[5] W. D. Lewis, "Electronic computers and telephone switching," Proc. IRE, vol. 41, pp. 1242-1244; October, 1953.

more efficiently by eliminating waste usage. Also, customers dial more rapidly, thereby reducing holding time of the call receiving circuit.

With the call information broken up into a number of digits it is not always possible for the signal receiving equipment in the switching machine to act on one digit at a time. Most systems require that a number of digits, such as the first 3 which represent the central office name, be received, before any action may be taken. This introduces the need for storage of digits in the central office until sufficient digits of the number are available for processing. These receiving and storage circuits must be provided in sufficient quantity to care for the maximum number of sources sending simultaneously. Interconnecting means must be provided to associate these circuits with the calling lines. Circuits which are called "registers," "senders," or "directors" are used only during the period when the customer is sending selection information into the machine. These circuits may be dropped from the line after this phase of each call to be reused by other customers. In this way they are provided and used more efficiently than if one stayed associated with each call until its completion. But still one of these call receiving and storage circuits is utilized for each call being dialed. Circuits of this type may serve both operators and customers, or separate groups may be provided for each class of input. This is a designer's choice which is determined by the degree of difference in the logic between a register used for operator calls and one used by customers. For example, if operators use 10-button keysets instead of dials the difference is sufficient to warrant a separate group of registers to work with keysets rather than providing a single group in which all registers are capable of recording either dial pulses or keyset pulses.

The holding time varies with the customer and the type of call. Some customers take longer to start dialing. Dialing time varies. The number of expected digits may vary; for example, local calls require 7 digits and long distance calls 10 digits. (This is equivalent to variable word length in computers.) The expected number of digits may be made known to the receiving circuits in several ways: 1) by the coding of the number dialed assignments, 2) by allowing time after each digit is dialed for another digit to be started; if no new digit is started after 2 or 4 seconds, it may be assumed that sufficient digits have been received, or 3) by an end of dialing signal which eliminates the need for timing for further digits and is most useful where coding conflicts or large differences occur in the number of expected digits.

To reduce the call receiving circuit holding time still further and to improve service, overlap features are sometimes provided so that when the circuit has received sufficient information to interpret the general destination of the call, this information is processed before awaiting the receipt of the complete called number. For example, while the fourth and fifth digits are being received the first three are interpreted and a connection is established to the desired office. While the sixth and seventh digits are being received the information interpreted from the fourth and fifth digits is being transmitted to the office of the called number. By introducing overlap operation, a system is better able to serve in real time with a minimum of delays. It means that the receiving circuits must be more complex and generally capable of sending as well as receiving. Overlap may also be employed within the control so that a single control unit may act simultaneously on different phases of the different calls. Again this improvement in real-time service requires more complex circuitry. In telephone system design this complexity must be matched against the additional delays that might be encountered without the feature or the cost of additional control circuits to provide equivalent capacity.

The logic of the call receiving circuits or program devised for interpreting call data must be capable of dealing with much more than the normally expected call inputs of 7 or 10 digits. There are the types of service calls with "0" or 3 digit codes. All possible codes are not used or usable. If one of these were dialed, the system must be capable of so informing the customer, and more important, of disposing of the call to free the common circuits for use in more productive work. The system must also handle such nonproductive situations as when the handset is knocked off the "hook" momentarily or even for extended periods, or incomplete dialing, or not hanging up at the end of a call. Finally, it must be prepared to receive a hang-up, disconnect, or abandonment of the call at any time and be ready to serve that input again as quickly as possible thereafter. This is usually the customer's way of indicating an error as well as a change of mind. In short, the logic or program for the system must be prepared for any eventuality and always have a plan of action. There can be no dead ends or stops in logic circuits or program operation if the next expected piece of information is not forthcoming.

To accommodate these factors, a series of tones and announcements are used to inform the calling customer of the status of his call. A dial tone, busy tone, and ringing tone all let the customer know of the progress being made to serve his request. They may also serve to notify the customer that the machine is ready to serve him, and thus discourage him from sending in information when the call receiving equipment is not ready. Recorded announcements are used to inform of expected duration of delays and for intercepting on incorrectly dialed or unassigned central office codes and telephone number series.

Most communication switching systems are designed with call storage means provided on a traffic or when-needed basis at the central office. Call storage can also be provided at each source.

Certain tape teletype systems are of the type which include source storage.[6] But here traffic is delayed to insure

[6] W. M. Bacon and G. A. Locke, "A full automatic private line teletypewriter switching system," *AIEE Trans.*, vol. 70, pt. 1, pp. 473-480; 1951.

a high occupancy of the communication channels. Telephone systems where the complete number is preset before sending it are also of this type.[7]

Multiple Inputs

The fact that communication switching systems serve a plurality of inputs has been referred to several times in the foregoing discussion. The traffic problems which this raises are probably the most important real-time aspect of communication switching systems. There are other factors that influence design, which might be of interest in other multiple input computers. Needless to say, when there is a plurality of inputs to be served in real time, there may, by necessity, be a plurality of control circuits provided to keep up with the input information processing. (It is possible where traffic is light or by introducing higher speed control devices a single control circuit will suffice.) Each input is two-way. It is designated by a number. Since there are few, if any, restrictions on the requests from any input with respect to what numbers may be called, the control circuits must be capable of reaching any number. The more inputs there are, the more digits must be received, the more complex the selecting functions each control circuit must perform, and the longer the time it may take to do them. Furthermore, with more inputs, there will be more control circuits and a greater interaction among them. Naturally, this greater complexity increases the unit cost.

In a single input system the call receiving portion is presumably always ready to serve. When the receiving circuits are provided on a traffic basis in multiple input systems, it is possible that one will not be available without some delay. Premature dialing due to these short delays in assigning call receiving equipment is one of the most difficult traffic problems in real-time telephone systems. This is the doorstep of the system. Once inside, delays can be controlled by providing adequate storage if the delays are tolerable and the control is alert to abandonment of calls by the customer. It is possible to develop conditions known as "snowballing" of troubles. Under these conditions, serious overloads, or the "nervous breakdowns" of communication switching systems that you may have heard about, can be produced. When a call receiving circuit is available it may be connected to an input which has already started to dial. A wrong number or partially dialed call will result since the system does not have the correct call information. This means wasted usage of the limited call receiving circuits when they are most needed and consequently system capacity is reduced during overload.

Other overload conditions peculiar to multimachine operation will be described in the next section.

There are other factors which must be considered with multiple input systems. We have already mentioned some differences, for example, between operator and customer inputs. There are many different types of customer inputs, *e.g.*, coin sources and business or residence sources with flat or message rate. Furthermore, the customers may be on single or multiparty lines, or have a subswitching office such as a PBX. Each of these classes of input may require some different treatment on calls originating from and even terminating to these lines. These differences as well as differences in signaling languages and the necessity of anticipating abnormal actions make complex the logic of the control circuits or the programs for these systems. Each request must be interpreted in accordance with the class of the input and the desired output. Some noncoin customers, for example, may be able to reach numbers not dialable by coin customers.

Despite all these differences in class of inputs, certain standards, particularly electrical, are set so that the same digital receiving equipment will operate with most classes of inputs. Standards are set on signaling limits and also for transmission so that the established communication path, regardless of length, will be satisfactory. Furthermore, where there is a large number of sources it is important that these be standardized as much as possible to insure low initial and repair costs. For this reason, it is important that the many needs of the customer be satisfied by combinations of standard instrumentation.

Multimachine Operation

It is well known that the automatic communication central office was the first successful large scale digital information processing machine, and that such machines are interconnected over great distances and communicate with one another. The network of these machines is the largest and most extensive digital processing equipment ever to be assembled or likely to be assembled. Machines therefore have inputs not only from customers but also from other machines. There are a number of interesting engineering problems which arise in networks of such machines.

As was the case for inputs from customers, these inputs also transmit digital information, and call receivers are connected to them when digital information is sent for processing. Since the interconnecting links are sometimes quite long and costly, it is usually economical to use them in two directions which means that a request for service may originate at either end. Once the channel is seized at one end, precautions must be taken to prevent seizure at the other end and to connect a call receiver. Guard means are also provided to prevent immediate reseizure of the channel or to delay digital transmission when an interoffice channel is reused after release from a previous connection.

When signaling between machines in this real-time system, the information to be transmitted is usually available by the time the path between offices is seized. It is desirable to devise signaling methods for this application which

[7] W. A. Malthaner and H. E. Vaughan, "An experimental electronically controlled automatic switching system," *Bell Sys. Tech. J.*, vol. 31, pp. 443-468; May, 1952.

are faster than those serving customers, since only a small part of the total time required by the customer to send digital information to the machine is signaling time. As the art has progressed, new and improved signaling techniques have been devised. Rather than thwart progress, the new signaling methods have been adopted with new systems. Therefore, when switching machines of different vintages are placed together in a network they do not necessarily have a common language. When it is determined to which machine a call is to be routed, the method of signaling is also determined. Means must be provided in the originating office to send at least one of the languages which the machine to which it connects is capable of receiving. The smaller the number of languages which an office must send or receive, the simpler its circuitry and the lower its cost.

Signaling distances between machines are generally greater than from the customer to the machine. Therefore, it is sometimes necessary to place intermediate signaling equipment in the intermachine paths to regenerate or amplify the signals. Regeneration usually involves storage which delays the retransmission of the information.

Also, when paths or connections are established between machines, a new signaling problem develops. It is necessary to send signals over the connection in the direction opposite to that of the original digital transmission to indicate when the called party answers so that call changing may start, and also when the called party disconnects to indicate that the connection should be taken down. In general, these interoffice or intermachine signals are known as "supervisory signals" and the planning for these signals is as important as the planning for the digital transmission. As a real-time problem it is even more critical, for the longer the time intervals in the various unguarded periods for seizure, release, and reseizure, the greater is the chance of malfunctioning of the system.

In a complex network of offices or machines it may not be economical to provide paths from every office to every other office. For this reason it was realized early that intermediate switching machines should be established to provide more efficient trunking. They could also be used to regenerate the signals and translate the languages in both directions.

Normal traffic between machines is sometimes handled by means of alternate routing so that when all direct paths are busy the originating machine reroutes the call to an intermediate machine which also has paths to the desired terminating machine. This means that both the numericals of the called number and the desired central office code must be sent ot the intermediate office. The signaling language between the originating and intermediate office may be different from that which would have been used on a direct connection to the called office. The control circuits must take all this into account in processing the call without greatly increasing the holding time. Calls routed through intermediate offices take longer to complete, but this is minimized by employing overlap in the signaling.

Once intermediate offices are set up for traffic reasons they can be used to concentrate other complex switching functions which are required for only a small percentage of the calls. Thus a hierarchy of information processing machines has been established. More recently, automatic long distance switching equipment has been placed directly at the disposal of many customers and in the near future a large percentage of the nation's telephones will be able to call one another completely automatically by "direct distance dialing" through combinations of local and long distance switching systems.

There are overload situations which occur where the machines talk with one another. An example of this is on calls coming into an office from other offices. The incoming call receiving circuits here seem to act fast since there are usually no delays waiting for the calling customer. He has already given all the required information by this time. The holding time of these circuits is short; therefore, not many are required. But at the called customer's number, particularly a private branch exchange (PBX), a bottleneck may develop even though the PBX has sufficient lines to handle most of the traffic. The more traffic to this number, the more hunting required to find an idle path. Hence, delays are encountered by the incoming call receiving equipment which causes delays in call sending equipment in offices all over town that are trying to reach this office. With the call sending circuits so tied up, they cannot be used to complete calls to other offices. Again, an overload reduces call carrying capacity when it is most needed.

There are several ways of dealing with these overload situations. In electronic switching systems now being devised[1] where all lines are supervised on a time division basis, it may be accomplished by abundant call storage since such devices are relatively inexpensive. In electromechanical systems the overloads may be partially alleviated by introducing a speed-up in the time allowed for certain real-time functions when the office or some part thereof is working near maximum capacity. For example, the time allowed to determine whether the call is partially dialed or incomplete may be cut from 10 seconds to 2.5 seconds. Another design feature is to eliminate certain safeguards or trouble detection features which utilize control circuit time on normal calls during these overload periods.

The transmission of digital information must be as accurate as possible. This is particularly true between machines as contrasted to human sources since they usually have higher occupancy and transmit over greater distances. Here it is not uncommon to insert in the digital signaling paths compensatory electrical networks to insure that the signaling paths are more nearly identical in electrical characteristics. Such networks are automatically inserted on each call based on the call information. In a similar manner, transmission compensation including amplifiers may be automatically added.

System Changes

Another important characteristic of communication switching is that the system is dynamic, ever changing. As the system is changed it must continue to function, in real-time. A communication switching system cannot be taken out of service for maintenance, to add new service features, to add facilities to handle an increase in the number of inputs served, or to obtain information for the benefit of those administering the system.

When a general purpose computer is designed, compromises are usually made to produce a design which will satisfy to a maximum degree the greatest number of potential customers. Thereafter, modifications may be made for specific applications where the basic machine is not satisfactory. In the application of communication switching systems the needs for each community to be served are different. One machine design must fit the needs of a heavy traffic area in a large metropolis where there are many calls but with shorter holding times. This means more control or digital processing equipment in proportion to the switching network facilities. Another office might be in a small isolated area with fewer long distance facilities and little call handling capacity. The machine design may also be influenced by the method of charging for service, particularly the extent to which coin, message rate or flat rate noncoin services are offered.

The central office switching machine must be designed so that it can be manufactured, installed, maintained, and expanded over its entire range of applications. There can be little compromise between the machine's requirements and those of the customers. We cannot, for example, reduce the amount of equipment by taking more time—adding another eight-hour shift. Furthermore, when we determine that additional equipment is required, we cannot shut down the machine while it is being added. "Real time" here also means "all of the time." The number of combinations of the services available to customers and administrative and service features available to the communications companies mapped into the characteristic needs of each community gives a very large number of design variables for which each installation must be manufactured and engineered.

Imagine adding an additional arithmetic unit to a computer while it is working. In most communication switching systems there are usually new additions periodically. Engineering of each machine installation is continuous. We install enough capacity to deal with the real-time needs for a limited period, say one or two years. It is necessary to obtain a compromise between the over-all investment in idle equipment and the cost of engineering and installing to suit each change in demand. This means that from the start the equipment must be designed and the installations planned for growth.

Traffic Measurement

To carry out an intelligent and efficient engineering program, the system must be fitted with built-in measuring devices so that the traffic characteristics and the degree to which the equipment is handling the load offered may be measured and compared, and engineering steps may be taken to insure a satisfactory grade of service. Since the system operates in real time these data cannot be recorded at any other time except when the calls are taking place. The measurements must be made without impairing the service.

The results of traffic measurements may show the need to rearrange the available plant on a seasonal basis in addition to providing new equipment. Digital data processing of these traffic measurement records is helping the traffic engineer to keep up with the real-time central office machines by shortening the interval between measurement and valuation.

In designing a complex digital data processing and switching system it is difficult to predict by theory or analysis the way it will respond to the real-time input conditions. Therefore, it is not uncommon to set up existing digital machines to simulate the functioning of the real time machine under typical and overload conditions. In this way, "real time" can be slowed up and studied microscopically.[8] With the advent of general purpose digital computers some communication switching system simulation problems have been solved with these tools. The difficulty of programming these nonmathematical problems and the frequent lack of sufficient memory capacity have impeded the use of digital computers for this application.

System Maintenance and Reliability

Earlier it was said that in communication switching systems real time also means all of the time. This means that the detection, location, and repair of system faults must go on with the system still giving service, preferably without impairment. This means that the system must contain redundancy so that it is not dependent upon one and only one of a certain element to handle the traffic. When more than one element is required for traffic reasons, then a failure of one merely reduces the capacity. By providing more elements than required for normal traffic two objectives may be fulfilled. First, overload peaks are better accommodated. Second, taking an element out of service for maintenance will not upset the normal traffic capacity.

Of course, once a system element fails and is removed from service it is important that the trouble location and repair time be kept small enough relative to the failure rate so that the multiple failures occur infrequently and are of short duration. To achieve this, the circuits are frequently designed with self-checking and even error-correcting features. Trouble recorders are provided to indicate the state of the circuits when error checks detect troubles. In the more complex systems the trouble records may be automatically analyzed to diagnose the trouble and to indicate its location.

[8] G. R. Frost, W. Keister, and A. E. Ritchie, "A throwdown machine for telephone traffic studies," *Bell Sys. Tech. J.*, vol. 32, pp. 292-359; March, 1953.

Some types of circuits, particularly those associated with signaling and transmission, cannot readily detect their own troubles so that auxiliary routine test circuits are provided which, once started, automatically connect to these circuits one at a time and put them through their paces, usually with marginally acceptable signals. Automatic recording is also provided with such test circuits.

To avoid calls from being lost due to malfunctioning equipment, second trial features are sometimes provided which allow a different combination of system elements to be employed on a call, if it does not progress satisfactorily on a first attempt. Failure of a second trial usually results in a tone connection which indicates to the customer to try again.

The above is an example in a real-time system where trouble not only cuts down the capacity of the system but, to insure some service to each call, additional work load is taken on when it can be least afforded. Features such as this may be automatically circumvented in periods of overload, but are provided to avoid failure of calls to be completed in nonbusy periods. In this way the modern offices with low failure rates may be left unattended by maintenance forces during nonbusy periods with reasonable assurance of providing good service to all customers. Even when the office is left unattended, remote alarm indications are given at a manned control center so that steps may be taken to repair serious troubles before they do affect traffic.

System Power

What has been said about service continuity in case of equipment failure applies equally well to power equipment. Communication switching systems in central locations normally use power that is available commercially. This power source is backed up by local diesel generators which usually start automatically if commercial power fails. Being a real-time system, a communication switching system cannot have power off even during the short period required to start a diesel engine. If this happened, all the communication paths established through the office would be temporarily or permanently lost, depending upon whether or not the memory associated with that part of the office maintaining the switched paths was "volatile." Such service would not be considered satisfactory, especially where connections would not be reestablished after power was available from the diesel generator. Therefore, power storage in the form of wet batteries has been an essential part of a communication switching office. The capacity provided in these batteries is sufficient to cover the maximum expected period between the loss of commercial power and the full operation of the reserve power source.

Other power considerations in these systems call for dispersion of power so that trouble on any one feeder will not put the entire machine out of service. Such considerations apply also to other intramachine cabling.

Other Forms of Systems

Another form of communication switching system which functions in real time is that used for network broadcasting of radio and television.[9–11] Here the real-time switching is cued to the actual time specified by the customer. A "program" of such times and desired connections are the inputs to the system. There can be no delay or information is lost. Perhaps with the increase in data transmission this type of "real" real-time system will find greater application.

Conclusion

It has been shown that communication switching systems are a form of real-time digital computers. Some of the engineering considerations in designing such systems have been presented. These requirements are difficult to meet because of their complexity, the dynamics of the service demands, numbers of inputs and their characteristics, and the need to provide absolute continuity of service. Despite this, communication switching systems have been designed, built, and installed, and are operating as the world's largest aggregation of real-time digital data processing machines.

[9] C. A. Collins and L. H. Hofman, "Switching control at television operating centers," *Bell Labs. Rec.*, vol. 35, pp. 10-14; January, 1957.

[10] A. L. Stillwell and A. D. Fowler, "Switching at tv operating centers," *Bell Labs. Rec.*, vol. 34, pp. 366-369; October, 1956.

[11] P. B. Murphy, "Program switching and pre-selection," *Bell Labs. Rec.*, vol. 20, pp. 142-148; February, 1942.