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IBM 2750 Voice and Data Switching System: Organization and Functions*

Abstract: This paper reviews the functions of private automatic branch exchanges (PABX's) and describes the organization of the IBM 2750 Voice and Data Switching System. This system has two main functional areas: (1) line switching, transmission and signaling, and (2) common control. The switching network uses a new integrated electronic crosspoint. The common control is performed by a built-in duplexed computer with stored programs dedicated to line switching.

The IBM 2750 offers a variety of normal and advanced voice features, and some entirely new data features, and is designed for interconnection with an IBM System/360. Four companion papers describe the electronic switching network, the network control program, and the integrated crosspoint in greater detail.

Introduction

A communication system consists generally of telephone sets, data terminals, lines, and exchanges; an exchange offers a concentration point for all lines, and provides the functions required to route and control calls or messages. Private telephone exchanges handle the traffic within a single large company. Although some private exchanges are designed for internal use only, most are also linked to the public switched network; they are then referred to as private automatic branch exchanges, or PABX's.

Telephone exchange techniques were, up to a few years ago, almost solely electromechanical. The general tendency has been to reduce mechanical movement that inevitably causes wear to the switching equipment, to separate the switching and the control functions, and to increase the speed, concentration and reliability of control.

Within the last 15 years, semi- or fully electronic exchanges have been developed, which show a marked trend towards centralized, and therefore duplexed, control; such techniques are obviously very similar to those developed for electronic computers. The actual switching is done either by time division or by space division.[1,2] Time division, which multiplexes several simultaneous voice calls by allocating different time slots to each one, implies the use of electronic switching devices. Space division, which sets up a continuous, physical connection between the two callers, uses either small encapsulated reed switches[1-4] or semiconductor crosspoints.[5]

The above references are given merely as examples and by no means cover the considerable development work done in electronic switching by Bell Telephone Laboratories, PTT† laboratories and others. (See Ref. 6 for an over-all review of electronic switching in the single area of public central exchanges.)

IBM activity in electronic switching prior to the development of the IBM 2750 comprised (1) data switching in computer systems; (2) voice switching, which included U. S. study contracts in time-division switching, Automatic Intercept System using reed relay switches,[7] and Audio Response System for the New York Stock Exchange[7a]; and (3) combined voice and data switching at the La Gaude laboratory, development and comparative study of time-division switches, reed contact switching matrices, and Integrated Switching Modules (ISM); this last approach was chosen for the 2750 for reasons of reliability, expandability, bandwidth performance and cost.

The IBM 2750 is an all-solid-state voice and data switching system with a maximum capacity of 756 extension lines and 84 public network lines. The switching is done with a new solid state electronic switch (ISM) offering the advantages of other semiconductor integrated devices: no mechanical wear, high reliability, high switching speed, microelectronic size, and low mass production cost. The IBM 2751 Switching Unit is illustrated in Fig. 1.

The operation of the 2750 is under the control of a built-in computer loaded with a resident program devoted to line switching. The built-in computer and its program is duplexed to satisfy the high reliability demanded of telephone installations. This centralized, stored program control is instrumental in offering a wide and flexible

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* The IBM 2750 has been planned for marketing in European countries by the IBM World Trade Corporation.

† "PTT" is the official designation of telephone administration agencies in Europe.

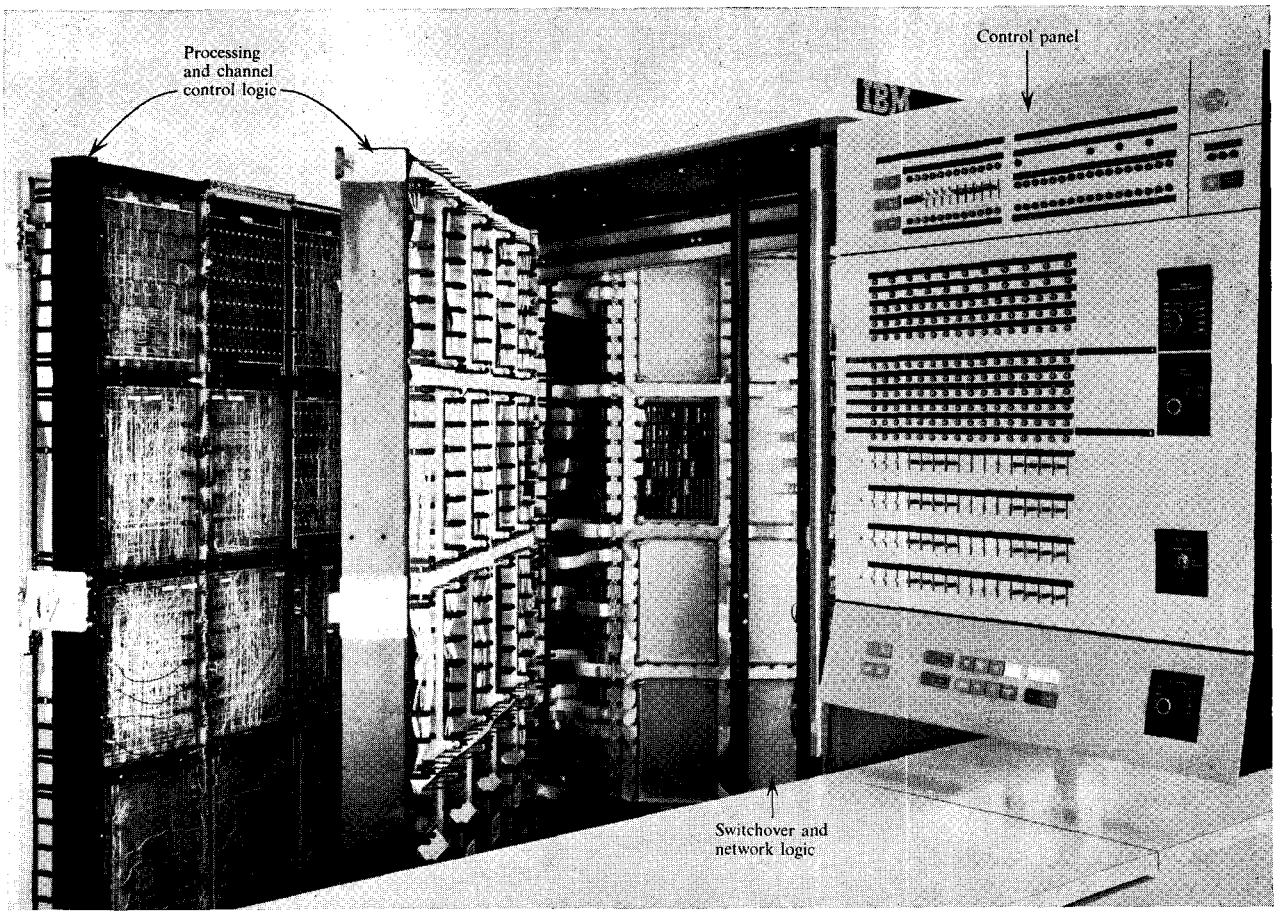

Figure 1 Partial view of main frame, IBM 2751 Switching Unit.

range of voice- and data-communication features to users. The 2750 combines telephone exchange and teleprocessing functions.

Data collection terminals can be attached to extension lines instead of telephones and can be switched in the same way. Contacts on extension lines can be sensed or operated. A direct data link between the 2750 and an IBM System/360 is available through which the data processing and line switching functions can interact on each other: for example, the System/360 in the course of its routine processing can request the 2750 to establish data transmission connections.

This paper gives an over-all description of the 2750 system. The main areas in the system are delineated and their interaction is explained. The central control organization and the trade-offs between hardware and software are described. The voice and data functions are explained. The system organization with respect to reliability problems is studied. Companion papers describe more fully the switching network,[8] the control program[9] and the electronic crosspoint.[10,11]

General description

The IBM 2750 system shown in Fig. 2 consists of one IBM 2751 Switching Unit and several IBM 2755 Operator Control Desks. For purposes of general description, telephone switching will be described in terms of voice paths. Data switching operations, however, proceed in a similar way.

All the extension lines of the private telephone installation and the public network lines are attached to the 2751. A voice path and a two-way control path connect each 2755 and the 2751.

The functions of the 2751 for telephone switching consist in:

1) Scanning the incoming signals from extension telephones, public network lines and operator desks.
2) Controlling the outgoing signals to extension telephones, public network lines and operator desks.
3) Establishing speech paths between extension telephones, public network lines and operator desks.

To perform these functions, the 2751 is divided into

two main parts: the switching network, where the physical switching takes place, and the control system, which operates the switching network, the operator desks, and other optional devices.

The control system is duplexed into two identical subsystems for reliability, each of which can control the switching network. The interface between the control system on the one hand, and the switching network and operator desks on the other hand, is called the "network control interface." Only one of the two identical subsystems is controlling the switching network at one time through the network control interface. To illustrate the succession of events to be handled by the control system for a specific call, let us consider two examples, the in-house call and the incoming external call, in the simplest cases; between these events, the control system must handle events related to other calls.

(1) *Local call* (A calls B)

Incoming signals (event to be scanned)	Resulting outgoing signals (to be controlled)	Speech path to be established
A goes off-hook	Dial tone to A	
A dials B	Ring back tone to A Ring current to B	
B goes off-hook A and B talk		A to B
A (or B) hangs up	Dissuasion tone* to B (or A)	Disconnect A to B

(2) *Incoming call* (Public line T calls A through operator O)

Ring current on T	Incoming call lamp on all 2755's	
Operator O takes T O and T talk	Close loop on T	T to O
Operator O calls A	Ring back lamp on desk O Ring current to A	
A goes off-hook		O to A
O retires A and T talk		T to A
A hangs up	Open loop on T	Disconnect T to A

Switching network

The switching network[12] (Fig. 3) provides speech paths between telephone users, and paths to signaling devices (e.g., data terminals) operating in the voice frequency band. The network is connected to the individual telephone lines and public lines through terminal circuits which provide the necessary matching between the telephone pair and the electronic switching network. The switching network is also equipped with telephone signal detectors and emitters. The signaling devices operating in the voice frequency band services are shared among the users by connections in the switching network. However, two kinds of signal do not cross the switching network—dc signals and ringing signals are handled by the individual terminal circuits.

* The "dissuasion tone" is a tone inviting the user to hang up.

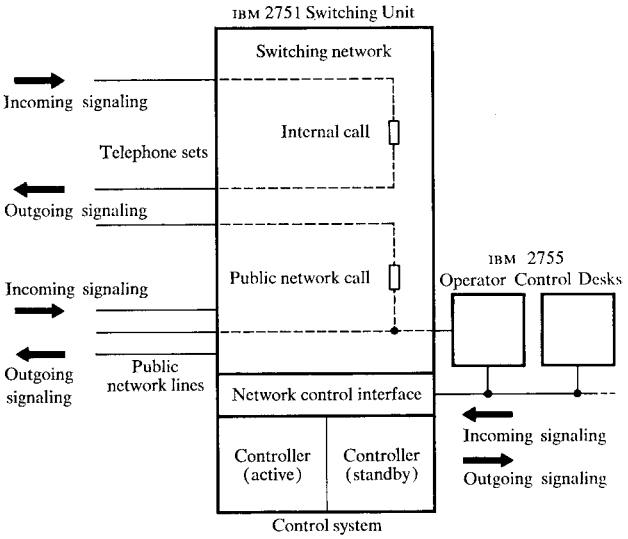

Figure 2 Organization of the IBM 2750, showing the functions of the switching unit.

The switching network has the following general characteristics:

1) It is logically passive and makes no decision. All decisions are made by the control system and transmitted through the control interface.
2) It has the property of latching the control pulses received from the control system. Therefore, control is required only when the status of the switching network has to be altered in some respect.
3) It is equipped with sensing points at both ends of each possible path; the control system can thus monitor the network so as to verify that operations have been correctly executed. Only the path ends need be monitored, and not all intervening network links.

A more detailed description of the switching network and its transmission characteristics is given in the paper by Reynier.[8]

Network control interface

The network control interface shown in Fig. 3 provides the buses needed to address and control the switching network and operator desks. There are four kinds of control, which are all performed by the control system through the network control interface, namely:

Scanning incoming signals detected in the terminal or service circuits, or generated by the operator keys. Eight status-bits are scanned simultaneously. They correspond either to the binary status of eight terminal circuits addressed simultaneously or to the status coded over eight bits of a single addressed service circuit, for example a multifrequency receiver used for pushbutton set signaling, or the 3-out-of-8 code identifying an operator control desk key.

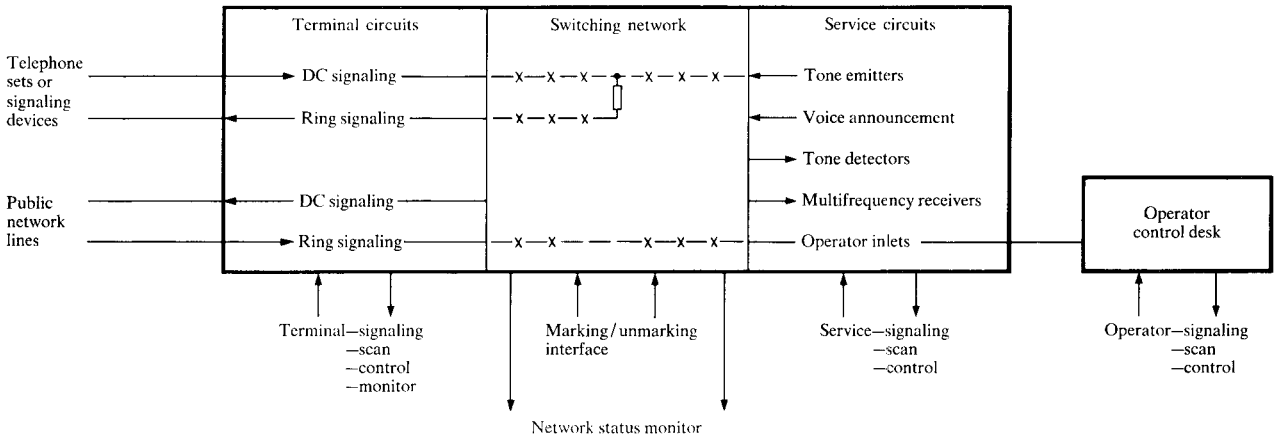

Figure 3 Switching network and control interface in IBM 2751.

Controlling outgoing signals emitted by the terminal or service circuits, or governing the condition of the operator desk lamps. Up to eight binary outgoing signals can be controlled at a time.

Connecting or disconnecting paths in the switching network, by means of specific marking circuits; the mark/unmark interface and its operation are described more fully in the paper by Reynier.[8]

Monitoring the terminal circuits and switching network paths to ensure that outgoing signals are correct, and that the right paths are connected or disconnected.

Control system

The control system scans, controls and monitors the switching network, the operators' keys and lamps, and other attached devices, through the interface shown above. It is fully duplicated into two identical subsystems or controllers; the relationship between them is described later under the section entitled "Reliability and serviceability". A paper tape reader and punch and a typewriter keyboard are available for system maintenance and can be connected by the IBM customer engineer to either subsystem. In addition, the typewriter keyboard can also be used to modify the numbering plan on site.

Optionally, a paper tape punch and a System/360 communication adapter can be provided for outgoing call recording or for data applications. These units are normally connected to the active subsystem but can be switched to the standby subsystem by the customer engineer for maintenance. Each control subsystem (Fig. 4) includes a built-in Arithmetic and Logic Unit or Supervisor Unit with its control program stored in ferrite cores (32K, 16-bit words), and a Network Control Unit, made up of a network interface decoder and a scanner. The Supervisor Unit handles one or two fixed-length 16-bit binary words, the instructions being one or two words long. An additional bit per word identifies those words that must not be modified. This avoids the program destruction in case of supervisor unit error, the program being written so that it does not modify itself.

The network interface decoder in the Control Unit decodes the Supervisor Unit commands to control outgoing signals, to connect or disconnect paths, and to address the points to be scanned or monitored.

The scanner performs the network scanning (or monitoring) function, at the request of the control program. First, the number of 8-bit groups to be scanned (word count) is obtained from storage; then the address of the first 8 bits to be scanned is fetched, together with their former status; then the new and former status of the 8 bits are compared. If there is no status change, 8 more bits are scanned, and so on, until either a status change is detected or scan end occurs. If there is a status change, the supervisor unit receives an interruption request, and the control program can obtain from the scanner the address of the circuit whose status changed during the current scan; the scanning is then resumed.

This function could have been performed step-by-step under program control but the method would have been too time-consuming. With this exception, all call processing functions are performed by software, including dialing pulse assembly from telephone sets, dialing pulse distribution to public lines, operator lamp flashing, tone pattern generation, et cetera.

- *Control program*

The existence of the scanning hardware avoids the necessity for the control program to constantly supervise all incoming signals; it need only take decisions for incoming signal status change and at specific time intervals. Similarly, owing to the latching property of the switching network, the control program acts on the network and operator desks only when outgoing signals and network paths need to be altered.

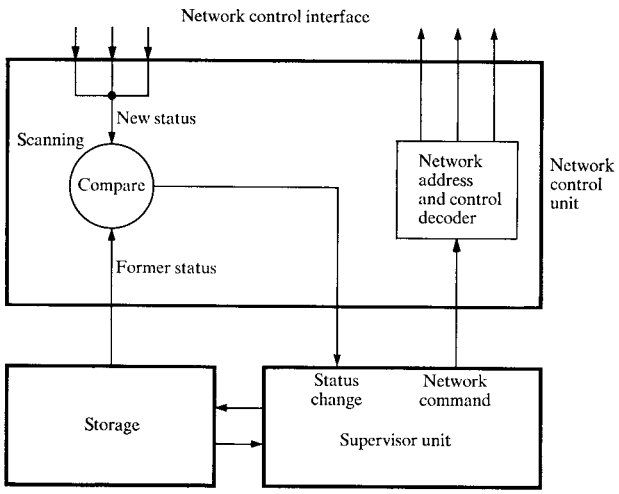

Figure 4 Control subsystem, including Network Control Unit and Arithmetic and Logic Unit in IBM 2751.

Incoming status changes and time intervals are signaled to the program by an interruption request. To decide what action to take, the program constantly updates tables which contain at all times the status of the whole system. A comparison between the event signalled by the interruption request and the former system status allows the program to modify the status of the network or the operator lamps through control unit commands, and to update the status of the system in the tables in storage. The monitoring function eliminates possible discrepancies between the actual status of the system and its image in the tables. A detailed description of the control program is given in the accompanying paper by J. D. Colas.[9]

2755 Operator Control Desk

The 2755 Operator Control Desks bear little resemblance to the cord or cordless switchboards associated with conventional switching units; calls do not physically pass through them, and neither trunk circuits nor call paths are supervised individually and simultaneously on the operator lamps.

Each desk has a telephone circuit for operator conversation, a set of lamps and keys for line control and supervision, and a set of function keys including a keyset for dialing telephone numbers. Separate lamps and keys are provided for each condition and function.

Operation of the keys is detected at the network control interface and interpreted by the control system; the lamps are switched on and off by the control system via the network interface. These operations are under stored program control, thus providing considerable flexibility in assignment and procedures. For example, incoming calls are queued by the program, and all operators are alerted when one or more incoming calls are pending. Any of the operators can take the first call in the queue, hence all calls are automatically distributed among the operators. To give another example, an operator can display the extension number of a caller which the control program fetches directly from storage.

Operational facilities

The great flexibility of program-controlled operation enables a wide range of facilities to be provided, most of which consist of specific routines run by the operational program. The features of the 2750 can be classified into system management, voice, data and contact monitoring features.

- *System management features*

The system management features affect the installation as a whole and include:

Choice of numbering plan and codes: the customer is free to decide the extension numbering scheme and the codes to be used.
Classes of service: the customer has a choice of up to 16 classes of service for extension sets, and is thus able to grade the facilities available to extension users.
System updating: extension numbers, codes and classes of service can be altered as required through the printer/keyboard by the customer engineer or in certain cases by the customer himself.
Night service: several methods are available to deal with external calls when the switchboard operators are absent.

- *Voice features*

The features for voice operation concern the various types of speech facilities that can be used when making telephone calls and include:

In-house calls, outgoing calls: these can be established through the operators or directly by the extension user, i.e., Direct Outward Dialing (DOD).
Incoming calls: again, these can be routed through the operators or, as in Germany, can be dialed, i.e., Direct Inward Dialing (DID), through to the extension user.
Hold for inquiry: an extension user can hold an outside party while talking to another extension user, and can alternate between them at will.
Transfer: after a hold for inquiry, the holding party can hang up, thereby automatically connecting the other two parties.
Pending call: on receiving a busy tone, the caller can dial a special code, causing a soft, interrupted tone ("beeps") to be sent to the called party; on hanging up, the called party is rung and automatically connected to the new caller.
Add-on third party: an ordinary internal or external telephone conversation can be extended to include a third participant.
Abbreviated dialing: calls to certain public network numbers can be made by dialing two digits only instead of the full number.
External number repetition: if an external subscriber cannot be reached at the first attempt, the extension user can repeat the call by redialing a single digit.
Automatic rerouting: if a called extension fails to reply, an alternative extension is automatically rung.
Dialed paging: this feature can be used from extension sets or operator desks; it operates a non-IBM paging system under the full control of the 2750.

Extension hunting: by calling the group number of several extensions, a caller is answered by a free extension in the group.
Priority access to operators: calls to operators from certain extensions are given priority by the operational program.
Recorded voice announcement: messages prerecorded on a non-IBM voice unit are sent to internal or external callers.
Outgoing call recording: outgoing call characteristics are automatically recorded for billing purposes.
Personal metering: an operator can obtain the cost of an outgoing call through the automatic display of the metering count and the calling extension number.
Switchboard operator facilities: the operator control desks are designed to provide not only all the control and supervision aids usually found on operator consoles, but also a range of more advanced features such as automatic number display and call chaining. Call chaining automatically returns an external caller to the operator when an extension hangs up.

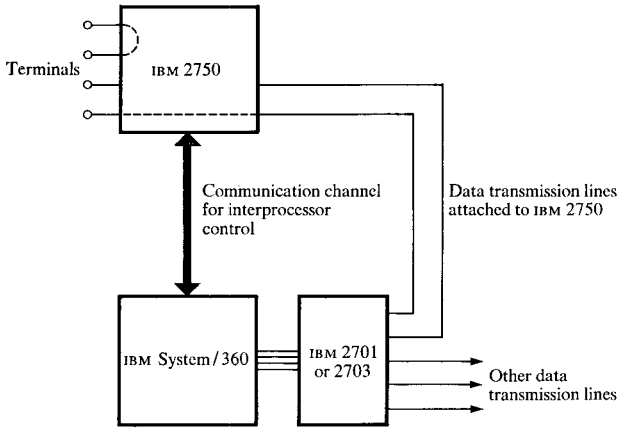

Figure 5 Teleprocessing configuration.

• *Data features*

A complex integration of line switching, data processing and teleprocessing is theoretically possible, but presents major reliability problems. Instead, the 2750 permits three types of data application: (1) data collection from multifrequency, parallel-transmission terminals, (2) serial data terminal line switching, and (3) contact monitoring. Moreover, a two-way data communications link is available to interconnect the 2750 and a System/360: in this type of configuration, shown in Fig. 5, the line switching ability of the 2750 is combined with the data processing power of the System/360 into a voice and data switching system having great application potential.

Data collection. Multifrequency terminals, including the pushbutton telephone set, can be used to send data to the 2750, in the same way as the called number is sent from a pushbutton set for a telephone call. Messages are assembled by the 2750, which checks the validity of each character, and the length of each message. In self-standing systems, customer data messages are sent to the paper tape punch; the 2750 adds to each message the time and date, and the type of message. When the 2750 is interconnected with a System/360, the data received by the 2750 can be routed to the paper tape punch, or to the S/360 processor, depending on the transaction code heading the message; in the latter case, the input data may be an inquiry leading to an immediate answer.

Switching of serial data terminals (Fig. 5). The 2750 can always interconnect serial data terminals, providing a telephone is used to initialize the transaction, for example, through a talk-data switch. With the Teleconnection feature, the same type of interconnection can be initialized from a standard telephone set associated in the storage tables with the calling terminal; the telephone set remains available for conventional speech exchange.

With the Autoconnection feature, data interchange can be made between a serial data terminal and a System/360 attached to the 2750 (through an IBM 2701 or 2703 multiplexer). The transaction can be initiated by the System/360 through the communication channel for interprocessor control, or by a telephone set associated with a data terminal.

The conditions in which the System/360 sends requests to the 2750, or processes data from the 2750, are programmed by the System/360 user.

Contact monitoring features. Contact monitoring facilities such as are used in process control applications can be provided at moderate cost, since the 2750 has the inherent ability to sense a contact closure (telephone signaling) or to operate a contact (public network signaling). The two elementary functions of contact monitoring are:

Contact sensing, which consists in detecting a change in the status (open or closed) of a contact provided by the customer, and is operated by mechanical or electrical means (for example, thermostats or meters).
Contact operating, which consists in causing a change in the status of a contact so as to control a remotely located device.

Also available are several other contact monitoring features which may be used independently, or in association with contact sensing and contact operating. By combining the contact monitoring features, process control type applications with differing degrees of complexity can be built up, for example:

1) Contact status recorded on a paper tape punch, or sent to the connected System/360.
2) Following a status change of a contact, recorded voice announcement sent to a predetermined extension.
3) Contact operated from an extension telephone set, or under control of a System/360, or following a change of status in another contact.

Reliability and serviceability

Traditionally, PABX's operate continuously for 24 hours each day; the availability of 2750 service must therefore be extremely high, although partial service degradation is allowed.

This means that (1) the system must be interrupted neither when a failure occurs nor while it is being repaired; (2) single failures must degrade only a small proportion of the service; and (3) double-coincident failures which would cause a system interruption must have a very low probability of occurrence. The problem is handled in different ways according to the system area.

• *Control system reliability*

The majority of the failures in the Supervisor Unit or Control Unit make the control inoperative, and this equipment must be duplexed. For this purpose, the control area is packaged in two identical gates, each one equipped with a supervisor unit and its associated core storage and control unit. More elaborate organization, such as access to all core storage positions from either supervisor unit, would theoretically bring higher reliability. However, the simpler solution of two independent and identical controllers was chosen because it allows straightforward and safe repair, the whole gate to be repaired being in a power-off condition and having no link with the other identical gate.

As for the way of using the two control gates, several solutions were possible, such as parallel synchronous operation, or sharing the load between both control gates, one gate being switched off in case of failure. The solution chosen is to have only one gate (the active gate) controlling the network, with the other standing by; in case of failure in the active gate, a switchover is automatically performed, the former standby gate then becoming active. The switchover monitoring and control logic are outside the control gates and are triplicated for reliability. The above solution was chosen to eliminate as much circuitry as possible that would be likely to induce failures or errors in both control gates simultaneously. Also, the single active control gate can easily perform asynchronous error analysis and/or recovery routines in case of intermittent errors.

The standby gate, although inactive, remains power-on to eliminate failures due to the stress of the power-off/power-on cycles. To improve even further the reliability of the standby gate, the standby gate exercising routines are run continuously to detect the majority of possible failures. A scheduled switchover is made automatically every 24 hours so that, when the former standby controller becomes active, failures which might not have been detected by the exercising routines will be detected within 24 hours.

Intermittent errors will normally not prevent the active controller from controlling the network. A supervisor unit error, however, may have led to discrepancies between the actual network status and its image in the storage tables. Therefore, upon detection of a supervisor unit error, the program enters a network recovery routine which allows quick reconstruction of the table contents by checking the real status of the network. During recovery (a few seconds), no new calls may be dialed. (After switchover, the same routine is entered by the newly active controller to update its tables.) Should the control program detect too many supervisor unit errors, it will request switchover. Plain failures, such as control program hangup, will of course also generate an automatic switchover request.

If this operation is not successful because of double coincident failures, a manual reconfiguration called FALL-BACK can be requested by the user: this consists in operating only a nucleus of basic features after a full network reset, incoming external calls being returned to the operators. If this operation in turn is unsuccessful, an EMERGENCY reconfiguration is possible in which the public network trunk lines are connected manually to predetermined extensions.

To summarize, a series of reconfigurations with increasing service degradation is provided to bypass not only single failures, but also many double coincident failures, the more serious service degradation corresponding to the more improbable failure configuration.

• *Network control interface and switching network reliability*

Duplication is not required here since the circuits are so designed that a failure will disturb only a small part of the traffic. Failing circuits are localized for repair either by the telephone user (terminal circuits) or by built-in hardware (control interface), or by the customer engineer (switching network).

Localization in the switching network is done by comparing on-line printouts of unsuccessful path connections: the control program monitors the network before and after a path connection/disconnection request, to ensure for example that the chosen path is in fact free before the connection and busy afterwards.

On-line checking is supplemented by additional utility programs that can be temporarily loaded by the customer engineer, such as traffic analysis or voice transmission analysis programs. They are interleaved with the standard control program, but operate with a lower priority.

Conclusion

Although the size range of the 2750 is from 200 to 756 extension lines, the switching techniques used are by no means applicable only to small systems but could equally well serve large ones.

The 2750 is, to our knowledge, the first private automatic branch exchange featuring within a single system integrated switching crosspoints, stored program control

and a broad range of voice, data teleprocessing and process control facilities.

A laboratory model[13] has been operating successfully at the La Gaude laboratory for a year, serving 500 telephone sets and data terminals and with normal connections to the public switched network. Although it does not embody all the reliability features of the 2750 system, it continues to give extremely reliable service.

Acknowledgments

I wish to emphasize that the architecture of the IBM 2750 is the work of a large team, of which Messrs. Bastian, de Backer, Chu, James, Leblanc and Milewski of the La Gaude laboratory were outstanding members. I should also like to thank Mr. Youdale for his help in the writing and editing stages of this paper.

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