14. PUBLIC SWITCHED TELEPHONE NETWORK

14.1. Introduction

Recently used public communication services (telephone, telex, data transmission, etc.) are provided by specific network. Characteristic common task of this network is to establish upon subscribers' demand a great number of simultaneous connections among end-equipment connected to the network. The general model of such a network contains end-equipment connected by the subscribers' lines to switched nodes (exchanges) and channels interconnecting the network nodes (see Fig. 14.1).

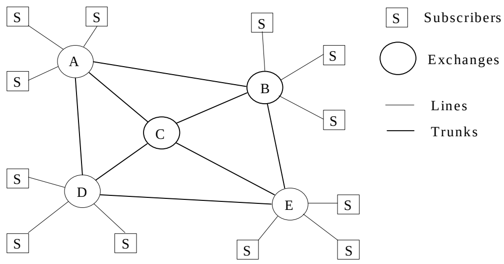

Figure 14.1. Theoretical Model of the Telephone Network

While the subscribers connected to *mobile* telephone network (see Chapter 17) can arbitrarily change their position even during communication, position of end-equipment connected to wired networks is fixed and it is rarely changed. According to the type of the end-equipment, the network is either *circuit switched* or *packet switched*. In the case of circuit switching, a communication path is established between two end-equipment by serial connection of channels. During the whole interval of the communication this part of the network is used exclusively by the two end-equipment. Since the communication path is continuously assigned to the link, the delay of the communication depends only on the parameters of the established path. Circuit switching is used in networks facing strict real-time specifications (e.g. telephone).

In the case of packet switching, there is not an individual path established for each communication, instead of, an identifier unanimously describing the source-to-destination path is assigned to each transfer. The end-equipment are sending their information to the node in *packets* with identifier placed in the *header* of the packet. The header is decoded by the node and according to its content, the packet is passed to the next node provided the channel is free. If the channel is engaged the collided packet is stored in a temporary buffer (e.g. in a FIFO register) and transmitted later.

Packet switching increases the channel efficiency, the delay time is however increased by waiting for the channel access. The delay can even fluctuate and packets can get lost when the buffer is full. Packet switching is therefore used in such areas where the real-time demand is not so strict and the time of the actual information transfer is significantly shorter than the interval of connection.

Old-established public switched services work on the base of circuit switching. This is due partly to the above mentioned aspects but also for the technological limits of the age these networks were established.

14.2. Structure of the Telephone Network

Public switched telephone network (PSTN) is the greatest automate of the Earth able to establish speech communication of good quality between any two points of the Earth. As the result of more than 100 years of evolution, the newest digital systems have to co-operate with several obsolete systems based on old technology and old techniques. The greatest challenge of operating telephone systems are therefore solutions for the co-operation of these greatly differing systems.

Telephone network is a classic example of circuit switched network and telephone exchanges are their principal elements necessary for switching functions. The general model of telephone exchanges is shown in Fig 14.2. The task of the *switch matrix* is the switching of the voice channels on the users demand. *Space-division* and *time-division* switching networks are used. The space-division switching network separates the simultaneous connections in space while the time-division switching network separates them in time.

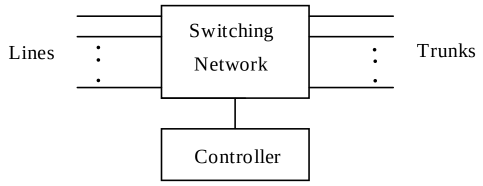

Figure 14.2 Principal Block Diagram of the Telephone Exchange

The task of the controller is to establish the connection between the caller and the called subscriber with respect to the actual state of the called line and that of the switching network. In manually operated exchanges, the switching network and the controller were separated indeed as shown in Fig. 14.2. In automatic exchanges the switching and the control functions have been partly or entirely merged. Latter these functions gradually split again and became fully independent in the Stored-Program-Control (SPC) exchanges.

In Figure 14.3 two versions of subscriber services are presented for an idealized area: a one-exchange and a four-exchange version. The latter reduces the average line length to one customer but new lines, called the *trunks* appear in the network. The total cost is then given by the costs of the subscriber lines and by the cost of the trunks. This cost is less, however, than it is in the case of the single exchange since the number of trunks is significantly smaller than the number of subscribers. A trunk can also pass any call of its subscribers, if it is not engaged by another call.

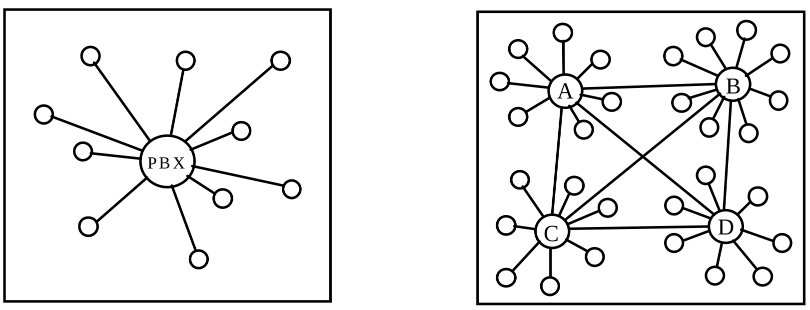

Figure 14.3 Local Networks

The arrangement shown in Fig. 14.3 b) is called the *meshed network* since all the exchanges are interconnected. Also such arrangements exist where some (or all) exchanges are connected to other exchanges via two serial trunks separated by so-called *tandem* exchange(s).

The subscriber lines are the most expensive but the least utilized parts of the telephone networks. The average traffic of a subscriber line is only about 10 per cent even in the busy hours of the day. Further cost-reducing techniques are used, therefore, besides the multi-exchange structure. The simplest of them is the party-line where two subscribers are connected to the exchange by the same cable pair.

If a greater group of subscribers is near to each other, *Remote Switching Units* (RSU) are used to bring a part of the switching equipment of the exchange closer to the subscribers (see Fig. 14.4.). The number of the connecting trunks *G* is nearly the same as the number of connections between the RSU and the rest of the exchange. The trunks have to provide also for the functional interfacing between the RSU and the exchange besides the simple interconnection.

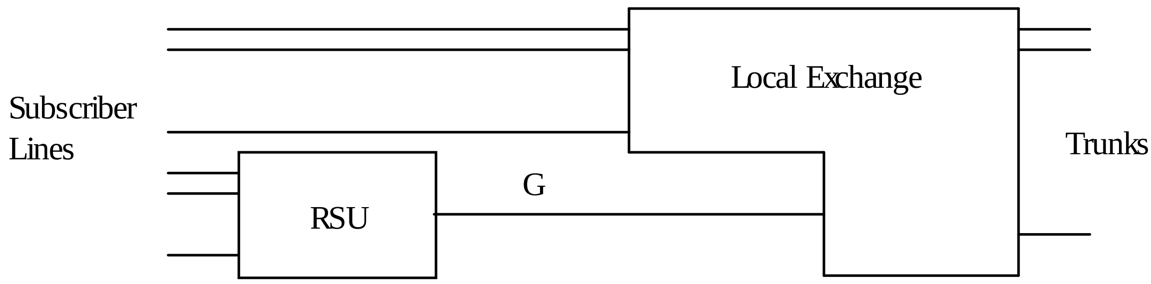

Figure 14.4 Exchange with Remote Switching Unit

An RSU can also play the role of a local exchange. In this case subscribers connected to the RSU can call each other even if the link between the RSU and the exchange is interrupted. Remote Switching Units are widely used in digital exchanges since they reduce network costs, operate reliably (with appropriate redundancy, if necessary) and do not need special buildings.

Reliable operation of the network devices is very important. Maintenance costs should be low otherwise the savings achieved by the economical network arrangement are spent on maintenance and the grade of the service deteriorates.

Local networks are connected into national networks. Joining the national networks, international, continental and intercontinental networks are formed (see Fig. 14.5.). Only a small portion of the originated traffic goes outside the local network. This traffic is passed to the so-called primary exchange where outgoing traffic of several local networks is collected and according to the destination address, it is directed to one of the local networks held together by the primary exchange or to a further (secondary) exchange. The secondary exchange holds together several primary exchanges and ternary exchanges may exist, as well.

Pure radial networks are easy to control but they are very sensitive to break-downs and not optimal from the point of view of the costs. The meshed network among secondary exchanges is more reliable since it enables to establish connections between two secondary exchanges even if the direct path is interrupted or there is a congestion in the direct path.

To explain the principle of the multipath routing on the level of primary exchanges, two examples are given in Fig. 14.5. The first example shows how the primary exchanges belonging to different secondary exchanges are controlled. Traffic from exchange A to exchange B is attempted first through the direct route. If this fails then A-II-B route is tried and if this also fails, then A-I-II-B route is attempted. The second example presents two possible routes of the international traffic outgoing of B.

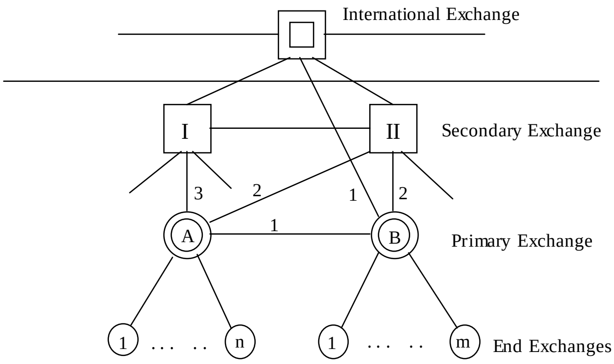

Figure 14.5 Hierarchical Telephone Network

As a general rule, always the shortest route, i.e. that containing the minimum of cascaded trunks has to be used. For instance, if direct route does not exists between the exchanges A and B, then the first selected route shall be the A-II-B route. Primary, secondary and international exchanges are the so-called transit exchanges which do not switch local lines, only trunks.

14.3. Telephone Sets

Before dealing with the exchanges, telephone sets have to be discussed briefly. The important parts of a telephone set are as follows:
- electroacoustical transducers: the microphone and the receiver,
- signalling device (dial or push-button type),
- cradle,
- ringer,
- speech circuit (hybrid), matching the 4-wire input/output of the telephone set to the 2-wire local line so that the signal of the microphone is attenuated towards its own receiver (sidetone reduction).

Carbon microphones have been exclusively used for almost 100 years. This type of microphone has to be fed by an external battery. In the beginning, a local battery (LB) was used, later it was substituted by a central battery (CB), which is still in use. CB-feeding has technical and economical advantage since the direct current can be used for the subscribers signalling towards the exchange.

As a signalling device, the dial was used exclusively for a long time. In this case the line current is chopped by the dialler at a speed of 10 impulses/s as many times as given by the dialled number. The signalling (ringing) tone is a 25 Hz, 75 V_{eff} AC signal transmitted to the called party by the exchange. For the customer's information other voice-band signals are also generated by the exchange (dial tone, busy tone, ringing tone, etc.)

The low-voltage, low-power microelectronic devices made it possible to develop modern telephone sets based entirely on the solid state technology which is very important because of the CB feeding. Here we discuss only the so-called dual tone multi-frequency (DTMF) dialler (see Fig. 14.6.) introduced instead of the slow and uncomfortable dial.

Two groups of four frequencies each are assigned to the rows and the columns of the keyboard. When a button is pressed, two frequencies are generated and passed to the exchange, one of them identifying the row and the other the column of the pushed button. (The buttons of the fourth column are not used in telephone sets.)

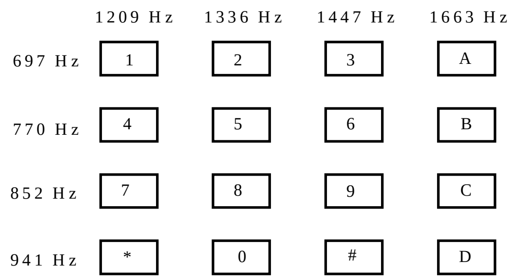

Figure 14.6. The DTMF Keyboard

With a DTMF keyboard the digits can be sent to the exchange much faster and since the used frequencies fall into the voice-band, information and control commands can also be sent to the called partner.

14.4. Automatic Telephone Exchanges

Telephone exchanges are seldom used in the full extent of their capacity. For economical reasons, only the minimum required amount of equipment should be installed and during their lifetime, the exchanges should be expandable to full capacity in several steps without disturbing the actual traffic. It is also important to use a structure which is able to cover the possible widest area of application. To meet these demands, a part of the network switching the local lines is formed in groups which are connected through a group selector which can also be gradually expanded (see Figure 14.7.)

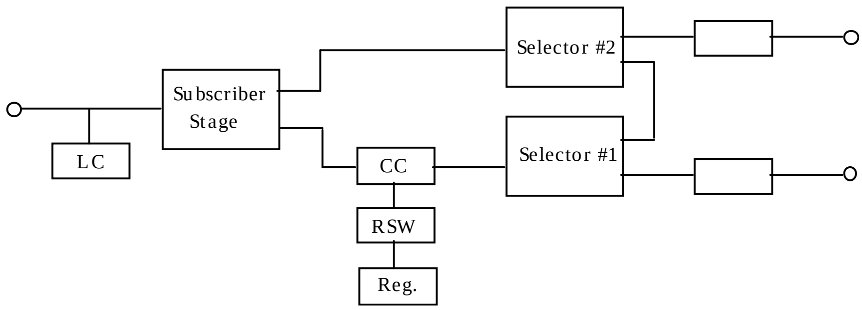

Figure 14.7. Block Diagram of a High Capacity Local Exchange

Functions which have to be performed in the course of a simple call can be classified as follows:

- functions to be performed per local lines,
- functions to be performed during the call set-up,
- functions to be performed during the call.

For economical reasons the above functions are realized by a separated equipment and are switched onto the local line only when it is necessary. There is a line circuit permanently assigned to each local line, the task of which is to signal the idle state, the call attempts, the busy state and the line-blocking (due to an error or to any other reason).

The number of junctor circuits is significantly less than that of the subscriber lines (about 10% of the latter) since they share them jointly. The subscriber stage connects a free junctor circuit to the calling line. When the call is ended the line becomes free thus being able to serve another call. The main functions of the junctor circuit are as follows:

- to supervise the calling and the called line (to detect the call-answer and the disconnection from both sides),
- to switch the ringing current for the called party,
- to switch the ringing tone for the caller,

- to supply the current for both microphones,
- to maintain the busy status of the calling and the called party for the time of the connection.

The register which controls the call set-up is switched by the register-switch to the junctor circuit for the time while the connection to the called party is set up. The main functions of the unit are as follows:

- to set the line circuit of the caller to the busy state,
- to send a dial tone to the caller,
- to receive, store and analyze the called address,
- to set-up the connection to the called customer,
- to supervise the status of the caller's line (early disconnection).

The above grouping of the control functions is characteristic for the so-called electromechanical exchanges used in the first generation of automatic exchanges. The particular feature of these exchanges is that the local line is always connected (galvanically) to the circuit which responds to the subscriber's 'logical' act -expectable in the given phase of the call- and generates the next state of the call.

If the called subscriber belongs to another exchange than the calling one then the group selector I. connects the junctor circuit to one of the free trunks leading to the called subscriber's exchange. The other end of the output trunk is connected as input to the group selector II. of the called subscriber's exchange. Information necessary to control the GS II. and the SS are sent via the established connection by the register of the caller's exchange. It is the task of the input trunk circuit to ring the called subscriber set and to feed its microphone.

If exchanges with different signalling systems take part in communication, it become more complex to handle the incoming and outgoing calls. Generally, the exchange newly entering the network has to be adapted to the actual signalling scheme which is a -frequently disadvantageous- constraint for a new system.

14.5. Stored Program Control Exchanges

In spite of the intensive research work, the development of the telephone switching and control equipment has been much slower and more protracted than that of the electronic computers. A spectacular break-through was achieved May 30. 1965 when No.1 ESS, the first SPC exchange, was installed in Succasunna (USA).

The essence of the stored program control is that all functions of the switching system are realized by programs stored in a memory. Processors, similar to those used in computers have been developed for this purpose. The operating programs as well as the parameters of the controlled equipment and the data of its actual state are stored in the processor memory.

Using the SPC the structure of the exchange does not determine its functions thus by means of appropriate programs an exchange can theoretically be adapted to any service and
to the co-operation with any environment. By loading a new program into the SPC exchange, it can be simply adapted to the demands of the newly introduced services.
On the other hand, a wide variety of controlling, supervisory and administrating programs had to be developed and difficulties caused by the handling and application of the programs had to be taken also into account. The program packet of the first No.1 ESS exchange contained more than 100.000 instructions, and today's up-to-date systems of exchanges contain at least one million instructions. The control programs are only a small part of all programs, the supervisory, diagnostic, managing, etc. programs forming their greater part.

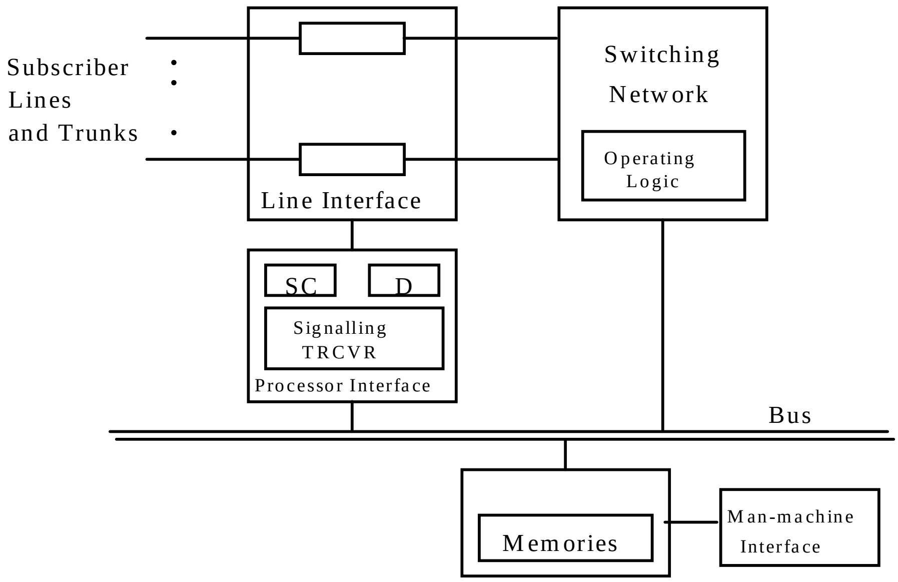

Figure 14.8. Functional Blocks of the SPC Exchange

The main blocks of the SPC exchanges are shown in Fig.14.8. This block diagram shows both exchanges with space-division and time-division switching networks. (Exchanges exist where after replacing the analog switch matrix with a digital one, the block diagram remains the same as before.)

The change of the inner structure can, of course, influence its environment. For instance, the functions of the junctor circuit used in exchanges operating with space-division switching jointly by more subscribers, have to be moved to the line interfacing circuits individually assigned to the local lines if replaced by the time-division digital switching network.

The first generation SPC exchanges have been equipped with hermetically sealed cross-points operating with fast, low-power galvanic switches (reed and ferreed relays). These switches were much slower than the electronic switches. At that time, however, semiconductor devices with the switching parameters necessary for the switching network were not known, yet.
An important block of the SPC exchange is the unit interfacing the processor to the environment via a network interface. The processor interrogates the status of the lines and that of the trunk by a scanner, compares them with the previous line status to find out the changes,
and stores the data until the next scan. The status change represents an event which is processed by the appropriate program and the required operation is then passed to the interface via the distributor circuit. According to different signalling systems, events or

information (e.g. the address of the calling or the called party, etc.) are transferred among the processor and the trunks by signalling receivers (such as the DTMF signalling receiver) and signalling transmitters.

14.6. Digital Exchanges

The development of the highly integrated semiconductor devices made it possible to realize digital speech encoding, switching and transmission at an acceptable price which was a decisive factor to use the *time-division* digital switching network. Functions which had to be realized when interfacing the subscriber lines to the digital switching network are symbolized by the acronym BORSCHT which stands for:

B: Battery feeding
O: Overvoltage-protection
R: Ringing
S: Signalling (or Supervision)
C: Coding (A/D conversion, see Chapter 5)
H: Hybrid (2/4-wire conversion, see Chapter 8)
T: Test (switching to the equipment testing the line and the line circuit)

The aim of the manufacturers of the equipment is to integrate the maximum of the above functions since the circuit implementing them represents the 30-40% of the cost of the local exchange. E.g., codecs with programmable time-slot assignment realize a part of the switching functions of the subscriber stage. Due to the rapid development of the semiconductor technology, all functions have been integrated except the T and the R function which are carried out by relays even at the beginning of the '90-s. The logical relations of the functions are shown in Figure 14.9.

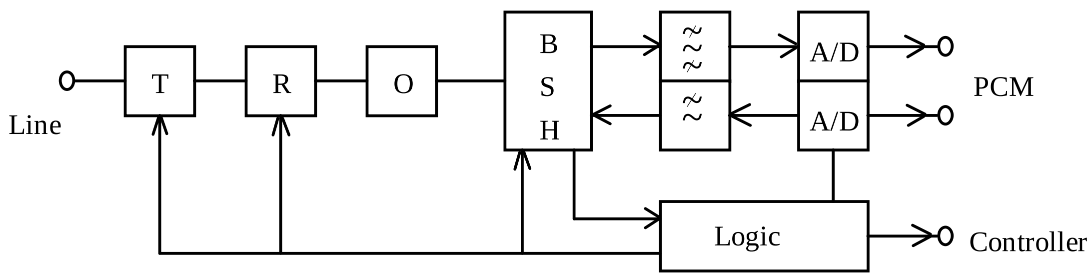

Figure 14.9. Relations Among the BORSCHT Functions

The time-division digital switching and transmission mutually enhance each other's efficacy, even more, certain functions of the switching and the transmission (e.g. multiplexing and concentration) can be unified. The wide-spread use of microprocessors made it more economical to decentralize the earlier centralized stored-program control used together with the above mentioned integrated switching and transmission technique (IDN - Integrated Digital Network). This resulted in bringing the units concentrating the traffic closer to the subscribers
thus reducing the cost of the local network. (On top of that, these small, reliable operating units do not require special buildings.)

In the latest stage of development, the digital transmission has been extended to the subscribers' sets enabling thus the telephone network to be used as a single common medium for the speech and data transmission (ISDN - Integrated Services Digital Network, see Chapter 18). Besides the basic services, users can subscribe to a wide variety of additional services. To implement such a system, a highly sophisticated signalling system is necessary between the telephone set and the exchange, and among the individual exchanges, respectively. Several signalling systems have been developed by the CCITT for this purpose, the most important of which are the DSS 1 (Digital Subscriber Signalling System No.1) and the CCS (Common Channel Signalling System No.7).

Control Questions

1. Economic design of subscriber networks.
2. Switching networks, types and structure aspects.
3. Classification of control functions.
4. Multi-path traffic control.
5. Functional blocks of the SPC exchanges.

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