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PROTOCOL PARAMETERS AND THEIR INTERRELATIONS IN X.25; INWG 96.1 SAMPLE NETWORK ARCHITECTURE

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ABSTRACT

The purpose of this paper is to have a close look at the class of problems that arise in the interconnection of different computer systems through a packet switching network.

The layered protocol's architecture is assumed to separate functionally and to identify the tasks to be performed in the various parts of the network, either in the packet switching subnetwork, or in the end processors. Concepts are then introduced to identify the characteristic parameters of each protocol layer. A further step is carried out by considering a sample architecture built on well-known protocols at different levels, up to the transport level, and developing an analysis of their interaction in order to identify interdependencies and constraint relations on the values of the characteristic parameters.

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1. INTRODUCTION

As computer networks continue to have an increasing impact on communications and resource sharing, the need is growing for a universally acceptable method of describing the means by which computer systems of different size and manufacture, and displaying different features, connected by a single network, can "speak" to each other in order to encourage cooperation and to provide all, or at least some, of the network users with their services.

The trend of establishing public data networks raises international standards of computer communication and of "open networking". Once a satisfactory set of standards has been agreed upon, any digital device, using the minimum amount of hardware/software resources required to comply with the standard rules of the "colloquy", can call any other and interact with it.

The discussion on "Open Systems Interconnection" has already led international standardization bodies to issue a draft proposal for the formulation of a vocabulary (International Organization for Standardization 1978a [referred to after this as ISO]) and, what is more relevant to the purpose of this paper, a "Reference Model" (ISO 1978b), to be taken into account for the implementation of Open Systems. The architecture of the Reference Model consists of layered functions based upon certain major layering concepts, some of which are as follows (Figure 1):

1. "The operation of a layer, i.e., the cooperation between entities in the layer, is governed by a set of protocols specific to that layer".

2. "The facilities of one layer are provided to the next higher layer, using the functions performed within that layer and the facilities available from the next lower layer";

3. "An interface is the means of access by which a pair of entities in adjacent layers use or provide services".

For the purpose of computer communication, a set of standards has been established over the last few years, applying to the lower levels. For example, the International Telegraph and Telephone Consultative Committee (referred to after this as CCITT) Recommendation, X.25 (CCITT 1977), covers the lowest, physical, level of protocols, a bit-oriented protocol at the second link level (HDLC) and a packet exchange protocol at the third level, intended to guarantee the reliable and sequential transfer of "packets", i.e., data-units of maximum agreed length, across the physical interface between the computer - or DTE: Data Terminal Equipment - and the access point of a public data network - or DCE: Data Circuit-Terminating Equipment - (Figure 2). However, the requirements of the reliable transfer of larger data-units through the network from one DTE to another, the recovery from network failures, and the selection from among different communication "modes" of those which fit in with a variety of user traffic patterns, should all be accomplished by a fourth layer of end-to-end protocols. This layer is called the "Transport Layer" in the Reference Model.

The long debate which has preceded, accompanied and followed X.25 is already well-known (Pouzin 1976). The most controversial point has been the matter that X.25 networks provide their users with a virtual-circuit (VC) service, at the expense of a more complex implementation of the network interface in the DTE, as well as the decrease in the efficiency of the communication subnetwork (Butrimenko and Sichra 1979). The need for the complementary standardization of a simpler interface, called "Datagram" (DG), has been expressed by many areas, and it is now being studied by various standardization bodies.

At present, no standard end-to-end protocol exists. Out of the various proposals, the document of the International Networking Group (referred to after this as INWG) 96.1 (Cerf et al. 1978) - even although a draft proposal - is of special interest, for the following reasons:

a) It is intended to be independent of the data transmission service characteristics, i.e., it can be implemented on top of either a Datagram service, or a Virtual Circuit (switched or permanent) service, or a Real Circuit (HDLC) service;

b) Experience of its implementation does already exist: a subset of it - only in the "liaison mode" - is the end-to-end protocol of the CYCLADES network (Garcia et al. 1975), and a version very close to it has already been implemented on top of a Datagram service, and used as a basis for higher level protocols - up to the Application Layer - in an international experimental network, the European Informatics Network (Deparis et al. 1976).

In the rest of this paper, the following "Sample Architecture" (a partial one, i.e., up to the Transport Layer) will be taken into consideration:

Hyp. 1. A packet switching network provides its users (DTEs) with an X.25 interface to the Data Transmission Service;

Hyp. 2. The INWG 96.1 is implemented on the DTEs to perform the Transport Layer functions.

It is the opinion of the authors that the interconnection of the protocols belonging to different layers can have quite a strong influence on the actual implementation of each of them: it is felt that the values of some characteristic parameters of each protocol should be tuned - and, perhaps, dynamically updated - taking into account the available information on what is outside-the-border of the protocol layer. Quoting from the Reference Model, as an example, it is found that:

> "The Transport Layer is required to optimise the use of the available communications resources to provide the performance required by each communicating transport user at the minimum cost. This optimisation will be achieved within the constraints imposed by considering the global demands of all concurrent transport users and the overall limited resources available to the Transport Layer".

The starting point is that, in the establishing of relations between parameters, one must distinguish the design phase from the operational phase.

In the design phase

a) some parameter values can be assumed by means of a forecast (generally speaking, this means all the parameters that are strongly dependent upon what is outside-the-border of the Architecture, or of the part of it that is going to be designed);

b) some others can be assumed as objectives (for example, some parameters that express the level of service provided to the users of the Architecture);

c) some others have to be referred to as constraint values and, finally,

d) other parameter values can be estimated - making use of theory and experience - in order to achieve those objectives (b), within those constraints (c), and under those hypotheses (a).

In the operation phase, measurements can reveal that hypotheses (a) need to be modified, and that objectives (b) can be improved, or must be reduced, within the constraints (c), by a different setting of (d) parameters.

In short,

in the design phase: $d = d(a,b,c)$

in the operational phase: $b = b(a,c,d)$

where both a and b parameters can be measured in the operational phase, whilst they are assumed to be "a priori" in the design phase.

Section 2 deals with some conceptual items that can be used generally to identify the characteristic parameters of a protocol. In the remaining sections, these items are used to carry out an analysis of the Sample Architecture, and to show evidence of some constraint relations and interdependencies on the values of the characteristic parameters.

2. CHARACTERISTIC PARAMETERS OF A PROTOCOL

A variety of methods - generally speaking - can be used to describe a protocol: from the least formal, such as word description, to the most formal methods, such as automata, grammars, etc., a wide spectrum of linguistic tools can be drawn upon. The importance of the word description is, however, fundamental, as the purpose of a protocol description is that can be correctly implemented. For this reason, a correct and an as simple as possible understanding is required by the implementors.

The word description can be accompanied - but not substituted - by a more formal description, in order to avoid the misunderstandings that the ambiguity of natural language may generate.

In every protocol description - be it a more or a less formal one - a set of variables can be found, the values of which do not determine the nature of the description itself (it is usually sufficient to mention their existence), but which can play a fundamental role in every implementation of the protocol. A few explanatory points can lead to more precise conceptual definitions:

1. A formalisation of a protocol carried out by means of automata theory requires a number of "states" to be assigned to the Finite State Machine (FSM) representing the couple of interlocutors that follow the rules of the protocol. In order to avoid deadlocks (and, in practice, wastage of resources), most of the states of the FSM must be transient, i.e., they have to be protected by a time-out, "T". A time-out expiry may generate a state transition: however, it usually happens after a number of retries, "N", of the same action; for each trial, T is started again, usually with the same value (but this is not mandatory; it is just common practice).

   In the literature available, there are different ways of taking into account the T expiry and/or the reaching of N: for example, Le Moli (1973) refers to these as "internal events", whilst Danthine and Bremer (1978) treat them as equivalent to existing or newly introduced inputs.

   However, a fully formal description of the protocol must indicate what actually constitutes the "transient" feature of its transient states. In the following, this parameter set will be referred to as "T-parameters".

2. In a layered architecture of protocols, each layer can be considered as the "communication device" of the next higher layer (Le Moli 1973). As such, it is characterised by a set of specification parameters that refer to the quality of service that it can provide to the next higher layer, with some environmental constraints.

   Throughput, response time, introduced delay, level of reliability, security, level of availability, are all concepts which require an unambiguous definition, i.e., the definition of a set of associated characteristic parameters, in the protocol specification, at least in the non-formal one.

   Moreover, closely related to these concepts, the implementation of a "function" (for example, the techniques adopted for error control and recovery, fragmentation and reassembly, multiplexing, sequencing, and so on) introduces a new kind of parameter set that refers to the price - relevant to the protocol - to be paid to perform that function in terms of overheads for address and control information, either in the header-portion of message-carrying data, or in "special" messages carrying no data, and invisible to the next higher level.

In other words, the service offered by a layer to the next higher one, and the performing of the functions needed to offer that service, can be analysed in terms of cost/benefit ratio: as such, two distinct, but related, sets of parameters can characterise the performance of the layer, each set referring to each term of the ratio. In the following, these parameter sets will be referred to as "C-parameters" and "B-parameters", respectively. It is also worthwhile stressing that, hitherto, only those parameters have been considered that refer to the protocol definition and operation, and not those that refer merely to a local interface among layers.

3. Finally, each layer implementation requires a set of parameters to be stated and - statically or dynamically - assigned a value, in order to make the best use of the resources and services offered by the next lower layer. It will be said that these parameters have dynamically assignable values if information about remote events is needed in order to pursue this optimization task, and if this information is available from the interface to the next lower layer. If this information is <u>either</u> not needed - for example parameters related to the network maximum configuration, which is usually fixed, at least in the short/medium run - <u>or</u> if this information is not available, and is therefore surrogated by average estimations - for example parameters related to the present network configuration, deduced from the routing tables, which are seldom available to the DTE processes -, these parameters will be said to have statically assignable values.

   Once again, it should be underlined that, even although these parameters refer to the local interface to the next lower layer, they will be taken into account if, and only if, their meaning is relevant to the protocol definition and operation. As the meaning of these parameters must always be related to the state of the "network", i.e., of what - globally - is under the layer, they will be referred to as "N-parameters".

In conclusion, the concepts hitherto developed can be grouped according to the following rationale:

The correct definition and the effective operation of a protocol in the layer L requires some protocol characteristic parameters to be stated, and suitable values to be - statically or dynamically - assigned to them. Our classification of the protocol characteristic parameters identifies the following sets:

a) T-parameters, defined to protect the transient states of the protocol;

b) B-parameters, defined to provide the layer L+1 with a specified quality of service;

c) C-parameters, defined to evaluate the cost, in terms of overhead, of implementing those functions of the protocol necessary to provide the layer L+1 with the L-layer's services;

d) N-parameters, defined to make the best use of the network resources in the operation of the functions considered above.

From the definitions of these classes of parameters, it follows that they have empty intersection.

A variable declared in the implementation will here be considered as a protocol characteristic parameter if, and only if, it is semantically both relevant to the protocol definition and operation, and assimilable into one of the four classes defined above.

3. CHARACTERISTIC PARAMETERS DEFINED FOR THE RECOMMENDATION X.25

Recommendation X.25 deals with the three lowest levels of the interface between DTE and DCE, for terminals operating in the packet mode.

3.1 The Physical Layer

The first level covers the physical, electrical, functional and procedural characteristics for the operation of the link between DTE and DCE: it is described in the preceding Recommendation, X.21. For the purpose of this paper, only B-parameters of the first layer are relevant, i.e., the capacity, C_1, of the physical link in bps, and its nominal error rate, E_1.

3.2 The Link Layer

The second level covers the link access procedure for the exchange of frames across the DTE/DCE interface. It is important to note that a list of "system parameters" is given in the last paragraph of this Section of the Recommendation: it is recalled here, specifying then the class of the "characteristic parameters" to which they belong.

T1 is the time-out started on the transmission of a frame, at the end of which the retransmission of the frame may be initiated.

T2 is the maximum time from the reception of a frame and the sending back of the acknowledgement: it applies to both the DTE and the DCE;

N2 is the maximum number of transmissions of a frame;

N1 is the maximum number of bits in an Information frame;

K is the maximum number of outstanding (i.e., unacknowledged) Information frames.

The values of T1 and K should be "agreed for a period of time with the Administration". The value of N2 is "a subject for further study". The value of N1 "depends upon the maximum length of the information fields transferred across the DTE/DCE interface": this maximum length will be mentioned in the following as N3.

From the definitions given in Section 2, it follows that:

a) T1 and N2 are T-parameters;

b) T2 and K are N-parameters, as they have to be tuned in order to make full use of the available bandwidth of the physical link;

c) N3 is a B-parameter, as it specifies a service offered to the third level, whilst N1 is just the sum of N3 and the maximum value of the overhead introduced by the non-information fields and by the extra-zeros of the error control algorithm. The maximum, minimum and average value of this overhead can be defined as C-parameters: they will be called H_M, H_m and H_a, respectively.

But, at this point, the services offered by level 2 need to be better defined. The following B-parameters are defined as follows:

d) E_L is the error rate as given to the third level: as the third level sends and receives "packets", i.e., the contents of the information field of the I-frames, E_L is defined here as the joint probability that

   1. a packet being in error or out of sequence is delivered to the third level, or

   2. an in-sequence error-free packet is not delivered to the third level; an average packet length, $\bar{L}_p$, is referred to, of which the maximum value is N3[1];

e) Cp is the throughput maximum as given to the third level: it is defined in terms of packets per second, referred to the average packet length, $\bar{L}_p$[1];

f) A_L specifies the availability of the link to the third level: it is defined as the complement to one of the probability that a command issued by the third level will be refused because the link is disconnected;

g) D_L specifies the average delay for the delivery of the packet embedded in the information field of an I-frame: it is defined as the average time which has elapsed from the delivery of the last bit to the second layer of the sender DTE (DCE), to the delivery of the first bit to the third layer of the receiver DCE (DTE)(which implies that the whole frame has been delivered to the second layer of the receiver side and processed by it), and it is referred to the average packet length, $\bar{L}_p$[1].

Table 1 summarizes the classification of the parameters defined in this Section for the physical and link layers of X.25.

3.3 The Network Layer

The third level covers the procedures for the transfer of packets at the DTE/DCE interface. It allows the communication between remote DTEs in a virtual "connection mode" (Le Moli 1978), and the multiplexing of the same physical link in several logical channels.

Unfortunately, no "list of system parameters" is detailed in this Section of the Recommendation. It is left "for further study. This study should include considerations of both time-outs and number of retries.

But, opportunely, the Annexes to the Recommendation give the state diagrams for a logical channel and tables specifying the action taken by the DCE on receipt of packets (from the DTE) in each of the given states; the corresponding tables for the DTE are not specified in the Recommendation (they are left for further study). The state diagrams can be used to identify the transient states for a logical channel and to define the associated T-parameters. For each phase of the operation of the logical channel (described by the corresponding state diagram), the T-parameters are defined here. Additional hypotheses will be introduced for details missing from the Recommendation.

3.3.1 *Procedures for Virtual Calls*

Two phases are regulated by these procedures: the call set-up phase and the call clearing phase. Each of these is described by a state diagram (Figure 3, which reproduces Figure 15/X.25 of the Annex I to Recommendation X.25). These procedures apply to permanent virtual circuits.

3.3.1.1 *Call Set-up Phase (Figure 3a)*

A time-out, TTp2,must protect the "DTE Waiting" state, p2: it is managed by the DTE. Similarly, a time-out, TCp3, must protect the "DTE Waiting" state, p3: it is managed by the DCE. No retrial should be attempted to retransmit a "call request" packet, as it could result in "ERROR" action on the DCE[2]. For symmetry, it is assumed here that no retrial is attempted by the DCE to retransmit an "incoming call" packet.

This is the minimum of protection required. Additionally, but out of the interface, two other timers can be defined, namely: TCp2, that is, a network time-out for the acknowledgement of call request packets between DCEs, and TTp3, that is, the DTE time-out for the answer to the incoming call from the destination (fourth level) process. Depending on the implementation, either of the subnetwork or of the DTE, each of these two parameters may or may not exist.

3.3.1.2 *Call Clearing Phase (Figure 3b)*

A time-out, TTp6, must protect the "DTE Clear request" state, p6: it is managed by the DTE. As retransmission of "Clear request" packets is allowed by the state diagram, a maximum number of retrials, NTp6, can be defined. Similarly, a time-out, TCp7[3], must protect the "DTE Clear indication" state, p7: it is managed by the DCE. Again, as retransmission of Clear indication packets is allowed by the state diagram, a maximum number of retrials, NCp7, can be defined.

This is the minimum protection required. Also in the call clearing phase, additional timers can be implemented out of the interface, to allow a faster protection mechanism: TCp6, for example, can be defined as the network time-out for the acknowledgement of a clear indication packet between DCEs, and TTp7 as the DTE time-out for the answer to the clear indication from the destination process. Both these two parameters depend on the implementation (the first one, of the subnetwork, the second one, of the DTE).

3.3.2 *Procedures for Data and Interrupt Transfer*

In the Data transfer state of the interface, for a logical channel assigned either to a virtual call or to a permanent virtual circuit, the procedures for flow control and reset are intended to guarantee the sequential transfer of the information between the two DTEs and to aid recovery from possible situations of subnetwork congestion.

The procedure for flow control does not apply to interrupt packets. No state diagram describes the exchange of interrupt packets. Furthermore, the significance of the Interrupt confirmation packets (i.e., local or end-to-end) is not specified in the Recommendation. It is assumed here that these packets have end-to-end significance; this hypothesis leads to the following possible sequence of events, illustrated by a state diagram (Figure 4):

1. The source DTE sends the DTE Interrupt packet: the local interface enters the "DTE Interrupt" state i2;
2. The local DCE sends the received interrupt to the remote DCE, waiting for acknowledgement;
3. The remote DCE receives the Interrupt and sends the DCE Interrupt packet to the destination DTE: the remote interface enters the "DCE Interrupt" state i3;
4. The destination DTE sends a DTE Interrupt Confirmation packet: the remote interface comes back to the "Interrupt ready" state i1;
5. The remote DCE sends the received confirmation to the local DCE, thereby acknowledging the Interrupt;
6. Having received the acknowledgement, the local DCE sends the DCE Interrupt confirmation packet to the source DTE: the local interface comes back to the "Interrupt ready" state i1.

As it is explicitly said in the Recommendation that "the DCE will ignore further DTE Interrupt packets until the first one is confirmed with a DCE Interrupt confirmation packet", retransmission of the DTE Interrupt is not possible: the only thing the DTE can do, after the first trial, is to reset the logical channel. For symmetry, the same rule is supposed to be followed here by the DCE.

Straightforwardly, the DTE has the responsibility for protecting state i2 with TTi2 time-out, and the DCE has the responsibility for protecting state i3 with TCi3 time-out. Following the same reasoning shown above for the set-up and clearing phases, additional timers - out of the interface domain - might be defined: for example, a network time-out, TCi2, managed by the local DCE (set on step 2 of the sequence above and cleared on step 6), and a DTE time-out, TTi3, managed by the destination DTE, for the answer to the interrupt from the destination fourth level process.

3.3.3 *Procedures for Flow Control*

Flow control is based on authorisation from the receiver: a window, W, which, for each direction of data transmission, is a parameter "agreed for a period of time with the Administration for the DTE", sets the range of unacknowledged packets that can cross the interface: W_{tc} will be the window for data transmission from DTE to DCE; W_{ct} will be the same from DCE to DTE. The lower window edge, P(R), is updated by the receiver; it is supposed here that the acknowledgement carried by P(R) has no end-to-end significance[4] : this task is left to the upper layer

The sender can be requested to suspend the transmission by means of a RNR (Receive Not Ready) packet; it can be resumed by means of either a RR (Receive Ready) packet, or the reset procedure.

It is supposed here that no time-out is associated with flow control, except in the reset phase, as a suspension in the flow of the information between the two DTEs can be managed by the upper layer, by means of interrupts.

3.3.3.1 *Procedures for Reset (Figure 5)*

A state diagram (Figure 5, that reproduces Figure 16/X.25 of the Annex I to the Recommendation) describes the reset procedure. By the same notation hitherto followed, a time-out, TTd2 - managed by the DTE - protects state d2, and a time-out, TCd3[5] - managed by the DCE - protects state d3. Retries are possible: NTd2 and NCd3 indicate, respectively, the corresponding maximum number of transmissions.

Out of the interface, time-out, TCd2 - with a maximum number of trials, NCd2 - might be defined for the acknowledgement of the reset between the two DCEs. However, it is supposed here that Reset confirmation does not have any end-to-end significance, and that the reset is transparent in the upper layer: this implies that no "TTd3" time-out is defined.

3.3.4 *Procedure for Restart (Figure 6)*

A state diagram (Figure 6, that reproduces Figure 17/X.25 of the Annex I to the Recommendation) describes the restart procedure. TTr1 is then the time-out - managed by the DTE - that protects state r1, and TCr2[6] is the one - managed by the DCE - that protects state r2.

Both for Restart request packets and for Reset indication packets, retransmissions are possible: let NTr1 and NCr2 indicate respectively the corresponding maximum number of trials.

Out of the interface, time-out, TCr1 - with a maximum number of trials, NCr1 - might be defined for the acknowledgement of the restart between DCEs. However, it is supposed here that the Restart confirmation does not have any end-to-end significance. The restart is not - generally - transparent to the upper layer, as all the virtual calls are reinitialized: therefore, a time-out, TTr2, might be defined in the DTE for the answer of the fourth level to the indication of a restart that comes from the third level.

3.3.5 *Other Parameters of the Network*

The overhead introduced by the network layer must be related to the "phase" of the connection, as some phases may or may not exist, depending on the switched or permanent nature of the connection.

Overhead, H_d, refers here to the number of bits per packet generated at the third level, not belonging to the "user data" field, and transferred on the connection. The other overheads are just expressed by the total number of bits exchanged in the relevant phase. It is defined as follows:

H_s: the overhead in the call set-up phase;

H_c: the overhead in the call clearing phase;

H_d: the overhead in the data transfer phase;

H_r: the overhead in the reset phase;

H_o: the overhead in the restart phase.

All these are C-parameters.

The window sizes, W_{tc} and W_{ct}, have to be considered as N-parameters.

Also the local maximum data field length L_p[7] has to be considered as a N-parameter, as the usage of the "More data mark" allows the transport layer to send "messages" of any length.

Some B-parameters are now defined here in order to characterize the services offered to the transport layer (for an interesting discussion of the terms "delay" and "throughput" for user implementation of X.25, see Sproule 1978).

Parameters defined in points a), c) and e) below, refer to a given average message length $\bar{L}_M$[8]; parameters defined in points c), e), f) and g) below, are formulated under the hypothesis that no other virtual connection (i.e., virtual call or permanent virtual circuit) is active (i.e., in the data transfer phase, and with the fourth-level using it) at the same time on both DTEs.

a) E_p is the error rate as given to the fourth level: it is defined as the joint probability that

1. a message, being in error or out of sequence, is delivered to the fourth level, or

2. an in-sequence error-free message is not delivered to the fourth level;

b) N_v is the maximum number of virtual connections that can be active at the same time on the DTE;

c) C_p is the maximum throughput on a virtual connection: it is defined in terms of messages (not "interrupt") per second;

d) A_p is the availability of the "virtual connection service" to the transport layer: it is defined as the complement to 1 of the probability that a requested connection is not established for reasons not dependent upon the transport layer (on both sides);

e) D_{pm} specifies the average delay for the delivery of a message (not "interrupt") in the data transfer phase: it is defined as the average time which has elapsed from the delivery of the last bit of the message to the third level of the sender DTE, to the delivery of the first bit of the message to the fourth level of the receiver DTE;

f) D_{pi} has the same definition as D_{pm}, except for the interrupt;

g) D_{pE} specifies the average delay for the connection establishment (it is zero for permanent virtual circuits by definition): it is defined as the average time which has elapsed from the point at which the fourth level issues the command to the third level for the "call establish", to the point at which the third level issues the command to the fourth level for the "call established".

3.3.6 *Summary of the Parameters of the Network Layer*

Table 2 summarizes the characteristic parameters hitherto defined for the network layer. Their classification, following the concepts expressed in Section 2, is also given. It is the opinion of the authors that this set is far from being complete. One reason is "structural": in that the X.25 level 3 specifies only the interface between DTE and DCE for packet transfer, that is a part of the whole network layer: but the network layer is spread all over the network in other functions, such as routing, local flow control, acknowledgement between DCEs, and so on. Strictly speaking, the parameters of the topology of the subnetwork also belong to this layer. This matter will be treated in Section 5. In any case, also the parameter set strictly referring to the third level interface between DTE and DCE could be "improved".

4. CHARACTERISTIC PARAMETERS DEFINED FOR INWG 96.1

Document INWG 96.1 is a draft revision of a proposal (INWG 96) submitted to ISO as an International Federation for Information Processing (referred to after this as IFIP) contribution for a standard end-to-end transport protocol: this earlier proposal was based on a datagram data transmission service, whilst the revised version takes into account the need for adaptation to a variety of data transmission facilities, particularly X.25 in public data networks.

No formalization of this transport protocol is given in the document[9].

The elements constituting the transport service are defined independently of the transport protocol mechanisms used to provide them: this is very useful for finding out what is called here the class of B-parameters, and also some C-parameters.

Moreover, the document specifies the combinations of those functions that lead to different classes of overall service: three classes of transport service are defined, namely: "lettergram", "regular liaison" and "super liaison". Consequently, the transport protocol characteristic parameters will be defined here with explicit reference to the class of the transport service within which they are relevant.

4.1 Parameters of the Transport Service

The transport service provides a set of addresses, called "ports", to allow communication between its users (i.e., the fifth level processes).

With reference to the addressing element of the transport service, the following parameters can be defined:

a) N_{TA} is the number of port addresses allowed by the port address space: it is a B-parameter;

b) H_{TA} is the overhead (in number of bits per message), introduced by the need for port addressing space: it is a C-parameter.

Within a port "association" - that constitutes the support for the colloquy between transport users - both independent, unrelated messages, called "lettergrams", and sequential, synchronized message exchange, called "liaison", are available. The following B-parameter is now defined:

c) A_{TL} is the availability of the liaison service, defined as the complement to 1 of the probability that a command for establishing a liaison is not accomplished for reasons independent of the transport user processes (of both the ports involved in the liaison association request).

The analogous parameter for the lettergram service has by definition the value 1, as "the lettergram service is always available on an association."

Transport users can exchange two kinds of messages: letters and telegrams. From the document, we find that:

> "a letter is a variable length piece of information with a maximum size."
>
> "a telegram is a fixed length piece of information (a few bits)."

The following definitions of B-parameters are straightforward:

d) L_{TL}: is the maximum length of the transport user's information that can be put into a letter;

e) L_{TT}: is the length of the transport user's information put into a telegram.

The error control reliability of the transport service is specified in the document with three levels of guarantee (minimum, regular and superior): for each of them, the signalled residual bit error rate, E1 and the residual bit error rate, E2, **which is not signal**led, are specified. With another index indicating the level of guarantee (M, R and S, respectively), the following objectives for the orders of magnitude of the residual bit error rates are indicated in the document:

$E1_M \leq 10^{-3}$, $E2_M \leq 10^{-4}$, $E1_R \leq 10^{-6}$, $E2_R \leq 10^{-8}$, $E1_S \leq 10^{-10}$, $E2_S \leq 10^{-12}$.

The corresponding parameters for the message error rate, referring to an average message length, can easily be defined. They will here be called "$E_{T'I'L'}$", where

$I \in \{1,2\}$ indicates "signalled" or "not signalled" residual message error rate, and

$L \in \{M,R,S\}$ indicates the level of guarantee.

The document also defines two levels of guarantee on sequence errors: the first level gives no guarantee (it should be selectable by the transport user only when there is a datagram-like data transmission service); the second level is characterised by a "maximum rate of residual letter sequencing errors", which will be called here, E_{TS1}, and by a "maximum rate of non-detected letter sequencing errors called here, E_{TS2}.

Orders of magnitude for these parameters, indicated in the document are:

$E_{TS1} \leq 10^{-4}$, $E_{TS2} \leq 10^{-8}$

For throughput and transit delays, the following specifications for maximum value objectives are indicated in the document:

1. 90% of the maximum throughput provided by the data transmission service: this percentage parameter is referred to here as C_{TP};
2. Additional delay introduced by the transport stations of less than 200 ms[10]: referred to here as D_{TA}.

Also a maximum transit delay is defined[10], that "is a function of the characteristics of the data transmission service": this parameter will be referred to here as D_{TM}.

These B-parameters will be integrated here with other ones, analogous to those defined for X.25 throughput and delay specifications (see Section 3), but characterized also by both the "mode" of the transport service (i.e., lettergram (G) or liaison (L)) and the "option" chosen in a set of further optional facilities offered by the transport layer, as drawn in the document. These facilities deal with synchronization of the access of the transport users to the queue representing the flow of letters between their pair of ports (Figure 7a, which reproduces Figure 3 of INWG 96.1), namely: the Delivery Confirmation (Figure 7b, which reproduces Figure 4 of INWG 96.1) related to a letter or a telegram, and the Credits for Transmission facility (Figure 7c, which reproduces Figure 5 of INWG 96.1), that "can be provided only within the liaison service and must be in effect during the whole liaison operation". In other words, in the lettergram service it is possible to access the queue without any synchronization facility or with Delivery Confirmation only: for liaison mode, there is a greater variety of choices and - in addition to those of lettergram mode - the queue can also be decreased with Credit for Transmission.

So, in the following part of this Section the indices "S" and "X" have the following meaning:

$S \in \{G,L\}$ stands for lettergram (G) or liaison (L) service;

$X \in \{B,E\}$ for $S = G$, $X \in \{B,C,E,F\}$ for $S = L$, stands for:

$X = B$: without any synchronization facility;

$X = C$: with Credits for Transmission only;

$X = E$: with Delivery Confirmation only;

$X = F$: with both synchronization facilities

The availability of the synchronization facilities increases the overall reliability of the transport service, that can be specified by the following B-parameters' definition:

R_{TSX}: expresses the reliability of the transport service[11]; it is defined as the probability that a command, issued on an already established port association, is successfully executed.

Throughput and delay can be characterized by the B-parameters' definitions given below. Parameters defined in points a), b) and e) are referring to a given average letter length, $\bar{L}_L$ (non-characteristic parameter of the transport layer); furthermore, the parameters defined below are all formulated under the hypothesis that no other port association is active (i.e., established and with transport user using it) at the same time on both the Transport Stations.

a) C_{TSX}: is the maximum throughput[11] achievable within an established association: it is defined in terms of letters per second;

b) D_{TLSX}: specifies the average delay for the delivery of a letter on an already established association: it is defined as the average time which has elapsed from the delivery of the last bit of the letter to the sender's transport layer, to the delivery of the first bit of the letter to the receiver's fifth level user process (that implies that the whole letter has been delivered to the receiver's transport layer and processed by it);

c) D_{TTX}: has the same definition as D_{TLSX}, except for the telegram;

d) D_{TEL}: specifies the average delay for the establishment of an association in liaison mode (it would be zero by definition in lettergram mode): it is defined as the average time which has elapsed from the point at which the transport user issued the command for "liaison establish", to the point at which the transport layer issues the command to the transport user for the "liaison established";

e) D_{TLRSX}: specifies the average round trip delay[11], when Delivery Confirmation is in operation: it is defined as the average time which has elapsed from the point at which the transport user issues the command for "send letter" to the point at which the transport layer issues the command for "delivery of letter confirmed";

f) D_{TTRX}: specifies the average round trip delay for the telegram: it is defined as for the preceding, except for the telegram.

4.2 Parameters of the Transport Functions

The set of functions taken into account in the actual implementation of the transport protocol depends upon both the required transport services and the available data transmission service. Both these aspects, or just one of them, may require the fragmentation of a transport data-unit, i.e., a letter, broken into smaller "fragments" - each of them put into a "transport frame" - and its reassembly at the receiver.

A first standard parameter is therefore defined, L_{TF}, being the basic standard maximum fragment length. The document provides also the option of "multifragment" text that can be put into the same transport frame. For this case, the parameter, N_{TMF}, is defined here: the maximum number of fragments in a transport frame.

"Reassembly at the receiver is protected by a time-out associated with each letter. A timer is set when the first (in time) fragment is received. It is reset on receipt of each fragment, and finally turned off when all the fragments of the letter have been received. If the time-out occurs, reassembly is aborted and the letter is considered erroneous; if error control is in effect, error recovery will take place".

The reassembly time-out is referred to here as T_{RS}.

In lettergram mode, the "error control" option means the acknowledgement of the letter by the receiver with a special message, the LG-ACK, as soon as the whole letter has been received. The introduced overhead for error control, H_{TGE}, is then just the length of the LG-ACK, as "a time-out allows the sender to detect possible loss of the letter (or of the acknowledgement) and to report this to the transport user": this parameter is referred to here as T_{GE}.

In liaison mode, some functions are common to all the options, others depend on them.

The document refers to the liaison established with only the common functions as "Basic"; the one with the Delivery Confirmation as "Error Control"; and the one with Credits for transmission + Delivery Confirmation options as "Flow Control"[12].

Basic liaison functions are:

- Initialization and termination;
- Sequential transfer of letters;
- Transfer of telegrams.

In Figure 8, which reproduces Figure 18 of the document, the initialization/termination state diagram is drawn. Three transient states are defined: local opening (state 1), remote opening (state 2) and closing (state 3). Time-outs, T_{LLO}, T_{LRO} and T_{LC}, respectively, protect each of them.

For the basic sequential transfer of letters - as well as whenever Error control is in operation - space is needed for message identification with a unique reference number. The corresponding overhead, in terms of number of bits per message (both letter and telegram), is called in this paper, H_{TR}.

The B-parameters for sequencing have already been defined (E_{TS1} and E_{TS2}).

For the transfer of telegrams (interrupt function) the possibility of requesting acknowledgement is always allowed. The corresponding overhead is a function of H_{TT}, the length of the LI-TAK message used for telegram acknowledgement. A time-out/retransmission mechanism performs error control on telegrams: T_{TT} and N_{TT} are the time-out and maximum number of transmissions, respectively.

For a liaison operated with Error control:

"The sending TS (Transport Station, NdA) sends letters (...) and expects acknowledgement within a maximum delay after the last fragment of each letter has been sent": This time-out is referred to here as T_{LE}; "the receiving TS acknowledges letters promptly, (within a maximum delay after the last fragment has been received)": this N-parameter[13] is referred to here as D_{LA}. Piggybacking of acknowledgements is allowed. After the time-out expiration, retransmission is performed, with a maximum number of transmissions: N_{LE}. If this threshold is reached without success, "the sending TS will declare an unrecoverable error, inform its user and terminate the liaison".

For a liaison operated in Flow control (that implies Error control), the following applies:

"At initialization of a liaison with Flow Control, each end of the liaison can indicate the maximum size of letters to be received (...); it is given in units of octects". This will be referred to as L_{TLF}. This is a B-parameter, as it can be set by the transport user (within possible constraints of local resourcesharing), upper limited by L_{TL} (see 4.1) but fixed only within a single liaison.

For the **credit** for transmissions option, a window is defined whose length in letters is expressed by the credit number parameter, which is set by the receiver: let this be W_c, an N-parameter with dynamically adjustable value.

Finally, the need for distinguishing the various kinds of messages (lettergrams, liaison letters, telegrams, acknowledgements of various kinds, etc.) and, in each mode, the need for additional fields such as "facilities" and so on, introduces a cost, very valuable in terms of overhead, for a benefit that cannot be measured in quantitative terms, i.e., modularity and adaptability to various transport user needs and traffic patterns. The overhead for these non-text fields of information will be called in this paper H_{TC}, defined in terms of the number of bits per message.

4.3 Summary of the Parameters of the Transport Layer

Table 3, which reproduces Figure 21 of the INWG 96.1 document, indicates the elements of the transport services that define the transport service classes: a short notation is added to the original Figure, for the purpose of abbreviation in the next Table.

Table 4 summarizes the characteristics parameters hitherto for the transport layer: it also shows their classification following the concepts expressed in Section 2, and the transport service classes and elements which they are relevant to.

As already mentioned in connection with the network layer parameters, this set may not be complete, also because some points in the INWG 96.1 document are "left for further study" (e.g., the specifications of "check sum on letters", negative acknowledgement, etc.).

5. THE SAMPLE ARCHITECTURE

The analysis hitherto developed has, among other things, taken into account the fact that each layer is "part of a whole": for each layer, characteristic parameters have been defined in such a way that it is known:

- how its transient states are protected;
- how it can use the services and resources available from the next lower layer;
- how much overhead is introduced in order to perform its functions;
- how its services, provided to the next higher layer, can be evaluated.

But, if the whole network architecture is taken into consideration, a first observation must be made: the analysis hitherto developed is not sufficient, as nothing has been assumed about the way in which the DCE to DCE transfer of information takes place (Figure 9). With regard to this question mark in the Figure, the following general working hypotheses have been made in this paper:

Hyp. 1. A packet switching subnetwork takes the responsibility of the transfer of the information between DCEs;

Hyp. 2. A distributed, adaptive, minimum-delay routing algorithm is defined in the subnetwork operation;

We will assume two possible modes of implementation:

a) A datagram-type service, which routes every packet separately, and

b) The establishing of a virtual call presumes that all packets of the same call are sent over the same route.

Hyp. 3. The "regime" topology of the subnetwork (i.e., when all the nodes and the lines are available and not congested) is known.

This is a preliminary step that had to be taken for the sake of completeness of the Sample Architecture: the routing functions will be considered as belonging to the set of functions performed on the network layer of each node[14].

As the Sample Architecture is drawn in a general configuration, it is now important to consider the consequences that the interconnection of different layers will have on the definition, for each layer, of the characteristic parameter set. This analysis will be made in the following part of this Section for some of the "qualitative" aspects of the interconnections; in the next Section some "quantitative" interrelations will be deduced.

In this paper, only the matching of the Transport Layer specifications, given in INWG 96.1, with those of the Network Layer in the DTE, given in the X.25 level 3[15], is considered. In this connection, INWG 96.1 explicitly states:

> "If the data transmission service and the way it is used already provides some of the transport service elements, then the corresponding elementary function of the transport protocol will not need to be put into operation".

In an X.25 network, the available data transmission service between two Transport Stations can be:

1. a (set of) permanent virtual circuit(s): PVC
2. a (set of) switched virtual circuit(s) : SVC

In both cases, in order to establish port associations, the Transport protocol may or may not be required to perform the multiplexing of the circuit(s) between its users. Therefore, the selection of the transport service elements that need actually to be put into operation, depends strongly on what kind of data transmission service is used (PVC or SVC), and how it is used (multiplexed or non multiplexed).

In the following, as a working hypothesis, it will be assumed that (see Section 3.3.5):

4. $N_V(a_T)$ switched virtual circuits are available to the Transport Station, the address of which is a_T; the Transport Station is required to perform the multiplexing of the virtual circuit between ports that have to be associated with remote ports belonging to the same remote Transport Station (i.e., are on the same DTE address).

Also for the liaison initialization/termination element of service, some choice has to be made, i.e., as to whether the exchange of LI-INIT messages has to be performed only on already set-up virtual circuits, or not[16].

It will be assumed here as a working hypothesis that:

5. the initialization of a liaison is always tried only on an already established virtual connection[17].

This hypothesis is quite different from the one assumed in Sexton 1976: the main reason is that it has been considered preferable in this paper to completely separate the connection between Transport Station, that is the establishment of an X.25 DTE-DTE virtual connection from the connection between Transport Users, that is a TS Port-Port association.

Regarding the transport of letters, even if the data transmission service can provide the sequential delivery of packets, having the more-data bit set to one, the need for fragmentation can still arise, in order to avoid long letters monopolizing the virtual connection, at the expense of other processes (on other TS ports) sharing the same virtual connection: the need for fragmentation is therefore a direct consequence of Hyp. 4. Moreover, when Error Control is in operation, the need for acknowledgement is a consequence of the fact that the updating of the lowest window edge, P(R), between DTE and DCE, has only a local meaning (see Section 3.3.3, note [3]): but if the Transport Stations have to operate only on a network that gives end-to end significance to P(R), no need exists for further acknowledgement: each TS needs only to be "informed" by the next lower layer whenever a reset has occurred on a local logical channel.

The transport of telegrams can be directly mapped onto the X.25 level 3 transfer of interrupts. It is the opinion of the authors, however, that the need for telegram acknowledgement with a time-out/retransmission mechanism should be more fully discussed; in fact, it should be noted that retransmission of an unconfirmed interrupt can only take place after a reset of the logical channel has been performed, whether the significance of the interrupt confirmation packet be local or end-to-end (see Section 3.3.2).

Finally, the optional performing of End-to-End Flow control should be maintained, as this element of the service is not provided by the X.25 data transmission service (see Section 4.2, note [12]).

6. SOME INTERDEPENDENCIES BETWEEN CHARACTERISTIC PARAMETERS

In this Section, a short analysis will be made of the interdependencies that necessarily arise in the evaluation or assignation of values to characteristic parameters of different protocol layers. A complete and detailed analysis of all the parameters is far from the intention of the authors: only a few of them will be taken into account, in order to show how, for sample features of the architecture, modeling, or experience, or (better) both, can be used as tools for the designers or the implementors of an architecture.

As a first example of this way of reasoning, the following approach to the problem of the agreement of the values for the T-parameters , T1 and N2, of the X.25 link level interface between DTE and DTE, proposed in the Recommendation X.25 (see Section 3.2), can be considered.

As this timer is started from the DTE (DCE) on the transmission of an I-frame, no waiting time for DCE (DTE) busy condition clearing has to be taken into account. The worst occurrence is when the longest frame (containing N1 bits) is transmitted by the sender and it is acknowledged, after the maximum time, T2, by the receiver by means of an acknowledgement piggybacked into the longest information frame. The following relation can be used:

$$T1 = T2 + 2\left(\frac{N1}{C1} + d^*\right) , \qquad (1)$$

where d* has to be a pessimistic estimation of additional delays introduced by modems, propagation time, and other possible secondary factors. The following relation, as anticipated in Section 3.2, takes place by definition:

$$N1 = N3 + H_M \quad , \qquad (2)$$

and, by the specifications of HDLC frame format, the following relations also take place:

$$H_M = (N3 + H_m - 16)/5 + H_m \quad , \qquad (3)$$

where this value of H_M can be achieved if the whole frame consists of ones. It is also clear that H_m includes flags (16 bits), address and control fields (16 bits) and checksum field (16 bits), and is always present. Therefore:

$$H_m = 48 \quad .$$

As a first result, we get:

$$T1 = T2 + 2(1.2N3 + 55)/C_1 + 2d^* \quad . \tag{5}$$

The evaluation of the maximum number of transmission of the same frame, N2, should take into account the error rate of the line, from one side, and the link level average delay, D_L and availability A_L (B-parameters), from the other side. It is quite obvious that, increasing N2 means increasing both: whilst the second is an improvement, an increased delay should, however, be maintained under acceptable values. A_L can be estimated by the following:

$$A_L = 1 - \frac{n_r \bar{d}_r}{t_{op}} \quad , \tag{6}$$

where t_{op} is a defined time of operation of the link, $\bar{d}_r$ is the average time spent for link reset, and n_r is the number of times that the link had to be reset during the time, t_{op}. It can be written as follows:

$$n_r = n'_r + n''_r \quad , \tag{7}$$

where n'_r (N2) is the component of n_r due to N2 unsuccessful transmissions of the same frame, and n''_r is the component of n_r due to other reasons (for example the receipt of the invalid frame format), and as a consequence:

$$A_L = 1 - \Delta A'_L - \Delta A''_L \quad . \tag{8}$$

with

$$\Delta A'_L = \frac{n'_r \bar{d}_r}{t_{op}} \quad . \tag{9}$$

$$\Delta A''_L = \frac{n''_r \bar{d}_r}{t_{op}} \quad . \tag{10}$$

The probability p_c that a frame is error-free depends upon the length of the frame, L_F, and the error rate of the line:

$$p_c(E_1,L_F) = (1 - E_1)^{L_F} \quad . \tag{11}$$

The probability, p_r, that a link reset condition is reached, after N2 transmissions of the same frame, depends upon the traffic pattern. The worst case is when the link is fully utilized in both directions with frames of maximum length, N1: in fact, in this case, the loss of an acknowledgement always generates the retransmission of the frame. This worst case is examined here, in order to find an upper limit expression for $\Delta A'_L$ (N2).

In this case, it is true that:

$$p_r(N2) = \left[1 - (1 - E_1)^{2N1}\right]^{N2} \qquad (12)$$

In fact, it is also true that:

$$p_r(N2) = \left[1 - p_c^2(E_1,N1)\right] p_r(N2 - 1) \quad ,$$

$$p_r(1) = 1 - p_c^2(E_1,N1) \quad ,$$

and, from (11), relation (12) follows.

The probability, p_s, that a frame will be successfully transmitted and acknowledged on the M-th trial ($M \leq N2$), always being in error in the preceding M-1 trials, is:

$$p_s(M) = \left[1 - p_c(E_1,N1)\right]^{(M-1)} p_c^2(E_1,N1) \quad ,$$

and again, from (11) it follows that:

$$p_s(M) = \left[1 - (1 - E_1)^{2N1}\right]^{(M-1)} (1 - E_1)^{2N1} \quad . \qquad (13)$$

The loss of a frame sent from A to B generates the "waste" of time T1, in the direction A → B, and the waste of the time t_{wr} in the direction B → A, where

$$t_{wr} = T1 - \left(\frac{N1}{C1} + d^*\right) = \frac{T1 + T2}{2} \quad ,$$

or

$$t_{wr} = T1 \quad ,$$

if the succeding frame is also lost[18]. The sum of the average times wasted in both directions for the loss of a frame is therefore

$$\bar{t}_w = T1 + p_c \frac{T1 + T2}{2} + (1 - p_c)T1 \quad , \tag{14}$$

and from (11)

$$\bar{t}_w = 2T1 - (1 - E_1)^{N1} \frac{T1 - T2}{2} \quad . \tag{14'}$$

Then the average time, $\bar{t}_s$ spent (in both directions) to transmit successfully a frame, can be calculated as

$$\bar{t}_s = \sum_{i=1}^{N2} p_s(i) \left[(i - 1)\bar{t}_w + \frac{N1}{C1} + d^*\right] \quad . \tag{15}$$

And from (1), (13) and (14'), it follows that

$$\bar{t}_s = (1 - E_1)^{2N1} \sum_{i=1}^{N2} \left[1 -(1 - E_1)^{2N1}\right]^{(i-1)}$$
$$\left\{(i - 1)\left[2T1 - (1 - E_1)^{N1} \frac{T1 - T2}{2}\right] + \frac{T1 - T2}{2}\right\} \quad . \tag{15'}$$

The time, t_r , spent in unsuccessfully transmitting a frame that causes the reset of the link is

$$t_r = N2 \cdot T1 \quad . \tag{16}$$

When $n''_r = 0$, it can be assessed that:

$$2t_{op} = 2n'_r(t_r + \bar{d}_r) + n_s\bar{t}_s \quad , \tag{17}$$

where n_s is the number of successfully transmitted frames during t_{op} (in both directions).

As it can be measured as follows:

$$p_r = \frac{n'_r}{n'_r + n_s} \quad , \tag{18}$$

(17) becomes:

$$2t_{op} = 2n'_r(t_r + \bar{d}_r) + \frac{1 - p_r}{p_r} n'_r \bar{t}_s \quad , \qquad (19)$$

that is:

$$n'_r = \frac{t_{op}}{t_r + \bar{d}_r + \frac{1 - p_r}{2p_r} \bar{t}_s} \qquad (19')$$

Introducing (19') and (16) in (9), it becomes finally:

$$\Delta A'_L = \frac{\bar{d}_r}{\bar{d}_r + f_a} \quad , \qquad (20)$$

with

$$f_a = f_a(p_r, \bar{t}_s) = \frac{1 - p_r}{2p_r} \bar{t}_s + t_r \quad , \qquad (21)$$

and here the following are recalled:

$$t_r = t_r(N2, T1) = N2 \cdot T1 \quad ; \qquad (22)$$

$$p_r = p_r(E_1, N1, N2) = \left[1 - (1-E_1)^{2N1}\right]^{N2} \quad ; \qquad (23)$$

$$N1 = N1(N3) = 1.2N3 + 55 \quad ; \qquad (24)$$

$$T1 = T1(T2, N1, C_1, d^*) = T2 + 2(N1/C_1 + d^*) \quad ; \qquad (25)$$

$$\bar{t}_s = \bar{t}_s(E_1, N1, N2, T1, T2) = v. \quad (15') \quad . \qquad (26)$$

$\bar{t}_s$ expresses also, in the worst case examined here, the average value of the component of the delays D_L(DTE → DCE) and D_L(DCE → DTE) - in each transmission direction - due to the transmission process. The actual value of this delay must take into account the waiting times due to "DCE busy" and "DTE busy" conditions, respectively. However, from (8), (9), (20), (21), (22), (23) and (26), one can easily see that the increase in N2 means, not only an increase in the availability, but also an increase in the delay.

It is now time to make a study from an upper-level point of view. An interesting problem can be the evaluation of interrelations between the time-outs that regulate the opening of a liaison, and B-parameters of this element of the transport service, such as delay, D_{TEL}, and availability, A_{TL} (see Section 4.1 and Table 4)

The setting of proper values for the time-outs, T_{LLO}, T_{LRO} (see Section 4.2, Figure 8 and Table 4), and TT_p2, TC_p3 (see Section 3.3.1.1, Figure 3a and Table 2), can be established, taking into account some parameters of the distributions of the proper components of the delays D_{TEL} and D_{pc} (see Section 3.3.5 and Table 2), respectively - by one side - and some objective values for the availabilities, A_{TL} and A_p (see Section 3.3.5 and Table 2), respectively - by the other side. The availability depends both on local factors, e.g. the number of buffers and the average and peak-hour number of concurrent connections (provided by third level) or associations (provided by fourth level), and on network factors, e.g., the influence of the load of the subnetwork on its component to the delay. If:

1. d_{lpA}, d_{rpB} are random variables that represent the local third level delays of DTE_A, DTE_B, respectively, for the establishment of a local-. remote - (respectively) requested connection;
2. d_{rTB} is the random variable that represents the local TS_B delay in accepting the establishment of the remote-requested connection;
3. $d_s(A,B,L_p)$ is the random variable that represents the delay introduced by the subnetwork for the transfer of a packet of length L_p from DCE_A to DCE_B (third level delays included);
4. $d_{lTC}(A,L_p)$, $d_{lCT}(A,L_p)$ are random variables that represent the link level delay from DTE_A to DCE_A, from DCE_A to DTE_A, respectively, for the transfer of a packet of length L_p;
5. d_{peAB} is the random value of the actual delay for the establishment of the virtual connection between TS_A and TS_B, requested by TS_A;

it is true that:

$$d_{peAB} = d_{lpA} + d_{rpB} + d_{rTB} + d_s(A,B,L_{RI}) + d_s(B,A,L_{AC}) +$$

$$+ d_{lTC}(A,L_{RI}) + d_{lCT}(A,L_{AC}) + d_{lTC}(B,L_{RI}) + d_{lCT}(B,L_{AC}) \quad , \tag{27}$$

where L_{RI} is the length of the packets' Call Request and Incoming Call, and L_{AC} is the length of the Call Accepted and Call Connected packets. In order that the connection actually be established, it is necessary that the following takes place:

$$TTp2_A > d_{peAB} - d_{lpa} = d_1 \quad ; \qquad (28)$$

$$TCp3_B > d_{lTC}(B,L_{RI}) + d_{lCT}(B,L_{AC}) + d_{rpB}$$

$$+ d_{rTB} = d_2 \quad . \qquad (28')$$

The availability, A_{pe}, can be expressed as follows:

$$A_{pe} = 1 - \Delta A'_{pe} - \Delta A''_{pe} + \Delta A'_{pe}\,\Delta A''_{pe} \quad , \qquad (29)$$

where $\Delta A'_{pe}$ represents the probability that the connection will not be established because either (28) or (28') is not respected, and $\Delta A''_{pe}$ represents the same, but for different reasons (e.g., lack of buffers). $\Delta A'_{pe}$ can depend, in its turn, on the number n_c of concurrent connections on each of the two DTEs. It can be foreseen that it is a function, growing with n_c. With the position:

$$\Delta A'_{pe\phi} = \Delta A'_{pe}(n_c = \phi) < \Delta A'_{pe}(n_c > 0) \quad , \qquad (30)$$

it can be established that:

$$\Delta A'_{pe} = \Delta A'_{pe\phi} + \Delta A'^{*}_{pe} \quad . \qquad (31)$$

If the delays that appear in (28), (28') are examined under the hypothesis that no other concurrent virtual connections will be (or are being) established, both on TS_A and on TS_B, the component, $\Delta A'_{pe\phi}$ of A_{pe} can be estimated.

Let us denote

$$d_{12} = d_1 - d_2 \quad .$$

From (28) and (28') it follows that

$$d_{12} = d_s(A,B,L_{RI}) + d_s(B,A,L_{AC}) + d_{lTC}(A,L_{RI})$$

$$+ d_{lCT}(A,L_{AC}) \quad . \qquad (33)$$

If nothing can be assessed about the distribution of d_2 and d_{12}, except that they have average values $\bar{d}_2$ and $\bar{d}_{12}$, and variances S_1^2 and S_{12}^2, respectively, and that they are mutually independent (that is a very broad hypothesis, under the assumption that no other traffic is generated by both DTE_A and DTE_B on the subnetwork), then the Kolmogorov's inequality can provide an upper bound to $\Delta A'_{pe\phi}$. In fact, it states, in this case, that - for every $t > 0$ - the probability of the simultaneous realization of the inequalities

$$|d_2 - \bar{d}_2| < t \cdot S_1 \quad ; \tag{34}$$

$$|d_1 - \bar{d}_1| < t \cdot S_1 \quad . \tag{34'}$$

is at least $1 - t^{-2}$ (being $\bar{d}_1 = \bar{d}_{12} + \bar{d}_2$; $S_1^2 = S_{12}^2 + S_2^2$, for the assessed stochastic independence of d_{12} and d_2). Considering, for obvious reasons, only the case in which $d_{12} > \bar{d}_{12}, d_1 > \bar{d}_1$, it follows that:

$$1 - \Delta A'_{pe\phi} \geq 1 - t^{-2} \quad .$$

That is:

$$\Delta A'_{pe\phi} \leq t^{-2} \quad ; \tag{35}$$

if

$$TCp3_B = \bar{d}_2 + tS_1 = \bar{d}_2 + t\sqrt{Var(d_{pe})} \quad ; \tag{36}$$

$$TTp2_A = \bar{d}_1 + tS_1 = D_{pe} + t\sqrt{Var(d_{pe})} - d^*_{lpA} \quad . \tag{36'}$$

where d^*_{lpA} is a constant, evaluating the minimum value of d_{lpA}. If the distributions of d_1 and d_2 can be approximated by well-known distributions, better interrelations can be found. It is, however, confirmed that large availability and small delay are opposite requirements, between which a balance should be not only made in the design phase, but furthermore controlled and updated in the operational phase.

The availability of the transport service can be expressed also as:

$$A_{LE} = 1 - (\Delta A'_{LE\phi} + \Delta A'^{*}_{LE}) - \Delta A''_{LE} + \Delta A''_{LE}(\Delta A'_{LE\phi} + \Delta A'^{*}_{LE}) \quad , \tag{37}$$

where the meaning of the components is analogous to that indicated for the third level. It is true that:

$$\Delta A'_{LE\phi} = \Delta A'_{pe\phi} + (1-\Delta A'_{pe\phi})\Delta A'_{LV\phi} ,$$

where $\Delta A'_{LV\phi}$ represents the probability that the liaison will not be established, once the connection has been established, because one of the time-outs, T_{LLO}, T_{LRO}, expired for the excessive value of the corresponding delay. It is left to the discretion of the reader to apply theoretical tools to this case also.

In order to indicate another case of interdependency between time-outs and other parameters of different layers, the "transport of letters" element of the transport service will be considered as the last (but not least) case.

As an example, we can look at the time delivery of user packets in the liaison mode in the INWG 96.1, and in particular parameter T_{LE} of the sending station, and parameter T_{RS} of the receiving station.

If the T_{RS} expires, and no new frame of the letter arrives, the letter is considered to be lost, and the letter should be retransmitted. Waiting time, T_{LE}, is set up at the sending station for expected acknowledgement from the receiving station.

It is quite obvious that, if T_{LE} is too small, this will lead to repetition of a letter, which can be particularly dangerous when the network is overloaded; therefore, if too small a T_{LE} is set up, the load will be unnecessarily increased. If T_{LE} is too great, this will slow down the whole system. Again, if T_{RS} is too small, this will lead to unnecessary interruption of the reassembly process, and if T_{RS} is too great, this will block the resources of the receiving station.

Similar problems arise also in the lettergram mode with T_{GE} and T_{RS} parameters. If T_{GE} is too small, there is a stronger possibility of the lettergram being considered lost, when it in fact is not, and unnecessary actions can be caused at the higher level. The secondary effect of the inadequate setting of T_{GE} or T_{LE} is that it leads to incorrect counting as errors, of all cases when time-out expires. The letter is, however, actually delivered and ACK is not lost, but comes in later.

In the case that the setting of T_{GE} and T_{LE} is too strict, this causes an unjustified increase in E_{T1M} and E_{T1R} (or E_{T1S}), respectively. In another set of B-parameters like R_{TGE}, R_{TLE} and R_{TLF}, which expresses the reliability of the transport service, too strict a setting of T_{GE} and T_{LE} will cause an unjustifiable decrease.

If we consider the transport service between stations A and B, which we assume, for simplicity, to be connected with the switching nodes - DCE_A and DCE_B - then T_{LE} depends, among other parameters, on the sum of t_B^A and t_A^B. where t_j^i is the delivery time of a packet from the node i, to the node j. If the routing mechanism is based upon the packet delivery time, as is assumed above in our model (Hyp. 2), e.g., "relief", or as it is used in the ARPA network, then t_j^i is just an entry of the corresponding routing matrix.

We do not know, however, t_j^i in node i, but a reasonable estimation of t_j^i can be obtained from t_i^j, assuming that they are equal. Some experimental tests have shown that this assumption is feasible in most cases, and is more applicable to large networks than to small ones.

In order to estimate T_{RS},again information from the routing matrix can be used. If receiving station B knows the t_A^B delivery time of a packet from A to B, or can estimate it on its own entry, t_B^A, then the following considerations could take place. As soon as a frame of a letter has been received, an estimation of the interval before the arrival of the next frame can be made. This interval depends on the time interval between the generated frames and some function of the distance and delays due to the queues in the network $t(l_B^A, d_B^A)$, where l_B^A is the distance and d_B^A the delay caused by the queues. If we know that the minimal distance is equal to one and therefore the whole queueing delay is concentrated at one node only, we can estimate that the variance of the delay will be:

$$D(d_B^A) = d_B^A + (d_B^A)^2 \quad .$$

If the delay is distributed over n transit nodes, and if we assume that the delays are evenly distributed over all n nodes, we can calculate the variance of the delay as:

$$D(d_B^A) = \sum_{i=1}^{n} D_i\left(\frac{d_A^B}{n}\right) = d_A^B + \sum_{i}^{n}\left(\frac{d_A^B}{n}\right)^2 ,$$

where D_i is the variance of delay at node i, and as we know is smaller than the value of the previous expression for the concentrated queue.

So if we explicitly know the delay between nodes, we can assume that the variation in this delay will be less for a long distance than for a short one, if the delay is the same. The estimation of the variance also allows one to set up time-out, to cover the risk of statistical oscillation of delivery time.

If INWG 96.1 is implemented on top of the X.25, as we assume in our reference model, and if X.25 is implemented in such a way that the actual route of the packets belonging to the same call is fixed for the whole duration of the call, the delivery time of a packet increases according to its number in the succession (Butrimenko and Sichra 1979). This dependence on the number of the packet is caused, as has been shown in Butrimenko and Sichra, by the decreasing efficiency of the fixed route with the time. The delivery time of every subsequent packet is greater by 5 - 20% than the previous interval between the packets. This percentage increases with the load of the network and the distance, I_A^B, between the communicating nodes. This has the practical consequence that the estimation of the time parameter, T_{RS} , should take into account the sequence number of the fragments of the same letters, and the load and distance.

7. CONCLUSIONS

In this paper the authors have made an attempt to look at the set of procotols as one entity and tried to identify interrelations between some of the parameters of various layers.

This led to the necessity of defining a number of classes of parameters which go through all the layers. This attempt, although limited to a sample architecture, has shown a large variety of these parameters and the rather complicated interconnections between them. Some of the interrelations found, as well as others which could be found by following a similar methodology, can be used both in the design phase of a computer network and in the operational phase. The authors intend to continue the work begun in this paper in order to achieve a more clear and comprehensive understanding of the interdependence of the parameters.

Table 1. X.25 parameters: 1st and 2nd level

	parameter	class
physical layer	C_1	B
	E_1	B
link layer	T2	N
	K	N
	T1	T
	N2	T
	H_m	C
	H_M	C
	H_a	C
	N3	B
	E_L	B
	C_L	B
	A_L	B
	D_L	B

Table 2. X.25 parameters: 3rd level

parameter	phase	def. on	class	note	parameter	phase	def. on	class	note
TTp2	Setup	DTE	T		TCr2	Restart	DCE	T	
TCp3	Setup	DCE	T		NCr2	Restart	DCE	T	
TTp3	Setup	DTE	T	(1)	TTr2	Restart	DCE	T	(1)
TCp2	Setup	DCE	T	(2)	TCr1	Restart	DCE	T	(2)
TTp6	Clear	DTE	T		NCr1	Restart	DCE	T	(2)
NTp6	Clear	DTE	T		W_{tc}	Transf.	DTE & DCE	N	
TCp7	Clear	DCE	T		W_{ct}	Transf.	DTE & DCE	N	
NCp7	Clear	DCE	T		L_p	Transf.	DTE & DCE	N	
TTp7	Clear	DTE	T		H_s	Setup	DTE-DTE	C	
TCp6	Clear	DCE	T		H_c	Clear	DTE-DTE	C	
TTi2	Transf.	DTE	T		H_d	Transf.	DTE-DTE	C	
TCi3	Transf.	DCE	T		H_r	Reset	DTE-DTE	C	
TTi3	Transf.	DTE	T	(1)	H_o	Restart	DTE-DTE	C	
TCi2	Transf.	DCE	T	(2)	E_p	Any	DTE	B	
TTd2	Reset	DTE	T		N_v	Any	DTE	B	
NTd2	Reset	DTE	T		C_p	Any	DTE-DTE	B	
TCd3	Reset	DCE	T		A_p	Setup	DTE-DTE	B	
NCd3	Reset	DCE	T		D_{pm}	Transf.	DTE-DTE	B	
TCd2	Reset	DCE	T	(2)	D_{pi}	Transf.	DTE-DTE	B	
NCd2	Reset	DCE	T	(2)	D_{pe}	Setup	DTE-DTE	B	
TTr1	Restart	DTE	T						
NTr1	Restart	DTE	T						

(1) This parameter is optional, as its existence depends upon the nature of the interface between the 3rd and 4th level of the DTE.

(2) This parameter is optional, as its existence depends upon the internal mechanisms implemented on the subnetwork.

Table 3. INWG 96.1: Transport service classes and elements

		G	L_R	L_S
	CLASS ELEMENTS	LETTERGRAM	REGULAR LIAISON	SUPER LIAISON
PA	Port addressing	yes	yes	yes
IT	Liaison init/term	no	yes	yes
TL	Transport of LETTERS	yes	yes	yes
TT	Transport of TELEGRAMS	no	yes	yes
GD	Guarantee on transit delays	yes	yes	yes
GE	Guarantee on errors	minimum	regular	superior
GS	Guarantee on sequence	no	yes	yes
EC	Delivery confirmation on request	yes	yes	yes
FC	Credits for transmission option	no	yes	yes
			L	
		A		

Table 4. INWG 96.1 parameters

parameter	class	t.s. class	t.s. element	note	parameter	class	t.s. class	t.s. element	note
N_{TA}	B	A	PA		D_{TTX}	B	L	TT	
H_{TA}	C	A	PA		D_{TEL}	B	L	IT	
A_{TL}	B	L	IT		D_{TLRSX}	B	S	TL	
L_{TL}	B	A	TL		D_{TTRX}	B	L	TT	
L_{TT}	B	L	TT		L_{TF}	N	A	TL	
H_{TC}	C	A	IT,TL,TT,EC,FC		N_{TMF}	N	A	TL	
H_{TR}	C	A	IT,TL,TT,EC,FC		T_{RS}	T	A	TL	
$E1_M, E_{T1M}$	B	G	GE	(1)	H_{TGE}	C	G	TL,EC	
$E2_M, E_{T2M}$	B	G	GE	(1)	T_{GE}	T	G	TL,EC	
$E1_R, E_{T1R}$	B	L_R	GE	(1)	T_{LLO}	T	L	IT	
$E2_R, E_{T2R}$	B	L_R	GE	(1)	T_{LRO}	T	L	IT	
$E1_S, E_{T1S}$	B	L_S	GE	(1)	T_{LC}	T	L	IT	
$E2_S, E_{T2S}$	B	L_S	GE	(1)	H_{TT}	C	L	TT	
E_{TS1}	B	L	GS		T_{TT}	T	L	TT	
E_{TS2}	B	L	GS		N_{TT}	T	L	TT	
C_{TP}	B	A	TL,TT		T_{LE}	T	L	TL,EC	
D_{TA}	B	A	TL,TT		N_{LE}	T	L	TL,EC	
D_{TM}	B	A	TL,TT		D_{LA}	N	L	TL,EC	
R_{TSX}	B	S	TL,TT,GE,GS		L_{TLF}	B	L	TL,IT,FC	
C_{TSX}	B	S	TL,TT		W_C	N	L	TL,FC	
D_{TLSX}	B	S	TL						

(1) The first parameter as bit error rate; the second as message error rate.

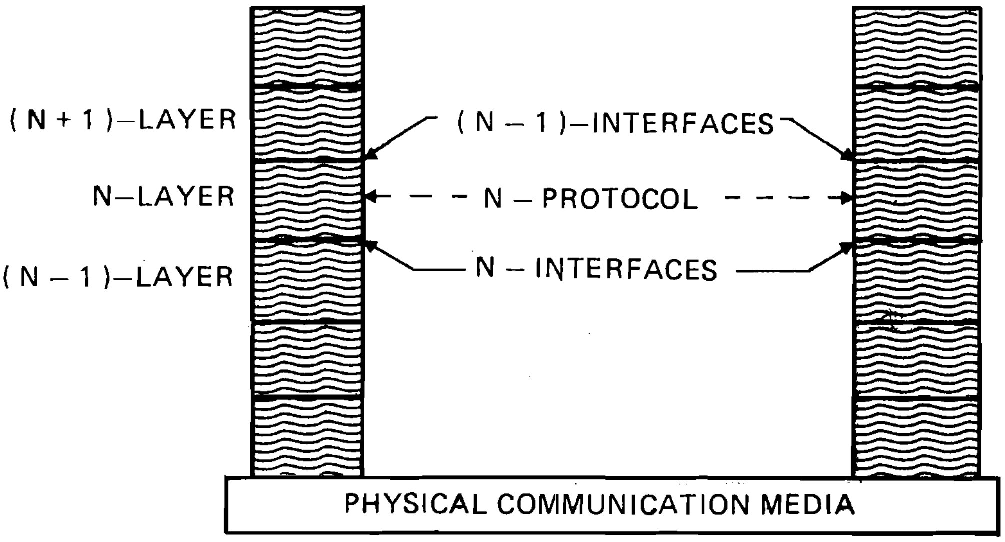


Figure 1. Hierarchical Structure of Protocol Layers and Interfaces

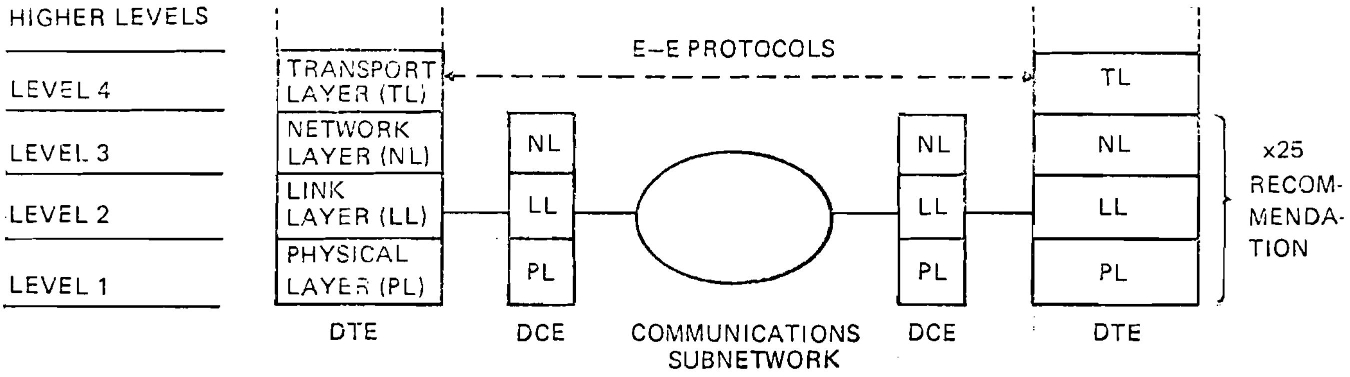
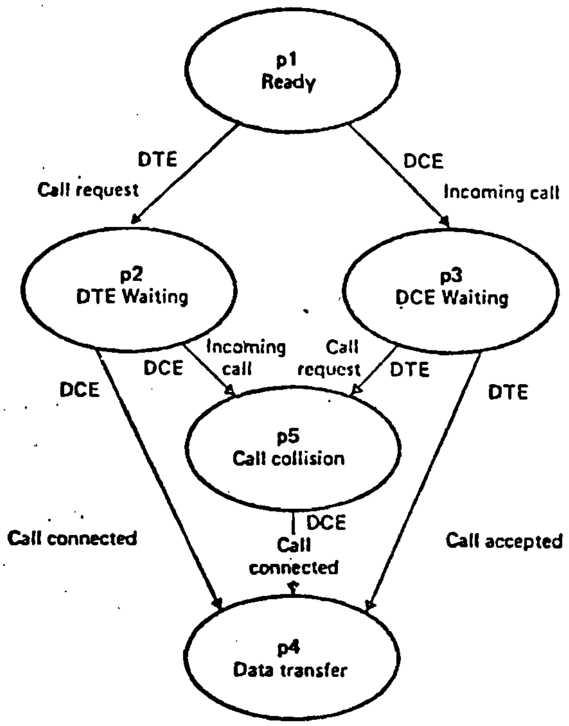
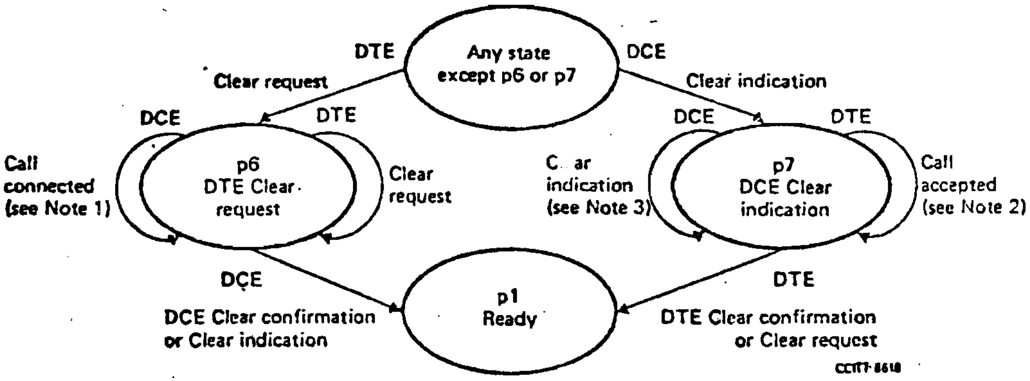


Figure 2. Layers Covered by X.25 Recommendation



a) Call Set-up Phase



Note 1. – This transition is possible only if the previous state was *DTE Waiting* (p2).
Note 2. – This transition is possible only if the previous state was *DCE Waiting* (p3).
Note 3. – This transition will take place after a time-out in the network.

b) Call Clearing Phase

Figure 3. Packet Level DTE/DCE Interface State Diagram for a Logical Channel

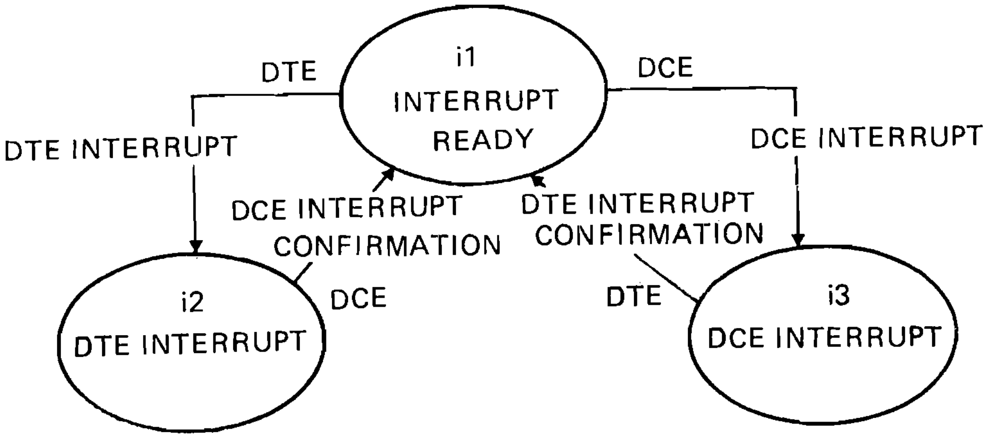
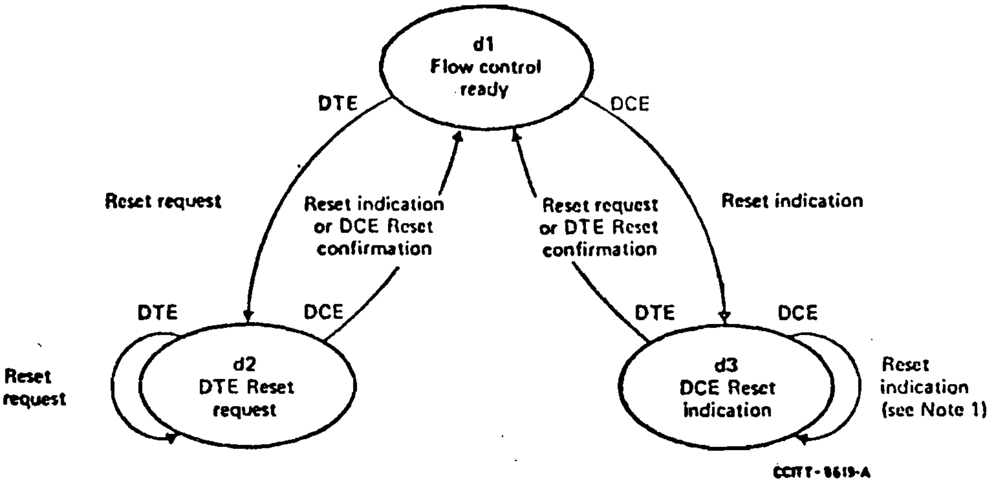
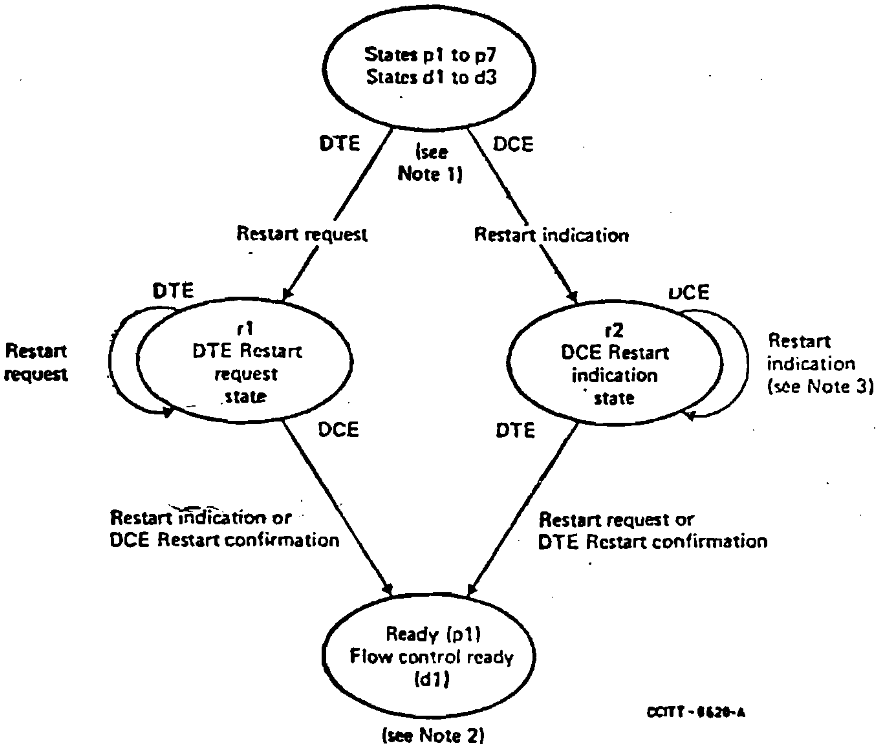


Figure 4. State Diagram for Exchange of Interrupt Packets



Note 1. – This transition will take place after a time-out in the network.

Figure 5. X.25 - Reset Phase



Note 1. – States p1 to p7 for virtual calls or states d1 to d3 for permanent virtual circuits.
Note 2. – State p1 for virtual calls or state d1 for permanent virtual circuits.
Note 3. – This transition will take place after a time-out in the network.

Figure 6. X.25 - Restart Phase

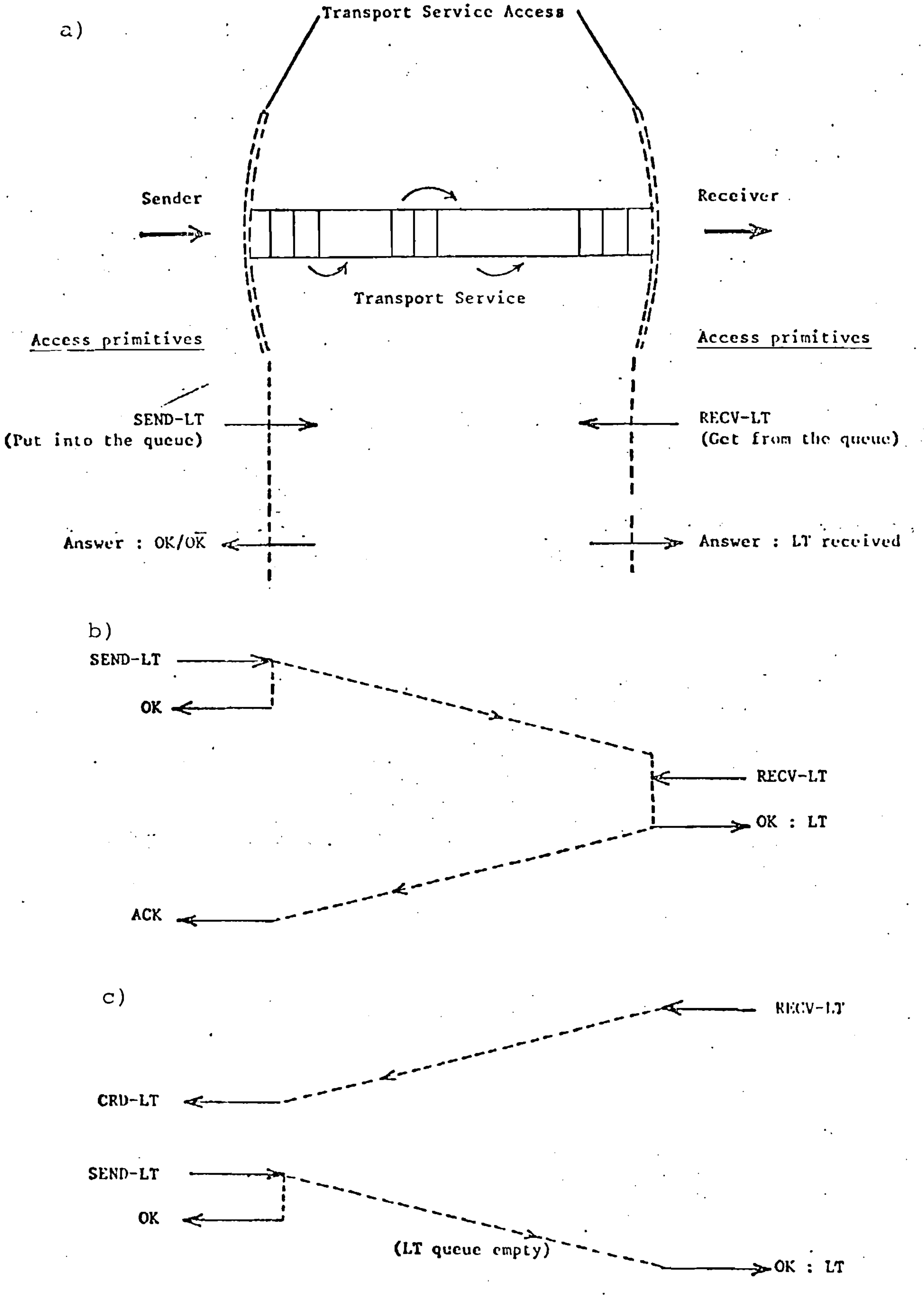


Figure 7. Flow of Letters, Lettergrams, Credits and Acknowledgements in INWG 96.1 Protocol

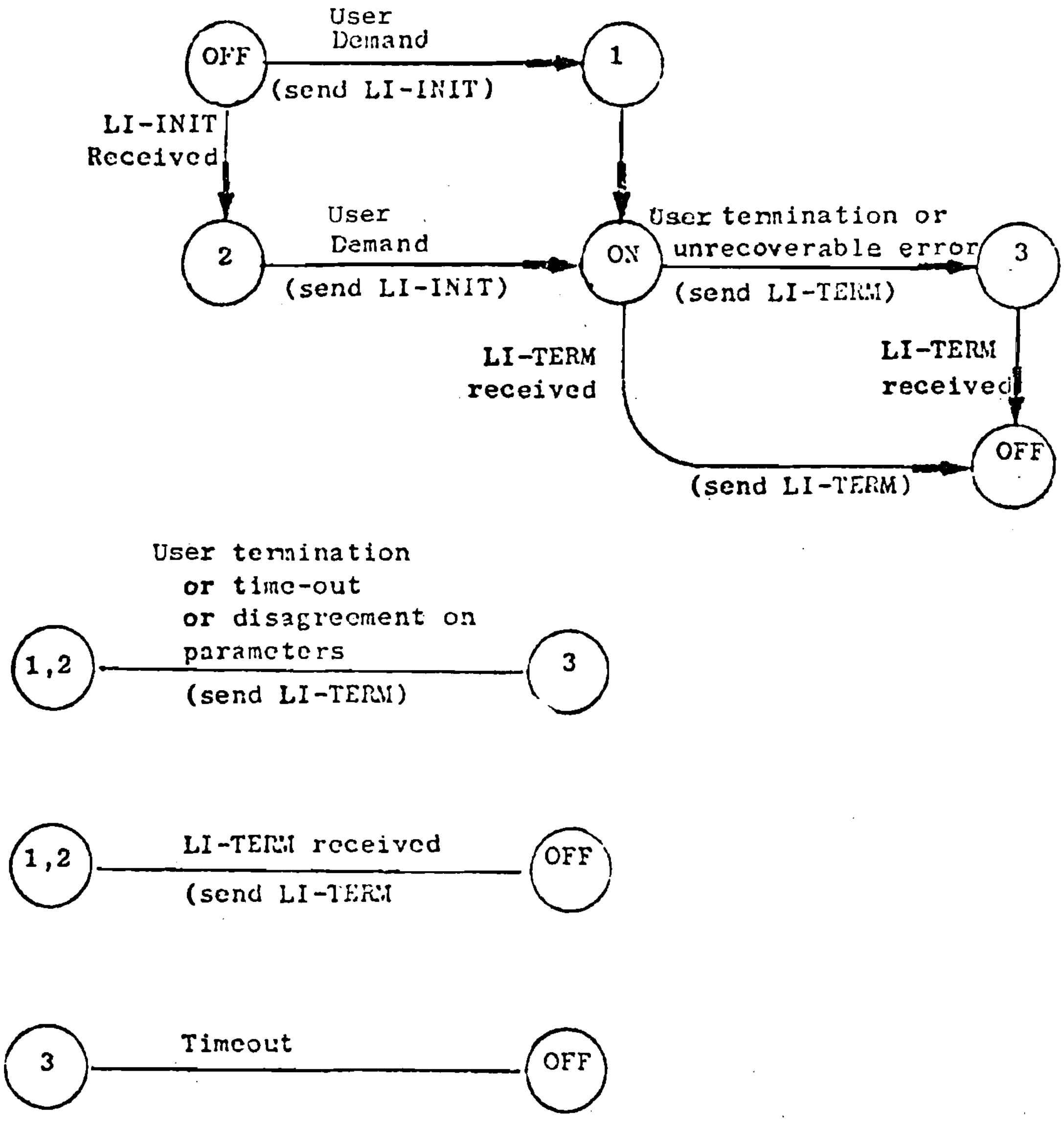
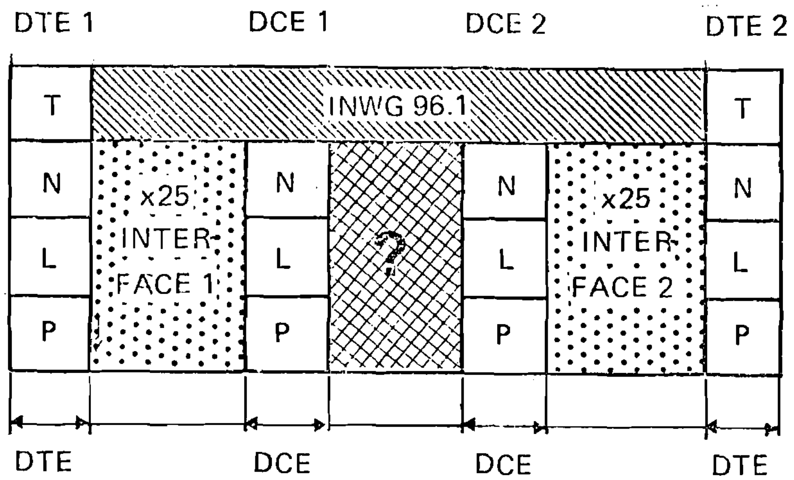


Figure 8. Initialization/Termination State Diagram of INWG 96.1 Protocol



P = PHYSICAL LAYER
L = LINK LAYER
N = NETWORK LAYER
T = TRANSPORT LAYER

Figure 9. Protocol Layers and Communication Network

NOTES

[1] This is not a characteristic parameter of the link layer.

[2] From the Annex 3 to Recommendation X.25: "ERROR: the DCE indicates a clearing by transmitting to the DTE a Clear indication packet, with an indication of Local Procedure Error. If connected through the virtual call, the distant DTE is also informed of the clearing by a Clear indication packet, with an indication of Remote procedure Error."

[3] This time-out is explicitly mentioned in Note 3 of Figure 15/X.25.

[4] In the Recommendation: "The only universal significance of a P(R) value is a local updating of the window across the packet level interface, but the P(R) value may be used within some Administrations' networks to convey an end-to-end acknowledgement."

[5] This time-out is explicitly mentioned in Note 1 of Figure 16/X.25.

[6] This time-out is explicitly mentioned in Note 3 of Figure 17/X.25.

[7] 128 octects in the Recommendation, but it is allowed to be 2^n - with n in the range from 4 to 10 - or, exceptionally, 255 octects, as supported by some Administrations.

[8] This is not a characteristic parameter of the network layer.

[9] It must, however, be mentioned that the transport protocol of CYCLADES, which implements substantially a subset of INWG 96, has been described by means of a modified version of the Theory of Colloquies (Danthine and Bremer 1978).

[10] "When the queues that represent the model of the association are empty and the receiver is willing to accept a letter".

[11] Of the "S"-mode transport service with the "X" option for synchronization.

[12] Credit for Transmission without Delivery Confirmation is not allowed by the protocol specifications in the document. It must be noted that in this paper "flow control" has a meaning quite different from the one in X.25, as it is intended to be between the end transport stations. In both cases, flow control is based on authorizations from the receiver, but the two flow control procedures do not overlap, as one (X.25) is a local matter, influenced, for example, by situations of subnetwork congestion, whilst the other (INWG) is exclusively operated by the transport stations, and is influenced by the availability of local resources.

[13] It is analogous to the N-parameter, T2, in the specifications of X.25, level 2.

[14] A "node" is not necessarily a DCE: it might have, for example, only a switching function between DCEs, or between DCEs and other "nodes". Each DCE is a node.

[15] It should be quite clear that no qualitative problem of adaptability does exist between the first three levels, as they are specified by the same document.

[16] The Call Request and Incoming Call packets can bring user data up to 16 octects, that are passed unchanged by the DCE.

[17] It must be noted that, as the term "virtual connection" indicates either PVC or SVC, Hyp. 4 and Hyp. 5 are independent of each other.

[18] Assuming that a frame is lost, then if the succeeding frame is not lost, it will be discarded by the receiver as it is out of sequence. The acknowledgement contained in it is, however, taken into account. Therefore, the receiver will not retransmit the frame as being acknowledged; if the succeeding frame is also lost, no acknowledging frame will reach the receiver during its "timer recovery condition" period.

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