INTEGRATED SERVICES NETWORKS

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Abstract

The introduction of digital technology at the switching and transmission levels, allows that the public telephone network is evolving towards a fully digital communication network, which will incorporate the different services presently offered in independent networks by the telecommunication operating companies. The Integrated Services Digital Network (ISDN), as it is called, will integrate voice, data, text and facsimile in a unique network, to be accessed by the user through a standard interface. An overview of the ISDN services, physical structure, protocol architecture , technology and interworking with data networks is given in the lectures.

1. INTRODUCTION

In today's telecommunications the user may have access to a number of independent public telecommunication networks, for example, the telephone, the telex and the data networks. Two good reasons for the separate evolution of the telecommunication networks are that each of them corresponds to different user needs and transmits a different type of information.

For the "Information Age" user, however, it is more natural and adequate to adhere to a unifying concept of the telecommunication networks. On the one hand, all the different types of information can be digitized and transmitted as streams of bits along a unique network. On the other hand, some users will strongly need and many others will appreciate to interact with the network to transmit and access multimedia information, namely voice, data, text and image. In these conditions, it is very convenient for the users to have a unique connection to the public network at their home or business premises, through which all the communications are established at the required speed. For the Telecommunication Operating Companies, it is also very attractive to support a unique network, with the corresponding advantages of easier maintenance and planning of the network.

This type of network is called an Integrated Services Network (ISN) and can be formally defined as a communication network in which the same switches and paths are used to establish connections for different services.

A recommended infrastructure for an ISN would be the public switched telephone network (PSTN), as at present, it is the most ubiquitous telecommunication network in the world. The PSTN, which until the seventies was essentially analog, is in the process of being digitized, both at the switching and transmission levels. The trend is to achieve a complete digitization of the telephone network in the future. This being the case, the digitized telephone network will be totally adequate to be the infrastructure of an ISN, and it will be called an Integrated Services Digital Network (ISDN). An ISDN should additionally offer speeds that are required by some more demanding telecommunication services, such as, the transfer of large files or other large ammounts of data, which presently are limited by the low speed available in the public data networks [1] [2].

The introduction of a public ISDN pursues a number of strategic objectives. The main ones are the following:

i) to offer a large spectrum of telecommunication services to the subscriber through a standard interface, at a speed higher than the one presently available in data networks;

ii) to have economical advantages in relation to a separate evolution of the different networks, by taking advantage of a factor of economy of scale;

iii) to offer a better quality of service;

iv) to allow better network maintenance procedures to be developed and to facilitate the planning of the network evolution.

The ISDN architecture is shaping the future of telecommunication networks and most of the Telecommunication Administrations are planning the evolution of their networks into ISDN in the near future. However, due to the large number of public and private networks that presently exist besides the PSTN, it will take some time before they can be integrated in the ISDN, and at least in an interim stage, they should be connected to the ISDN through suitable gateways.

2. EVOLUTION TOWARDS ISDN

During the late sixties the digitization of the telephone networks started in several countries, replacing the earlier analogue technologies. The speed of digitization has been different among the different countries, and this is still the case. Although this process is well advanced in some countries, it is, however, far from being complete.

The digitization consists in the introduction of digital transmission facilities in the trunk network, and of digital exchanges in the local and toll network. Time division multiplexing for 64 kbit/s full duplex channels is used for switching and transmission, and data and signalling are transmitted in separate channels.

The subscriber loops are, however, still analogue, and the analogue/digital conversion occurs in the interface units of the local exchanges, as it is shown in Fig.1. A telephone network

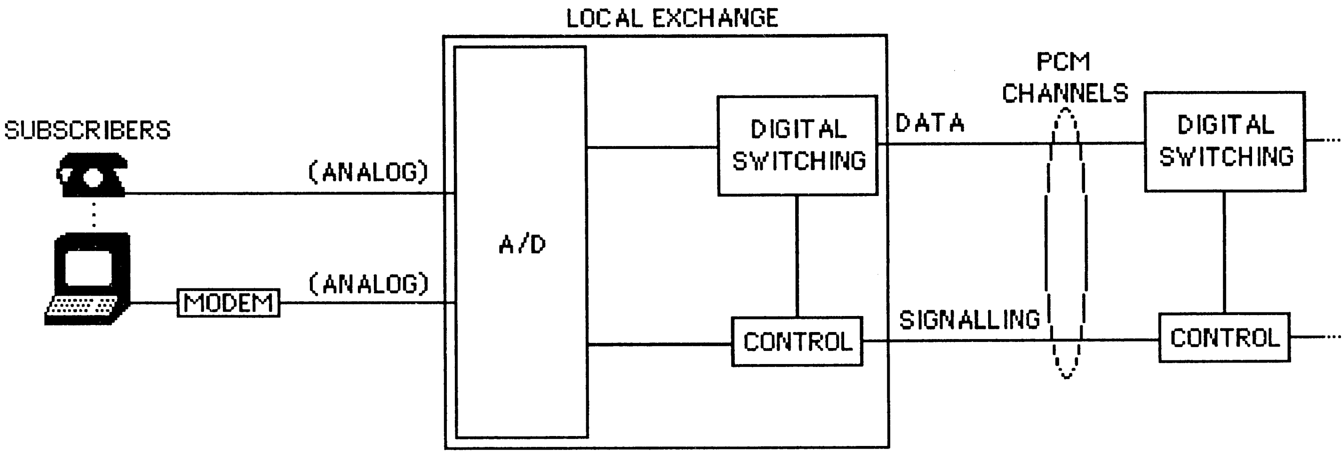


FIG. 1 - Integrated Digital Network

with these characteristics is called an Integrated Digital Network (IDN) [3].

The IDN evolves towards the ISDN by digitization of the subscriber loop and terminals. There is then, a complete digital connectivity among the subscribers and between subscribers and service providers, as it is shown in Fig. 2. In this figure, multifunctional terminals are represented at the user's premises. The term multifunctional refers to the capability of the terminal to use more than one network service, possibly at the same time.

The most important characteristics that the public ISDN will present to the user may then be summarized:

i) integration of voice, data, text and image in the same network;

ii) use of the existing 2-wire subscriber loop, but with digital transmission and a separate signalling channel;

iii) a universal interface between the user terminals and the network for all the ISDN services;

iv) use of multifunctional digital terminals with direct connection to the ISDN;

v) standard terminal adaptors to connect some non-ISDN terminals to the ISDN;

vi) availability of switched channels with different transmission rates (64, 384, 1920... kbit/s);

vii) simultaneous use of different services;

viii) possibility of accessing services which require processing and storage in the network, for example, videotex, teletex and electronic mail;

ix) interworking with other networks , through suitable gateways.

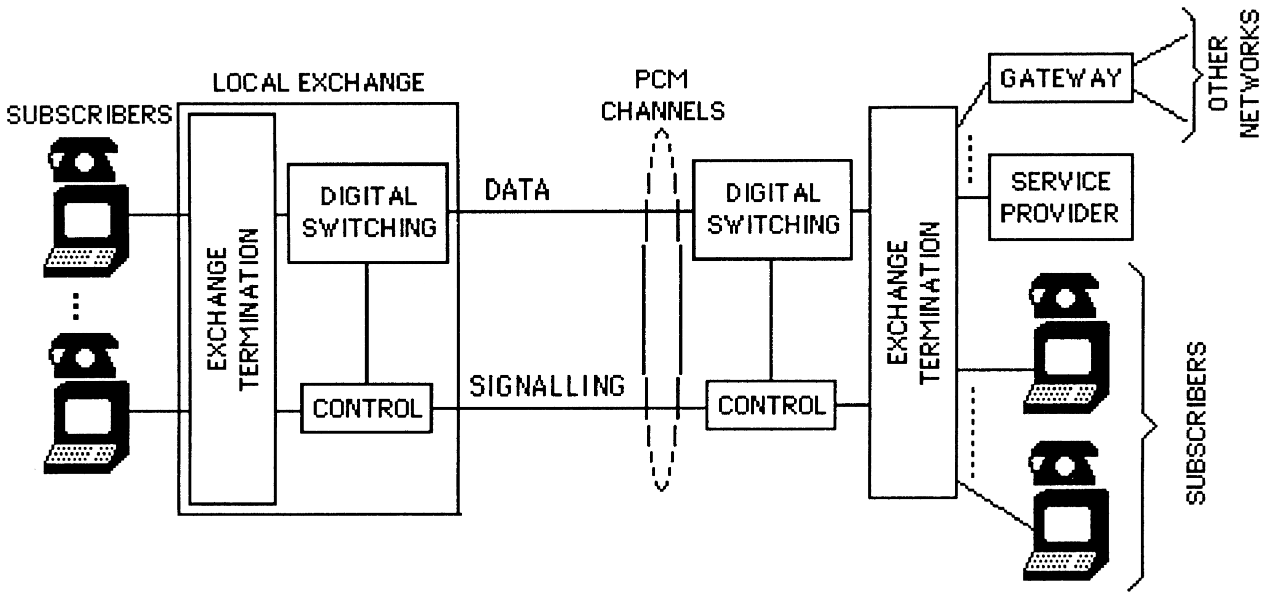


FIG. 2 - Integrated Services Digital Network (ISDN)

In 1984, the CCITT approved a series of ISDN recommendations [4] on services, user-network interfaces, communication protocols and interworking. It is based on these recommendations that national implementations of ISDN are being developed in many countries. The ISDN operation is first tested in field trials before a public service is offered. A public ISDN service for a restricted number of users, mainly business users, will be available in some countries by the end of the decade.

3. SERVICE CONCEPTS

In ISDN terminology the concept of service has two different meanings, depending on being used in the context of a layered protocol architecture or in the context of the network operation [5].

3.1 - Service concept in the context of layered protocol architecture

In ISDN the communication between different application processes is logically structured in layers, having been adapted the Basic Reference Model for Open Systems Interconnection (OSI) [6].

The OSI model has seven layers: application layer (7), presentation layer (6), session layer (5), transport layer (4), network layer (3), data link layer (2) and physical layer (1). Layers 1 to 3 implement the communication functions, and layers 4 to 7 correspond to the storage and processing functions of the end systems.

The connection between two open systems according to the OSI model is shown in Fig. 3. The communication between peer entities belonging to the same (N)-layer in different systems, is governed by a set of rules on an OSI (N)-Protocol.

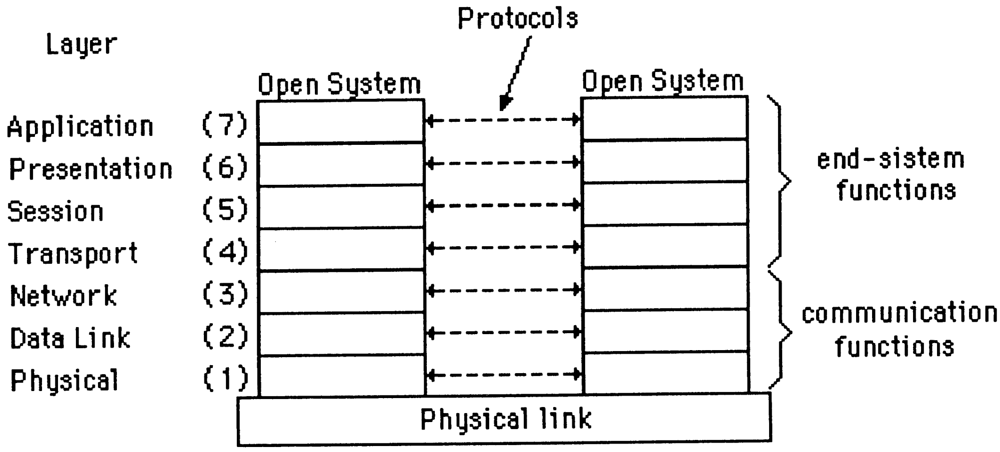


FIG. 3 - The connection between two open systems

The layer at the highest level is the application layer, which contains the application entities that cooperate in the OSI environment. The layers 1 to 6 provide the services that allow the application entities to cooperate.

The (N+l)-entity is the service-user of the capacity of the (N)-entity. The (N)-entity is the service-provider for the (N+l) entity. The communication between the adjacent layers (N+l) and (N) in the same system is governed by a set of (N)-service primitives: Request, Indication, Response and Confirmation, as it is shown in Fig. 4.

Request is a primitive originated at a layer (N+l) that activates a specific service at layer (N). Indication is a primitive originated at layer (N) that indicates to layer (N+l) the activation of an (N)-service. Response is a primitive originated at layer (N+l) as an acknowledgement of the Indication primitive. Confirm is a primitive originated at layer (N) that completes the cycle.

All the communication between the adjacent layers (N+l) and (N) is executed by the exchange of data units, called (N)-Service Data Units.

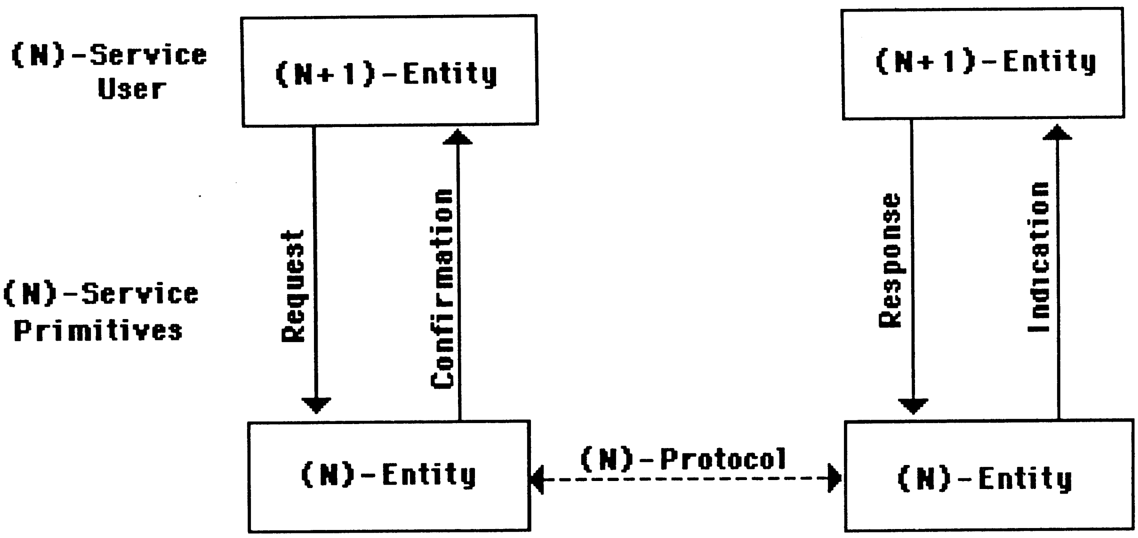


FIG. 4 - The Service concept in the OSI model

3.2 - Service concept in the context of network operation

The notion of service in the context of the network operation consists of all the commercial, operational and technical aspects relative to a certain type of communication between users, end systems and the network provider [7] [8].

In ISDN two different kinds of services are distinguished: bearer services and teleservices.

The ISDN bearer services enable the transfer of digital information in the network. They guarantee the transport of information in circuit or packet switched mode between two user-network interfaces, regardless of the compatibility of the terminals. In the OSI model they correspond to levels 1-3, the communication levels. Typical examples of bearer services are the data transmission services as defined in the X-series of CCITT recommendations.

The ISDN teleservices permit an application-directed communication to be completely implemented between the users or between the user and the service providers, guaranteeing the compatibility of the terminals. The teleservices cover all the seven layers in the OSI model. The independence of layers in the OSI model allow that the standards for the levels 4 to 7 of the teleservices can be established independently of the bearer services that support them.

Teleservices may be supplied for telematic, office or data processing applications. Examples of teleservices in each of these categories are: i) teletex, facsimile and videotex in telematics, ii) directory and electronic mail in office applications, and iii) file transfer and job transfer in data processing. A set of standards for teleservices have been defined by the ISO and the CCITT. A sample list of these standards for the teleservices given as an example, is shown in Fig. 5.

Both the bearer services and the teleservices can be extended by supplementary services, which improve the performance of those services compared to the basic service. This means that the supplementary services cannot be offered autonomously, but they must always be offered to users as options of the basic service. Examples of supplementary services are abbreviated dialing, call barring, conference calls and reverse charging.

OSI LAYER	TELETEX	FACSIMILE	MIXED TELETEX FACSIMILE	VIDEOTEX	DIRECTORY	MAIL	FILE TRANSFER	JOB TRANSFER
7	T60 T63,T90 T91,F200 F201 DP9063/2 DP9064/2	T0,T2 T3,T4,T5 DP9063/1 DP9064/1	T62,T72	F300 T100 T101	XDS1 XDS2 XDS3 XDS4 XDS6 XDS7	F40,F350 X400 X401 X408 X420 X410 X411	DP8571	DP8831 DP8832
6	T50,T51,T61,T73 X409 IS6937 DP8822,DP8823,DP8824,DP8825							
5	T62 X215,X225 DIS8326,DIS8327							
4	T70 X214,X224 DIS8072,DIS8073,DIS8602							
1-3	BEARER SERVICES							

FIG. 5 - A sample list of standards for teleservices

4. USER - NETWORK INTERFACES

The establishment of user-network interface standards is fundamental to guarantee the availability of low cost terminals, able to support various applications, which can be connected to the ISDN [9].

In the recommendations I410, I411 and I412 issued by the CCITT, the reference model for the user-network interface in the ISDN was defined as it is represented in Fig. 6. The concepts of functional groups and reference points are central to the definition of the model. A functional group is a set of functions which may be needed in ISDN user access arrangements. The blocks TE1, TE2, TA, NT2 and NT1 represent different functional groups in the reference model. A reference point is a conceptual point dividing functional groups. In a specific configuration, a reference point may correspond to a physical interface between equipments. The reference points R,S, T and U are identified in the reference model.

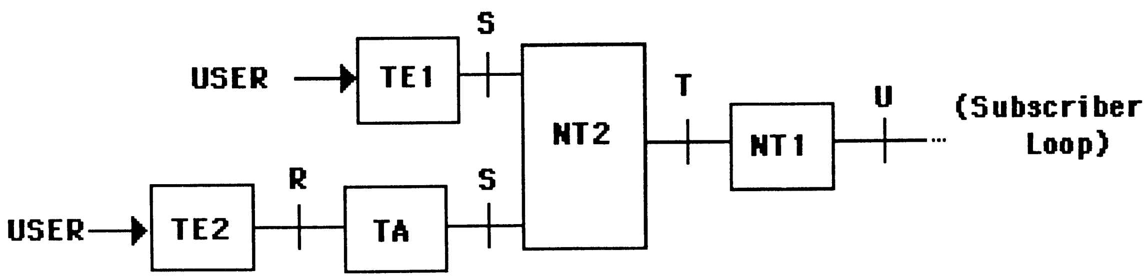


FIG. 6 - Reference model for the user access to the ISDN

The terminal equipment (TE) includes functions belonging to layer 1 and higher layers of the OSI model. There is the possibility of having different types of terminals at the user's premises: i) ISDN compatible terminals (TE1), for example, digital telephones, data terminals or multifunctional terminals having an S-interface; ii) terminals non-compatible with ISDN (TE2), but with Terminal Adaptation (TA) for protocol conversion to the S-interface, for example data terminals compatible with CCITT X or V recommendations.

The network termination 2 (NT2) corresponds to user's equipments, such as, PABXs, LANs and terminal controllers. NT2 typically includes functions from layers 1, 2 and 3 of the OSI model, such as, protocol handling, multiplexing and switching. It is connected to NT1 through the T-interface.

The network termination 1 (NT1) includes functions belonging to layer 1, such as, transmission line termination, timing and power transfer. It isolates the public network from the user's premises network. NT1 connects to the subscriber loop through the U-interface. It must be noted that if the NT2 equipment does not exist in the user's configuration, the reference points S and T coincide. This leads to the important fact that the same interface specifications apply at both reference points S and T. The CCITT has fully specified the S-interface, which is considered to be the standard user-network interface.

The transmission of information through the user-network interface is characterized in terms of channels. Two distinct interface structures have been defined: basic structure and primary structure. In the basic structure there are 2 B-channels and 1 D-channel available to the user, and in the primary structure there are 30 B-channels (23 in U.S.A.) and one D-channel available. A B-channel is a 64 Kbit/s, full-duplex, information carrying channel. B channels are used to carry a variety of user-information streams and they provide access to circuit or packet-switched modes of communication.

A D-channel is a full-duplex channel primarily intended for signalling. It is a 16 kbit/s channel in the basic interface and a 64 kbit/s channel in the primary interface. The transmission of signalling in a D-channel has a layered protocol architecture, recommended by the CCITT. The D-channel, in addition to signalling, may be used to carry user information in packet-switched mode or teleaction information.

The total bit rate of the basic structure (2B+D) through the user-network interface is 192 kbit/s in each direction, in which 144 kbit/s result directly from the B and D channels, and 48 kbit/s are used for control and synchronization. The total bit rates of the primary structure (30B+D in Europe, 23B+D in USA) are respectively 2048 kbit/s and 1544 kbit/s in each direction. It must be noted that the bit rates in the primary structure, are those already used in digital transmission in the IDN.

There is also the possibility of defining higher-capacity data channels in this primary structure, by using H-channels. These channels can have the following bit rates: H0-384 kbit/s, H11-1536 kbit/s and H12-1920 kbit/s. They are used to carry user data in applications that require high bit rates, such as, fast facsimile, teleconferencing and high speed data transfer.

The capacity provided by the basic interface is normally enough for the residential user. The primary mode of access is mainly needed by the business user that has NT2 equipment in its premises configuration, or for high bit rate applications.

The specifications for the U interface have not yet been recommended by the CCITT; this mainly derives from the fact that technology for digital transmission in the 2-wire subscriber circuit at ISDN speeds was not yet stabilized at the end of the last study period of the CCITT, in 1984. The transmission of the digital signals at a high bit rate in the existing subscriber loops, physically based on the use of multipair cables, presents some problems [10]. A multipair cable consists of individually insulated twisted pairs of conductors enclosed in a common protective sheath. The maximum data rate that can be transmitted over a twisted pair is dependent, among other factors, on the distance and the wire gauge. This is graphically shown in fig. 7. For example, it can be seen that for 24-gauge wire it is possible to transmit at 1.5 Mbit/s, over a distance of up to 2km.

The subscriber loop can, however, be up to 6 km long in some cases, and a full-duplex 144 kbit/s data rate, plus some control bits, needs to be achieved on the 2-wire loop; this requires the development of special transmission techniques. Two different techniques have been proposed: Time Compression Multiplexing (TCM) and Echo Cancellation (EC) [II].

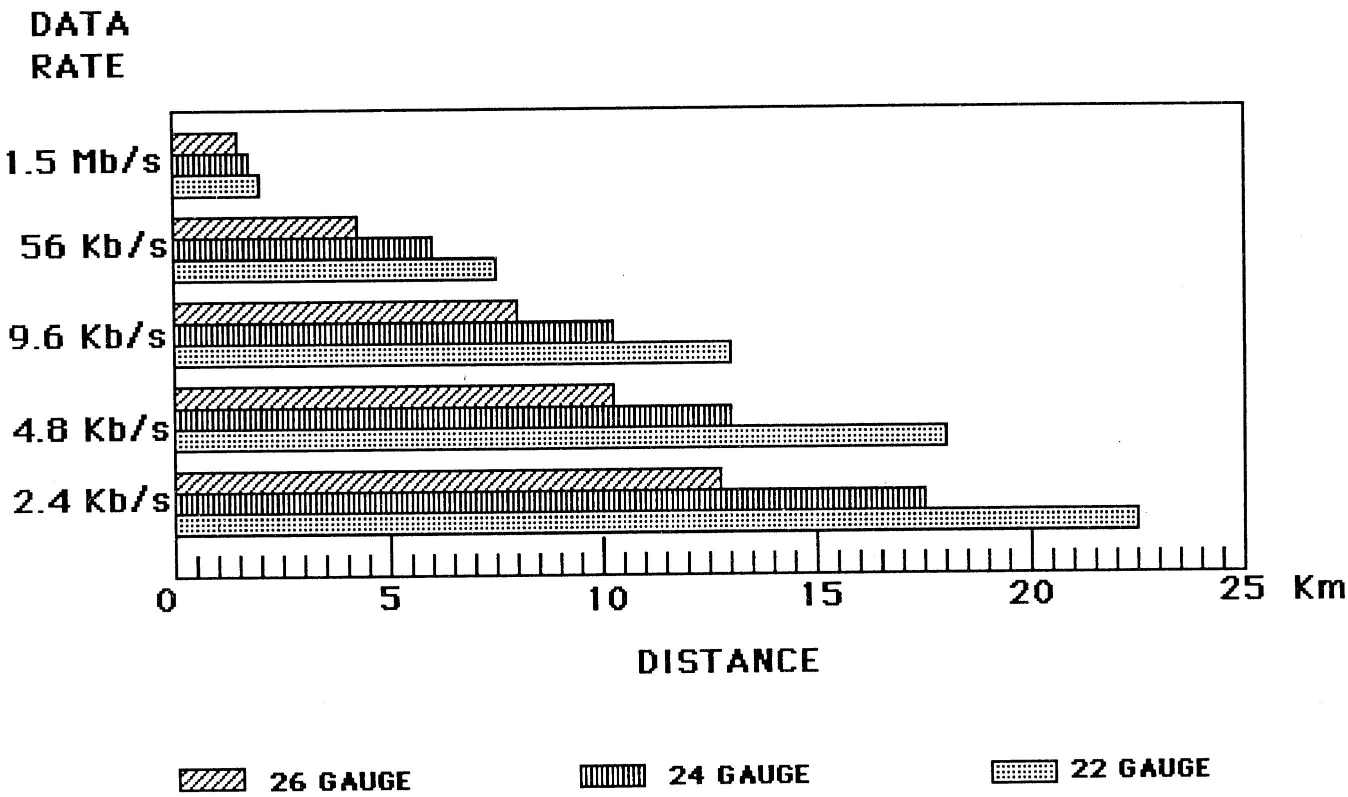
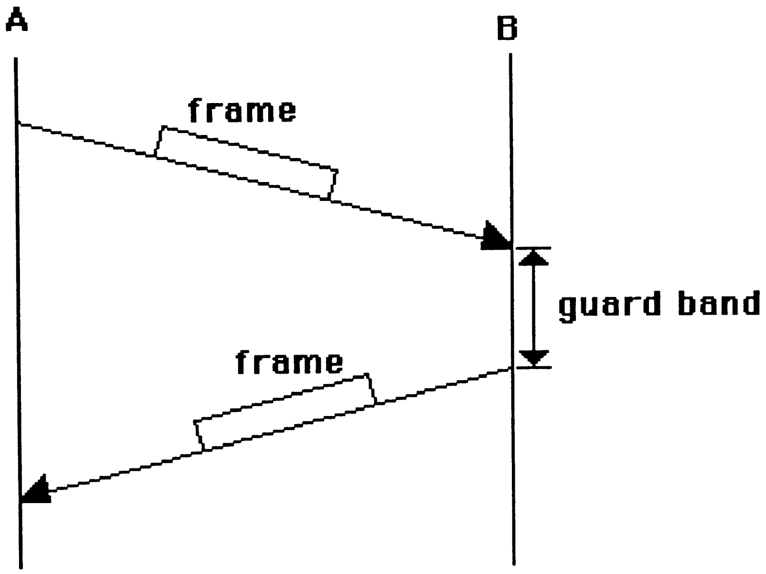


FIG. 7 - Transmission capabilities of cable pairs at various rates

In TCM, also called ping-pong, the 2-wire subscriber loop is used on a time-division multiplexing method, by transmitting a little faster than twice the required bit-rate in each direction, to simulate a two-way transmission in real time at ISDN speeds. In this method, a guard band during which the channels are quiet between the reception of a stream of data and the sending of the next one, is used. This is shown in the diagram of Fig. 8.

In the EC technique represented in Fig. 9, both sides transmit simultaneously on the subscriber loop. Side A sends a signal to side B, originating an echo to be sent from B to A. By means of an adaptive digital filter the equipment at A generates an inverse signal to cancel out the echo. The equipment at B performs also the same action while sending a signal to A. The implementation of this method requires the development of sophisticated VLSI signal processing circuits to do the necessary operations. The EC technique, although more complicated than the TCM, permits to use the original bit rate in each direction and therefore to transmit over longer distances.



Subscriber loop bit-rate : 2 * 144 Kbit/s + x

FIG. 8 - Time compression multiplexing

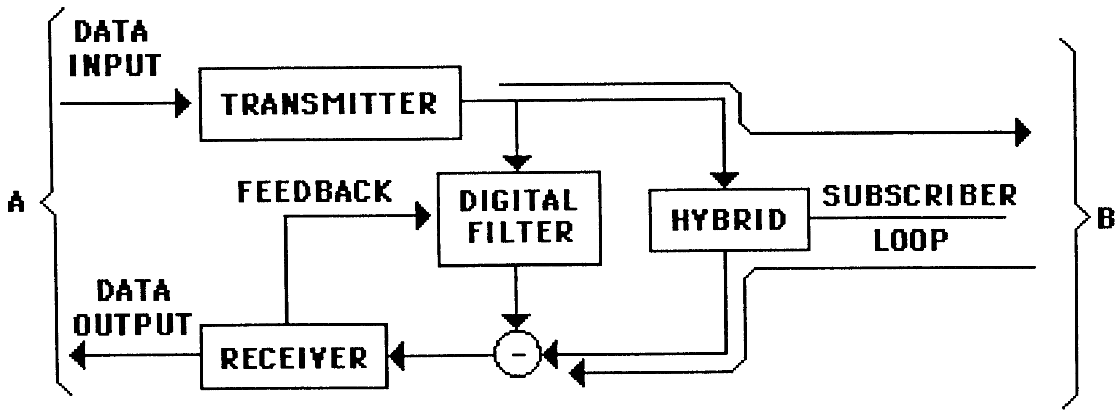


FIG.9 - The echo cancellation technique

A concrete example of a user's premises configuration is shown in Fig. 10. In this example, a group of users have TE1 multifunctional terminals directly connected to NT2, and another user has a V.24 data terminal connected to NT2 through a terminal adaptor TA. The 2B+D interface is used for these connections. The connection between NT2 and NT1 for large capacity installations is typically made through a primary interface structure, which requires at the U interface, a digital trunk line capable of supporting a 2 Mbit/s bit rate in each direction (4 wires). The TCM or EC techniques are used when lower bit rates, typical of the basic interface, are to be transmitted (2 wires).

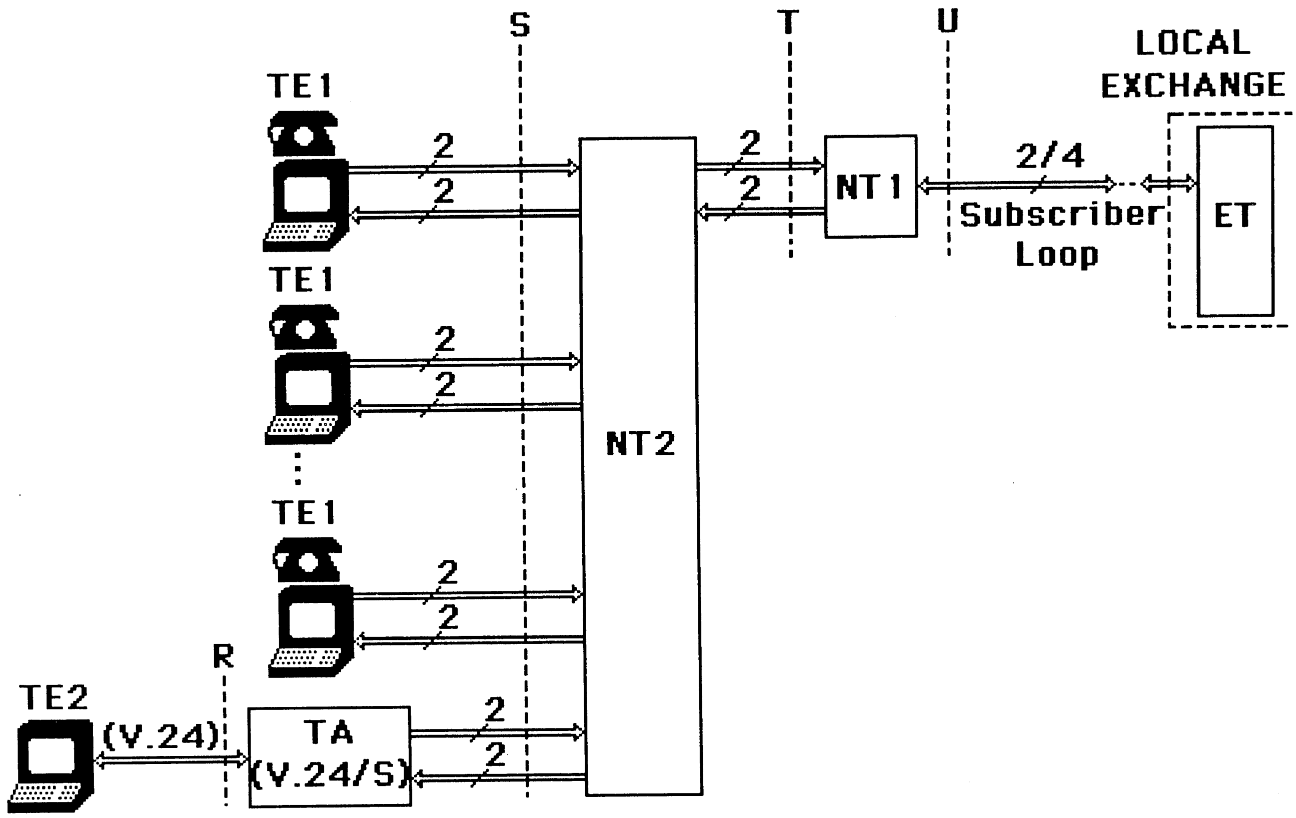


FIG. 10 - Example of a configuration at an ISDN user's premises

5. PROTOCOL ARCHITECTURE

The flow of information between peer entities in ISDN, is governed by a set of rules defined in a communication protocol. CCITT has defined a set of ISDN protocols, which cover the levels 1 to 3, the communication levels, of the OSI model. The protocols for the levels 4 to 7, depend on the application, having some of them been already indicated in Fig. 5.

The relation among the different ISDN protocols is shown in Fig. 11. The B channels are used to carry the user information streams and can provide access to circuit switched or packet switched communication modes in the ISDN. In the case of circuit switching, the B-channel provides a transparent 64 kbit/s connection. In the case of packet switching, it carries layers 2 and 3 protocols of the X25 recommendation.

The D channel is primarily used to carry signalling information for the circuit-switched mode in the ISDN. For the signalling entity (s) at layer 3, it is used the protocol defined in recommendations I450 and I451. At layer 2 it is used the protocol known as LAP-D, defined in I440 and I441.

The D channel may also be used to carry packet-switched data (p) and teleaction information (t). For the entity (p) it is used the X25-layer 3 protocol, but for the entity (t) no standard protocol has yet been defined.

At the layer 1 all the channels communicate into the physical link, by using a protocol specified in recommendations I430 and I431, respectively for the basic and the primary structures.

For signalling between exchanges in the ISDN, the Signalling System no. 7 (SS7) has been adopted. The SS7 is a common channel signalling system specified by the CCITT, and future efforts are directed towards achieving end-to-end ISDN signalling compatibility, by harmonization of the SS7 and D-channel procedures.

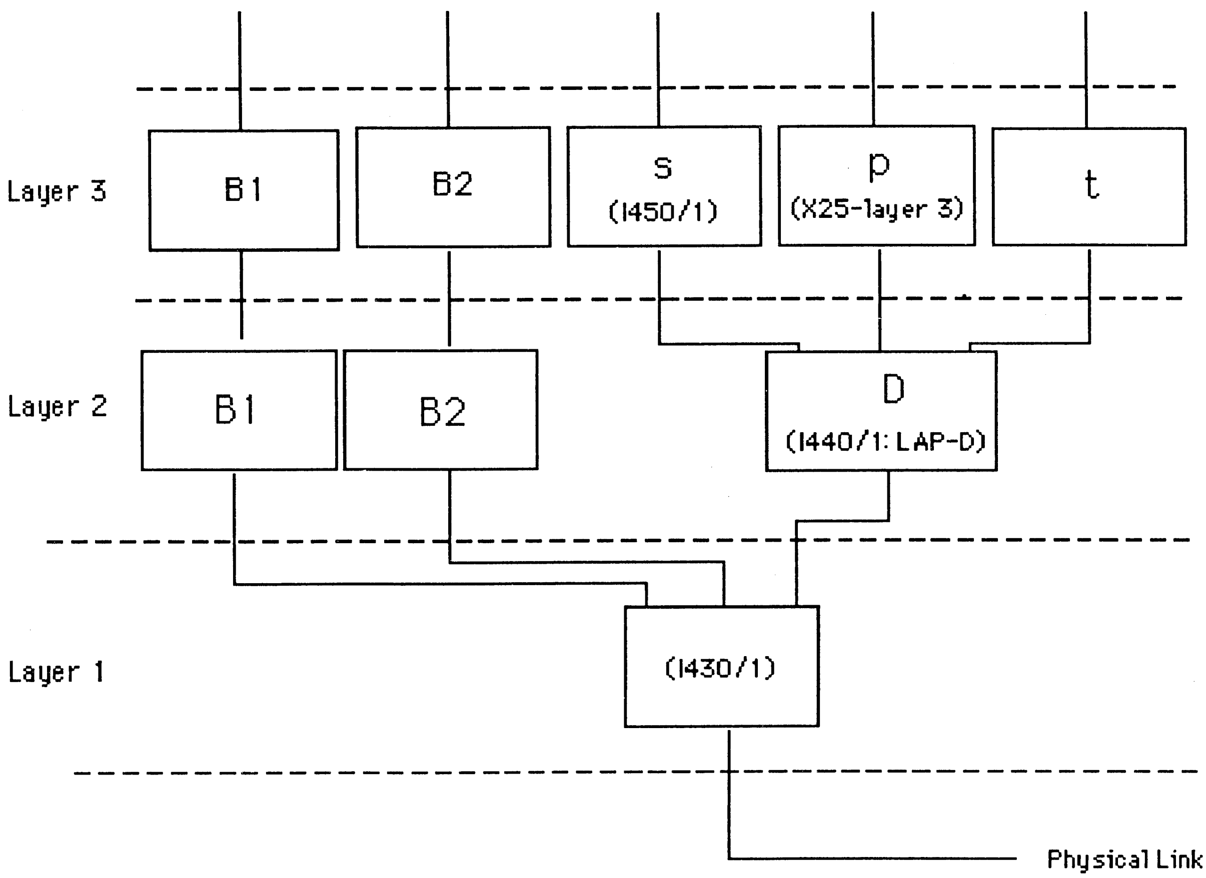


FIG. 11 - ISDN protocols

5.1 -The physical layer

5.1.1 - The basic interface structure

The physical layer characteristics of the user-network interface at the S or T reference points are defined in the recommendation I430, for the basic interface structure. In the following, a review of the most important characteristics of the interface and of the communication protocol is made.

Modes of operation

There are three possible modes of operation, which are established by the connection of the terminals to NT (NT1 or NT2): point-to-point, point-to-multipoint (short passive bus) and point-to-multipoint (extended passive bus). The different modes of operation are illustrated in Fig. 12.

In the point-to-point operation each connection between a TE and the NT requires an independent physical link. The maximum permitted length is 1 km, due to cable attenuation.

In the point-to-multipoint operation (short passive bus), a maximum of 8 TE's may be connected to the bus. The maximum distance from the NT is between 100 and 200m, being dependent on the round trip delay in the bus.

The extended passive bus is a particular case of the passive bus in which all the terminals are grouped at the far end of the cable, which allows the maximum distance to be extended to 500m.

Functional characteristics

The line code is a pseudo-ternary code. A binary "1" is represented by no line signal and a binary "0" is represented alternatively by a positive and a negative pulse, as it is shown in Fig. 13. Due to the particular structure of the code, if additional balancing bits are criteriously inserted in the data stream, the physical layer frame has no DC component.

The physical layer frame structure consists of 48 bits. The frame structures are different for each direction of transmission, as it is shown in Fig. 14. Every frame is transmitted in 250μs, which gives a total bit rate of 192 Kbit/s in each direction at the S/T interface.

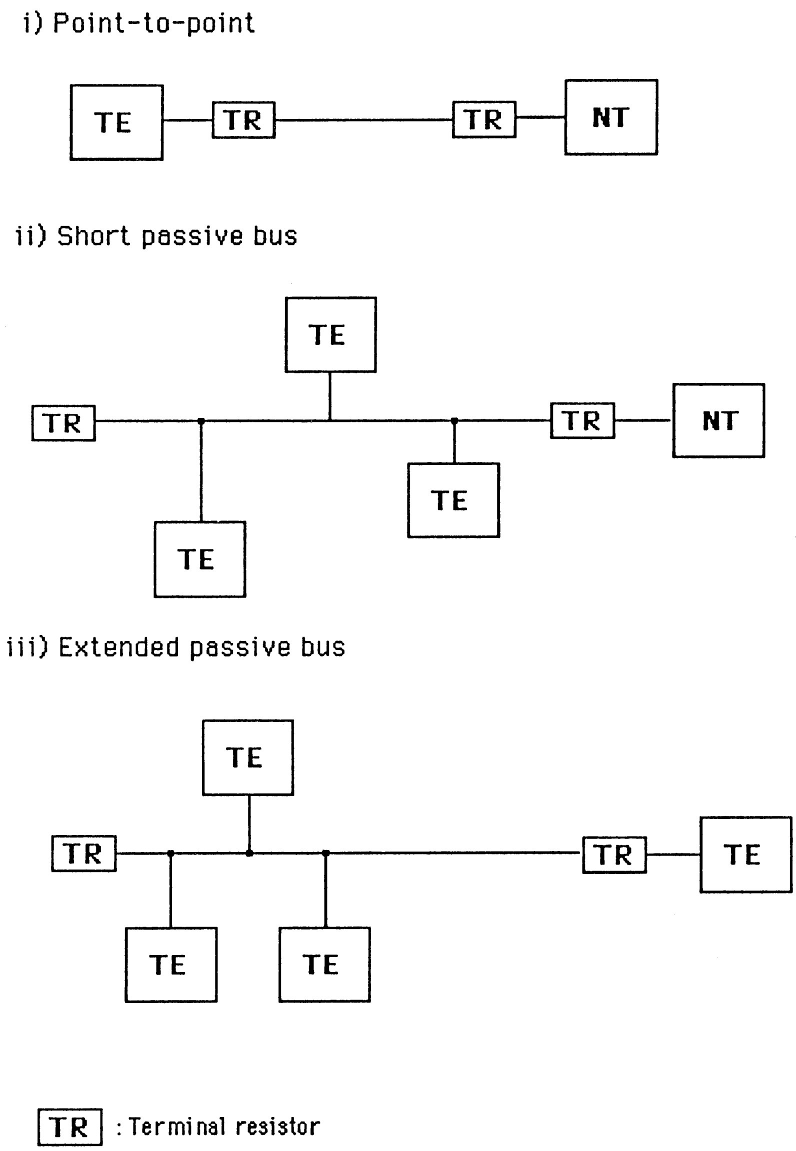


FIG. 12 - Terminal wiring configurations

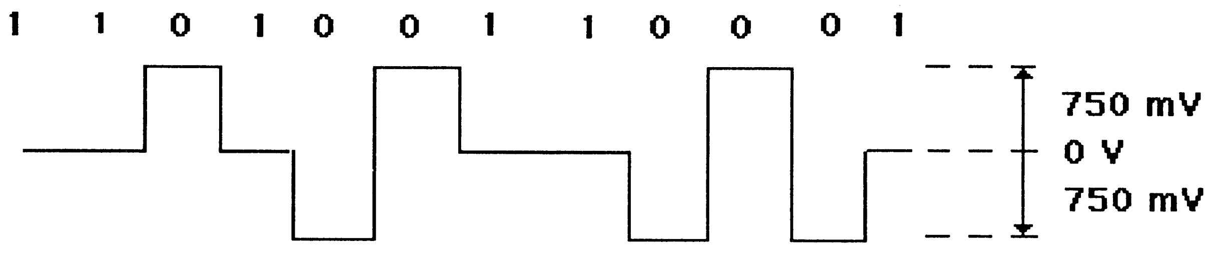
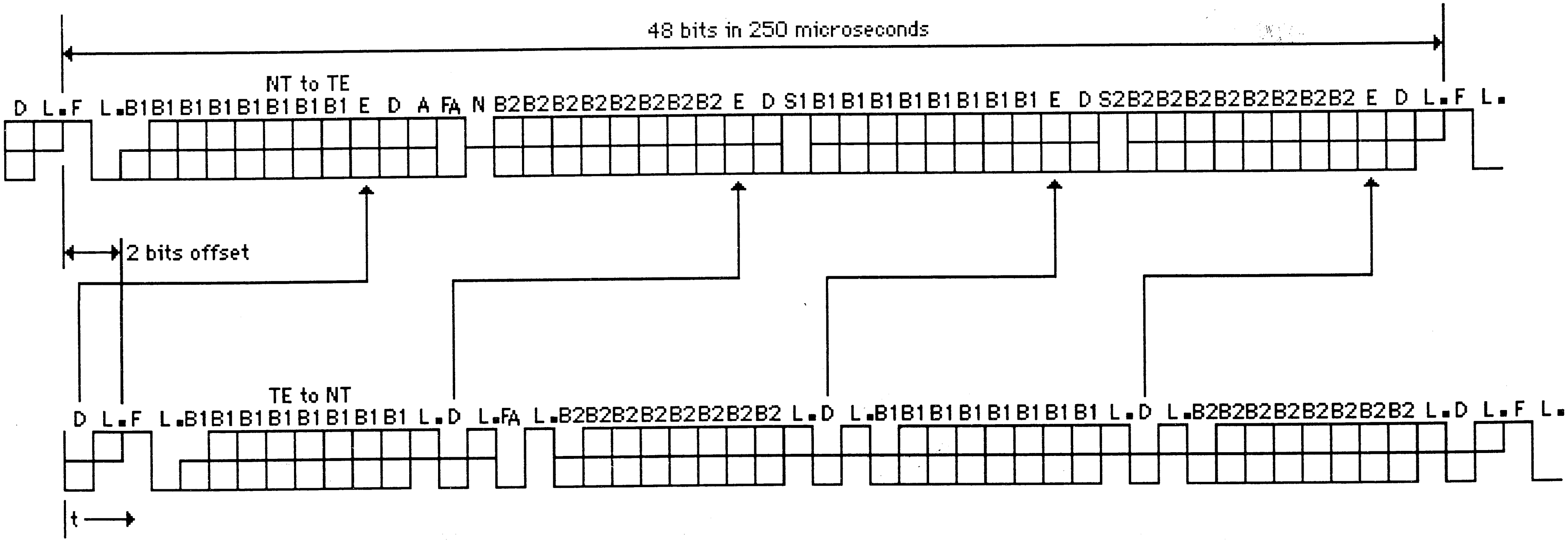


FIG. 13 - A binary configuration using the pseudo-ternary code



F = framing bit
L = DC balancing bit
D = D-channel bit
E = D-echo-channel bit
FA = Auxiliary framing bit (=0)

N = bit set to a binary value N=$\overline{FA}$
B1 = bit within B channel 1
B2 = bit within B channel 2
A = bit used for activation
S1, S2 = Reserved for future standardization

Note - Dots demarcate those parts of the frame that are independently DC-balanced.

B1	B2	D	Overhead
64 Kbit/s	64Kbit/s	16 Kbit/s	

192 Kbit/s

FIG. 14 - Frame structure at reference points S and T

The most important aspects of the frame structure are the following:

i) in every frame 4 bytes are reserved for the B1 and B2 channels and 4 bits for the D channel;

ii) the frame transmitted by NT has 4 E bits, that are D-echo bits, used to control the access of the different TE's to the D channel, in the point-to-multipoint operation;

iii) F is the start bit in every frame. It is a binary "0", with the same polarity as the previous pulse. A is a bit transmitted by NT for TE activation. L bits are used for DC-balancing. S1 and S2 bits are reserved for future standardization. The use of the FA and N bits for multiframing facilities are under study, and for the time being FA is set to "0";

iv) the transmission start of the frame from TE to NT has a 2 bit delay in relation to the first bit of the previous frame received from NT. The timing in the direction from TE to NT may then be derived from the frames received from NT. NT derives its own timing from the network clock.

D-channel access control

There is a procedure to permit that the different terminals connected to the bus in a point-to-multipoint configuration have a controlled access to the D-channel. The procedure guarantees that in the case of two or more terminals try to use the bus simultaneously, one of them will successfully complete the transmission.

To understand this procedure it must be said in first place that layer 2 frames are delimited by the binary configuration (flag) 01111110. Inside the frame, whenever five consecutive 1's occur, a 0 is inserted to avoid the imitation of the flag.

The procedure operates in the following way:

i) when an active TE or NT have no layer 2 frames to transmit in the D-channel, they send binary "1's" into the channel (absence of signal);

ii) detection and resolution of collisions are the responsibility of the TE's, which use the D-channel echo bits for that purpose;

iii) monitoring of the D-channel is done by an active TE, by counting the number of consecutive 1's in the D-channel. If a 0 is detected, TE restarts counting the number of 1's. When the number of consecutive 1's equals a fixed value Xi, the counter is reset to 0 and the TE can access the D-channel;

iv) This mechanism permits to attribute different access priorities to the TE's, by fixing different values for the Xi's;

v) When a TE has access to the D-channel, possible collisions can be detected by monitoring the D-channel echo bit and comparing it with the previously transmitted D bit. If they are equal the transmission continues, if they are different, the TE stops transmitting and returns to the state of monitoring the D-channel.

5.1.2 - The primary interface structure

The layer 1 characteristics of the primary interface structure are described in recommendation I431, both for the 1544 and the 2048 Kbit/s rates. They have been derived from the CCITT recommendation G703 that contains the electrical characteristics and the frame structures used by PCM systems.

In the primary interface, only the point-to-point configuration is supported between the TE's and the NT, which eliminates the need for a contention resolution mechanism in the bus. For the interface at 1544 Kbit/s, the frame structure contains 193 bits, and the transmission rate is 8000 frames/s. For the interface at 2048 Kbit/s, the frame structure contains 256 bits, and the transmission rate is also 8000 frames/s. The frames carry the user information from the B, H0, H11 or H12 channels, the signalling information from the D-channel and frame alignment bits.

In the primary interface structure, it is also foreseen that the NT derives its timing from the network clock and that the TE synchronizes its own timing from the signal received from the NT.

5.2 - The data link layer

The general aspects of the ISDN layer 2 protocol are defined in recommendation I440 and the detailed specification is indicated in recommendation I441.The layer 2 protocol is called LAP D, and it is based on the X25 LAPB protocol.

LAPD is a bit oriented protocol whose main functions are:

- frame delimiting and alignment;
- flow and sequence control;

- multiplexing of several data link connections in the D-channel, corresponding to the different layer 3 entities;
- error checking.

The LAPD frame format is shown in Fig. 15.

Nr. of Bytes	1	2	1 or 2	max 128 or 260	2	1
	Flag	Address	Control	Data	Frame Check Sequence	Flag

FIG. 15 - The LAPD frame format

All frames are delimited by an opening flag and a closing flag. Both flags are identical and they consist of the binary configuration 01111110. To ensure that the flag is not simulated in the other fields of the frame, a "0" must be inserted after all sequences of five contiguous "1's" for transmitting (bit stuffing). At reception, every "0" that follows five contiguous "1's" is discarded.

The address field consists of two bytes that contain the subfields indicated in Fig. 16.

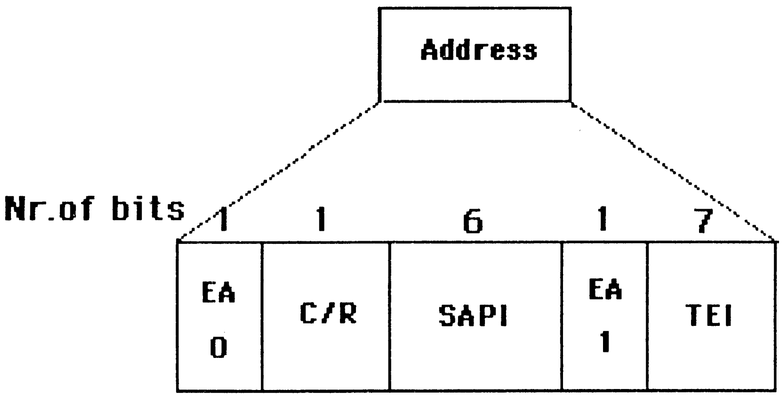


FIG. 16 - The address field of the LAPD frame

FIG. 16

The Extended Addressing bit (EA) is a bit that when has the value "1" indicates the last byte in the adress field. It exists for compatibility with LAPB.

The C/R bit indicates if the frame is a command or a response. The user sends commands with C/R=0 and responses with C/R=1. The network side does the opposite, it sends commands with C/R=1 and responses with C/R=0.

A specific data link connection is identified by the Service Access Point Identifier (SAPI) and the Terminal Endpoint Identifier (TEI). The SAPI identifies a point at which layer 2 services are provided to layer 3. The SAPI actually indicates the layer 3 procedures for which the layer 2 service is intended. The SAPI values that have already been allocated are the following:

- SAPI=0, identifies a layer 2 service for call control procedures (entity s) in layer 3;

- SAPI=16, identifies a layer 2 service for packet communication procedures (entity p) in layer 3;

- SAPI=32-47, reserved for national use ;

- SAPI=63, identifies a layer 2 service for management procedures.

The TEI identifies a specific data link connection point within a Service Access Point. In LAPD, it normally identifies a specific terminal.

The control field identifies the type of frame. Three different types of frames are possible: numbered information transfer (I), supervisory (S), and unnumbered information transfer and control (U).

An I frame performs an information transfer between layer 3 entities. Each I frame is sequentially numbered from 0 to 7 (modulo 8) or 0 to 127 (modulo 128). A multiple frame operation for the transfer of information is used. In this operation method new frames may be sent, before an acknowledgment has been received for the frame previously sent, thus a number of transmitted frames may not have been acknowledged at a certain time. The sequence number of a transmitted frame may not exceed the sequence number of the last acknowledged frame by more than K. The value of k is in the range $0<k<8$ for modulo 8 operation and $0<k<128$ for modulo 128 operation. I frames are always issued as a command.

An S frame performs layer 2 supervisory functions, such as, acknowledge I frames, request transmission of I frames and request a temporary suspension of transmission of I frames. S frames may be issued either as a command or as a response.

A U frame may perform unnumbered information transfers, which happens when a layer 3 entity requests an unacknowledged information transfer to be done. In this case a layer 2 frame is issued as a command, without sequence number. A U frame may also be used for control functions, for example, commands to establish and to finish a multiframe operation, or a response indicating an error condition.

The length of the control field is 1 or 2 bytes depending on using modulo 8 or 128, respectively.

The data field has the maximum default value of 128 bytes for a service access point supporting a layer 3 s-entity and 260 bytes when a layer 3 p-entity is supported.

The frame check sequence field is two-byte long and a cyclic redundancy code with the generator polynominal $x^{16} + x^{12} + x^5 + x^1$ is used. This code catches all single and double errors, all errors with an odd number of bits, all burst errors of length 16 or less and 99.99% of 17-bit and longer bursts.

5.3 - The network layer

The general aspects of the ISDN layer 3 protocol are defined in recommendation I450 and the detailed specification is done in recommendation I451. The layer 3 protocol basically permits to establish, maintain and terminate network connections between communicating application entities. To perform its functions the layer 3 protocol utilizes the services provided by layer 2, namely the establishment and release of data link connections, error-protected transmission of data and notification of data link layer failures.

The layer 3 protocol can provide access to circuit-switched and packet-switched connections in the ISDN. The procedures required for both types of calls are now examined.

5.3.1 - Circuit-switched connections

Circuit-switched connections are controlled by a sequence of messages transmitted along the D-channel. A B-channel is used for the carrying of data.

A typical procedure for the control of a circuit-switched call in ISDN is exemplified in Fig. 17. The procedure starts when the calling user requests a call to be established. For that purpose the following sequence of messages is transmitted:

- SET UP

This is the initial message sent by the calling terminal or by the network to require the establishment of the call.

- CALL PROCeeding

This message is sent to the calling terminal to indicate that the requested call establishment is being done.

- ALERTing

Message sent to the calling terminal to indicate that the network has already informed the called terminal of a pending call, e.g., by ringing.

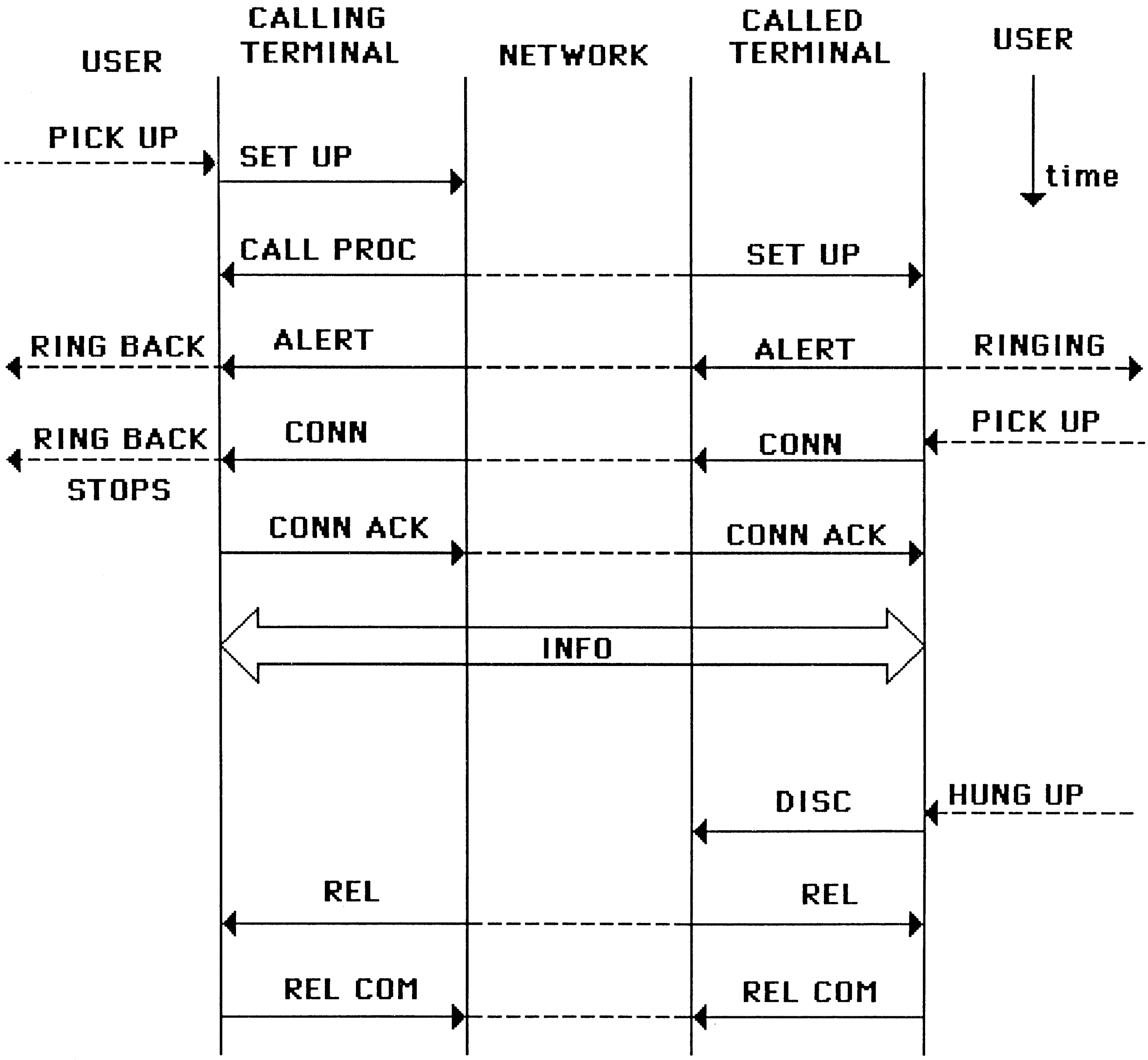


FIG. 17 - Procedure for an ISDN call

- CONNect

Message sent by the called terminal to the network and by the network to the calling terminal to indicate that the call has been accepted.

- CONNect ACKnowledge

Message sent to the called terminal to acknowledge the reception of CONNect.

The call is then established and the information may flow between the users. The termination of the call is required by the user who hungs up, which in turn originates another sequence of messages in the D-channel:

- DISConnect

Message sent by the user to indicate that the call is complete and the release of the channel is required.

- RELease

Message sent by the network to indicate that the channel has been released and that the terminals should also release the channels.

- RELease COMplete

Message sent to the network indicating that the terminals have released the channel, which is now ready to be reused.

The layer 3 message structure is indicated in Fig.18.

Nr.of bytes	1	1		1 or 2	1		variable
	Protocol discriminator	0000	Length of CRV	Call Reference Value	0	Message type	Information elements
	common to all messages						specific of the message

FIG. 18 - The layer 3 message structure

The protocol discriminator distinguishes call control messages from other types of messages.

The call reference value identifies the call at the local user network interface.

The message type distinguishes the different types of messages used to establish, maintain and terminate a call, for example, ALERTing, CONNect, SET UP, SUSPend, RELease, etc.

The information elements may carry a variety of information that is specific to a message, for example, information to describe the current status of a call, diagnostic information, the specification of a bearer service to be used, etc.

5.3.2 - Packet-switched connections

A packet-switched call can be made through a B or the D-channel. When a B-channel is utilized, the calling terminal must first establish a circuit-switched connection, by using the normal ISDN signalling procedure, to the packet-switching communication facility. The connection can then be utilized to carry packet data according to the X25 layers 2 and 3 protocols.

If the D-channel is used for the packet-switched call, the calling terminal may access a packet handling function within the ISDN through the establishment of a data link connection in the D-channel, and then use the X25 layer 3 protocol for the packet communication.

6 - INTERWORKING WITH EXISTING DATA INTERFACES

In order to guarantee a smooth transition to ISDN, the CCITT issued recommendations I461 and I462, which indicate how to support the existing data network terminal interfaces on the ISDN, for circuit and packet switching modes, respectively.

6.1 - Support of circuit-switched interfaces: X21

Two distinct scenarios are foreseen: minimum and maximum integration.

6.1.1 - Minimum integration

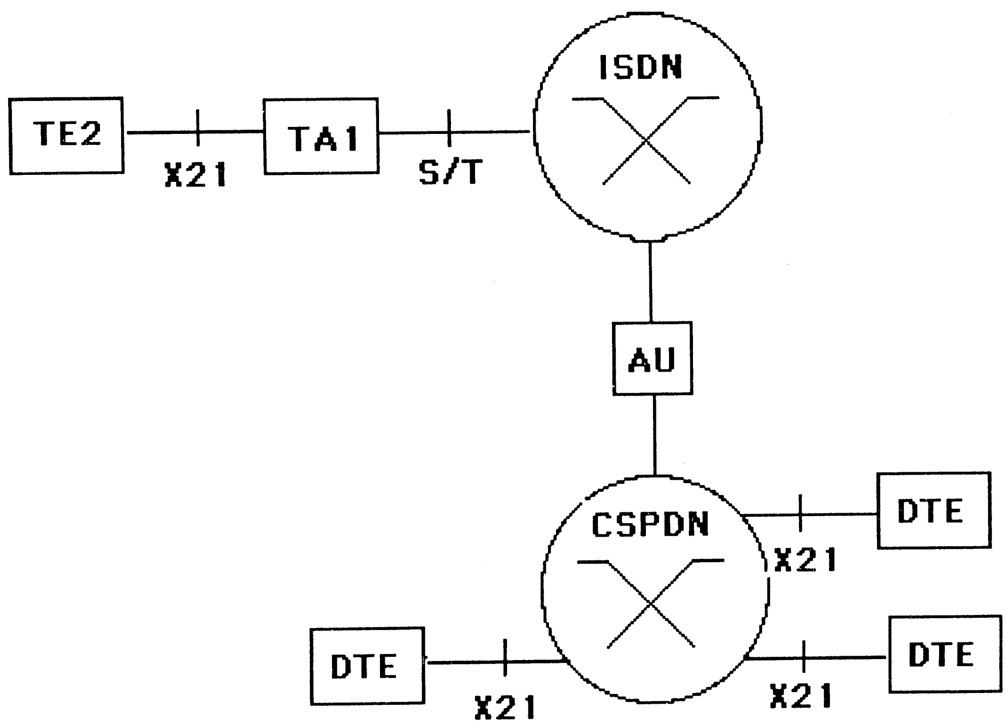


FIG. 19 - Minimum integration to support X21

The mimimum integration scenario is ilustrated in Fig. 19.

TA1 connects TE2 terminals having an X21 interface, to the ISDN. In this case TE2 is physically connected to the ISDN but logically connected to the circuit switching public data network (CSPDN). Terminals use the ISDN connection only to provide a physical 64 kbit/s link between the TA1 and the appropriate CSPDN port. The Access Unit (AU) performs towards the ISDN the same role as the TA1. The TA1 functions are basically bit rate adaption and establishment of a B-channel connection to the AU controlled by the ISDN D-channel procedure.

6.1.2 - Maximum integration

The maximum integration scenario is shown in Fig. 20.

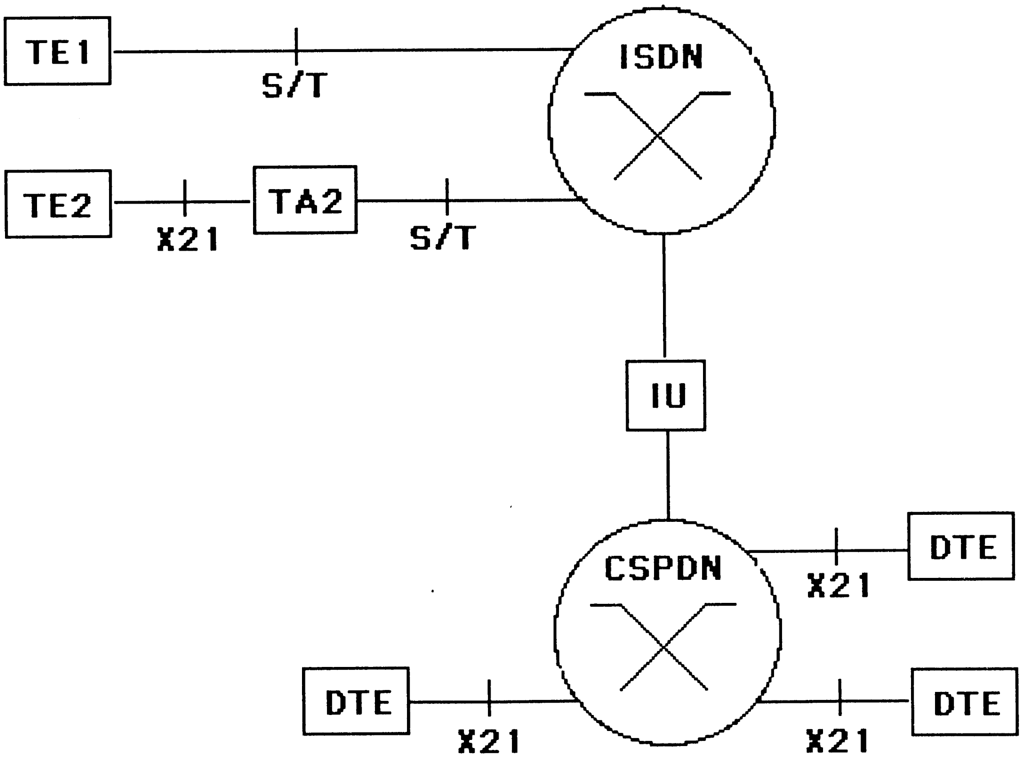


FIG. 20 - Maximum integration to support X21

In this integration scenario TE2 is physically and logically connected to the ISDN. The ISDN should itself offer the same service to TE2 terminals as an X21 CSPDN, as to what concerns the user facilities, quality of service and call progress signals. The TA2 would provide bit rate adaption, ready for data alignment and signalling conversion between X21 and the D-channel layer 3 protocol. An Interface Unit (IU) must exist to interconnect the ISDN to an independent CSPDN.

6.2 - Support of packet-switched interfaces

A minimum and a maximum integration scenarios are also foreseen in this case.

6.2.1 - Minimum integration

The minimum integration scenario is represented in Fig. 21.

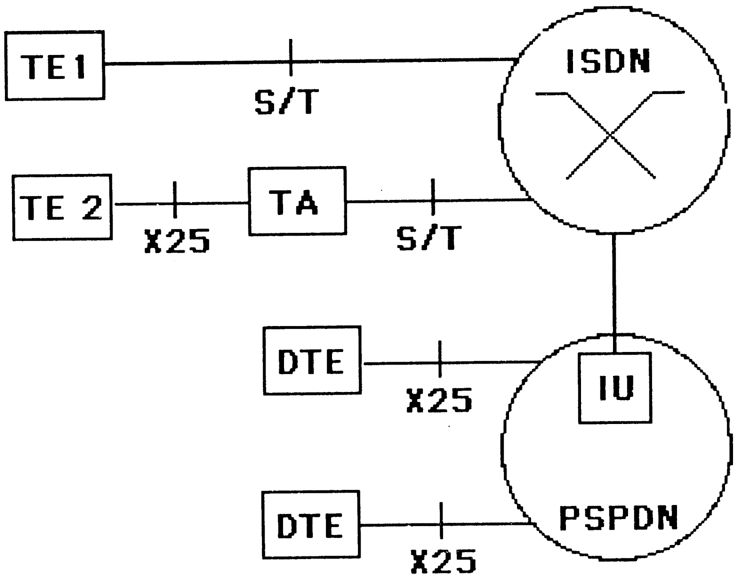


FIG. 21 - Minimum integration to support X25

In this scenario, the ISDN provides a transparent connection via a B-channel, to carry X25 packets between the TE2 terminal and a port in the packet switching public data network (PSPDN). The call establishment and termination is made through the D-channel and follows the procedures already described in 5.3.2. For calls to TE2 from the PSPDN, an Interface Unit Port (IU) in the packet network establishes the link to TE2 before initiating the X25 procedures. The TA performs only bit-rate adaption.

6.2.2 - Maximum integration

This scenario is shown in Fig. 22.

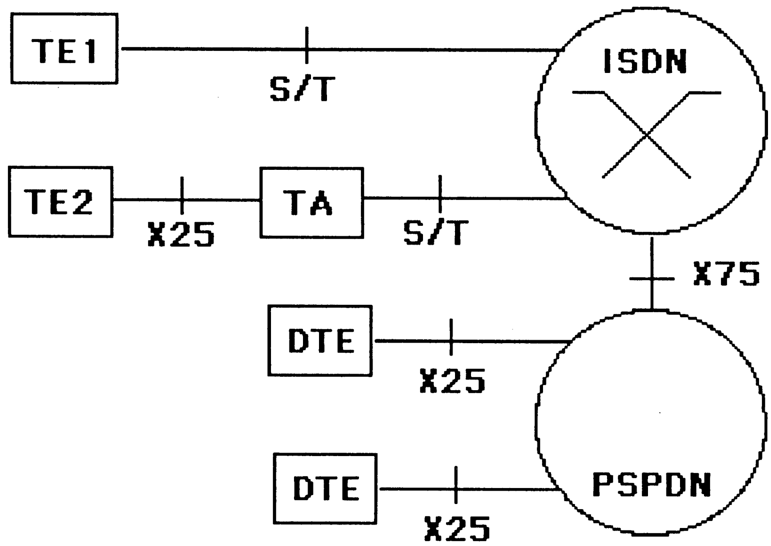


FIG. 22 - Maximum integration to support X25

In this case, the ISDN provides a packet handling function, and the access to this function can be made via a B or the D-channel. If a B-channel is used, the connection is established to a packet handling port in the ISDN, which supports X25 function for layers 2 and 3. If a D-channel access is chosen, then the packets are sent to a packet handling port in the ISDN that supports X25 layer 3 protocol.

The interworking between the ISDN with maximum integration and an independent packet network is made according to recommendation X75.

7 - TECHNOLOGY

The introduction of the ISDN requires the development of a new technology for switching equipment, terminals and user access interfaces.

The upgrade of todays digital switching exchanges towards switching in an ISDN environment, requires the addition of functions able to deal, for example, with syncronization issues, signalling system nº 7, handling of the digital subscriber lines and their D-channel protocols, and new management aspects.

If the digital exchange has a modular design, the upgrade of the exchange can be made by the addition of peripheral modules, which, however, can be quite complex [13] [14]. Additionally, the development of new ISDN-compatible terminals and private switching equipment for the user's premises is central to ensure a wide availability for ISDN.

The perspectives of a large market have fostered the development of specific VLSI chips for ISDN implementations. A word of warning must however be given, as the desired compatibility among all ISDN implementations cannot still be guaranteed at this time. There are at least two reasons for this fact: i) some ISDN tests and the respective chip development, were already being planned when the 1984 ISDN recommendations were approved; ii) the 1984 recommendations need still to be completed for some aspects of the S-interface, and the U-interface needs to be standardized.

Many IC vendors are, however, already supplying VLSI chips implementing the recommended S/T interface and also implementations of the U-interface that have a good chance of being in agreement with the future recommendations of the CCITT. Intel, National, NEC, Mitel, Motorola, Siemens and Signetics, among others, can be referred as examples of vendors which have already announced chips for ISDN products [15].

Most vendors have put their efforts in the basic interface structure, 2B+D, and almost all have implemented the layer 1 of the S-interface in silicon. Some have already implemented parts of LAP-D in silicon, and provided a suitable interface to a microprocessor chip, where the layers 2 and 3 protocols may be implemented in software. Chips to provide access to the subscriber line, i.e., implementing the U-interface, using either TCM or EC techniques, are also available from some vendors.

An example of some possible configurations for ISDN access, by using the chips available from Siemens [16] [17], are shown in Fig. 23.

The first configuration shows the connection of a voice and data terminal to a PABX, through the S-interface. The ISDN interface for the user terminal basically consists of the SICOFI, ICC, SBC and microcomputer chips. The SICOFI is a signal processing codec filter, which makes A/D-D/A conversion and PCM coding/decoding. The ICC is an ISDN Communication Controller, whose main functions are to switch the 64 kbit/s B-channels and to handle the LAPD protocol in the D-channel. The SBC, S-Bus Interface Circuit, implements the 4-wire S interface at layer 1. ICC and SBC functions have also been integrated in a single chip, ISAC-S (ISDN Subscriber Access Controller), which can be used instead of the two separate chips. The layer 3 protocol procedures are programmed in the microcomputer.

The PABX line interface has a structure symetrical to the terminal interface for the S-bus. The PBC, Peripheral Board Controller, has the function of switching between subscriber lines, and PCM transmission lines.

The second configuration represents the connection of a terminal to the public network. The terminal interface is the same described before, but, here the S-bus multipoint capability is shown explicitly . The network termination is based on an SBC chip and an IEC. The IEC, ISDN Echo Cancellation Circuit, enables full duplex transmission on the subscriber line by using an

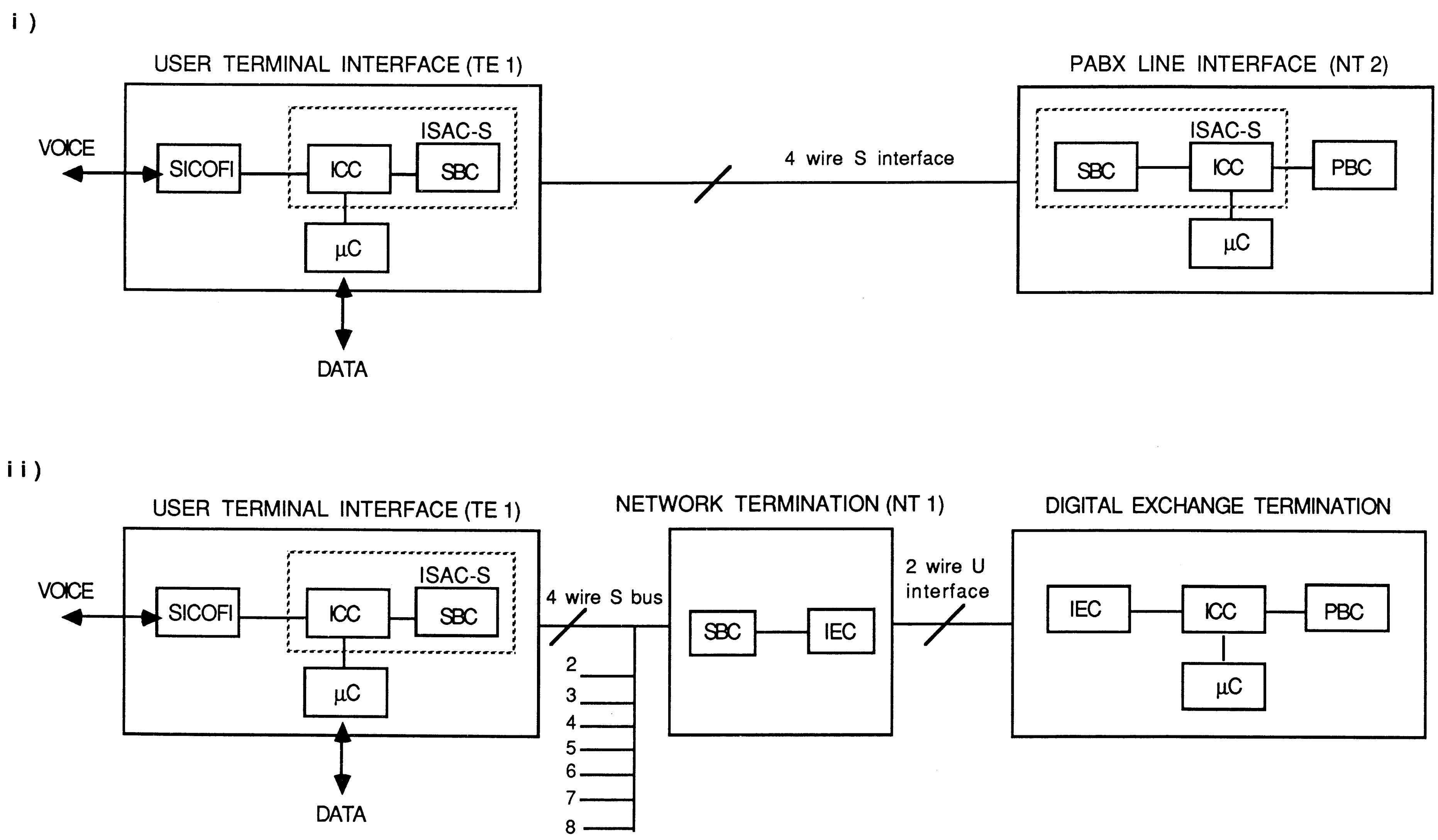


FIG. 23 - Examples of ISDN configurations : i) TE 1 access to a PABX, ii) TE 1 access to the public network

echo cancellation technique. The digital exchange termination has an IEC for interfacing with the subscriber line, and an ICC, PBC and microcomputer with the same functions already described for the PABX.

8. FIELD TRIALS AND NETWORK EVOLUTION

ISDN field trials are being done by the major Telecommunication Administrations, and digital switching equipment suppliers. The main objectives are to gain experience on the technological and operational aspects of providing a public ISDN, and to stimulate the interest of customers and terminal suppliers in the ISDN concept.

In the United Kingdom, British Telecom launched a pilot network service in 1985 [18] [19]. The network was initially based on 4 System X local exchanges, serving about 1000 subscriber lines in the London, Manchester and Birmingham areas. The service is known as IDA (Integrated Digital Access), and basic and primary ISDN interfaces have been implemented, however, they are not identical to the standard ones, as they have been planned in advance of the CCITT recommendations. The basic interface has two data channels, one at 64 Kbit/s and the other at 8 Kbit/s, plus a signalling channel using the BT digital access signalling system number 1 (DASS 1). The primary interface consists of thirty 64 Kbit/s data channels plus a 64 Kbit/s signalling channel using the BT digital access signaling system number 2 (DASS 2). The Network Termination equipment provides two ports, at 64 Kbit/s and 8 Kbit/s respectively, with X21 interfaces to the subscribers. The use of TCM or EC depends on the subscriber loop characteristics and both have been used. Extension of this pilot network for 2400 subscriber lines is planned for 1987. A migration towards the ISDN standards is also planned.

In West Germany, Deutsche Bundespost scheduled a pilot network to begin operation in 1987 [20] [21]. About 400 ISDN basic accesses will be provided in the Mannheim and Stuttgart areas. The pilot network will be installed in five phases : i) initial tests of the ISDN performance in the connection betwen local exchanges and some types of equipment; ii) installation of most of the network components, such as NT's and TA's; iii) connection of PABX's and non-voice terminal equipment; iv) installation of a number of ISDN telephones; v) test of the SS 7 between local exchanges and trunk exchanges. The ISDN standards recommended by the CCITT are taken into account and an EC technique is used for transmission in the subscriber loop.

In France, the DGT launched the RENAN project in 1983, to implement a pilot ISDN network, under the supervision of CNET [22]. The network will be implemented in 1987 and 1988. The first area to be covered is a department in the West of France, where around 300 users will be connected, and later a second area in the surroundings of Paris will have about 1000 subscribers. The network will be compatible with the CCITT recommendations, it will be built upon equipment developed by the french telecommunication industry and it is based on an evolution of the digital exchanges already existing in the network. Both TCM and EC techniques will be experimented in the subscriber loop.

In Italy, SIP plans to introduce a pilot network in 1988 with an initial capacity of 2 000 customers in a limited number of major cities [23]. The network will be based on some new exchanges with ISDN capability, and initially only a basic access will be offered, both for circuit-switched and packet-switched services. About one year later, the primary interface will also be available to users. All the interfaces will be offered according to the CCITT recommendations.

Examples of ISDN field trials in development or already planned can also be found in a number of other Telecommunication Operating Companies, such as on the Bell Operating Companies in the U.S.A. [24], Bell Canada [25], Nippon Telegraph and Telephone Corporation [26], and many others.

The plans for the future evolution of the pilot networks into an ISDN public service during the nineties have already been established by many Telecommunication Administrations. Some detailed objectives for the ISDN introduction in the European Community were announced by the EEC in 1986. These objectives are concerned with the bearer services, teleservices, supplementary services and adaptors that should be provided in the network until 1993. The level of ISDN penetration foreseen in the EEC is for 5% of the 1983 subscriber lines, to have access to ISDN services in 1993 [27].

The next step in the development of the telecommunication networks, will be the implementation of Integrated Broadband Communications (IBC). An IBC network, also called Broadband ISDN, would integrate broadband services such as, television and hi-fi sound broadcasting, video communication, videoconferencing and high bit rate data transmission, together with the services offered in the ISDN [28]. This will require high bit-rate transmission and switching systems, probably at speeds of up to 140 Mbps or even higher, and also the introduction of optical fibers on the transmission medium, to substitute the old copper wire used in most of the world network, which cannot cope with these high bit rates.

The evolution of the ISDN towards a Broadband ISDN is presently the aim of a large European research project, the RACE project, supported by the EEC, and associating Telecommunication Administrations, Industries and Universities [29]. RACE pursues the aim of introducing Broadband ISDN in Europe, by 1995. Research projects towards the development of Broadband networks exist also independently in some European countries, the United States and Japan.

9 . CONCLUSIONS

The introduction of the ISDN will definitely represent an important evolution in the telecommunication network. The users will have access to a large number of services, through a standard interface and hopefully, at reasonable tariffs. For the High Energy Physics community, the possibility of being able to use a public network, that can carry data at high bit rates is specially attractive, due to the huge ammount of information, in various forms, that needs to be transferred among the several Research Institutes and Universities involved in the experiments during the next decade. The Telecommunication Administrations will also have significant advantages, that will be reflected in the long term by better operational, development and maintenance facilities.

The ISDN architecture is already established and its main aspects have been standardized by the CCITT, however, there is still some work to be done at the CCITT to complete the ISDN specifications, namely at the level of end-to-end signalling, U-interface protocols, layer 3 protocol for the t-entity, supplementary services and maintenance procedures.

There is already technology available for the ISDN implementation. A few VLSI chips implementing ISDN functions are offered by a number of semiconductor vendors, others will appear in the market following a further standardization of the ISDN. The development of these chips in a large scale, is crucial for the ISDN to be economically attractive.

The interconnection of the ISDN to other types of public networks, that will, very probably, continue to exist as independent networks, at least in the near future, has to be considered. In particular, specifications for data terminal adaptations to ISDN, have already been specified by the CCITT for the V.24, X21 and X25 interfaces. The interworking of ISDN PABX's with different types of user LAN's is a subject that, due to its importance, requires the development of further work.

The implementation of a public ISDN service is being considered by many Administrations. Field trials of pilot networks are being done in a few countries and an ISDN general availability, will be a reality in many countries during the nineties. The evolution towards a Broadband ISDN is already foreseen, although the technology for its implementation is not yet stable. A strong research effort on Broadband technologies is being done by European countries, United States and Japan, in order to have pilot Broadband networks available during the second half of the nineties.

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