RESEAU CYCLADES

INWG #61

SCH 519.1

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Identification : Transport Protocol. Standard host-host protocol for heterogeneous computer networks.

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Purpose : Interconnecting computer networks of different organizations (nations, manufacturers, administrations, companies, etc...) raises the need for a well defined and widely accepted host-host protocol. Several discussions are been conducted within various national and international bodies, with the experience of several computer networks. The present paper is an attempt to define such a protocol that matches most of the requirements encountered in the related discussions, including connection of terminals.

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CONTENTS.

Nota : This document is a revised version of SCH 519 (INWG note 43, NIC 20856) issued in December 1973. It should be considered as a step towards clarity (rephrasing), simplicity and robustness (a few changes). It also includes a complete description of formats.

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TABLE OF FIGURES.

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1. NETWORK ARCHITECTURE AND TERMINOLOGY.

In a network, computers are linked together by a data-communication subsystem (fig. 1). As one computer may contain several systems, as well as one system can be made of several computers, we shall not consider computers, but "virtual installations" linked together by a "communication function" (fig. 2). That communication function may be a packet switching network, a set of lines, or any machinery, provided it presents the required characteristics (see § 3).

The communication function will be said to offer "communication services" to "communication users" through "communication interfaces". With that terminology, virtual installations considered here are communication users.

Within each virtual installation we find distinct entities such as jobs, processes, tasks, programs, terminals, etc... Those entities need to exchange information by means of the network. They must therefore share the communication interface. Moreover, communication services will be considered as too basic for some of them. Therefore, we shall introduce in each virtual installation a piece of machinery (usually software) that will perform those additionnal functions. We shall call it a "transport station" (fig. 3). Those entities will now be called "transport subscribers" or, for short, "subscribers" (SB) of the "transport function" (fig. 4). The transport function is performed by transport stations communicating by means of the communication function, and cooperating according to the "transport protocol" (fig. 5 & 6).

Each SB has a set of subadresses called "ports" (PT), used to send or receive informations to and from other ports (fig. 7). The informations exchanged in both directions between a pair of ports make a "flow" (FL).

Nota : A port looks like the home address of a person and a flow can be thought of as the flow of letters exchanged by mail between a pair of individuals.

2. IDENTIFYING TRANSPORT SUBSCRIBERS, PORTS AND FLOWS.

Within the network, each TS is uniquely identified by a TS number (TS-NB). Each SB belongs to a TS where it is uniquely identified by a SB number (SB-NB). Each PT of a SB is uniquely identified within that SB by a PT number (PT-NB). A flow is identified as a pair of ports. Inside a packet, as source and destination TS-NB are included in packet header (see § 3), a flow will be identified by :

FL-ID = DEST (PT-ID) / SRCE (PT-ID)
with PT-ID = SB-NB / PT-NB

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3. COMMUNICATION FUNCTION EXTERNAL CHARACTERISTICS.

The transport protocol is adapted to various communication functions, provided they have about the same characteristics. More precisely that protocol is intended to be usable with most packet switching networks as well as with standard line procedures (between systems directly connected by a line).

Typical external characteristics of the communication function are the following :

- The communication function transfers "packets" from a source transport station to a destination transport station.
- The length of the text of the packet is limited to a maximum (typically 1000 or 2000 bits).
- The transfer delay of a packet is short (typically less than .5s) but may vary from one packet to the other.
- The error rate on bits is low (typically less than 10 E - 10 error per bit).
- The error rate on packets (loss or duplication) is low (typically less than 10 E - 4 error per packet).
- A packet is made of (see fig. 8) :
  * A packet header containing namely,
    . DEST TS - NB : destination transport station identification
    . SRCE TS - NB : source transport station identification
    . TEXT LG : length of the packet text
  * A packet text containing any pattern of bits (i.e. the communication function is transparent to the text of the packet).

Nota 1 : On some communication functions, the packet header may be different, but the parameters defined here must appear, even implicitly. The text length for instance may be replaced by a flag allowing to find the end of the packet ; if two machines are directly connected by a line, the source and destination transport stations may be implicitly known ; the header may contain other parameters, such as a packet reference. To be adapted to various communication functions, the transport protocol will only use those parameters defined above.

Nota 2 : When the characteristics of the communication function are very different from the typical figures indicated here, some changes have to be made to the protocol. E.g. if the maximum size of the packet is 8 K bytes, (on a high quality line directly connecting two machines), fragmentation is no more needed. In some cases the protocol may even be inadequate (e.g. if the maximum size of the packet is 4 bytes...).

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4. EXCHANGE OF INFORMATION BETWEEN TRANSPORT STATIONS.

To deal with transportation of informations between ports, packets will be flying back and forth between TS. Each one of those packets contains (in the packet text) information related to only one flow, and referred to as a "flow command". That flow command contains :

- OP-CODE (indicating the type of command)
- FL-ID (identifying the flow)
- Other parameters including control information and data.

Using FL-ID contained in each command, TS can multiplex and demultiplex commands that are then handled according to flow (port to port) procedures described hereafter.

5. BASIC TRANSPORT SERVICE.

The basic service offered by any TS allows subscribers to exchange "letters" (LT) and "telegrams" (TG) in both directions on flows. This basic service represents the minimum any TS must be able to handle.

- A letter is a variable-length piece of information with a maximum size of several K-bytes, intended for transfer of data.

- A telegram is a fixed-length piece of information of a few bits, intended for interrupt or control information.

For that basic service, TS performs only multiplexing between flows and "fragmentation/reassembly" of letters within flows (see § 6).

The basic service can be considered as a letter and telegram switching service between ports and does not require any initial synchronization or pre-arangement since it is performed on a LT (or TG) per LT (or TG) basis and any TS is prepare to do it. Fragments of letters are sent in "flow letter" (OP-CODE = FL-LT) commands, telegrams are sent in "flow telegram" (OP-CODE = FL-TG) commands.

6. FRAGMENTATION - REASSEMBLY.

When necessary the source transport station divides letters into pieces called "fragments (FR) that can go in one packet. Each fragment is sent in one FL-LT command, with proper control information. The destination transport station reassembles received fragments into letters (see fig. 10).

Each letter gets from the source TS a reference (MY-REF), unique within the flow, that avoids mixing fragments of different letters of the same flow.

Fragments are numbered (FR-NB) within the letter and a flag "end of letter" (EØL) indicates the last fragment of the letter. To make reassembly easier, all fragments do have the same size (except the last fragment of the letter). That fixed size is a parameter of the network that depends upon the maximum size of the packet. The reassembly process in the destination TS is protected by a "reassembly time-out" T.0.1 associated with each letter under reassembly. This time out is set when receiving the first (in time, but may be it is not number one) fragment, it is reset on receipt of each fragment and finally turned off when all fragments of the letter have been received. If the time out occurs, reassembly is aborted, and the letter considered erroneous.

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7. ADDITIONAL SERVICES.

Additional services on a flow may be performed on SB's request, on a "session" basis. A session is the period of time during which a set of additional services is performed on a flow by common agreement between the pair of TS.

The following additional services are already specified :

- error control on letters
- flow control on letters
- reduced addressing

If necessary, new services such as error control on bits will be specified later on.

8. SESSION NEGOTIATION.

Initializing and terminating a session (see § 7) on a flow requires agreement between the pair of TS. The session is successfully initiated if :

- Both end SBs have required the same set of services on that flow,
- Both TS know how to perform those services and have resources to do it,
- The corresponding mechanisms are coherently initialized at both ends.

The session is terminated if any one of the following conditions occ...

- The session initialization fails (in this case, the session does not even start),
- Any one of the SBs asks for termination,
- An unrecoverable error is detected by any one of the TS.

When the session is terminated, the basic service only can again be used on the flow.

The session negotiation mechanism is composed of two identical parts (one at each end of the flow), that can be represented by the state diagram on figure 11. It uses a "flow initialization"(OP-CODE = FL-INIT) command and a "flow termination" (OP-CODE = FL-TERM) command. The first stage going from "OFF" to "ON" via "1" or "2" is intended for initialization on SB's request. The second stage going from "ON" back to "OFF" ensures proper termination of the session. Of course, any "waiting state" is protected by a time-out (T02).

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9. ERROR CONTROL ON LETTERS.

Error control on letters within one flow (see fig. 12) is performed on top of the basic service. (This means in particular that error recovery is done on letters and not on fragments). When in use on a flow it is performed in both directions and works as follows (see fig. 13) :

- The sending TS sends letters with cyclic sequencial reference 'MY-REF' and expects acknowledgement within a maximum delay T03 after the last fragment of the letter has been sent.

- The receiving TS acknowledges letters promptly (within a maximum delay T04 after the last fragment of the letter has been received), sending back "YR-REF" (your reference), meaning that letter with that reference and all preceding ones have been received without error and passed to the receiving SB (see Nota below).

- If acknowledgement is not received by the sending TS within the prescribed delay T03, all unacknowledged letter will be supposedly lost and sent again, starting with the first unacknowledged letter. Acknowledgment will again be expected within T03. If acknowledgment is not received, that process will be repeated.

- If a letter has been sent "N" times without success, the sending TS will declare an unrecoverable error inform its SB and terminate the session.

- Duplicate letters must be dropped but an acknowledgement must be turned back by the receiving TS.

To ensure uniqueness of letter references, possible anticipation is restricted to half a cycle :

- the source TS should not send letters more than half a cycle ahead of the last acknowledged letter.
- the destination TS should not accept letters more than half a cycle ahead of the last acknowledged letter. Moreover, the cycle should be long enough to make sure that late letters do not arrive in the next cycle.

At initialization of a session with error control, all references on the flow are initialized to zero. The first letter to be sent or received has reference equal to one.

Nota : It seems important to comment on the meaning of the acknowledgment from SB's point of view. The way of "passing" a LT to a SB may slightly differ from one system to the other. In most cases, SBs will give buffers in advance and the ST will consider that a LT has been passed as soon as it has been placed in the SB buffer. In some other systems, according to some prearrangement, the ST will receive LT in its own buffers and inform the SB when a LT has been received, considering the LT is passed this way.

In other words, the acknowledgment means the LT has been made available to the receiving SB. It does not mean the SB has read it. It does not mean that the SB agrees with its contents. It just means that the SB agreed to receive a LT on that flow, the LT was correctly received by the TS and made available to the subscriber.

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10. FLOW CONTROL ON LETTERS.

Flow control may be added to error control on letters. (Flow control cannot be performed without error control on letters). When in use on a flow, it is performed in both directions and works as follows :

- At initialization of a session with error and flow control, both TS must agree on the maximum size of letters to be sent in each direction on that flow (that size may be different for each direction).
- The receiving TS goes on allocating "CREDITS" (CRD) on that flow to the sending TS. One credit represents the permission to send one letter. Each credit allocation refers to sender's reference (YR-REF), and contains a "credit number" (CRD-NB), meaning : you may now send letters with references going from (YR-REF) + 1 up to (YR-REF) + (CRD-NB).
- The sending TS restricts to this upper limit that progresses under receiver's control. This upper limit is updated as commands with allocation information are received.

11. REDUCED ADDRESSING (See fig. 14).

In some cases, the overhead associated with flow identification may be considered as too high by some SBs. In this case, reduced addressing will be offered, working the following way :

- Each TS offering reduced addressing has a set of "plugs" (PG) identified within that TS by a PG-NB.
- At initialization of a session with reduced addressing, each TS allocates a PG-NB to the flow and gives notice to the other party. Each TS then knows the local PG-NB and the distant PG-NB allocated to that flow for that session..
- In commands exchanged between TS, that flow will be identified by the PG-NB in the destination TS, instead of the identification of the pair of ports.
- PG-NB are deallocated at session termination.
- Within the TS, local PG-NB could be used as an index to the context of the flow, reducing the address processing overhead.
- The existence of PG does not have to be known by SB.

12. FLOW ERROR COMMAND.

When an erroneous command is received on one flow, a "flow error" (OP-CODE = FL-ERROR) command should be turned back on the flow, containing an error code and the beginning of the erroneous command. This is intended for debugging purpose and is not mandatory in normal operation, but any TS should be prepared to receive a FL-ERROR command on any flow at any time.

13. TS MAINTENANCE FUNCTIONS.

Each TS will have a privileged SB called "TS Manager" and responsible for TS maintenance. So far, only the ECHO function has been defined.

ECHO : TS Manager has an "ECHO port". Every LT or TG received on that PT will be sent back to the originating PT.

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14. FLOW COMMANDS AND THEIR PARAMETERS. *

FL LT/FL ID [/YR-REF [/CRD-NB]]/MY-REF/FR-NB/EOL/FR TEXT

Used to send fragments of letters on one flow as well as reverse acknowledgments and allocations (for error and flow control when they are performed).

FL-LT : op-code of that command

FL-ID : identification of the flow

YR-REF : reference of the acknowledged letter (used only with error control on LT)

CRD-NB : allocates credits for letters with reference up to YR-REF + CRD-NB (used only with flow control on LT)

MY-REF : reference of the letter the fragment belongs to

FR-NB : number of the fragment sent in that command

EOL : end of letter bit, indicates current/last fragment of the letter

FR-TEXT : text of the fragment.

FL-ACK/FL ID/YR-REF [/CRD-NB]

Used to send acknowledgments and allocations when no FL-LT command on that flow is available to carry that reverse control information.

FL-ACK : op-code of that command
FL-ID : see in FL-LT
YR-REF : see in FL-LT
CRD-NB : see in FL-LT

FL-TG/FL-ID/TG-TEXT

Used to send telegrams on one flow

FL-TG : op-code of that command
FL-ID : see in FL-LT
TG-TEXT : text of the telegram

* This is a logical description of commands and the order of the parameters is not necessarily as shown. For precise formats, see § 18 and fig. 13.

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FL-INIT/FL-ID/S1,S2,...SN/PI,PJ,...PL

Used to initialize a session on a flow

FL-INIT : op-code of that command
FL-ID : see in FL-LT
SI : indicates wether or not service number "I" is required
SI = 0 means "no"
SI = 1 means "yes"

The following services are defined :
1 : error control on letters
2 : flow control on letters (implies S1)
3 : reduced addressing

Any combination of those defined services is valid, except flow control implies error control (S1 = 0 and S2 = 1 is not valid).
E.g. : S1 = 1, S2 = 1 and S3 = 0 means error and flow control without reduced addressing.

PI : parameters of initialization of service number "I"
P1 : no parameter for error control on letters
P2 : MY LT LG
P3 : MY PG NB

PI,PJ,...PL : list of parameters for required services.
If a service SK is not required, the associated parameter PK is not in that list.
If a service SK is required but has no associated parameter (e.g. error control on LT), PK is neither in that list.
E.g. : (1) S1 = 1, S2 = 0, S3 = 0
the list of parameters is empty
(2) S1 = 0, S2 = 0, S3 = 1
list of parameters = MY-PG-NB
(3) S1 = 1, S2 = 1, S3 = 1
list of parameters = MY-LT-LG/MY-PG-NB

MY LT LG : maximum size (in octets) of the letters to be sent on that flow by the TS originating the command.
MY PG NB : PG-NB allocated to that flow in the TS originating the command.

FL-TERM/FL-ID/TERM-REASON

Used to terminate a session on a flow, or to refuse initialization.

FL-TERM : op-code of that command
FL-ID : see in FL-LT
TERM-REASON : reason of the termination. The following possible values have been specified :

0 : "any reason" (should be used when no more precise explanation is available)

1 : "PT not active" (this port is not handled at the present time)

2 : "SB requests to terminate of refuses to initialize"

3 : "parameters not accepted" (e.g. LT-LG to big for the receiver)

4 : Unrecoverable error

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- PG-LT/YR-PG-NB [/YR-REF [/CRD-NB]] /MY-REF/FR-NB/EOL/FR TEXT

Used during sessions with reduced addressing to send fragments of letters as well as possible acknowledgment and allocations (see FL-LT).

PG-LT : op-code of that command
YR-PG-NB : plug number allocated to that flow in the TS destination of that command
Others : see in FL-LT

PG-ACK/YR-PG-NB/YR REF [/CRD-NB]

Used, during sessions with reduced addressing, to send acknowledgments and allocations when no PG-LT command on that flow is available to carry that reverse control information.

PG-ACK : op-code of that command
YR-PG-NB : see in PG-LT
Others : see in FL-ACK

PG-TG/YR-PG-NB/TG TEXT

Used, during sessions with reduced addressing, to send telegrams.

PG-TG : op-code of that command
YR-PG-NB : see in PG-LT
TG-TEXT : see in FL-TG

FL-ERROR/FL-ID/ERROR-CODE/BEGINNING OF ERRONEOUS COMMAND

Used to indicate that an erroneous command has been received on that flow.

FL-ERROR : op-code of that command
FL-ID : see in FL-LT
ERROR-CODE : gives some indication on the error detected. The following possible values have been specified so far : 0 any error.
BEGINNING OF COMMAND : copy of the first octets of the erroneous command.

15. PARAMETERS FORMAT.

PT-ID = SB-NB/PT-NB	16 bits
FL-ID = DEST-PT-ID/SRCE PT-ID	32 bits
MY-REF or YR-REF	8 "
FR-NB	7 "
EOL	1 "
CRD-NB	4 "
FR-TEXT	n x 8 "
TG-TEXT	16 "
PG-NB	8 bits
S1/S2/.../S8	8 "
LT-LG	16 "
TERM-REASON	8 "
ERROR-CODE	8 "
Op-Codes	4/8 "

.../...

16. PT-ID FORMAT.

The transport protocol handles PT-ID as a whole and is not directly concerned with the subdivision of that field :

PT-ID = SB-NB / PT-NB

However the existence of SB is most important for protection, and accounting and will also be used by higher levels of protocols. Transport stations offer subscriptions, each SB being responsible for proper handling of its ports. Most SBs only need a few (e.g. 16) ports. Therefore, two kinds of SBs are defined :

	PT-ID x x x x x x x x x x x x x x x x	
"Few-Ports SBs"	SB-NB 0 x x x x x x x x x x x	PT-NB x x x x
"Many-Ports SBs"	SB-NB 1 x x x x x x x	PT-NB x x x x x x x x
	8	8

Each TS has then a maximum of :

. 2048 "few-ports SBs" with 16 ports each

. 128 "many-ports SBs" with 256 ports each

17. OP-CODES FORMAT.

The first octet of the command contains the op-code. In some cases, room is left for one parameter. It is coded as follows :

	1st OCTET							
Command	0	1	2	3	4	5	6	7
FL-LT	0	0	1	1	CRD-NB			
FL-ACK	0	0	1	0	CRD-NB			
FL-TG	0	0	0	0	not used (set to 0)			
FL-INIT	0	1	0	0	0	0	0	0
FL-TERM	0	1	0	0	0	0	0	1
FL-ERROR	0	1	0	0	0	0	1	0
PG-LT	1	0	1	1	CRD-NB			
PG-ACK	1	0	1	0	CRD-NB			
PG-TG	1	0	0	0	not used (set to 0)			

.../...

18. COMMAND FORMAT (see fig. 13).

Each command starts with its op-code followed by the sequence of parameters as indicated below :

FL-LT/CRD-NB/FL-ID/YR-REF/MY-REF/EOL/FR-NB/FR-TEXT

If no error control, then YR-REF = 0
If no flow control, then CRD-NB = X 'F'

FL-ACK/CRD-NB/FL-ID/YR-REF

If no flow control, then CRD-NB = X 'F'

FL-TG/FL-ID/TG-TEXT

PG-LT/CRD-NB/YR-PG-NB/YR-REF/MY-REF/EOL/FR-NB/FR-TEXT

If no error control, then YR-REF = 0
If no flow control, then CRD-NB = X 'F'

PG-ACK/CRD-NB/YR-PG-NB/YR-REF

If no flow control, then CRD-NB = X 'F'

PG-TG/YR-PG-NB/TG-TEXT

FL-INIT/FL-ID/S1/.../S8/P1/...P8

If SI = 0 then PI does not exist
If S1 = 1 then P1 does not exist either (error control on LT)
If S2 = 1 then P2 = MY-LT-LG (flow control on LT)
If S3 = 1 then P3 = MY-PG-NB (reduced addressing)
S4, S5, ..., S8 = 0

E.g. error control, without flow control, with reduced addressing will be :

S1 = 1/S2 = 0/S3 = 1/S4 = 0/.../S8 = 0/P3 = MY-PG-NB

Error and flow control, without reduced addressing will be :

S1 = 1/S2 = 1/S3 = 0/S4 = 0/.../S8 = 0/P2 = MY-LT-LG

FL-TERM/FL-ID/TERM-REASON

FL-ERROR/FL-ID/ERROR-CODE/FIRST 8 OCTETS OF ERRONEOUS COMMAND

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19. TRANSPORT INTERFACE.

That interface should allow SBs to send and receive letters and telegrams within its flows and to request special services when needed. The primitive interactions between TS and SB can be summarized as follows :

	SB to TS	TS to SB
Sending a letter	DEST-TS/FL-ID LT-TEXT	
Receiving a letter		SRCE-TS/FL-ID LT-TEXT
Sending a telegram	DEST-TS/FL-ID TG-TEXT	
Receiving a telegram		SRCE-TS/FL-ID TG-TEXT
Opening sessions (i.e. request for additional services)	SB request or acceptation or refusal	Distant request or acceptation or refusal
Closing sessions	SB request	Distant request

Though not listed here, error conditions might of course come back from TS to SB.

Each TS must know its SBs and their PTs, some of which may be active, some others inactive. That knowledge may be passed to the TS during interactions with SBs through their interface or may be in other cases part of the TS code (static knowledge).

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20. ACKNOWLEDGMENTS.

This set of proposals is certainly not the final say on the subject. However, it attempts to evolve a synthesis of various earlier studies. Full considerations have been given to software manufacturer's problems, since host-host protocols will presumably be integrated in the core of future operating systems. In particular, several improvements were introduced after stimulating discussions with E. ANDRE, B. JACQUIOT and J.F. LASSALLE (CII). Various concepts and mechanisms took shape in the course of discussions within IFIP-TC6.1 (INWG), and have already been formulated by V. CERF and B. KAHN (ARPANET). Substantial inspiration is due to D. DAVIES (NPL), whose pioneering work is permeating most present day network issues. Lastly, L. POUZIN's (CYCLADES) keen and sensible views on networking deeply influenced the fundamental options of that design.

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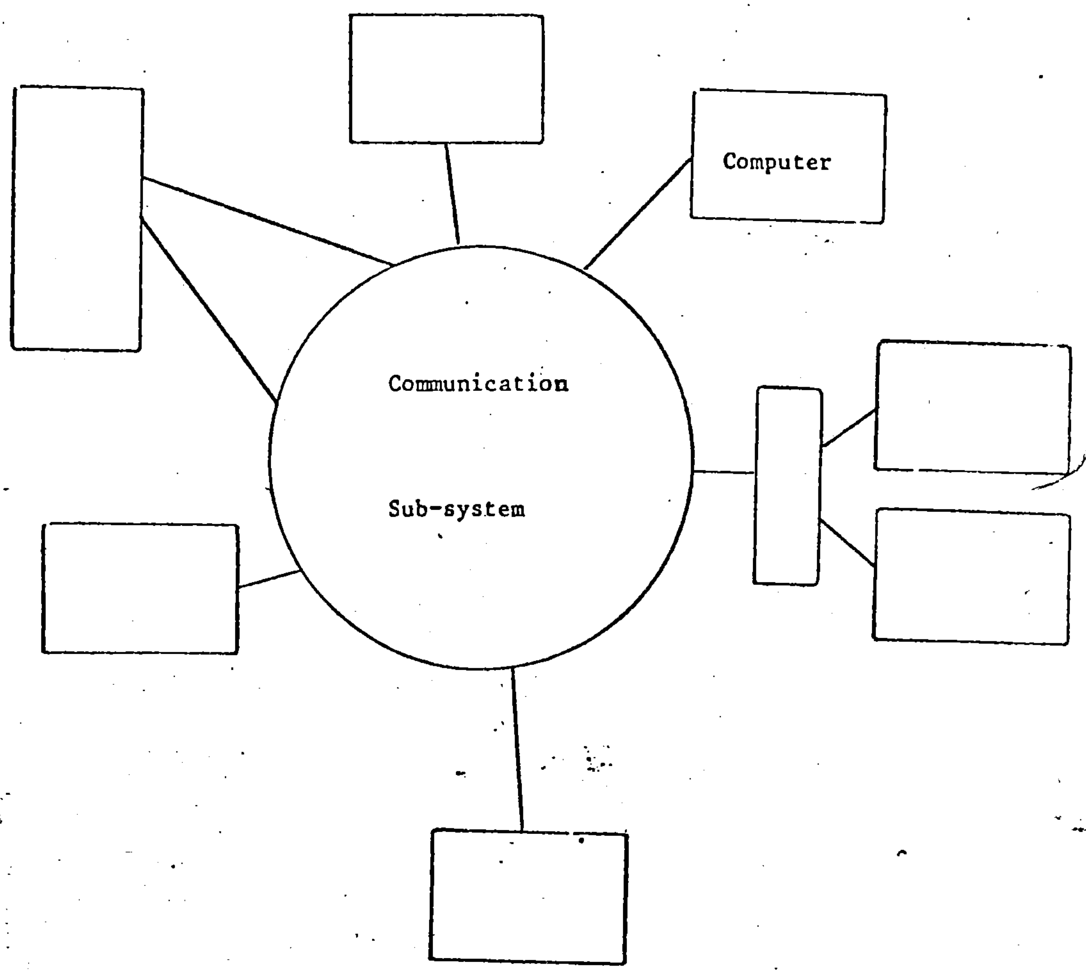


Figure 1. - Computer Network

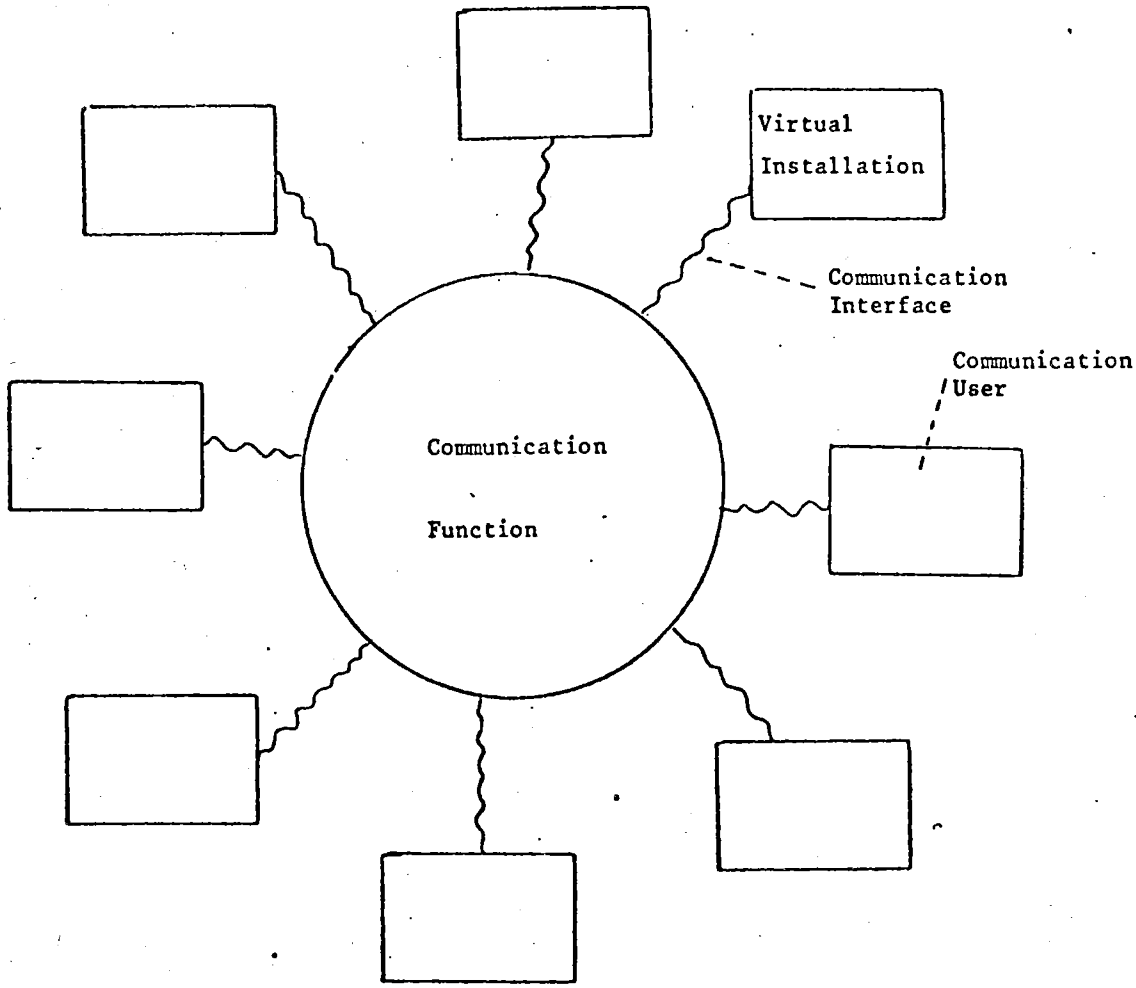


Figure 2. - Virtual installations

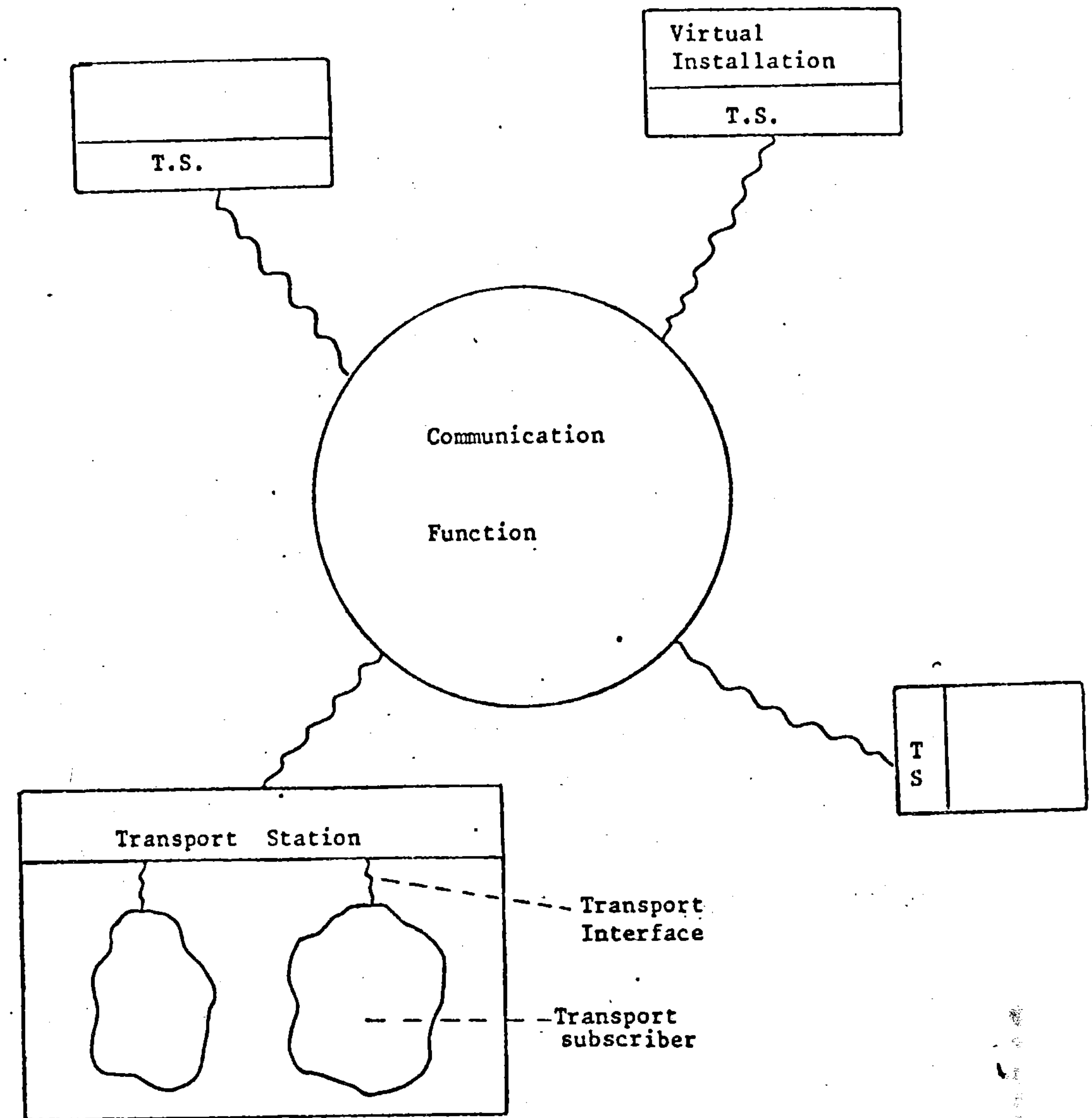


Figure 3. - Transport stations

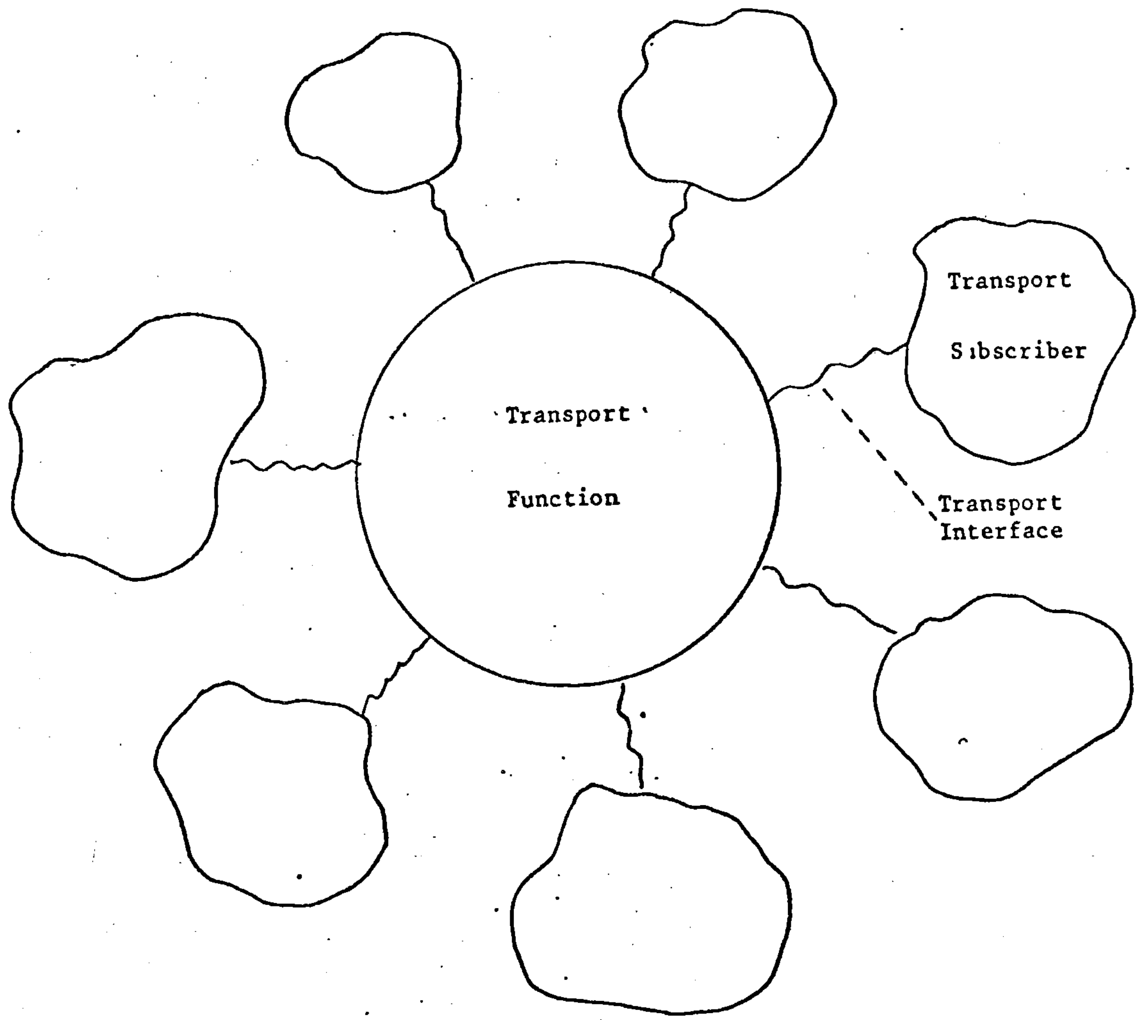


Figure 4. - Transport function

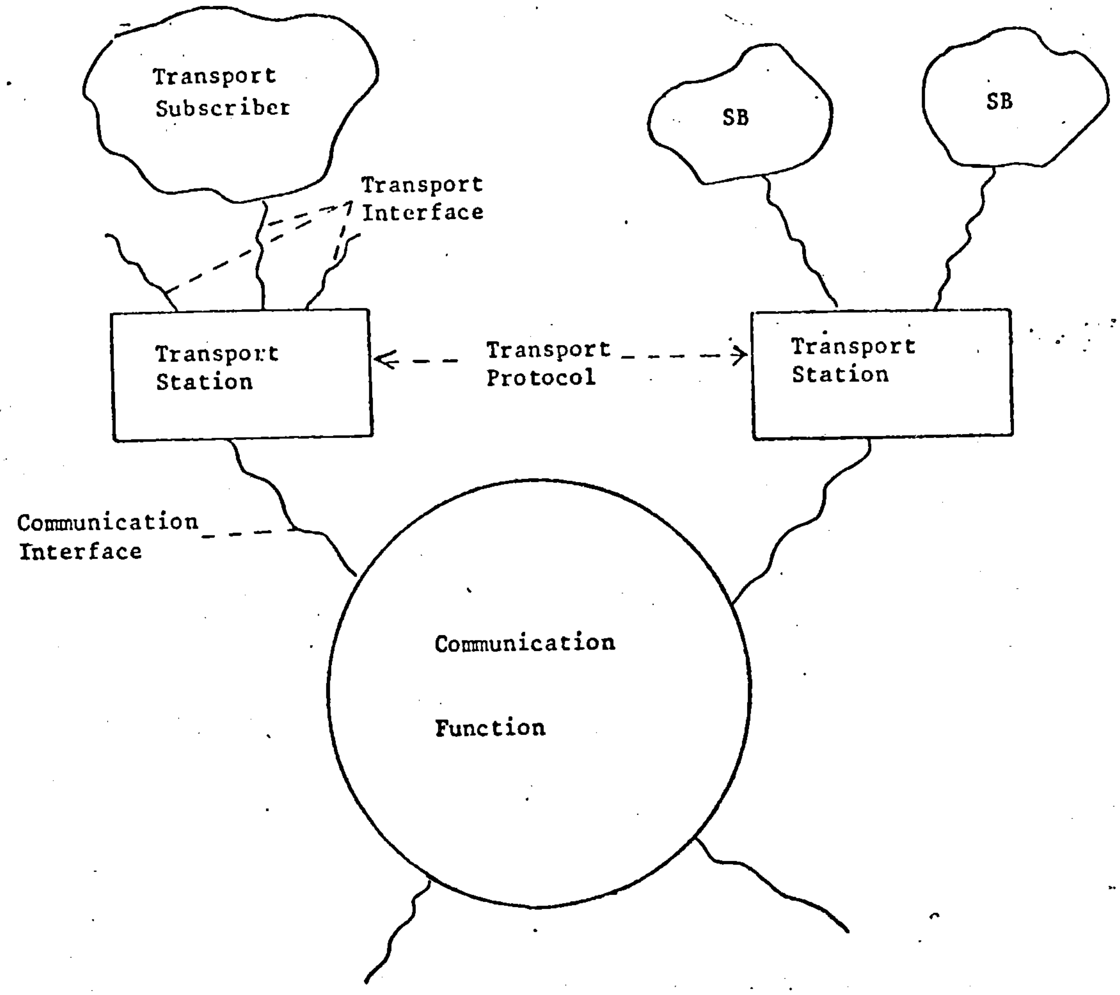


Figure 5. - Transport protocol (a)

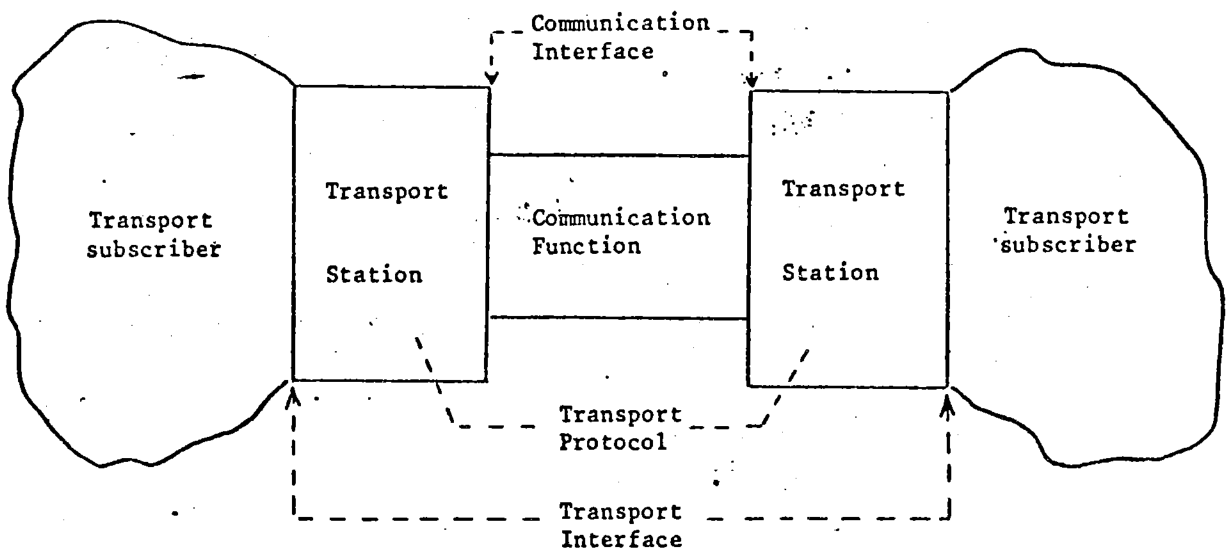


Figure 6. - Transport protocol (b)

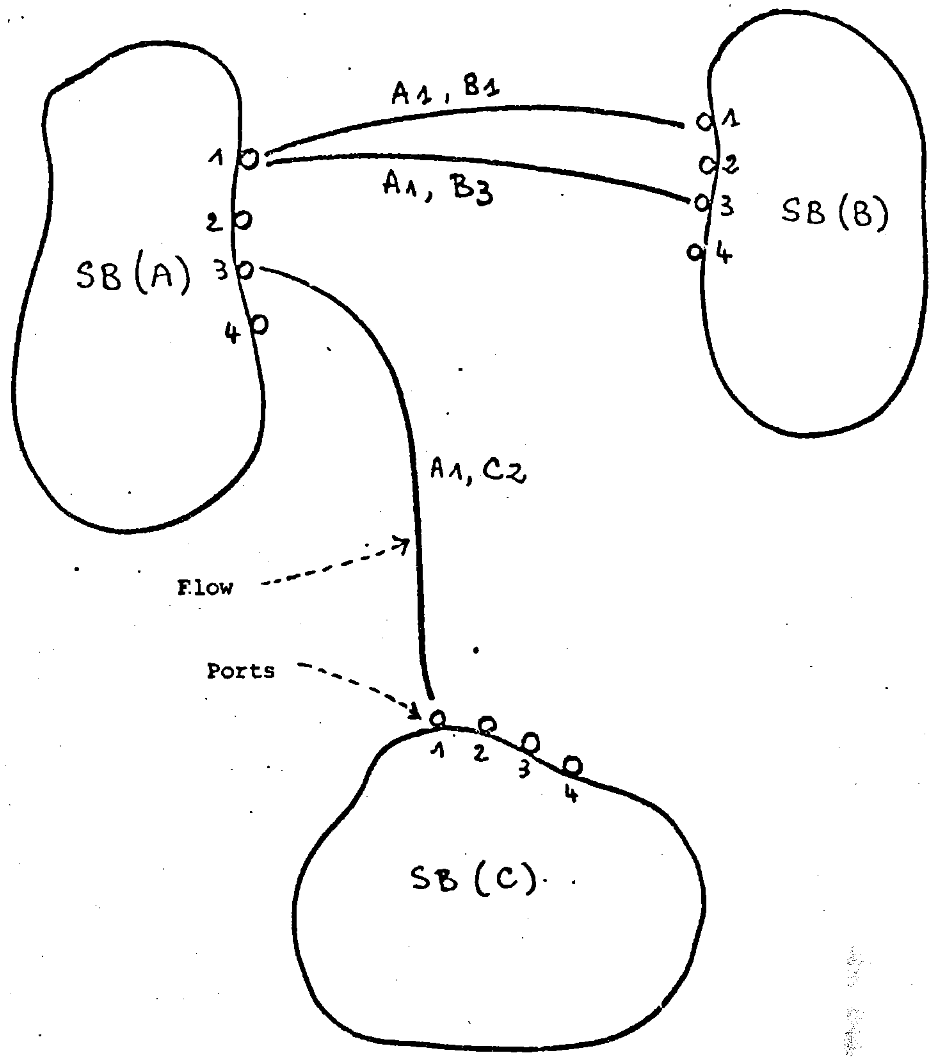


Figure 7. - Transport subscriber ports

PACKET HEADER	PACKET TEXT

DEST TS NB	SRCE TS NB	TEXT LG	PACKET TEXT

Figure 8. - Minimum packet format

Packet Header	Packet Text = Flow Command

Figure 9.-Commands and packets

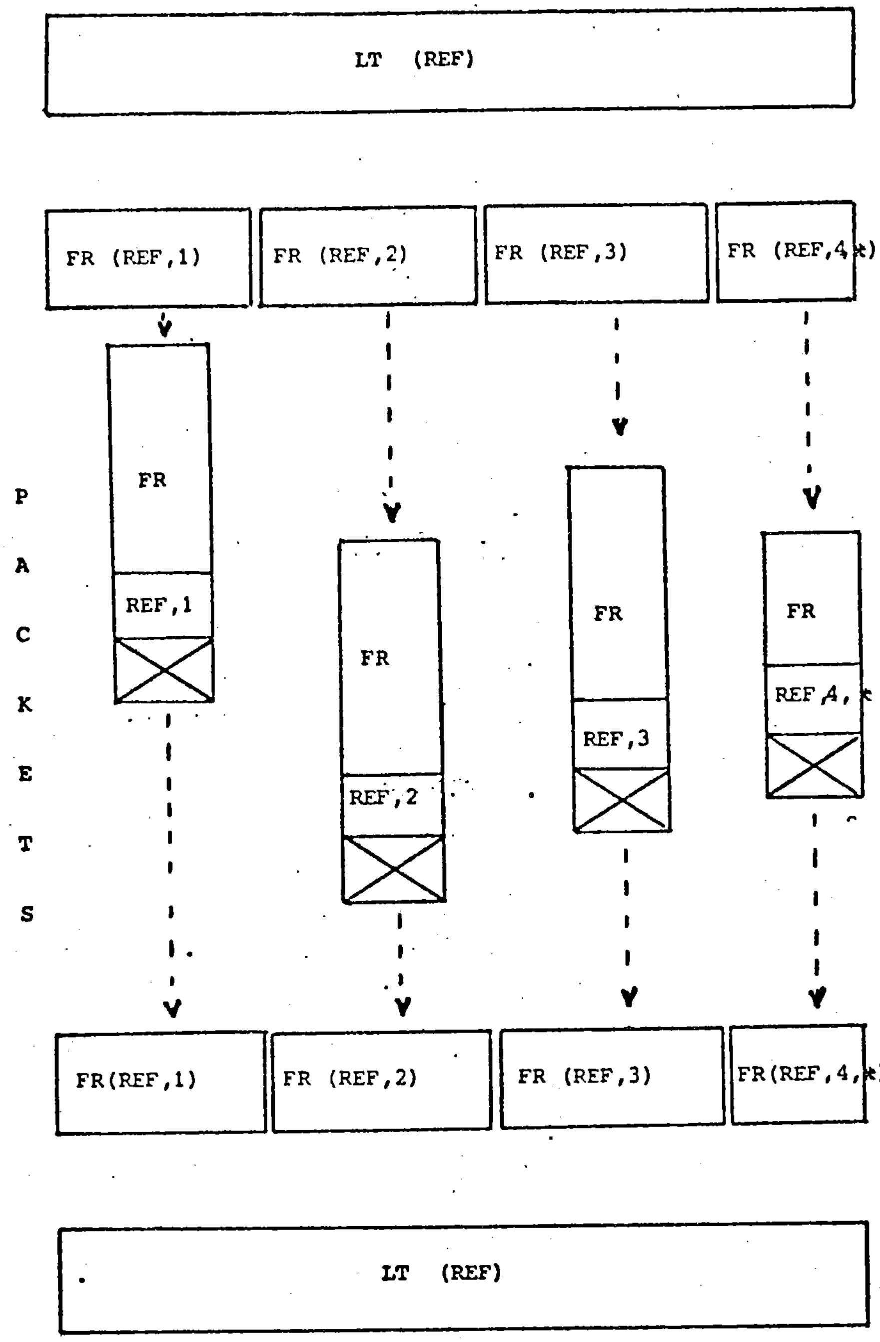


Figure 10. - Fragmentation reassembly

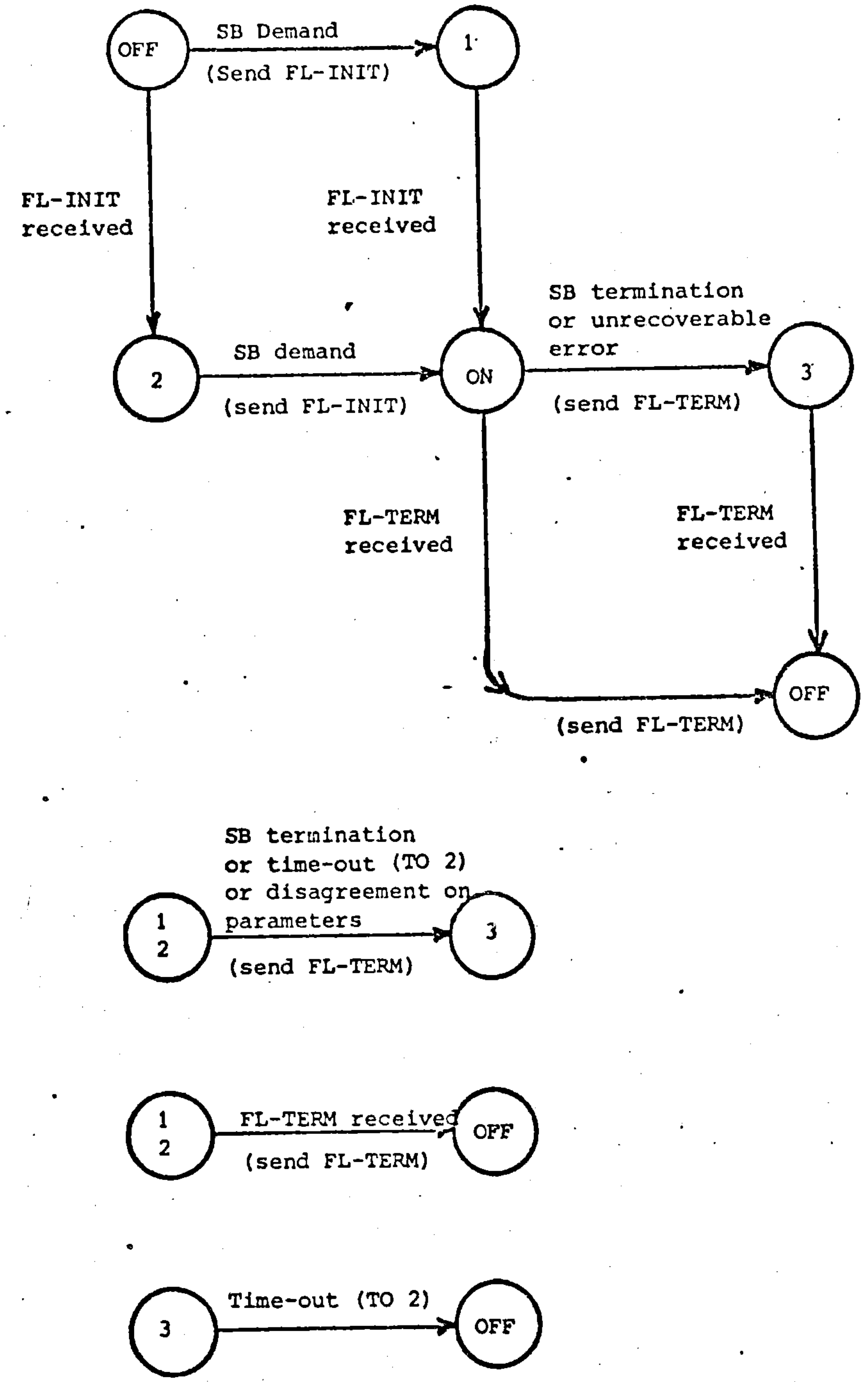
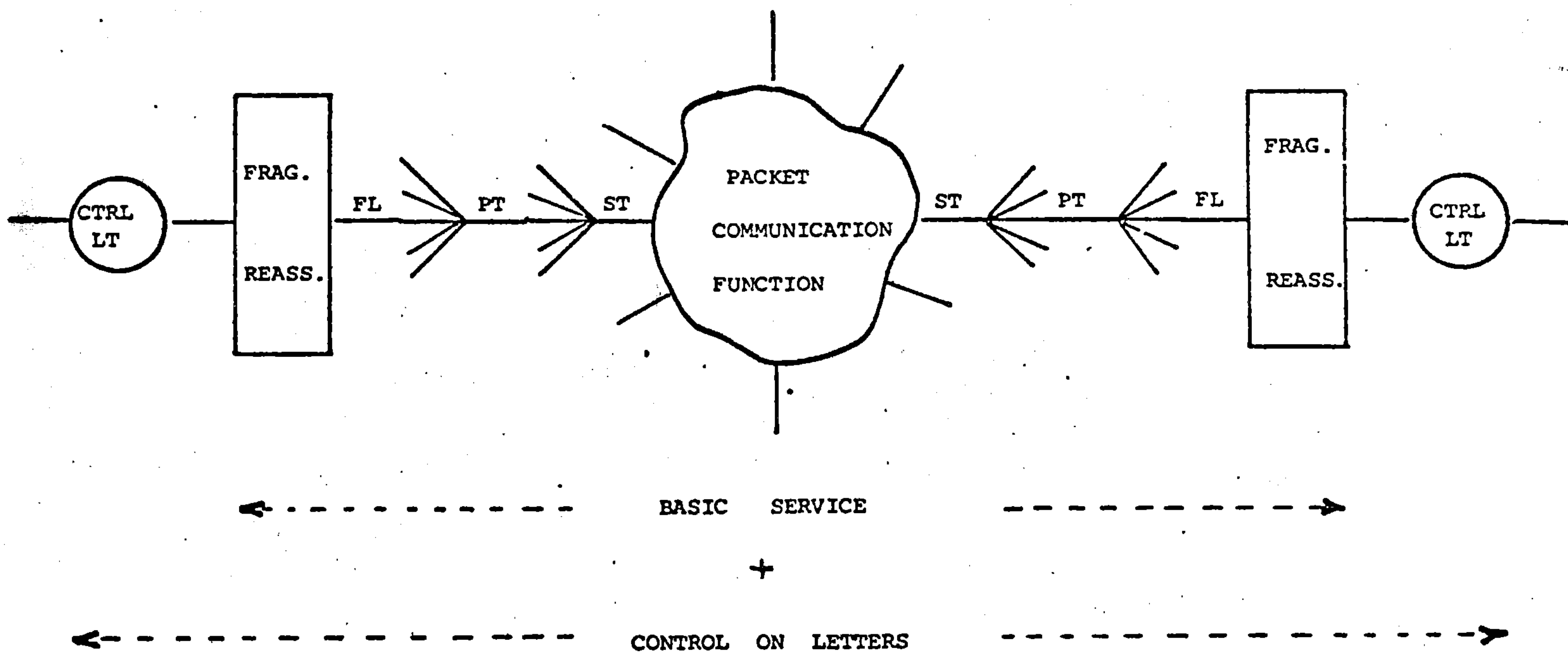


Figure 11. - Session negotiation state diagram



<u>Figure 12.</u> - <u>Transport services architecture</u>

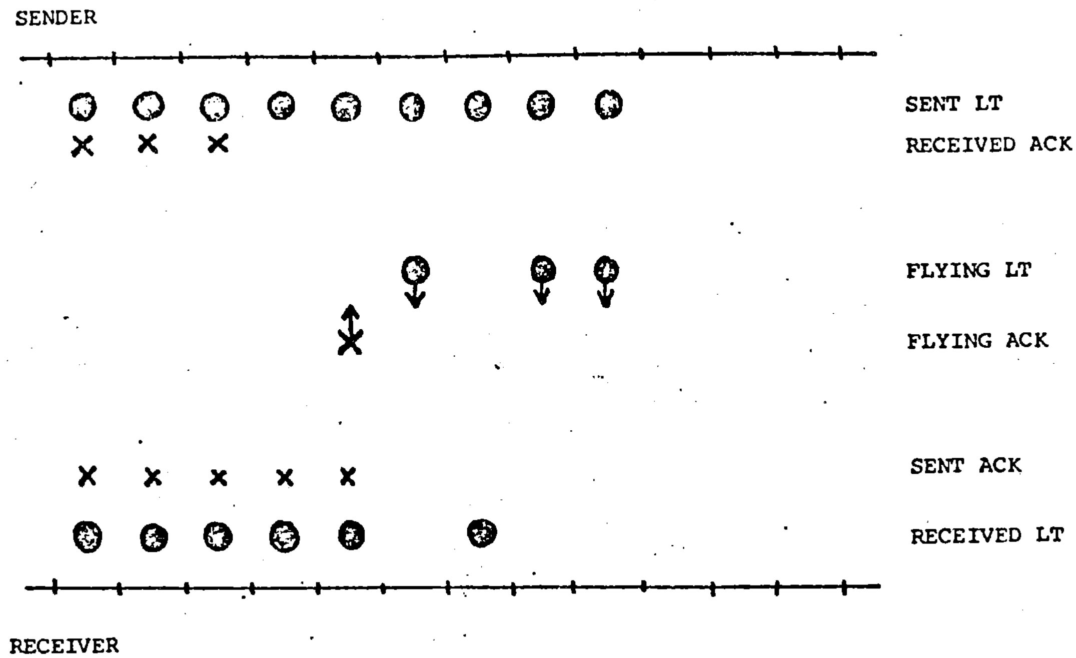


Figure 13. - Error control on letters

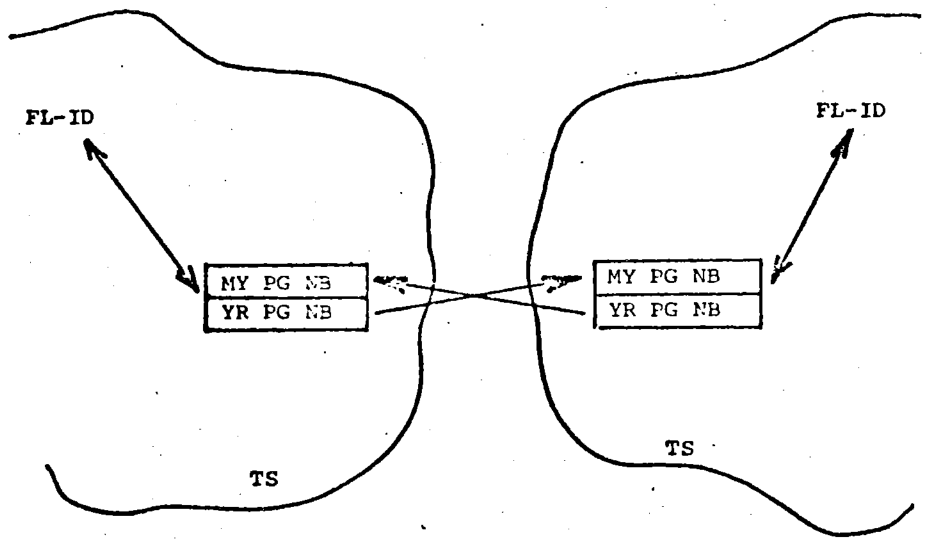


Figure 14. - Reduced addressing

Octet 0		1	2	3	4	5	6	7	8	. . . .
FL LT	CRD-NB	DEST PT-ID		SRCE PT-ID		YR-REF	MY-REF	EOL/FR-NB	FR-TEXT	. . . .
FL ACK	CRD-NB	DEST PT-ID		SRCE PT-ID		YR-REF				
FL-TG		DEST PT-ID		SRCE PT-ID		TG-TEXT				
FL-INIT		DEST PT-ID		SRCE PT-ID		S1/.../S8	P1/.../P8			
FL-TERM		DEST PT-ID		SRCE PT-ID		TERM-REASON				
PG-LT	CRD-NB	YR-PG-NB	YR-REF	MY-REF	EOL/FR-NB	FR-TEXT . . .				
PG-ACK	CRD-NB	YR-PG-NB	YR-REF							
PG-TG		YR-PG-NB	TG-TEXT							
FL-ERROR		DEST PT-ID		SRCE PT-ID		FIRST 8 OCTETS OF THE ERRONEOUS COMMAND				

Fig. 15.- Commands format