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Request for Comments: 979 BBN Communications Corp.

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PSN END-TO-END FUNCTIONAL SPECIFICATION

Status of this Memo

This memo is an updated version of BBN Report 5775, "End-to-End

Functional Specification". It has been updated to reflect changes

since that report was written, and is being distributed in this form

to provide information to the ARPA-Internet community about this

work. The changes described in this memo will affect AHIP (1822

LH/DH/HDH) and X.25 hosts directly connected to BBNCC PSNs.

Information concerning the schedule for deployment of this version of

the PSN software (Release 7.0) in the ARPANET and the MILNET can be

obtained from DCA. Distribution of this memo is unlimited.

1 Introduction

This memo contains the functional specification for the new BBNCC PSN

End-to-End (EE) protocol and module (PSN stands for Packet Switch

node, and has previously been known as the IMP). The EE module is

that portion of the PSN code which is responsible for maintaining EE

connections that reliably deliver data across the network, and for

handling the packet level (level 3) interactions with the hosts. The

EE protocol is the peer protocol used between EE modules to create,

maintain, and close connections. The new EE is being developed in

order to correct a number of deficiencies in the old EE, to improve

its performance and overall throughput, and to better equip the PSN

to support its current and anticipated host population.

The initial version of the new EE is being fielded in PSN Release

7.0. Both the old and new EEs are resident in the PSN code, and each

PSN may run either the old or the new EE (but not both) at any time,

under the control of the Network Operations Center (NOC). The NOC

has facilities for switching individual PSNs or the entire network

between the old and new EEs. When the old EE is running, PSN 7.0's

functionality is equivalent to that provided by PSN 6.0, and the

differences listed in this memo do not apply. Hosts on PSNs running

the old EE cannot interoperate with hosts on PSNs running the new EE.

There are two additional sections following this introduction.

Section two describes the motivation and goals driving the new EE

project.

Section three contains the new EE's functional specification. It

describes the services provided to the various types of hosts that

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are supported by the PSN, the addressing capabilities that it makes

available, the functionality required for the peer protocol, and the

performance goals for the new EE.

Two notes concerning terminology are required. Throughout this

document, the units of information sent from one host to another are

referred to as "messages", and the units into which these messages

are fragmented for transmission through the subnetwork are referred

to as "subnet packets" or just "packets". This differs from X.25's

terminology; X.25 "packets" are actually messages. Also, in this

report the term "AHIP" is used to refer to the ARPANET Host-IMP

Protocol described in BBN Report 1822, "Specifications for the

Interconnection of a Host and an IMP".

2 Motivation

The old EE was developed almost a decade ago, in the early days of

packet-switching technology. This part of the PSN has remained

stable for eight years, while the environment within which the

technology operates has changed dramatically. At the time the old EE

was developed, it was used in only one network, the ARPANET. There

are now many PSN-based networks, some of which are grouped into

internets. Originally, AHIP was the only host interface protocol,

with NCP above it. The use of X.25 is now rapidly increasing, and

TCP/IP has replaced NCP.

This section describes the needs for more flexibility and increases

in some of the limits of the old EE, and lists the goals which this

new design should meet.

2.1 Benefits of a New EE

Network growth and the changing network environment make improved

performance, in terms of increasing the PSN's throughput, an

important goal for the new EE. The new EE reduces protocol

traffic overhead, thereby making more efficient use of network

line bandwidth and transit PSN processing power.

The new EE provides a set of network transport services which are

appropriate for both the AHIP and X.25 host interfaces, unlike the

old EE, which is highly optimized for and tightly tied to the AHIP

host interface.

The new EE has an adjustable window facility instead of the old

EE's fixed window of eight outstanding messages between any host

pair. The old EE applies this limit to all traffic between a pair

of hosts; it has no notion of multiple independent channels or

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connections between two hosts, which the new EE allows. A network

with satellite trunking, and consequently long delays, is an

example of where the new window facility increases the EE

throughput that can be attained. TACs and gateways provide

another example where the old EE's fixed window limits throughput;

all of the traffic between a host and a TAC or a gateway currently

uses the same EE connection and is subject to the limit of eight

outstanding messages, even if more than one user's traffic flows

are involved. With the new EE, this restriction no longer

applies.

Supportability also motivates rewriting the EE software. The new

EE can be written using more modern techniques of programming

practice, such as layering and modularity, which were not as well

understood when the old EE was first designed, and which will make

the EE easier to support and to enhance.

Finally, the new EE includes a number of new features that improve

the PSN's ability to provide services which are more closely

optimized to what our customers need for their applications.

These include new addressing capabilities, precedence levels,

end-to-end data integrity checks, and monitoring and control

capabilities.

2.2 Goals for the New EE

The new EE's X.25 support is greatly improved over that provided

by the old EE. One element of this improvement is at least

halving the amount of per-message EE protocol overhead. Another

element is the unification of the different storage allocation

mechanisms used by the old EE and X.25 modules, where data

transferred between the old EE and X.25 must be copied from one

type of structure to the other.

The new EE presents, as much as possible, a non-blocking interface

to the hosts. If a host overwhelms the PSN with traffic, the PSN

ultimately has to block it, but this should happen less frequently

than at present.

In the old EE, all of the hosts contend for the same pool of

resources. In the new EE, fairness is enforced in resource

allocation among different hosts through per-host minimum

allocations for buffers and connection blocks as part of a general

buffer management system. This insures that no host can be

completely "shut out" of service by the actions of another host at

its PSN.

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The EE supports four precedence levels and optional (on a per-

network basis) preemption features.

Addressing capabilities have been extended to include hunt groups.

Instead of a fixed window of eight outstanding messages between

any host pair, the maximum window size on an EE connection is

configurable to a maximum of 127. The EE allows host pairs to set

up multiple connections, each with an independent window.

A result of the old EE's reliance on destination buffer

reservation is that subnet packets can be lost if an intermediate

node goes down. The new EE uses source buffering with

retransmission in order to provide more reliable service.

The new EE has a duplex peer protocol, allowing acknowledgments to

be piggybacked on reverse traffic to reduce protocol overhead.

When reverse traffic is not available, acknowledgments are

aggregated and sent together.

The result of this development will be end-to-end software with

greater performance, supportability, and functionality.

3 End-to-End Functionality

This section contains the new EE's functional specification. It

describes the services provided to the various types of hosts that

are supported by the new EE, the addressing capabilities that it

makes available, the functionality required for the peer protocol,

the performance goals for the new EE, the EE's network management

specification, and provisions for testing and debugging.

3.1 Network Layer Services

The most important part of designing any new system is determining

its external functionality. In the case of the new EE, this is

the network layer services and interfaces presented to the hosts.

3.1.1 Common Functionality

The following three sections list details concerning the new

EE's support for the X.25, AHIP and Interoperable network layer

services. In the interest of brevity, however, additional

functionality available to all three services is listed herein:

o In order to check data integrity as packets cross through

the network, the old EE relies on a trunk-level,

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hardware/ firmware-generated, per-packet CRC code (which

is either 16 or 24 bits in size, depending on the PSN-PSN

trunk protocol in use) and a software-generated

per-packet 16-bit checksum. Neither of these are

end-to-end checks, only PSN-to-PSN checks. For the new

EE, the software checksum has been extended to be an

optional 32-bit end-to-end checksum, and the per-packet

software checksum has been reduced to a parity bit.

The network administration now has a choice as to which

is most important, efficient utilization of network

trunks (due to the reduced size of the per-packet

headers), or strong checks on data integrity.

Those hosts that require strong data integrity checking

can request, in their configuration, that all messages

originating from this host include a 32-bit per-message

end-to-end checksum. This checksum is computed in the

source PSN, is ignored by tandem PSNs along the path, and

is checked in the destination PSN. If the checksum does

not check, the EE's regular source retransmission

facilities are used to have the message resent.

o The old EE's access control mechanism allows 15 separate

communities of interest to be defined, and uses an

unnecessarily complicated algorithm to define which

communities can intercommunicate. This mechanism is

being expanded to allow 32 communities of interest,

rather than the previous limit of 15. The feature that

allowed hosts to communicate with a community without

actually being a member of that community has been

removed because it was never utilized.

o The addressing capabilities of the PSN have been improved

by the new EE. In addition to continuing to support the

old EE's logical addressing facility, hunt groups (for

both AHIP and X.25 hosts) have been added. These are

described further in Section 3.2.

o Connection block preemption is supported on a

configurable per-network basis. If a network is

configured to use connection block preemption, then

lower-precedence connections can be closed by the PSN,

if necessary, in order to maintain configured

reserves of PSN resources for higher-precedence

connections.

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o The new EE supports congestion control and improved

resource allocation policies which ensure fairness and

graceful degradation of service under extreme load.

Certain resources can be prereserved to each host port,

and each port can also be limited in its use of shared

resources. This ensures that no host can be totally shut

out from PSN resources by the actions of other hosts at

the same PSN. In addition, each PSN is sensitive to

congestion in both of the PSNs at the endpoints of each

connection, and it can exert backpressure (flow control)

on hosts, as necessary, to prevent congestion.

3.1.2 X.25

The new EE's X.25 service represents an improvement over the

X.25 service available from the old EE. The following

paragraphs summarize the X.25 support in the new EE:

o The new EE provides both DDN Standard and Basic X.25

service, as described in BBN Reports 5476, "DDN X.25 Host

Interface Specification," and 5500, "C/30 PSN X.25

Interface Specification," respectively. In addition, the

description of DDN Standard Service, Version 2, is found

in Section 3.1.4 of this document.

o All data packets and call requests are source-buffered in

the source PSN to provide a better level of reliability

for network traffic. This should keep the network from

issuing a reset on an open connection as a result of a

lost packet in the subnet or any other occasional

subnetwork failure. Except in cases of extreme network

or node congestion, recovery from lost subnet packets is

automatic and transparent to the end user or host.

o Both local and end-to-end significance for host window

advancement (based upon the D bit from the host) are

planned, but only end-to-end significance is included in

the initial release (the old EE did not include local

significance). The D bit is passed through the network

transparently.

3.1.3 AHIP

Another service provided by the new EE is defined in BBN Report

1822, "Specifications for the Interconnection of a Host and an

IMP", as amended by Report 5506, "The ARPANET 1822L Host Access

Protocol". This ARPANET Host-IMP Protocol (AHIP) service is

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supported in a backwards-compatible manner by the new EE; since

this is a BBNCC-private protocol, the new EE can improve the

service to better match its current uses (the AHIP protocol was

first designed over twelve years ago). The main changes to

AHIP are to remove the absolute eight-message-in-flight

restriction for connection-based traffic, and to improve the

PSN's "datagram" support for non-connection-based traffic.

For this new support, datagram service is planned (for PSN

Release 8.0) to include fragmentation and reassembly by the

network, but without requiring the network overhead used by

connections, and without the reliability, message sequencing,

and duplicate detection that connections provide. However,

"destination dead" indications will be provided to the source

host where possible and appropriate.

With the new EE, hosts are also able to create multiple

connections between host pairs by using the 8-bit "handling

type" field to specify up to 256 different connections. The

field is divided into high-order bits that specify the

connection's precedence, and low-order bits that distinguish

between multiple connections at the same precedence level.

Since the new EE is using four precedence levels, the handling

type field is used to specify 64 different connections at each

of the four precedence levels.

AHIP connections will continue to be implicitly created and

automatically torn down after a configurable period (nominally

three minutes) of inactivity, or because of connection block

contention.

To summarize the new end-to-end's AHIP support:

o The old EE's AHIP services are supported in a

backwards-compatible manner (except where listed below).

o The old EE's uncontrolled (subtype 3) message service

will be replaced, in PSN Release 8.0, by the datagram

service mentioned above. This service will provide

fragmentation and reassembly, so that there is no special

restriction on the size of datagrams; will not insure

that messages are delivered in order or unduplicated, or

provide a delivery confirmation; will notify the source

host if the destination host or PSN is dead; will not

require the connection block overhead associated with

connections; and may lose messages in the subnet, without

notification to the source host, in the event of subnet

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congestion or component failures. This service could be

useful for applications that do not need the absolute

reliability or sequentiality of connections and therefore

wish to avoid their associated overhead.

Datagrams are not supported by the new EE in PSN Release

7.0.

o Connections no longer have the old EE's "eight messages

in flight" restriction, and a pair of hosts can be

connected with up to 256 simultaneous implicit

connections. In addition, multiple precedence levels are

supported.

o The new EE supports interoperability between AHIP and

X.25 hosts (see Section 3.1.4 for further details).

o AHIP local, distant, and HDH (both message and packet

mode) hosts are supported. The new EE does not support

VDH hosts. VHA and 32-bit leaders are supported.

o Packet-mode HDH has been extended to allow longer packet

data frames (see BBN Report 1822, Appendix J, for a

description of the HDH protocol). Middle packet frames

can now contain up to 128 octets of data, rather than the

previous 126 (although there must still be an even number

of octets per frame). Last packet frames can now contain

up to 127 octets of data, rather than the previous 125,

and the number of octets need not be even. However, the

maximum total message size is still 1007 data octets. The

PSN uses these new packet frame size limits when sending

packet frames to packet-mode HDH hosts unless the host is

configured to allow only 126-octet frames. In addition,

there are restrictions on packet-mode HDH when

interoperating with DDN Standard X.25 hosts; these

restrictions are discussed in Section 3.1.4.

3.1.4 Interoperability (DDN Standard X.25)

One of the main goals of the new EE is to provide

interoperability between AHIP and X.25 hosts. On the surface,

this may appear difficult, since the two host access protocols

have little in common: X.25 presents a connection-oriented

interface with explicit windowing, while AHIP presents a

reliable datagram-oriented interface with implicit flow

control. However, they both have the same underlying

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functionality: they allow the hosts to submit and receive

messages, and they both provide a reliable and sequenced

delivery service.

The key to interoperability is the fact that in the new EE,

both X.25 and AHIP connections use the same underlying

protocols and constructs. The new EE has AHIP and X.25 Level 3

modules that translate between the specific host protocols and

the EE mechanisms. Since these Level 3 host modules share a

common interface with the EE, the fact that the two hosts on

either side of an EE connection are not using the same access

protocol is largely hidden.

As a result, the new EE supports basic interoperability.

However, there are some special cases that need to be mapped

from one protocol to the other, or just not supported because

no mapping exists. For example, AHIP has no analogue of X.25's

Interrupt packet, while X.25 does not support an unreliable

datagram service such as AHIP's subtype 3 messages. For each

of these cases, the recommendations of BBN Report 5476, "DDN

X.25 Host Interface Specification," have been followed.

The interoperable service provided by the new EE is called DDN

Standard Service, Version 2. Standard Service, Version 1, is

defined in BBN Reports 5760, "Preliminary Interoperable

Software Design," and 5900 Revision 1, "Supplement to BBN

Report Nos. 5476 and 5760".

The major differences between Versions 1 and 2 are:

o Version 2 offers improved performance over Version 1.

o The EE now provides four precedence levels. Therefore,

the four precedence levels allowed in the DDN-private

Call Precedence Negotiation are mapped directly to subnet

precedence levels, instead of being collapsed into two

subnet precedence levels as in Version 1.

o On an interoperable connection, the X.25 protocol ID in

an X.25-originated message is translated to an AHIP link

number (the upper eight bits of the message-ID field)

using a lookup table. Version 1 supports only the IP

protocol ID and corresponding link number of 155

(decimal). Version 2 allows new values to be added to

the lookup table. At present, IP is the only protocol

supported. In addition, the AHIP link number is also

used to distinguish one connection from another. This

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guarantees that when an AHIP host is sending messages to

an X.25 host, messages using different link numbers come

into the X.25 host on different X.25 connections.

o Since a "translation module" is no longer necessary in

the PSN, interoperable connections now have end-to-end

significance, with a direct correspondence between X.25

RRs and AHIP RFNMs. This preserves the meaning of the

RFNM as defined in Report 1822. Although Release 7.0

only offers end-to-end significance, the D bit is passed

transparently on Standard Service connections between two

X.25 hosts.

o Up to 256 simultaneous connections are supported between

host pairs that are using the same addresses and

precedence levels. Version 1 only supported one such

connection.

The following Version 1 services are not offered by Version 2:

o Permanent Virtual Circuits.

o X.25 protocol bypass (a BBN-private service).

A number of items in Report 5760 were the subject of some

discussion, and three of them need to be specifically mentioned

here. First, for DDN Standard Service, Version 1,

acknowledgments have local significance only, and the D bit

must be set to 0 in the call request. In DDN Standard Service,

Version 2, only end-to-end significance is being provided, as

was mentioned above. For backwards compatibility with Version

1, the D bit can be set to 0 or 1 in a call, but hosts are

advised that only end-to-end significance is provided in

Version 2.

Second, non-standard Default Precedence is not supported by

either Standard Service Version 1 or Version 2. Support for

this facility in Version 1 was withdrawn at the request of DCA.

Third, although DTEs are allowed to request maximum packet

sizes of 16, 32, and 64 octets, the DCE always negotiates up to

128 octets, as per Section 6.12 ("Flow Control Parameter

Negotiation") of the CCITT 1984 X.25 Recommendation. This is

true of both Version 1 and Version 2. Since IP and TCP are

required when Standard Service is in use, this is a reasonable

restriction (due to the length of IP and TCP headers).

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One issue must be raised concerning interoperability between

X.25 and packet-mode HDH hosts. In order to efficiently

interoperate, packet-mode HDH hosts should completely fill

their middle packet frames with 128 octets of data.

Packet-mode HDH hosts that send or require receiving middle

packet frames with less than 128 octets of data can still

interoperate with X.25 hosts, but at a greater expense of PSN

CPU resources per message.

3.2 Addressing

The old EE supports, for both AHIP and X.25 hosts, two forms of

host addressing, physical and logical.

Physical addressing consists of identifying a host port by the

combination of its PSN number and the port number on that PSN.

Logical addressing allows an arbitrary 16-bit "name" to refer to a

list of one or more host ports. The EE tries to open a connection

to one of the ports in the list according to the criterion chosen

for that name: first reachable in the ordered list, closest port

(in terms of routing delay), or round-robin load sharing.

For the new EE, logical addressing is supported on an explicit

per-connection basis: all logical-to-physical address translations

take place in the source PSN when a connection is established.

Once this translation has occurred, all data messages on the

connection are sent to the same physical address.

In addition, hunt groups are also now supported for both X.25 and

AHIP hosts. This new capability allows host ports on a

destination PSN to be combined into a "hunt group". The ports

share the same group identifier, and incoming connections are

evenly spread over the ports in the group. This differs from

logical addressing's load sharing, where all name translations

take place in the source PSN, the different ports can be on any

number of PSNs, and the load sharing is on a per-source-PSN basis.

By contrast, all of the host ports in a hunt group are on the same

PSN, the group-to-port resolution takes place in the destination

PSN, and the load sharing of incoming connections can be

guaranteed over the ports by the destination PSN. For X.25, hunt

groups comply with Section 6.24 of the 1984 X.25 Recommendation.

Note that Called Line Address Modification is not supported.

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3.3 Protocol Functionality

The EE peer protocol runs between EE modules in PSNs on either end

of an EE connection. This protocol and its mechanisms have to

perform the following functions:

o Provide full duplex connections (the old EE provides simplex

connections, and any two-way traffic, such as that generated

by TCP, requires two subnet connections).

o Open a connection and optionally send a full message's worth

of data as a part of the open request (the old EE requires a

separate opening sequence in each direction before data can

flow).

o Reliably send connection-oriented messages, properly

fragmented/reassembled and sequenced.

o Close (clear) a connection (normally, or in a "clean-up"

mode after a host or PSN dies).

o Reset a connection (like the X.25 reset procedure).

o Be able to send a limited amount of out-of-band traffic

associated with a connection (like the X.25 interrupt).

o Use source buffering with message retransmission (after a

timeout) to insure delivery (the old EE depends on

destination buffer preallocation, which adds protocol

overhead and cannot recover from lost packets in the

subnet).

o Use an internal connection window of up to 127 messages.

o Support two types of ACKs, Internal ACKs (IACKs) and

External ACKs (EACKs), which are further described following

this list

o Have an inactivity timer for each connection. For AHIP and

Standard X.25, the connection is closed if the timer fires.

For Basic X.25, the EE uses an internal Hello/I-Heard-You

sequence with the PSN on the other end of the connection to

check if the other end's host or PSN is still alive. If

not, then the connection is closed.

o Be able to gracefully handle resource shortages and avoid

reassembly lockup problems.

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As mentioned above, the protocol supports two types of

acknowledgments, IACKs and EACKs. Both types of ACKs apply to

messages only; individual packets are not acknowledged. Since

windowing is being used, an individual ACK can be used to

acknowledge more than one message.

IACKs are used to cancel the retransmission timer and free source

buffering, and are sent when a message has been completely

reassembled and delivered from the EE to either the AHIP or X.25

level 3 module. This allows the EE to avoid unnecessary message

retransmissions, and speeds up the process of freeing source

buffering when destination hosts are slow to accept messages or,

in the case of X.25, slow to advance the PSN's window to the

destination (X.25 does not specify any time limit for a host to

acknowledge that it received a message).

EACKs are used to advance the end-to-end window and to cause one

or more end-to-end X.25 RRs or AHIP RFNMs to be sent to the source

host. An EACK is sent when an X.25 host acknowledges a message or

when an AHIP host actually receives it.

Both types of ACKs are piggybacked, if possible, on reverse

traffic to the source PSN (for any connection). Whenever a packet

is sent to another PSN, it is filled to the maximum allowed

subnetwork packet size with any outstanding ACKs that may be

waiting to be sent to that PSN. After a configurable period, all

outstanding ACKs for the same PSN are aggregated together and

sent. In addition, succeeding ACKs for the same connection can be

combined into one, and EACKs can be used to imply that a message

is being IACKed as well (if the destination host is speedy enough

when receiving or acknowledging messages to allow IACKs and EACKs

to be combined).

This ACK aggregation timer interacts with the source buffering

retransmission timer in the following manner: whenever a message

is sent from a host on one PSN to a host on a second PSN, an IACK

is sent back to the first PSN when the message has been completely

reassembled by the destination EE, and an EACK is sent when it has

been delivered (and perhaps ACKed) by the destination host. The

IACK must make it back to the source PSN within the limits of the

retransmission timer, or unnecessary retransmissions could be sent

across the network. This limits the ACK aggregation timer to

being shorter than the source buffering retransmission timer.

If the destination host is quick enough when accepting traffic

from its PSN (with respect to the ACK aggregation timer), then the

EACK can be combined with the IACK, and only the EACK would be

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sent. If the destination host is even quicker, multiple IACKs and

EACKs could be combined into one EACK. In the best case, if there

is a steady stream of traffic going between the two PSNs in both

directions (but not necessarily over the same connection or even

between the same pairs of hosts in each direction), then all of

the IACKs and EACKs could be piggybacked on data packets and cause

no additional network packets other than the data packets already

required to send the data messages across the network. In the

worst case, however, such as when there is only a one-way flow

from a source PSN to a destination PSN and the destination host is

very slow to accept the messages from the network, then each data

message could result in separate IACKs and EACKs being sent back

to the source PSN in individual packets. However, even though the

IACKs may cause additional packets to cross the network, they are

still less expensive than the source retransmissions that they are

used to prevent, and they also serve to free up valuable source

buffering space.

3.4 Performance and Capacity Goals

Performance and capacity goals for the new EE include:

o Throughput: The AHIP host-host and host-trunk maximum

throughput (in packets/second) will be at least as good as

at present, and should improve for those situations that

currently entail traffic limitations based upon the old EE's

underlying protocol. The current X.25 intrasite host-host

and host-trunk throughput will each improve by at least 50%.

The store-and-forward throughput for the new EE's X.25-based

traffic will improve by at least 100%.

o Connections: The new EE will support at least 500

simultaneous connections per PSN, and will be able to handle

at least 50% more call setups per second than at present.

o Buffering: The EE will have at least 400 packet buffers

available to source-buffer and/or reassemble messages.

o Network size: The EE protocol and module will use data

structure and message field sizes sufficient to support at

least up to 255 hosts per PSN and 1023 PSNs per network

(however, other PSN protocols and modules presently

constrain these figures to 63 hosts per PSN and 253 PSNs per

network).

o Other: The EE will support four message precedence levels

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and a maximum message length of 1024 bytes. For logical

addressing, the EE will support at least 1024 logical names

and at least 2048 address mappings per network.

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