Novell®

NetWare® Link Services Protocol™ (NLSP™) Specification

Draft 2.0

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Contents

1. Introduction

This document defines the NetWare® Link Services Protocol™ (NLSP™) specification, which provides link state routing for Internetwork Packet Exchange™ (IPX™) networks. Routing is the function in network computing that accomplishes two objectives:

- End-to-end delivery of data traffic over an internetwork; an internetwork contains disjoint media segments, so traffic must be relayed from segment to segment to reach its destination.
- Accommodation to the characteristics of the diverse underlying data-link transmission media; the links used in modern networks vary dramatically, and routing smoothes over the differences for the benefit of more general-purpose software components.

Routing is a software function. In this document, a *router* refers to a specialized network node, but a multipurpose system can offer both routing functionality and other kinds of service simultaneously. For example, file service, electronic mail, gateway to mainframe systems, hub, and network management. For brevity, the term *router* indicates a network node that runs routing software, even if it is a multipurpose system.

A router attaches to two or more disjoint segments and forwards data traffic as needed from one segment to another. It exchanges information with other routers to acquire sufficient information to make the best forwarding choices.

NLSP is (essentially) a protocol for information exchange among routers geared to the needs of large IPX internetworks. IPX is the Network-Layer protocol used by the Novell® NetWare network operating system, and by the compatible products of other system providers.

NLSP incorporates the *link state* approach to network-layer routing that is being adopted broadly in the industry. Link state routing can be hierarchical; networked systems are grouped into routing areas and areas are grouped into routing domains. Hierarchy promotes scalability. This specification covers the first level, Level 1 of the hierarchy—the protocol for operation within a routing area. Subsequent specifications will expand the scope to cover hierarchical operation.

1.1. Document Organization

This document is for network software developers who build implementations compatible with Novell's NLSP products.

Section 2 provides an overview of the NLSP design. Reading it provides necessary background for the details covered later.

The subsequent sections specify the protocol and procedures in sufficient detail for implementation. Each contains a *Database* subsection (where applicable), describing constants, configurable parameters, and dynamic values pertinent to that part of the design. The specification in each chapter uses the database items defined not only in that chapter but in previous chapters—the databases are cumulative. Where relevant, each concludes with a *Packet Structures* subsection specifying the formats of messages exchanged among routers.

Section 3 documents the IPX WAN version 2 (IW2) protocol, which specifies initial connection setup methods for various WAN media. It has relevance not only to NLSP, but also to other IPX routing protocols.

Section 4 covers the local database each router maintains to describe the router's immediate neighborhood, and covers the protocol exchanges that take place with neighboring routers to keep the information current.

Section 5 describes methods for the "immediate neighborhood" information to be disseminated throughout a routing area. The routers cooperate to ensure that they keep a consistent, up-to-date representation of the state of all routers and links in the area; hence the name "link state." From the representation, they can make informed decisions about how to forward data traffic.

Section 6 describes the Decision Process, which uses the link state representation to decide the best paths for forwarding data traffic to all destinations accessible in a routing area.

Section 7 covers compatibility with the previously existing RIP and SAP protocols. These two protocols have been used pervasively in IPX internetworks for routing and resource location. With NLSP, they continue to be the protocol used for communication between end nodes and routers. Moreover, for communication among routers, there is a compatibility specification enabling NLSP routers and RIP routers to coexist constructively.

Section 8 itemizes the network management aspects of NLSP operation. The specification there identifies Management Information Base (MIB) variables accessible to management stations from NLSP routers. The MIB supports configuration, monitoring, and troubleshooting.

Section 9 lists design differences between NLSP and the ISO 10589 IS-IS Standard. The core design of NLSP is based on IS-IS, which is familiar in the industry.

Section 10 describes the framing of IPX packets on LANs. It covers the three most common standard media: CSMA/CD, token ring, and FDDI.

Section 11 is a bibliography. References cited in the body of the specification are listed there.

1.2. Typographic Conventions

In this specification, new and important terms and concepts appear in *italic* type when introduced for the first time.

Protocol constants and management parameters appear in sansSerif type with multiple words run together. The first word is lowercase. The first character of each subsequent word is uppercase.

Protocol field names appear in Sans Serif type with embedded spaces and with the first character of each word uppercase.

Descriptive values of constants, parameters, and protocol fields appear enclosed in "double quotation marks." For example, with electric switches:

0 = "Off"
1 = "On"

Patches of pseudocode are in `monospace type`. Unless otherwise specified, arithmetic is performed using non-negative integers, with remainders truncated on division.

Hexadecimal values are preceded by "0x". Numbers appearing without such qualification are decimal. For example, 17 = 0x11.

In diagrams, this document uses a diamond-shaped symbol to represent a router, a horizontal or vertical line to represent a LAN, an oblique line to represent a WAN, and a cloud to represent a collection of networks whose internal organization is not applicable to the immediate discussion. See Figure 1-1.

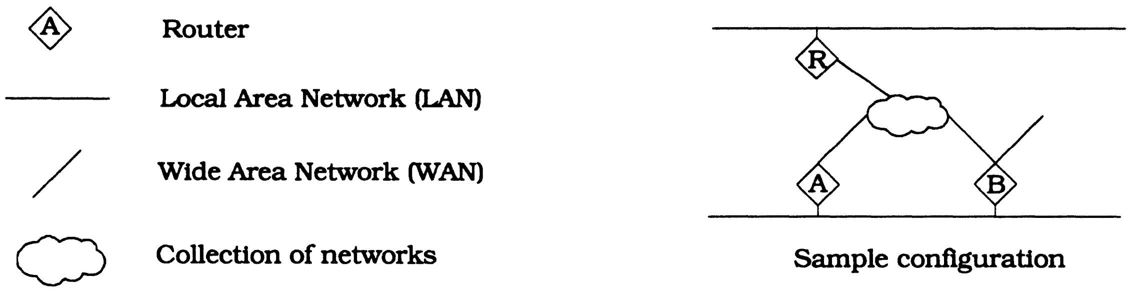


Figure 1-1: Diagram Conventions

2. Basic Concepts

The goal of routing is to convey data traffic from the source end node to the intended destination. Routing methods are implemented in special network nodes called *routers*, which are connected to two or more network segments of like or unlike kind. The router forwards traffic from segment to segment. A given packet might have to be forwarded several times. To make good decisions, routers exchange information with each other about the topology of the internetwork. Several approaches to the information exchange have been used in the industry. The NLSP™ specification uses the*link state* approach. With this approach, every router keeps a road map representing the states of the links and routers in a routing area.

2.1. Link State Databases and Algorithms

The method is called link state because routers keep track of the state of every communication link in a routing area. The router keeps a record of all the routers in the area, the links connecting them, the operational status of the routers and links, and related parameters. NLSP operates within a *routing area* of links and routers. Figure 2-1 illustrates a simple example. Keep the example in mind as the discussion turns to databases, protocols, and algorithms.

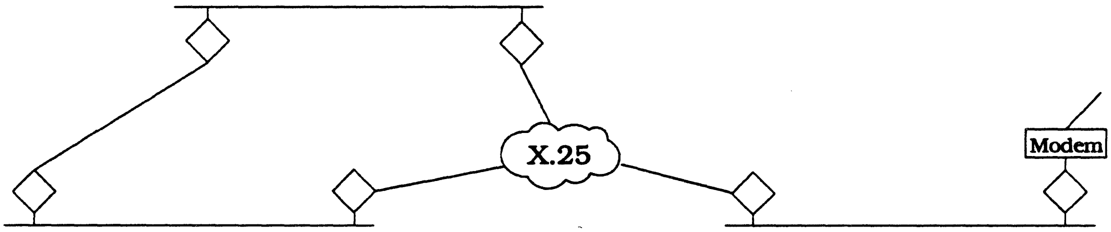


Figure 2-1: Example Internetwork

Figure 2-2 illustrates the data exchanges among routers, the information databases each router maintains, and the processing steps to accomplish routing functions.

In the figure, a horizontal line represents a LAN, an oblique line represents a point-to-point link, and the cloud in the center represents a packet data network using X.25. The diamond-shaped symbols represent routers. End nodes, such as workstations, personal computers, and nonrouting servers, are not shown in the diagram.

Each router maintains a database describing the entire area. For each point-to-point link, the database records the end point routers and the state of the link. For each LAN, the database records the routers connected to the LAN. The X.25 network is modeled as a set of point-to-point links that go up and down as calls are established and cleared. Likewise for the dial-up modem link.

2.1.1. Maintaining Adjacencies between Routers and their Neighbors

The first database, "Adjacency," keeps track of the router's immediate neighbors and the operational status of the directly attached links. Regular exchanges of *Hello* messages maintain this information with each neighbor. When a circuit is enabled, the router begins a periodic transmission of Hello messages and listens for the messages from its neighbors. When the router detects (through these exchanges) that the link is reliably operational, it enters a record of the neighbor (or neighbors) in the Adjacency database. If the exchange is interrupted, the router updates the Adjacency database to reflect this fact. This way, it keeps track of its immediate neighborhood.

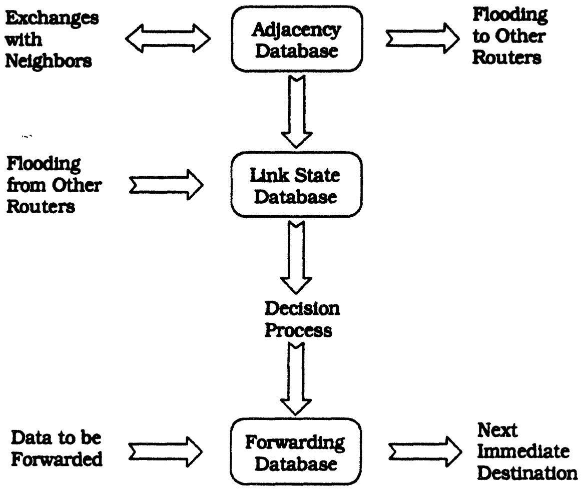


Figure 2-2: NLSP Overview

2.1.2. Synchronizing Link State Information Among Routers

Imagine aggregating the immediate neighborhood information from all routers into one database; it would represent the connectivity of an entire routing area. This is the Link State database. It is helpful to think of the Adjacency database as a subset of the Link State database—the portion describing the directly attached links. (The way things actually work, portions of the Adjacency database are combined with local information to become the part of Link State database describing a router's immediate neighborhood.) The NLSP design aims for every router in a routing area to have a copy of the Link State database locally. Moreover, they synchronize their views of the database among themselves. To a great extent, the work of NLSP is synchronization of a replicated database—keeping the copies of the Link State database consistent among the routers. When a topology change occurs, there is a short transitional period when the copies differ. Operation of NLSP makes them converge again.

The Link State database represents routers and links. It does not represent end nodes; that is, it does not represent client workstations or personal computers.

When all the copies of the Link State database are identical and conform with the actual connectivity of the internetwork, forwarding decisions made by successive routers in a packet's path are consistent with each other. The packet progresses from its source to the intended destination successfully and efficiently. If the copies become different from each other, or if they fail to reflect the connectivity of the internetwork accurately, things can go wrong. A packet can find itself in an endless forwarding loop among routers and eventually be discarded. A packet can be routed into a *black hole*, a router that has no way to progress the packet toward the intended destination. This is why consistency of the Link State database is so important.

When a link comes up or goes down, it takes time for knowledge of that event to percolate throughout the internetwork. Meanwhile, there is a temporary inconsistency. This might wreak havoc for a Network-Layer protocol that guarantees delivery. The IPX™ protocol does not—it operates on a best-effort basis, meaning that occasional data loss is tolerable. Still, any disruption must be minimized by making the Link State databases converge to a consistent view as fast as possible. Experience in the industry indicates that Link State algorithms achieve synchronization faster than other designs for large-scale internetworks.

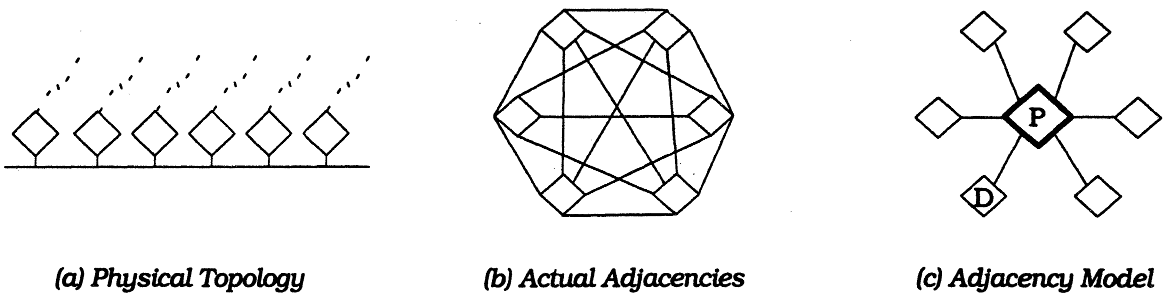
Flooding is the means used to achieve synchronization. Each router sends information from its Adjacency database to each of its neighbors. The information takes the form of *Link State Packets*, or *LSPs*. A numbering scheme detects when the same LSP arrives more than once. When a new LSP arrives—one not seen before—two things happen. First, it is retransmitted on all links except those on which that particular LSP was received. Second, it is merged into the receiving router's Link State database. The database is the collection of LSP packets of two kinds: LSP packets derived from the router's own Adjacency database and LSP packets received from other routers by flooding.

If an adjacency is lost, each router detecting this event floods an LSP indicating that the link is down. This forces routers receiving the LSP to tag the link as down. Records of unreachable destinations are not removed from the Link State database at this point.

Each LSP includes a Remaining Lifetime field, initialized to the value maxAge seconds by the originating router. Each router holding a copy of the LSP counts down the Remaining Lifetime, reinitializing it if a new copy of the LSP arrives. If the LSP times out, it is purged from the Link State database. At the same time, the router doing the purging floods the expired LSP. The purging mechanism cleans up stale information that has little prospect of becoming useful.

2.1.3. Determining a Designated Router and Constructing Pseudonodes

To keep the size of the Link State database reasonable, LANs need special measures. Consider Figure 2-3, which shows many routers connected to the same LAN. Part (a) shows each router able to relay between the LAN and a particular WAN. In terms of physical connectivity, each router can reach all the others in one hop. There is full mesh adjacency, as shown in part (b) (the WAN links are not shown there). If there are *n* routers, this means $n \times (n-1) \div 2$ links.



(a) Physical Topology (b) Actual Adjacencies (c) Adjacency Model

Figure 2-3: Designated Router and Pseudonode

It would be unduly burdensome to convey so much information to all the other routers in the routing domain, and to have them all process the information to make routing decisions. Instead, the LAN adjacencies among the routers are modeled conceptually, as shown in part (c). A fictitious *pseudonode* ("P" in the diagram) represents the LAN as a whole in the Link State database. Each of the routers represents itself as being directly connected to P. There are *n* "links." End nodes are thought of as being directly connected to P, although they are not represented in LSPs. It's unnecessary to represent them—they are located by having the same network number as the pseudonode.

Because P is fictitious, some actual router is chosen to represent P for Link State protocol exchanges. This is the *Designated Router* ("D" in the diagram). A regular protocol exchange occurs among routers of a LAN by which one (and only one) Designated Router is chosen and a replacement takes over in case the original one goes out of service (or becomes ineligible for some other reason). Periodically, every router multicasts a Hello packet on the LAN. The one with the highest priority (a configurable parameter) wins. In case of a tie, the IEEE MAC addresses are compared numerically, and the higher value wins. If a router is attached to several LANs, it might be Designated for some but not for others—the Designated Router election is independent on different LANs, and is decided by priority and address numbers.

The Designated Router originates LSPs on behalf of the pseudonode. If it resigns because a new router has a higher priority, it floods the area with a null LSP indicating that the old pseudonode is no longer valid.

2.1.4. Incorporating Switched Circuits into the Design

Certain wide-area media use switched, connection-oriented data-link media. To reach a remote destination, you initiate a call. If the call is established successfully, you can then transmit data over the connection. Finally, when you are finished, the call can be cleared. Because IPX is a connectionless Network-Layer protocol, there is no necessary association between an application session and a data-link connection.

One type of switched network is a packet-switched network using the X.25 standard. These networks support multiple concurrent connections (called *virtual circuits*) using a single network attachment. In NLSP, each connection is treated as a distinct adjacency, and hence as a distinct link in the Link State database. If a router is connected to an X.25 network and has five connected IPX virtual circuits at the current time, it's as if there were five point-to-point links. X.25 is not modeled as a fully connected cloud, but as a collection of point-to-point links that come up and down as virtual circuits are established and cleared. Operation of NLSP does not by itself cause virtual circuits to be established or cleared.

Another type of switched network is an asynchronous dial-up circuit using a modem. Each modem supports one connection at a time, at most. A modem link is treated as a point-to-point link that can be up (if connected) or down (if not connected). Operation of NLSP does not by itself cause calls to be established or cleared.

2.1.5. The Circuit Concept in Link State Design

NLSP has the concept of a *circuit* both for LANs and WANs. With LANs, a circuit is a point of attachment to a network segment, through which the router can reach many other systems. If the router has two points of attachment to the same network segment, it is treated as two circuits. With a two-party WAN (either a dedicated or a dialed link), each point of attachment is treated as a circuit. The situation is different for multipoint WANs like X.25 and Frame Relay. For these WAN media, a single point of attachment provides access to many other systems using a connection-oriented Data-link layer. NLSP treats each X.25 or Frame Relay *virtual circuit* (switched or permanent) as a separate circuit for operation of the routing protocol, even though virtual circuits can share the same network point of attachment.

2.1.6. Example of Link State Database

Figure 2-4 illustrates the same example as Figure 2-1, but with the parts labeled. Each router is labeled with a letter toward the end of the alphabet. Each LAN is labeled with a letter toward the beginning of the alphabet. A pair of letters denotes a link. For example, RT denotes the point-to-point link connecting the router R with the router T. Likewise, RA denotes the (conceptual) link between R and the pseudonode that represents the LAN A. The designated routers (R, U, and W) are shown with heavy borders.

For the sake of discussion, suppose there are two active X.25 virtual circuits: SV and UV. Also, suppose the modem attached to W is not currently connected to a remote party.

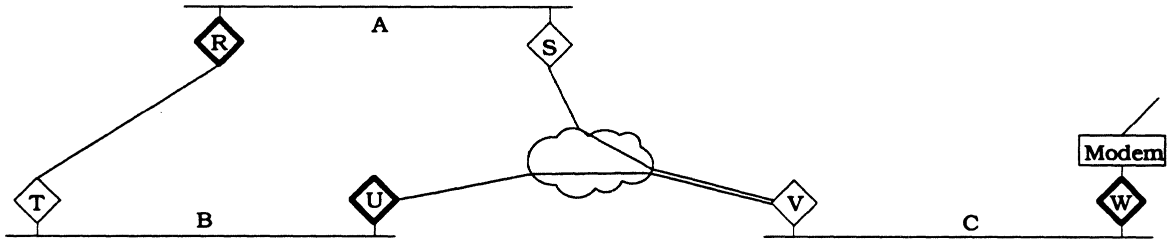


Figure 2-4: Labeled Example

Figure 2-5 shows a simplified view of the Link State database describing the example. There is one table for nodes and a second one for links. Notice that each link is represented twice: once as reported by the router at one end of the link and again as reported by the router at the other end of the link. Cost is discussed in more detail later; for now, simply consider a link to have a non-negative measurement assigned to it. Notice also that a pseudonode reports zero cost to reach the real nodes of the LAN.

Node ID	Type
A	Pseudonode
B	Pseudonode
C	Pseudonode
R	Router
S	Router
T	Router
U	Router
V	Router
W	Router

Link	Cost	Link	Cost
AR	0	RA	10
AS	0	SA	10
RT	19	TR	19
BT	0	TB	11
BU	0	UB	11
SV	40	VS	40
UV	40	VU	40
CV	0	VC	10
CW	0	WC	10

Figure 2-5: Link State Database

2.1.7. Decision Process and Forwarding

The typical routing decision is, "given that you have a packet to a particular final destination, what should the next hop be from here to get it to the destination with least cost"? (It is also possible to split the load among several next-hop links.)

The cost table in Figure 2-5 contains the information from which you can deduce routing decisions, but its form is not conducive to deciding the next hop. The *Decision Process* is a computation that puts the cost-table into a new form, called the *Forwarding database*. Unlike the Link State database, each router has a unique version of the Forwarding database, expressed from its own vantage point. The Forwarding database can be thought of as a table that maps a network number into the next hop. Figure 2-6 illustrates a Forwarding database from the vantage point of router V.

Network #	*Next Hop*
0xCCC47689	S
0xCCC47666	C
0xCCC47600	U
0x0082392C	U
0x845FAC11	S
0x05551212	W
0xC3141592	V

Figure 2-6: Forwarding Database Example

The first column in Figure 2-6 contains all the network numbers in the area. For each network number, the next hop in that row indicates which outgoing link—and destination on that link —to use for traffic destined to that network. When the router transmits a data frame, the table determines how to forward it. To take one new concept, 0xCCC47666 is the network number for LAN C; end nodes on C are reached by recourse to that table row. As another example, an NLSP router has an *internal network number*, and 0xC3141592 is the one for V. Packets addressed to that network are not forwarded by V. Of course, the internal representation of the Forwarding database is not typically a linear array, but a structure designed for fast lookup.

The Decision Process rebuilds the Forwarding database whenever the router detects a change in the Link State database. There is a hold-down timer, however. This is a minimum interval between reruns of the Decision Process. Topology changes can occur clustered in time. The hold-down timer allows the cluster of changes to be absorbed into the Link State database before running the Decision Process. Otherwise, it would run for each change of the cluster, wasting processing resources.

The Decision Process is called Dijkstra's algorithm, after Edsger W. Dijkstra, who devised the underlying method. It treats each router or pseudonode as a node in a graph, and each link as an arc connecting two nodes. Each link has a cost—actually, two costs, one in each direction, as reported by the router (or pseudonode) at each end. For example, the graph for Figure 2-4 and 2-5 looks like Figure 2-7.

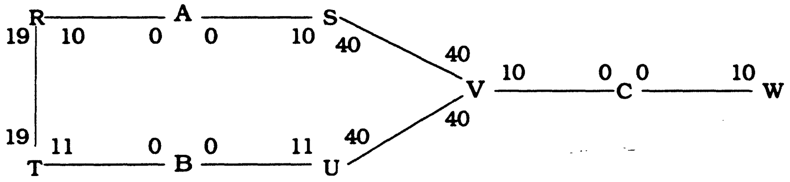


Figure 2-7: Graph with Costs

The object is to find the shortest distance from the local node (that is, from the router where the computation is running) to every other node of the graph. Here are the essential elements of Dijkstra's algorithm:

- Maintain a set of nodes whose shortest distance is already known. Call this the *Known Set*. Initially, it contains only the local node, with zero cost.

- The algorithm operates iteratively. At each iteration, add one node to the Known Set.

- How do you decide which to add? Look at the links from nodes in the Known Set to those outside it. This gives you a subset of links to consider for this step of the iteration. (The subset is equivalent to the *tentative list* used by some texts in describing Dijkstra's algorithm.) Each link in the subset has a *near node*, in the Known Set, and a *far node*, outside the Known Set. From the subset, choose the one whose far node has the lowest total cost from the local node. The node at the other end of that link is the one chosen. Add it to the Known Set.

- After *n* iterations, all the reachable nodes are in the Known Set (*n* is the number of reachable nodes in the graph).

How does this method build a Forwarding database? Each iteration identifies three things: a chosen far node, a link connecting it to a previous member of the Known Set, and the previous near node itself. For the Forwarding database, the next hop to the chosen node must be determined. If the near node is the local node itself, the next hop is the link chosen in this iteration. Otherwise, the next hop is the same as the near node's next hop.

Figure 2-8 illustrates the iterations of Dijkstra's algorithm for the graph shown in Figure 2-7. It shows the computation performed by node U.

Step 6 is interesting because it involves choosing between two routes to the same node. The algorithm selects the better path, rejecting the suboptimal one. In either case, the same node (S in the example) is added to the Known Set, but it is important that the better route to it be the one recorded as the result of the step.

The computational burden to run Dijkstra's algorithm is proportional to $n \times k \times \log n$, where n is the number of routers, and k is the number of neighbors per router. Several optimizations are possible. Memory requirements are proportional to $n \times k$. For a detailed discussion, see Reference [Per92], pages 2-24 through 2-28.

Step 1

Known Set

Node	Cost	Next Hop
U	0	–

Step 2

Known Set

Node	Cost	Next Hop
U	0	–
B	11	B

Step 3

Known Set

Node	Cost	Next Hop
U	0	–
B	11	B
T	11	B

Step 4

Known Set

Node	Cost	Next Hop
U	0	–
B	11	B
T	11	B
R	30	B

Step 5

Known Set

Node	Cost	Next Hop
U	0	–
B	11	B
T	11	B
R	30	B
A	40	B

Step 6

Known Set

Node	Cost	Next Hop
U	0	–
B	11	B
T	11	B
R	30	B
A	40	B
V	40	V

Step 7

Known Set

Node	Cost	Next Hop
U	0	–
B	11	B
T	11	B
R	30	B
A	40	B
V	40	V
S	40	B

Step 8

Known Set

Node	Cost	Next Hop
U	0	–
B	11	B
T	11	B
R	30	B
A	40	B
V	40	V
S	40	B
C	50	V

Step 9

Known Set

Node	Cost	Next Hop
U	0	–
B	11	B
T	11	B
R	30	B
A	40	B
V	40	V
S	40	B
C	50	V
W	50	V

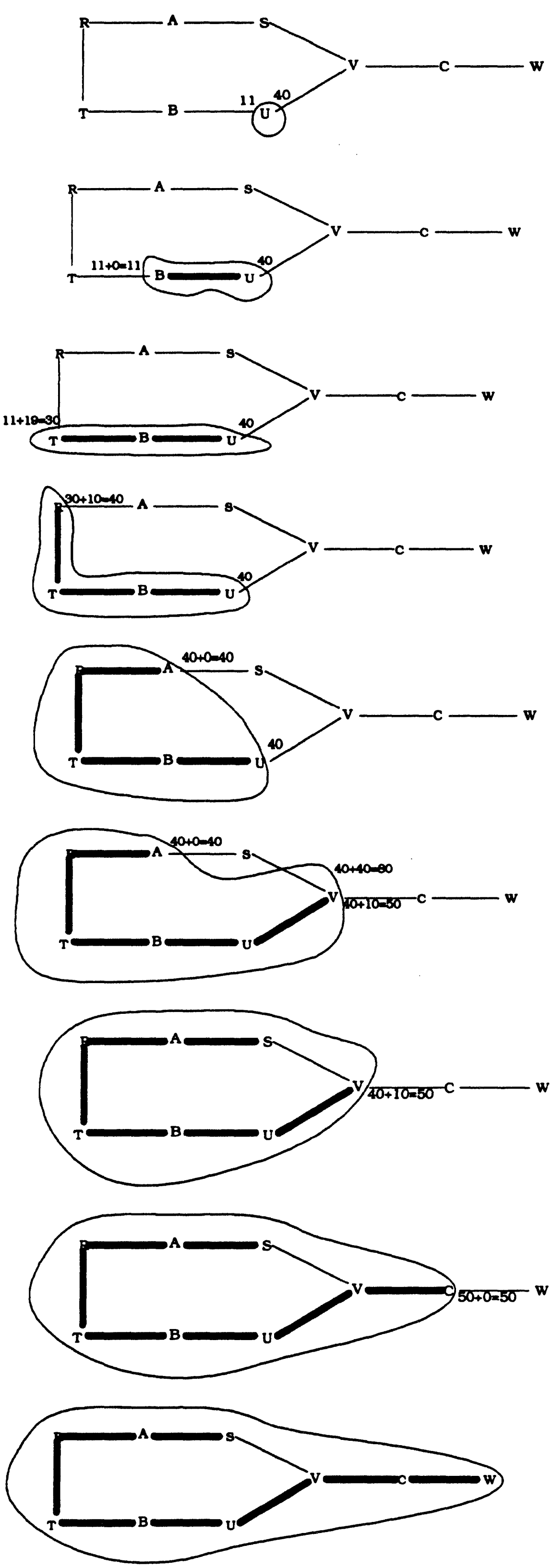


Figure 2-8: Decision Process Steps

Each iteration of Dijkstra's algorithm identifies a node and a link. The chosen links, taken together, form a subset of the graph called a *single source shortest path spanning tree.* The tree is shown in the diagram with a heavy line. Section 6 presents an alternate description of Dijkstra's algorithm. It is more akin to pseudocode.

2.1.8. Load-Splitting

NLSP supports load-splitting. That is, if there are equal cost paths, the traffic can be divided among them to make fuller use of the internetwork.

There is a *maximal splitting degree* defined. This is a number, MSD, assigned by the network administrator. It can be different for different routers in a routing area. If there are equal cost paths, MSD is an upper limit on the number used for routing. If MSD=1, the router does not do load-splitting. Load-splitting focuses on the step in Dijkstra's algorithm where you choose which node to add to the known set.

In case of a tie to the same far node, the Forwarding database has more than one entry added to it, instead of just one. How many? If the tie is among *m* links, the number of entries added is the smaller of *m* and MSD. If *m* is greater than MSD, the choice of which to add is based on a prescribed ordered list of criteria.

2.2. Reliability Features of NLSP

A number of NLSP features specifically ensure reliable operation.

2.2.1. Disseminating Updates Reliably

LAN and WAN links often do not provide guaranteed delivery. They operate on an unreliable best-effort basis. The LSP exchange protocol includes reliability features to ensure that the Link State database replicas in the routers become synchronized.

As mentioned earlier, each router sends LSP packets to its neighbors. Some LSPs describe the contents of the sender's Adjacency database; others are forwarded from other neighbors. To ensure that the Link State databases throughout the routing area are synchronized, a reliability feature is applied to these transmissions. There are two methods: one for point-to-point links and the other for broadcast links such as LANs.

For point-to-point links, a router sets a *Send Routing Message* (SRM) flag locally on an LSP before transferring it to a neighbor. The flag remains set until an acknowledgment is received. Periodically, LSPs with the SRM flag are sent.

A router replies each time it receives an LSP on a point-to-point link. Suppose A sends an LSP to B. In the typical case, the LSP is equal to the one B already has, or newer. In this case, B replies with a Partial Sequence Number Packet (PSNP), with the LSP source's identity, sequence number of the LSP, remaining lifetime of the entry, and other information. This is the form of the acknowledgment. A router can acknowledge more than one LSP in a PSNP.

On the other hand, if the received LSP is older than the one already in the Link State database, B sends the newer LSP.

Reliability works differently for broadcast networks. The Designated Router multicasts a Complete Sequence Number Packet (CSNP) series periodically. This does not contain the entire Link State database, but just enough information about each LSP so that each of the other routers can determine whether it is synchronized with the Designated Router. If the receiver of a CSNP determines that the Designated Router is out of date, it multicasts the newer information. On the other hand, if the CSNP receiver itself is out of date, it multicasts a PSNP identifying the LSPs for which it requests an update. The Designated Router responds with the missing information.

2.2.2. Operating with Database Overload

A router might find that it has insufficient resources to process an incoming LSP. The problem might be insufficient memory, misconfiguration, or certain transitory conditions. When this happens, the router cannot make correct decisions, so other routers must be warned. A bit in the LSP designates database overload, and the router experiencing overload floods an LSP with the bit set. Traffic is routed around the overloaded router until the situation returns to normal. A router must always preallocate space for the database overload LSP, so memory shortage does not prevent sending it.

2.2.3. Calculating and Testing Checksums

A checksum is used on each LSP sent, to detect corruption of data in transit. The computation is the same as the one used in ISO 8473 (Reference [ISO88]). If the receiver detects a checksum error, the packet is dropped and an error is logged.

2.2.4. Coping with System Bugs

In rare situations, a hardware or software bug can cause a memory location in a computer to be overwritten erroneously. If the computer is acting as a router, and if the corrupted data is part of the Link State database, the erroneous information causes incorrect routing decisions.

NLSP includes a provision to recover from situations like this automatically. Periodically, every router performs a checksum computation on the Link State database. The checksum result is compared with the checksum values originally received with each LSP. Detecting a mismatch is cause for drastic action—the entire LSP database is discarded and reacquired from scratch.

In the typical case, where everything checks out correctly, the Decision Process is run immediately after the checksum calculation. This protects against undetected corruption of the Forwarding database.

2.2.5. Implementing Fail-Stop Operation

Routers must be implemented with high reliability of hardware and software in mind. In particular, there should be a very low probability of corrupting data. Although NLSP does contain fault-tolerance features to recover from corrupted data and resource overload, such misadventures do take their toll on smooth operation of the network.

Routers should be implemented in a fail-stop manner. If the system detects that its routing operation might be compromised, the routing function should be deactivated, and then reactivated with an empty routing database. The routing database is a transitory one, without an archival requirement. If one router's database is lost, the information can be reacquired readily (a) from other routers, and (b) by probing the network environment anew. Newly acquired routing information is more useful than old information. Plunging ahead with a possibly corrupted database risks spreading the failure's impact widely to other routers. Consequently, it is better to restart and gather the information anew.

2.3. The Criterion Used in Determining Routes

When making routing decisions, a router tries to determine the best path for packets to follow from source to destination. But "best" according to what criterion? To address this question, a *cost* is assigned to each link. The cost is a non-negative integer. The Decision Process operates to minimize the total cost for packets to travel from source to destination.

Each type of media has a predefined default cost defined later in this specification. This cost is an indication of the throughput capacity of a given link. The end user can override the cost assigned to a given link. This allows the user to customize routing behavior. Each side of a link has a separate view of the cost. It is recommended (but not required) that the views indicate the same cost. If they don't, routing can be asymmetric. That is, the route from A to B can traverse different links than the route from B to A. Asymmetric routing still works, but problems can be more difficult to diagnose than with symmetric routes.

2.4. Information Useful to Higher Layers

NLSP conveys information about the characteristics of the links throughout the routing area: the connectivity, the costs, the media types, and so forth. This information is used within the IPX network layer, to do a good job of routing. Because NLSP includes all the mechanisms to convey such information reliably throughout the area, those mechanisms are exploited to convey information not used for routing, but which is useful to other software. There are three items currently defined, with room to add more in the future. The three are identified as follows:

MTU size. This is the maximum packet size (in bytes of IPX user data) that can be transmitted over a link in a given direction. Knowing this value for each link allows a router to determine the MTU size end-to-end from an originator to a final recipient. This allows the originator to send data packets of just the right size, making best use of the internetwork's capacity.

Delay. This is a measurement of the time (in microseconds) to send a byte of data (excluding protocol headers) across the link. Aggregating this measurement over the links in an end-to-end path, a router can calculate end-to-end delay with fine granularity. This information allows a transport protocol to fine-tune the timeout interval to use waiting for an acknowledgment. The better the fine-tuning, the better the performance achieved.

Throughput. This is the amount of data (in bits per second) that can flow through the interface. This information helps the Transport layer decide the maximum useful unacknowledged data to have in its output queue. It allows fine-tuning of the offered window size of a transport connection.

These values can be accessed using network management. In future protocol revisions there might be additional, more specialized protocols to access the values.

2.5. Routing Information Protocol

The Routing Information Protocol (RIP) has been used with IPX from the early days, and its use continues. RIP is a distance vector routing protocol modeled after the Xerox* XNS* protocol of the same name (Reference [Xer81]). Routers exchange routing information with their neighbors through periodic broadcasts. They consolidate the information and pass the summarized data along to other RIP routers and to nonrouting end nodes.

NLSP is a successor to RIP for communicating among routers. For router/end node communication, however, RIP continues to be the one method used.

Reference [Nov92] contains a complete specification of RIP.

RIP uses a value called *RIP Link Delay* as its measurement criterion. It is measured in *ticks* (18.21 ticks per second). RIP Link Delay is the time to deliver a 576-byte packet to a destination across the link (it must be at least one). Conceptually, this value contains components of latency and throughput. NLSP deals separately with latency (called *NLSP Delay* in the protocol) and throughput (*NLSP Throughput*), but combines them for the benefit of RIP compatibility.

2.5.1. RIP for Communicating with End Nodes

This part of RIP support must be operational unconditionally. It provides the way for end nodes to learn (a) the network number of their directly connected network, and (b) which router provides the best next hop to an intended destination. It does not include periodic broadcast.

RIP is a request/reponse protocol. The request includes space to ask about routes to specific network numbers, or the requester can send a general request for routes to all networks. Every router on the directly connected segment responds with a measurement of the distance through it to the networks. Based on the reponse, an end node decides which router provides the best path to a given network. This is purpose (b).

When an end node begins operation, it does not know the network numbers of the segments to which it is attached. It broadcasts any RIP or SAP request on its directly connected LAN segments, using zero as the source and destination network number in the IPX header. A router (or server) receiving such a request makes the appropriate reply, and includes in the reply's IPX header the segment's actual network number. From a response's IPX header, the end node learns the segment network number. This is purpose (a). If there are no routers operating, the end node can still communicate with peers on the same network using network number zero.

When a router replies to a RIP request, it supplies two measurements for each destination network:

- Number of hops (the number of routers that must be traversed to reach the destination network)
- Number of ticks

NLSP routers determine the number of hops from the tree constructed by the Decision Process. The number of ticks is calculated from the delay and throughput measurements described in Section 2.4, "Information Useful to Higher Layers."

2.5.2. RIP for Backward Compatibility

Internetworks can contain both RIP and NLSP routers. NLSP routing includes the method to connect the two worlds into a unified whole. When activated, this compatibility feature involves (a) generating RIP broadcasts so that RIP routers learn how to send data traffic to NLSP routers, and (b) heeding RIP broadcasts, so that NLSP routers learn how to send data traffic to RIP routers.

This part of RIP support is operational conditionally, on a per-link basis.

RIP routes are absorbed into the Link State database as *external routes*, like those to other routing areas. This means, in particular, that NLSP routes are preferred over RIP routes if both are available to the same destination. The RIP route for a network is attached to the node that detects a RIP broadcast on a directly connected network. For a LAN, it is attached to the pseudonode. The two RIP measurements (hop count and tick count) are included. When LSPs are flooded, the RIP information is carried along.

When composing a RIP broadcast, an NLSP router uses the information from (a) the external routes, and (b) the tree calculated by the Decision Process. First, consider an NLSP route; that is, a network number accessible by traversing NLSP routers only—no RIP routers. The router determines the number of hops from the tree constructed by the Decision Process. The number of ticks is calculated from the delay and throughput measurements described in Section 2.4, "Information Useful to Higher Layers."

Next, consider a network number reachable by a concatenation of an NLSP path and a RIP route. The router determines the number of hops using the RIP portion of the path alone. What matters is the best values of hops and ticks reported by any RIP router, detected by any NLSP router. The portion of the path within the NLSP routing area between NLSP routers is not counted when composing a RIP broadcast.

RIP filtering is implemented when sending and receiving RIP broadcasts on a per-link basis. The user can configure network numbers (or number patterns) to be included or excluded from consideration. However, the RIP routes carried along in LSPs flooded among NLSP routers are not filtered.

Routers allow the RIP broadcast frequency to be configurable on each link individually. The default is once per minute.

RIP routes are purged if they are not refreshed by receipt of a new RIP broadcast. This timeout interval is configurable on each link individually. The default is four minutes.

2.6. Service Advertising Protocol

The Service Advertising Protocol (SAP) has been used with IPX from the early days, and its use continues. SAP uses a broadcast method similar to RIP for disseminating information, but instead of routing information it conveys information about network services and their addresses. Servers advertise their services and addresses, and routers gather the information to share with other routers and with end nodes.

With the newer NetWare® Directory Services™ (NDS™) design, the use of SAP can be considerably reduced. Workstations locate services of interest by consulting an NDS server. The information about services on the NDS server is disseminated by direct, unicast-based protocols. It is not disseminated by broadcast-based SAP. NDS is part of NetWare 4. However, even in a network of all NetWare 4 nodes, some uses of SAP remain. For example, SAP locates the nearest NDS server on startup. SAP usage can be considerably reduced with NDS, but is not eliminated at this point. Moreover, other IPX systems have a customer presence and are still being deployed: NetWare 3, NetWare 2, and products from many parties that add value to those environments. For all these reasons, NLSP routers must support SAP.

Incoming SAP broadcasts are processed in a way similar to incoming RIP broadcasts. The received SAP information is included in the receiving router's Link State database, and from there is flooded to other routers. For a LAN, the SAP information is attached to the pseudonode. Information can come from a RIP router, a nonrouting end node, or a software module running a network service on the router system itself. It is all treated similarly.

An NLSP router responds to SAP resource-location requests using the SAP information gleaned from SAP broadcasts and from other NLSP routers. It also generates periodic SAP broadcasts based on the same information. SAP support is configurable on a per-link basis.

SAP filtering is implemented on a per-link basis when sending and receiving SAP broadcasts. The user can configure names (or name patterns) to be included or excluded from consideration. However, the SAP carried along in LSPs flooded among NLSP routers is not filtered.

Routers allow the SAP broadcast frequency to be configurable individually on each link. The default is once per minute.

SAP information is purged if it is not refreshed by receipt of a new SAP broadcast. This timeout interval is configurable individually on each link. The default is four minutes.

2.7. NetBIOS and Packet Type 20

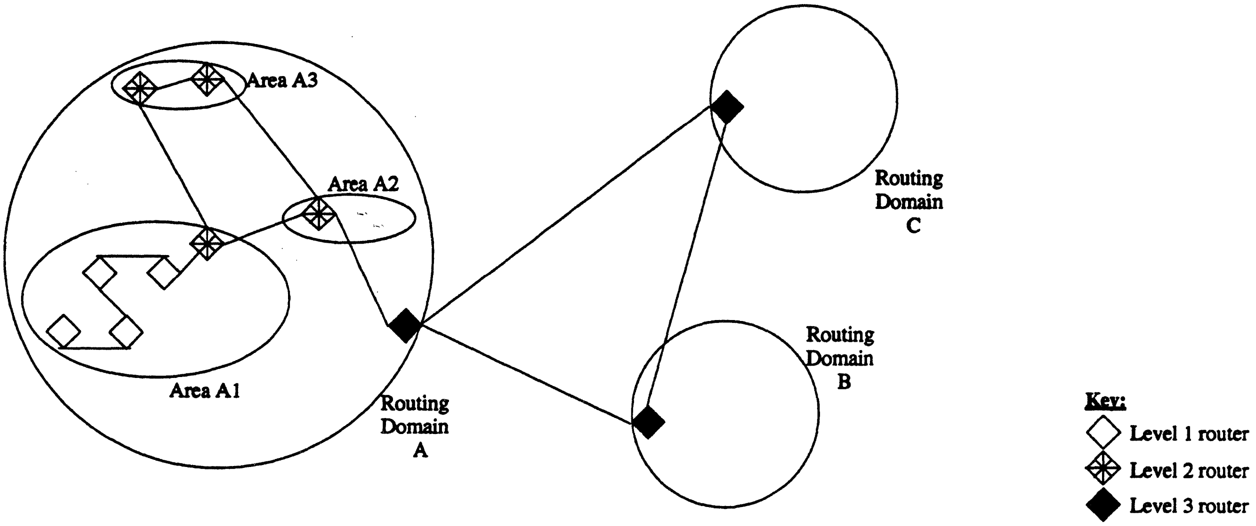
For certain protocol implementations to function correctly, NLSP routers propagate certain broadcast packets. The protocol most affected is IPX-based NetBIOS. The IPX packet type 20 is used specifically for this purpose. The special handling applies only to broadcast packets—those with destination node number all-ones in the IPX header. Details are in Section 5 of Reference [Nov92].

End users require the ability to set boundaries on the propagation of these packets. Routers implement a user-configurable, per-link filter governing whether packets of type 20 are sent and heeded on that link.

2.8. Enhancing NLSP to Hierarchical Routing

Refer to Chapter 6 "Hierarchical NLSP" for information concerning Route Aggregation and Information Leaking between areas. This framework provides for multiple levels of hierarchy.

~~This document specifies routing within a routing area—Level 1 routing. As NLSP develops in the future, there will be facilities for linking areas together into routing domains (Level 2), and routing domains into a global internetwork (Level 3). Figure 2-9 illustrates the hierarchy of domains and areas. Figure 2-9 shows the internals of one of the areas for clarity, and one of the domains. Imagine each area as containing LANs and WANs such as in Figure 2-1. Areas are connected to each other by Level 2 routers; domains are connected to each other by Level 3 routers.~~



~~*Figure 2-9: Hierarchical Routing*~~

~~Hierarchical routing intends that each independent organization is a separate routing domain. This could be a company, a university, or an agency. It could be a public carrier connecting organizations with each other. Within a routing domain, each local campus, or other suborganization having its own administrative staff, constitutes a routing area.~~

~~Level 2 routing aims to enhance scalability by reducing the amount of information that every router must store and process to route throughout a domain. Instead of keeping the link states throughout the routing domain, it keeps this level of detail only for its own area. To get to other areas, it need only maintain information on a per-area basis, and be able to find the Level 2 router for each area other than its own. This information is a much coarser level of detail. Hierarchical routing wins information compression and economy of computation.~~

~~Level 3 routing aims first to provide another level of scalability and information compression, and then to imagine different routing domains belonging to different organizations entirely—companies or agencies with an arms-length relationship. A public network service provider that connects different organizations together might have a domain of its own. To support administrative separation, interdomain routing is usually considered with imposing policy criteria on forwarding decisions. For example, imagine that each of the three domains in Figure 2-9 is a separate company's internal internetwork. Domain B might want to forbid transit traffic from Domain A bound for Domain C.~~

~~A Level 2 router also acts as a Level 1 router within its own area; likewise, a Level 3 router also acts as a Level 2 router within its own domain.~~

2.9. IPX Addressing and its Relationship to Routing

The IPX Network-Layer address contains three parts:

- A four-byte network number
- A six-byte node number
- A two-byte socket number

A network number is assigned to each LAN segment. Also, NetWare 3 and 4 servers have *internal network numbers*. Network numbers receive the most attention in this document, because they guide routing decisions.

The node number identifies a specific system attached to the network. It is taken from the MAC address space administered by IEEE. This makes it globally unique. (In some situations, it must really be unique only within a network. This fact is sometimes exploited, bypassing global uniqueness.)

The socket number identifies a higher-layer entity within a system.

Two 32-bit quantities identify each routing area: a network address and a mask. The mask contains *n* leading "one" bits and *32–n* trailing "zero" bits. The pair of numbers is called an *area address*. The term *Category n* area refers to an area where the mask has *n* leading "one" bits. The larger *n* is, the smaller the area. An example is

```
        01234500
        FFFFFF00
```

The first number identifies the area: address `01234500`. The second number, the mask, indicates how much of the area number identifies the area itself, and how much identifies an individual network within the area. In the example, the first 24 bits of the address (`012345`) are the routing area. (Twenty-four is six hex F's times four bits per hex digit.) When writing the area address as a number/mask pair as above, write zeros after `012345` to pad it to 32 bits.

There is a relationship between an area address and the IPX network numbers in the area. If the mask part of an area address has *n* leading one bits, the first *n* bits of an network number must equal those of the area's address part. When this happens, the network number *matches* the area address, and the network assigned that number is in the area. In the example of the preceding paragraph, every network number in the area starts with `012345`. The remaining eight bits identify individual network numbers in the routing area; for example, `012345AB` and `01234500` are network numbers in the area. The example is a Category 24 area.

A routing area can have as many as three area addresses. NLSP treats the three as synonymous identifiers of the same routing area. To be in the area, an IPX network number matches any one of the three. The three can be of different categories. In fact, no numerical relationship is prescribed between the addresses. Having more than one address allows the routing areas to be reorganized without interrupting operation. For example, to split a routing area in half, you introduce the new area address into half the routers, one by one. Then, remove the old address from those routers, one by one. As long as one of the routers has both addresses, there is one routing area. As soon as the routers become two disjoint groups, there are two areas.

Figure 2-10 provides a simple example, with four routers (R, S, T, U) in a linear sequence. All four start in one area, and conclude with two areas of two routers each.

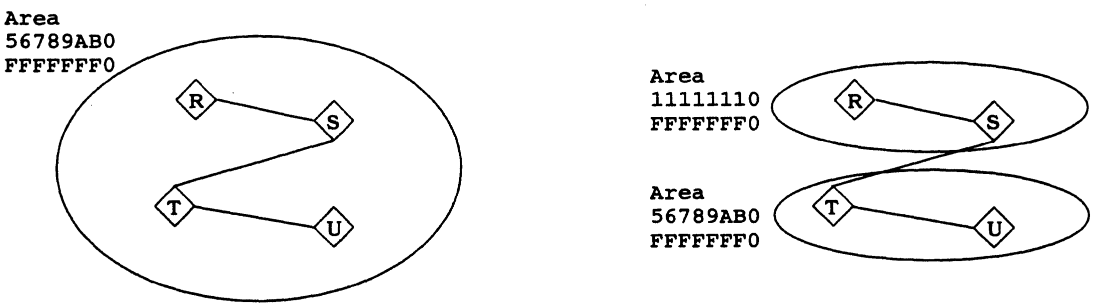


Figure 2-10: Splitting a Routing Area

To accomplish the split, the following steps can be followed:

Step 1	This is the starting point, one area address.			
Router	R	S	T	U
Level	1	1	1	1
Area Addresses	56789AB0 FFFFFFF0	56789AB0 FFFFFFF0	56789AB0 FFFFFFF0	56789AB0 FFFFFFF0

Step 2	Add the second area address to R.			
Router	R	S	T	U
Level	1	1	1	1
Area Addresses	56789AB0 11111110 FFFFFFF0 FFFFFFF0	56789AB0 FFFFFFF0	56789AB0 FFFFFFF0	56789AB0 FFFFFFF0

Step 3	Add it to S. Remove the old area address from R. It's still all one area, though.			
Router	R	S	T	U
Level	1	1	1	1
Area Addresses	11111110 FFFFFFF0	56789AB0 11111110 FFFFFFF0 FFFFFFF0	56789AB0 FFFFFFF0	56789AB0 FFFFFFF0

Step 4	Promote S and T from Level 1 to Level 2 Routers. It's still one area.			
Router	R	S	T	U
Level	1	2	2	1
Area Addresses	11111110 FFFFFFF0	56789AB0 11111110 FFFFFFF0 FFFFFFF0	56789AB0 FFFFFFF0	56789AB0 FFFFFFF0

Step 5	Remove S's original address. The routers now see two nonoverlapping areas.			
Router	R	S	T	U
Level	1	2	2	1
Area Addresses	11111110 FFFFFFF0	11111110 FFFFFFF0	56789AB0 FFFFFFF0	56789AB0 FFFFFFF0

Now go from routing areas to the next level of aggregation: routing domains. There is no numerical relationship required among area addresses within a domain, except that no two areas can contain the same area address. When Level 3 routers convey traffic between domains, they share a description of which addresses belong in which domain. This is a list of all the area addresses contained in each domain.

Area addresses in a routing domain do not have to share a common prefix for NLSP to work correctly. Any area addresses can be combined in a domain. But if common prefixes are, in fact, used, routing can operate more efficiently. First, the data shared among domains is more compact, because the data can be expressed using the common prefix instead of by listing all the area addresses. Second, as a consequence, routers making routing decisions have less data from other domains to process, so they have less work to do. This saves compute cycles. Finally, confidentiality can play a role: a company or carrier might not want to reveal its internal network topology. Consequently, those planning address assignments should consider assigning them hierarchically, even though such an assignment is not required for correct operation. For example, if addresses in the Figure 2-9 internetwork were assigned hierarchically, the Level 3 router in Domain A might have the following address list:

Domain A		Domain B		Domain C	
Area A1	CCCC1500	All areas	CCCC2000	All areas	CCCC3000
	FFFFFF00		FFFFF000		FFFFF000
Area A2	CCCC1520				
	FFFFFFF0				
Area A3	CCCC1600				
	FFFFFFF0				

Note that the information about domains B and C have collapsed to a single entry each. Likewise, information about Domain A collapses to a single entry from the point of view of B or C. This works because they all differ in the fifth hexadecimal digit: the digit is "1" for domain A; "2" for B, and "3" for C. Within Domain A, only one entry need be circulated to the Level 1 and Level 2 routers to describe Domains B and C. If address assignment is not hierarchical, there are many entries. This consumes network bandwidth to convey to all routers, memory to record the entries, and computational capacity to process them.

2.10. Network Management

NLSP routers are managed using the SNMP (Simple Network Management Protocol) standard. SNMP runs over IP and IPX.

Specifying NLSP network management amounts to defining an SNMP MIB. The MIB is a set of values that can be read and changed remotely by action of the SNMP protocol, and a set of traps that can be generated by the router to raise alarms about exceptional conditions. The NLSP MIB is divided into groups, as follows:

System Group Global information about the IPX protocol entity

Circuit Group Information about each interface on the system

Forwarding Group	Forwarding database used to route data traffic
Services Group	Known Services that advertise themselves using SAP
Neighbors Group	Information about neighboring NLSP routers and the adjacencies with them
LSP Group	Tables representing the LSP database
Translation Group	Various mappings (for example, System ID to Server Name)
Graph Group	Representation of the network topology
Traps Group	Notifications of significant events

There are actually three MIBs, as follows:

- IPX MIB includes basic information about IPX Network-Layer operation. It is applicable to all IPX-speaking systems, both routers and end nodes. It includes information in the following groups: System, Circuit, Forwarding, Services, and Traps.
- RIP/SAP MIB augments IPX MIB with information specific to the RIP and SAP protocols. It extends the System and Circuit groups.
- NLSP MIB augments IPX MIB with information specific to the NLSP routing protocol. It extends the System, Circuit, and Forwarding groups, and adds the Neighbors, Translation, Graph, and LSP groups.

2.11. Capabilities Assumed in the System Environment

Certain characteristics are required of a system for it to be suitable to act as an NLSP router. Certain characteristics of the underlying data links are also required for support of NLSP.

2.11.1. Configuration of Parameters by End Users

Certain operational values and characteristics are configurable by the end user. To accommodate this requirement, a router needs a method for user interaction. The method is an implementation choice. For example, it could be one of the following:

a) Terminal attached directly to the router

b) Remote terminal-emulation facility

c) File edited by the user and read by the router

d) An implementation-dependent protocol

e) The NLSP MIB defined in this specification

f) Different MIB for a different network management protocol

g) Combination of methods

2.11.2. Event Handling

There are various places in the specification where it is convenient to describe behavior of the router in terms of events. The term *event* is meant in a generic sense. Implementation of event handling is system-specific.

Event handling can include notifying a system manager of abnormal conditions, making an entry in an error log, and incrementing a counter.

2.11.3. Characteristics of Links to Support NLSP

The links connecting routers with each other must support frames of 576 bytes. This number is the data portion of the frame, including the Network-Layer (IPX) header, but not data-link headers. If larger frames are supported, performance and scalability can improve.

Links can operate on a best-effort datagram basis, providing a high probability of delivering individual frames. There is no requirement for the links to provide confirmed or guaranteed delivery. There is no requirement for the links to guarantee that the order of delivery matches the order of transmission. (However, if frames are reordered often, performance can be affected.) NLSP includes reliability features that allow it to operate over unreliable links. NLSP operates over all sorts of links: broadcast, nonbroadcast, local area, metropolitan area, wide area, connectionless, connection-oriented, point-to-point, multipoint, switched, dedicated, and high and low data rates.

The router needs a way to detect when a link becomes active or inactive, and when failures or degraded conditions prevail.

Certain kinds of multipoint networks have the ability to address multiple stations with the same data-link frame. Addressing all stations attached to a network segment is called *broadcast*; when a subset is addressed, the function is called *multicast*. NLSP uses multicast addressing (on those links where it is available) to address all the NLSP routers on the network segment, without burdening other systems. Where broadcast is available but not multicast, the same frames (which would have been multicast) are sent using the broadcast mechanism.

2.11.4. Imposing Jitter on Timed Operations

When packets are transmitted as a result of timer expiration, there is a danger that timers of individual systems might become synchronized. This would result in a traffic distribution containing peaks of intense activity. Where there are large numbers of synchronized systems, the peaks can overload both the transmission medium and the receiving systems. To prevent this from occurring, periodic timers that cause packet transmissions have *jitter* introduced. When jitter is applied, the actual time interval varies randomly between 75% and 100% of the specified value.

The procedure `DefineJitteredTimer` below indicates how jitter operates in NLSP. In the description, `BaseTimeValueInSeconds` is the nominal timeout value for a specific action, and `ExpirationAction` is a procedure that can be called to perform that action. For example, `DefineJitteredTimer (10, SendHelloPacket)` causes the action *SendHelloPacket* to be performed at random intervals of between 7.5 and 10 seconds.

```
DefineJitteredTimer (BaseTimeValueInSeconds, ExpirationAction)

 CONSTANTS:

     Jitter = 25           -- Percentage jitter defined in this specification.

     Resolution = 100      -- Timer resolution in milliseconds for a
                           -- particular router.

 VARIABLES FOR THE PROCEDURE AS A WHOLE:

     BaseTimeValue         -- BaseTimeValueInSeconds, converted to timer
                           -- intervals.

     MaximumTimeModifier   -- Largest possible jitter.

     Running               -- Starts as TRUE; set to FALSE to halt the
                           -- activity.

 VARIABLES REEVALUATED IN THE INNER LOOP:

     WaitTime              -- Time interval for this loop's timeout.

     NextExpiration        -- next clock time at which the ExpirationAction occurs.

 METHOD:

     BaseTimeValue ← BaseTimeValueInSeconds × 1000 / Resolution

     MaximumTimeModifier ← BaseTimeValue × Jitter / 100

     WHILE Running

           BEGIN           -- Running loop

           WaitTime ← BaseTimeValue - Random (MaximumTimeModifier)

           NextExpiration  ← CurrentTime () + WaitTime

           ExpirationAction ()

           WaitUntil (NextExpiration)

           END           -- Running loop
```

The description assumes availability of the following functions in the environment:

```
Random (max)      -- Returns a uniformly distributed random integer with
                  -- 0 < Random(max) < max.

CurrentTime ()    -- Returns the current time in milliseconds.

WaitUntil (time) -- This procedure waits until the current time is "time,"
                  -- then returns.
```

The essential point of the algorithm is that the expiration time is randomized within the inner loop. Note that the new expiration time is set immediately on expiration of the last interval, rather than when `ExpirationAction` has completed.

2.12. IPX Protocol

IPX is a connectionless datagram Network-layer protocol, adapted from the Xerox Network Systems design, Reference [Xer81]. The IPX packet structure is defined on page 2-29.

Packets whose processing is specified in this document use the IPX header values listed in Figure 2-11.

Protocol	Socket	Packet Type	Where Specified
IPX Ping	0x9086	0x04	Page 2-27
RIP	0x0453	0x01	Section 7
SAP	0x0452	0x04	Section 7
IW2	0x9004	0x04	Section 3
Propagated Packet	Varies	0x20	Chapter 5 of Reference [Nov 92]
NLSP	0x9001	0x00	Sections 4 and 5

Figure 2-11: Socket Values and Packet Types Pertinent to This Document

2.12.1. General Processing of Incoming IPX Packets

When a router receives a valid IPX packet, it proceeds in the following order:

a) If the final destination of the packet is on the same system as the router, it is processed by the software entity identified by the Destination Socket field. This includes packets addressed directly to this system, as well as packets sent by a data-link multicast or broadcast on a directly connected network segment. Exit after completing step a) for such a packet—the remaining steps do not apply. If there is no software entity on the system prepared to receive the packet, the packet is discarded.

   The following general acceptance tests apply to incoming packets destined for the routing software entity on this system:

   1. Size consistency tests apply to NLSP packets. Suppose

      D is the data-link user data size reported by the Data-Link layer,

      I is the Packet Length reported in the IPX header, H is the IPX header size (30 bytes), and

N is the Length Indicator in an NLSP packet.

Every valid packet has

$D \geq I$

$I = N + H$

If a received packet fails these size consistency tests, a packetRxSmall event is generated and the packet is discarded.

The "$D \geq I$" test also applies to all arriving IPX packets.

2. The IPX Packet Type field determines how to process the packet. For the IPX Ping, IW2, and NLSP packets specified in Sections 2 through 5 of this document, check that the IPX Destination Socket field is compatible with the Packet Type. Valid combinations are in Figure 2-11. Discard packets having an invalid combination. Do not perform this check for RIP and SAP packets.
3. If the Major Version field of an incoming NLSP packet is not one, a mismatchedVersion event is generated and the packet is discarded. (The Minor Version field is not checked.)
4. If an NLSP packet arrives on a circuit for which the NLSP protocol is not active, the packet is discarded.

b) If Packet Type = 20, process it as specified in Chapter 5 of Reference [Nov92].

c) If the Transport Control field is maxHops or greater, the packet is discarded. Traditionally, the value of maxHops is 16. It is configurable. When a packet is discarded, an ipxInTooManyHops event is logged.

d) All other packets are data packets to be relayed by operation of the router's traffic forwarding role. If the next hop is impossible because the packet is too large for the medium's supported data-link frame size, the packet is discarded. When the router forwards a packet, it increments the Transport Control field by one.

Note: If either the Source or Destination Network Number field is zero, it should be filled in with the actual Network Number before being passed to the appropriate software entity, or before being forwarded. When forwarding a packet, the only two modifications a router can make to the IPX header or data are (a) incrementing the Transport Control field and (b) filling in the actual Network Number.

It is valid to forward a packet even if the Destination Node is all-ones, indicating a broadcast. If the router is attached directly to such a packet's Destination Network, the packet is forwarded as a data-link broadcast on that circuit.

2.12.2. IPX Checksum

A checksum can optionally be included by the originator of the IPX packet. The checksum is end-to-end, from originator to final destination. A Checksum field containing all-ones (0xFFFF) signifies that the originator did not compute the checksum for that packet. Typically, upper-layer protocols negotiate the use or non-use of checksums for a session.

> **Note:** Use of the Checksum field is a recent addition to IPX. In the past, the Checksum field of IPX packets was set unconditionally to all ones. Many installed systems still do not calculate the checksum.

The IPX checksum is generated over the range of bytes starting with the Checksum field itself, and ending with the last byte of the IPX Data. For the purpose of checksum calculation, the Checksum field and the Transport Control field are both considered to contain zero. Because Transport Control reflects hop count, this provision means that a router does not update the Checksum of forwarded packets.

The range of bytes is treated as an array of 16-bit words. If there would be an odd number of bytes, the range is considered to be padded with an extra zero byte for the purpose of the calculation. The first byte of each word is considered the most significant numerically.

The checksum calculation uses a variable S containing the partial sum. Denote by w[i] the i-th word from the array of 16-bit words. The checksum calculation proceeds as follows.

```
a.  Initialize S to zero.
b.  Iterate over index values i covering the array of 16-bit words:
        b.1  S ← S + w[i];  this is a twos-complement arithmetic sum.
        b.2  If Step b.1 resulted in a carry,  S ← S + 1.
c.  Replace S with its bit-wise logical "not," inverting each bit.
```

Because Step b includes adding in the carry bit, 32-bit processors can employ 32-bit operations (rather than 16-bit operations) to calculate the checksum efficiently. The final 32-bit sum after Step b would be split into two 16-bit words and added (with the carry added in as in step b.2) before Step c.

The final value of S is stored in the Checksum field, with the numerically most-significant byte appearing first.

> **Note:** The calculated checksum cannot be all-ones, based on the following line of reasoning.
>
> - Step c is a bit-wise logical "not," so it is enough to show that the last iteration of Step b cannot result in zero.
> - Each iteration of Step b involves summing two terms, then adding in the carry out of that sum. The only way this result can be zero is if both of the terms are zero. To see why, consider three cases.
>   - ➢ If Step b.1 produces all ones, there cannot be a carry, so b.2 produces all ones, not zero.
>   - ➢ If Step b.1 produces zero and at least one term is nonzero, there is a carry, so Step b.2 produces one, not zero.
>   - ➢ If Step b.1 produces anything other than zero or all ones, Step b.2 cannot produce zero.
> - Consequently, as soon as Step b encounters nonzero w[i], S becomes nonzero and remains nonzero for the subsequent iterations.

- An IPX packet cannot be all zeros. For example, the Packet Length field is always at least 30.
- Combining the last two points shows that the calculated checksum cannot be all-ones.

If a packet reaches its final destination with an IPX checksum error, the packet is discarded.

Note: One of the LAN encapsulations used with IPX is 802.3 (without an 802.2 header). A packet having a calculated checksum must not be transmitted over a link using this encapsulation.

2.12.3. IPX Ping Protocol

The IPX Ping Protocol (Version 1) provides a simple, end-to-end Network layer reachability test. It uses the packet format described on page 2-31. The Ping packet is transmitted as the data portion of an IPX packet.

Note: The Ping Protocol is a recent innovation. Many installed systems do not support it.

When sending a Ping Request

- The Destination Socket in the IPX header is 0x9086, denoting the Ping protocol.
- The Source Socket in the IPX header is arbitrary.
- The Type field of the Ping packet is 0x00, denoting a Ping Request.
- The Data field of the Ping packet is arbitrary.
- The other IPX Ping fields are as described on page 2-31.

When a Ping Request destined for this system arrives, perform the following steps:

a) If the packet is too small (less than 40 bytes, including the IPX header), discard it.

b) If the Signature field is incorrect, discard the packet.

Note: The Version field is not tested.

c) If the above tests succeed, transmit a Ping Response to the request's originator, with the following field values:

- Copy the Request's IPX header Source Socket into the Response's Destination Socket.
- The Source Socket in the IPX header is 0x9086.
- The Type field of the Ping packet is 0x01, denoting a Ping Response.
- Copy the Data and Ping ID fields from the Request.
- Store in the Result field one of the following two values:
  0x00 if the Ping Request's Data field was empty,
  Or
  0x01 if the Ping Request's Data field contained one or more bytes.

Note: In future versions of IPX Ping, the responder might perform additional steps based on a Request's Version, Reserved, and Data fields. If the Request is version 1, the Data field will still be ignored and returned unchanged.

- The other IPX Ping fields are as described on page 2-31.

An arriving Ping Reply destined for this system is recognized by its IPX Destination Socket equaling a previously transmitted Ping Request's Source Socket, and by the value 0x01 in the

Ping packet's Type field. When a Ping Reply destined for this system arrives, perform the following steps:

d) If the packet is too small (less than 40 bytes, including the IPX header), discard it.

e) If the Signature field is incorrect, discard the packet.

Note: The Version field is not tested.

f) If the Result field is neither 0x00 nor 0x01, discard the packet.

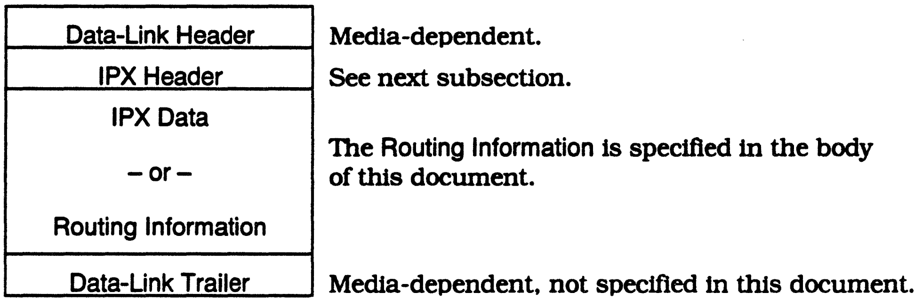
g) If the packet does not originate from a system to which a Ping Request was sent previously, discard the packet.

h) If the Ping ID field matches that of a Ping Request previously transmitted to the Response's sender, process that Ping Request as completed.

2.13. Packet Structures

All the packets defined in this specification are carried as the data portion of IPX Network layer packets. In the packet, they immediately follow the IPX header specified on page 2-29.

The IPX Network layer packets, in turn, are carried as the data portion of data-link frames. They immediately follow the data-link header, and immediately precede the data-link trailer (if any). Data-link headers are media-dependent, and are not defined in this specification. This is illustrated in Figure 2-12. The data-link headers are specified in Section 2 for WANs and Section 10 for standard LANs.



Data-Link Header
Media-dependent.
IPX Header
See next subsection.
IPX Data
– or –
Routing Information
The Routing Information is specified in the body of this document.
Data-Link Trailer
Media-dependent, not specified in this document.

Figure 2-12: Data-Link Packet

All multibyte fields are transmitted with the most significant byte first.

When NLSP packets are sent by multicast to all NLSP routers on the directly connected segment, the following destination MAC addresses are used in the data-link header:

IEEE 802.3	— `0x09001BFFFFFF`
IEEE 802.5	— `0xC00010000000`
FDDI	— `0x09001BFFFFFF`

The two structures specified in this section are the IPX header and the IPX Ping packet.

2.13.1. IPX Header

IPX Header	Number of Bytes
Checksum	2
Packet Length	2
Transport Control	1
Packet Type	1
Destination Address	12
Source Address	12

Checksum: The contents of this field are described on page 2-26.

Packet Length: The number of bytes in the IPX packet, including the IPX header and the subsequent IPX data.

Transport Control: The number of routers a packet has traversed on its way to its destination. Sending nodes always set this field to zero when originating an IPX packet.

Packet Type: The type of service offered or required by the packet. Values pertinent to this specification are in Figure 2-11.

> **Note:** For some versions of existing products, the Packet Type field is not a reliable indicator of the type of packet encapsulated. The source and destination Socket fields should be used to determine the packet type when this determination is required. Propagated packets are an exception; the Packet Type should be checked for the value 20 to determine whether the packet is to be propagated.

Destination Address: The IPX address identifying the final destination of the packet. Each IPX address has three subfields, as follows:

IPX Address	Number of Bytes
Network Number	4
Node Number	6
Socket	2

- Network number: Identifies the physical network segment to which a system is attached. If a system is attached to more than one segment, it has a corresponding address for each. Certain systems (for example, NLSP routers and NetWare 3 servers) also have an *internal network number* that does not correspond to an actual network segment, but is thought of as a virtual network residing inside the system. There is no broadcast network number. Network Numbers must be unique throughout an internetwork.

  Network number 0 (zero) has a special meaning: "The directly attached network segment onto which this packet is being transmitted." Systems that are starting up, and have not yet discovered the network number of a segment, use this value. Routers do not forward packets with Destination Network Number 0.

  Network number 0xFFFFFFFF (all ones) is not valid.

- Node number: Identifies a particular system on the network segment. The value is media-dependent. When the Network Number refers to an IEEE 802.3, 802.4, or 802.5 LAN, the value is the six-byte MAC address. If a medium has a smaller address (for example, Omninet), it is right-justified and zero-padded. The Node Number of a router or server on its internal network is one, by current convention. The broadcast value 0xFFFFFFFFFFFF means "all systems on the directly attached segment." Node numbers must be unique within a Network Number.

- Socket: Identifies a software entity within a networked system. Values pertinent to this specification are in Figure 2-11.

Source Address: The IPX address identifying the originator of the packet. It has the same three-part IPX Address structure as the destination address. Broadcast addresses are not allowed in the Source Node Number.

2.13.2. IPX Ping

IPX Ping	Number of Bytes
Signature	4
Version	1
Type	1
Ping ID	2
Result	1
Reserved	1
Data	Variable

Signature: 0x50696E67 (ASCII for "Ping").

Version: 1, ignored on receipt.

Type: 0 = "Ping Request"
1 = "Ping Response"

Ping ID: A unique identifier assigned by the requester and echoed in the response. It is used to match responses with requests.

Result: In a Ping Request, this field is zero. In a Ping Response, it reports the responder's actions or observations.

Reserved: 0, ignored on receipt.

Data: Zero or more arbitrary bytes chosen by the requester and echoed in the response.

3. IPX WAN Version 2

This section describes how the Novell® IPX™ protocol and routing protocols for IPX operate over various WAN media.

As its name implies, the IPX WAN version 2 (IW2) protocol specified in this section is the successor to the IPX WAN protocol specified in Reference [All94~~2~~]. This document supersedes that specification, and is backward-compatible with it.

Reference [All94~~2~~] specifies how to operate IPX, RIP, and SAP over the relevant media. IW2 adds what is needed to support several additional routing protocols. Part of IW2 is to negotiate which routing protocol is used over a particular link.

Reference [All94~~2~~] specifies how to operate over PPP, ~~and~~ X.25 and Frame Relay. This specification adds one more ~~two~~ media type~~s~~: ~~Frame Relay and~~ IP Relay.

3.1. Support of Several Routing Protocols

The routing protocols covered by this specification are as follows:

- RIP, as specified in Reference [Nov92].
- Unnumbered RIP. This operates the same way as RIP, but the link over which IW2 is being run is not assigned an IPX network number.
- On-demand, static routing. This method serves two purposes related to economizing network cost.
- Client-router connection. This is the method for an individual client personal computer or workstation to connect remotely to an internetwork.
- The NLSP™ protocol, as specified in sections 4 through 8 of this document.

Unnumbered RIP is motivated by administrative convenience. In an internetwork in which there are many WAN circuits, it is inconvenient to set aside IPX network numbers for them all, and to make sure that there is no duplication.

On-demand, static routing applies to transient data-link connections (like dial access and X.25 switched virtual circuits) as well as persistent data-link connections (like dedicated point-to-point links and X.25 permanent virtual circuits). This method serves two purposes. The "on-demand" part means that a router initiates communication to a destination only when there is data to be forwarded to that destination. Here, *initiating communication* includes making a call (where necessary) and conducting the IW2 exchange. A transient connection is closed after a period of inactivity. The *static routing* part means that no routing information is sent over the link—no RIP, no SAP, and no NLSP. Instead, the router at each end is configured with the routes and services accessible through the link.

Client-router connection is fundamentally different from the other routing types described in this chapter. Its operation is asymmetric. It does not connect two routers—the client system performs no routing functions. No routing protocol is used on the link, except when the client makes an explicit RIP or SAP information request. The router assigns a six-byte node number to the client, a number that plays the role of the IEEE MAC address. This way, a router can share a network number among many clients.

Of the router-to-router protocols, only RIP involves assigning a network number to the link running IW2. RIP is called a *numbered* routing protocol type.

NLSP, Unnumbered RIP, and On-demand static routing do not use a network number for the WAN link. They are called *unnumbered* routing protocol types.

Additional routing protocols of numbered and unnumbered types might be specified in the future. The categorization of routing protocols into numbered or unnumbered is an important distinction, which must be considered when planning new designs.

3.2. Implementing Media-Dependent Functions

IW2 strives to treat all media the same way. Different treatment of different media is limited to the minimum needed for effective communication.

Link establishment and termination are procedures that vary from one medium to the next. Other details (for example, encapsulation) are also media-dependent. Recall that the NLSP and RIP packets ride within IPX packets, as do the IPX WAN and IW2 protocols, so no additional information about their encapsulation need be specified, beyond that of IPX.

Operation over individual media types is described one type at a time.

3.2.1. Operation over PPP

IPX and its routing protocols use PPP (Reference [Sim92]) when operating over point-to-point synchronous and asynchronous networks. The normal PPP frame encapsulation applies.

With PPP, link establishment means the IPXCP (IPX Control Protocol, Reference [Sim92a]) reaches the "Open" state. The IW2 protocol must not begin until the IPXCP reaches the "Open" state. (Novell's implementation of IPXCP rejects all options.) If IPXCP negotiates options conflicting with those negotiated later with IW2, the IW2 negotiation takes precedence.

PPP allows either side of a connection to stop forwarding IPX if one end sends an IPXCP or an LCP Terminate-Request. When a router detects this, it immediately reflects the lost connectivity in its routing information database instead of aging it out naturally.

3.2.2. Operation over X.25 Switched Virtual Circuits

With X.25, link establishment means successfully opening an X.25 switched virtual circuit (SVC). As specified in Reference [Mal92], the protocol identifier 0x800000008137 is used in the X.25 Call User Data field of the Call Request frame, and indicates that the SVC is devoted to IPX.

Each IPX packet is encapsulated directly in X.25 data frame sequences without additional framing.

Either side of the SVC can close it, thereby tearing down the IPX link. When a router detects this, it immediately reflects the lost connectivity in its routing information database instead of aging it out naturally.

3.2.3. Operation over X.25 Permanent Virtual Circuits

The nature of permanent virtual circuits (PVCs) is that no call request is made. When the router is informed that X.25 Layer 2 is up, the router assumes that link establishment is complete.

Each IPX packet is encapsulated in an X.25 data frame sequence without additional framing. Local configuration determines which PVCs are devoted to IPX.

If a router receives a Layer 2 error condition (X.25 Restart, for example), it should reflect lost connectivity for the PVCs in its routing information database and perform the necessary steps to obtain a full IPX connection again.

3.2.4. Operation over Frame Relay

To determine when a PVC has become active or inactive, the router interacts periodically with either a private Frame Relay switch or a public Frame Relay network. The method used depends on the switch or service provider. Some support Section 6 of Reference [DEC90]; others, Annex D of Reference [ANS91]. NLSP supports both these specifications.

When a router is restarted, IW2 exchanges over active Frame Relay PVCs (that is, PVCs that have remained active before and after restart) can begin immediately.

When a router detects that a Frame Relay PVC has switched from an inactive state to an active state, link establishment is considered complete and IW2 exchange over this newly activated PVC begins.

When an active PVC becomes inactive, the router reflects the lost connectivity in its routing information database.

Framing of IPX packets is specified in Reference [Bra92], Section 6. The NLPID (Network layer Protocol ID) used for IPX is 0x800000008137.

3.2.5. Operation over IP Relay

IP Relay is a streamlined method to convey IPX traffic through an IP internetwork. IP Relay operates like a collection of PVCs with two end points, although the traffic travels as UDP/IP datagrams (References [Pos80] and [Pos81]). Each end point of each PVC is an IP address. Each router implementing the IP Relay feature is configured to know the opposite end of each PVC that terminates at its IP address.

When an IPX router is first activated and notices that IP is active on its system (or if IP becomes active while NLSP is already active), all the configured PVCs are considered to be established data-link connections. IW2 exchanges can begin immediately.

A router can receive an ICMP packet (Reference [Pos81a]) indicating nondelivery of an IP Relay datagram. The IP Relay function ignores any such ICMP packets. In particular, ICMP packets do not cause the router to consider a PVC to be closed.

If the IPX router detects that its IP protocol operation has been deactivated, it considers that the IP Relay PVCs have all been cleared and it reflects the lost connectivity in its routing information database.

Each IPX packet comprises the data portion of a UDP packet, with the first byte of the IPX header immediately following the UDP header. The UDP port used is 213 decimal.

Any IP implementation supporting this encapsulation technique must be capable of sending and receiving 1472-byte UDP packets (before any IP fragmentation that might be necessary). The 1472 bytes cover the data portion of the UDP packet, excluding the UDP and IP headers.

A system can optionally implement source validation. When source validation is in force, any packet arriving at IP Relay's UDP port from an IP address not in the receiver's PVC list is discarded.

3.2.6. Operation over other WAN media

Additional WAN media will be added here as specifications are developed.

3.3. Outline of the Stages of IW2 Operation

After the underlying data-link connection is established as described in the preceding media-dependent description, the IW2 protocol is activated to exchange identities and determine certain operational characteristics of the link.

There are three steps of IW2 operation:

- Negotiating the master/slave role and choice of routing protocol. The master/slave roles persist for the IW2 interactions only. The master keeps the rest of IW2 proceeding in an orderly way by initiating the request/reponse exchanges.
- Exchange of packets to determine certain link characteristics empirically. The details of this step depend on the routing protocol negotiated.
- Final exchange of the routers' configuration information

After these steps are concluded, transmission of IPX routing packets begins—using the routing protocol negotiated—as well as transmission of IPX data traffic.

3.4. IW2 Packets and their Usage

IW2 involves exchanges of IPX WAN packets, whose structure is defined on page 3-19. There are nine types of IW2 packets:

- Timer Request—a 576-byte packet sent from both ends of the WAN link to measure packet turnaround time
- Timer Response—response to a Timer Request; this packet is also 576 bytes long
- Throughput Request—a pair of n-byte packets sent back-to-back from the Master to measure the media throughput
- Throughput Response—acknowledgment of the Throughput Request packet pair
- Delay Request—sent by the Master to measure media delay
- Delay Response—response to the Delay Request packet; it has the same size as the request
- Information Request—sent by the Master at the conclusion of the IW2 negotiation to exchange delay and throughput measurements, a network number, and the router names
- Information Response—response packet to the Information Request
- NAK—negative acknowledgment; sent back to a party that sent an illegal packet

Certain packets apply to certain routing types but not others. Details follow.

If the router's software environment includes a priority system, IW2 packets should be processed with higher priority than all other IPX packets.

3.5. Steps of the Initial Negotiation for Router-Router Operation

The several router-router protocols all begin operation the same way, as described in this section. The client-router protocol is a variation on the theme. It is discussed later, starting on page 3-13.

The first exchange of packets decides the master/slave roles and the routing protocol to be used on the link. It also gauges the link delay, by measuring the turnaround time for a moderately sized packet exchange. The initial negotiation is the same for all routing types. It is illustrated in Figure 3-1.

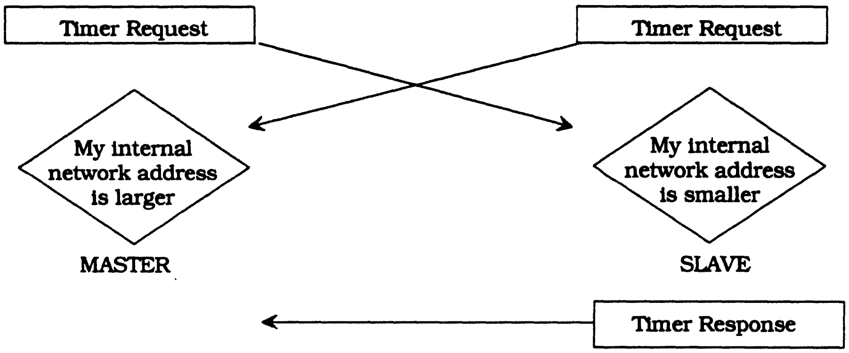

Timer Request
Timer Request
My internal network address is larger
My internal network address is smaller
MASTER
SLAVE
Timer Response

Figure 3-1: Initial Negotiation

After link establishment, both sides of the link send Timer Request packets and start a timer waiting for a Timer Response. See page 3-19 for a specification of packet contents. These Timer Request packets are sent every 20 seconds until a response is received or retry counter is exhausted. Usually, the retry counter is set to 16. If the retry counter is exhausted, the data-link connection is closed.

In composing the Timer Request packet, the router takes into consideration

- Which types of routing protocols it supports.
- Whether it is prepared to assign an IPX network number to the link.
- Whether it can support IPX header compression.
- For client-router connection, whether there is a need to specify the node number on a reconnect.

For each routing protocol supported, place the corresponding option in the Timer Request packet. They appear in the originator's order of preference, with the most preferred first.

For each compression method supported, place the corresponding option in the Timer Request packet.

If the router is prepared to assign an IPX network number to the link, it sends its internalNetworkNumber in the WNode ID field, and omits the Extended Node ID option. On the other hand, if this~~e~~ router does~~is not prepared to~~ assign an IPX network number to the link, it sends zero in the WNode ID field. In the latter case, it also includes its internalNetworkNumber in the Extended Node ID option. Furthermore, this router must be prepared to support Unnumbered links.

On receiving a Timer Request packet, a router determines its role—Master or Slave—for the remainder of the IW2 exchanges. The Master role does not denote special privilege. It merely means that the router is the requester in the ensuing request/response exchanges. The decision is made as follows:

a) If the WNode ID field is zero in both the sent and the received Timer Requests

  i) If both Timer Requests include an Extended Node ID, the router with the higher numeric value of this field is the Master. If the two Extended Node ID fields are equal, a configuration error has occurred. After reporting the error, the router issues a disconnect on the underlying data-link connection. Manual intervention is needed to correct the error condition.

  ii) If only one Timer Request includes the Extended Node ID, the router sending it is the Master.

  iii) If neither Timer Request includes the Extended Node ID, a connection cannot be established. The data-link circuit is cleared by the system that initiated it.

b) If either the sent or received Timer Request (or both) contains a nonzero WNode ID field, the router with the higher WNode ID is the Master.

c) If the two WNode ID fields are equal and nonzero, a configuration error has occurred. After reporting the error, the router issues a disconnect on the underlying data-link connection. Manual intervention is needed to correct the error condition.

The numeric comparisons are done by considering each byte as an unsigned integer, and the first byte as most significant. Note that in Figure 3-1 the decisions in the diamond-shaped symbols are simplified; the actual decision takes into account the two fields: WNode ID and Extended Node ID.

The Slave responds to the Timer Request with a Timer Response. To do so, it determines the routing protocol to be used on the link according to the following rule:

```
For each routing Routing Type in the received Timer Request,
  in order of appearance
   BEGIN      -- LOOP
   If the Routing Type is one supported by this router
         BEGIN      -- TEST
         If the Routing Type is an unnumbered type,
               choose it and exit.
         If the received WNode ID is nonzero,
               choose this Routing Type and exit.
         END        -- TEST
   END        -- LOOP
```

Note: It is permitted for a router to support a numbered routing type, but not be able to assign the network number. In this case, that routing type can be selected only if the other router supports it and can assign the network number. The rules for determining the Master/Slave role and routing protocol ensure the following:

- Routers implementing IW2 are interoperable with those implementing Reference [All942].
- If only one router is prepared to assign a network number, it is the Master (the role that does the assignment), so that if a numbered routing type is chosen, the Master has a network number to assign.

The remainder of IW2 depends on the routing type selected. A separate subsection follows for each alternative. The WNode ID value in all subsequent IW2 packets is the sender's actual internalNetworkNumber, not zero.

3.6. Remaining Steps for the Numbered RIP Routing Type

When the Timer Request/Response exchange concludes with RIP as the chosen routing type for the link, the Information Request/Reply is the next (and only) remaining step in IW2 (See Figure 3-2). This reiterates the specification in [All942]. Once the negotiation is completed, the link can be used for RIP, SAP, and IPX data traffic, but not for NLSP packets.

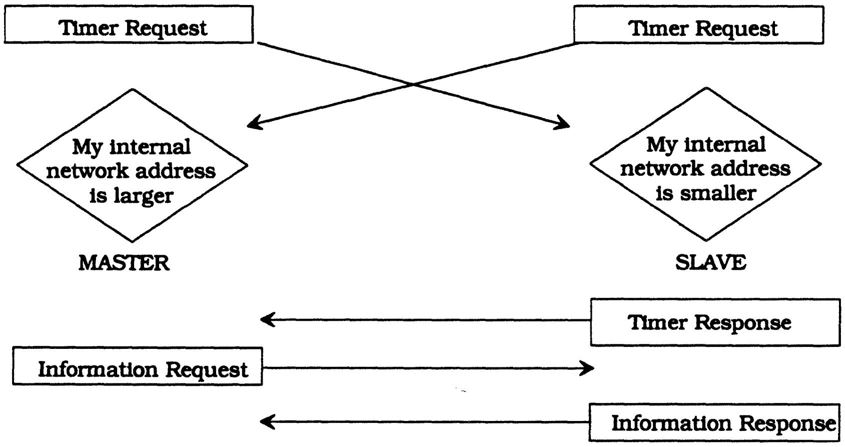


Figure 3-2: IW2 Exchanges for the RIP Routing Type

The following option subfield in the Information Request/Reponse exchange contain operational information used in RIP.

- RIP/SAP Info Exchange option—WAN Link Delay subfield. This link delay is used in the RIP information propagated to the router's other links. The following algorithm determines the IPX WAN link delay, based on the Timer Request/Response exchange. Here, `start_time` is the time that the Timer Request is sent, and `end_time` is the time that the Timer Response is received.

```
link_delay ← end_time - start_time              -- 1/18th second
link_delay ← MAX ( link_delay, 1 )    -- Ensure link delay is at least 1
link_delay ← 6 × link_delay
```

Note: Workstations use the link delay to timeout sessions. The factor of six is in anticipation of queuing delays for the WAN link that can readily impact round-trip time when data traffic starts flowing. It is a biasing value to prevent timeout of multiple workstation sessions sharing the link.

```
     link_delay ← 55 × link_delay   -- Convert link delay to milliseconds
```

The Link Delay is used as the network transport time when advertised in the IPX RIP packet. For a consistent network, a common link delay is required at both ends of the link and is calculated by the link Master.

Note: IPX WAN in its initial version does not retry the Information Request exchange. If no Information Response is received after the first Information Request, the data-link connection is cleared and starts again.

Only a Timer Response whose sequence number matches the last sent Timer Request sequence number is acted upon. This rule applies to all the routing types.

Once the IW2 exchanges are complete, RIP operates over the link as specified in Reference [Nov92].

3.7. Remaining Steps for the Unnumbered RIP Routing Type

With RIP and IPX WAN, an IPX network number is assigned to each (virtual) circuit by operation of the protocol. With Unnumbered RIP, there are no network numbers used for circuits. This is an advantage, because it is easier to administer. The Unnumbered RIP routing type exploits this administrative ease, while still using RIP and SAP as the routing protocols for the circuit.

The IW2 packets exchanged for Unnumbered RIP are the same as for RIP. If the Timer Response selects Unnumbered RIP, that mode is in effect on the link. The next exchange is the Information Request/Response. The Common Network Number field in the RIP/SAP Info Exchange field is zero, as a placeholder.

Once the IW2 exchanges are complete, RIP operates over the link as specified in Reference [Nov92], with the following exceptions. The Network Numbers in the source/destination addresses of RIP/SAP packets traversing this link are set to zero. These RIP/SAP packets are originated by the routers at either end. Forwarded packets, by contrast, continue to have the originator's and the final destination's network numbers. Because the two ends of the link are routers, the fact that this link has no network number is inconsequential. If one end were an end node, there would have to be a way for systems far away in the internetwork to address it, requiring a network number. If services are accessible on the same system as the router, or if there are software elements that act as clients, they are attached to the system's internal network number.

3.8. Remaining Steps for On-Demand, Static Routing

On-demand, static routing serves two purposes. The *on-demand* part means that a router initiates communication to a destination only when there is data to be forwarded to that destination. *Initiating communication* includes making a data-link call (where necessary) and performing the IW2 exchange. A transient connection is closed after a period of inactivity.

The *static routing* part means that no routing information is sent over the link—no RIP, no SAP, and no NLSP. Instead, the router at each end is configured with the routes and services accessible through the link.

The IW2 exchange for this routing type is a variation of Unnumbered RIP's. The differences are as follows:

In the Timer Request, the calling router offers ***only*** the on-demand static routing Routing Type. This implies that on-demand static routing is the only routing type that can be negotiated successfully on the link. If the Slave detects a mismatch in routing types, it disconnects the link.

With on-demand, static routing, the routers must be able to identify one another using data-link information. For example, with X.25 switched virtual circuits, the calling DTE address can be used; with IP Relay, the remote IP address can be used; with transient point-to-point links, PPP authentication can be used. With a persistent data-link connection, the physical port identifier or a PVC identifier can be used. The choice of identifier is an implementation decision. Whatever value the called router uses is called a *Remote System Identifier*, or *RSI*.

> **Note:** In Novell implementations of on-demand static routing over PPP, the authentication features of PPP identify the peer router. For interoperability with Novell routers in this context, systems must implement PPP authentication.

A router implementing on-demand, static routing must maintain a database of RSIs, and lists describing the network numbers and services reachable through each RSI. These lists determine the reachability information it transmits to other routers in a routing area. Other routers treat each on-demand, static routing link as though it were permanently available.

For a persistent data link, there might be no discernable link establishment event. For such media, arrival of a Timer Request plays the role of detecting link establishment.

As with Unnumbered RIP, there is no network number assigned to the link. NLSP packets are not sent on the link. Moreover, periodic RIP and SAP packets are not sent on the link. However, a router must respond to RIP and SAP queries received on the link.

3.9. Remaining Steps for the NLSP Routing Type

NLSP employs an exchange of IW2 packets lengthier than those of other routing types.

3.9.1. Normal IW2 Exchanges for NLSP

Figure 3-3 shows the complete IW2 exchange in preparation for using NLSP on the link for the normal case of no error conditions.

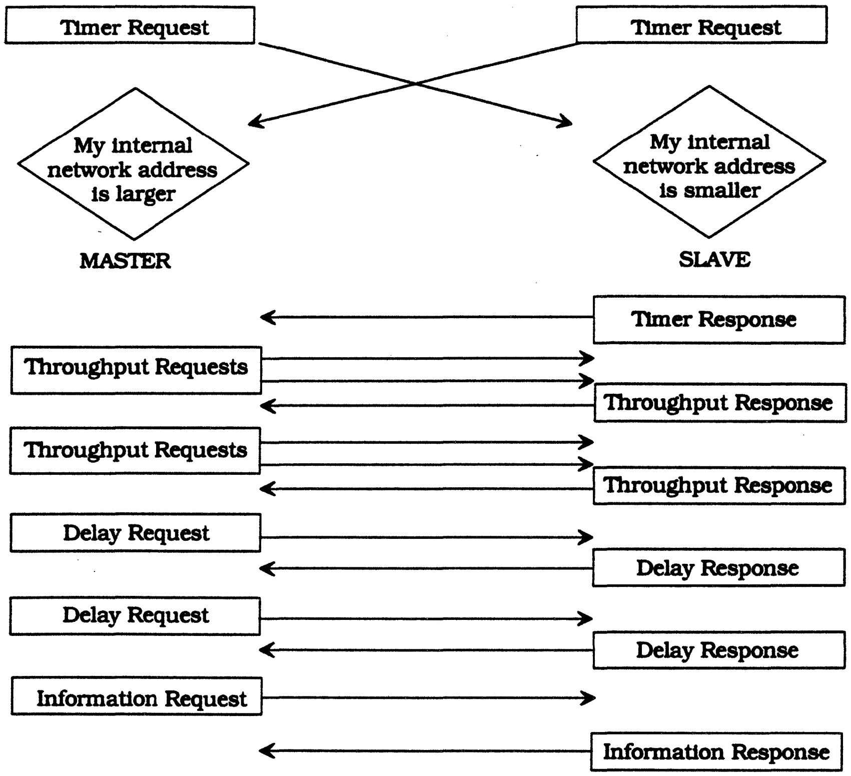


Figure 3-3: IW2 Protocol for NLSP

The Master initiates Throughput Request and Delay Request packets to calculate those two circuit characteristics. See page 3-19 for a specification of packet contents. Throughput Request and Delay Request packets are re-sent every 20 seconds until a response is received or the retry count is exhausted. If no response is received after the 16 retries, the router issues a disconnect to the link. The Sequence Number field matches a response with the corresponding request. For the Throughput Request, the matched pair contains the same sequence number (not an even/odd pair).

The Throughput and Delay packet exchanges provide empirical measurements of those two characteristics of the link. The measurements are used later during NLSP operation. *Throughput* is the amount of data (in bits per second) that can flow across the link. *Delay* is how long it takes to send a zero-byte packet to the destination. (Actually, it is an indication of the wire propagation delay to reach from one point to the other.)

Finally, the IW2 Master sends an Information Request packet to provide the Slave with operational information about the link. The Slave responds to acknowledge receipt. The exchange also informs each router of the other's textual name. If the Master does not receive the reply, NLSP retries every 20 seconds until a response is received or the retry count (16) is exhausted. If the retry counter is exhausted, close the data-link connection.

The following option subfields in the Information Request/Response exchange contain operational information used in NLSP. The following discussion indicates how to calculate the values that appear in the subfields, based on prior exchanges.

- NLSP Information option—Throughput subfield. This value is calculated based on the Throughput Request/Response exchange: two equal-sized Throughput Request packets are sent back to back. Each is *R* bytes. Nominally, R = 512, but the Master might use a different size based on local configuration, network management action, or the results of earlier exchanges on the link. The receiver (Slave) of these back-to-back packets measures the time between two packets and sends a Throughput Response packet with delta time and the Throughput Request packet length. The Master calculates the actual throughput capacity of the circuit by dividing packet size by delta time. The method assumes that packet size is large enough to offset the driver's holding time, and that the lower level driver is sending the packets one after another. The method also expects that an X.25 network delivers packets one after another to the receiving side. As illustrated in Figure 3-3, the request is repeated twice; the results are averaged, as follows:

```
R-byte packets
  --------->
  --------->
                       ---------> t1
                       ---------> t2
throughput1 =  R / (t2 - t1)
R-byte packets
  --------->
  --------->
                       ---------> t3
                       ---------> t4
throughput2 =  R  / (t4 - t3)
```

Measured throughput = (throughput1 + throughput2) / 2

- NLSP Information option—Delay subfield. This Delay measurement appears in the Link Information option of the Link State packet. The quantity conceptually represents the one-way electrical propagation delay between the two points. It is calculated based on the Delay Request/Response exchange. The idea behind the calculation is that the measured time interval between sending a full packet and receiving its echo from the other router consists of two parts: (a) the time to clock the bits onto the wire, and (b) the propagation delay. Now, the time to clock bits onto the wire is the reciprocal of the Throughput. Combining these facts,

  Echo_time / 2 = Delay + (1 / Throughput).

  The division by 2 converts from round-trip to one-way. Now, Delay is the number being sought, Throughput was determined by the previous exchange, and Echo_time is measured by the Delay exchange. (Actually, it is measured twice and the measurements are averaged.) The calculation is made by solving the above equation for Delay.

Delay = Echo_time / 2 - (1 / Throughput)
with the proper conversion of units. This is depicted as follows:

```
576-byte packet
t1  ---------->           ---------->+
t2  <----------           <----------+
echo1 = (t2 - t1) / 2     (microseconds), the division by 2 is included here
576-byte packet
t3  ---------->           ---------->+
t4  <----------           <----------+
echo2 = (t4 - t3) / 2     (microseconds), the division by 2 is included here
```

Measured delay = (echo1 + echo2) / 2 -
[1,000,000 × 8 × 576 / Throughput]

- RIP/SAP Info Exchange option—WAN Link Delay subfield. This value is calculated as described on page 3-7. It must be present and calculated correctly even when NLSP has been chosen.

On receiving the Information Request, the Slave records the pertinent information and reponds with an Information Response packet, in which its own router name and node identifier are substituted.

After the Slave has received the Information Request and the Master has received the Information Response, NLSP packets and IPX data packets can start being sent over the link.

3.9.2. NLSP Configured Values

A router can permit the two values described in IW2 packets (NLSP Delay and NLSP Throughput) to be configured manually. This can be accomplished either by local action at the router or remotely by network management action.

Whether or not a router is configured manually, it proceeds through the IW2 exchange as specified above, reporting the measured values. After the IW2 exchange, when Link State packets begin flowing, the values in the Link State packets are the manually configured ones. The values appearing in the Information Request/Response are disregarded by routers that have overriding manually configured values.

If either (a) the router at only one end of a link is configured, or (b) the routers at the two ends of a link are configured with different values, the two routers can report different values in their respective Link State packets. This can result in asymmetric routes, but NLSP operates with asymmetric routes. (An asymmetric route is one in which traffic from *A* to *B* traverses different links than traffic from *B* to *A*.) However, asymmetric routes are considered harmful because of troubleshooting difficulties.

In no event does a router attempt to assert its configured values by manipulating the numbers sent in IW2 exchanges.

3.10. Client-Router Connection

Client-router connection is the method for an individual client personal computer or workstation to connect remotely to an internetwork. The IW2 exchanges to initiate client-router operation use the same basic structure as router-router operation. There are additional provisions. Some of these provisions result from the asymmetric nature of this routing type, which makes it quite different from router-router operation. Other additions are designed for the client to learn addressing information from the router. Finally, there are additions are designed to support *reconnection.*

Reconnection is a feature to deal with a practical aspect of dial access. A data-link disconnect can occur if software detects a period of inactivity, or if the line is low quality. If a client-router connection is broken and reestablished, it is desirable that the application software continue as though the interruption had not occurred. In particular, it is important that file server connections be maintained. To support this need, IW2 has provisions that permit the address information assigned in the initial connection to be asserted for the reestablished connection.

Clients must have an IPX network number and a unique IPX node number on that network to be individually addressable. However, clients do not need periodic RIP and SAP broadcasts. This allows routers to reduce background traffic on a client link by not sending any periodic RIP or SAP data. (Sending RIP and SAP does not cause a functional problem, but it does impact performance.)

RIP and SAP information should only be sent if the client makes a specific request for information: a service or route request.

If a router assigns the same IPX network number to multiple clients, broadcasts on that network — whether originated from a workstation or the router—must reach all the (other) workstations sharing the network number. The router duplicates the packet on all those client links.

3.10.1. Agreeing on Master/Slave Roles and Routing Type

Because client-router operation is asymmetric, additional rules apply to the initial negotiation to ensure that a client can only rendezvous with a router. Client-client communication is not supported by IW2, and router-router communication must use a different routing type.

As with router-router operation, the routing type is determined from the Timer Request. A client's Timer Request is recognized by including **only** the client-router Routing Type. A router offering the "client-router" Routing Type must also include at least one additional Routing Type in the Timer Request, to distinguish itself from a client. If the router does not happen to implement any additional routing type, it includes Routing Type zero (RIP) in the Timer Request with "No" as WAccept Option. Because of the "No," it is impossible to agree on "RIP."

If a client receives a Timer Request with either

- the client-router Routing Type missing

or

- only one Routing Type in the packet,

it disconnects the link.

In summary, as long as

- exactly one of the two parties is a client

and

- the other party supports the router side of client-router operation

the provisions of the preceding paragraph ensure that client-router operation is negotiated based on the Timer Request packets.

3.10.2. Choosing the Network Number

If this is the first time the client is connecting to the router, the client sets the WNodeID to zero in the Timer Request, indicating that the router should be the Master and allocate a network number for the new link. The Extended Node ID option is omitted. The client is the Slave.

If the client is reconnecting a link after an earlier disconnect, it must be able to specify its earlier network number. In this case, the client sets its WNodeID field to 0xFFFFFFFF, forcing itself to be the link Master. In this case, the router responds with only the client-router Routing Type acknowledged.

If the router can assign a network number

- for client-router operation

but not

- for router-router operation

it sets its the WNodeID to zero in the Timer Request. With client-router operation, the router must be willing to assign the network number, regardless of the WNodeID value in the Timer Request. This is precisely what happens when the client is connecting to the router for the first time.

All dial-in clients could share the same network number and be assigned unique node numbers by the router, or each workstation could be assigned a different network number. This is a router-specific implementation detail. Use of a single network for all clients is preferred; however, this does involve extra work by the router to replicate broadcast frames.

If a router receives an inappropriate Information Request from a client trying to set the network number, the router overwrites the values with a preferred value. When the client receives the Information Response, it must note the new value. If the client cannot adjust to the new value, it disconnects the link.

3.10.3. Choosing the Node Number

In client-router operation, the router can typically be communicating with many dial access clients simultaneously. To conserve address space, many clients are considered nodes on a single network, with one IPX network number. Because the clients are independent of each other, this requires a mechanism to assign IPX node numbers dynamically at the time a connection is made. (The node number is a six-byte value playing the role of the IEEE MAC address in the IPX header.) The mechanism is a Node Number option in the Information Request and Response packets.

As was explained in the previous section, the router is the Master for an initial client-router connection, but the client is Master for a reconnection. In both cases, the Master determines the IPX network number for use over the link. In the same way, the Master chooses the node number that the client uses on the link. The choice is transmitted in the Node Number field of the Information Request.

The most-significant byte of the Node Number must be the value 0x02. (In the IEEE MAC address space, the two least-sigificant bits of this value indicate that the Node Number is a nonmulticast, locally assigned value.) Other values are reserved. The router's own node number should be avoided.

> Note: Because future versions of this specification might use some of the reserved values, the client should accept any Node Number assigned by the router, even if the most-significant byte is not 0x02.

When the router is the Master and allocating node numbers on a single network, it should always use a unique value by incrementing the Node Number for each client connection. This allows a reconnecting client to specify its old network and node numbers. It is unlikely with five bytes free in the node number that a wraparound in the numbers could occur. The router stores in permanent memory the range already consumed, to avoid confusion between re-connecting clients should the router be restarted.

If a router receives an inappropriate Information Request from a client trying to set the node number, the router overwrites the value with a preferred value. When the client receives the Information Response, it must note the new value. If the client cannot adjust to the new value, it disconnects the link.

3.11. Checking and Recovery Features of IW2

Packets received on socket number 0x9004 not having the WIdentifier field set to 0x5741534D are discarded.

If an unknown WPacket Type is received, the receiver should respond with a NAK packet.

If an invalid or unsupported WOption Number is received in a request, the receiver should respond to the packet with a WAccept Option set to "No" for that option.

If a router determines that it cannot support any of the Routing Types included in the Timer Response or Timer Request packet, it issues a disconnect on the underlying data-link connection.

If a Timer Request arrives after the router has sent or received a Timer Response, the exchange reverts to the start. That is, the router reverts to sending its Timer Request packet.

When a router assumes the Slave role, it starts a 60-second timer. If the IW2 exchange has not concluded by the time the timer expires, the router issues a disconnect on the underlying data-link connection.

If a protocol error is detected, the router issues a disconnect on the underlying data-link connection. Protocol errors include (a) packets received out of order, and (b) a Slave receiving a Timer Response. The same happens if no response is detected after the request retries are exhausted. If this happens before the Master role is decided, either router issues the disconnect.

If a router receives a packet with an illegal WPacket Type, or if the options are malformed (for example, they extend beyond the end of the packet), the router sends a NAK packet, and otherwise ignores the offending packet. (There is an exception. If the routing type is RIP, or if it is not yet decided, a NAK is not sent. ~~This is because Reference [All942] does not include the NAK.) When a router receives a NAK packet, it can try something different or it can cause a disconnect.~~

After a disconnect, the router that initiated the original connection can (at its option) try to establish a new data-link connection. With X.25 switched circuits, this means establishing a new virtual circuit before restarting IW2. With dial-up PPP, this means establishing a new data-link connection before restarting PPP and then IW2. With a dedicated PPP link, this means that both peers restart the PPP protocol from the beginning, then IW2.

For an X.25 PVC, a Frame Relay PVC, or IP Relay, establishing a new data-link connection means restarting IW2 from the beginning. In these cases, the Timer Request can be retried indefinitely.

Under certain circumstances—particularly on X.25 or Frame Relay PVCs—it is only possible to detect that the remote router went away when it comes back up again. In this case, one side of the link receives a Timer Request packet when IPX is in a fully connected state. The side receiving the Timer Request must realize that a problem occurred and start tearing down the link to reestablish the connection.

Note: Resolving call collisions is outside the scope of this specification. Call collisions occur when two routers are configured to maintain a circuit to each other on the same physical connection, and the two call requests are issued at the same time. Resolving call collisions is the responsibility of the underlying Data-link layer.

Note: It might happen that two circuits become established connecting the same two end points. In fact, this might be desirable to increase throughput in some situations. IW2 does not include any protocol provision to discriminate between wanted and unwanted duplicates. Every circuit is kept, unless clearing it is forced by local manual action or by operation of network management.

3.12. Recalibrating Throughput and Delay

The specification does not currently include a provision for the Throughput or Delay to be recalibrated after completion of the IW2 exchange, while the circuit is actively conveying routing traffic and data traffic.

To allow this capability to be added in the future, a router that receives a Throughput Request or Delay Request after completion of the IW2 exchange ignores those packets, without generating an alarm and without disconnecting the circuit.

3.13. Forwarding "Type 20" Packets

Section 5 of reference [Nov92] documents the use of IPX Packet Type 20 to implement a form of internetwork broadcast. That reference specifies a list in the IPX packet of up to eight Network Number fields. The list indicates the path traversed by the packet so far. There are two cases in which a WAN link does not have a network number for inclusion in the list.

- When a system forwards an IPX Type 20 packet on an Unnumbered RIP link, add the internal network number of the sending system to the Network Number list.
- When a system forwards an IPX Type 20 packet on an NLSP WAN link, add the internal network number of the receiving system to the Network Number list. That network number is learned previously as part of the IW2 exchange.

IPX Type 20 packets are not forwarded over on-demand, static routing links.

3.14. IW2 Database

3.14.1. Constant Values

minMTU

The packet size that every router must be prepared to handle: 576 bytes, including IPX header and data, but not data-link headers or trailers.

3.14.2. Configured Values

internalNetworkNumber

Every NLSP router and every NetWare 3 or 4 server has an IPX network number internal to the system itself. The network number is within the relevant routing area, but is distinct from the network numbers of the physical network segments in a routing area. Any application services operating on the system are attached to the internalNetworkNumber. Network management packets to a router should be sent to the internalNetworkNumber. (In previous specifications, such as Reference [All942], there is the concept of a *primary network number* for systems not| necessarily having an internal network number. A *primary network number* can be either an internal one or the network number of a distinguished permanently attached network segment. The internalNetworkNumber idea supersedes that of a primary network number.)

nodeNumber

In some situations, a router needs a six-byte IPX node number value for itself on a WAN link, to play the role of the IEEE MAC address. For example, the value would be used as the source node number in the IPX header of an outgoing RIP or SAP packet. The node number is formed from the internalNetworkNumber. It is the four-byte internalNetworkNumber followed by two zero bytes.

routerName

Every router has a readable textual, symbolic name. It is especially useful for network management purposes to identify systems by a user-defined mnemonic name. The name is 1 to 47 characters, containing uppercase English letters, underscore (_), hyphen (-), and "at" sign (@). When a router coexists on the same system as a NetWare server, the routerName coincides with the server name. For a client-router connection, the client should use a string reflecting the user's name; if the name is not known, use the default string "DIAL-IN-CLIENT".

nlspDelayOverride

A router can provide to the user a mechanism to (optionally) override the NLSP Delay, usually determined empirically by the IW2 protocol exchange.

nlspThroughputOverride

A router can provide to the user a mechanism to (optionally) override the NLSP Throughput, usually determined empirically by the IW2 protocol exchange.

3.14.3. Dynamic Values

ipxWanNetworkNumbers

As a result of IW2 exchanges, each WAN circuit is either (a) determined to run an unnumbered routing protocol, or (b) has an IPX network number assigned. The router keeps track of the network number (or lack thereof) for each circuit. The router can optionally have a pool of network numbers to assign dynamically during IW2 operation to circuits being brought into service.

3.14.4. Dynamic Values per Circuit

Delay

The electrical propagation delay for a signal to flow from one end point to the other, in milliseconds.

Throughput

The amount of data, in bits per second, that can flow through the circuit if there is no other traffic.

RIP Link Delay (Ticks)

The amount of time it takes a 576-byte packet to reach a location. It is measured in ticks, with 18.21 ticks per second (minimum of one).

3.15. Packet Structures

IW2 employs one kind of packet structure: IPX WAN (page 3-19).

These packets ride in the data portion of IPX packets. The IPX header fields are encoded:

Destination Network	zero
Destination Node	0xFFFFFFFFFFFF
Destination Socket	0x9004
Source Network	zero
Source Node	zero
Source Socket	0x9004
Packet Type	4

IPX WAN packets never exceed minMTU bytes in size, including the IPX header but excluding the data-link headers. All multibyte fields are transmitted with the most significant byte first.

3.15.1. IPX WAN 2

WIdentifier: 0x5741534D (ASCII for "WASM") indicates packets of the IPX WAN family of protocols.

IPX WAN 2	Number of Bytes
WIdentifier	4
WPacket Type	1
WNode ID	4
WSequence Number	1
WNum Options	1
Variable Length Fields	Variable

WPacket Type: Identifies a specific type of IW2 packet:

0 = "Timer Request"

1 = "Timer Response"

2 = "Information Request"

3 = "Information Response"

4 = "Throughput Request"

5 = "Throughput Response"

6 = "Delay Request"

7 = "Delay Response"

0xFF = "NAK;" the packet content is an exact copy of the received, rejected packet, except that (a) the Packet Type indicates NAK, and (b) the WNode ID is that of the sending router. Only packets with the proper Identifier are replied to with NAK.

Packet Types 0 through 4~~3~~ are defined in Reference [All94~~2~~]. Packet types 5~~4~~ through 7 and 0xFF apply only to IW2.

WNode ID: The internalNetworkNumber of the sending router. There are three exceptions, each applying only to the Timer Request packet.

- If the router cannot assign a network number to the link, this field contains zero and the internalNetworkNumber is conveyed in the Extended Node ID option.
- If a client is connecting initially, it places a zero in this field.
- If a client is reconnecting to a router, it places all-ones in this field.

WSequence Number: This field starts with zero for each request packet type and is incremented by one for each retry of that packet type. Each response echoes the sequence number of the request. This allows each response to be matched with the request that provoked it.

WNum Options: Indicates how many options are present in the variable length fields. Options in a packet can occur in any order.

Variable Length fields: A series of optional fields, each of which has the following four-part Option form.

Option	Number of Bytes
WOption Number	1
WAccept Option	1
WOption Data Len	2
WOption Data	WOption Data Len

WOption Number: Identifies a particular option. Currently defined codes are in the following bullet list.

WAccept Option: This field is used for negotiating options between the two parties:

0 = "No"

1 = "Yes"

3 = "Not Applicable"

WOption Data Len: The length, in bytes, of the WOptionData field.

WOption Data: Details specific to a particular code.

Currently defined codes, and the corresponding values, are as follows:

- Routing Type

  Code = 0x00   Length = 1

  Value = Type of IPX routing protocol the sender can support (or cannot support if this is a Timer Response and WAccept Option is "No"):

  0 = "RIP"
  1 = "NLSP"
  2 = "Unnumbered RIP"
  3 = "On-demand, static routing"
  4 = "Client-router connection"

- RIP/SAP Info Exchange

  Code = 0x01   Length = 54

  Value = The following three subfields:

RIP/SAP Info Exchange	Number of Bytes
WAN Link Delay	2
Common Network Number	4
Router Name	48

  - WAN Link Delay: The metric IPX RIP uses for routing; the RIP Delay in milliseconds.

    Note: The units here are different from the units (Ticks) in RIP packets.

  - Common Network Number: For numbered Routing Types, this field contains the IPX network number assigned to the link; for unnumbered Routing Types, the value zero occupies this field.

  - Router Name: A unique textual identifier for the router, one byte per character, seven-bit ASCII, flush-left, null-filled.

- NLSP Information

  Code = 0x02   Length = 8

  Value = Two subfields, Delay and Throughput, containing values estimated by IW2 exchanges.

NLSP Information	Number of Bytes
Delay	4
Throughput	4

- NLSP Raw Throughput Data

  Code = 0x03   Length = 8

  Value = The following two subfields:

NLSP Raw Throughput Data	Number of Bytes
Request Size	4
Delta Time	4

  - Request Size: Size of the Throughput Request packet.

  - Delta Time: The time interval, in microseconds, between receipt of equal size Throughput Request packets.

- Extended Node ID

  Code = 0x04   Length = 4

  Value = Sending router's internalNetworkNumber. This option occurs only in Timer Requests and only when WNode ID is zero.

- Node Number

Code = 0x05 Length = 6

Value = IPX node number to be used by the client on a client-router connection. It is comparable to the IEEE MAC address.

- Compression

Code = 0x80 Length = variable

Value = The first byte indicates a style of compression; the remaining bytes specify parameters pertaining to that style.

Currently, one compression type is specified:

Telebit compression (option length = 3 bytes), see Reference [Mat92].
Byte 0: Contains the value 0 to indicate Telebit compression.
Byte 1: Compression options.
Byte 2: Number of compression slots.

- Pad

Code = 0xFF Length = variable

Value = A sequence of totally random bytes to fill the packet to the required size. The Value is ignored on receipt.

Note: The purpose of randomness is to prevent data-compressing modems from defeating accurate estimations of the link's operational characteristics. ~~Randomness is a change from reference [All942].~~

Figure 3-4 summarizes which options are permitted in which request/response packets. The text of this chapter explains which are actually present under what circumstances. The notes are itemized immediately after the figure.

Timer Request	Notes
IW2 Header (fixed part)	See page 3-19
Routing Type	R d
Extended Node ID	A i
Compression	O y
Pad	M i

Timer Response	Notes
IW2 Header (fixed part)	See page 3-19
Routing Type	= 4 c
Compression	E 3 c
Pad	M i

Throughput Request	Notes
IW2 Header (fixed part)	See page 3-19
Pad	M P i

Throughput Response	Notes
IW2 Header (fixed part)	See page 3-19
NLSP Raw Throughput Data	M P y

Delay Request	Notes
IW2 Header (fixed part)	See page 3-19
Pad	M P i

Delay Response	Notes
IW2 Header (fixed part)	See page 3-19
Pad	M P i

Information Request	Notes
IW2 Header (fixed part)	See page 3-19
RIP/SAP Info Exchange	M y
NLSP Information	N y
Node Number	D y

Information Response	Notes
IW2 Header (fixed part)	See page 3-19
RIP/SAP Info Exchange	= y
NLSP Information	= y
Node Number	D y

Figure 3-4: IW2 Option Usage

Notes for Figure 3-4

M	Mandatory field.
N	Mandatory for NLSP; optional otherwise.
O	Optional field; can appear more than once.
=	Response fields contain the same WOption Data as the corresponding request fields.
E	Response fields correspond one-for-one with request fields; the response can zero out zero or more option bits of the Telebit options field; it must not set bits that were zero in the request.
P	Throughput and Delay exchanges occur only with NLSP.
R	Routing types appear in order of preference (most preferred first). At least one must be present.
A	Appears if and only if the WNode ID field is zero.
3	Each WAccept Option field is set to indicate acceptance or rejection; the responder selects, **at most,** one of the choices offered in the Request.
4	Each WAccept Option field is set to indicate acceptance or rejection; the responder selects **exactly** one of the routing types offered in the Request.
D	Negotiation in client-router routing type only.
y	WAccept Option must be "Yes."
d	WAccept Option must be "Yes," except for one special case in client-router operation.
c	WAccept Option must be "Yes" or "No."
i	Value of WAccept Option is immaterial.

4. Adjacencies

Before routers can spread topology and status information throughout a routing area, each router determines that information for the links to which it is directly connected and for the routers to which it can communicate directly (without forwarding) over those links.

This section deals with the *local neighborhood discovery* part of the protocol.

The NLSP™ specification treats two categories of networks differently. In this specification, the terms *LAN* (local area network) and *WAN* (wide area network) are used for these categories. For each medium of interest, it is specified whether NLSP treats it as a LAN or WAN. In most cases, the categorization is obvious, but not always. In general terms, a LAN is capable of broadcast addressing at the Data-Link layer. IEEE 802.3 and IEEE 802.5 are LANs. Because IEEE 802.6 and FDDI support broadcast, they are treated as LANs even though they are not always local networks. In general terms, a WAN is either connection-oriented (requiring a call setup at the Data-link layer) or is a point-to-point network. Examples are PPP (dedicated or dialed links) and X.25.

Section 4.1 deals with WANs, while Section 4.2 deals with LANs.

By exchanging Hello packets on circuits, a router determines the reachability of its neighbors. An *adjacency* is the record that a router keeps about the state of its connectivity with a neighbor, and about the attributes of the neighboring router.

4.1. Maintaining Adjacencies over WANs

Adjacency establishment goes through several stages on a WAN:

- The underlying data-link connection is established. The details depend on the type of medium.
- If a connection is successfully established, the two neighbors use the *IPX WAN version 2* (IW2) protocol to exchange identities and determine certain operational characteristics of the link. Section 3 covers IW2.
- If IW2 concludes successfully, the two neighbors begin to exchange Hello packets and update their Adjacency Databases. Details follow in this section.
- Once the Hello packets establish an adjacency, the routers start exchanging Link State packets. These are defined in Section 5.
- Finally, the routers start forwarding IPX data packets over the link.

4.1.1. Maintaining WAN Links

For each adjacency, the router maintains a state variable that assumes one of three values: "Up," "Initializing," or "Down."

Whenever a circuit is created and the first Hello packet is received, the state initializes to "Down." Whenever there is a Layer 2 data-link reset of the circuit, an adjacencyStateChange (Down) event is generated and the state is set to "Down." The same actions are taken if the link (or the entire router) is reset by local management action or by operation of NLSP (for example, detection of a checksum error in the locally stored Link State database).

See Figure 4-1 for the complete state machine.

If a neighbor is not heard from in the time indicated by the holdingTimer recorded when accepting a WAN Hello packet, the router generates an adjacencyStateChange (Down) event and deletes the adjacency.

4.1.2. Sending WAN Hello Packets

Sending WAN Hello packets allows routers on a circuit to discover each other's identity, decide whether they are in the same routing area, and determine whether the other router and the link between them remains operational.

A router sends a WAN Hello packet on a WAN link when

a) The circuit is first enabled and the IW2 protocol exchange is complete

b) The interval nonBcastHelloInt expires

c) The contents of the next Hello to be transmitted would be different from the contents of the previous Hello transmitted by this system, and one or more seconds have elapsed since the previous Hello

Hello packets are sent regardless of the value of the local state, as long as the circuit exists.

The WAN Hello packet is constructed as follows:

d) The Local WAN Circuit ID field is set to the localCircuitID value assigned by this router when the circuit is created. This value must be unique among all WAN circuits attached to this router. (It is recorded in the circuitID entry of the Adjacency database.)

e) The WAN State field is set to this router's current state for this link.

f) The MTU Size field must be included. It indicates the largest packet (in bytes, including the IPX™ header but not the data-link header) that the router is capable of receiving on the circuit; that is, the localMaxPacketSize.

4.1.3. Receiving WAN Hello Packets

Upon receipt of a WAN Hello packet, perform the following acceptance tests:

a) The general packet acceptance tests described in Section 2 under "General Processing of Incoming IPX Packets."

b) If the length of the packet, as described in its header, is greater than the buffer in which it was received, discard the packet and log a packetRxSmall event.

c) If the options in the variable part of the packet are ill-formed, or if they extend beyond the end of the packet, discard the packet and log a malformedOption event.

d) Compare each of the area addresses from the Area Addresses field with the set of manualAreaAddresses configured locally. Consider a match to be detected if the Address and the Mask portion are identical. If no match is detected between any pair (that is, if the local and remote system have no area address in common),

    i) If there is an adjacency and it is not in the "Up" state, generate an areaMismatch.

    ii) If the adjacency is in the "Up" state, delete the adjacency and generate an adjacencyStateChange (Down—Area Mismatch) event.

    iii) Otherwise, ignore the packet.

e) If the Circuit Type field in the received Hello packet is other than 1 or 3,

    i) If the adjacency already exists, generate an adjacencyStateChange (Down) event and delete the adjacency.

ii) If the adjacency does not already exist, discard the packet and generate a wrongSystemType event.

f) If the Local MTU option is absent, discard the packet and generate a missingOption event.

g) If the value of the Local MTUfield is less than minMTUAllowed, discard the packet and generate a malformedOption event.

Once the packet has passed the preceding tests, the router invokes a state machine comparing the router's own internal current state for the link with the value of the state field of the received packet. Figure 4-1 illustrates the state machine. Each cell of the table indicates the new state for the router's own state of the link.

		1	2	3	4
		Received packet indicates “Down”	Received packet indicates “Initializing”	Received packet indicates “Up”	Link is reset by local action, or a data-link reset is detected.
A	Current state is “Down”	“Initializing”	“Initializing”	“Down”	“Down”
B	Current state is “Initializing”	“Initializing”	“Up”	“Up”	“Down”
C	Current state is “Up”	“Initializing”	“Up”	“Up”	“Down”

Figure 4-1: WAN Adjacency State Machine

Note: The state machine deals with the case where one end of the point-to-point link wants to bring down the adjacency and must ensure that the remote system is aware of this. This could happen in the following scenarios:

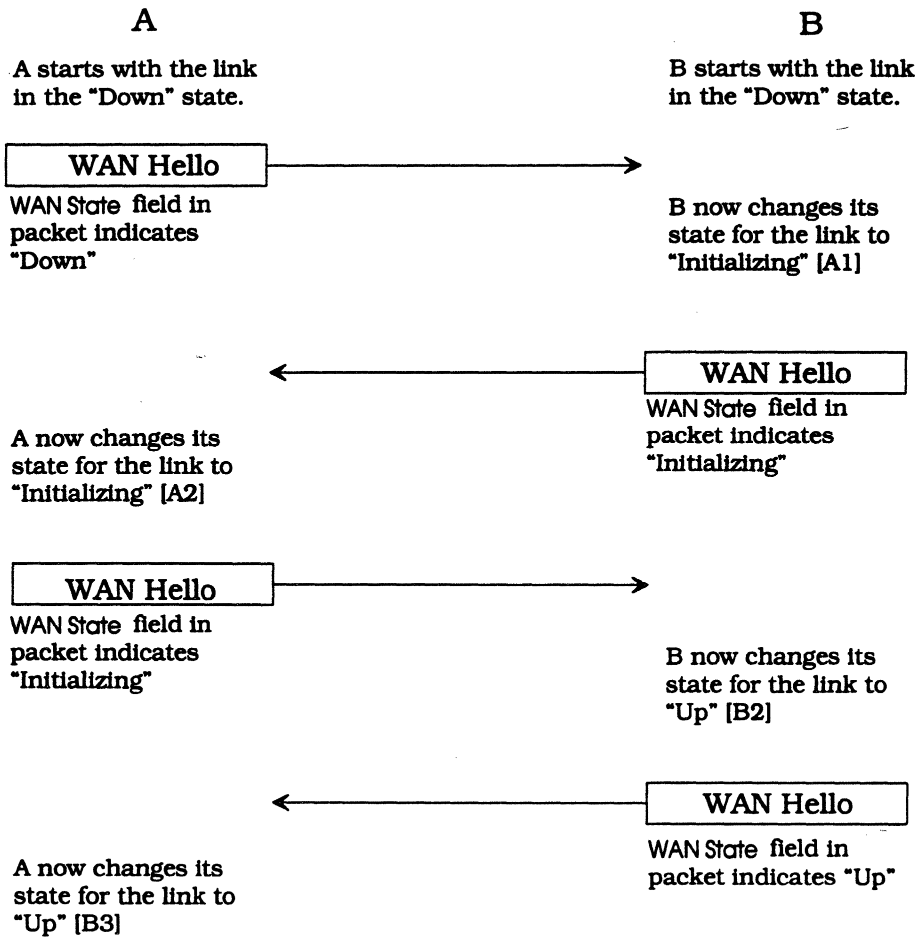
1. A circuit is deleted and re-created.

   Although NLSP sends a Hello with zero holding time when the circuit is deleted, there is no guarantee that this will get through. Thus, the remote system might be unaware that the next Hello that is received is from a new adjacency, so it does not attempt to resynchronize its LSP database.

2. When the router is reset, or an LSP with an incorrect checksum is found in memory.

In either case, NLSP attempts to reacquire the information from its neighbors. This can be done simply if the remote system can be forced to bring down and then bring up its adjacency to the local system. Adjacency state procedures are independent of the IW2 protocol, to allow for new types of unreliable data-link media.

Figure 4-2 illustrates a typical startup scenario involving routers *A* and *B*. The notations in square brackets refer to the row and column of Figure 4-1. For example, [A3] refers to a router in the "Down" state receiving a Hello indicating that its neighbor is in the "Up" state.



A starts with the link in the "Down" state.

B starts with the link in the "Down" state.

WAN State field in packet indicates "Down"

B now changes its state for the link to "Initializing" [A1]

WAN State field in packet indicates "Initializing"

A now changes its state for the link to "Initializing" [A2]

WAN State field in packet indicates "Initializing"

B now changes its state for the link to "Up" [B2]

WAN State field in packet indicates "Up"

A now changes its state for the link to "Up" [B3]

Figure 4-2: New WAN Adjacency

Once a system considers a link to be "Down," it stays "Down" until its neighbor reports that the link goes "Down" then "Up" again. Figure 4-3 illustrates what happens when an adjacency is lost, then recovered. In that figure, note that if B makes the first move rather than A, the sequence is the same except that the first step is absent.

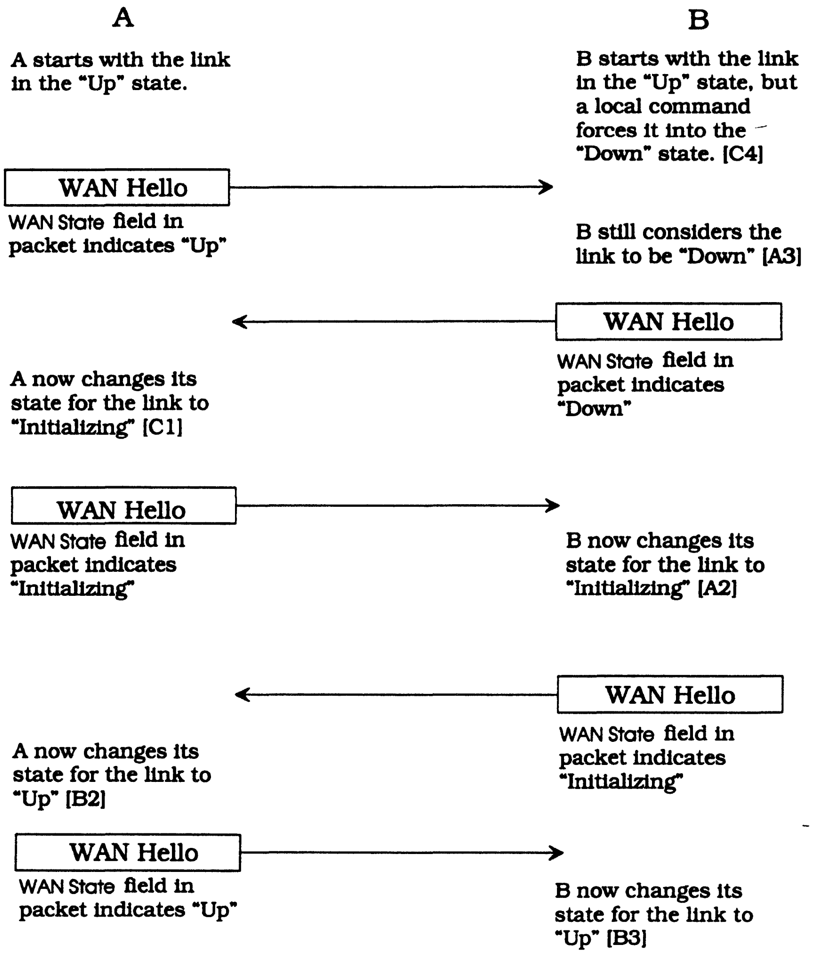

A
B
A starts with the link in the "Up" state.
B starts with the link in the "Up" state, but a local command forces it into the "Down" state. [C4]
WAN Hello
WAN State field in packet indicates "Up"
B still considers the link to be "Down" [A3]
WAN Hello
WAN State field in packet indicates "Down"
A now changes its state for the link to "Initializing" [C1]
WAN Hello
WAN State field in packet indicates "Initializing"
B now changes its state for the link to "Initializing" [A2]
WAN Hello
WAN State field in packet indicates "Initializing"
A now changes its state for the link to "Up" [B2]
WAN Hello
WAN State field in packet indicates "Up"
B now changes its state for the link to "Up" [B3]

Figure 4-3: Recovering a WAN Adjacency

If the state changes from "Up" to a different state, generate an adjacencyStateChange (Down) event.

If it is a new adjacency, that is, if the state machine changes from "Initializing" to "Up," then

a) Generate an adjacencyStateChange (Up) event.

b) Transmit a WAN Hello packet.

c) Compare the Source ID field (call it *x*) of the received packet with the local systemID (call it *y*). The numeric comparison is done by considering each byte as an unsigned integer, and the first byte as most significant.

   i) If $x < y$, set the circuit's circuitID to the concatenation of the local systemID and the localCircuitID of this circuit (as in the Local Circuit ID field of WAN Hello packets sent by this router on this link).

ii) If $x > y$, set the circuit's circuitID to the concatenation of the Source ID field of the received packet and the Local Circuit ID field of the received packet.

Note: Do not change the value included in the Local Circuit ID field of Hello packets transmitted by this router. That value is assigned once when the circuit is created and is not subsequently changed.

iii) If $x = y$, the local systemID and local localCircuitID are used.

Note: The two values would be equal if it is some form of loopback circuit.

d) Note that the packet was accepted.

If the adjacency already exists in the "Up" state and remains "Up," compute a CircuitID as in item c) immediately prior. Then,

e) If the computed circuitID is the same as the one previously recorded for the link, simply note that the packet was accepted.

f) If the computed circuitID differs from the one previously recorded for the link, generate an adjacencyStateChange (Down) event, and delete the adjacency.

If, in the above steps, you note that the packet was accepted,

g) Copy the adjacency areaAddressesOfNeighbor entries from the Area Addresses field of the packet.

h) Set the holdingTimer to the value of the Holding Timer field of the packet.

i) Set the neighborSystemID to the value of the Source ID field of the packet.

j) From the MTU Size field in the packet, update the actualMaxPacketSize value for the circuit; it is the lowest value of the MTU size field received on the circuit (this allows packets exceeding minMTU bytes to be transmitted confidently).

4.2. Maintaining Adjacencies over LANs

Multipoint networks with broadcast capabilities include LANs, some Metropolitan Area Networks (MANs), such as Switched Multimegabit Data Service (SMDS), and other emerging technologies. For simplicity, the term LAN refers to broadcast networks of all types.

At various places, packet fields contain the six-byte IEEE MAC address. Sometimes decisions are made based on the six-byte IEEE MAC address reported for an incoming packet by the Data-link layer. When the medium is an IEEE 802.3, 802.4, or 802.5 LAN, the value used is an actual six-byte IEEE address. If a medium has a smaller address (for example, Omninet), it is right-justified and zero-padded. If a medium has a larger data-link address (for example, SMDS), a specification is needed for that medium to resolve values between data-link addresses and IEEE addresses.

4.2.1. Enabling LAN Circuits

When a broadcast circuit is enabled on a router, the router takes the following actions:

a) Begin sending Hello packets (page 4-7)

b) Begin accepting Hello packets from other routers on the LAN (page 4-8)

c) After waiting for a determined time interval, run the Designated Router election process (page 4-11).

4.2.2. Sending LAN Hello Packets

Sending Hello packets allows for routers on the broadcast circuit to discover the identity of other Level 1 routers of the same routing area on that circuit.

The LAN ID field of the Hello packet is the concatenation of a router's System ID and a one-byte Local LAN Circuit ID assigned by that router, to be unique among all the LAN circuits directly attached to that router. If the router sending a LAN Hello believes that another router is the Designated Router for that LAN, it puts in the LAN ID field the value of the LAN ID observed in the other router's LAN Hello. Otherwise (either it believes itself to be Designated Router or perhaps it has seen no Hello packets yet), the router sending a LAN Hello uses its own systemID in the System ID field and a Local LAN Circuit ID it assigns when filling in the LAN ID field. It uses the circuitID entry to keep track of the assigned values for different circuits.

The priority is a manually configured value. It comes into play with Designated Router election.

The No Multicast bit is set to zero if the router is capable of receiving packets addressed to the selective link-level multicast addresses. Otherwise, the bit is set to one.

The variable-length fields include the following:

a) The area addresses with which the router has been configured (manualAreaAddresses).

b) The LAN addresses of the adjacencies on this circuit. The adjacency list includes only Level 1 routers within the same area. Only those adjacencies in the "Initializing" or "Up" states are included. The states are described in section 4.2.5.

c) The MTU Size field must be included. It indicates the largest packet (in bytes, including the IPX header but not data-link header) that the router can receive on the circuit.

A router transmits a LAN Level 1 Hello packet immediately when any circuit has been enabled. Hello packets are transmitted to the multidestination address allL1Routers. Routers listen on this address for arriving Hello packets.

A router also transmits a LAN Level 1 Hello packet when at least one second has elapsed since the last such transmission on this circuit by this router, and

- bcastHelloInt seconds have elapsed[1] since the last periodic LAN Level 1 Hello transmission:

> The Holding Time is set to holdingTimeMultiplier X bcastHelloInt. For a Designated Router, the value of drBcastHelloInt is used instead of bcastHelloInt[1]. The Holding Time for this packet is therefore set to holdingTimeMultiplier X drBcastHelloInt seconds. This permits a failed Designated Router to be detected more rapidly.
>
> There is an exception. When a system resigns as Designated Router, it sends the first holdingTimeMultiplier Hello packets at the interval of drBcastHelloInt, with a holding time of holdingTimeMultiplier X bcastHelloInt. This prevents other systems from timing out the adjacency if a Hello is dropped. The same rule applies for router implementations that permit timers to be changed dynamically, in the case that the hello interval is increased.

[1] Jitter is applied, as described in Section 2.

Or

- The contents of the next Hello to be transmitted would differ from the contents of the previous Hello transmitted by this system.

  Or

- The system has determined that it is to become or resign as Level 1 Designated Router.

When a router transmits a Hello packet, it must not exceed the actualMaxPacketSize. If the number of adjacencies is so large that actualMaxPacketSize would be exceeded, the router generates a tooManyAdjacencies event and transmits a Hello packet with as many Neighbors as fit.

Note: For example, with a circuit having an actualMaxPacketSize of 1500 bytes, and with a router having three manual area addresses, a Hello packet can report at most 233 neighbors.

	Bytes	
IPX header	30	
LAN Hello header	27	
Three Area Addresses	26	= 3 × 8 + 2
Local MTU Option	6	
Neighbors	1270	= 5 options containing 42 neighbors each = 5 × (6 × 42 + 2)
Neighbors	140	= 1 option containing 23 neighbors = 6 × 23 + 2
Total Bytes	1499	
Total Neighbors	233	= (5 × 42) + 23

To minimize the possibility of the Hello transmissions of all routers on the LAN becoming synchronized, the hello timer is only reset when a Hello is transmitted as a result of timer expiration, or on becoming or resigning as Designated Router. It is not reset if the Designated Router changes from one remote system to another.

4.2.3. Receiving LAN Hello Packets

Upon receipt of a LAN Hello packet, perform the following acceptance tests:

a) The general packet acceptance tests described in Section 2 under "General Processing of Incoming IPX Packets."

b) If the source network number in the IPX header differs from this router's view of the circuit's network number, discard the packet and log a mismatchedNetworkNumber event.

c) If the source node number in the IPX header differs from the six-byte IEEE MAC address reported by the data-link layer, discard the packet and log a mismatchedNodeAddress event.

d) If the length of the packet as described in its header is greater than the buffer in which it was received, discard the packet and log a packetRxSmall event.

e) If the options in the variable part of the packet are ill-formed, or if they extend beyond the end of the packet, discard the packet and log a malformedOption event.

f) If the Circuit Type field is other than 1 or 3, discard the packet.

g) Compare each of the area addresses from the Area Addresses field with the set of manualAreaAddresses configured locally. Consider a match to be detected if the Address and the Mask portions are identical. If a match is not found between any pair (that is, if the local and remote system have no area in common), reject the adjacency and generate an areaMismatch event.

h) If the Local MTU option is absent, discard the packet and generate a missingOption event.

i) If the value of the Local MTUfield is less than minMTUAllowed, discard the packet and generate a malformedOption event.

If the preceding tests succeed, the router accepts the adjacency and sets the neighborSystemType to "L1 Router."

Use the MTU size field in the packet to update the actualMaxPacketSize value for the circuit; it is the lowest value of the MTU size field received on the circuit.

If a Level 1 LAN Hello is received with the No Multicast bit set to one, the router sends future NLSP packets for that network segment to the broadcast address, where it would otherwise use the multicast address. ~~There is no provision for returning to the multicast address.~~

If no futher Level 1 Hellos are received with the No Multicast bit set, the router starts to use the multicast address for that network segment to send NLSP packets, if the router is capable of using the multicast address. One possible implementation scheme is to maintain a bit in each adjacency with the setting of the No Multicast bit received in the last Level 1 LAN Hello;when no adjacency has this bit set, the router returns to using the multicast address. A count of the number of adjacencies with this bit set to one can be maintained as a way of avoiding periodic scans of the adjacency database.

4.2.4. Maintaining Existing LAN Adjacencies

When a Level 1 LAN Hello is received from a router for which there is already an adjacency with

a) The adjacency neighborNICAddress equal to the six-byte IEEE MAC source address of the packet

b) The adjacency neighborSystemID equal to the Source ID field of the packet

c) The adjacency neighborSystemType equal to "L1 Router"

the router updates the adjacency's holdingTimer, priorityOfNeighbor, and areaAddressofNeighbor according to the values in the packet.

4.2.5. Detecting New LAN Adjacencies and Updating Adjacency States

When

a) A LAN Level 1 Hello is received (from router *R*)

b) There is no adjacency for which

    i) The adjacency neighborNICAddress is equal to the six-byte IEEE MAC source address of the packet

    ii) The adjacency neighborSystemID is equal to the Source ID field of the packet

    iii) The adjacency neighborSystemType is equal to "L1 Router" the router creates a new adjacency. However, if the Adjacency database has insufficient space to allow creating a new adjacency, the router instead merely ignores the Hello packet.

In the new adjacency, the router sets the following:

c) The neighborSystemType to "L1 Router"

d) The holdingTimer, neighborPriority, and areaAddressOfNeighbor according to the values in the packet

e) The neighborNICAddress equal to the six-byte IEEE MAC source address of the packet

The router sets the state of the adjacency to "Initializing" until it is known that the communication between this system and *R* (the source of the Hello packet) is two-way. However, R is included in future LAN Level 1 Hello packets transmitted by this system.

When R reports this router's LAN Address in its LAN Level 1 Hello packet, this router

f) Sets the adjacency's state to "Up"

g) Generates an adjacencyStateChange (Up) event

Figure 4-4 illustrates a typical scenario. In the figure, router B is already running and router A comes on line.

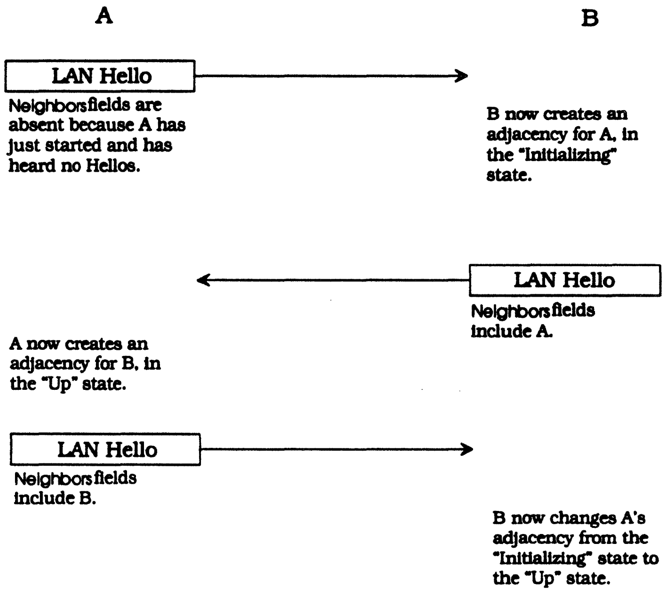

A
B
LAN Hello
Neighborsfields are absent because A has just started and has heard no Hellos.
B now creates an adjacency for A, in the "Initializing" state.
LAN Hello
Neighborsfields include A.
A now creates an adjacency for B, in the "Up" state.
LAN Hello
Neighborsfields include B.
B now changes A's adjacency from the "Initializing" state to the "Up" state.

Figure 4-4: New LAN Adjacency

4.2.6. Detecting Obsolete LAN Adjacencies

The router keeps a separate holding timer (adjacency holdingTimer) for each Level 1 adjacency. The value of holdingTimer is initialized to the holding time, as reported in the Holding Time field of the LAN Level 1 Hello packet. If a neighbor is not heard from in that time, the router

a) Purges it from the Adjacency database

b) Generates an adjacencyStateChange (Down) event

If a LAN Level 1 Hello packet is received from neighbor *N*, and this system's LAN Address is no longer in *N*'s Hello packet, this router

c) Sets the adjacency's adjacencyState to "Initializing"

d) Generates an adjacencyStateChange (Down) event

4.2.7. Designated Router Election

The Level 1 Designated Router is the highest priority Level 1 router on a LAN. In case of a tie, the numerically highest MAC address wins, from among the routers having highest priority. The numeric comparison is done by considering each byte as an unsigned integer, and the first byte as most significant.

When a LAN circuit changes state to "Up," a system waits 2 × drBcastHelloInt before electing a Designated Router on that circuit. However, if in this time an adjacency is formed (reaching the "Up" state) to a system on that LAN, and that system reports that it is the Designated Router itself, the Designated Router election process is run at once.

The priority to become Designated Router on a LAN is configurable, per router per LAN attachment. The default is 44. If a system elects itself Designated Router, it raises its priority by 20. The purpose is to avoid unnecessary area-wide traffic in LSPs as Designated Router roles change for a LAN with routers that can go up and down from time to time.

> **Note:** In a router implementation, the increment by which the priority is raised when a system elects itself Designated Router can be configurable. The default value of the increment should still be 20.

The set of routers considered as candidates include the local router, together with routers from which LAN Level 1 Hello packets have been received and to which Level 1 adjacencies exist in adjacencyState "Up."

A router runs the election process whenever a LAN Level 1 Hello packet is received or transmitted. (For these purposes, transmission of one's own Hello is equivalent to receiving it.) If there has been no change to the information on which the election is performed since the last time it was run, the previous result can be assumed. The relevant information is

a) The set of router adjacency states

b) The set of router priorities (including this system's)

The LAN ID field in the LAN Level 1 Hello packets transmitted by this system is set to the value of the LAN ID field reported in the LAN Level 1 Hello packet received from the system that this system considers to be the Designated Router. The value is also used as the pseudonode ID, to enable LSPs to be issued for this system claiming connectivity to the pseudonode.

If this system determines by the election process that it is itself the Designated Router, it sets the LAN ID field to be the concatenation of the system's own ID and the locally assigned one-byte Local LAN Circuit ID.

If the system determines that it is the Designated Router for a LAN circuit, it should allocate memory and other resources sufficient to generate the pseudonode LSPs for the circuit. If sufficient resources are unavailable, the router takes the following steps:

c) Enter the LSP database overload state, as described in Section 5.

d) As described in Section 5, part of entering the LSP database overload state is lowering the router's priority for the circuit in question. This likely causes the overloaded router to no longer be elected Designated Router for the circuit. However, it is still possible for it to be elected the Designated Router.

4.3. Adjacency Database

4.3.1. Constant Values

allL1Routers

The LAN data-link address used to send multicast packets. The value is specific to a particular medium. A list is included in Section 2.

minMTUAllowed

The smallest packet size to support NLSP. If a router cannot send and receive packets of at least this size, NLSP and IPX cannot operate on the circuit. The value is 576 bytes, including the IPX header but not the data-link header.

4.3.2. Configured Values of the Local System

manualAreaAddresses

One to three IPX routing area addresses. Each is a 32-bit IPX network number, paired with a 32-bit mask of leading one bits. The mask indicates how many bits of the network number identify the area. All the manualAreaAddresses of the routers in a routing area are synonymous in identifying the area. The default area address is (area = 0, mask = 0), meaning that all networks in the reachable internetwork are in one area.

systemID

A six-byte value assigned to a router. It must be unique in the entire internetwork.

nonBcastHelloInt

The interval, in seconds, between NLSP Hello packets sent on WAN circuits. Default is ~~5~~ 20 seconds.

bcastHelloInt

The interval, in seconds, between NLSP Hello packets sent on a LAN circuit by systems other than the circuit's Designated Router. Default is ~~10~~ 20 seconds.

drBcastHelloInt

The interval, in seconds, between NLSP Hello packets sent on a LAN circuit by the circuit's Designated Router. Default is ~~3~~ 10 seconds.

holdingTimeMultiplier

The multiplier used to specify the holding time for NLSP neighbor entries as a function of the NLSP Hello interval. Default is ~~5~~ 3.

4.3.3. Configured Values per Circuit

localMaxPacketSize

The maximum size, in bytes, that the system supports locally on this circuit. The IPX header is included, but not the data-link header or trailer.

localHoldingTimer

This router's holding time, in seconds, sent in an NLSP Hello packet.

priority

The priority of this router to become the NLSP LAN Level 1 Designated Router on a broadcast circuit. The default is 44. If a system elects itself Designated Router, it raises its priority by 20.

4.3.4. Dynamic Values per Circuit

localCircuitID

A local one-byte identifier assigned to a circuit by the local system. The value across all directly attached WANs must be unique, and the value across all directly attached LANs must be unique.

circuitID

A seven-byte value identifying a circuit. It is derived by combining a router's systemID with that router's localCircuitID for the circuit.

actualMaxPacketSize

The maximum size, in bytes, that are sent and received on this circuit. The IPX header is included, but not the data-link header or trailer.

noMulticast

A bit recording whether a Hello packet has been received indicating that another router on a LAN circuit is incapable of receiving multicast packets. If set, packets are sent by broadcast instead of multicast.

4.3.5. Dynamic Values per Adjacency

state

A variable with three values: "Up," "Initializing," and "Down." There is a WAN state machine for the steps in establishing an adjacency, and a different state machine for LANs.

holdingTimer

The initial holding time, in seconds, for this NLSP neighbor entry as specified in the NLSP Hello packet.

neighborSystemID

The six-byte systemID of the neighboring router.

neighborNICAddress

The six-byte IEEE MAC address of the neighbor's network interface point of attachment to a LAN circuit shared with this router.

neighborSystemType

The types are "L1 router" and "L1 and L2 router." This version of the NLSP specification covers L1 operation. Provision for L2 is to ensure forward compatibility.

areaAddressesOfNeighbor

The neighbor's manual area addresses.

neighborPriority

The priority of the neighboring NLSP router for becoming the LAN Level 1 Designated Router.

4.3.6. NLSP Events

packetRxSmall

A truncated packet was received, containing only a portion of the information sent.

mismatchedNodeAddress

The source node number is incorrect in a received packet.

malformedOption
A syntax check failed for a received packet, or an option's value is outside the legal range for the option.

missingOption
A Hello packet was received in which a mandatory option (for example, Local MTU) was absent.

areaMismatch
Another router reported a set of area addresses disjoint from manualAreaAddresses.

wrongSystemType
Attempt by another router to communicate outside the realm of the Level 1 routing.

mismatchedNetworkNumber
A neighbor disagrees with this router on the IPX network number assigned to a circuit.

tooManyAdjacencies
This system has more NLSP adjacencies on a LAN circuit than fit into a LAN Hello packet.

adjacencyStateChange
Indicates that the state variable has changed in value for a circuit.

4.4. Packet Structures

The following packet types are relevant to maintaining the Adjacency Database.

- WAN Hello (page 4-16)
- LAN Level 1 Hello (page 4-17)

These packets ride in the data portion of IPX packets. The IPX header fields are encoded as follows:

	WAN Hello	LAN Level 1 Hello
Destination Network	zero	zero
Destination Node	0xFFFFFFFFFFFF	0xFFFFFFFFFFFF
Destination Socket	0x9001	0x9001
Source Network	internalNetworkNumber of the router sending the packet	Network number of the LAN on which the packet is being transmitted
Source Node	Node number of the router sending the packet on its internalNetworkNumber (0x000000000001)	IEEE MAC address of the LAN interface through which the packet is being transmitted
Source Socket	0x9001	0x9001
Packet Type	0	0

The maximum size of Hello packets on any circuit is determined by the media type and the buffer sizes used by neighbors on that circuit. Each Hello packet includes the Local MTU option, containing the sender's localMaxPacketSize for the circuit. This is the way routers communicate the packet size they are able to receive on that circuit. Every router calculates the minimal value of Local MTU for active adjacencies on each circuit. It then takes the smaller of that value and its own localMaxPacketSize for that circuit. The result is the actualMaxPacketSize value for that circuit. Hello packets can be as large as that value, but no larger.

Note: In practice, the actualMaxPacketSize value for a circuit is the circuit's maximum data-link user data payload size in most situations. There are, however, certain situations where the value is smaller. For example:

a) A bridged LAN that includes LAN segments of different media

b) A circuit on which one router uses a smaller buffer size than the circuit's maximally supported size, owing to resource limitations or misconfiguration

4.4.1. WAN Hello

<table>
<tr><th colspan="3">WAN Hello</th><th>Number of Bytes</th></tr>
<tr><td colspan="3">Protocol ID</td><td>1</td></tr>
<tr><td colspan="3">Length Indicator</td><td>1</td></tr>
<tr><td colspan="3">Minor Version</td><td>1</td></tr>
<tr><td colspan="3">Reserved</td><td>1</td></tr>
<tr><td>Reserved</td><td colspan="2">Packet Type</td><td>1</td></tr>
<tr><td colspan="3">Major Version</td><td>1</td></tr>
<tr><td colspan="3">Reserved</td><td>2</td></tr>
<tr><td>Reserved</td><td>State</td><td>Cct Type</td><td>1</td></tr>
<tr><td colspan="3">Source ID</td><td>6</td></tr>
<tr><td colspan="3">Holding Time</td><td>2</td></tr>
<tr><td colspan="3">Packet Length</td><td>2</td></tr>
<tr><td colspan="3">Local WAN Circuit ID</td><td>1</td></tr>
<tr><td colspan="3">Variable Length Fields</td><td>Variable</td></tr>
</table>

Protocol ID: 0x83, identifies the NLSP routing layer.

Length indicator: The number of bytes in the fixed portion of the header (up to and including the LAN ID field).

Minor Version: 1 or, 2 (if the router supports Aggregated Routes). ignored on receipt.

Reserved: 0, ignored on receipt.

Reserved (3 bits): 0, ignored on receipt.

Packet Type (5 bits): 17.

Major Version: 1.

Reserved: 0, ignored on receipt.

Reserved (4 bits): 0, ignored on receipt.

State (2 bits): The sending router's state associated with this link:
0 = "Up"
1 = "Initializing"
2 = "Down"

Circuit Type, abbreviated Cct Type in the diagram (2 bits):

0 = Reserved value, ignore entire packet.

1 = Level 1 routing only.

2 = Level 2 routing only (sender uses this link for Level 2 routing only).

3 = Both Level 1 and Level 2 (sender is a Level 2 router and uses this link for Level 1 and Level 2 traffic).

Source ID: The system ID of the sending router.

Holding Time: Holding Timer, in seconds, to be used for the sending router.

Packet Length: The entire length of this packet, in bytes, including the NLSP header.

Local WAN Circuit ID: A unique identifier assigned to this circuit when it is created by this router.

Option	Number of Bytes
Code	1
Length	1
Value	Length

Variable Length fields: A series of optional fields, each of which has the following three-part code/length/value Option form.

Currently defined codes, and the corresponding values, are as follows:

- Area Addresses: The set of Manual Area Addresses of the sending router. This field must be present.

  Code = 0xC0. Length = Total length of the value field, in bytes; either 8, 16, or 24.

  Value = Up to three area addresses. Each area address consists of a four-byte network number, followed by a four-byte address mask. The mask contains from zero to 32 (inclusive) most-significant one bits to indicate which bits of the network number make up the address prefix identifying the routing area. The remaining bits are zero. The bit-wise AND of an Address and Mask pair must be equal to Address. For example, it would be a mistake to send Address = 0x84300000 paired with Mask = 0xFF000000.

Area Addresses

	Number of Bytes
Address	4
Mask	4
... ...	
Address	4
Mask	4

- Local MTU: indicates how large a packet the sender can transmit. This field must be present.

  Code = 0xC5. Length = 4.

  Value = The maximum number of bytes that the sending router can transmit on this interface. The count includes the IPX header, but not the data-link header.

4.4.2. LAN Level 1 Hello

LAN Level 1 Hello

<table>
<tr><th colspan="4"></th><th>Number of Bytes</th></tr>
<tr><td colspan="4">Protocol ID</td><td>1</td></tr>
<tr><td colspan="4">Length Indicator</td><td>1</td></tr>
<tr><td colspan="4">Minor Version</td><td>1</td></tr>
<tr><td colspan="4">Reserved</td><td>1</td></tr>
<tr><td>Reserved</td><td colspan="3">Packet Type</td><td>1</td></tr>
<tr><td colspan="4">Major Version</td><td>1</td></tr>
<tr><td colspan="4">Reserved</td><td>2</td></tr>
<tr><td>Reserved</td><td>NM</td><td>Res</td><td>Cct Type</td><td>1</td></tr>
<tr><td colspan="4">Source ID</td><td>6</td></tr>
<tr><td colspan="4">Holding Time</td><td>2</td></tr>
<tr><td colspan="4">Packet Length</td><td>2</td></tr>
<tr><td>R</td><td colspan="3">Priority</td><td>1</td></tr>
<tr><td colspan="4">LAN ID</td><td>7</td></tr>
<tr><td colspan="4">Variable Length Fields</td><td>Variable</td></tr>
</table>

Protocol ID: 0x83, identifies the NLSP routing layer.

Length indicator: The number of bytes in the fixed portion of the header (up to and including the LAN ID field.

Minor Version: 1 or, 2 (if the router supports Aggregated Routes). , ignored on receipt.

Reserved: 0, ignored on receipt.

Reserved (3 bits): 0, ignored on receipt.

Packet Type (5 bits): 15.

Major Version: 1.

Reserved: 0, ignored on receipt.

Reserved (3 bits): 0, ignored on receipt.

No Multicast, abbreviated NM in the diagram (1 bit): When set to one, indicates that the sender of the packet cannot receive traffic addressed to a multicast address; future packets on this LAN (which would otherwise be transmitted multicast) must be sent to the broadcast address.

Res (2 bits): 0, ignored on receipt.

Circuit Type, abbreviated Cct Type in the diagram (2 bits):

0 = Reserved value, ignore entire packet.

1 = Level 1 routing only.

2 = Level 2 routing only (sender uses this link for Level 2 routing only).

3 = Both Level 1 and Level 2 (sender is a Level 2 router and uses this link for Level 1 and Level 2 traffic).

Source ID: The system ID of the sending router.

Holding Time: The Holding Timer, in seconds, to be used for the sending router.

Packet Length: The entire length of this packet, in bytes, including the NLSP header.

R (1 bit): 0, ignored on receipt.

Priority (7 bits): The priority for being the LAN Level 1 Designated Router. Higher numbers have higher priority. An unsigned integer.

LAN ID: A field composed of the system ID (6 bytes) of the LAN Level 1 Designated Router, followed by a low-order Pseudonode ID byte assigned by that Designated Router. This field is copied from the Designated Router's Hello packet.

LAN ID

	Number of Bytes
System ID	6
Pseudonode ID	1

Variable Length fields: A series of optional fields, each of which has the following three-part code/length/value Option form:

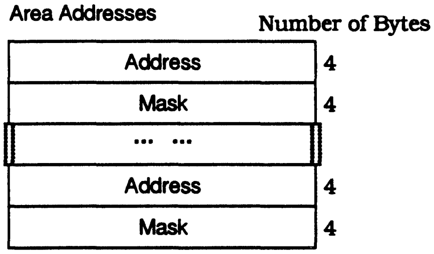
Option

	Number of Bytes
Code	1
Length	1
Value	Length

Currently defined codes, and the corresponding values, are as follows:

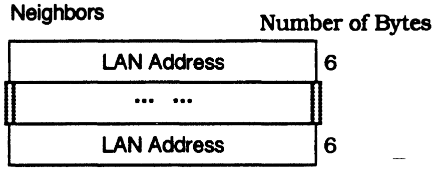
- Area Addresses: The set of Manual Area Addresses of the sending router. This field must be present.

  Code = 0xC0. Length = Total length of the value field, in bytes; either 8, 16, or 24.

  Value = Up to three area addresses. Each area address consists of a four-byte network number, followed by a four-byte address mask. The mask contains from zero to 32 (inclusive) most-significant one bits to indicate which bits of the network number make up the address prefix identifying the routing area. The remaining bits are zero. The bit-wise AND of an Address and Mask pair must be equal to Address; for example, it would be a mistake to send Address = 0x84300000 paired with Mask = 0xFF000000.

- Neighbors: The set of routers on this LAN to which adjacencies of type "Level 1 Router" exist in state "Up" or "Initializing"; that is, those from which Level 1 Hello packets have been heard. This field can occur more than once

  Code = 6. Length = A multiple of six.

  Value = Each six-byte field is the IEEE 802 MAC address of the neighbor router's point of attachment to this LAN segment

  Note: The IEEE 802 MAC address is specified in native mode. i.e. the same as the MAC address presented in the MAC header or the IPX header. For example the IEEE 802 MAC address is presented in the Universal Address Representation or LSB first on Ethernet and is represented by default with the MSB first on Token Ring and FDDI. Also, note that the MAC drivers could also be made to operate in the LSB first mode, in which case the IEEE 802 MAC address should be represented in the LSB first mode form. Refer to Chapter 10 for a description of the IEEE 802 MAC address representations.

- Local MTU: Indicates how large a packet the sender can transmit. This field must be present.

  Code = 0xC5. Length = 4.

  Value = The maximum number of bytes that the sending router can transmit on this interface. The count includes the IPX header, but not the data-link header.

5. Link State

Each router extracts certain information from the Adjacency database, adds locally derived information, and constructs a Link State Packet (LSP) that describes its immediate neighbors. The totality of these LSPs constructed by all the routers in the routing area make up the Link State database for the area. The NLSP™ specification aims for each router to maintain a copy of the Link State database and to keep these copies synchronized with each other.

5.1. Overview of the Protocol

The Link State database is synchronized by propagating LSPs reliably from a router that observes a topology state change throughout the routing area. The format of an LSP is described on page 5-29.

If an LSP is too large to fit in lspBufferSize bytes, the router originating it splits the information into several LSPs, each identified by an LSP Number (think of this as a fragment number). Each of these LSPs propagates from the originator independently of the others. When there is a topology change, only the LSP (that is, the fragment) affected by the change is propagated. Each has an independent sequence number (incremented when the LSP content changes) to allow a recipient router to discriminate between new and outdated information.

Each fragment is complete and self-contained. From here onward the term *LSP* refers to one of these fragments, because this is the basic unit of information propagated in the routing area. When referring to the set of fragments originated by a router, the term *LSP series* is used.

There are two parts to the propagation method: flooding and receipt confirmation.

Flooding is instigated when a router detects a topology state change. The router constructs a new LSP and transmits it to each of its neighbors. On a WAN, this is a directed packet; on a LAN, it is multicast. Upon receiving an LSP, a router first decides whether it is newer; that is, whether the sequence number is higher than the one in its current copy of the database. (Other factors enter into the newness decision; complete details follow later.) If it is new, the router retransmits the LSP to all its neighbors except on the circuit over which the LSP was received.

Receipt confirmation is different for LANs and WANs. A router receiving an LSP on a WAN replies with a Partial Sequence Number Packet (PSNP). This serves as an acknowledgment for the LSP (or LSPs) and sequence numbers identified in the PSNP.

On a LAN, there is no explicit acknowledgment. A router multicasts the new LSP and (if all goes well) the other routers on the LAN receive the LSP and absorb it into their databases. To allow for the possibility that the LSP was not successfully received by all the LAN's rcuters, the Designated Router periodically multicasts a Complete Sequence Number Packet (CSNP) containing all the LSP identifiers and sequence numbers it has in its database for the entire routing area. (It does not send the LSPs; it sends just enough information to allow another router to detect whether it is out of step with the Designated Router.) If all has gone well, the other routers on the LAN verify that they have the same set of LSPs and sequence numbers indicated in the CSNP.

If there is a discrepancy, what happens next depends on which router has the higher sequence number (that is, newer information) for the LSP: the Designated Router or the CSNP-recipient router. If the Designated Router has newer information, the

CSNP-recipient transmits a PSNP, which acts as a request for the missing LSPs. The Designated Router receiving the PSNP replies by multicasting each requested LSP. If the CSNP-recipient has newer information, it multicasts the up-to-date LSP on the LAN, and the Designated Router updates its database (as do the other routers on the LAN).

The remainder of this chapter describes the algorithms in more detail. A number of timing considerations govern when and how often to send certain packets. To accommodate these considerations, it is convenient to describe operation of the protocol in terms of two flags. For each LSP and for each circuit over which routing messages are exchanged, a router maintains two local flags:

- *Send Routing Message* (SRMflag): When set, this flag indicates that LSP should be sent on that circuit. On a LAN, SRMflag is cleared as soon as the LSP is transmitted. On a WAN, it is cleared only on receipt of a PSNP (acknowledging the LSP) or an LSP (indicating that the neighbor was already at least as current as this router). A router regularly scans the Link State database for LSPs for which

  a) SRMflags are set

  b) The LSP was propagated no more recently than minimumLSPTransmissionInterval

  When such an LSP is found, the router transmits it on all circuits having SRMflags set, and updates the lastSent time for it.

- *Send Sequence Number* (SSNflag): When set, this flag indicates that information about that LSP should be included in a PSNP sent on that circuit. When the PSNP has been sent, the flag is cleared.

5.2. Generating and Checking the LSP Checksum

The checksum allows detection of transmission errors and memory corruption, to prevent both (a) the use of incorrect routing information, and (b) propagation of incorrect routing information to other routers. The router originating an LSP computes the checksum when the LSP is generated. The checksum is never modified by any other system as the LSP propagates.

The checksum is computed over all fields in the LSP after the Remaining Lifetime field. This field (and those before it) are excluded so that the LSP can be aged by systems without recomputing the checksum.

This specification makes use of the checksum function defined in ISO 8473 (Reference [ISO88]). The following subsections define the computation.

5.2.1. Symbols and Conventions

`C0` and `C1` are variables used in the computation.

`i` is the number (that is, the position) of a byte in the data block having the checksum performed; the first byte has `i=1`.

`B[i]` is the value of byte `i` in the block being checked.

`L` is the length of the data block being checked, in bytes.

`X` is the first byte of the calculated checksum.

`Y` is the second byte of the calculated checksum.

Addition is performed in one of the following modes:

- Modulo 255 arithmetic
- Eight-bit one's complement arithmetic in which, if any of the variables has the value minus zero (that is, 255), it is regarded as though it had the value plus zero (that is, 0)

5.2.2. Generating a Checksum

To perform a checksum on an LSP being generated, proceed as follows:

```
Construct the complete packet, with the value of the Checksum field set
to zero.

C0 ← C1 ← 0.

For i incrementing by 1 sequentially from 1 to L:

      BEGIN   -- Loop
      C0 ← C0 + B[i]
      C1 ← C1 + C0
      END    -- Loop

Calculate:

      X ← ( L - 8 ) × C0 - C1   (mod 255)
      Y ← ( L - 7 ) × ( - C0 ) + C1   (mod 255)

If X = 0 then X ← 255
If Y = 0 then Y ← 255

Place the values of X and Y in the Checksum field of the packet.
```

There is one exception: if the Remaining Lifetime field of the LSP is zero, the correct value of the checksum is zero.

5.2.3. Checking a Checksum

To verify the checksum of an arriving LSP or an LSP stored in memory, proceed as follows:

```
If either byte (or both bytes) of the Checksum field is zero,
     then the checksum is incorrect; do not proceed further.

C0 ← C1 ← 0

For i incrementing by 1 sequentially from 1 to L:

      BEGIN   -- Loop
      C0 ← C0 + B[i]
      C1 ← C1 + C0
      END    -- Loop

If C0 = C1 = 0 (mod 255) when all bytes have been processed,
     then the checksum calculation has succeeded.

Otherwise, the checksum calculation has failed.
```

There is one exception: if the Remaining Lifetime field of the LSP is zero, the correct value of the checksum is zero.

5.2.4. Partial Precomputation

The portion of the LSP covered by the checksum starts with the Source ID portion of the LSP ID field.

Partial Precomputation is an extra fault-tolerance method that a router can include as an implementation option. It is described in the next paragraph. It protects against a failure in which a router's memory of its own systemID becomes corrupted. Even if very rare, such a failure could cause widespread disruption if not detected. Partial Precomputation contains the failure by causing LSPs generated by the failing router to have checksum errors.

An originating router precomputes the first few steps of the checksum and saves the result for use with each LSP. Specifically, it precomputes the checksum of the systemID portion of the Source ID when the router is activated or whenever the systemID changes. When performing a checksum on a packet, then, it initializes the variables `C0` and `C1` to the saved values, and resumes the computation after the systemID portion of the Source ID field; that is, starting with the Pseudonode ID portion of the LSP ID.

5.3. The Need for Multiple LSPs

Packets for LSPs are limited in size to lspBufferSize. It might not be possible to include all the information about one's neighbors in one packet. In such cases, a router uses multiple LSPs to convey this information. (Even if the information can fit into one packet, a router can optionally use more than one LSP to convey it.) Each LSP of the set carries the same Source ID, but sets its LSP Number individually. Each of the several LSPs is propagated independently in the routing area, allowing pipelining of activity. On the other hand, the Decision Process that builds the Forwarding database recognizes that they constitute a particular router's LSP series because they have the same Source ID.

When some event requires changing the LSP information for a router, that router reissues the one (or more) LSPs that have different contents. It is not required to reissue unchanged LSPs.

The first LSP of a series has LSP Number zero. It is treated in a special way.

a) The following fields are meaningful to the Decision Process only when they are present in the LSP number zero:

   i) The setting of the LSP Database Overload bit.

   ii) The value of the IS Type field.

   iii) The Attached Flag.

   iv) The Area Addresses option field. This option is present only in LSP zero.

   v) The Multi-homed Non-routing Server (NR) field.

   vi) The Management Information option field. This option is present only in LSP zero, and must precede any Link Information options.

   Note: There must be exactly one Area Addresses option and one Management Information option in each LSP number zero. If a router receives one of these options in an LSP with a nonzero number, or if a router receives a second instance within LSP zero, these additional options are ignored.

b) When any of the preceding items are changed, a router reissues LSP zero to inform other routers of the change. Other LSPs need not be reissued.

Once a particular Option field has been assigned to a particular LSP Number, it is desirable (but not required) that it not be moved to a different LSP number. This is because moving an Option field from one LSP to another can cause temporary loss of connectivity to the entity (for example, a neighbor, service, or external route) represented by the field. This can occur if the new version of the LSP that originally contained the field (but which does not now contain it) is propagated before the new version of the other LSP (which now contains the field).

> **Note:** In most situations, it improves performance to ensure that the number of LSPs generated by a router is close to the optimal number that would be required if the LSPs were densely packed with Link Information options. This can be accomplished by reusing space in LSPs with a lower LSP Number for new adjacencies. Fewer LSPs means consuming less processing capacity, less network bandwidth, and less router memory. However, there are situations in which a link alternates often between active and inactive. Putting such a link in a small LSP consumes less network bandwidth when flooding the LSP to other routers each time it changes. Consequently, implementers are faced with a trade-off on this issue.

If an Option field moves from one LSP to another, the SRMflags of the two updated (or new) LSPs must be set as an atomic action.

> **Note:** If they are not set atomically, a race condition exists, in which one of the two LSPs can propagate quickly, while the other waits for an entire propagation cycle. If this occurs, entities are erroneously eliminated from the topology and routing can become unstable for a period of time potentially as large as maximumLSPGenerationInterval.

5.4. Determining Which of Two LSPs is Newer

At certain points in the algorithms described later, a router has two copies of an LSP with the same LSP ID and must compare the two to determine which is newer, or whether the two are the same. At certain other times, the router does not have an LSP in hand, but has information about a neighbor's copy of an LSP, and must make the comparison with its own copy of the LSP. (The information arrives in sequence number packets from the neighbor.) These are the steps in making the comparisons:

a) If the two have different sequence numbers, the higher sequence number is considered newer.

b) If

   i) the sequence numbers are the same and

   ii) exactly one of the two has zero lifetime,

   the one with zero lifetime is considered newer.

c) If

   i) the sequence numbers are the same and

   ii) the remaining lifetimes are either both zero or both nonzero and

   iii) the checksums match,

   the two are considered the same.

d) If, on the other hand,

i) the sequence numbers are the same and

ii) the remaining lifetimes are either both zero or both nonzero **but**

iii) the checksums **do not** match,

the LSPs are considered different, and the one with the higher numerically valued checksum (treated as a four-byte unsigned number) is considered to be newer. This is the *Preference of Checksums* rule.

> **Note:** If two routers are misconfigured with the same systemID, and they both generate LSPs with the same sequence number, this provision at least ensures that the LSPs are treated in a consistent way by all routers.

5.5. Pseudonodes and Designated Routers

There are two types of pseudonodes: *LAN Pseudonodes* and *WAN pseudonodes.*

LAN pseudonodes have been discussed already. They streamline NLSP operation when many routers are attached to the same LAN. There is an election process by which one of the routers is selected to be the Designated Router representing the LAN pseudonode for LSP generation.

Every NLSP router on a LAN retains in its local memory all the information needed for it to become the Designated Router, should the need arise. This local information is referred to as a *Potential Pseudonode.*

WAN pseudonodes serve a different purpose. Section 3 discusses methods by which an NLSP router can establish communication with a RIP router over a WAN (virtual) circuit. For each such circuit, a pseudonode represents the RIP routes and SAP services discovered over that circuit. The NLSP router on the circuit is the WAN Designated Router representing the WAN pseudonode. There is no election process.

Section 3 actually specifies two ways of using RIP: numbered and unnumbered. The first assigns an IPX™ network number to the circuit; the second does not. Depending on this choice, there is either a *Numbered WAN Pseudonode* for the circuit or an *Unnumbered WAN Pseudonode.* The latter appears if any unnumbered router-router protocol is used on the link; for example Unnumbered RIP or On-Demand Static Routing.

Figure 5-1 illustrates the three kinds of pseudonodes.

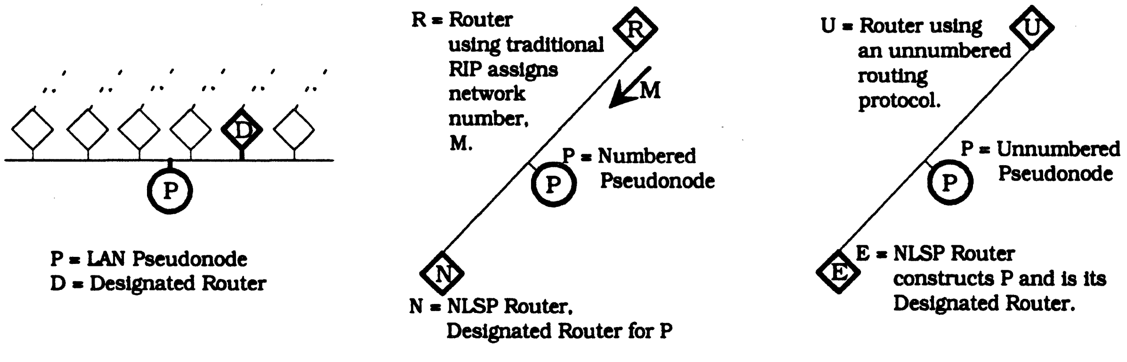

D
P
P = LAN Pseudonode
D = Designated Router
R = Router using traditional RIP assigns network number, M.
R
M
P = Numbered Pseudonode
P
N
N = NLSP Router, Designated Router for P
U = Router using an unnumbered routing protocol.
U
P = Unnumbered Pseudonode
P
E
E = NLSP Router constructs P and is its Designated Router.

Figure 5-1: Pseudonodes

As in the numbered pseudonode case, Unnumbered RIP uses RIP and SAP on the WAN, not NLSP. As far as the traffic on the WAN is concerned, Unnumbered RIP operation really has no connection with NLSP. If—like node E in the figure—either or both ends of the (virtual) circuit are NLSP routers, that router constructs an unnumbered pseudonode (P) representing the WAN to the NLSP routing area (not shown in the diagram) to which it is attached. The same is true with On-Demand Static Routing, except that the network numbers and services reported in the pseudonode are configured statically, rather than learned by receiving periodic RIP and SAP packets on the link. To other routers in the NLSP routing area, an On-Demand Static Routing link is indistinguishable from an Unnumbered RIP link.

5.6. Aging Out an LSP and Purging Superseded LSPs

When the source generates an LSP, it sets the Remaining Lifetime field to maxAge.

When a router holds an LSP before successfully transmitting it to a neighbor, it decrements the Remaining Lifetime field by the holding time. Before transmitting an LSP to a neighbor, a router decrements the Remaining Lifetime field by at least one.

When the Remaining Lifetime of an LSP in memory becomes zero, the router takes the following actions:

a) Retains only the LSP header (that is, the fixed-length fields), and changes the Remaining Lifetime field to zero

b) Updates the Packet Length and Checksum fields to reflect the changes indicated in Step a)

c) Records the time at which the Remaining Lifetime for the LSP became zero

d) Purges the LSP header from the database when zeroAgeLifetime has expired since the Remaining Lifetime became zero

Any time a router purges an LSP with **nonzero** Remaining Lifetime, it performs the four steps just indicated, but the retention interval in Step d) is maxAge + zeroAgeLifetime.

Note: This could happen for one of several reasons; for example, (a) resignation as Designated Router, (b) compaction of LSPs to reduce their number, (c) receiving from another router one's own LSP from a prior incarnation (Section 5.12.3, Step b.2).

When a router purges an LSP it may or may not increment the sequence number.

5.7. Periodic LSP Generation

The timer maximumLSPGenerationInterval governs periodic LSP generation. Within every time interval of length maximumLSPGenerationInterval, a router regenerates every LSP at least once. Jitter is applied, as described in Section 2. It is not required to synchronize regeneration of the individual LSPs.

The purpose of periodic LSP generation is to remove stale information from the routing area at a coarse time granularity. For example, suppose two large, usually disjoint campuses, A and B, temporarily link with each other using a switched network. While the link persists, the Link State information of each area flows into the other. Then the link is taken down. Fine-grained operation of NLSP does not remove B's link state information from routers in A. In case the link is reestablished, it would be costly to reacquire all that information. However, the two campuses might not link with each other again for a very long time. So, at a coarse time scale, a method is needed to purge B's link state information from routers in A. The method is refreshing LSPs by periodic regeneration, and aging out LSPs that are not refreshed.

A second result of periodic regeneration and aging of LSPs is to handle the very rare event of an LSP corruption not being detected by the checksum check. Ultimately, the corrupted information is aged out of the LSP database.

5.8. Event-Driven LSP and CSNP Generation

A router generates an LSP when an event occurs that would cause the LSP content to change. Events that can cause such a change include

- An Adjacency or Circuit Up/Down event
- A change in a circuit's cost
- A change in manualAreaAddresses
- A change in a router's systemID or name
- A change of Designated Router on a LAN
- A change of network number
- A change in SAP services or external RIP routes
- A change in the waiting status (entering or leaving an overloaded state)

When such an event occurs, the router regenerates changed LSPs with a new sequence number. If the event necessitated generation of an LSP that had not been generated previously (for example, an Adjacency Up event for an adjacency that cannot be accommodated in an existing LSP), the Sequence Number is set to one. The router then propagates the LSPs on every circuit by setting the SRMflag for each circuit. The timer maximumLSPGenerationInterval is reset.

When the local router either becomes or resigns as the Designated Router for a LAN, it generates a lanL1DesRouterChange event. In addition, when it becomes the Designated Router, it

a) Generates and transmits Level 1 pseudonode LSPs

b) Purges the pseudonode LSPs issued by the previous Designated Router (if any)

When a router resigns as the Designated Router for a LAN, it purges the pseudonode LSPs as described on page 5-7.

There is a hold-down timer, minimumLSPGenerationInterval, on the generation of each individual LSP.

When a WAN circuit starts or restarts, that is, whenever an adjacency changes to the "Up" state

c) The router sets the SRMflag for that circuit on all LSPs

d) The router sends a complete set of CSNPs on that circuit

5.9. Generation of Level 1 Non-Pseudonode LSPs

Each router generates a Level 1 non-pseudonode LSP on its own behalf. The LSP describes the router itself and the router's adjacencies.

A Level 1 non-pseudonode LSP contains the following information in its variable-length fields:

- In the Area Address Mask option, the set of manualAreaAddresses for this router (that is, the source router for the LSP).
- In the Management Information option, configuration and version information about this router:
  - Network Number is the router's internalNetworkNumber.
  - Node Number is the router's internal node number (0x000000000001).
  - IPX Version is one.
  - Router/Server Name is a textual identifier of the router originating the LSP. If the system is also a NetWare® server, this field contains the server name. This is the same name that appears in the IPX WAN version 2 (IW2) Information Request/Reply packets.
- ~~The External Routes option does not appear in non-pseudonode LSPs.~~
- The Services Information options contain information about services that reside on the same system as the router, and that advertise themselves using SAP. ~~All such services must advertise themselves as residing on the internalNetworkNumber.~~
- An instance of the Link Information option for each neighboring router, formed from the following:

  a) The set of WAN NLSP adjacencies in the "Up" state

  b) The LAN pseudonode for each directly attached active LAN circuit

  c) The WAN pseudonode for each RIP/SAP circuit for which this router is the WAN Designated Router

  Fields of the Link Information option contain values as follows:

  - The cost of the link from this router's viewpoint is reported in the Cost field. There is a default cost, based on the link's data rate (throughput). Figure 5-3 shows how to derive the default Cost from the throughput of the link. For WAN media, the throughput value is determined empirically during the IW2 protocol exchange described in Section 3, and a router determines the default cost from that value using Figure 5-3. For both WANs and LANs, a network administrator can configure a nondefault cost manually.
  - The Neighbor ID for a LAN adjacency is the neighbor's circuitID (the neighboring pseudonode ID); that is, this value is the LAN ID of the LAN Level 1 Hello packets sent on that circuit.
  - The Neighbor ID for a WAN NLSP adjacency is the neighbor's neighborSystemID with appended zero byte (indicating non-pseudonode).
  - The Neighbor ID for a WAN pseudonode adjacency is the WAN Designated Router's (that is, this router's) systemID followed by a one-byte pseudonode ID, unique among all pseudonodes for which this router is Designated Router.
  - MTU Size is the maximum number of bytes that can be transmitted by this router on this link, including the IPX header but not data-link headers.
  - Delay is the period of time (in microseconds) that it takes to transmit one byte of data (excluding protocol headers) to a destination, if the media were free of other traffic. For a WAN circuit, this value is determined as part of the IW2 protocol. The value used for a LAN circuit is 100 microseconds.

- Throughput is the amount of data, in bits, that can flow through the media and be received at the other side in one second, if there is no other traffic using the interface. For a WAN circuit, this value is determined as part of the IW2 protocol. For a LAN circuit, the value is the bit rate defined for the particular media technology.

  Note: For example, if router A is attached to an X.25 network with an interface speed of 64 Kbps, and router B is attached to the same network with an interface speed of 19.2 Kbps, then both report the adjacency between them as having a throughput of 19.2 Kbps.

- Media Type contains the media code described in Figure 5-2. Additional types will be added in the future. Note that WAN media have codes with the high-order bit set; LAN media have it reset.

Media Code	*Description*
0x0000	Generic LAN for use when no applicable medium is defined
0x8000	Generic WAN for use when no applicable medium is defined
0x0001	LocalTalk*
0x0002	Ethernet II
0x0003	IEEE 802.3 with IEEE 802.2 without SNAP
0x0005	IEEE 802.3 with IPX header immediately following the 802.3 header
0x000A	IEEE 802.3 with IEEE 802.2 and SNAP
0x0004	IEEE 802.5 with IEEE 802.2 without SNAP
0x000B	IEEE 802.5 with IEEE 802.2 and SNAP
0x0006	IEEE 802.4
0x0007	IBM* PC Network II
0x0008	Gateway's G/Net*
0x0009	Proteon's ProNET*
0x000C	Racore's LANPAC
0x800D	ISDN
0x000E	ARCnet*
0x000F	IBM PC Network II with 802.2 without SNAP
0x0010	IBM PC Network II with 802.2 and SNAP
0x0011	Corvus OmniNet at 4 Mbps
0x0012	Harris Adacom
0x0013	IP tunnel
0x8013	IP Relay
0x0014	FDDI with 802.2 without SNAP
0x0015	Commtex IVDLAN
0x0016	Dataco OSI
0x0017	FDDI with 802.2 and SNAP
0x0018	IBM SDLC tunnel
0x0019	PC Office frame
0x001A	Hypercommunications WAIDNET
0x801C	PPP (IETF Point-To-Point Protocol)
0x801D	Proxim RangeLAN
0x801E	X.25
0x801F	Frame Relay
0x0020	Integrated Workstations BUS-NET
0x8021	Novell® SNA Links™

Figure 5-2: Media Codes

Throughput *		*Default*	*Typical Media*
At least	*Strictly less than*	*Cost*	
0 K	16 K	61	
16 K	32 K	55	
32 K	48 K	55	
48 K	64 K	45	ISDN (U.S.)
64 K	128 K	45	ISDN (European)
128 K	256 K	40	
256 K	512 K	35	
512 K	1 M	30	
1 M	2 M	27	T1 (1.5 M), Corvus Omninet (1 M)
2 M	4 M	26	E1 (2 M), ARCnet (2.5 M)
4 M	8 M	25	Token Ring (4 M), Corvus Omninet (4 M)
8 M	10 M	23	
10 M	16 M	20	Ethernet
16 M	32 M	19	Token Ring (16 M)
32 M	64 M	15	
64 M	128 M	14	FDDI (100 M), CDDI (100 M)
128 M	256 M	9	
256 M	512 M	9	
512 M	1 G	6	
1 G	2 G	6	
2 G	4 G	6	
4 G	8 G	3	
8 G	16 G	3	
16 G	32 G	3	

Figure 5-3: Default Costs

* K = 10^3 bits/second
M = 10^6 bits/second
G = 10^9 bits/second

5.10. Generation of Level 1 Pseudonode LSPs

A router generates a pseudonode LSP on behalf of each circuit for which it is a Designated Router. The LSP specifies the following information in its variable-length fields:

- The Area Addresses option is **not** present. (The set of area addresses for the issuing router is already available from its own non-pseudonode LSP.)
- The Management Information option contains configuration and version information about the circuit:
  - Network Number is the IPX network number for LAN pseudonodes and for numbered WAN pseudonodes. This field is zero for unnumbered WAN pseudonodes.
  - Node Number is the IPX node number (typically, the MAC address) of the Designated Router generating the LSP on the LAN to which the LSP refers. This field is zero for WAN pseudonodes.

    Note: The zero network number is merely a placeholder to hold XRoutes and Services, and is not an actual IPX network number.
  - Router/Server Name gives a textual name for the circuit. It need not be present.
- The External Routes and Services Information parts contain information gleaned from (respectively) RIP and SAP packets received by this Designated Router over the (LAN or WAN) circuit represented by this pseudonode.

  Note: The RIP/SAP packets considered for this purpose are only those from RIP/SAP-only systems. NLSP implementations must be sure not to report here other NLSP routers that are sending RIP/SAP packets for backward compatibility. These "compatibility" RIP/SAP packets are recognizable because they originate from nodes that have NLSP adjacencies with this router. Adjacencies in both the "Up" and "Initializing" states are included. The RIP and SAP packets are intended for consumption by RIP/SAP-only devices sharing the circuit with this router.

  Details of RIP/SAP compatibility are in Section 7.

  If this is an On-Demand Static Routing link, the External Routes and Services Information parts are derived not from periodically received RIP/SAP packets, but from the locally configured RSI database. Details are in Section 3.
- An instance of the Link Information option for each neighboring router, formed from
  - a) The Designated Router itself.
  - b) If this is a LAN pseudonode, other NLSP routers for which an adjacency with this Designated Router exist in the "Up" state over the circuit represented by the pseudonode.

  Fields of the Link Information option contain values as follows:

  - Zero Cost.
  - The Neighbor ID for the Designated Router itself is its own systemID with appended zero byte (indicating non-pseudonode).
  - The Neighbor ID for each of the other NLSP routers is the other router's systemID with appended zero byte (indicating non-pseudonode).

- The MTU Size and Delay and Throughput fields are zero for pseudonode LSPs.
- Media Type codes are indicated in Figure 5-2.

5.11. Preparing to Initiate Transmission

When generating an LSP as in the preceding sections—periodic or event-driven, pseudonode or non-pseudonode—a router

a) Stores the LSP in its own Link State database, overwriting any previous LSP with the same LSP Number generated by this router

b) Increments the sequence number

c) Calculates the checksum

d) Sets all the SRMflags for that LSP, indicating that it is to be propagated on

- All active LAN circuits (whether or not adjacencies exist for the circuit)
- All WAN circuits having adjacencies in the "Up" state

Circuits running RIP only are excluded, as are On-Demand Static Routing links.

A router must ensure (by reserving resources or otherwise) that it can always store and internalize its own non-pseudonode LSP number zero. If it cannot store and internalize one of its own LSPs, it enters the overload state as described on page 5-24.

Note: It is recommended that a router ensures (by reserving resources or otherwise) that it can always store and internalize all its own LSPs: zero and nonzero, pseudonode and non-pseudonode.

Sometimes an existing LSP is retransmitted, with the same or different sequence number, but with the same information content; that is, the same variable-length part. There is no change of information content because there have been no local topology changes. When this happens, the order of information in the variable-length part must be the same as in the previously transmitted LSP.

Note: This provision allows the receiver to detect that there has been no change of information content by making a byte-wise comparison of the variable-length part. This is an efficient way to check that it is unnecessary to rerun the Decision Process. If a sequence of topology changes results in the local topology returning to some previous state, there is no requirement to preserve the ordering. Preservation is required only if there have been no changes at all.

5.12. Receipt and Propagation of LSPs

A router accepts LSPs as large as actualMaxPacketSize on each circuit. Upon receipt of an LSP on circuit C, a router first performs the following acceptance tests:

a) The general packet acceptance tests described in Section 2 under "General Processing of Incoming IPX Packets."

b) If C is a LAN, and the source data-link address of the LSP does not match the neighborNICAddress of an existing adjacency on C in the "Up" state, the router discards the LSP without generating an event.

Note: A LAN might contain routers from more than one routing area. Checking for existence of an adjacency ensures that only LSPs for the router's own routing area are accepted.

c) If C is a WAN and there is no adjacency on C, the router discards the LSP without generating an event.

d) If the Checksum is zero, set the Remaining Lifetime to zero and proceed.

e) If the Checksum is incorrect (~~including~~ excluding the case of either or both checksum bytes being zero, and including the zero Remaining Lifetime case described previously), log a badChecksum event and discard the packet.

f) If the Router Type field is not "Level 1" or "Level 1 and Level 2," discard the packet.

g) If the length of the packet, as described in the header, is greater than the buffer in which it was received, log a packetRxSmall event and discard the packet.

h) If the variable part of the LSP is malformed, or contains malformed options, log the malformedOption event and discard the packet.

> **Note:** Do not test the Network Number of the LSP Management Information field against area addresses. Accept any Network Number that arrives in Management Information from an NLSP neighbor.

Depending on two tests of the received LSP, there are four different ways to process the LSP. The tests are as follows:

- Examine the Remaining Lifetime field. If it contains zero, the LSP is *expired.*
- Compare the Source ID field with this router's own systemID. If they match, this is a case of the *same system ID.*

The following four subsections specify the actions to take in the four cases. These subsections use the following shorthand:

- "Send an LSP on circuit C" means
  "Clear SSNflag and set SRMflag for that LSP for C."
- "All circuits" means
  "All WANs having adjacencies in the 'Up' state, and all active LANs regardless of adjacencies."
- "Acknowledge an LSP on circuit C" means
  "Clear the SRMflag for the LSP for C. If C is a WAN, also set the SSNflag for the LSP for C."

When comparing two LSPs for newness, the test on page 5-5 is applied.

5.12.1. Expired LSP with the Same System ID

a) If an LSP with this LSP ID is in the LSP database

  a.1) If the local LSP is also expired

    a.1.1) If the LSPs are equal, acknowledge the LSP on C.

    a.1.2) If the received LSP is older, send the local LSP on C.

FF(?) a.1.3) If the received LSP is newer, update the local LSP's sequence number to be one more than the incoming LSP's and send the resulting LSP on all circuits.

  a.2) If the local LSP is not expired

    a.2.1) If the received LSP is older, send the local LSP on C.

FF = faster flooding (5-21)

FF(?) a.2.2) If the received LSP is newer or equal, update the sequence number to be one more than the incoming LSP and send the local LSP on all circuits.

b) If an LSP with this LSP ID is **not** in the LSP database, acknowledge the LSP on C without storing it.

5.12.2. Expired LSP with a Different System ID

a) If an LSP with this LSP ID is in the LSP database

a.1) If the LSPs are equal, acknowledge the LSP on C.

a.2) If the received LSP is older, send the local LSP on C.

FF a.3) If the received LSP is newer, store the new LSP, replacing the local copy, send it on all circuits except C, and acknowledge it on C.

b) If you do not have an LSP with this ID in the LSP database, ~~acknowledge the LSP on C without storing it~~ do not store it and if C is a WAN circuit acknowledge the LSP by generating and transmitting a PSNP.

5.12.3. Unexpired LSP with the Same System ID

a) If there is an LSP with this LSP ID in the LSP database

a.1) If the LSPs are equal, acknowledge the LSP on C.

a.2) If the received LSP is newer than the local LSP

FF(?) a.2.1) Update the local LSP's sequence number to be one more than the incoming LSP and flood the local LSP.

a.2.2) If this is a non-pseudonode LSP and it is LSP number 0, and it contains the Management Information option, compare the server name and the network number fields with those parameters of the local system. If the network numbers do not match, log the duplicateLSPSystemID event. If the network numbers match but the server names do not, log the duplicateInternalNet event.

a.3) If the received LSP is older than the local LSP, send the local LSP on C.

b) If there is no LSP with this ID in the LSP database

b.1) Create an LSP with a sequence number one more than the incoming LSP.

b.2) Follow the procedures for aging an LSP with nonzero remaining lifetime on page 5-7.

5.12.4. Unexpired LSP with a Different System ID

a) If there is an LSP with this ID in the LSP database

a.1) If the LSPs are equal, acknowledge the LSP on C.

a.2) If the received LSP is older, send the local LSP on C.

a.3) If the received LSP is newer

a.3.1) Store the new LSP, replacing the local copy

FF a.3.2) Send the new LSP on all circuits except C and acknowledge it on C.

b) If you do not have an LSP with this ID in the LSP database

   b.1) Store the incoming LSP.

FF b.2) Send it on all circuits except C and acknowledge it on C.

5.13. Storing a New LSP

When storing a new LSP, the router first ensures that it has enough memory to store the LSP and whatever internal data structures will be required to process the LSP. If the resources are unavailable, the LSP is ignored—it is neither stored nor acknowledged. When an LSP is ignored for this reason, the router enters the *Waiting State* (see page 5-24).

When attempting to store a new version of an existing LSP whose length has not increased, it is recommended that removing the old and storing the new occur as a single atomic action. There is no increase in the resources required. This ensures that such an LSP (which might be carrying the LSP Database Overload indication from an overloaded router) is never ignored for lack of memory resources.

5.14. Receipt of Sequence Number Packets

A router sends Sequence Number Packets (SNPs) to its immediate neighbors and they are not propagated. By sending an SNP, the router communicates the current LSP sequence numbers in its database. A PSNP reports a subset of the LSPs and their sequence numbers. A complete set of CSNPs reports on the total LSP database. A complete set of CSNPs is a set whose Start LSP ID and End LSP ID ranges cover the complete possible range of LSP IDs. That is, every possible LSP ID value appears within the range of one of the CSNPs in the set.

Upon receipt of a PSNP or CSNP on circuit C, a router first performs the following acceptance tests:

a) The general packet acceptance tests described in Section 2 under "General Processing of Incoming IPX Packets."

b) If C is a LAN, and the source data-link address of the SNP does not match the neighborNICAddress of an existing adjacency on C in the "Up" state, the router discards the SNP without generating an event.

   Note: SNPs from a neighbor in the "Initializing" state are ignored. A persistent "Initializing" state might be the result of a neighbor with a faulty network interface—it can send but not receive. The SNPs are ignored to avoid repeated transmissions of LSPs to such a neighbor.

c) If C is a WAN and there is no adjacency on C, the router discards the SNP without generating an event.

d) If a PSNP is received on a LAN for which this system is not the Designated Router, discard the packet.

e) If a CSNP is received on a LAN for which this system is the Designated Router, discard the packet.

f) If the length of the packet, as described in the header, is greater than the buffer in which it was received, log a packetRxSmall event and discard the packet.

g) If the variable part of the SNP is malformed, or contains malformed options, log a malformedOption event and discard the packet.

For each LSP reported in the SNP, use the method on page 5-5 to compare the reported LSP with the corresponding LSP in the local database, and take the following action for C:

> **Note:** No check is made against the receiving router's own systemID. Refer to "Resolving LSP Confusion" later for a rationale.

h) If C is a WAN and the reported LSP is the same as the one stored in the local Link State database, clear the SRMflag.

i) If the reported LSP is older than the local LSP, clear the SSNflag and set the SRMflag.

j) If the reported LSP is newer than the database LSP

   j.1) Set the SSNflag.

   j.2) If C is a WAN, clear the SRMflag.

k) If no database entry exists for the LSP, and if the reported Remaining Lifetime, Checksum, and Sequence Number fields of the LSP are all nonzero

   k.1) Create an LSP entry with sequence number zero and lifetime equal to zeroAgeLifetime.

   k.2) Set the SSNflag for that entry for C.

> **Note:** SRMflag must never be set for an LSP having a zero sequence number. Possessing a zero sequence number is equivalent semantically to having no information about that LSP. If such an LSP were propagated by setting the SRMflag, it would result in unnecessary consumption of both bandwidth and memory resources.

l) For an SNP to be valid, the LSP Entries must be ~~me~~ in increasing LSP ID order. If a system detects out-of-order entries, it generates a misorderedSNP event. When this happens, which (if any) of the SNP's LSP Entries to process is a local implementation choice.

If the received packet is a CSNP, set the SRMflag for C for LSPs for which

m) The LSP is in this router's database.

n) The LSP has nonzero Sequence Number and nonzero Remaining Lifetime.

o) The LSP ID is within the range specified by the Start LSP ID and End LSP ID fields of the CSNP, inclusive.

p) The LSP is not mentioned in the CSNP.

> **Note:** Because entries in the CSNP are ordered, the LSP screening process can be accomplished in a single pass through the CSNP.

5.15. Transmitting the Packets

In the preceding discussions, packets were composed and generated, flags were set, and the router made preparations to send packets. But they were not actually transmitted. The actual transmission of packets is governed by certain timers. The subsections to follow provide the details.

5.15.1. Expiration of a Complete SNP Interval

For each LAN circuit, a router maintains a local flag: SendCSNPflag.

Note: On WAN links, CSNPs are sent only at initialization.

When a system elects itself Level 1 Designated Router on a circuit, or when a system that is Level 1 Designated Router forms a new adjacency (in the "Up" state) on a LAN, it sets the SendCSNPflag for that circuit.

The router performs the following actions every minimumCompleteSNPInterval; with jitter applied as described in Section 2.

a) for each LAN circuit C for which this system is the Level 1 Designated Router

a.1) If either

- SendCSNPflag is set

Or

- at least maximumCompleteSNPInterval has elapsed since the last CSNP was sent on C

transmit a complete set of Level 1 CSNPs on C. (Ignore the setting of SSNflag on the LSPs.)

a.2) Clear SendCSNPflag for C.

A complete set of CSNPs is a set whose Start LSP ID and End LSP ID ranges cover the complete possible range of LSP IDs. That is, every possible LSP ID value appears within the range of one of the CSNPs in the set. When sending a complete set of CSNPs, observe the following detailed rules.

- The Start LSP ID of the first CSNP of a set is zero. The End LSP ID of the last CSNP of the set is 0xFFFFFFFFFFFFFFFF (all ones).
- The Start LSP ID value of a CSNP is exactly one greater than the End LSP ID value of the preceding CSNP. Do not duplicate the end point LSP IDs. Do not leave gaps.
- If there is a gap in the list of known LSP IDs, there is no relationship between the gap in the LSP ID number space and the boundaries of CSNPs. The Start LSP ID and End LSP ID values might or might not be known LSP IDs.
- As indicated on page 5-18, there can be LSPs in the local database with sequence number zero. These are not included in any CSNP LSP Entries; they are a local bookkeeping device only.
- Include in each CSNP the greatest number of LSP Entries allowed by the circuit's actualMaxPacketSize. An exception is the set's last CSNP, which can have fewer. This rule implies that each CSNP's End LSP ID is strictly greater than its Start LSP ID.
- Do not compute the entire set of LSPs to report at the outset. Rather, each CSNP after the first should reflect those changes in the database that might have occurred since sending the previous CSNP that affects the LSP range not yet covered in this complete CSNP set.

For example, suppose a router holds LSPs with LSP IDs 2, 3, 4, 5, 6, 7, 11, 12, 33, 34, 35, 36, 37, 45, 46, 55. A valid complete set of CSNPs is:

	Start LSP ID	End LSP ID	LSP Entries
CSNP #1	0	5	2, 3, 4, 5
CSNP #2	6	12	6, 7, 11, 12
CSNP #3	13	36	33, 34, 35, 36
CSNP #4	37	0xFFFFFFFFFFFFFFFF	37, 45, 46, 55

Another, equally valid, complete set of CSNPs for the same example is as follows:

	Start LSP ID	End LSP ID	LSP Entries
CSNP #1	0	5	2, 3, 4, 5
CSNP #2	6	32	6, 7, 11, 12
CSNP #3	33	36	33, 34, 35, 36
CSNP #4	37	84	37, 45, 46, 55
CSNP #5	85	0xFFFFFFFFFFFFFFFF	(none)

The empty CSNP #5 could result if, for example, the router held LSP ID 85 at the time CSNP #4 was transmitted, but purged it from the Link State database before CSNP #5 was transmitted.

When multiple CSNPs are transmitted on a circuit, they are separated by an interval of at least 1/18 second. Because of this provision, the interval between transmitting the last CSNP packet of a set and transmitting the first CSNP of a new set might actually be less than minimumCompleteSNPInterval.

Note: Minor variations are sometimes inevitable when adhering to the 1/18 second rule, owing to the timer granularity of the router. Such variations are not material.

5.15.2. Expiration of a Partial SNP Interval

The router performs the following actions every partialSNPInterval for each circuit C, with jitter applied as described in Section 2:

If either

a) C is a WAN

Or

b) C is a LAN and this router is **not** the Designated Router for C

then transmit a PSNP on C containing entries for as many LSPs with SSNflag set as fit in the packet. Then clear the SSNflag for these entries. To avoid starvation, the scan of the LSP database (for those with SSNflag set) starts with the next LSP that was not included in the previous scan. If there are no LSPs with SSNflag set, do not transmit a PSNP.

5.15.3. Expiration of Minimum LSP Transmission Interval

A router takes the following action every minimumLspTransmissionInterval, with jitter applied as in Section 2:

The router scans the LSP database and sends on each circuit C those LSPs having the SRMflag set for C. If C is a LAN, clear the SRMflag.

Where multiple LSPs are transmitted on a circuit, they must be separated by a minimum gap of 1/18 second.

> **Note:** Minor variations are sometimes inevitable when adhering to the minimum gap rule, owing to the timer granularity of the router. Such variations are not material.

> **Note:** In practice, it would be inefficient to scan the entire database this often, particularly when only a few LSPs had SRMflags set. Implementations would typically use additional data structures to optimize this operation.

There is an optional enhancement to the way flooding works. It is an exception to the general rule of waiting for the minimumLspTransmissionInterval to expire. When a system receives a new LSP on a circuit, it floods the LSP immediately (instead of setting SRM flags) on all other circuits. On WAN circuits, it sets the SRMflag as well. (The SRMflag is cleared on a WAN when an SNP acknowledges the LSP.) The objective of this enhancement is faster flooding. Locally generated LSPs are not sent this way. Also, a system that implements faster flooding must still observe circuit pacing (see next subsection). In other situations (for example the receipt of an SNP), or if the circuit is a WAN, the router should follow the normal procedure: set the SRMflag, and actually send the LSP only on expiration of the minimumLspTransmissionInterval. In implementing faster flooding, circuit pacing should be applied, as described in the next subsection; however, do not observe the 1/18 second minumum gap of the previous paragraph.

5.15.4. Circuit Pacing to Avoid Circuit Congestion

Circuit pacing applies to transmission of LSPs and CSNPs on each circuit. This rule is in addition to the minimal 1/18 second gap.

Circuit pacing specifies that no more than paceRate CSNPs are sent per second on the circuit, and no more than paceRate LSPs. The value of paceRate is calculated based on the circuit's Throughput in bits per second (bps), as follows:

paceRate = Throughput / 10,000

with a minimum of 1. For example, at 19,200 bps or less, paceRate is one packet per second. At 19,200 bps and 512-byte packets, no more than 25% of the circuit bandwidth is consumed by LSPs or by CSNPs.

5.15.5. Multiple Circuits Connected to the Same LAN

As an implementation option, a router can take special measures to reduce overhead when there are multiple circuits connected to the same LAN. It is not necessary that distinct routers make the same choice of supporting (or not supporting) these measures.

When a system has two or more separate connections to the same LAN, it can designate one as the *primary circuit* and the others as *secondary circuits*. A router should only do so if the primary circuit is running NLSP and has at least one adjacency in the "Up" state. These circuits must all be configured with the same IPX network number.

A system should treat secondary circuits like all other circuits with the one exception: it need not send LSPs that it is flooding immediately (see page 5-21) on that circuit. Instead of sending the LSP, it takes no action on that circuit. However, it should send LSPs on the secondary circuits in the normal way if SRMflag has been set on that circuit.

Packets received on secondary circuits are processed as usual. For example, SRMflags are cleared on this circuit when receiving an LSP.

5.16. Determining the Latest Information

Several provisions govern manipulation of the values that appear in LSPs. The subsections to follow provide details.

5.16.1. Operation of Sequence Numbers

The Sequence Number is a four-byte unsigned value. When a system initializes, it starts with sequence number one for its own LSPs.

The intent is for the Sequence Number to be incremented monotonically. If a router restarts after being deactivated, it jumps to using sequence numbers beyond the range it used in its previous incarnation. See the next section, "Resolving LSP Confusion," for the details about how this is accomplished.

The sequence numbers a router generates for LSPs of different LSP Number are independent. The algorithm for choosing the numbers is the same, but the numbers advance separately, without being synchronized.

It might happen that a sequence number reaches the maximum value representable in the four-byte sequence-number space. The router owning the LSP, and needing to regenerate it, purges the LSP by sending the LSP with the same sequence number but zero Remaining Lifetime. This causes the LSP to be aged by all other routers. It sets a timer to regenerate the given LSP after (2 x maxAge) + zeroAgeLifetime. Then the source router starts regenerating the LSP with sequence number 1.

Note: NLSP is less severe than IS-IS in this regard; here, the router need not be disabled. (However, if the router is disabled, a wait of maxAge + zeroAgeLifeTime is necessary before restarting it. In NLSP, recovery from the overflow is automatic. Also, because the router is not shut down, there is only a partial loss of connectivity to the services, external routes, and adjacencies known by the router, rather than a total loss of all connectivity through the router.

5.16.2. Resolving LSP Confusion

This subsection does not add specification logic to the document. It shows how steps in preceding sections fit together to keep LSPs progressing monotonically in an orderly way throughout the routing area despite router restarts.

When a router restarts, losing memory of its previous state, it is possible that an LSP generated by the router in a previous incarnation (that is, by the same system but before the restart) is alive in the routing area. In this case, the collective memory of the other routers advances the sequence numbers of the restarted router's LSPs into a range beyond the numbers used by the router's previous incarnation. Many of the details in processing incoming LSPs and CSNPs are motivated by the need to resolve LSP Confusion.

Suppose router A has restarted and it has immediate neighbors B and C. A sends its first LSP with sequence number one (Section 5.16.1). B still has an old LSP from A with a higher sequence number. So B, considering A to be out of date, helpfully provides A with the "newer" (actually older) LSP (Section 5.12.4, Step a.2). When A receives that LSP from B, it discovers how far its sequence number reached prior to the restart. In then advances its sequence number for the LSP to make it newer still (Section 5.12.3, Step a.2.1). When the restarted router receives its own LSP from a neighbor and the received LSP has an LSP Number not in use, it purges the LSP from the routing area (Section 5.12.3, Step b.2).

It is even possible for an LSP generated by a system in a previous incarnation to be alive in the routing area and have the same sequence number as the current LSP. To deal with this case, the comparison described on page 5-5 includes the Preference of Checksums rule. With this rule, routers detect that the LSPs are different and all routers make the same decision about which is newer. With this rule, resolution of LSP confusion works the same way for equal and unequal sequence numbers.

Another aspect of LSP confusion is a misconfiguration in which two routers, A and B, are given the same systemID. One of the two, say A, generates an LSP number zero that all routers consider newer than B's LSP number zero. By operation of the protocol, A's LSP eventually reaches B. When this happens, B can readily detect the problem and report A's Network Number and Router/Server Name from the Management Information field of the LSP (Section 5.12.3, Step a.2.2).

References in the preceding paragraphs cited steps in LSP processing. To ensure that LSPs are propagated to the routers that execute these steps, SNP processing must operate in a supportive way. For example, to resolve LSP confusion, a router A requires its neighbors to send A their versions of A's own LSPs. This is the reason that SNP processing does not discriminate in Section 5.14 between this router's and other routers' LSPs.

5.16.3. Synchronizing LSP Expiration

This subsection does not add specification logic to the document. It shows how steps in preceding sections fit together to make old LSPs age out of different routers' Link State databases at (approximately) the same time.

If a router detects that another router has become unreachable, the other router's LSPs are kept anyway. If this were not done, repair of a brief network partition could prompt extensive consumption of network bandwidth and computing resources to reacquire and reabsorb connectivity information that has not changed since before the partition.

Nonetheless, stale information must eventually be removed because the routers in question might not become reachable again. As long as routers in a routing area remain mutually reachable, their LSPs remain in each other's Link State databases. They are refreshed by periodic regeneration (page 5-7). If a router holds an LSP whose remaining lifetime reaches zero, it purges the LSP, as described on page 5-7.

To keep the routers in the routing area consistent with each other, it is not enough that they act independently in purging stale LSPs. Routers' timers are not synchronized with each other. Routing could be disrupted if there was an extended period of mismatched databases. So when the first router ages out an LSP, it conveys this fact to other reachable routers by truncating the LSP and propagating it with zero lifetime (Section 5.6 Step a).

When a router receives such a truncated LSP, it accelerates the aging of the LSP in its own database (Section 5.4 Step b and Section 5.12.4 Step a.3). Once one router has aged an LSP, this provision ensures that all other routers reachable from it purge the LSP as soon as possible.

After purging the LSP, a router keeps it in truncated form in its Link State database for a time (page 5-7). This way, unexpired versions of the same LSP cannot propagate widely. Such unexpired versions might be in the process of being propagated by a router that is aging it slower than the one instigating the purge. The expired version is considered newer than an unexpired counterpart (Section 5.4 Step b). Keeping the truncated LSP for a while acts as a lock-down on the expiration of the LSP. Including the Remaining Lifetime in Sequence Number Packets reinforces the rapid, firm spread of the expiration news (Section 5.14 Step i).

5.17. Validation of Databases

Corruption of information in router memory is possible from a failure in hardware or software. A router must not continue to operate for an extended period with corrupted routing information. Routers operate in a fail-stop manner. If a failure is detected, the router is disabled until the failure is corrected. Developers can take implementation-specific steps to guarantee this. In the absence of such a guarantee, the router performs the following actions at least every maximumLSPGenerationInterval:

a) To detect corruption of the LSP database while in memory, recheck the checksum of every LSP in the database, except those with zero Remaining Lifetime. If any checksum is incorrect

   i) Log a badIntChecksum event.

   ii) Delete the entire LSP database.

   iii) Reset every WAN adjacency to the "Down" state, as described in Section 4.

   iv) Cause the database to be reacquired.

   Note: One way to accomplish ii, iii, and iv is to disable the router and restart.

b) When the checks are completed, notify the Decision Process, even if all checksums were correct. This causes the Decision Process to be run and the Forwarding database to be recomputed. This protects against corruption of the Forwarding database in memory, which might otherwise persist undetected in memory with a stable topology.

c) Reset the timer for maximumLSPGenerationInterval, with jitter applied as described in Section 2.

5.18. Managing LSP Database Overload

If there are insufficient memory resources to store a received LSP, the receiving router's Link State database might become inconsistent with those of other routers. The router takes the following steps to ensure that other routers do not rely on forwarding paths through the overloaded router:

a) Ignore the LSP that cannot be stored.

b) Enter the Waiting State; start a timer for waitingTime, to limit the duration of the Waiting State.

c) Generate an enteringL1DatabaseOverload event.

d) Generate and flood the router's own LSP having zero LSP Number with the LSP Database Overload bit set.

e) Lower to zero the priority of becoming the Designated Router for every LAN circuit for which the router is not already the Designated Router. (Circuits for which the router is already the Designated Router are unaffected.) The lowering of priority lasts as long as the overload state, after which the priority reverts to the initial value.

Even if received LSPs can be stored, it is possible that resources become exhausted while running the Decision Process. If this happens, the router enters the Waiting State (as just described) until resources are available and waitingTime has elapsed since the last received LSP was ignored.

While in the Waiting State

a) If an LSP cannot be stored, the router ignores it, restarts the timer for waitingTime, and generates a InL1DatabaseOverload event.

b) If the Decision Process cannot be run because of insufficient resources, the router restarts the timer for waitingTime and generates a remainingInL1DatabaseOverload event.

c) Propagation of LSPs, running the Decision Process, and forwarding data traffic proceed as normal.

d) When the waitingTime expires, the router

   i) Generates an exitingL1DatabaseOverload event

   ii) Clears the LSP Database Overload bit in its own Level 1 LSP with zero LSP Number and reissues it

   iii) Resumes normal operation

5.19. Link State Database

5.19.1. Configured Values

maxAge

The time interval after which an LSP is considered to expire. Default is 7500 seconds.

zeroAgeLifetime

The time interval that a router retains an LSP in its database once the LSP has expired. The expiration can be locally detected, or it can be learned from a neighbor by receiving an expired LSP. Default is 60 seconds.

maximumLSPGenerationInterval

The maximum interval, in seconds, between the generation of the same LSP. Default is 7200 seconds.

lspBufferSize

The maximum size of Level 1 LSPs originated by this router. Default is 512 bytes (including the IPX header but not the data-link headers). Every router must be able to send LSPs of at least 512 bytes and accept LSPs of actualMaxPacketSize bytes on a circuit.

Note: The end user should be sure to configure lspBufferSize to be no larger than the smallest MTU size of any router for any circuit in the area.

minimumLSPTransmissionInterval

The minimum interval, in seconds, between sending LSPs on a circuit. There can be two separate values: one for LANs and one for WANs. Default is ~~2~~ 5 seconds for LANs and 10 seconds for WANs.

minimumLSPGenerationInterval

The minimal interval, in seconds, between regenerations of the same LSP. Default is 5 seconds.

minimumCompleteSNPInterval

The smallest interval, in seconds, between generation of Complete Sequence Number Packets by a Designated Router on a LAN. Default is 5 seconds.

maximumCompleteSNPInterval

The largest interval, in seconds, between generation of Complete Sequence Number Packets by a Designated Router on a LAN. Default is 30 seconds.

partialSNPInterval

The minimum interval, in seconds, between transmission of Partial Sequence Number Packets. Default is 1 second.

waitingTime

The number of seconds to remain in the waiting (LSP database overload) state before returning to normal operation. Default is ~~60~~ 120 seconds.

5.19.2. Configured Values per Circuit

cost

The measure attached to a circuit used to make routing decisions. The Decision Process determines the smallest aggregate cost to each reachable NLSP destination. Default values are listed in Figure 5-3.

5.19.3. LSP Database

LSPdatabase

The set of LSP packets received by this router and still in memory.

SRMflag

For each LSP and each circuit, a bit indicating that the LSP should be sent on that circuit.

SSNflag

For each LSP and each circuit, a bit indicating that the LSP should be reported in a PSNP sent on that circuit.

SendCSNPflag

This flag is set when an event occurs indicating that a complete set of Level 1 CSNPs should be sent on a circuit when the next maximumCompleteSNPInterval elapses.

lastSent

For each LSP and each circuit, a record of the time at which that LSP was most recently sent on that circuit.

5.19.4. NLSP Events

lanL1DesRouterChange

The role of Designated Router on a LAN circuit is transferred from one NLSP router to another.

badChecksum

An LSP was received for which checksum verification failed.

badIntChecksum

A checksum error was detected in an LSP stored in router memory, indicating a memory corruption error.

misorderedSNP
An arriving Sequence Number packet contains LSP Entries out of order. The entries must be in increasing LSP ID order.

duplicateLSPSystemID
An arriving LSP reports a systemID conflicting with this system's systemID, but with a different internal network number.

duplicateInternalNet
An arriving LSP reports an internalNetworkNumber conflicting with this system's internalNetworkNumber, and with the same systemID and different Router/Server Name.

enteringL1DatabaseOverload
The router state changes from normal operation to a situation in which the LSP database is overloaded.

remainingInL1DatabaseOverload
While in an overloaded state, another event occurred to prolong the LSP database overload state.

exitingL1DatabaseOverload
The router is no longer in the LSP database overload state. Normal operation is resuming.

5.20. Packet Structures

The following packet types are relevant to the link state methods in this section.

- Level 1 LSP (page 5-29)
- Level 1 CSNP (page 5-33)
- Level 1 PSNP (page 5-35)

If this router is capable of receiving packets addressed to the selective link-level multicast address,

- This router's LAN Hello packets are sent with zero as the No Multicast bit.
- The three types of Link State packets are sent initially by multicast when transmitted on a LAN.
- If a LAN Hello packet has been received with the No Multicast bit set, a router must use the broadcast address on that circuit (instead of multicast).

If this router is **not** capable of receiving packets addressed to the selective link-level multicast address,

- This router's LAN Hello packets are sent with the No Multicast bit set to one.
- The three types of Link State packets are sent by broadcast on a LAN.

These packets ride in the data portion of IPX packets. The IPX header fields are encoded as shown in Figure 5-4.

	LSPs and SNPs sent on a WAN	LSPs and SNPs sent on a LAN
Destination Network	zero	zero
Destination Node	0xFFFFFFFFFFFF	0xFFFFFFFFFFFF
Destination Socket	0x9001	0x9001
Source Network	internalNetworkNumber of the router sending the packet	Network number of the LAN on which the packet is being transmitted
Source Node	Node number (0x000000000001) of the router sending the packet on its internalNetworkNumber	IEEE MAC address of the LAN interface through which the packet is being transmitted
Source Socket	0x9001	0x9001
Packet Type	zero	zero

Figure 5-4: IPX Header Fields

These Level 1 LSPs never exceed lspBufferSize bytes in size, including the IPX header but excluding the data-link header.

The maximum size of sequence number packets on any circuit is determined by the media type and the buffer sizes used by neighbors on that circuit. Each Hello packet includes the Local MTU option, containing the sender's localMaxPacketSize for the circuit. This is the way routers communicate the packet size they can receive on that circuit. Every router calculates the minimal value of Local MTU for active adjacencies on each circuit. It then takes the smaller of that value and its own localMaxPacketSize for that circuit. The result is the actualMaxPacketSize value for that circuit. SNPs can be as large as that value, but no larger.

The valid option fields in the variable parts of these packets can appear in any order, except where otherwise noted in the text.

5.20.1. Level 1 LSP

Level 1 LSP

	Number of Bytes
Protocol ID	1
Length Indicator	1
Minor Version	1
Reserved	1
NR | Res | Packet Type	1
Major Version	1
Reserved	2
Packet Length	2
HF | Remaining Lifetime	2
LSP ID	8
Sequence Number	4
Checksum	2
P | Attached Flag | LSP DBOL | Router Type	1
Variable Length Fields	Variable

Protocol ID: 0x83, identifies the NLSP routing layer.

Length Indicator: The number of bytes in the fixed portion of the header (up to and including the Router Type field).

Minor Version: 1 or, 2 (if the router supports Aggregated Routes). , ignored on receipt.

Reserved: 0, ignored on receipt.

Multi-homed Non-routing Server, abbreviated NR in the diagram, (1 bit): When this field contains one, the system has more than one network interface, but does not forward traffic from one network segment to another.

Res (2 bits): 0, ignored on receipt.

Packet Type (5 bits): 18.

Major Version: 1.

Reserved: 0, ignored on receipt.

Packet Length: The entire length of this packet, in bytes, including the fixed portion of the NLSP header.

Hour Flag, abbreviated HF in the diagram, (1 bit): When this field is set to one, the Remaining Lifetime field represents the number of hours before this LSP is considered to expire.

Remaining Lifetime: The number of seconds before this LSP is considered to expire.

LSP ID: A field composed of three parts:

- Source ID: The system ID of the router that originated the LSP.
- Pseudonode ID: Is zero if this is a non-pseudonode LSP; otherwise, it is a unique (for this Source ID) number designating this pseudonode.
- LSP Number: If a would be LSP is too large to send, the source breaks it into fragments identified by this monotonically increasing number.

LSP ID

	Number of Bytes
Source ID	6
Pseudonode ID	1
LSP Number	1

Sequence Number: The sequence number of the LSP.

Checksum: The checksum of the LSP contents from Source ID (the first part of LSP ID) to the end.

P: (one bit): zero—Indicates that this router does not support partition repair.

Attached Flag (four bits): Indicates whether the router can provide a path to other routing areas.

0 = "No," other routing areas cannot be reached through this router.

1 = "Yes," other routing areas can be reached through this router.

Other values are reserved.

LSPDBOL: (one bit): Set to one when the LSP database is overloaded.

Router Type: (two bits):

1 = "Level 1 Router;" operation is specified in this document.

3 = "Level 1 and Level 2 Router;" accept this value from other routers, for forward compatibility.

Other values are reserved.

<u>Variable Length fields</u>: A series of optional fields, each of which has the following three-part code/length/value Option form:

Option	Number of Bytes
Code	1
Length	1
Value	Length

Currently defined codes, and the corresponding values, are

- Area Addresses: The set of manualAreaAddresses of the sending router; not present in pseudonode LSPs.

  Code = 0xC0. Length = Total length of the value field, in bytes; either 8, 16, or 24.

  Value = Up to three area addresses. Each area address consists of a four-byte network number, followed by a four-byte address mask. The mask contains from zero to 32 (inclusive) most-significant one bits to indicate which bits of the network number make up the address prefix identifying the routing area. The remaining bits are zero. The bit-wise AND of an Address and Mask pair must be equal to Address; for example, it would be a mistake to send Address = 0x84300000 paired with Mask = 0xFF000000.

Area Addresses	Number of Bytes
Address	4
Mask	4
... ...	
Address	4
Mask	4

- Management Information: Several fields with information about the router originating the LSP.

  Code = 0xC1. Length = 12 to 60, or more.

  Value = The following five subfields:

  Note: To allow future versions of this protocol to add fields at the end and remain compatible with routers implementing this version, routers receiving this option ignore any fields after those listed here.

Management Information	Number of Bytes
Network Number	4
Node Number	6
IPX Version Number	1
Name Length	1
Router / Server Name	Name Length

  - Network Number: The internal IPX network number of the router generating the LSP. For a LAN pseudonode or a numbered WAN pseudonode, it is the IPX network number of the network segment that the pseudonode represents. For an unnumbered WAN pseudonode, the value is zero.
  - Node Number: For a non-pseudonode LSP, the internal IPX node number (0x000000000001) of the router generating the LSP. For a LAN pseudonode, the node number (typically, the MAC address of the point of attachment) of the Designated Router generating the LSP on the LAN to which the LSP refers. For a WAN pseudonode, the value is zero.
  - IPX Version Number: 1.
  - Name Length: Length of the Router/Server Name field; zero if none is present.

- Router/Server Name: A string of 1 to 47 bytes identifying the router originating the LSP. If this is a pseudonode LSP, this field might not be present; but if it is, it identifies the network segment to which the LSP refers. It is one byte per character, seven-bit ASCII.

  Note: Although the server name is null-terminated in many NetWare protocols, this string is not null-terminated.

- Link Information: Several subfields with information about one adjacency of the source router. This option occurs several times, in general, once for each adjacency.

  Code = 0xC2. Length = 25 or more.

  Value = The following subfields.

  Note: To allow future versions of this protocol to add fields at the end and remain compatible with routers implementing this version, routers receiving this option ignore any fields after those listed here. When sending, use 25 as the Length. When receiving, accept any number 25 or larger.

Link Information			Number of Bytes
S1	I/E	Cost	1
Reserved			3
Neighbor ID			7
MTU Size			4
Delay			4
Throughput			4
Media Type			2

  - S1 (1 bit): Zero, indicating that the Cost is present.
  - Internal/External, abbreviated I/E in the diagram (1 bit): Zero, indicating that the Cost is an internal metric. Note, a Level 1 LSP is rejected if the bit is not set to zero.

    Note: With hierarchical routing, costs internal to one's own routing area are not usually comparable with those outside it. An internal route is chosen over an external one, if there is a choice. The I/E bit provides information to the Decision Process that allows the choice to be made.
  - Cost (6 bits): The cost of a link to the listed neighbor; an unsigned positive integer.
  - Reserved (three bytes): 0, ignored on receipt.
  - Neighbor ID: For a non-pseudonode neighbor, the neighboring router's system ID plus one byte of zero; for a pseudonode neighbor, the first six bytes are the Designated Router's system ID and the seventh byte is the unique nonzero Pseudonode ID value assigned to this pseudonode by the Designated Router.
  - MTU Size: The maximum number of bytes that can be transmitted on this link by the originating router, including the IPX header but not including the data-link headers. It is zero for a pseudonode LSP.
  - Delay: The time, in microseconds, that it takes to transmit one byte of data (excluding protocol headers) to a destination, if the media is free of other traffic. It is zero for a pseudonode LSP.
  - Throughput: The amount of data, in bits, that can flow through the media and be received at the other side in one second, if there is no other traffic using the interface. It is zero for a pseudonode LSP.
  - Media Type: A code identifying the type of circuit; the most significant bit is one for WAN media, zero for others. See Figure 5-2 for the assigned values.

- Services Information: Describes services that advertise themselves by the SAP protocol.

  Code = 0xC3. Length = 16 to 62.

  Value = The following subfields.

  - Hops: The number of hops to reach the service.
  - Network Number, Node Number, Socket: The IPX address at which the service is available.
  - Type: The type of service offered, see Reference [Nov92] for a partial list of defined types.
  - Service Name: The name of the service; its length is determined implicitly by the length of this option—the name is **not** null-terminated.

Services Information	Number of Bytes
Hops	1
Network Number	4
Node Number	6
Socket	2
Type	2
Service Name	1 to 47

- External Routes: Describes routes obtained by the source router through non-NLSP protocols; for example, RIP (see Reference [Nov92]).

  Code = 0xC4. Length = $7 \times n$; $n \geq 0$.

  Value = The following subfields.

  - Hops: The number of hops reported by the non-NLSP protocol.
  - Network Number: The IPX network number to which this entry refers.
  - Ticks: The RIP Delay (that is, the number of RIP timer ticks) from the source router to network Network Number, as reported by the non-NLSP protocol.

External Routes	Number of Bytes
Hops	1
Network Number	4
Ticks	2

5.20.2. Level 1 CSNP

<table>
<tr><th colspan="2">CSNP</th><th>Number of Bytes</th></tr>
<tr><td colspan="2">Protocol ID</td><td>1</td></tr>
<tr><td colspan="2">Length Indicator</td><td>1</td></tr>
<tr><td colspan="2">Minor Version</td><td>1</td></tr>
<tr><td colspan="2">Reserved</td><td>1</td></tr>
<tr><td>Reserved</td><td>Packet Type</td><td>1</td></tr>
<tr><td colspan="2">Major Version</td><td>1</td></tr>
<tr><td colspan="2">Reserved</td><td>2</td></tr>
<tr><td colspan="2">Packet Length</td><td>2</td></tr>
<tr><td colspan="2">Source ID</td><td>7</td></tr>
<tr><td colspan="2">Start LSP ID</td><td>8</td></tr>
<tr><td colspan="2">End LSP ID</td><td>8</td></tr>
<tr><td colspan="2">Variable Length Fields</td><td>Variable</td></tr>
</table>

Protocol ID: 0x83, identifies the NLSP routing layer.

Length Indicator: The number of bytes in the fixed portion of the header (up to and including the End LSP ID field).

Minor Version: 1 or, 2 (if the router supports Aggregated Routes). , ignored on receipt.

Reserved: 0, ignored on receipt.

Reserved (3 bits): 0, ignored on receipt.

Packet Type (5 bits): 24.

Major Version: 1.

Reserved: 0, ignored on receipt.

Packet Length: The entire length of this packet, in bytes, including the fixed portion of the NLSP header.

Source ID: The six-byte system ID of the sending router, followed by one byte of zero.

Start LSP ID, End LSP ID: The first and last LSP in the range covered by this CSNP. Each is a field composed of three parts:

- Source ID: The systemID of the router that originated the LSP being reported.
- Pseudonode ID: Zero if this is a non-pseudonode LSP; otherwise, it is a unique (for this Source ID) number designating this pseudonode.
- LSP Number: If a would be LSP is too large to send, the source breaks it into fragments identified by this monotonically increasing number.

LSP ID	Number of Bytes
Source ID	6
Pseudonode ID	1
LSP Number	1

Variable Length fields: A series of optional fields, each of which has the following three-part code/length/value Option form:

Option	Number of Bytes
Code	1
Length	1
Value	Length

Currently defined codes, and the corresponding values, are

- LSP Entries: This option can appear more than once; if so, instances must be sorted in ascending LSP ID order.

  Code = 9. Length = 16 × *n*; *n* > 0.

  Value = A list of LSP entries, sorted in ascending LSP ID order (the LSP Number byte of the LSP ID is the least significant byte). Each entry has four subfields:

  - Remaining Lifetime: Seconds remaining until the indicated LSP expires.
  - LSP ID: Identifies the LSP referred to by this LSP Entry. It has the same three-part Source ID/Pseudonode ID/LSP Number form described on page 5-33.
  - Sequence Number: The sequence number of the indicated LSP.
  - Checksum: The checksum reported in the indicated LSP.

LSP Entries	Number of Bytes
Remaining Lifetime	2
LSP ID	8
Sequence Number	4
Checksum	2
••• •••	
Remaining Lifetime	2
LSP ID	8
Sequence Number	4
Checksum	2

5.20.3. Level 1 PSNP

Protocol ID: 0x83, identifies the NLSP routing layer.

Length Indicator: The number of bytes in the fixed portion of the header (up to and including the Source ID field).

Minor Version: 1 or, 2 (if the router supports Aggregated Routes). , ignored on receipt.

Reserved: 0, ignored on receipt.

Reserved (3 bits): 0, ignored on receipt.

Packet Type (5 bits): 26.

Major Version: 1.

Reserved: 0, ignored on receipt.

Packet Length: The entire length of this packet, in bytes, including the fixed portion of the NLSP header.

Source ID: The six-byte system ID of the sending router, followed by one byte of zero.

<table>
<tr><th colspan="2">PSNP</th><th>Number of Bytes</th></tr>
<tr><td colspan="2">Protocol ID</td><td>1</td></tr>
<tr><td colspan="2">Length Indicator</td><td>1</td></tr>
<tr><td colspan="2">Minor Version</td><td>1</td></tr>
<tr><td colspan="2">Reserved</td><td>1</td></tr>
<tr><td>Reserved</td><td>Packet Type</td><td>1</td></tr>
<tr><td colspan="2">Major Version</td><td>1</td></tr>
<tr><td colspan="2">Reserved</td><td>2</td></tr>
<tr><td colspan="2">Packet Length</td><td>2</td></tr>
<tr><td colspan="2">Source ID</td><td>7</td></tr>
<tr><td colspan="2">Variable Length Fields</td><td>Variable</td></tr>
</table>

Variable Length: A series of optional fields, each of which has the following three-part code/length/value Option form:

Option	Number of Bytes
Code	1
Length	1
Value	Length

Currently defined codes, and the corresponding values, are

- LSP Entries: This option can appear more than once; if so, instances must be sorted in ascending LSP ID order.

  Code = 9. Length = 16 × n; $n > 0$.

  Value = A list of LSP entries, sorted in ascending LSP ID order (the LSP Number byte of the LSP ID is the least significant byte). Each entry has four subfields:

  - Remaining Lifetime: Seconds remaining until the indicated LSP expires.
  - LSP ID: Identifies the LSP referred to by this LSP Entry. It has the same three-part Source ID/Pseudonode ID/LSP Number form described on page 5-33.
  - Sequence Number: The sequence number of the indicated LSP.
  - Checksum: The checksum reported in the indicated LSP.

LSP Entries	Number of Bytes
Remaining Lifetime	2
LSP ID	8
Sequence Number	4
Checksum	2
... ...	
Remaining Lifetime	2
LSP ID	8
Sequence Number	4
Checksum	2

6. Hierarchical NLSP

This section describes Hierarchical NLSP which will provide for flexible and scalable topologies. Hierarchical NLSP comprises of:

- ***Route Aggregation*** allows for lists of address summaries, so that a router can report, with a small amount of information, many IPX network numbers.
- ***Information Leakage*** is the ability to pass information learned from one NLSP area into another NLSP area.

6.1. Route Aggregation

An aggregated route is simply a method of compactly describing many IPX network numbers simultaneously. This is accomplished by adding an option to a LSP that gives a quantity (masklength, net), where "net" is a 4 byte IPX network number and a "masklength" is a 1 byte quantity that gives the length, in bits, of the portion of the network number common to all the summarized addresses. For example, (16, C5 1F 00 00) is the set of all IPX network numbers with the first two bytes equal to C51F*.

6.1.1 Target Topology

The common topology this will support is to have some backbone network and various NLSP areas hanging off of it.

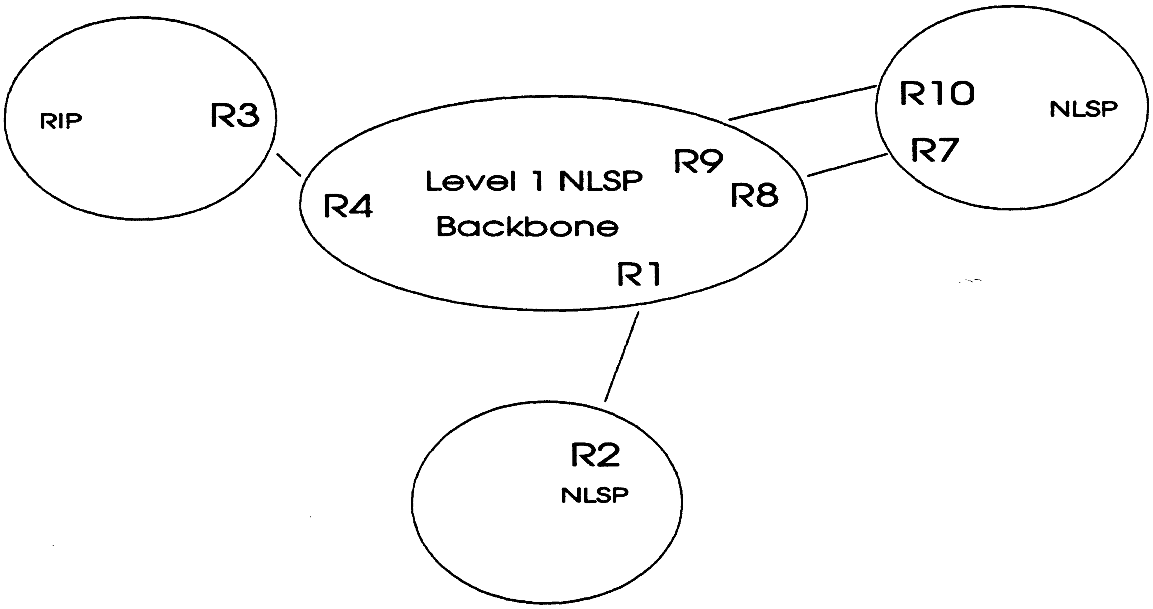


Figure 6-1: Aggregated Routes Topology

In figure 6-1, information inside the backbone is minimized by having R4, R1, R9 and R8 each reporting address summaries for the attached NLSP areas. Information inside the attached networks is minimized because the only information that needs to be transmitted inside is a default route, (-2 Network into RIP clouds or a Level 2 route into NLSP.

6.1.2 Route Aggregation Option

An aggregated route is represented by a 1 byte mask length and a 4 byte IPX address prefix. The mask length defines a number of bits (between 0 and 32) that is significant in determining the portion of the 4 byte IPX address prefix common to all summarized addresses. The mask is created by having the number of 32 bits in the length filled with 1s starting from the most significant bit. The longer the length the fewer addresses are in the range. The purpose of an aggregated route is to be able to report reachability of many network numbers in a compact fashion. The option to a LSP for route aggregation is as follows:

- Route Aggregation: Variable length structure compactly describing many IPX network numbers simultaneously.

  Code = 0xC6. Length = 8 x n; n > 0. Total length in bytes of the value field which is variable length.

  Value = A list of route summaries. Each entry has the following four sub fields.

  - Length of Mask: A 1 byte value that gives the length, in bits, of the portion of the network number common to all summarized addresses.
  - Aggregated Route: a 4 byte IPX network number representing the aggregate route.
  - Ticks: The ticks associated with reaching this aggregated route. The minimum value is equal to the number of ticks for the link from which you aggregate the route on.
  - Area Count: The number of areas that this aggregated route can be leaked to. Default is 6.

Route Aggregation	Number of Bytes
Length of Mask	1
Aggregated Route	4
Ticks	2
Area Count	1
... ...	
Length of Mask	1
Aggregated Route	4
Ticks	2
Area Count	1

6.1.3 Introducing Aggregated Routes

Aggregated routes are introduced into NLSP just like external routes. There are two methods of introducing aggregated routes into NLSP:

- Aggregated routes are introduced through static configurations.

  If an aggregated route is configured for a static link, a link over which routing is done merely by configured static routes, the configured aggregated route is reported into the NLSP cloud as soon as the link is up.

- Aggregated routes are learned from RIP/NLSP.

An address summary can be configured for a link, but unless at least one address matches that address summary, as learned through RIP/NLSP, that summary is not reported.

For example, on a link running RIP, R1 might be configured with the address summaries 572* and 5279*. If R1 learns from that link that destination is 57285489 is reachable, and no other matching destinations are learned, then R1 reports the aggregated route 572* in its LSP in the NLSP cloud. If R1 learns from that link that destination 57298381 is reachable, then R1 will report both 5729* and 572*.

An address summary is configured together with filtering information. To configure an address summary, you need to specify the summary itself (a 4 byte number and a mask length), and you need to specify the addresses filtered as a result of the summary. The usual case would be that the addresses filtered would be the same as the summary. For example, "don't report anything of the form 572*. Instead report just the aggregated route 572*." It should be possible to configure exceptions. For example, "don't report anything of the form '*' except for things of the form '85*'. Instead just report the aggregated route '*'. The result of that configuration would be that only addresses of the form 85* would get passed, in addition to the summary '*'. If the configuration were "don't report anything of the form '*', just report the summaries '*' and '85*', then both summaries * and 85* would get reported.

6.1.4 Mixing Old and New Routers

The term "new routers" refers to routers which support route aggregation. Consequently the term "old routers" refers to routers which do not support route aggregation.

Route aggregation into an NLSP area can only be done if all the routers in that area support address summaries. Routers that support route aggregation will transmit the minor version number as 2 in their LSPs. If a router R1 is configured to inject an address summary into the area, and there is any reachable LSP in that area with the minor version number set to 1, then the router will generate an error trap.

Mixing old routers and new routers is not a problem unless an aggregated route is introduced into the area. New routers will route to the router that has introduced the aggregated route. Old routers, since they will not recognize the destination address, will either drop the packet (if no level 2 router is advertising itself in the area), or route to the router advertising itself as a level 2 router. Since different routers would be routing in different directions, routing loops could occur.

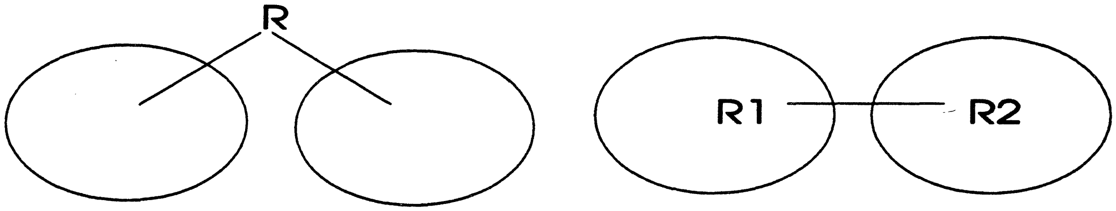
To maximize usability in this situation, if a new router detects that the next hop router on the path to an aggregated destination is an old router, it will drop the packet.

6.1.5 Interaction With SAP

Refer to Chapter 9 "Default Route".

6.3. Information Leakage between Clouds

There are two methods of interconnecting two NLSP clouds. One is through a router that is directly connected to both clouds, i.e., it has a port in each cloud. The other is by having router R1 in one cloud, R2 in the other, and having a link between them.



R connected to both clouds R1 and R2 connected

Figure 6-2: Information Leakage between clouds

The first case is really identical to having one of the clouds being a RIP cloud. R learns information in two different clouds. R is running two routing protocols. It should make no difference whether one is RIP and one is NLSP, or if R is running two instances of NLSP.

In this case, R is configured with filtering information as to what should pass from one cloud to another. For aggregated routes, the filtering information should be enhanced with route summaries ("don't pass routes of the form XXX. Inject the following route summary if anything matches this summary"). The default should be that the area addresses for each cloud are the address summaries that should be passed between the two areas, and any addresses not subsumed by those summaries should also be passed through. Area address is derived as a union of configured (manual) plus computed area addresses. The default can be overridden by configuring the router not to pass certain routes, or to have different address summaries.

The second case can actually be thought of as three clouds, and then it becomes the same as the other case. There's the NLSP cloud in which R1 resides, the NLSP cloud in which R2 resides, and another NLSP cloud which consists only of R1, R2, and the point-to-point link between them. The only LSPs that will appear on that cloud are R1's LSP, that summarizes the information learned in the left NLSP cloud, and R2's LSP, that summarizes the information R2 has learned in the right NLSP cloud.

If a router R advertises a summary of, say, 72*, then R must add an entry for 72* in its forwarding table indicating "drop". In other words, if R receives a packet for a destination for which the most explicit match is 72* (a summary R is advertising), then R needs to drop the packet, since R itself is where the network will forward packets to that destination.

Rules for a router R with links in multiple areas, say A and B, are:

- As a default, for each of A's area addresses, if at least one address matching that area address is reachable within A, advertise that area address as a summary into B. This need not be an individually advertised address. It might be an address summary equal to or more specific than that area address. Also, filter all addresses subsumed by that area address. Do the same for B's area addresses in terms of filtering and advertising those as summaries into A.

- If R is configured with any summaries, advertise those as well, though for each one make sure that at least one address (or more or equally specific address summary) is reachable.
- By default, any addresses or learned summaries not subsumed by area addresses or configured summaries are also advertised. A configurable flag allows this behavior to be reversed on a per-area basis. In other words, R can be configured not to advertise exception addresses (those not subsumed by A's area addresses or the summaries B has been configured to advertise).

6.3.1 Metrics

If R is configured to introduce an address summary into an NLSP cloud, it does so, with ticks equal to 1 (as default), and "area-count" equal to 6 (as default) with the ability to configure a different value into area-count and/or ticks. The "area-count" is the number of areas through which the information is allowed to propagate, and is counted down. This allows the first router to control the spread of the information.

Address summaries are not exported out of an NLSP area into a RIP cloud, since there is no way to express a summarized route within RIP and it is not worth updating RIP to do this, since default route will probably work for enough topologies with RIP.

Address summaries may be carried from one NLSP cloud to another by a router that resides in both clouds. For example:

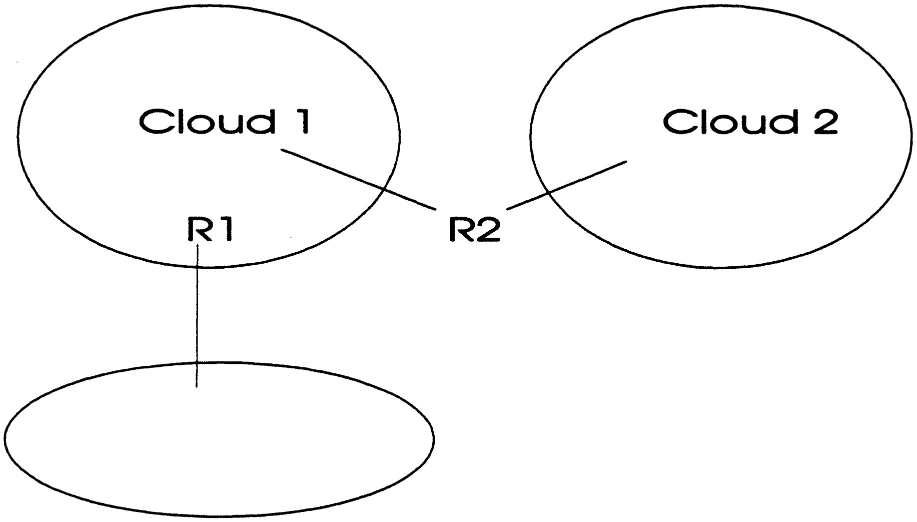


Figure 6-3: Importing from one NLSP cloud to another

Assume R1 has introduced an aggregated route into cloud1. R2 learns of the aggregated route through R1's LSP. Assuming R2 is not configured to filter out that information, or subsume it into a more inclusive address summary, R2 exports the address summary from cloud1 to cloud2. R2 adds the ticks to router R1 to the ticks in the address summary and reports that total as the new tick value. R2 also decrements the "area-count". If more than one router in cloud1 announces the address summary in their LSPs within cloud1, then R2 reports the minimum ticks to that address summary. If ticks are tied, break the tie by choosing the router with the least NLSP cost to that address summary. If there is still a tie, apply the order of preference of routes listed in section 7, with (optional) load-splitting.

Very similarly, address summaries can be exported over a point to point link connecting two NLSP areas by considering the point to point link and the two routers as a separate area.

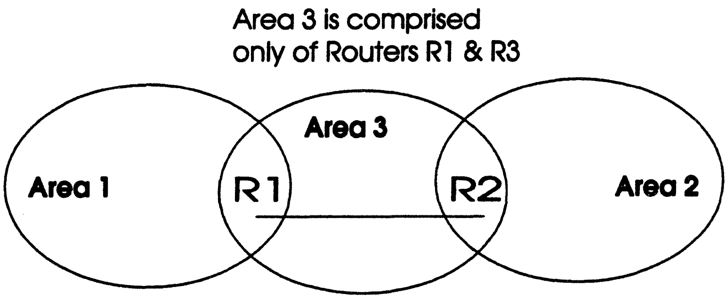


Figure 6-4: Address summaries exported between two NLSP areas

In this case, R1 is configured so that the port to R2 is area 3, and it exports the address summaries learned in R1 into "area 3". Likewise, R2 accepts routes learned from "area 3" and injects them into area 2. Whenever taking route information from one area and importing it into another, the ticks increases and the area-count decreases, unless the information is subsumed into a more inclusive summary.

For example, R1 learns of the route summary 53* in area 1, and is configured to report the address summary 5* into "area 3". Then it will report 5* with ticks of 1 (and the configured value for area-count, or 6 as default) (not the sum of the learned ticks to 53* plus the cost to the reporting router, for ticks and a decremented value of area-count).

The rules for a router R that has a port in area 1 and a port in area 2 are as follows:

- for each destination network number learned in area 1, report it as an "external route" in area 2, with total computed path ticks and hops, except as filtering rules into area 2 or out of area 1 disallow. "Learned in the area" means that some other router in that area has reported it in its LSP, (either directly or as an "external route") or that R has been configured with that address as the address of one of its directly connected ports. Specifically, "learned in area 1" does NOT include addresses imported by R from the area information on a different port.

- for each address summary learned in area 1, report it, with total computed ticks, and area-count decremented, in the LSP R generates in area 2 except as filtering rules into area 2 or out of area 1 disallow. Just like in the previous bullet, this information is only for information that was specifically learned in area 1, NOT information imported by R from an area that R is attached to on a different port.

- for each address summary R is manually configured to report into area 2, report it in the LSP R generates in area 2 with ticks of 1 and area-count of 6 (as default, unless a different value is configured). The address summary must actually represent some reachable addresses. Address summaries are configured as part of filtering information. R is told, "don't explicitly export destinations of the form X, rather summarize them with address summary Y (where X usually would equal Y).

The tick value of an address summary is guaranteed to increase and the area-count is guaranteed to decrease as it is passed from cloud to cloud, or the summary gets more inclusive (smaller number of bits in mask length). This guarantees that, if a summary ceases to exist, normal distance vector routing behavior will eventually purge it.

Address summaries are an enhancement to filtering. A router can be configured with addresses it should filter when summarizing out of an area, or into an area. Ordinary filtering rules would say something like, "do not report addresses of the form 5.*. With address summaries, the filtering might be configured as "do not report addresses of the form 5.*, and instead report the single summary 5.*. In such a case, 5.* is only reported if at least one address (or address summary) that matches 5.* is reachable.

6.3.2 Area IDs

Area IDs option for LSPs ??? (TBD)

This was discussed in IPX Forum.

7. Decision Process

The Link State protocol allows each router to construct a graph representing the routing area. The vertices of the graph are the nodes and pseudonodes—one for every LSP series. The arcs of the graph are the links between (pseudo)nodes. They are reported in the Link Information fields of LSPs. The Decision Process operates on this graph. It uses Dijkstra's algorithm to produce the Forwarding database. For each IPX™ network number in the Link State database, the Forwarding database indicates the next hop from this router toward that destination network number. The network numbers are in the LSPs—and consequently attached to nodes of the link state graph—in the Management Information field and the External Routes field.

The Decision Process is also responsible for determining equal cost paths, computing the throughput and delay characteristics of the end-to-end path, and calculating the RIP delay (Ticks) to report to RIP routers and to end nodes.

7.1. Running the Decision Process

The Decision Process runs when a change occurs to the Link State database. It is not run immediately, but rather the router waits for five seconds after detecting the change. This allows several changes clustered in time to be dealt with at once.

Implementations should ensure that the Link State database is not modified while the Decision Process is running. There is more than one way to accomplish this, and the approach chosen is influenced by the operating environment surrounding the routing software.

One approach is for the Decision Process to signal when it is running. During this time, incoming LSPs are queued but not inserted in the Link State database. If more LSPs arrive than can fit in the space allotted for the queue, the router drops any excess LSPs without acknowledging them; that is, without including their sequence numbers in any SNPs transmitted.

A second approach is to use two copies of the Link State database. When the Decision Process starts, it takes a snapshot copy of the database, keeping the snapshot static until completion of the process. Meanwhile, updates continue to be incorporated into the dynamic copy. If there is a separate memory area for each copy, the areas can alternate between the static and dynamic roles.

The first approach uses less memory, but the second approach avoids dropping incoming LSPs.

Once started, an execution of the Decision Process should not be abandoned due to new information arriving. To do so could lead to starvation; the process might never be run to completion. If an event occurs that would change the Link State database while the Decision Process is running, the five-second timer restarts when the Decision Process is completed.

7.2. Dijkstra's Algorithm in Pseudocode

The description of Dijkstra's algorithm in Section 2 is intended to appeal to your graphical intuition. Here is another description of the same algorithm, more akin to pseudocode.

```
START:
   Keep a list containing all "unplaced" nodes, and associate a cost with
   each.
   Start with all nodes in the unplaced list.
   Set the cost of all nodes to infinite except the local node, which is set
   to 0.

   Keep a list of nodes that are already in the "shortest path" spanning tree.
   (This is the Known Set of the description in Section 2.)
   This set starts empty.

NEXT_NODE:
   Select a node in the unplaced list with lowest cost that is not infinite.
   Remove the selected node from the unplaced list and add it to the shortest-
   path list.
   If there is no such node, the algorithm is complete and all nodes remaining
   in the unplaced list are unreachable.
   In the unplaced list, update the costs of all nodes adjacent to the node
   just removed. The new cost is the minimum of
           (a) the previous cost of the adjacent node, and
           (b) the sum of
                (i) the cost of the node just removed, and
                (ii) the link cost of the adjacency.
   goto NEXT_NODE
```

For example, at Step 6 in Section 2.1.7, the unplaced list looks like this, after removing V from the list:

S	40
C	50
W	infinite

Because S has the lowest cost, it is next to be removed.

When there is a tie comparing costs, additional criteria are applied, in a specified order, until the tie is broken. The list of criteria is called the *order of preference of routes.*

(a) End-to-end path with the lowest cost

(b) End-to-end path providing the highest net Throughput

(c) End-to-end path providing the lowest total Delay

(d) End-to-end path supporting the largest MTU size

(e) First Hop node with the Lowest System ID

(f) Circuit with the lowest localCircuitID on the local router

(g) Neighbor with the lowest LAN MAC address on the remote router

The MTU Size, Delay, and Throughput are in the Link Information of LSPs. System IDs are assigned by an administrator to each router; circuit IDs are assigned by router software. The reason for these criteria are (a) to provide the best routes, and (b) to provide deterministic routes (for reproducibility in problem resolution).

7.3. Load-splitting

The NLSP™ specification supports load-splitting. That is, if there are equal cost paths, the traffic can be divided among them to make fuller use of the internetwork.

First, define a *maximal splitting degree*. This is a number, MSD, assigned by the network administrator. It can be different for different routers. If there are equal cost paths, MSD is an upper limit on the number used for routing. If MSD=1, the router does not do load-splitting. Load-splitting focuses on the step in Dijkstra's algorithm where you choose which node to add to the known set.

In case of a tie in cost to the same far node, the Forwarding database has more than one entry added to it, instead of just one. How many? If the tie is among *m* links, the number of entries added is the smaller of *m* and MSD. If *m* is greater than MSD, the choice of which to add is based on the order of preference of routes listed on page 7-2.

Figure 7-1 shows examples of rules (e), (f), and (g). (There are no parts (a)-(d) in the figure.) In each example, the links are of equal cost, and MSD is two.

Part (e) shows the system IDs of the routers (single-digit for brevity). When router #4 adds #8 to the Known Set, it uses the two links to #5 and #6, omitting the link to #7.

In part (f), the localCircuitIDs are shown. When router P adds Q to the known set, it uses links #1 and #2, but not #3.

Part (g) shows two routers connected by two LANs, with S having three connections to one of the LANs. (The MAC addresses are shown as single-digit numbers for brevity.) When router R adds S to the known set, it chooses S's two lowest-numbered MAC addresses, 7 and 8.

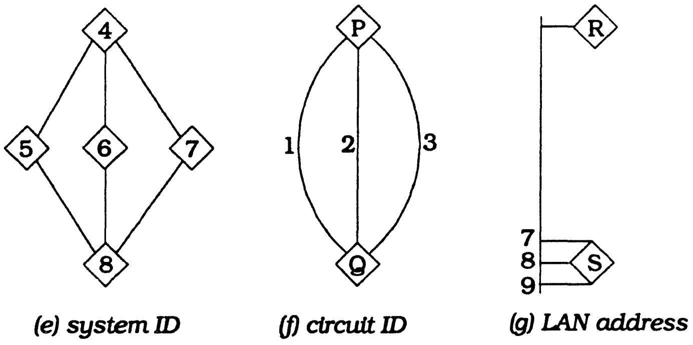


Figure 7-1: Load-splitting

Finally, when comparing the number of links with MSD, count the number of nodes traversed, not the number of partial paths. Figure 7-2 illustrates this point. When A adds D to the Known Set, it considers the number of paths to D to be two. So it splits the A-to-D load between B and C. For the B part of that, it has already decided to split traffic between the two links.

There is an alternative acceptable implementation. Instead of focusing on the node being added, look at the set of next-hop adjacencies and prune these to, at most, MSD. With this approach, node A in Figure 7-2 splits traffic destined to D two ways rather than three.

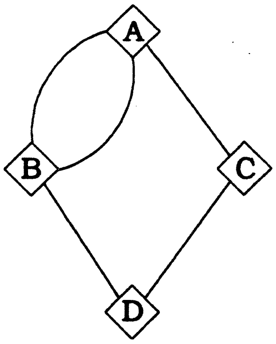


Figure 7-2: Count Nodes, Not Links

7.4. Information Used and Not Used

The Decision Process makes a special provision for an overloaded router; that is, for a router in the area having the LSP database overload bit set in its LSP number zero. Data traffic whose final destination is in the overloaded system itself is delivered to that system. (This leaves the door open for management action to diagnose the problem and perhaps even to reconfigure things and extricate the router from its predicament.) However, data traffic is not routed through an overloaded router to any other system—not to other routers and not to end nodes.

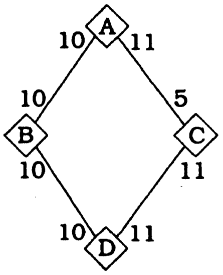
A system can indicate in its LSP that it is a multihomed nonrouting server. Such a server is attached to more than one network segment, but does not forward data traffic from one segment to another. However, it does participate with routers in NLSP exchanges to advertise its services and its internal network number. It also runs the decision process, so it can determine on which network segment to transmit outgoing data packets it originates. When a system running the decision process detects the LSP of a multihomed nonrouting server, it treats that server like an overloaded router. Data traffic whose final destination is in the server itself is delivered to that system. However, data traffic is not routed through that system to any other system.

Implementing this provision involves the step in Dijkstra's algorithm where a node is added to the shortest-path list. At this step, the router checks whether the node being added is overloaded. If so, it adds it anyway, as usual, but after that point all outgoing links from the overloaded router are disregarded for the remainder of the Decision Process.

The Decision Process does not use a link between two routers unless each router reports a link to the other router.

Note: There is no way to determine that the links reported by the two routers are the same link. This is not a problem. Data traffic is still forwarded over the (possibly asymmetric) paths.

It is possible for the two routers to report different costs for the link. In this case, routes might be asymmetric. Figure 7-3 shows an example.



Numbers shown are link costs reported by the nearby router.

Note that A and C report different values for the same link.

The consequence is that traffic from A to D goes through B, while traffic from D to A goes through C. The total cost from A to D is 20; for D to A, the total cost is 16.

Figure 7-3: Example of an Asymmetric Route.

The IPX network numbers in the routing area are accumulated from the Management Information and External Route options of LSPs in the Link State database. It is possible that a network number is accessible both through NLSP and through RIP. That is, it appears in the Management Information option of one LSP and the External Route option of another. The Decision Process ignores the external route in this case.

7.5. Products of the Decision Process

The Forwarding database consists of a set of pairs (network number, next hop). The next hop indicates on which circuit, and to which neighbor on that circuit, traffic to the network number should be immediately forwarded by this router. If load-splitting applies (page 7-3), there might be more than one next hop for a network number.

In certain cases (for example, LSP database overload, or a recent network partition), some network numbers might be known but unreachable.

If the Decision Process determines that certain nodes are unreachable, the router still keeps the associated LSPs in the Link State database. They persist until the LSP to which they refer expires or is deleted. The reason is that links can disappear and then reappear soon. Because a link can provide reachability to a large number of networks, it is inadvisable to delete them all only to re-create them soon after.

7.6. Routing in the Face of a LAN Partition

While running the Decision Process, a router might discover two Designated Routers for the same IPX network number. Consider Figure 7-4. The LAN with IPX network number *N* can become partitioned if the MAC-level bridge fails. Routers *A*, *B*, and *C* all still consider the LAN to have IPX network number *N*. By the election process, both *A* and *B* could become Designated Routers for *N*.

For traffic whose final destination is network *N*, the routers *R*, *S*, and *T* have no way to know whether *A* or *B* is the route to choose. By default, they choose whichever is closer to them. Reaching the destination is problematic. There is not much that can be done to improve on this situation.

For other routing decisions, however, the situation is better in the face of this partition. Consider traffic from *R* destined for network *M*. By tracing the adjacencies, *R* readily determines that the path *R-S-B-C-T* will reach network *M*. Likewise, router *A* can reach network *M* by a circuitous path.

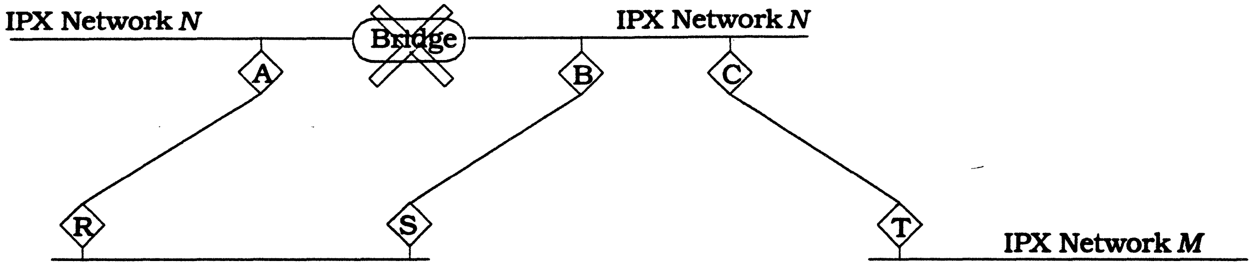


Figure 7-4: LAN Partition Example

Other hardware failure modes can cause partitions. Suppose, for example, that (instead of the bridge failing) the network interface connecting *B* to the LAN *N* were to fail. Again, both *A* and *B* could emerge as Designated Routers for *N*. But this time, *A* and C are adjacent, instead of *B* and C. *R* and *S* can route to anywhere through *A*. In addition, the *S-B* link is used from anywhere to reach SAP services residing on system B (because they are associated with *B*'s internal network number, not with network *N*).

7.7. Routing Outside the Routing Area

Although this specification encompasses Level 1 routing only, the Level 1 router must implement certain features to operate in an internetwork that includes both Level 1 and Level 2 routing.

7.7.1. Calculating the Actual Area Address

Each router reports its manualAreaAddresses in the Area Addresses option of its LSP number zero. The Decision Process collects these values. The collected list forms the set of synonymous area address values that define and delimit the routing area. The combination is called the actualAreaAddress.

Note: Level 1 routers from other areas can share circuits with routers of this area, but they fail to form adjacencies—an adjacency is formed only if the two routers have at least one manual area address in common. Consequently, LSPs from other routing areas do not appear in the Link State database.

Note: The collection of area addresses includes all systems in the Link State database, whether currently reachable or not. It also includes those in this router's own Level 1 LSP number zero.

If there are more than three area addresses in the collected list, the router retains three of them, as follows:

a) If the address parts are unequal, the lowest address is preferred.

b) Otherwise, the lowest mask is preferred.

For example, (0xC9000000,0xFF000000) is preferred over (0xC9000000, 0xFFFF0000).

If the preceding steps cause one of the router's own manualAreaAddresses to be dropped, the event manualAddressDroppedFromArea is generated. This is a means to detect misconfigurations.

Note: Implementors should document the following warning for the benefit of end users in administering networks based on NLSP.

> The multiple area address support is not intended to permit all routers that share an area address to form a single area automatically in all situations. The intention is that under typical circumstances, all routers within the area have identical sets of manual area addresses. The ability to form adjacencies to systems that only have a subset of manual area addresses in common is intended to allow area addresses to be added or removed from the set of the whole area in a graceful manner; for example, given a set of routers all with area addresses A and B, it is possible to add area address C to routers in the area one by one.
>
> The area is defined by the set of routers that are all connected by Level 1 adjacencies.
>
> There are circumstances where divergence from this rule causes problems. If a LAN has three routers with area addresses A, AB, and B, then adjacencies are formed A-AB and AB-B, but not A-B. If the Designated Router priorities of A and B are higher than AB, then both A and B are elected Designated Router for the LAN, with the consequence that two sets of pseudonode LSPs are generated for the LAN. This does not compromise reachability, but if the LSPs are large (for example, if there are a large number of routers on the LAN), it is possible that the memory limits of routers in the area are exceeded, causing them to go into the overloaded state.

7.7.2. Routing to an Exit Router

The key to relaying data traffic to destinations outside the routing area is to locate the nearest *Exit Router*. An Exit Router could be either

- A Level 2 NLSP router

Or

- A router that attaches this area to other networks using a different method.

Either way, an Exit Router is recognized by examining the Attached Flag and Router Type fields in the LSPs of the Level 1 Link State database. An Exit Router has the Attached Flag set to "Yes" and the Router Type set to "Level 1 and Level 2 Router." These flags are significant only in a router's LSP number zero.

The Decision Process determines the Exit Router whose NLSP cost is smallest. Figure 7-5 illustrates an example of an Exit Router, E. Its Attached Flag is set to indicate that it can reach outside the routing area. It also is a Level 1 router, and, for example, conveys traffic from A to D as necessary. The links to the right of E are not in the Link State database. Exactly how E routes outside the area is not part of the NLSP specification. It could be by NLSP Level 2 routing, or it could use a different method.

Load-splitting can be applied, as with other routes. The router chooses one Exit Router and splits the load between paths to that router. (As an implementation option, a router can split the load between two or more equally distant Exit Routers.)

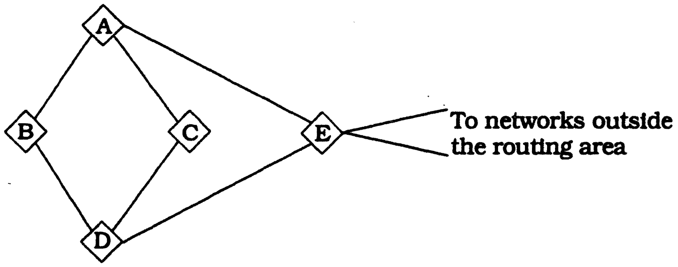


Figure 7-5: Exit Router Example

7.7.3. Forwarding Data Packets

When the router forwards an IPX data packet, it proceeds as follows:

a) Look up the route in the Level 1 Forwarding database. If found, use the information to identify the corresponding next hop.

b) If not found, forward the packet to the nearest Exit Router (do not check whether the destination is in the area).

Note: Lack of the destination check means that some packets destined inside the area might be sent to the Exit Router unnecessarily. However, checking for each packet would be a performance burden.

c) If in the preceding step there is no Exit Router accessible, discard the packet and generate an ipxOutNoRoutes event.

7.8. Decision Process Database

7.8.1. Configured Values

MSD

Maximal Splitting Degree: the maximum number of equal-cost paths the router uses to any one destination. Default is 1; no splitting.

7.8.2. Dynamic Values

actualAreaAddress

The collected manualAreaAddresses of the routers in the routing area. The combined set of up to three synonymous area addresses identifies the routing area.

7.8.3. NLSP Events

manualAddressDroppedFromArea

More than three manualAreaAddresses were detected in the area, and this router dropped one of its own when forming the actualAreaAddress.

ipxOutNoRoutes

An IPX packet could not be forwarded because the destination network number is unreachable and there is no reachable Exit Router.

8. RIP and SAP

RIP is the traditional routing protocol used with the IPX™ protocol. Like IPX itself, RIP is derived from the Xerox Network System specifications. SAP is a protocol used with IPX for a server to advertise availability of a service, and for clients to find that service (that is, to determine its IPX network address). Both use a broadcast mechanism. The two are usually implemented together.

As described in Section 2, the NLSP™ specification includes RIP/SAP as its end node/router protocol. End nodes include

a) Clients that want to find services and routes

b) Servers that want to advertise their existence using SAP, and to find routes

This part of RIP/SAP support is an indispensable part of NLSP operation. It must always be active for all circuits. It includes

- Responding to RIP requests for route information
- Responding to SAP requests for service information
- Absorbing SAP information about services that reside on the same system as the router

The router-to-router part of RIP/SAP support is also included in the NLSP design, so that customers can deploy NLSP routers in the same internetwork with RIP routers. It includes

- Absorbing RIP broadcasts from RIP routers
- Absorbing SAP broadcasts transmitted by servers
- Generating RIP and SAP broadcasts for consumption by RIP routers and NetWare® servers

The compatibility part of RIP support is operational conditionally, on a per-circuit basis. The end user chooses between three alternatives, for each router attached to each link:

a) "On"..... cause RIP packets to be generated and absorbed on the link.

b) "Off"..... inhibit RIP from being generated or absorbed on the link.

c) "Auto".. If a RIP router is detected on the link, generate and absorb RIP packets; otherwise, don't.

The default choice is "Auto."

The basic idea of "Auto" mode is

- Run RIP on a circuit where there are non-NLSP routers, but
- Deactivate RIP once all routers are running NLSP, except to respond to client (workstation) requests.

If an "Auto" circuit has RIP deactivated, receipt of certain RIP packets reactivates RIP (see page 8-14). In the absence of these packets, RIP is deactivated after (ripUpdate × ripAgeMultiplier).

Likewise, the compatibility part of SAP support is operational only conditionally, on a per-circuit basis. Its activation or deactivation is independent of RIP's. The end user chooses between the same three alternatives, with the same "Auto" default. If an "Auto" circuit has SAP deactivated, receipt of certain SAP packets reactivates SAP. In the absence of these packets, SAP is deactivated after (sapUpdate × sapAgeMultiplier).

The remainder of this chapter should be read in conjunction with Reference [Nov92].

In the diagrams of this section, square-shaped symbols represent RIP routers. Diamond-shaped symbols continue to represent NLSP routers, including their RIP/SAP-emulation roles.

8.1. Maintaining RIP and SAP Information

NLSP routers keep track of specific information to fulfill their RIP/SAP compatibility requirements.

8.1.1. XRoutes and Services Defined

RIP information consists of *external routes*, abbreviated *XRoutes* in this chapter. Each XRoute summarizes the distance to a particular IPX network from the router reporting the XRoute. Specifically, each XRoute contains the following values:

- Network Number: The IPX network number to which this XRoute refers.
- Hops: The number of hops to reach that network. Each router traversed is counted as one hop.
- RIP Delay, or Ticks: The number of RIP timer ticks to reach that network. There are 18.21 ticks per second. The value is the time to deliver a 576-byte packet one way.

Each RIP packet sent or received conveys information about routes. When an NLSP router receives a RIP packet, the route information from the packet is absorbed into the Link State database as XRoutes, subject to the procedures specified in this chapter. When an NLSP router sends a RIP packet, it reports not only XRoutes, but also routes reachable by NLSP: the network numbers of routers and pseudonodes in the Link State database.

SAP information consists of *Services*. Each Service identifies a potentially reachable application service that is accessible using the IPX Network layer protocol. Each Service record contains the following values:

- Service Name: The name of the service. This is a text string up to 47 bytes. It identifies the service uniquely in the internetwork. Routers need not be concerned with the naming conventions.
- Service Type: The type of service offered. Novell assigns these values; for example, NetWare servers use the value 4. See Reference [Nov92] for a (partial) list of defined types and the contact point for registering new service types. Routers need not be concerned with the semantics of the Service Type value.
- IPX Network-Layer Address. The address at which the service resides.
- Hops: The number of hops to reach that service. Each router traversed is counted as one hop.

The Name/Type combination identifies a service. There can be several distinct Services having the same Name if their Types are different. If a Service appears with the same Name/Type combination as one previously known but at a different Address, it is an indication that the Service has changed location.

Each SAP packet sent or received is, in essence, a list of zero or more Services. The router does not transmit a SAP reporting a Service unless that router has a route to the network number on which the service resides.

8.1.2. Relation to Link State Database of Receiving RIP/SAP

RIP routes are absorbed by NLSP routers as they receive RIP packets from other RIP routers on directly connected networks. Those RIP routes that are kept as XRoutes are included in the pseudonode LSPs for the network on which they were received.

On each LAN, one of the NLSP routers is the Designated Router, chosen by a dynamic election procedure. The Designated Router for the LAN maintains the pseudonode LSP. The Designated Router is responsible for flooding the pseudonode LSP to the other NLSP routers on behalf of that network segment. Only the Designated Router propagates received RIP information in LSPs. Other NLSP routers on the network also retain received RIP information, maintaining a *potential pseudonode*. The potential pseudonode is information that a router keeps in anticipation of possibly becoming the Designated Router and being required to produce an actual pseudonode.

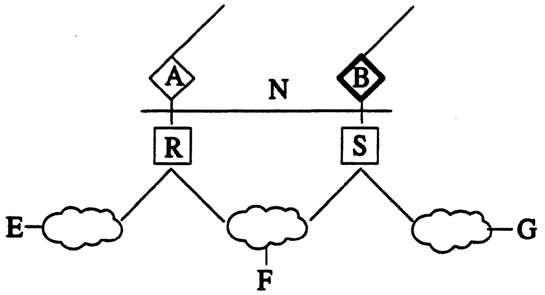
For each WAN circuit connecting an NLSP router with a RIP router, the NLSP router has the Designated Router responsibilities.

A router can be maintaining more than one pseudonode (or potential pseudonode)—different ones for different directly connected circuits.

After determining that a RIP route received is not already reachable as an NLSP destination, the router must determine whether to keep that route as an XRoute in the pseudonode (or potential pseudonode) for that circuit. The router only absorbs an XRoute if it is the best XRoute (or tied for best) known in the area. The criteria for deciding the best is to consider ticks first. In case of a tie consider the hops. Only the ticks and hops reported by RIP are considered; the NLSP portion of the path is ignored for this purpose. If another router later advertises the same network number in a better XRoute, delete the local XRoute. Likewise, delete it if the network number becomes reachable as an NLSP route. A result of these rules is that any particular XRoute is advertised by, at most, one NLSP router in an area (except during a transitional period). Ties are an exception. If both ticks and hops are tied, there can be several routers in an area reporting the same XRoute.

XRoutes are not constrained by area addresses. When a router receiving a RIP packet absorbs a network number into a pseudonode (or potential pseudonode) LSP as an XRoute, it does not compare that network number with the router's own manualAreaAddresses. Neither does it compare the network number with other area addresses in the routing area.

Other NLSP routers—those not acting as Designated Routers—also gather the RIP information, even though they do not propagate the information in LSPs they originate. First, they do so to be prepared to become the Designated Router should the need arise by failure or resignation of the current Designated Router. Second, the RIP packets are needed for the immediate address to use when forwarding data packets destined for the network number reported in the RIP packet. The XRoute in the pseudonode LSP does not contain the immediate address, so information from directly received RIP packets is indispensable. (Data packets are not forwarded to the Designated Router to be forwarded over the same LAN again.) Consider Figure 8-1. Network numbers E, F, and G are all attached to the pseudonode for N, which is generated by Designated Router B. However, the pseudonode does not indicate which of the RIP routers (R or S) provides access to each of the three network numbers. So when A receives data traffic from its WAN link destined for E, for example, the pseudonode itself does not contain enough information to forward that traffic. To supplement the pseudonode, A keeps information it receives by RIP over the LAN. Specifically, it records that R is the path to E, that S is the path to G, and whichever of R and S is the better path to F.



A and B are NLSP routers.
B is Designated Router for N.

R and S are RIP routers.
R reports a route to networks E and F.
S reports a route to networks F and G.

Figure 8-1: Routing between NLSP and RIP

When an NLSP router is connected by a WAN circuit to a RIP router, the NLSP router constructs a WAN pseudonode (numbered or unnumbered) for the circuit and acts as the WAN Designated Router for that pseudonode. There is no election procedure. RIP and SAP packets it receives over the circuit are advertised as XRoutes and Services in the pseudonode LSP.

Incoming RIP packets from NLSP routers are ignored. Those packets are presumed to have been sent for backward compatibility. An NLSP router is recognized by its data-link address matching that of a router for which an NLSP adjacency exists in either the "Up" or the "Initializing" state.

From the Link State database, each router builds an exactly matching Link State graph, which includes the XRoutes. Each XRoute has forwarding information (hops and ticks) relative to the network where its existence was discovered. For a WAN pseudonode, the Designated Router assigns the NLSP Delay to be 15 milliseconds and the NLSP Throughput is calculated from the measurements of the Timer Request/Response exchange in Section 3:

```
start_time = time when Timer Request packet is sent, 1/18 second

end_time = time that matching Timer Response packet is received, 1/18 second

Throughput = 8 × 1,000 × 576 /
                  [ { 55 × MAX ( 1, end_time - start_time) / 2 } - 15 ]
```

SAP packets and Services are like RIP packets and XRoutes. Received SAP packets report network Services that are absorbed into Services Information options of pseudonode LSPs, flooded, and kept synchronized. The rules for absorbing SAPs are the same as for RIP: ~~check the network number against manualAreaAddresses, and~~ check that the sender is not an NLSP router. Each Service has forwarding information (hops) relative to the network where its existence was discovered.

A system that is Designated Router on two circuits need only accept SAP packets received on one of them. However, if a system connected to two circuits is Designated Router for the first but not the second, it must accept SAP packets received on the first. Otherwise, a SAP might fail to be included in any LSP.

8.1.3. Relation to Link State Database of Sending RIP/SAP

When sending RIP and SAP packets on a LAN, a router's behavior is the same whether or not it is the Designated Router for the LAN.

RIP routers include in the ticks value the cost of the network onto which they are broadcasting a RIP packet. This value is included in LSPs. This must be taken into account when reporting ticks in outgoing RIP packets: the value must be adjusted back to duplicating that portion in the report. For example, consider Figure 8-2. When RIP router C reports about LAN P by broadcasting a RIP packet on LAN M, it reports two ticks: one for P and one for M. The pseudonode LSP for M includes an XRoute for P showing two ticks. Then, when NLSP router B broadcasts a RIP on LAN N describing P, it reports three ticks, not four. The three includes provision for N itself.

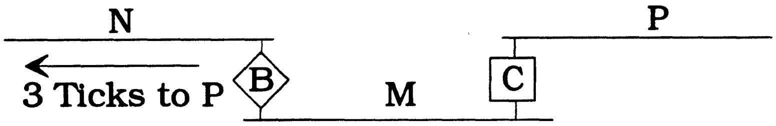


Figure 8-2: Adjusting the Ticks in RIP

There is an additional provision for the internal network numbers of routers (either RIP or NLSP). An additional tick is added to traverse the (conceptual) gap from the router entity within the system to the internal network number within the same system. There is no corresponding additional hop. An internal network number is considered to be 1 tick and 0 hops away from the router entity within the same system. In Figure 8-3, suppose NLSP router A has internal network number AA, NLSP router B has internal network number BB, and RIP router R has internal network number RR. When A sends a RIP on LAN N advertising AA, it reports 1 hop and 2 ticks. When it sends a RIP on LAN N advertising BB, it reports 2 hops and 3 ticks. The 3 are as follows: one for the network being transmitted onto, one for the AB link, and one additional tick from router B to its internal network BB. When A sends a RIP on LAN N advertising RR, it bases the ticks on the XRoute in the pseudonode representing LAN M. The tick value in the pseudonode is 2, and already contains the additional tick within R. So, A adds one for the AP link and one for N, making 4.

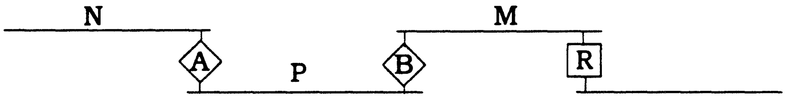


Figure 8-3: Additional Tick for Internal Networks

Counting hops is easier than dealing with ticks. The adjustments described for ticks do not apply. Each traversal of a router is one hop. The total hop count is reported in both RIP and SAP broadcasts. For example, when sending a SAP onto network N, router A reports 1 hop to a Service residing on its internal network AA, two hops to a Service on BB, three hops to a Service on network M, and three hops to a Service on network RR. In the latter case, the pseudonode for M shows one hop to a Service on RR, because R sends a SAP for the Service having hop count 1.

Each NLSP router continues to receive RIP/SAP broadcasts and to keep the information current in its local database, in its potential pseudonode. However, RIP/SAP broadcasts sent by the NLSP router are based on the XRoute information in the Link State graph built by the Decision Process. This means that RIP/SAP broadcasts by NLSP routers reflect only the Designated Router's view of that particular LAN. The broadcasts change in content only when the Designated Router detects a change. (By the Split Horizon rule described later, the broadcasts are being sent on a different LAN than the one where the information was learned.) In Figure 8-3, for example, suppose A is the Designated Router for LAN P. When B sends RIP/SAP information about P onto M, it uses information from the pseudonode built by A representing P; it does not use information from RIP/SAP packets B itself received over P (even though it absorbs that information for other purposes).

8.1.4. XRoutes, NLSP Routes, Services, and the Decision Process

The Decision Process constructs a Link State graph of the routing area. An *NLSP route* is a path in the Link State graph using only network numbers that appear in the Management Information field of LSPs. As will be seen in the following discussion, NLSP routes are preferred over other routes (which include External Route fields of LSPs).

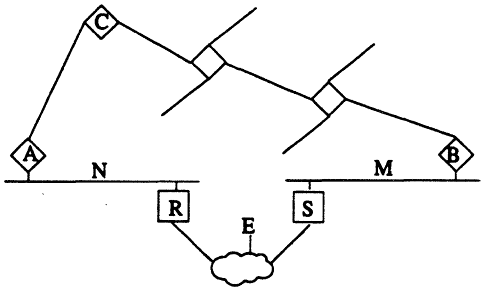
The Decision Process determines the best path for inclusion in the Forwarding database, based only on the ticks and hops reported in XRoutes known to the router. This means that only the portion of a packet's path in the RIP domain is taken into account. The NLSP portion of the path is ignored when choosing the best route. Consider Figure 8-4. Generally, only one route from C to E is in the Link State database (except for ties). In a transient situation, though, the pseudonodes for M and N might both contain XRoutes for E. When C determines its route to E, it compares

- The ticks and hops in the pseudonode for M

with

- The ticks and hops for E in the pseudonode for N.

Consider the ticks first. In case of a tie, consider the hops. Neither the path from C to A nor the path from C to B enters the decision to this point.



A, B, and C are NLSP routers.

R and S are RIP routers.
Both report paths to network E..

The pseudonodes of both network N
and network M report paths to E.

Figure 8-4: Multiple XRoutes for a Destination

If both ticks and hops are tied, break the tie by choosing the least NLSP cost. In Figure 8-4, this means comparing the NLSP path from C to A with the NLSP path from C to B. If there is still a tie, apply the order of preference of routes listed in section 76, with (optional) load-splitting.

Likewise, the router discovering SAP information determines the smallest hop count to that Service, for each network address at which it is accessible, for inclusion in the pseudonode (or potential pseudonode). As with RIP, a Service appears only once in an area, except for ties and for transient conditions.

When XRoute or Service information changes, the link state method propagates the information throughout the routing area. This implies updating the Forwarding database of each router accordingly. However, the computational burden is comparatively small. The Decision Process actually consists of two parts.

a) Run Dijkstra's algorithm to build the Link State graph and spanning tree. This includes determining the costs to every NLSP destination.

b) Determine the best costs of XRoutes, based on the spanning tree and the RIP costs reported at nodes of the tree.

XRoutes and Services are like leaf nodes connected to various LSP nodes of the Link State graph. So, when an XRoute or Service appears, disappears, or changes in ticks or hops, there is no structural change to the graph. A router performs only part b). Because there are no structural changes to the graph, there is no need to run Dijkstra's algorithm.

8.1.5. Building a RIP Route from the Link State Graph

When an NLSP router transmits a RIP packet, it must insert values for ticks and hops. It combines values from the NLSP area with values appearing in the XRoute.

As part of the Decision Process, each router maintains hop count and RIP Delay values for each Link State graph node's *upstream NLSP route*; that is, the route from itself to that node. Call this the *Upstream RIP Delay*. The value is the sum of individual RIP Delay values of the links the route traverses. For each link, the individual RIP Delay is calculated from the NLSP Delay and Throughput values. For a LAN, the calculation is

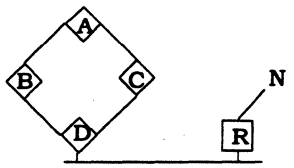
```
MAX [ 1, ( 576 × 8 × 18  / Throughput) + (Delay × 18  / 1,000,000 )]
```

For a WAN, the calculation is

```
MAX [ 1, ( 576 × 64 × 18 / Throughput) + (2 × Delay × 18 / 1,000,000 ) ]
```

Note: When receiving LSPs, calculate the ticks immediately from throughput and delay. Do not wait until the Decision Process. The chances are that the Decision Process is run several times before that particular LSP (with its throughput and delay) is received again. You might as well calculate only once and save the result. There is less computing burden overall, especially because multiplication and division are involved. Also, you want to limit the duration of the Decision Process, because input of new LSPs is deferred during that interval.

When summing the individual RIP Delay values, special attention is needed when load-splitting is in force. It can happen that several paths have equal NLSP costs—so load-splitting is applied—but with different RIP Delay values. In this case, apply the highest of the several RIP Delay values to the path. Figure 8-5 shows an example.



NLSP router A is load-splitting between B and C to reach D.

That is, AB+BD = AC+CD, with values in NLSP's cost.

The RIP Delay from A to D is MAX(AB+BD, AC+CD), where this time the values are the individual RIP Delays.

Figure 8-5: RIP Delay and Load-splitting

XRoutes maintain hop count and ticks that are relative to the LSP to which they are attached.

Using

a) The upstream RIP delays (defined previously) stored in the graph nodes

b) The values reported in XRoutes

this router can generate RIP route values to all reachable IPX networks, as follows:

- If a network is an internal route (that is, it appears in the graph as a non-XRoute), then
  a) Its RIP ticks value is the upstream RIP Delay
  b) Its RIP hop count is the number of links traversed by the downstream route (excluding WAN pseudonodes)
- If a network is an XRoute, then one starts with the downstream hop/tick values (as above) to the pseudonode where it is reported, and adds the respective hop/tick values reported in the External Routes field.

Likewise, the hops from this router to a Service is computed by adding

a) The number reported in the Services Information field

To

b) The number of graph links (excluding pseudonodes) to the pseudonode whose LSP includes the Services Information.

8.1.6. Aging XRoutes and Services

XRoutes and Services are aged in a way similar to the one RIP routers use to age entries.

An aging timer is applied to each XRoute and Service in the local potential and actual pseudonode LSPs maintained by this router. When a RIP Response arrives, each route reported has its timer reinitialized if it is already represented by an XRoute. Likewise for SAP and Services.

The interval at which RIP is activated for its periodic broadcast is ripUpdate. For SAP, the corresponding value is sapUpdate.

The aging timer after which a stale XRoute is purged from its pseudonode is ripAgeMultiplier × ripUpdate. The aging timer after which a stale Service is purged from its pseudonode is sapAgeMultiplier × sapUpdate.

If the timer expires, the XRoute or Service is removed from the LSP. If an XRoute is removed from a potential pseudonode LSP, all Services residing on that network number are also removed from that potential pseudonode LSP. If this router is the Designated Router for that LSP, this change in the pseudonode LSP results in removal of the XRoute from the Link State graph. This causes a triggered update to reflect the changes to the XRoutes. As with other triggered RIP/SAP updates, this causes routers to update their respective Forwarding databases, but does not require Dijkstra's algorithm to be run.

8.2. Generating Periodic Updates

If a router (or link) were to stop operation without warning, a way is required for other routers to discover the loss of connectivity. This is accomplished by periodically broadcasting current RIP/SAP information and aging any database entries not refreshed by received broadcasts.

All NLSP routers generate RIP periodic update broadcasts every ripUpdate for its connected links supporting RIP compatibility. The default is 60 seconds, but the interval is configurable on a per-link basis.

Note: The ability to configure the periodic broadcast interval and the timeout to age out RIP routes and SAP entries is a recent design, not supported by all installed systems. Older versions of IPX RIP/SAP routers use 60-second periodic timers and a four-minute timeout. All routers on any one network segment (LAN or WAN) must be configured with the same values.

The network numbers to report in these broadcasts are all the IPX network numbers that are reachable—link-state destinations (pseudonodes, internal networks) and XRoutes alike. In RIP, reporting a hop count of 16 means that the network is unreachable. Only destinations whose total hop count is less than 16 are reported in the periodic updates. (This is not affected by a possible configured node limit greater than 16.) When sending a RIP update reporting 16 hops, the ticks value is unspecified.

If more than 50 routes are to be reported, multiple RIP packets are used, each with 50 entries or fewer. If more than seven Services are to be reported, multiple SAP packets are used, each with seven entries or fewer. These packet size limitations can be relaxed by an overriding user configuration on a per-circuit basis. The value ripPacketSize determines the size, in bytes, that a RIP packet is allowed to reach. The corresponding value for SAP is sapPacketSize.

8.3. Split Horizon

RIP implements a split horizon heuristic to cut down on sending and processing redundant RIP traffic. Split horizon applies equally whether a route is learned by RIP or NLSP. There are two parts:

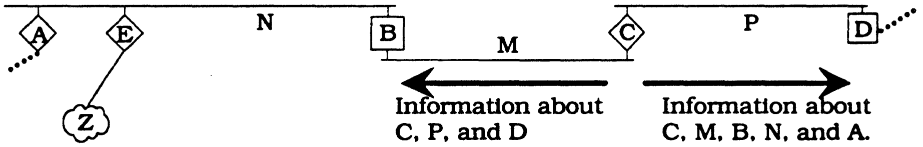


Figure 8-6: Split Horizon

a) A router about to broadcast onto a particular circuit, C, does not include any information about other networks for which another router on C has a better route. For example, in Figure 8-6, suppose B is a RIP router and C is an NLSP router. When router C broadcasts a RIP packet on LAN M, it does not include information received from B about LAN N. (Otherwise, a system on M might erroneously conclude that there are two paths to N.)

Moreover, if A is an NLSP router, it does not broadcast RIP packets onto N reporting routes in the network cloud Z (it does not matter whether E is a RIP or an NLSP router).

A way to implement this heuristic is to ask the following questions when preparing to broadcast information about network H onto circuit J: "Is J the best next hop to H? Is J one of the candidate equal-cost best hops to H?" If the answer to either of these questions is "yes," then refrain from broadcasting information about network H onto circuit J. In the equal-cost path case, it does not matter which of the paths are actually chosen for forwarding. Figure 8-7 illustrates this. In this example, the LANs have equal cost. When A runs the Decision Process, it notes that it can reach H through either B or C with equal cost. Suppose the maximal splitting degree is one, and A chooses B as the forwarding path to H. Nonetheless, A does not broadcast RIP information about H onto J, because C is one of the candidate equal-cost best hops from A to H.

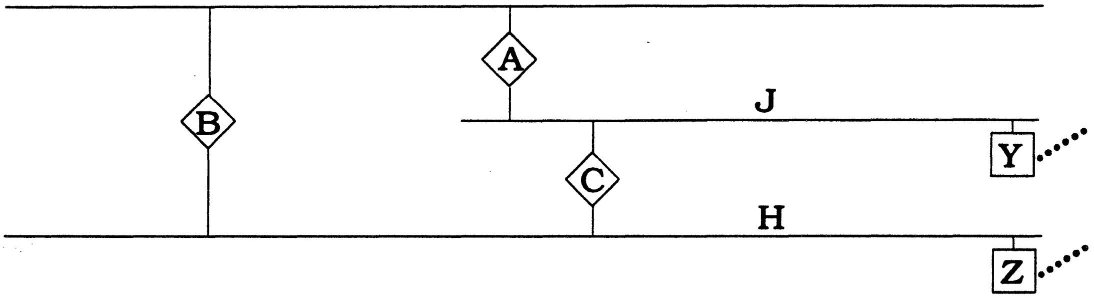


Figure 8-7: Split Horizon and Load-Splitting

b) A router about to broadcast on a particular segment does not include any information about the network on which the packet is to be sent. Router C does not include information about H in its RIP broadcast on H.

The RIP Delay values in outgoing RIP reports on a link include provision for that link itself. On the other hand, hops correspond to router traversals. For example, when C transmits a RIP on M describing P, the report indicates "1 hop, 2 ticks"—one tick transits M; another transits P.

SAP broadcasts also conform with the split horizon rule. Refer to Chapter 9 Section 9.3.

8.4. Generating Triggered Updates

When there are changes in the routes that have been broadcast as RIP routes, or when the router discovers changes to local links, or when internally provoked events occur (for example, activating or deactivating a circuit), triggered updates of RIP routes are broadcast on circuits supporting RIP compatibility.

The form and content of triggered updates are the same as those of periodic broadcasts.

8.4.1. Changes in XRoutes and Services

When an XRoute is added to or deleted from the database, a triggered update is generated to reflect the changes. One is also generated when an XRoute's forwarding information (hops, ticks) changes.

When a router detects that a route becomes unreachable, it generates a triggered update to convey this. The cause can be (a) the Decision Process finds a network to become unreachable, or (b) the hop count reaches 16 or more.

Likewise, SAP updates are generated when Services are added or deleted from the Link State database, or there is a change in hop count as reported in LSPs.

When the router detects that a network number becomes inaccessible, it marks Services on that network as inaccessible as well, and sends triggered SAP updates accordingly.

When a change is detected, there is a hold-down timer of 0.55 seconds before transmitting the resulting RIP or SAP packet. This allows multiple changes occurring close in time to be consolidated.

8.4.2. Changes in the Link State Graph

RIP triggered updates are generated when the following occurs:

- Nodes are added to the Link State graph
- Something changes in the Link State database that changes the Hops or Ticks (a link going up or down, a cost changing, or similar change)
- Any node's upstream route first hop changes, or its upstream hop count or IPX Delay changes
- Any node becomes unreachable

Only the new or changed routes are broadcast. Even if an XRoute does not itself change, the ticks and hops to it can change when there are changes to the Link State graph between this router and the pseudonode to which the XRoute is attached.

If, prior to some change, a node or XRoute was within the hop count range for RIP (15 hops), but after the change it was outside the RIP range, it is included in at least one update with its unreachable hop count, so that neighboring RIP routers delete that route.

Likewise, SAP triggered updates are generated when an LSP having Services is added to or deleted from the Link State database, or when a Link State graph change causes the hop count for a Service to cross the 16-hop threshold (in one direction or the other).

When the router detects that a network number becomes inaccessible, it marks Services on that network as inaccessible.

When a change is detected, there is a hold-down timer of 0.55 seconds before transmitting the resulting RIP or SAP packet. This allows multiple changes occurring close in time to be consolidated.

8.4.3. Circuit Activation and Deactivation

When a directly attached circuit becomes active, the router's actions depend on the configured mode for that circuit.

- If the RIP compatibility mode is "Off," there is no RIP-compatibility action to perform.
- If the RIP compatibility mode is "On,"
  a) Send the first NLSP Hello on the circuit.
  b) Transmit a complete RIP update on the circuit.

c) Start the timer that controls periodic broadcasts.

d) Broadcast a RIP "All Routes" request on the circuit.

- If the RIP compatibility mode is "Auto,"

  a) Send the first NLSP Hello on the circuit.

  b) Broadcast a RIP "All Routes" request on the circuit.

  c) If a RIP response is received from a non-NLSP router, the first time this happens

    i) Transmit a complete RIP update on the circuit.

    ii) Start the timer that controls periodic broadcasts.

    iii) Tag the circuit as having RIP activated.

Note: An NLSP router is recognized by its data-link address matching that of a router for which an NLSP adjacency exists in either the "Up" or the "Initializing" state.

The result of this is that with NLSP active and RIP in "Auto" mode, RIP periodic responses and triggered updates are sent only if there are other non-NLSP routers on a LAN. With RIP compatibility mode "On," RIP packets are always sent.

The same procedure is used for SAP, depending on the SAP support configuration choice for the circuit.

It is possible that another NLSP router responds to the RIP request and this router receives the response before it recognizes that the other router is an NLSP router. In this case, the adjacency is formed later, and the other router's LSPs begin to arrive. The RIP routes previously learned from that router duplicate the information in the now expanding Link State database. To prevent having that duplicate information in pseudonode LSPs, the router removes any XRoutes that were absorbed from RIP packets from that router. If the router is in "Auto" mode for that link, and if the RIPs just described had been the ones that activated RIP compatibility for the circuit, the RIP compatibility is deactivated when the XRoutes are removed.

When a directly attached circuit supporting SAP compatibility becomes active, the router broadcasts a SAP general request to discover Services accessible over the circuit. It then starts the timer for generating periodic updates. As soon as any SAP packet is received from a non-NLSP router, it acts as though the periodic interval has expired and broadcasts the Service information contained in its database (with split horizon applied).

When a directly attached circuit is about to become inactive, the router sends RIP/SAP updates on that circuit indicating that destinations reached through the router through that link are now unreachable. (There is no hold-down timer applied for this part, and no interpacket gap is required.) It then generates triggered RIP/SAP updates to all the other RIP/SAP-support circuits about the routes/Services that have become unreachable as a result of the deletion.

8.4.4. Router Activation and Deactivation

When a router begins operation,

a) It determines the network numbers of its directly attached RIP-support links.

b) If the system itself contains application Services, it records the Service names as Services in its database.

c) It performs the circuit activation procedures described on page 8-11 for each circuit.

When router operation is about to terminate, the system performs the circuit deactivation procedures described on page 8-12 for each circuit.

8.5. Receiving RIP and SAP Packets

When a valid RIP packet arrives on circuit *C*, the router takes the following steps:

a) If *C* is a LAN, and the packet's source MAC data-link address matches that of a router for which an NLSP adjacency exists, the packet is ignored.

> **Note:** The other router is an NLSP router doing RIP compatibility. Ignoring the packet prevents this router from having to process RIP routes for destinations it already knows about through LSPs.

b) If the packet is a RIP Request,

i) If the request is for a specific route (or routes), the response is returned to the requester's address. Information is returned no matter how large the hop count is.

> **Note:** This allows end nodes to access the larger networks possible through NLSP. With RIP/SAP alone, without NLSP, the maximum supported network diameter is 15 hops.

The split horizon rule is applied. In other words, the router responds with any information typically sent in a periodic broadcast packet that would be applicable to the request.

If the router does not have any record of the requested network number,

i.1) If the network number is outside the local area, and if an Exit Router (offering a path to other routing areas) is known to this router, the router responds to the request. The hops and ticks reported in the response are those of the path to the Exit Router.

i.2) Otherwise, the router does not reply regarding the requested network number.

One exception to the split horizon rule occurs if a specific RIP request is received on a network segment for the network number of the segment itself. The router responds with the requested information. Even though the information is not useful for routing, it allows a system to learn the node addresses of all routers on a local network segment.

ii) If the request is a general request (for "All Routes"), the response is returned to the requester's address only if the circuit is configured to be in "On" or "Auto" mode. If the mode is "Off," a general request is ignored. Responding to a general request is the same as generating a periodic update. Entries that would have a total reported hop count of 16 or greater are not included. This prevents other RIP routers from having to process entries that they automatically discard. Split horizon is applied.

c) If the packet is a RIP Response,

i) If the circuit has RIP compatibility configured to be "Off," the packet is ignored.

ii) The source and destination network numbers in the IPX header are compared. If they are not the same, the packet is ignored.

iii) If RIP is in "Auto" mode and deactivated, it is reactivated. If SAP is in "Auto" mode and deactivated, it is reactivated.

iv) For each route in the RIP Response, the Link State database is searched.

- If the destination network is reachable by an NLSP route (that is, by a path in the Link State graph using only network numbers that appear in the Management Information field of LSPs), the RIP route is ignored.
- If the network number is not within the ranges delineated by any one of the router's own manualAreaAddresses, the RIP route is ignored.
- If the destination is not a Link State destination, this RIP route information is searched for in the local existing database. That is, if this is the Designated Router for *C*, it is searched for in the pseudonode LSP; if it is not the Designated Router, it is searched for in the potential pseudonode.
    - If the route is absent, and this is the best RIP route known in the area (or tied for best), it is added.
    - If it is present from the same RIP router, changes in value are recorded and the timeout for the XRoute is refreshed.
    - If it is present from a different RIP router, and if the route received is better than the one in the database, the old information is replaced by the new.
    - If this is the Designated Router, any change is reflected in the pseudonode LSP, triggering an LSP regeneration.

Any time a received RIP packet indicates a hop count of 16, it means that the network number cannot be reached through the router sending the packet. If this is the only path to that network number, it (the network number) is removed from the pseudonode (or potential pseudonode) and a triggered update results.

The logic to process arriving SAP packets is the same as for RIP, with a few additional considerations.

As with RIP XRoutes, SAP Services discovered by SAPs arriving over directly attached circuits are maintained as part of the corresponding pseudonode LSP (or potential pseudonode). If this router is the Designated Router for that pseudonode, it (the router) floods the pseudonode LSP throughout the routing area. As with RIP, SAP packets arriving from another NLSP router (performing SAP compatibility) are ignored.

In the SAP counterpart of step c) part iii), it is not enough that a SAP response has arrived. Before reactivating RIP and SAP for an "Auto" circuit, check that the SAP packet contains at least one entry of type "File Server" (0x04). In the absence of such an entry, do not reactivate RIP and SAP. The purpose of the additional check is to avoid activating RIP and SAP just because there is, for example, a print server on the LAN, advertising its Service as reachable on the LAN itself.

If SAP is in "Off" mode for a LAN circuit, Services advertised as reachable on the LAN itself are absorbed into the locally generated pseudonode LSP for the circuit. The same is true if SAP is in "Auto" mode and deactivated. The purpose of this provision is to be able to run in SAP "Off" mode and still advertise systems (such as the print server in the preceding paragraph) directly reachable on that LAN.

When receiving a SAP packet advertising that a Service is now reachable at a new address, a router accepts this Service and deletes the old Service if the new address is nearer than (or at the same distance as) the old address. (This is to deal with the situation where, for example, a server is brought up with a new internal network number.) To decide that the SAP describes the same Service, compare both the Service name and the Service type. SAPs with the same name but different types represent different Services.

As with RIP, each SAP Service is absorbed once, at most (except for ties). Each Service is represented in, at most, one locally generated LSP, even if its SAP is received on multiple circuits.

The router is responsible not only for absorbing the SAP packets as they are received, but also for representing "local" SAP Services detected within the router's own system. Services advertised on the router's own internal network are always accepted, and those Services are added to the local LSP, the one describing this NLSP router.

When responding to a "Get Nearest Server" SAP request, a system considers all known Services of the requested type, determines the IPX address of each, and responds with the one that is closest to itself. The closeness criterion is ticks, applying the same method as in building a RIP route. If there is a tie for best, hops are used to break the tie.

8.6. Maintaining a Proper Interpacket Gap

Certain nodes can have problems properly processing a sequence of RIP packets arriving too close together. Currently, the minimum interpacket gap time allowed for transmitting RIP packets is 55 milliseconds.

Similarly, the minimum interpacket gap time allowed for transmitting SAP packets is currently 55 milliseconds.

8.7. RIP and SAP Filters

An NLSP router can be configured on a per-link basis to filter incoming and outgoing reports of RIP routes (by network number or a pattern of numbers) and Services (by Service name or name pattern). The end user is responsible for maintaining uniformity in the configured filters. In Figure 8-8, for example, if A has different RIP/SAP filters on the LAN than B does, router C perceives radical changes in what is accessible through R if the Designated Router status changes on the LAN.

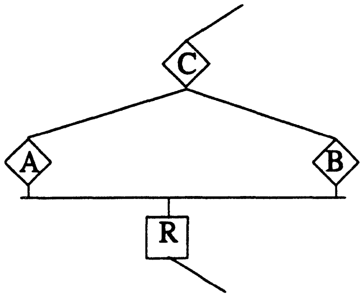


Figure 8-8: Filter Uniformity

Filtering applies to the transmission and absorption of information by the RIP/SAP protocols. It does not apply to exchange of XRoute and Service information in LSPs. Once information about a route or Service is in one router's LSP, that information is propagated throughout the routing area. This means that users can control the amount of RIP/SAP traffic, but cannot necessarily prevent RIP/SAP information from reaching another region of an internetwork, if NLSP routers provide connectivity to that region.

8.8. RIP/SAP Database

8.8.1. Configured Values per Circuit

ripState
Mode of support for RIP on the circuit: "On," "Off," or "Auto." Default is "Auto."

ripUpdate
The RIP periodic update interval, in seconds. Default is 60 seconds.

ripAgeMultiplier
After this many ripUpdate intervals, unrefreshed RIP information is considered expired. Default is four; it ages out after three or four minutes.

ripPacketSize
The maximum RIP packet size used on this circuit. Default is 432 bytes (header plus 50 entries).

sapState
Mode of support for SAP on the circuit: "On," "Off," or "Auto." Default is "Auto."

sapUpdate
The SAP periodic update interval, in seconds. Default is 60 seconds.

sapAgeMultiplier
After this many sapUpdate intervals, unrefreshed SAP information is considered expired. Default is four; it ages out after three or four minutes.

sapPacketSize
The maximum SAP packet size used on this circuit. Default is 480 bytes (IPX header plus seven entries).

9. Default Route

This chapter describes RIP Default Route advertisement and the interactions with NLSP. RIP uses network number -2 (hex ff ff ff fe) to indicate the default route.

NLSP treats a system which claims to be a Level 2 router as advertising a default route. In addition to having a RIP default route, NLSP routes towards the RIP default route if the NLSP default route is not present.

9.1. RIP Handling

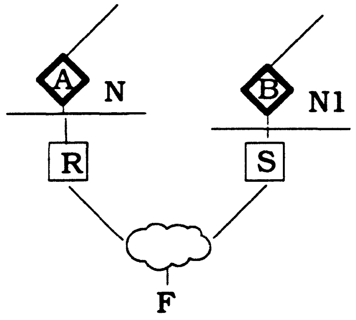
If a RIP router cannot find the destination network number in its forwarding table it should, rather than drop the packet, send it towards network number -2, if it exists.

If a router receives a request for a specific route and router does not have any record of the requested network number, the router should reply to the request, if a Default Route (NLSP Level 2 or Default RIP Route) is known to the router. The hops and ticks in the response are those of the path to the Default Route.

9.2. NLSP Handling

NLSP advertises default route by claiming to be a Level 2 router, or by advertising zero length address prefix. NLSP should also recognize the destination -2 as a less preferable default route. The order of preference of routes is as follows:

1) Look for the longest reachable address prefix matching the destination. If such exists (including zero length prefix) route to that prefix.
2) Else, route to the nearest router advertising itself as a Level 2 router.
3) Else, route to the network number -2.
4) Else, drop the packet.



A and B are connected NLSP routers
A is the Designated Router for N.
B is the Designated Router for N1.
R and S are RIP routers.
R reports Network (-2) 2hops and 3ticks.
S reports Network (-2) 2hops and 5ticks.

Figure 9-1: Absorbing Default Route

In the above figure, A and B are Level 1 NLSP routers and are also designated routers on the networks N and N1 respectively. R and S are RIP routers advertising the Default Route (Network -2) at 2 hops and 3 ticks and at 2 hops and 5 ticks respectively. Router A will follow the standard NLSP rules for inserting destination -2 into its LSP, and Router B will not insert it into its LSP (e.g., only the router that can advertise the smallest ticks to the Default RIP Route puts the network [-2] into its LSP), with one exception: if any NLSP router in the area is advertising itself as a Level 2 router or is advertising zero length prefix, then router A does not insert the external route (-2) into a LSP. If Router A or B are being advertised as Level 2 routers, the -2 Network advertised via RIP is not absorbed.

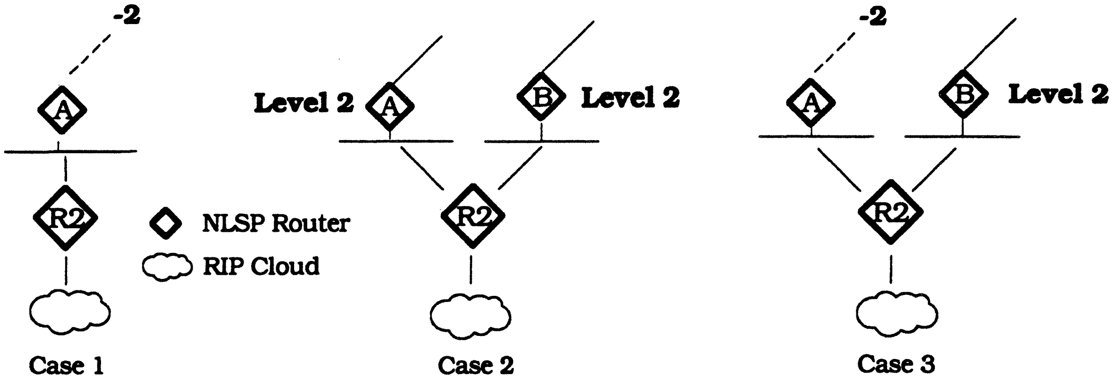


Figure 9-2: Advertising a -2 Network

There are two cases where NLSP router R2 advertises a route to -2 to its RIP neighbor. One is through the usual rules for external routes, where R2 can reach XRoute for network -2. R2 combines the values of the hops and ticks for the path within the NLSP area, with the values appearing in the XRoute, in order to advertise the -2 Network into the RIP cloud. The other case is where one or more routers advertise themselves as Level 2 routers or advertise zero length prefix. In that case, R2 advertises a -2 into the RIP cloud with hops and ticks equal to the hops and ticks of the path to the nearest Level 2 router (nearest according to the NLSP cost metric). In the case where R2 can reach a Level 2 router and an external route for the -2 Network Number, then R2 advertises -2 into the RIP cloud based on the hops and ticks to the nearest Level 2 router.

A NLSP router should not include the destination -2 into its LSP if another router is advertising itself as a Level 2 router. But there can be transition times when both "I am a Level 2 router" from R3 and "external router -2 is reachable through me", from R2, might both exist. In that case, routing is towards R3, the router advertising itself as a Level 2 router.

9.3. Interaction With SAP

Currently in RIP, if a service is announced with address x, and x is not explicitly reachable, then RIP assumes the service is unreachable. This requirement in RIP is no longer valid.

The rule in NLSP and RIP is that SAP is accepted provided that a packet to the corresponding network number be forwardable, because of the existence of default route, an address summary, or the explicit advertisement of that network number. In other words, if default route is advertised into a RIP cloud, then all SAP advertisements will be accepted, and a service will only go away when the SAP advertisement itself counts to infinity.

9.3.1. SAP Propagation

SAP can be thought of as a simple distance vector protocol where the "destinations" advertised are SAP names, and the hop count is the metric. For purposes of propagation and split horizon for the SAP advertisement, the IPX address associated with the SAP name is irrelevant. Therefore it is possible for a service to be advertised from a different location in the network than the network number.

Suppose router R receives the SAP advertisement (NAME, IPX address, hops=3) from link L. The rules are:

a) if a packet for a IPX address is dropped, then ignore the SAP advertisement. However, if a packet for that IPX address is forwardable because that network number is explicitly reachable, or if that network number is subsumed in a reachable summary, or if default route/a level 2 router is reachable, then accept the SAP advertisement.

b) if "NAME" is unknown, or stored with hops > 3, then remember (NAME, IPX address, hops=4, link L)

c) Assuming (NAME, IPX address, hop=4, link L) is what is stored, advertise (NAME, IPX address, hops=4) on all interfaces except L. If your implementation is capable of storing more than one optimal path, and you've also heard (NAME, IPX address, hops=3) from links L2 and L3, then also exclude L2 and L3 from the set of links upon which you advertise (NAME, IPX address, hops=4).

d) Split horizon rules apply to L (and L2 and L3 if you also remember them). Do not advertise NAME on link L (or L2 or L3 if you can remember more than one link).

9.3.2. Choosing "Nearest Server"

When responding to a "get nearest server": for each matching service (NAME, IPX address), the ticks corresponding to IPX address is what determines which service is "nearest". Ticks applies whether IPX address is reachable by being explicitly advertised or by being part of a summary. In the case of ties, hops is used, but the "hops" for a summary is considered to be always greater than the "hops" for an explicitly advertised network number. (Note that the exact number of hops to a summary isn't known.) In the case of ties in both ticks and hops, the choice is arbitrary.

10. Network Management

The management of NLSP™ routers uses SNMP running over the IPX™ protocol, as specified in [Wor92]. As an implementation option, the same management information can be accessed by SNMP running over IP or other Network layer protocol supported by the router.

An extensive suite of network management information has been defined for IPX, encompassing not only the IPX protocol itself but also RIP, SAP, and NLSP. The information has been defined in three separate Management Information Bases (MIBs): IPX, RIP/SAP, and NLSP.

The IPX MIB serves as the foundation for the other two MIBs. It contains the management information for the IPX protocol, as well as the common information supplied by both RIP/SAP and NLSP. The RIP/SAP and NLSP MIBs extend the groups and tables defined in the IPX MIB with their own protocol-specific information. Additionally, the NLSP MIB defines new groups that are not present in the IPX MIB.

Before the MIBs are described, you need to know how to use the MIBs in managing an NLSP routing area.

10.1. Managing an NLSP Area

Management stations can be implemented to manage an NLSP area. An NLSP management station would

- Identify potential network problems
- Isolate network faults when they occur
- Make network layer connectivity visible to the network administrator

The following subsections include guidelines for using the MIBs to implement a management station.

10.1.1. Examining Error Statistics and Counters

Within the IPX and NLSP MIBs are a series of error statistics and counters that help determine problems in an NLSP area.

If many packets are discarded because of excessive hop count (ipxAdvSysInTooManyHops), there is an error condition.

Also revealed by the MIBs are the number of routes (ipxAdvSysDestCount) and services (ipxAdvSysServCount) known. This number should be consistent between all routers in an NLSP area.

A rise in any of the following IPX MIB statistics indicates a network failure.

From the IPX system entry:

- Header Errors (ipxBasicSysInHdrErrors)
- Bad Checksums (ipxBasicSysInHdrErrors)

- Outbound Malformed Requests (ipxBasicSysInMalformedRequests)
- Open Sockets Fails (ipxBasicSysOpenSocketFails)

For IPX header compression:

- Compression Discards (ipxBasicSysInDiscards)
- Outbound Compression Discards (ipxBasicSysInOutDiscards)

The following NLSP MIB counters indicate potential problems:

- The number of corrupt LSPs detected (nlspSysCorrLSPs)

  If this value is anything other than zero, there is a problem. There are several reasons why this counter can increase:

  a) An NLSP router is generating corrupt LSPs.

  b) A data link is corrupting LSPs.

  c) LSPs are being corrupted after they are received.

  d) The system's NLSP software incorrectly believes that the LSP is corrupted, when it is not.

  Any one of these errors is very severe, and should be brought to the network administrator's attention immediately.

- The number of times the NLSP Level 1 LSP database has become overloaded (nlspSysL1DbaseOloads).

  Running out of memory is a severe problem because it compromises the ability of a system to perform the routing function. It is possible that this condition is transitory across the entire NLSP area. This might occur when a network administrator connects two areas, creating a routing area that requires too much memory. This problem can be fixed permanently by altering the routing area.

  A currently overloaded router should be brought to the network administrator's attention immediately. The number of times a router has been overloaded should also be monitored, so that the network administrator can distinguish between a transitory, correctable condition and the permanent condition of a router having insufficient memory.

- The number of times the router has attempted to exceed the NLSP maximum sequence number (nlspSysMaxSeqNums).

  This value indicates the number of times that this system's sequence number has wrapped. Because this condition should occur, at most, once every 160 years, a wrapping sequence number indicates an error condition. This error condition is probably internal to the router.

- The number of times a sequence number skip has occurred (nlspSysSeqNumSkips).

  This value indicates the number of times that another router has purged this router's LSPs. This can occur at startup under normal conditions, but thereafter this value should not increase. If this value is increasing, it is likely that two systems have the same system ID. This is a severe error that can cause network wide disruption.

- The number of times a zero-aged copy of the router's own LSP has been received from some other node (nlspSysOwnLSPPurges).

  This value indicates the number of times that another router has originated this system's LSPs. Similar to nlspSysSeqNumSkips, this can occur normally at startup. Thereafter, it should not occur and should be treated as a severe error that can cause network wide disruption

The following NLSP MIB counters in the circuit group indicate problems:

- The number of times the NLSP LAN Level 1 Designated Router has changed on this circuit (nlspCircLANL1DesRouterChanges).

  This value can change normally over time, but each change causes a disruption in the network. If this value is rising rapidly (more than three times per day), there is a problem on the LAN segment. It can mean that routers are being restarted, or it can mean that the LAN segment is dropping a large amount of network traffic

- The number of times an NLSP neighbor state change has occurred on this circuit (nlspCircNeighChanges).

  This value can change normally over time, but each change causes a disruption in the network. If this value is rising rapidly (more than once every five minutes), there is a problem on the LAN segment.

- The number of times that an NLSP neighbor has been rejected on this circuit (nlspCircRejNeighbors).

  If this value is greater than zero, it is most likely that two NLSP systems have been incorrectly configured with nonmatching NLSP area addresses.

10.1.2. Using the Graph and the LSP Database to Locate Problems

Network topology information determined from a single NLSP system is adequate to describe the entire routing area. Information obtained from the graph table is sufficient to determine the network topology, the frame types in use, and the characteristics of WAN links. It can also be used to determine where RIP routes and SAP services are being injected. From the graph, a management station can construct a table of routers, obtain statistics from these routers, and maintain a record of the statistics.

Through periodic polling of the NLSP graph table of a single NLSP system, you can check for connectivity and quickly determine when and where links are down between systems. Broken links can then be flagged, and the frequency with which they (or LAN NLSP systems) are down can then be logged. Bouncing links and bouncing systems can also be determined by continuous polling of the graph table. Keeping a log of downed systems helps administrators to identify trouble spots in the network.

Duplicate network numbers can cause loss of connectivity. If two networks have the same network number, only one of them receives packets from any given router in the internetwork. By checking the graph table, it is possible to detect duplicate network numbers in an NLSP area. Recall, however, that zero is used as a null value (placeholder) for unnumbered RIP links. Expect multiple links having network number zero. This is not a problem because zero is a reserved value, not used as a destination in routing decisions. It is also typical, for the network number of an external route to appear in more than one LSP.

Duplicate NLSP network numbers occur for one of two reasons:

- Incorrect configuration
- Data-link connectivity loss

In the latter case, a bridge or repeater fails, causing a network to split. Another possible cause of data-link connectivity loss is a failed network interface device on a router; the router might determine that it is the only router on a particular segment when, in fact, there are several other routers. Using the NLSP graph, it is possible to highlight a system that has a duplicate network number and provide the name of the system and the location of the system in the topology.

On the other hand, there are transient conditions that can cause a network to appear divided, when in fact it is not. When a duplicate network number is indicated by the NLSP graph, the network number should be flagged as a suspected duplicate. Checking again several minutes later eliminates typical transient conditions as a cause.

The graph tables of two different systems within a single NLSP area can be retrieved and compared for consistency. (Do not include expired LSPs in the check.) Within an NLSP area, two NLSP systems should have identical graphs except during transitions. So if system A knows of a link that system B does not, an error is indicated. You can also check using LSP headers. If system A has an LSP that system B does not, or if system A's LSP is newer, either

- B soon receives the LSP in question from A or
- There is an error

Two NLSP systems that are directly connected can be monitored to ensure that the LSP database is synchronizing. Slow convergence (propagation of the LSP database) can also be detected this way. Slow convergence can make a network inoperable, and should be brought to the network administrator's attention.

You can compare the potential paths reported by two systems to track down lost connectivity problems. For example, if system A indicates that it uses system B to reach a particular destination, system B should also have the remainder of the potential path. Otherwise, the network has not converged (which it should do within a minute), or there is a problem in the network preventing convergence between system A and system B (perhaps problems with the software).

10.1.3. Using the Neighbors Table and Statistics to Locate Problems

NLSP provides a two-way connectivity check intrinsically. However, it is possible that a system A might have only one-way connectivity to a system B. This occurs because of malfunctioning hardware or incorrect configuration. A neighbor that is continually in the "Initializing" state might be able to send packets on the indicated network, but not receive them.

On any given LAN, all systems should have the same Neighbors table (except that a system is not a neighbor of itself). If the Neighbors tables are inconsistent among routers on a LAN, there might be a software failure. Another possible cause is insufficient processing, memory, or buffers in a router to process the information about its neighbors.

Finally, a frequently increasing number of either

- Designated Router changes (nlspCircLANL1DesRouterChanges) or
- Neighbor state changes (nlspCircNeighChanges)

indicates trouble. Perhaps a system on the network cannot process arriving Hellos, causing it to time out its neighbors. Perhaps a network has a physical connectivity problem (for example, excessive collisions or too much traffic). Perhaps a system's holding time is not high enough.

10.1.4. RIP and SAP Parameters That Must Be Consistent

RIP and SAP do not allow the same kinds of checks as NLSP. Still, it is possible to detect certain misconfigurations that cause connectivity loss. This kind of error is difficult for an administrator to isolate with current tools.

The following parameters must be identical for all systems on a LAN:

ripCircPacketSize

ripCircUpdate

sapCircPacketSize

sapCircUpdate

If any of these parameters are different, there might be a connectivity loss.

10.2. IPX Network Management Information

The IPX MIB defines the network management information for the IPX protocol and is intended for use by both routers and workstations that run IPX. Given the broad scope of this MIB, it is likely that there is some information that is not kept by some IPX implementations. In such cases, zero (or a similar value appropriate to the actual data type specified) should be returned for single items that are not supported. If the entire contents of a table are not supported, the table should be treated as containing no entries.

The primary index of every table in the IPX MIB is a system instance. This value identifies a unique instance of IPX running on a system. This system instance allows for a managed system to be running more than one instance of the IPX protocol at a time. This same instance value is used in the RIP/SAP and NLSP MIBs to associate their information with the information present in the IPX MIB. In cases where this value has read-write access in the MIB, it can be written only when adding a new entry to a table. If an attempt is made to change the system instance value of an existing entry in a table, the SNMP error code readOnly should be returned.

The IPX MIB defines five groups of network management information: the System group, the Circuit group, the Forwarding group, the Services group, and the Traps group. The groups are describe in more detail in the following sections.

10.2.1. System Group

The System group contains the general information about each instance of IPX running on a system. It contains information such as the system's IPX network number, counters of packets received and sent, and other such information. Two tables are defined in this group: the Basic System table and the Advanced System table.

Basic System Table

The Basic System table contains the basic information about an instance of the IPX protocol. There must be an entry in this table for each instance of IPX present on the managed system. In addition, given the basic nature of the information in this table, every attempt should be made to keep and return meaningful values for each item in the table.

Advanced System Table

The Advanced System table contains information that might not be kept by all IPX implementations (especially in the case of workstations), and it is acceptable for this table to contain no entries. However, much of the information in this table is applicable to IPX routers and should be kept by such systems.

10.2.2. Circuit Group

The Circuit group defines the management information that should be kept for each IPX circuit (a connection to a LAN, a WAN, or a direct link to another IPX system). The circuit information exists at a higher level than the interface information defined in MIB II. There might be more than one circuit associated with a single interface.

Some of the information contained in the Circuit table (the only table in the Circuit group) is applicable only to WAN circuits. On non-WAN circuits, zero (or a similar value appropriate to the item's data type) should be returned for such items.

Some of the items in the Circuit table have read-write access, but should only be written when adding a new circuit to the table. If an attempt is made to write new values for these items in an existing circuit, the SNMP error code readOnly should be returned. Items that can be written only when creating a new circuit contain the sentence "This value may be written only when creating a new entry in the table" in the DESCRIPTION portion of their MIB definition.

10.2.3. Forwarding Group

The Forwarding group contains the information about each IPX destination. The group contains two tables: the Destination table, and the Static Routes table.

Destination Table

The read-only Destination table contains information about every destination known to IPX. This table contains the minimum information that must be supplied by any IPX routing protocol. Meaningful values should be returned for every item in this table.

Static Routes Table

The Static Routes table is a subset of the destination that shows all static routes configured for an IPX system. The items in this table have read-write access so that static routes can be added or changed through SNMP requests.

10.2.4. Services Group

The Services group contains information about the known services. Three tables are defined in this group: the Services table, the Destination Services table, and the Static Services table.

Services Table

The Services table contains information about every service known to the system. It contains the basic information about the service that must be available, no matter what method was used to learn about the service (SAP, NLSP, static configuration, and so on). Meaningful values should be returned for every item in this table. The primary index (after the system instance, of course) for this table is the service type. This allows network management applications to easily show all services of a specific type that are available (for example, all the print servers) to a system.

Destination Services Table

The Destination Services table contains the same information kept in the Services table. There should be an entry in both of these tables for each service known to the system. The difference between the tables is in the order of the indexes. The Destination Services table is indexed in such a way that all the services provided by a specific destination can be obtained without having to read the entire table.

Static Services Table

The Static Services table is a subset of the Services and Destination Services tables that contains information about all of the services that have been statically configured for a system. This table has read-write access to allow the addition and deletion of statically configured services through network management.

10.2.5. Traps Group

Two enterprise-specific traps are defined in IPX MIB. One trap is used to notify a network management application when a new circuit comes up and the other for notification when a circuit goes down.

10.3. RIP and SAP Network Management Information

The RIP/SAP MIB defines the network management information for the RIP and SAP protocols. It is intended for use by all routers that support the two protocols. The RIP/SAP MIB extends the IPX MIB's System and Circuit groups with information that is specific to the two protocols. The tables in the RIP/SAP MIB are directly associated with the information in the IPX MIB via their primary index, the system instance.

10.3.1. System Group

The System group contains information about each instance of RIP and SAP that is running on the system. This group extends the information contained in the System group of the IPX MIB. This group contains two tables: the RIP System table and the SAP System table. For every entry in either of the two tables, there must be a corresponding entry in the IPX Basic System table with the same system instance value.

10.3.2. Circuit Group

The Circuit group extends the IPX MIB's Circuit group with additional information about RIP and SAP usage of IPX circuits. This group contains two tables: the RIP Circuit table and the SAP Circuit table. For every entry in either of the tables, there must be a corresponding entry in the IPX Circuit table with the same system instance and circuit index.

10.4. NLSP Network Management Information

The NLSP MIB defines the network management information for the NLSP routing protocol. It is intended for use by all NLSP routers. In addition to extending the IPX MIB's System, Circuit, and Forwarding Groups, the NLSP MIB also defines the NLSP Neighbors group, the NLSP Translation group, the NLSP Graph group, and the NLSP LSP group.

As with the other two MIBs, the primary index of every table is a system instance. The value of the system instance is used to link the NLSP information with the corresponding instance of IPX.

10.4.1. System Group

The NLSP System group contains information about each instance of NLSP running on a system. It contains information about the system's NLSP ID, the configurable NLSP parameters, as well as the area addresses. Three tables are defined in this group: the NLSP System table, the System Area Address table, and the Actual Area Address table.

NLSP System Table

The NLSP System table extends the IPX MIB's System table with global information for each instance of NLSP on the system. Among the numerous items contained in this table are the global configuration parameters for NLSP. The configuration parameters are defined with read-write access to allow the configuration of NLSP through network management. NLSP implementations that do not support configuration through network management should return the SNMP readOnly error code if an attempt is made to write a new value. NLSP implementations should be able to return meaningful values for all the items in this table. For every entry in this table, there must be a corresponding entry in the IPX Basic System table with the same system instance value.

System Area Address Table

The System Area Address table contains all the NLSP area addresses that were configured locally for this system.

Actual Area Address Table

The Actual Area Address table contains all the NLSP area addresses actually being used by this system.

10.4.2. Circuit Group

The NLSP Circuit group extends the IPX MIB's Circuit group with additional information about NLSP usage of IPX circuits. For every entry in the NLSP Circuit table (the only table in this group) there must be an entry in the IPX Circuit table with the same system instance and circuit index.

10.4.3. Forwarding Group

The NLSP Forwarding group extends the Destination table from the IPX MIB's Forwarding group with additional information about those destinations that were learned through NLSP. For every entry in the NLSP Destination table, there must be an entry in the IPX Destination table with the same system instance and IPX network number.

10.4.4. NLSP Neighbors Group

The NLSP Neighbors group contains information about each neighboring NLSP router known to the system. This group consists of one table: the NLSP Neighbors table.

10.4.5. Translation Group

The Translation group contains mappings between NLSP system IDs, IPX network numbers, and router names. The group consists of three tables: the NLSP ID Mapping table, the IPX Network Number Mapping table, and the Name Mapping table.

NLSP ID Mapping Table

Given an NLSP system ID, this table allows the corresponding IPX network number and readable system name to be determined. Although every NLSP system ID always has a corresponding IPX network number, it is possible that there is no readable name associated with the ID. In such a case, a zero length string should be returned if the name is requested.

IPX Network Number Mapping Table

Given an IPX network number, this table allows the corresponding NLSP system ID and readable system name to be determined. While every IPX network number will have a corresponding NLSP system ID, it is possible that there will be no readable name associated with the network number. In such cases, a zero length string should be returned if the name is requested.

Name Mapping Table

Given a readable name for a system, this table allows the corresponding NLSP system ID and IPX network number to be determined. Both items are always known for every name in this table.

10.4.6. Graph Group

The Graph group gives a network management application access to the NLSP graph that represents the network topology. Using this group, a network management application can draw a representation of the network topology by querying only one NLSP router instead of all the routers in the network, identify which LANs are still running the RIP and SAP protocols, and show the potential paths a packet can take between systems.

The Graph group consists of five tables: the Node table, the Link table, the Path table, the Graph XRoutes table, and the Graph Services table. Each table is described in more detail next.

Node Table

The Node table contains an entry for each node in the NLSP graph. This table can be used to determine all the LANs, routers, and so on that exist in the network.

Link Table

The Link table contains an entry for each node's links. For every link between routers *X* and *Y* in the graph, there are actually two entries in this table: one representing the link from *X* to *Y* and the other from *Y* to *X*.

Path Table

The Path table can be used to determine the paths a data packet can take to reach a particular destination from the router reporting the information. The entries in this table provide the index values of the entries in the Link table that are used in the path a data packet takes. When a link's index appears in the path table, it means that link is on one of the least-cost paths from the router reporting the information. (There can be more than one when a router implements load-splitting.)

To find the paths a data packet can take from A to B, address the following network management queries to A:

a. Retrieve all entries in the Path table for B.

b. Using the values obtained from the Path table, obtain the corresponding entries from the Link table.

c. In the Link table, examine the neighbor reached from B via the link.

   c.1 If it is A, you have identified a path.

   c.2 If not, you have identified a router one step closer to A on the least-cost path.

d. For each "one step closer" router in Step c.2, repeat Steps a through c, using the "one step closer" router in place of B. With this iteration, links are concatenated into paths. The iteration is guaranteed to terminate because every step carries it closer to A.

Graph XRoutes Table

If a node in the graph is the source of one or more XRoutes, this table contains an entry for each of those XRoutes.

Graph Services Table

This table contains entries for the services provided by each node in the graph.

10.4.7. LSP Group

The LSP group provides access to the information in an NLSP router's LSP database. This is an optional group that consists of two tables: the LSP Header table and the LSP Options table.

LSP Header Table

The LSP header table contains summary information (lifetime, sequence number, checksum, and so on) about each LSP in the database, as well as an OCTET STRING containing the LSP header as it was received.

LSP Options Table

This table provides access to the options received in LSPs in a generic manner. There is an entry in this table for each option received in an LSP. This table is indexed by system instance (of course), the 8-byte LSP ID, and the ordinal position of the option within the LSP (starting with the value of 1 for the first option in each

LSP). Entries in the table consist of the option code, length, and an OCTET STRING representing the value portion of the option. It is up to the network management application to actually decode the option's value.

10.5. MIB Definitions

The managed objects defined in the remainder of this section are presented in the concise MIB definition syntax specified in Reference [Ros91]. The same MIB definitions are also made available in electronic form. Every effort has been made to keep the material in this section identical to the electronic form, but in case of any discrepancy the electronic form is authoritative.

10.6. IPX MIB

```
IPX DEFINITIONS ::= BEGIN

– This MIB defines the management information for a system using the IPX
– protocol. The MIB consists of four groups:
–
–   1. System Group - contains general information about all instances
–                   of IPX on the system
–
–   2. Circuit Group - contains information about all circuits used by
–                   IPX on the system
–
–   3. Forwarding Group - contains generic routing information that
–                      must be provided by any IPX routing protocol.
–
–   4. Services Group - contains information about all known services.
–
– The MIB is designed to support multiple instances of the IPX
– protocol on one system via a system instance identifier which is the
– primary index for every table in this MIB.
–
– This MIB is designed to provide a basic framework for the management
– of systems implementing the IPX protocol. Additional MIBs may be
– created (especially in the area of IPX routing protocols) to contain
– more specific information. Whenever possible, these additional MIBs
– should follow the format of this IPX MIB. Information in these MIBs
– should be linked to this MIB via the use of the system instance
– identifier mentioned above.


IMPORTS
      enterprises, Counter
            FROM RFC1155-SMI
      OBJECT-TYPE
            FROM RFC-1212
      TRAP-TYPE
            FROM RFC-1215
      PhysAddress
            FROM RFC1213-MIB;

novell     OBJECT IDENTIFIER ::= { enterprises 23 }
mibDoc      OBJECT IDENTIFIER ::= { novell 2 }
ipx        OBJECT IDENTIFIER ::= { mibDoc 5 }

– Groups

ipxSystem OBJECT IDENTIFIER ::= {ipx 1}
ipxCircuit OBJECT IDENTIFIER ::= {ipx 2}
ipxForwarding OBJECT IDENTIFIER ::= {ipx 3}
ipxServices OBJECT IDENTIFIER ::= {ipx 4}
ipxTraps OBJECT IDENTIFIER ::= {ipx 5}

– Types

NetNumber ::= OCTET STRING (SIZE(4))

– System Group
–   This group contains global information about each instance of IPX
–   running on one system.

– Basic System Table
–   This table contains one entry for each instance of IPX running on
–   the system. It contains the management information that should
–   be made available by all implementations of the IPX protocol.

ipxBasicSysTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF IPXBasicSysEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The IPX System table - basic information."
  ::= {ipxSystem 1}

ipxBasicSysEntry OBJECT-TYPE
  SYNTAX     IPXBasicSysEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one instance of IPX running
          on the system."
  INDEX      {ipxBasicSysInstance}
  ::= {ipxBasicSysTable 1}

IPXBasicSysEntry ::= SEQUENCE {
                ipxBasicSysInstance
                  INTEGER,
                ipxBasicSysExistState
                  INTEGER,
                ipxBasicSysNetNumber
                  OCTET STRING,
                ipxBasicSysNode,
                  OCTET STRING,
                ipxBasicSysName
                  OCTET STRING,
                ipxBasicSysInReceives
                  Counter,
                ipxBasicSysInHdrErrors
                  Counter,
                ipxBasicSysInUnknownSockets
                  Counter,
                ipxBasicSysInDiscards
                  Counter,
                ipxBasicSysInBadChecksums
                  Counter,
                ipxBasicSysInDelivers
                  Counter,
                ipxBasicSysNoRoutes
                  Counter,
                ipxBasicSysOutRequests
                  Counter,
                ipxBasicSysOutMalformedRequests
                  Counter,
                ipxBasicSysOutDiscards
                  Counter,
                ipxBasicSysOutPackets
                  Counter,
                ipxBasicSysConfigSockets
                  Counter,
                ipxBasicSysOpenSocketFails
                  Counter
              }

ipxBasicSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of IPX to which this
          row corresponds. This value may be written only when
          creating a new entry in the table."
  ::= {ipxBasicSysEntry 1}

ipxBasicSysExistState OBJECT-TYPE
  SYNTAX      INTEGER {
                off(1),
                on(2)
              }
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The validity of this entry in the IPX system table.
          Setting this field to off indicates that this entry may be
          deleted from the system table at the IPX implementation's
          discretion."
  ::= {ipxBasicSysEntry 2}

ipxBasicSysNetNumber OBJECT-TYPE
  SYNTAX      NetNumber
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The network number portion of the IPX address of this
          system."
  ::= {ipxBasicSysEntry 3}

ipxBasicSysNode OBJECT-TYPE
  SYNTAX      OCTET STRING (SIZE(6))
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The node number portion of the IPX address of this
          system."
  ::= {ipxBasicSysEntry 4}

ipxBasicSysName OBJECT-TYPE
  SYNTAX      OCTET STRING (SIZE(0..48))
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The readable name for this system."
  ::= {ipxBasicSysEntry 5}

ipxBasicSysInReceives OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The total number of IPX packets received, including
          those received in error."
  ::= {ipxBasicSysEntry 6}

ipxBasicSysInHdrErrors OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of IPX packets discarded due to errors in
          their headers, including any IPX packet with a size less
          than the minimum of 30 bytes."
  ::= {ipxBasicSysEntry 7}

ipxBasicSysInUnknownSockets OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of IPX packets discarded because the
          destination socket was not open."
  ::= {ipxBasicSysEntry 8}

ipxBasicSysInDiscards OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of IPX packets received but discarded due to
          reasons other than those accounted for by
          ipxBasicSysInHdrErrors, ipxBasicSysInUnknownSockets,
          ipxAdvSysInDiscards, and ipxAdvSysInCompressDiscards."
  ::= {ipxBasicSysEntry 9}

ipxBasicSysInBadChecksums OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of IPX packets received with incorrect
          checksums."
  ::= {ipxBasicSysEntry 10}

ipxBasicSysInDelivers OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The total number of IPX packets delivered locally,
          including packets from local applications."
  ::= {ipxBasicSysEntry 11}

ipxBasicSysNoRoutes OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of times no route to a destination was
          found."
  ::= {ipxBasicSysEntry 12}

ipxBasicSysOutRequests OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of IPX packets supplied locally for
          transmission, not including any packets counted in
          ipxAdvForwPackets."
  ::= {ipxBasicSysEntry 13}

ipxBasicSysOutMalformedRequests OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of IPX packets supplied locally that contained
          errors in their structure."
  ::= {ipxBasicSysEntry 14}

ipxBasicSysOutDiscards OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of outgoing IPX packets discarded due to
          reasons other than those accounted for in
          ipxBasicSysOutMalformedRequests, ipxAdvSysOutFiltered,
          and ipxAdvSysOutCompressDiscards."
  ::= {ipxBasicSysEntry 15}

ipxBasicSysOutPackets OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The total number of IPX packets transmitted."
  ::= {ipxBasicSysEntry 16}
```

```
ipxBasicSysConfigSockets OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The configured maximum number of IPX sockets that may be
          open at one time."
  ::= {ipxBasicSysEntry 17}

ipxBasicSysOpenSocketFails OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of IPX socket open calls which failed."
  ::= {ipxBasicSysEntry 18}


-- Advanced System Table
--  This table contains one entry for each instance of IPX running on
--  the system.  It contains the advanced management information that
--  may not be available from all implementations of the IPX protocol.

ipxAdvSysTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF IPXAdvSysEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The IPX System table - advanced information."
  ::= {ipxSystem 2}

ipxAdvSysEntry OBJECT-TYPE
  SYNTAX     IPXAdvSysEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one instance of IPX running
          on the system."
  INDEX      {ipxAdvSysInstance}
  ::= {ipxAdvSysTable 1}

IPXAdvSysEntry ::= SEQUENCE {
              ipxAdvSysInstance
                INTEGER,
              ipxAdvSysMaxPathSplits
                INTEGER,
              ipxAdvSysMaxHops
                INTEGER,
              ipxAdvSysInTooManyHops
                Counter,
              ipxAdvSysInFiltered
                Counter,
              ipxAdvSysInCompressDiscards
                Counter,
              ipxAdvSysNETBIOSPackets
                Counter,
              ipxAdvSysForwPackets
                Counter,
              ipxAdvSysOutFiltered
                Counter,
              ipxAdvSysOutCompressDiscards
                Counter,
              ipxAdvSysCircCount
                Counter,
              ipxAdvSysDestCount
                Counter,
              ipxAdvSysServCount
                Counter
              }

ipxAdvSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of IPX to which this
          row corresponds.  This value may be written only when
          creating a new entry in the table."
  ::= {ipxAdvSysEntry 1}

ipxAdvSysMaxPathSplits OBJECT-TYPE
  SYNTAX     INTEGER (1..32)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The maximum number of paths with equal routing metric
          value which this instance of the IPX may split
          between when forwarding packets."
  DEFVAL     { 1 }
  ::= {ipxAdvSysEntry 2}

ipxAdvSysMaxHops OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The maximum number of hops a packet may take."
  DEFVAL     { 64 }
  ::= {ipxAdvSysEntry 3}

ipxAdvSysInTooManyHops OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of IPX packets discarded due to exceeding the
          maximum hop count."
  ::= {ipxAdvSysEntry 4}

ipxAdvSysInFiltered OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of incoming IPX packets discarded due to
          filtering."
  ::= {ipxAdvSysEntry 5}

ipxAdvSysInCompressDiscards OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of incoming IPX packets discarded due to
          decompression errors."
  ::= {ipxAdvSysEntry 6}

ipxAdvSysNETBIOSPackets OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of NETBIOS packets received."
  ::= {ipxAdvSysEntry 7}

ipxAdvSysForwPackets OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of IPX packets forwarded."
  ::= {ipxAdvSysEntry 8}

ipxAdvSysOutFiltered OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of outgoing IPX packets discarded due to
          filtering."
  ::= {ipxAdvSysEntry 9}

ipxAdvSysOutCompressDiscards OBJECT-TYPE
  SYNTAX      Counter
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of outgoing IPX packets discarded due to
          compression errors."
  ::= {ipxAdvSysEntry 10}

ipxAdvSysCircCount OBJECT-TYPE
  SYNTAX      INTEGER
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of circuits known to this instance of IPX."
  ::= {ipxAdvSysEntry 11}

ipxAdvSysDestCount OBJECT-TYPE
  SYNTAX      INTEGER
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of currently reachable destinations known to
          this instance of IPX."
  ::= {ipxAdvSysEntry 12}

ipxAdvSysServCount OBJECT-TYPE
  SYNTAX      INTEGER
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The number of services known to this instance of IPX."
  ::= {ipxAdvSysEntry 13}


- Circuit Group
-  This group contains management information for each circuit known
-  to this system.

- Circuit Table
-  The Circuit table contains an entry for each circuit known to the
-  system.

ipxCircTable OBJECT-TYPE
  SYNTAX      SEQUENCE OF IPXCircEntry
  ACCESS      not-accessible
  STATUS      mandatory
  DESCRIPTION "The Circuit table."
  ::= {ipxCircuit 1}

ipxCircEntry OBJECT-TYPE
  SYNTAX      IPXCircEntry
  ACCESS      not-accessible
  STATUS      mandatory
  DESCRIPTION "Each entry corresponds to one circuit known to the
          system."
  INDEX     {
          ipxCircSysInstance,
          ipxCircIndex
          }
  ::= {ipxCircTable 1}

IPXCircEntry ::= SEQUENCE {
            ipxCircSysInstance
              INTEGER,
            ipxCircIndex
              INTEGER,
            ipxCircExistState
              INTEGER,
            ipxCircOperState
              INTEGER,
            ipxCircIfIndex
              INTEGER,
            ipxCircName
              OCTET STRING,
            ipxCircType
              INTEGER,
            ipxCircDialName
              OCTET STRING,
            ipxCircLocalMaxPacketSize
              INTEGER,
            ipxCircCompressState
              INTEGER,
            ipxCircCompressSlots
              INTEGER,
            ipxCircStaticStatus
              INTEGER,
            ipxCircCompressedSent
              Counter,
            ipxCircCompressedInitSent
              Counter,
            ipxCircCompressedRejectsSent
              Counter,
            ipxCircUncompressedSent
              Counter,
            ipxCircCompressedReceived
              Counter,
            ipxCircCompressedInitReceived
              Counter,
            ipxCircCompressedRejectsReceived
              Counter,
            ipxCircUncompressedReceived
              Counter,
            ipxCircMediaType
              INTEGER,
            ipxCircNetNumber
              NetNumber,
            ipxCircStateChanges
              Counter,
            ipxCircInitFails
              Counter,
            ipxCircDelay
              INTEGER,
            ipxCircThroughput
              INTEGER,
            ipxCircNeighRouterName
              OCTET STRING,
            ipxCircNeighInternalNetNum
              NetNumber
           }

ipxCircSysInstance OBJECT-TYPE
  SYNTAX      INTEGER
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The unique identifier of the instance of IPX
          to which this entry corresponds.  This value may be
          written only when creating a new entry in the table."
  ::= {ipxCircEntry 1}

ipxCircIndex OBJECT-TYPE
  SYNTAX      INTEGER
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The identifier of this circuit, unique within the
          instance of IPX.  This value may be written
          only when creating a new entry in the table."
  ::= {ipxCircEntry 2}

ipxCircExistState OBJECT-TYPE
  SYNTAX      INTEGER {
                off(1),
                on(2)
              }
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The validity of this circuit entry.  A circuit with this
          value set to off may be deleted from the table at the
          IPX implementation's discretion."
  ::= {ipxCircEntry 3}

ipxCircOperState OBJECT-TYPE
  SYNTAX      INTEGER {
                down(1),
                up(2),
                sleeping(3)
              }
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The operational state of the circuit."
  ::= {ipxCircEntry 4}

ipxCircIfIndex OBJECT-TYPE
  SYNTAX      INTEGER
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The value of ifIndex for the interface used by this
          circuit.  This value may be written only when creating
          a new entry in the table."
  ::= {ipxCircEntry 5}

ipxCircName OBJECT-TYPE
  SYNTAX      OCTET STRING (SIZE(0..48))
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The readable name for the circuit."
  ::= {ipxCircEntry 6}

ipxCircType OBJECT-TYPE
  SYNTAX      INTEGER {
                other(1),
                broadcast(2),
                ptToPt(3),
                wanRIP(4),
                unnumberedRIP(5),
                dynamic(6),
                wanWS(7)
              }
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The type of the circuit."
  ::= {ipxCircEntry 7}

ipxCircDialName OBJECT-TYPE
  SYNTAX      OCTET STRING (SIZE(0..48))
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The symbolic name used to refernce the dialing information
          used to create this circuit.  This value may be written
          only when creating a new entry in the table."
  ::= {ipxCircEntry 8}

ipxCircLocalMaxPacketSize OBJECT-TYPE
  SYNTAX      INTEGER
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The maximum size (including header), in bytes, that the
          system supports locally on this circuit."
  ::= {ipxCircEntry 9}

ipxCircCompressState OBJECT-TYPE
  SYNTAX      INTEGER {
                off(1),
                on(2)
              }
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The compression state on this circuit.  This value may
          be written only when creating a new entry in the table."
  DEFVAL      { off }
  ::= {ipxCircEntry 10}

ipxCircCompressSlots OBJECT-TYPE
  SYNTAX      INTEGER
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "The number of compression slots available on this
          circuit.  This value may be written only when creating a
          new entry in the table."
  DEFVAL      { 16 }
  ::= {ipxCircEntry 11}

ipxCircStaticStatus OBJECT-TYPE
  SYNTAX      INTEGER {
                unknown(1),
                current(2),
                changed(3),
                read(4),
                reading(5),
                write(6),
                writing(7)
              }
  ACCESS      read-write
  STATUS      mandatory
  DESCRIPTION "Indicates whether the information about static routes
          and services reached via this circuit matches that
          saved in permanent storage (current).  Setting the
          value to write when it had the value changed will write
          the currently in use information to permanent storage,
          if supported.  Setting the value to read when it had
          the value changed will replace any routes and services
          currently defined for the circuit with those read from
          permanent storage, if supported."
  ::= {ipxCircEntry 12}
```

```
ipxCircCompressedSent OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of compressed packets sent."
  ::= {ipxCircEntry 13}

ipxCircCompressedInitSent OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of compression initialization packets sent."
  ::= {ipxCircEntry 14}

ipxCircCompressedRejectsSent OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of compressed packet rejected packets sent."
  ::= {ipxCircEntry 15}

ipxCircUncompressedSent OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of packets sent without being compressed
          even though compression was turned on for this circuit."
  ::= {ipxCircEntry 16}

ipxCircCompressedReceived OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of compressed packets received."
  ::= {ipxCircEntry 17}

ipxCircCompressedInitReceived OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of compression initialization packets received."
  ::= {ipxCircEntry 18}

ipxCircCompressedRejectsReceived OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of compressed packet rejected packets received."
  ::= {ipxCircEntry 19}

ipxCircUncompressedReceived OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of packets received without having been
          compressed even though compression was turned on for
          this circuit."
  ::= {ipxCircEntry 20}

ipxCircMediaType OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(2))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The media type used on this circuit."
  ::= {ipxCircEntry 21}

ipxCircNetNumber OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number of this circuit."
  ::= {ipxCircEntry 22}

ipxCircStateChanges OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times the circuit has changed state."
  ::= {ipxCircEntry 23}

ipxCircInitFails OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times that initialization of this
          circuit has failed."
  ::= {ipxCircEntry 24}

ipxCircDelay OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The period of time, in microseconds, that it takes to
          transmit one byte of data, excluding protocol headers,
          to a destination on the other end of the circuit, if
          the circuit is free of other traffic."
  ::= {ipxCircEntry 25}

ipxCircThroughput OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The amount of data, in bits per second, that may flow
          through the circuit if there is no other traffic."
  ::= {ipxCircEntry 26}

ipxCircNeighRouterName OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(0..48))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The name of the neighboring router on a WAN circuit."
  ::= {ipxCircEntry 27}

ipxCircNeighInternalNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The internal network number of the neighboring router
          on a WAN circuit."
  ::= {ipxCircEntry 28}


– Forwarding Group
–  This group provides a representation of the forwarding database used
–  by all instances of IPX on the system.

– Destination Table
–  The Destination table contains information about all known
–  destinations. The routing information shown in this table represents
– the path currently being used to reach the destination.

ipxDestTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF IPXDestEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The Destination table contains information about all
          known destinations."
  ::= {ipxForwarding 1}

ipxDestEntry OBJECT-TYPE
  SYNTAX     IPXDestEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one destination."
  INDEX      {
          ipxDestSysInstance,
          ipxDestNetNum
          }
  ::= {ipxDestTable 1}

IPXDestEntry ::= SEQUENCE {
              ipxDestSysInstance
                INTEGER,
              ipxDestNetNum
                NetNumber,
              ipxDestProtocol
                INTEGER,
              ipxDestTicks
                INTEGER,
              ipxDestHopCount
                INTEGER,
              ipxDestNextHopCircIndex
                INTEGER,
              ipxDestNextHopNICAddress
                PhysAddress,
              ipxDestNextHopNetNum
                NetNumber
              }

ipxDestSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of IPX
          to which this row corresponds."
  ::= {ipxDestEntry 1}

ipxDestNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number of the destination."
  ::= {ipxDestEntry 2}

ipxDestProtocol OBJECT-TYPE
  SYNTAX     INTEGER {
               other(1),
               local(2),
               rip(3),
               nlsp(4),
               static(5)
               }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The routing protocol from which knowledge of this
          destination was obtained."
  ::= {ipxDestEntry 3}

ipxDestTicks OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The delay in ticks to reach this destination."
  ::= {ipxDestEntry 4}

ipxDestHopCount OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of hops necessary to reach the destination."
  ::= {ipxDestEntry 5}

ipxDestNextHopCircIndex OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the circuit used to reach the
          next hop."
  ::= {ipxDestEntry 6}

ipxDestNextHopNICAddress OBJECT-TYPE
  SYNTAX     PhysAddress
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NIC address of the next hop."
  ::= {ipxDestEntry 7}

ipxDestNextHopNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number of the next hop."
  ::= {ipxDestEntry 8}


– Static Routes Table
–  This table contains the information about all the static routes
–  defined.  There may be more than one static route to any given
–  destination.  Only the route currently being used will also be
–  present in the Destination Table defined above.

ipxStaticRouteTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF IPXStaticRouteEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The Static Routes table contains information about all
          destinations reached via statically configured routes."
  ::= {ipxForwarding 2}

ipxStaticRouteEntry OBJECT-TYPE
  SYNTAX     IPXStaticRouteEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one static route."
  INDEX      {
          ipxStaticRouteSysInstance,
          ipxStaticRouteCircIndex,
          ipxStaticRouteNetNum
          }
  ::= {ipxStaticRouteTable 1}

IPXStaticRouteEntry ::= SEQUENCE {
                ipxStaticRouteSysInstance
                  INTEGER,
                ipxStaticRouteCircIndex
                  INTEGER,
                ipxStaticRouteNetNum
                  NetNumber,
                ipxStaticRouteExistState
                  INTEGER,
                ipxStaticRouteTicks
                  INTEGER,
                ipxStaticRouteHopCount
                  INTEGER
                }

ipxStaticRouteSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of IPX to
          which this row corresponds."
  ::= {ipxStaticRouteEntry 1}

ipxStaticRouteCircIndex OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the circuit used to
          reach the first hop in the static route."
  ::= {ipxStaticRouteEntry 2}

ipxStaticRouteNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The IPX network number of the route's destination."
  ::= {ipxStaticRouteEntry 3}

ipxStaticRouteExistState OBJECT-TYPE
  SYNTAX     INTEGER {
               off(1),
               on(2)
             }
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The validity of this static route.  Entries with the
          value set to off may be deleted from the table at the
          implementation's discretion."
  ::= {ipxStaticRouteEntry 4}

ipxStaticRouteTicks OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The delay, in ticks, to reach the route's destination."
  ::= {ipxStaticRouteEntry 5}

ipxStaticRouteHopCount OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The number of hops necessary to reach the destination."
  ::= {ipxStaticRouteEntry 6}
```

```
-- Services Group
--  The Services group contains management information for all known
--  services.

-- Services Table
--  This table contains the services information indexed by service
--  name and type.

ipxServTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF IPXServEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The table of services, indexed by name and type."
  ::= {ipxServices 1}

ipxServEntry OBJECT-TYPE
  SYNTAX     IPXServEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one service."
  INDEX     {
          ipxServSysInstance,
          ipxServType,
          ipxServName
          }
  ::= {ipxServTable 1}

IPXServEntry ::= SEQUENCE {
             ipxServSysInstance
               INTEGER,
             ipxServType
               OCTET STRING,
             ipxServName
               OCTET STRING,
             ipxServProtocol
               INTEGER,
             ipxServNetNum
               NetNumber,
             ipxServNode
               OCTET STRING,
             ipxServSocket
               OCTET STRING,
             ipxServHopCount
               INTEGER
             }

ipxServSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of IPX
          to which this entry corresponds."
  ::= {ipxServEntry 1}

ipxServType OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(2))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The service type."
  ::= {ipxServEntry 2}

ipxServName OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(1..48))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The service name."
  ::= {ipxServEntry 3}

ipxServProtocol OBJECT-TYPE
  SYNTAX     INTEGER {
               other(1),
               local(2),
               nlsp(4),
               static(5),
               sap(6)
             }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The protocol from which knowledge of this service was
          obtained."
  ::= {ipxServEntry 4}

ipxServNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number portion of the IPX address of the
          service."
  ::= {ipxServEntry 5}

ipxServNode OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(6))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The node portion of the IPX address of the service."
  ::= {ipxServEntry 6}

ipxServSocket OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(2))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The socket portion of the IPX address of the service."
  ::= {ipxServEntry 7}

ipxServHopCount OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of hops to the service."
  ::= {ipxServEntry 8}


– Destination Services Table
–  This table contains the services information indexed by address,
–  name, and type.

ipxDestServTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF IPXDestServEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The table of services, indexed by address, name,
          and type."
  ::= {ipxServices 2}

ipxDestServEntry OBJECT-TYPE
  SYNTAX     IPXDestServEntry
  ACCESS     not-accessible
  STATUS     mandatory
```

```
  DESCRIPTION "Each entry corresponds to one service."
  INDEX      {
               ipxDestServSysInstance,
               ipxDestServNetNum,
               ipxDestServNode,
               ipxDestServSocket,
               ipxDestServName,
               ipxDestServType
             }
  ::= {ipxDestServTable 1}

IPXDestServEntry ::= SEQUENCE {
               ipxDestServSysInstance
                 INTEGER,
               ipxDestServNetNum
                 NetNumber,
               ipxDestServNode
                 OCTET STRING,
               ipxDestServSocket
                 OCTET STRING,
               ipxDestServName
                 OCTET STRING,
               ipxDestServType
                 OCTET STRING,
               ipxDestServProtocol
                 INTEGER,
               ipxDestServHopCount
                 INTEGER
               }

ipxDestServSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of IPX
          to which this entry corresponds."
  ::= {ipxDestServEntry 1}

ipxDestServNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number portion of the IPX address of the
          service."
  ::= {ipxDestServEntry 2}

ipxDestServNode OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(6))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The node portion of the IPX address of the service."
  ::= {ipxDestServEntry 3}

ipxDestServSocket OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(2))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The socket portion of the IPX address of the service."
  ::= {ipxDestServEntry 4}

ipxDestServName OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(1..48))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The service name."
  ::= {ipxDestServEntry 5}

ipxDestServType OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(2))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The service type."
  ::= {ipxDestServEntry 6}

ipxDestServProtocol OBJECT-TYPE
  SYNTAX     INTEGER {
              other(1),
              local(2),
              nlsp(4),
              static(5),
              sap(6)
             }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The protocol from which knowledge of this service was
          obtained."
  ::= {ipxDestServEntry 7}

ipxDestServHopCount OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of hops to the service."
  ::= {ipxDestServEntry 8}


– Static Services Table
–  This table contains information for all services reached via a
–  static route.

ipxStaticServTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF IPXStaticServEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The Static Services table contains information about
          all services reached via statically configured routes."
  ::= {ipxServices 3}

ipxStaticServEntry OBJECT-TYPE
  SYNTAX     IPXStaticServEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one service."
  INDEX      {
          ipxStaticServSysInstance,
          ipxStaticServCircIndex,
          ipxStaticServName,
          ipxStaticServType
         }
  ::= {ipxStaticServTable 1}

IPXStaticServEntry ::= SEQUENCE {
                ipxStaticServSysInstance
                  INTEGER,
                ipxStaticServCircIndex
                  INTEGER,
                ipxStaticServName
                  OCTET STRING,
                ipxStaticServType
                  OCTET STRING,
                ipxStaticServExistState
                  INTEGER,
                ipxStaticServNetNum
                  NetNumber,
                ipxStaticServNode
                  OCTET STRING,
                ipxStaticServSocket
                  OCTET STRING,
                ipxStaticServHopCount
                  INTEGER
                }

ipxStaticServSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of IPX to which
          this entry corresponds."
  ::= {ipxStaticServEntry 1}

ipxStaticServCircIndex OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The circuit used to reach this service."
  ::= {ipxStaticServEntry 2}

ipxStaticServName OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(1..48))
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The service name."
  ::= {ipxStaticServEntry 3}

ipxStaticServType OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(2))
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The service type."
  ::= {ipxStaticServEntry 4}

ipxStaticServExistState OBJECT-TYPE
  SYNTAX     INTEGER {
              off(1),
              on(2)
             }
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The validity of this static service.  Entries with the
          value set to off may be deleted from the table at the
          implementation's discretion."
  ::= {ipxStaticServEntry 5}

ipxStaticServNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The IPX network number portion of the IPX address of the
          service."
  ::= {ipxStaticServEntry 6}

ipxStaticServNode OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(6))
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The node portion of the IPX address of the service."
  ::= {ipxStaticServEntry 7}

ipxStaticServSocket OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(2))
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The socket portion of the IPX address of the service."
  ::= {ipxStaticServEntry 8}

ipxStaticServHopCount OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The number of hops to the service."
  ::= {ipxStaticServEntry 9}


-- Traps
-- The section describes the traps defined for IPX.

ipxTrapCircuitDown TRAP-TYPE
  ENTERPRISE   ipxTraps
  VARIABLES    {
            ipxCircSysInstance,
            ipxCircIndex
           }
  DESCRIPTION   "This trap signifies that the specified circuit has
            gone down."
  ::= 1

ipxTrapCircuitUp TRAP-TYPE
  ENTERPRISE   ipxTraps
  VARIABLES    {
            ipxCircSysInstance,
            ipxCircIndex
           }
  DESCRIPTION   "This trap signifies that the specified circuit has
            come up."
  ::= 2

END
```

10.7. RIP/SAP MIB

```
RIPSAP DEFINITIONS ::= BEGIN

– This MIB defines the management information for the RIP and SAP
– protocols running in an IPX enviroment.  It provides information in
– addition to that contained in the IPX MIB itself.  All tables in this
– MIB are linked to an instance of IPX via the system instance
– identifier as defined in the IPX MIB.


IMPORTS
   enterprises, Counter
         FROM RFC1155-SMI
   OBJECT-TYPE
         FROM RFC-1212
   PhysAddress
         FROM RFC1213-MIB;

novell     OBJECT IDENTIFIER ::= {enterprises 23}
mibDoc       OBJECT IDENTIFIER ::= {novell 2}
ripsap     OBJECT IDENTIFIER ::= {mibDoc 20}


– Groups

ripsapSystem  OBJECT IDENTIFIER ::= {ripsap 1}
ripsapCircuit OBJECT IDENTIFIER ::= {ripsap 2}


– Types

NetNumber ::= OCTET STRING (SIZE(4))


– System Group
–   This group contains global information about each instance of
–   RIP/SAP running on one system.

– RIP System Table
–   This table contains an entry for each instance of RIP
–   running on the system.

ripSysTable OBJECT-TYPE
   SYNTAX      SEQUENCE OF RIPSysEntry
   ACCESS      not-accessible
   STATUS      mandatory
   DESCRIPTION "The RIP system table."
   ::= {ripsapSystem 1}

ripSysEntry OBJECT-TYPE
   SYNTAX      RIPSysEntry
   ACCESS      not-accessible
   STATUS      mandatory
   DESCRIPTION "Each entry corresponds to one instance of RIP
            running on the system."
   INDEX      {ripSysInstance}
   ::= {ripSysTable 1}

RIPSysEntry ::= SEQUENCE {
                ripSysInstance
                   INTEGER,
                ripSysState
                   INTEGER,
                ripSysIncorrectPackets
                   Counter
                }

ripSysInstance OBJECT-TYPE
   SYNTAX      INTEGER
   ACCESS      read-write
   STATUS      mandatory
   DESCRIPTION "The unique identifier of the instance of RIP to
            which this row corresponds.  This value links the
            instance of RIP to an instance of IPX running on the
            system  (i.e. the value of ripSysInstance should be the
            same as a value of ipxSysInstance).  This value may be
            written only when creating a new entry in the table."
   ::= {ripSysEntry 1}

ripSysState OBJECT-TYPE
   SYNTAX      INTEGER {
                 off(1),
                 on(2)
                }
   ACCESS      read-write
   STATUS      mandatory
   DESCRIPTION "Indicates the operational state of this instance of RIP."
   ::= {ripSysEntry 2}

ripSysIncorrectPackets OBJECT-TYPE
   SYNTAX      Counter
   ACCESS      read-only
   STATUS      mandatory
   DESCRIPTION "The number of times that an incorrectly formatted RIP
            packet was received."
   ::= {ripSysEntry 3}


– SAP System Table
–   This table contains an entry for each instance of SAP
–   running on the system.

sapSysTable OBJECT-TYPE
   SYNTAX      SEQUENCE OF SAPSysEntry
   ACCESS      not-accessible
   STATUS      mandatory
   DESCRIPTION "The SAP system table."
   ::= {ripsapSystem 2}

sapSysEntry OBJECT-TYPE
   SYNTAX      SAPSysEntry
   ACCESS      not-accessible
   STATUS      mandatory
   DESCRIPTION "Each entry corresponds to one instance of SAP
            running on the system."
   INDEX      {sapSysInstance}
   ::= {sapSysTable 1}

SAPSysEntry ::= SEQUENCE {
                ripSysInstance
                   INTEGER,
                sapSysState
                   INTEGER,
                sapSysIncorrectPackets
                   Counter
                }
```

```
sapSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of SAP to
          which this row corresponds. This value links the
          instance of SAP to an instance of IPX running on the
          system (i.e. the value of SApSysInstance should be the
          same as a value of ipxSysInstance). This value may be
          written only when creating a new entry in the table."
  ::= {sapSysEntry 1}

sapSysState OBJECT-TYPE
  SYNTAX     INTEGER {
              off(1),
              on(2)
             }
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "Indicates the operational state of this instance of SAP."
  ::= {sapSysEntry 2}

sapSysIncorrectPackets OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times that an incorrectly formatted SAP
          packet was received."
  ::= {sapSysEntry 3}


- Circuit Group
-  This group contains RIP and SAP management information for each
-  circuit known to this system.

- RIP Circuit Table
-  The RIP Circuit table contains an entry for the RIP information for
-  each circuit known to the system.

ripCircTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF RIPCircEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The RIP Circuit table."
  ::= {ripsapCircuit 1}

ripCircEntry OBJECT-TYPE
  SYNTAX     RIPCircEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one circuit known to the
          system."
  INDEX     {
          ripCircSysInstance,
          ripCircIndex
          }
  ::= {ripCircTable 1}

RIPCircEntry ::= SEQUENCE {
              ripCircSysInstance
                INTEGER,
              ripCircIndex
                INTEGER,
              ripCircState
                INTEGER,
              ripCircPace
                INTEGER,
              ripCircUpdate
                INTEGER,
              ripCircAgeMultiplier
                INTEGER,
              ripCircPacketSize
                INTEGER,
              ripCircOutPackets
                Counter,
              ripCircInPackets
                Counter
              }

ripCircSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of RIP and IPX
          (via ipxSysInstance) to which this entry corresponds.
          This value may be written only when creating a new entry in
          the table."
  ::= {ripCircEntry 1}

ripCircIndex OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The identifier of this circuit, unique within the
          instance of RIP. This value corresponds to the circuit
          identifier found in ipxCircIndex. This value may be
          written only when creating a new entry in the table."
  ::= {ripCircEntry 2}

ripCircState OBJECT-TYPE
  SYNTAX     INTEGER {
              off(1),
              on(2),
              auto-on(3),
              auto-off(4)
             }
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "Indicates whether RIP information may be sent/received
          over this circuit."
  DEFVAL     { auto-off }
  ::= {ripCircEntry 3}

ripCircPace OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The maximum pace, in packets per second, at which RIP
          packets may be sent on this circuit."
  ::= {ripCircEntry 4}

ripCircUpdate OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The RIP periodic update interval, in seconds."
  DEFVAL     { 60 }
  ::= {ripCircEntry 5}

ripCircAgeMultiplier OBJECT-TYPE
```

```
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The holding multiplier for information received in RIP
          periodic updates."
  DEFVAL    { 4 }
  ::= {ripCircEntry 6}

ripCircPacketSize OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The RIP packet size used on this circuit."
  ::= {ripCircEntry 7}

ripCircOutPackets OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of RIP packets sent on this circuit."
  ::= {ripCircEntry 8}

ripCircInPackets OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of RIP packets received on this circuit."
  ::= {ripCircEntry 9}


- SAP Circuit Table
-  The SAP Circuit table contains an entry for the SAP information for
-  each circuit known to the system.

sapCircTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF SAPCircEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The SAP Circuit table."
  ::= {ripsapCircuit 2}

sapCircEntry OBJECT-TYPE
  SYNTAX     SAPCircEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one circuit known to the
          system."
  INDEX      {
          sapCircSysInstance,
          sapCircIndex
          }
  ::= {sapCircTable 1}

SAPCircEntry ::= SEQUENCE {
            sapCircSysInstance
              INTEGER,
            sapCircIndex
              INTEGER,
            sapCircState
              INTEGER,
            sapCircPace
              INTEGER,
            sapCircUpdate
              INTEGER,
            sapCircAgeMultiplier
              INTEGER,
            sapCircPacketSize
              INTEGER,
            sapCircGetNearestServerReply
              INTEGER,
            sapCircOutPackets
              Counter,
            sapCircInPackets
              Counter
            }

sapCircSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of SAP and IPX
          (via ipxSysInstance) to which this entry corresponds.
          This value may be written only when creating a new entry in
          the table."
  ::= {sapCircEntry 1}

sapCircIndex OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The identifier of this circuit, unique within the
          instance of SAP.  This value corresponds to the circuit
          identifier found in ipxCircIndex.   This value may be
          written only when creating a new entry in the table."
  ::= {sapCircEntry 2}

sapCircState OBJECT-TYPE
  SYNTAX     INTEGER {
              off(1),
              on(2),
              auto-on(3),
              auto-off(4)
              }
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "Indicates whether SAP information may be sent/received
          over this circuit."
  DEFVAL     { auto-off }
  ::= {sapCircEntry 3}

sapCircPace OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The maximum pace, in packets per second, at which SAP
          packets may be sent on this circuit."
  ::= {sapCircEntry 4}

sapCircUpdate OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The SAP periodic update interval, in seconds."
  DEFVAL     { 60 }
  ::= {sapCircEntry 5}

sapCircAgeMultiplier OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The holding multiplier for information received in SAP
          periodic updates."
  DEFVAL    { 4 }
  ::= {sapCircEntry 6}

sapCircPacketSize OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The SAP packet size used on this circuit."
  ::= {sapCircEntry 7}

sapCircGetNearestServerReply OBJECT-TYPE
  SYNTAX     INTEGER {
              no(1),
              yes(2)
             }
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "Indicates whether to respond to SAP get nearest server
          requests received on this circuit."
  DEFVAL    { yes }
  ::= {sapCircEntry 8}

sapCircOutPackets OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of SAP packets sent on this circuit."
  ::= {sapCircEntry 9}

sapCircInPackets OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of SAP packets received on this circuit."
  ::= {sapCircEntry 10}

END
```

10.8. NLSP MIB

This is a preliminary version of the NLSP MIB which includes the addition of Aggregated Routes. It is currently subject to change.

```
NLSP DEFINITIONS ::= BEGIN

– This MIB defines the management information for the NLSP protocol
– running in an IPX enviroment. It provides information in addition
– to that contained in the IPX MIB itself. All tables in this MIB are
– linked to an instance of IPX via the system instance identifier as
– defined in the IPX MIB.
–
– Change History:
–
– 01/11/94
–   The following DEFVAL values were changed to match the NLSP
–   specification:
–
–     nlspSysMinNonBcastLSPTransInt  5 -> 10
–     nlspSysBcastHelloInt          10 -> 20
–     nlspSysNonBcastHelloInt       10 -> 20
–     nlspSysHoldMult                5 -> 3
–     nlspSysPartSNPInt              5 -> 1
–     nlspCircHelloTimer            10 -> 20
–
–   The units of nlspDestEstDelay, nlspNodeEstDelay, and nlspLinkDelay
–   were changed from milliseconds to microseconds.

– 08/09/95
–   Added Aggregated Routes Table to the Forwarding group
–   and Circuit Aggregated Routes table to the Circuit group.

IMPORTS
  enterprises, Counter
        FROM RFC1155-SMI
  OBJECT-TYPE
        FROM RFC-1212
  PhysAddress
        FROM RFC1213-MIB;

novell OBJECT IDENTIFIER ::= {enterprises 23}
mibDoc OBJECT IDENTIFIER ::= { novell 2 }
nlsp   OBJECT IDENTIFIER ::= {mibDoc 19}


– Groups

nlspSystem       OBJECT IDENTIFIER ::= {nlsp 1}
nlspCircuit      OBJECT IDENTIFIER ::= {nlsp 2}
nlspForwarding   OBJECT IDENTIFIER ::= {nlsp 3}
nlspNeighbors    OBJECT IDENTIFIER ::= {nlsp 4}
nlspTranslation  OBJECT IDENTIFIER ::= {nlsp 5}
nlspGraph        OBJECT IDENTIFIER ::= {nlsp 6}
nlspLSP          OBJECT IDENTIFIER ::= {nlsp 7}


– Types –

SystemID  ::= OCTET STRING (SIZE(6))
NLSPID    ::= OCTET STRING (SIZE(7))
NetNumber ::= OCTET STRING (SIZE(4))


– System Group
–  This group contains global information about each instance of NLSP
–  running on one system.

– System Table
–  This table contains an entry for each instance of NLSP running on
–  the system.

nlspSysTable OBJECT-TYPE
  SYNTAX      SEQUENCE OF NLSPSysEntry
  ACCESS      not-accessible
  STATUS      mandatory
  DESCRIPTION "The NLSP system table."
  ::= {nlspSystem 1}

nlspSysEntry OBJECT-TYPE
  SYNTAX      NLSPSysEntry
  ACCESS      not-accessible
  STATUS      mandatory
  DESCRIPTION "Each entry corresponds to one instance of NLSP running
          on the system."
  INDEX       {nlspSysInstance}
  ::= {nlspSysTable 1}

NLSPSysEntry ::= SEQUENCE {
              nlspSysInstance
                INTEGER,
              nlspSysState
                INTEGER,
              nlspSysID
                SystemID,
              nlspSysMinNonBcastLSPTransInt
                INTEGER,
              nlspSysMinBcastLSPTransInt
                INTEGER,
              nlspSysMinLSPGenInt
                INTEGER,
              nlspSysMaxLSPGenInt
                INTEGER,
              nlspSysMaxLSPAge
                INTEGER,
              nlspSysBcastHelloInt
                INTEGER,
              nlspSysNonBcastHelloInt
                INTEGER,
              nlspSysDRBcastHelloInt
                INTEGER,
              nlspSysHoldTimeMultiplier
                INTEGER,
              nlspSysCompSNPInt
                INTEGER,
              nlspSysPartSNPInt
                INTEGER,
              nlspSysWaitTime
                INTEGER,
              nlspSysOrigL1LSPBufSize
                INTEGER,
              nlspSysVersion
                INTEGER,
              nlspSysCorrLSPs
```

```
            Counter,
          nlspSysL1Overloaded
            INTEGER,
          nlspSysL1DbaseOverloads
            Counter,
          nlspSysMaxSeqNums
            Counter,
          nlspSysSeqNumSkips
            Counter,
          nlspSysTransmittedLSPs
            Counter,
          nlspSysReceivedLSPs
            Counter,
          nlspSysOwnLSPPurges
            Counter,
          nlspSysVersionErrors
            Counter,
          nlspSysIncorrectPackets
            Counter,
          nlspSysNearestL2DefaultExists
            INTEGER,
          nlspSysNearestL2DefaultRouter
            SystemID,
          nlspSysResourceFailures
            Counter,
          }

nlspSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP to which this
          corresponds. This value links the instance of NLSP to an
          instance of IPX running on the system (i.e. the value
          of nlspSysInstance should be the same as a value of
          ipxSysInstance). This value may be written only when
          creating a new entry in the table."
  ::= {nlspSysEntry 1}

nlspSysState OBJECT-TYPE
  SYNTAX     INTEGER {
              off(1),
              nlspLevel1Router(2)
             }
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "Indicates the operational state of this instance of NLSP."
  ::= {nlspSysEntry 2}

nlspSysID OBJECT-TYPE
  SYNTAX     SystemID
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The system ID for this instance of NLSP."
  ::= {nlspSysEntry 3}

nlspSysMinNonBcastLSPTransInt OBJECT-TYPE
  SYNTAX     INTEGER (1..30)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The minimum interval, in seconds, between transmission
          of LSPs on a non-broadcast circuit."
  DEFVAL     { 10 }
  ::= {nlspSysEntry 4}

nlspSysMinBcastLSPTransInt OBJECT-TYPE
  SYNTAX     INTEGER (1..30)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The minimum interval, in seconds, between transmission
          of LSPs on a broadcast circuit."
  DEFVAL     { 5 }
  ::= {nlspSysEntry 5}

nlspSysMinLSPGenInt OBJECT-TYPE
  SYNTAX     INTEGER (1..30)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The minimum interval, in seconds, between the generation
          of the same LSP."
  DEFVAL     { 5 }
  ::= {nlspSysEntry 6}

nlspSysMaxLSPGenInt OBJECT-TYPE
  SYNTAX     INTEGER (1..50000)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The maximum interval, in seconds, between the generation
          of the same LSP."
  DEFVAL     { 7200 }
  ::= {nlspSysEntry 7}

nlspSysMaxLSPAge OBJECT-TYPE
  SYNTAX     INTEGER (1..50000)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The value, in seconds, placed in the lifetime field of
          LSPs generated by this instance of NLSP."
  DEFVAL     { 7500 }
  ::= {nlspSysEntry 8}

nlspSysBcastHelloInt OBJECT-TYPE
  SYNTAX     INTEGER (1..100)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The interval, in seconds, at which NLSP Hellos will be
          sent on a broadcast circuit, if this system is not the
          designated router."
  DEFVAL     { 20 }
  ::= {nlspSysEntry 9}

nlspSysNonBcastHelloInt OBJECT-TYPE
  SYNTAX     INTEGER (1..100)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The interval, in seconds, at which NLSP Hellos will be
          sent on a non-broadcast circuit."
  DEFVAL     { 20 }
  ::= {nlspSysEntry 10}

nlspSysDRBcastHelloInt OBJECT-TYPE
  SYNTAX     INTEGER (1..100)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The interval, in seconds, at which the designated
          router sends NLSP Hellos on a broadcast circuit."
  DEFVAL     { 3 }
  ::= {nlspSysEntry 11}

nlspSysHoldTimeMultiplier OBJECT-TYPE
```

```
  SYNTAX     INTEGER (2..20)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The holding time multiplier used to specify the holding
          time for NLSP neighbor entries as a function of the NLSP
          Hello interval."
  DEFVAL    { 3 }
  ::= {nlspSysEntry 12}

nlspSysCompSNPInt OBJECT-TYPE
  SYNTAX     INTEGER (1..600)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The interval, in seconds, between generation of Complete
          Sequence Number Packets by a designated router on a
          broadcast circuit."
  DEFVAL    { 30 }
  ::= {nlspSysEntry 13}

nlspSysPartSNPInt OBJECT-TYPE
  SYNTAX     INTEGER (1..60)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The minimum interval, in seconds, between transmission of
          Partial Sequence Number Packets."
  DEFVAL    { 1 }
  ::= {nlspSysEntry 14}

nlspSysWaitTime OBJECT-TYPE
  SYNTAX     INTEGER (1..300)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The number of seconds to delay in the waiting state
          before entering the on state."
  DEFVAL    { 120 }
  ::= {nlspSysEntry 15}

nlspSysOrigL1LSPBufSize OBJECT-TYPE
  SYNTAX     INTEGER (512..4096)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The maximum size of Level 1 LSPs originated by
          this instance of NLSP."
  DEFVAL    { 512 }
  ::= {nlspSysEntry 16}

nlspSysVersion OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The version number of this instance of NLSP."
  ::= {nlspSysEntry 17}

nlspSysCorrLSPs OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of corrupt LSPs detected."
  ::= {nlspSysEntry 18}

nlspSysL1Overloaded OBJECT-TYPE
  SYNTAX     INTEGER {
               no(1),
               yes(2)
             }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "Indicates whether the NLSP Level 1 database is overloaded."
  ::= {nlspSysEntry 19}

nlspSysL1DbaseOloads OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times the NLSP Level 1 LSP database has
          become overloaded."
  ::= {nlspSysEntry 20}

nlspSysMaxSeqNums OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times the router has attempted to exceed
          NLSP's maximum sequence number."
  ::= {nlspSysEntry 21}

nlspSysSeqNumSkips OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times a sequence number skip has occurred."
  ::= {nlspSysEntry 22}

nlspSysTransmittedLSPs OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of LSPs transmitted by this system."
  ::= {nlspSysEntry 23}

nlspSysReceivedLSPs OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of LSPs received by this system."
  ::= {nlspSysEntry 24}

nlspSysOwnLSPPurges OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times a zero-aged copy of the router's own
          LSP has been received from some other node."
  ::= {nlspSysEntry 25}

nlspSysVersionErrors OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times that a received NLSP packet was
          rejected because its version number was invalid."
  ::= {nlspSysEntry 26}

nlspSysIncorrectPackets OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times that an incorrectly formatted NLSP
          packet was received."
  ::= {nlspSysEntry 27}
```

```
nlspSysNearestL2DefaultExists OBJECT-TYPE
  SYNTAX     INTEGER {
                no(1),
                yes(2)
               }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "Indicates whether this instance of NLSP knows
           of a NLSP Level 2 router that currently can reach other
           areas using the default metric."
  ::= {nlspSysEntry 28}

nlspSysNearestL2DefaultRouter OBJECT-TYPE
  SYNTAX     SystemID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The system ID of the nearest NLSP Level 2 router that
           currently can reach other areas using the default
           metric.  The value is undefined if the value of
           nlspSysNearestL2DefaultExists is no."
  ::= {nlspSysEntry 29}

nlspSysResourceFailures OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times this instance of the NLSP has been
           unable to obtain needed resources (memory, etc.)"
  ::= {nlspSysEntry 30}


- System Area Address Table
-  The System Area Address table contains the area addresses configured
-  for NLSP.

nlspSysAreaTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPSysAreaEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The System Area Address table contains the area addresses
           configured for NLSP."
  ::= {nlspSystem 2}

nlspSysAreaEntry OBJECT-TYPE
  SYNTAX     NLSPSysAreaEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry in the table corresponds to one NLSP
           System Area Address."
  INDEX     {
           nlspSysAreaSysInstance,
           nlspSysAreaNet,
           nlspSysAreaMask
           }
  ::= {nlspSysAreaTable 1}

NLSPSysAreaEntry ::= SEQUENCE {
                 nlspSysAreaSysInstance
                   INTEGER,
                 nlspSysAreaNet
                   OCTET STRING,
                 nlspSysAreaMask
                   OCTET STRING
                 }
```

```
nlspSysAreaSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
           (via ipxSysInstance) to which this row corresponds."
  ::= {nlspSysAreaEntry 1}

nlspSysAreaNet OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(4))
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The network address portion of the area address."
  ::= {nlspSysAreaEntry 2}

nlspSysAreaMask OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(4))
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The mask portion of the area address."
  ::= {nlspSysAreaEntry 3}


- Actual Area Address Table
-  The Actual Area Address table contains the area addresses actually
-  used by NLSP.

nlspActAreaTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPActAreaEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The Actual Area Address table contains the area addresses
           actually used by NLSP."
  ::= {nlspSystem 3}

nlspActAreaEntry OBJECT-TYPE
  SYNTAX     NLSPActAreaEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry in the table corresponds to one NLSP
           Actual Area Address."
  INDEX     {
           nlspActAreaSysInstance,
           nlspActAreaNet,
           nlspActAreaMask
           }
  ::= {nlspActAreaTable 1}

NLSPActAreaEntry ::= SEQUENCE {
                 nlspActAreaSysInstance
                   INTEGER,
                 nlspActAreaNet
                   OCTET STRING,
                 nlspActAreaMask
                   OCTET STRING
                 }

nlspActAreaSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
           (via ipxSysInstance) to which this row corresponds."
  ::= {nlspActAreaEntry 1}
```

```
nlspActAreaNet OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(4))
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The network address portion of the area address."
  ::= {nlspActAreaEntry 2}

nlspActAreaMask OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(4))
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The mask portion of the area address."
  ::= {nlspActAreaEntry 3}


– Circuit Group
–  This group contains the NLSP information for each circuit known
–  to this system.

– Circuit Table
–  The Circuit table contains an entry containing the NLSP information
–  for each circuit known to the system.

nlspCircTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPCircEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The Circuit table."
  ::= {nlspCircuit 1}

nlspCircEntry OBJECT-TYPE
  SYNTAX     NLSPCircEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one circuit known to the
          system."
  INDEX     {
          nlspCircSysInstance,
          nlspCircIndex
          }
  ::= {nlspCircTable 1}

NLSPCircEntry ::= SEQUENCE {
               nlspCircSysInstance
                 INTEGER,
               nlspCircIndex
                 INTEGER,
               nlspCircState
                 INTEGER,
               nlspCircPace
                 INTEGER,
               nlspCircHelloTimer
                 INTEGER,
               nlspCircL1DefaultCost
                 INTEGER,
               nlspCircL1DesRouterPriority
                 INTEGER,
               nlspCircL1CircID
                 OCTET STRING,
               nlspCircL1DesRouter
                 SystemID,
               nlspCircLANL1DesRouterChanges
                 Counter,
               nlspCircNeighChanges
                 Counter,
               nlspCircRejNeighbors
                 Counter,
               nlspCircOutPackets
                 Counter,
               nlspCircInPackets
                 Counter,
               nlspCircActualMaxPacketSize
                 INTEGER,
               nlspCircPSNPsSent
                 Counter,
               nlspCircPSNPsReceived
                 Counter
               }

nlspCircSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
          (via ipxSysInstance) to which this entry corresponds.
          This value may be written only when creating a new
          entry in the table."
  ::= {nlspCircEntry 1}

nlspCircIndex OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The identifier of this circuit, unique within the
          instance of NLSP.  This value may be written
          only when creating a new entry in the table."
  ::= {nlspCircEntry 2}

nlspCircState OBJECT-TYPE
  SYNTAX     INTEGER {
              off(1),
              on(2)
             }
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "Indicates whether NLSP information may be sent/received
          over this circuit."
  DEFVAL     { on }
  ::= {nlspCircEntry 3}

nlspCircPace OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The maximum pace, in packets per second, at which NLSP
          packets may be sent on this circuit."
  ::= {nlspCircEntry 4}

nlspCircHelloTimer OBJECT-TYPE
  SYNTAX     INTEGER (1..100)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The interval, in seconds, between NLSP Hello packets
          sent on this circuit."
  DEFVAL     { 20 }
  ::= {nlspCircEntry 5}

nlspCircL1DefaultCost OBJECT-TYPE
  SYNTAX     INTEGER (1..63)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The NLSP default cost of this circuit for Level 1
          traffic."
  ::= {nlspCircEntry 6}

nlspCircL1DesRouterPriority OBJECT-TYPE
  SYNTAX     INTEGER (1..127)
  ACCESS     read-write
  STATUS     mandatory
  DESCRIPTION "The priority for becoming the NLSP LAN Level 1
          Designated Router on a broadcast circuit."
  ::= {nlspCircEntry 7}

nlspCircL1CircID OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(7))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NLSP ID for this circuit."
  ::= {nlspCircEntry 8}

nlspCircL1DesRouter OBJECT-TYPE
  SYNTAX     SystemID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The system ID of the NLSP LAN Level 1 Designated Router
          on this circuit."
  ::= {nlspCircEntry 9}

nlspCircLANL1DesRouterChanges OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times the NLSP LAN Level 1 Designated
          Router has changed on this circuit."
  ::= {nlspCircEntry 10}

nlspCircNeighChanges OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times a NLSP neighbor state change has
          occurred on this circuit."
  ::= {nlspCircEntry 11}

nlspCircRejNeighbors OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of times that a NLSP neighbor has been
          rejected on this circuit."
  ::= {nlspCircEntry 12}

nlspCircOutPackets OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of NLSP packets sent on this circuit."
  ::= {nlspCircEntry 13}

nlspCircInPackets OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of NLSP packets received on this circuit."
```

```
  ::= {nlspCircEntry 14}

nlspCircActualMaxPacketSize OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The actual maximum packet size (including header),
          in bytes, that has been used on this circuit."
  ::= {nlspCircEntry 15}

nlspCircPSNPsSent OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of PSNPs sent on this circuit."
  ::= {nlspCircEntry 16}

nlspCircPSNPsReceived OBJECT-TYPE
  SYNTAX     Counter
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of PSNPs received on this circuit."
  ::= {nlspCircEntry 17}


– Circuit Aggregated Routes Table
–  The Circuit Aggregated Routes table contains information about the
–  aggregated routes configured on each circuit.

nlspCircAggRouteTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPCircAggRouteEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The Aggregated Route table contains information about the
          aggregated routes configured on a circuit."
  ::= {nlspCircuit 2}

nlspCircAggRouteEntry OBJECT-TYPE
  SYNTAX     NLSPCircAggRouteEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one aggregated route."
  INDEX      {
          nlspCircAggRouteSysInstance,
          nlspCircAggRouteCircIndex,
          nlspCircAggRouteNetNum,
          nlspCircAggRouteMaskLength
          }
  ::= {nlspCircAggRouteTable 1}

NLSPCircAggRouteEntry ::= SEQUENCE {
   ÿÿ•2•         É™•r•••lÁpP
pCircAggRouteSysInstance
                         INTEGER,
                       nlspCircAggRouteCircIndex
                         INTEGER,
                       nlspCircAggRouteNetNum
                         NetNumber,
                       nlspCircAggRouteMaskLength
                         INTEGER,
                       nlspCircAggRouteTicks
                         INTEGER,
                       nlspCircAggRouteAreaCount
                         INTEGER,
                       nlspCircAggStatus
```

```
                    INTEGER
                }

nlspCircAggRouteSysInstance OBJECT-TYPE
    SYNTAX      INTEGER
    ACCESS      read-write
    STATUS      mandatory
    DESCRIPTION "The unique identifier of the instance of NLSP and IPX
            (via ipxSysInstance) to which this row corresponds."
    ::= {nlspCircAggRouteEntry 1}

nlspCircAggRouteCircIndex OBJECT-TYPE
    SYNTAX      INTEGER
    ACCESS      read-write
    STATUS      mandatory
    DESCRIPTION "The circuit on which the summary is
            configured."
    ::= {nlspCircAggRouteEntry 2}

nlspCircAggRouteNetNum OBJECT-TYPE
    SYNTAX      NetNumber
    ACCESS      read-write
    STATUS      mandatory
    DESCRIPTION "The address summary."
    ::= {nlspCircAggRouteEntry 3}

nlspCircAggRouteMaskLength OBJECT-TYPE
    SYNTAX      INTEGER (0..32)
    ACCESS      read-write
    STATUS      mandatory
    DESCRIPTION "Length in bits of the address summary."
    ::= {nlspCircAggRouteEntry 4}

nlspCircAggRouteTicks OBJECT-TYPE
    SYNTAX      INTEGER
    ACCESS      read-write
    STATUS      mandatory
    DESCRIPTION "The delay in ticks to ???."
    ::= {nlspCircAggRouteEntry 5}

nlspCircAggRouteAreaCount OBJECT-TYPE
    SYNTAX      INTEGER
    ACCESS      read-write
    STATUS      mandatory
    DESCRIPTION "The number of areas into which this aggregated
            route can be leaked."
    ::= {nlspCircAggRouteEntry 6}

nlspCircAggRouteStatus OBJECT-TYPE
    SYNTAX      INTEGER {
                    unknown(1),
                    current(2),
                    changed(3),
                    read(4),
                    reading(5),
                    write(6),
                    writing(7)
                }
    ACCESS      read-write
    STATUS      mandatory
    DESCRIPTION "Indicates whether the information about the aggregated
            routes configured on this circuit matches that
            saved in permanent storage (current).  Setting the
            value to write when it had the value changed will write
            the currently in use information to permanent storage,
            if supported.  Setting the value to read when it had
            the value changed will replace any routes and services
            currently defined for the circuit with those read from
            permanent storage, if supported."
    ::= {nlspCircAggRouteEntry 7}



– Forwarding Group
–   This group contains NLSP forwarding information in addition to that
–   contained in the IPX forwarding group.

– Destination Table
–   The Destination table contains additional NLSP forwarding
–   information about all destinations learned about via NLSP.

nlspDestTable OBJECT-TYPE
    SYNTAX      SEQUENCE OF NLSPDestEntry
    ACCESS      not-accessible
    STATUS      mandatory
    DESCRIPTION "The Destination table contains information about all
            known destinations learned about via NLSP."
    ::= {nlspForwarding 1}

nlspDestEntry OBJECT-TYPE
    SYNTAX      NLSPDestEntry
    ACCESS      not-accessible
    STATUS      mandatory
    DESCRIPTION "Each entry corresponds to one destination."
    INDEX       {
            nlspDestSysInstance,
            nlspDestNetNum
            }
    ::= {nlspDestTable 1}

NLSPDestEntry ::= SEQUENCE {
                    nlspDestSysInstance
                      INTEGER,
                    nlspDestNetNum
                      NetNumber,
                    nlspDestID
                      NLSPID,
                    nlspDestEstDelay
                      INTEGER,
                    nlspDestEstThroughput
                      INTEGER,
                    nlspDestNextHopID
                      NLSPID,
                    nlspDestCost
                      INTEGER
                }

nlspDestSysInstance OBJECT-TYPE
    SYNTAX      INTEGER
    ACCESS      read-only
    STATUS      mandatory
    DESCRIPTION "The unique identifier of the instance of NLSP and IPX
            (via ipxSysInstance) to which this row corresponds."
    ::= {nlspDestEntry 1}

nlspDestNetNum OBJECT-TYPE
    SYNTAX      NetNumber
    ACCESS      read-only
    STATUS      mandatory
    DESCRIPTION "The IPX network number of the destination."
```

```
  ::= {nlspDestEntry 2}

nlspDestID OBJECT-TYPE
  SYNTAX    NLSPID
  ACCESS    read-only
  STATUS    mandatory
  DESCRIPTION "The destination NLSP ID (6-octet system ID plus 1-octet
          pseudo-node ID)."
  ::= {nlspDestEntry 3}

nlspDestEstDelay OBJECT-TYPE
  SYNTAX    INTEGER
  ACCESS    read-only
  STATUS    mandatory
  DESCRIPTION "The estimated delay, in microseconds, to reach the
          destination."
  ::= {nlspDestEntry 4}

nlspDestEstThroughput OBJECT-TYPE
  SYNTAX    INTEGER
  ACCESS    read-only
  STATUS    mandatory
  DESCRIPTION "The estimated throughput, in bits per second, to the
          destination."
  ::= {nlspDestEntry 5}

nlspDestNextHopID OBJECT-TYPE
  SYNTAX    NLSPID
  ACCESS    read-only
  STATUS    mandatory
  DESCRIPTION "The NLSP ID (6-octet system ID plus 1-octet pseudo-node
          ID) of the next hop."
  ::= {nlspDestEntry 6}

nlspDestCost OBJECT-TYPE
  SYNTAX    INTEGER
  ACCESS    read-only
  STATUS    mandatory
  DESCRIPTION "The total path default cost to reach this destination."
  ::= {nlspDestEntry 7}


– Aggregated Routes Table
–  The Aggregated Routes table contains information about the
–  aggregated routes known to this system.

nlspAggRouteTable OBJECT-TYPE
  SYNTAX    SEQUENCE OF NLSPAggRouteEntry
  ACCESS    not-accessible
  STATUS    mandatory
  DESCRIPTION "The Aggregated Route table contains information about all
          known aggregated routes."
  ::= {nlspForwarding 2}

nlspAggRouteEntry OBJECT-TYPE
  SYNTAX    NLSPAggRouteEntry
  ACCESS    not-accessible
  STATUS    mandatory
  DESCRIPTION "Each entry corresponds to one aggregated route."
  INDEX     {
          nlspAggRouteSysInstance,
          nlspAggRouteNetNum,
          nlspAggRouteMaskLength,
          nlspAggRouteNextHopCircIndex
          }
```

```
  ::= {nlspAggRouteTable 1}

NLSPAggRouteEntry ::= SEQUENCE {
              nlspAggRouteSysInstance
                INTEGER,
              nlspAggRouteNetNum
                NetNumber,
              nlspAggRouteMaskLength
                INTEGER,
              nlspAggRouteNextHopCircIndex
                INTEGER,
              nlspAggRouteTicks
                INTEGER,
              nlspAggRouteAreaCount
                INTEGER,
              nlspAggRouteNextHopNICAddress
                PhysAddress,
              nlspAggRouteNextHopNetNum
                NetNumber
              }

nlspAggRouteSysInstance OBJECT-TYPE
  SYNTAX    INTEGER
  ACCESS    read-only
  STATUS    mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
          (via ipxSysInstance) to which this row corresponds."
  ::= {nlspAggRouteEntry 1}

nlspAggRouteNetNum OBJECT-TYPE
  SYNTAX    NetNumber
  ACCESS    read-only
  STATUS    mandatory
  DESCRIPTION "The address summary."
  ::= {nlspAggRouteEntry 2}

nlspAggRouteMaskLength OBJECT-TYPE
  SYNTAX    INTEGER (0..32)
  ACCESS    read-only
  STATUS    mandatory
  DESCRIPTION "Length in bits of the address summary."
  ::= {nlspAggRouteEntry 3}

nlspAggRouteNextHopCircIndex OBJECT-TYPE
  SYNTAX    INTEGER
  ACCESS    read-only
  STATUS    mandatory
  DESCRIPTION "The unique identifier of the circuit used to reach
          the next hop. When looking at this table on
          the router configured to advertise the aggregated
          route, this is the circuit on which the summary is
          configured."
  ::= {nlspAggRouteEntry 4}

nlspAggRouteTicks OBJECT-TYPE
  SYNTAX    INTEGER
  ACCESS    read-only
  STATUS    mandatory
  DESCRIPTION "The delay in ticks to ???."
  ::= {nlspAggRouteEntry 5}

nlspAggRouteAreaCount OBJECT-TYPE
  SYNTAX    INTEGER
  ACCESS    read-only
  STATUS    mandatory
  DESCRIPTION "The number of areas into which this aggregated
          route can be leaked."
  ::= {nlspAggRouteEntry 6}

nlspAggRouteNextHopNICAddress OBJECT-TYPE
  SYNTAX     PhysAddress
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NIC address of the next hop.  When looking
          at this table on the router configured to advertise
          the aggregated route, this value will be 0 when the
          route is not being summarized."
  ::= {nlspAggRouteEntry 7}

nlspAggRouteNextHopNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number of the next hop.  When
          looking at this table on the router configured to
          advertise the aggregated route, this value will be 0
          when the route is not being summarized."
  ::= {nlspAggRouteEntry 8}




– NLSP Neighbors Group
–  This group contains management information for each neighboring
–  NLSP router known to the system.

– NLSP Neighbors Table
–  This table contains an entry for each neighboring NLSP router
–  known to the system.

nlspNeighTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPNeighEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The NLSP Neighbors table."
  ::= {nlspNeighbors 1}

nlspNeighEntry OBJECT-TYPE
  SYNTAX     NLSPNeighEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corressponds to one neighboring NLSP router
          known to the system."
  INDEX     {
          nlspNeighSysInstance,
          nlspNeighCircIndex,
          nlspNeighIndex
          }
  ::= {nlspNeighTable 1}

NLSPNeighEntry ::= SEQUENCE {
                  nlspNeighSysInstance
                    INTEGER,
                  nlspNeighCircIndex
                    INTEGER,
                  nlspNeighIndex
                    INTEGER,
                  nlspNeighState
                    INTEGER,
                  nlspNeighNICAddress
                    PhysAddress,
                  nlspNeighSysType
                    INTEGER,
                  nlspNeighSysID
                    SystemID,
                  nlspNeighName
                    OCTET STRING,
                  nlspNeighUsage
                    INTEGER,
                  nlspNeighHoldTimer
                    INTEGER,
                  nlspNeighRemainingTime
                    INTEGER,
                  nlspNeighPriority
                    INTEGER
                  }

nlspNeighSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
          (via ipxSysInstance) to which this row corresponds."
  ::= {nlspNeighEntry 1}

nlspNeighCircIndex OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The identifier of the parent circuit of this neighbor
          within this instance of the NLSP and IPX."
  ::= {nlspNeighEntry 2}

nlspNeighIndex OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The identifier for this NLSP neighbor entry, unique
          within the parent circuit."
  ::= {nlspNeighEntry 3}

nlspNeighState OBJECT-TYPE
  SYNTAX     INTEGER {
              initializing(1),
              up(2),
              failed(3),
              down(4)
              }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The state of the connection to the neighboring NLSP
          router."
  ::= {nlspNeighEntry 4}

nlspNeighNICAddress OBJECT-TYPE
  SYNTAX     PhysAddress
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NIC Address of the neighboring NLSP router."
  ::= {nlspNeighEntry 5}

nlspNeighSysType OBJECT-TYPE
  SYNTAX     INTEGER {
              unknown(1),
              nlspLevel1Router(2)
```

```
             }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The type of the neighboring NLSP router."
  ::= {nlspNeighEntry 6}

nlspNeighSysID OBJECT-TYPE
  SYNTAX     SystemID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The neighboring NLSP router's system ID."
  ::= {nlspNeighEntry 7}

nlspNeighName OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(0..48))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The readable name for the neighboring NLSP router."
  ::= {nlspNeighEntry 8}

nlspNeighUsage OBJECT-TYPE
  SYNTAX     INTEGER {
              undefined(1),
              level1(2)
             }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The usage of the connection to the neighboring NLSP
          router."
  ::= {nlspNeighEntry 9}

nlspNeighHoldTimer OBJECT-TYPE
  SYNTAX     INTEGER (1..65535)
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The initial holding time, in seconds, for this NLSP
          neighbor entry as specified in the NLSP Hello packet."
  ::= {nlspNeighEntry 10}

nlspNeighRemainingTime OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The remaining time to live, in seconds, for this NLSP
          neighbor entry."
  ::= {nlspNeighEntry 11}

nlspNeighPriority OBJECT-TYPE
  SYNTAX     INTEGER (1..127)
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The priority of the neighboring NLSP router for
          becoming the LAN Level 1 Designated router if the value
          of nlspNeighSysType is nlspLevel1Router."
  ::= {nlspNeighEntry 12}


– Translation Group
–  The translation group contains tables providing mappings between
–  network numbers, NLSP system IDs, and router names.

– NLSP ID Mapping Table
–  This table maps NLSP system IDs to router names and IPX network
–  numbers.
```

```
nlspIDMapTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPIDMapEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "This table maps NLSP system IDs to router names and
          IPX network numbers."
  ::= {nlspTranslation 1}

nlspIDMapEntry OBJECT-TYPE
  SYNTAX     NLSPIDMapEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry maps one NLSP system ID to its corresponding
          router name and IPX network number."
  INDEX      {
          nlspIDMapSysInstance,
          nlspIDMapID
          }
  ::= {nlspIDMapTable 1}

NLSPIDMapEntry ::= SEQUENCE {
                    nlspIDMapSysInstance
                      INTEGER,
                    nlspIDMapID
                      NLSPID,
                    nlspIDMapServerName
                      OCTET STRING,
                    nlspIDMapNetNum
                      NetNumber
                   }

nlspIDMapSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
          (via ipxSysInstance) to which this row corresponds."
  ::= {nlspIDMapEntry 1}

nlspIDMapID OBJECT-TYPE
  SYNTAX     NLSPID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NLSP ID (6-octet sytem ID plus the pseudo-node ID)."
  ::= {nlspIDMapEntry 2}

nlspIDMapServerName OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(0..48))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The readable name corresponding to this NLSP ID."
  ::= {nlspIDMapEntry 3}

nlspIDMapNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number corresponding to this NLSP ID."
  ::= {nlspIDMapEntry 4}


– IPX Network Number Mapping Table
–  This table maps IPX network numbers to router names and NLSP IDs.

nlspNetMapTable OBJECT-TYPE
```

```
  SYNTAX     SEQUENCE OF NLSPNetMapEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "This table maps IPX network numbers to router names
          and NLSP IDs."
  ::= {nlspTranslation 2}

nlspNetMapEntry OBJECT-TYPE
  SYNTAX     NLSPNetMapEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry maps one IPX network number to its
          corresponding router name and NLSP ID."
  INDEX     {
          nlspNetMapSysInstance,
          nlspNetMapNetNum
          }
  ::= {nlspNetMapTable 1}

NLSPNetMapEntry ::= SEQUENCE {
                nlspNetMapSysInstance
                  INTEGER,
                nlspNetMapNetNum,
                  NetNumber,
                nlspNetMapServerName
                  OCTET STRING,
                nlspNetMapID,
                  NLSPID
                }

nlspNetMapSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
          (via ipxSysInstance) to which this row corresponds."
  ::= {nlspNetMapEntry 1}

nlspNetMapNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number."
  ::= {nlspNetMapEntry 2}

nlspNetMapServerName OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(0..48))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The router name corresponding to the IPX network number."
  ::= {nlspNetMapEntry 3}

nlspNetMapID OBJECT-TYPE
  SYNTAX     NLSPID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NLSP ID corresponding to the IPX network number."
  ::= {nlspNetMapEntry 4}


- Name Mapping Table
-  This table maps router names to their corresponding IPX network
-  number and NLSP ID.

nlspNameMapTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPNameMapEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "This table maps router names to the corresponding IPX
          network number and NLSP ID."
  ::= {nlspTranslation 3}

nlspNameMapEntry OBJECT-TYPE
  SYNTAX     NLSPNameMapEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry maps one router name to its corresponding
          IPX network number and NLSP ID."
  INDEX     {
          nlspNameMapSysInstance,
          nlspNameMapServerName
          }
  ::= {nlspNameMapTable 1}

NLSPNameMapEntry ::= SEQUENCE {
                nlspNameMapSysInstance
                  INTEGER,
                nlspNameMapServerName
                  OCTET STRING,
                nlspNameMapNetNum
                  NetNumber,
                nlspNameMapID
                  NLSPID
                }

nlspNameMapSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
          (via ipxSysInstance) to which this row corresponds."
  ::= {nlspNameMapEntry 1}

nlspNameMapServerName OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(0..48))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The readable name for this system."
  ::= {nlspNameMapEntry 2}

nlspNameMapNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number corresponding to the router name."
  ::= {nlspNameMapEntry 3}

nlspNameMapID OBJECT-TYPE
  SYNTAX     NLSPID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NLSP ID corresponding to the router name.  This value
          is undefined if the value of nlspSysState is off."
  ::= {nlspNameMapEntry 4}


- Graph Group
-  The Graph group provides a representation of the network topology.
-  The group is optional.
```

```
– Node Table
–  The node table contains an entry for each node in the graph.

nlspNodeTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPNodeEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The node table contains an entry for each node in the
          graph."
  ::= {nlspGraph 1}

nlspNodeEntry OBJECT-TYPE
  SYNTAX     NLSPNodeEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one graph node."
  INDEX      {
          nlspNodeSysInstance,
          nlspNodeID
          }
  ::= {nlspNodeTable 1}

NLSPNodeEntry ::= SEQUENCE {
              nlspNodeSysInstance
                INTEGER,
              nlspNodeID
                NLSPID,
              nlspNodeNetNum
                NetNumber,
              nlspNodeType
                INTEGER,
              nlspNodeEstDelay
                INTEGER,
              nlspNodeEstThroughput
                INTEGER,
              nlspNodeMaxPacketSize
                INTEGER,
              nlspNodeCost
                INTEGER,
              nlspNodeOverload
                INTEGER,
              nlspNodeReachable
                INTEGER
              }

nlspNodeSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
          (via ipxSysInstance) to which this row corresponds."
  ::= {nlspNodeEntry 1}

nlspNodeID OBJECT-TYPE
  SYNTAX     NLSPID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NLSP ID for this node."
  ::= {nlspNodeEntry 2}

nlspNodeNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number of this node."
  ::= {nlspNodeEntry 3}

nlspNodeType OBJECT-TYPE
  SYNTAX     INTEGER {
              unknown(1),
              nlspLevel1Router(2),
              nlspLevel2Router(3),
              router(4),
              network(5)
              }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The type of system the node represents."
  ::= {nlspNodeEntry 4}

nlspNodeEstDelay OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The estimated delay, in microseconds, to reach the
          destination represented by this node."
  ::= {nlspNodeEntry 5}

nlspNodeEstThroughput OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The estimated throughput, in bits per second, to the
          destination represented by this node."
  ::= {nlspNodeEntry 6}

nlspNodeMaxPacketSize OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The maximum packet size, in bytes, that can be sent to
          the destination represented by this node."
  ::= {nlspNodeEntry 7}

nlspNodeCost OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The cost to reach this node."
  ::= {nlspNodeEntry 8}

nlspNodeOverload OBJECT-TYPE
  SYNTAX     INTEGER {
              no(1),
              yes(2)
              }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "Indicates whether this node is overloaded."
  ::= {nlspNodeEntry 9}

nlspNodeReachable OBJECT-TYPE
  SYNTAX     INTEGER {
              no(1),
              yes(2)
              }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "Indicates whether the destination represented by this
          node is reachable."
  ::= {nlspNodeEntry 10}

  Link Table
–  This table contains the entries for all of the links in the graph.

nlspLinkTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPLinkEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The Link table contains entries for all of the links in
          the graph."
  ::= {nlspGraph 2}

nlspLinkEntry OBJECT-TYPE
  SYNTAX     NLSPLinkEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one link."
  INDEX      {
          nlspLinkSysInstance,
          nlspLinkNLSPID,
          nlspLinkIndex
          }
  ::= {nlspLinkTable 1}

NLSPLinkEntry ::= SEQUENCE {
               nlspLinkSysInstance
                 INTEGER,
               nlspLinkNLSPID
                 NLSPID,
               nlspLinkIndex
                 INTEGER,
               nlspLinkNeighNLSPID
                 NLSPID,
               nlspLinkFromNeighCost
                 INTEGER,
               nlspLinkMaxPacketSize
                 INTEGER,
               nlspLinkThroughput
                 INTEGER,
               nlspLinkDelay
                 INTEGER,
               nlspLinkMediaType
                 OCTET STRING,
               nlspLinkToNeighCost
                 INTEGER
               }

nlspLinkSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
          (via ipxSysInstance) to which this row corresponds."
  ::= {nlspLinkEntry 1}

nlspLinkNLSPID OBJECT-TYPE
  SYNTAX     NLSPID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NLSP ID (6-byte system ID plus 1-octet pseudo-node
          ID) of the node to which this link belongs."
  ::= {nlspLinkEntry 2}
```

```
nlspLinkIndex OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique value identifying the link within the node."
  ::= {nlspLinkEntry 3}

nlspLinkNeighNLSPID OBJECT-TYPE
  SYNTAX     NLSPID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NLSP ID (6-byte system ID plus 1-octet pseudo-node
          ID) of the neighboring node."
  ::= {nlspLinkEntry 4}

nlspLinkFromNeighCost OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The cost to use this link to reach this node from
          the neighboring node."
  ::= {nlspLinkEntry 5}

nlspLinkMaxPacketSize OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The maximum size, in bytes, of a packet that may be sent
          over this link."
  ::= {nlspLinkEntry 6}

nlspLinkThroughput OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The link's maximum throughput, in bits per second."
  ::= {nlspLinkEntry 7}

nlspLinkDelay OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The delay, in microseconds, on this link."
  ::= {nlspLinkEntry 8}

nlspLinkMediaType OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(2))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The media type of this link."
  ::= {nlspLinkEntry 9}

nlspLinkToNeighCost OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The cost to use this link to reach the neighbor from
          this node."
  ::= {nlspLinkEntry 10}


– Path Table
–  This table allows the path(s) that a packet may take to reach a
–  destination to be reconstructed. The entries in this table
–  represent those links that are one hop closer to the source and
```

```
-  would be used for the minimum cost path(s) to reach the
-  destination.

nlspPathTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPPathEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The path table."
  ::= {nlspGraph 3}

nlspPathEntry OBJECT-TYPE
  SYNTAX     NLSPPathEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each row in this table represents a link to a node that
          is one hop closer to the source and would be used for
          the minimum cost path(s) to reach the destination."
  INDEX     {
          nlspPathSysInstance,
          nlspPathDestNLSPID,
          nlspPathLinkIndex
          }
  ::= {nlspPathTable 1}

NLSPPathEntry ::= SEQUENCE {
              nlspPathSysInstance
                INTEGER,
              nlspPathDestNLSPID
                NLSPID,
              nlspPathLinkIndex
                INTEGER
              }

nlspPathSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
          (via ipxSysInstance) to which this row corresponds."
  ::= {nlspPathEntry 1}

nlspPathDestNLSPID OBJECT-TYPE
  SYNTAX     NLSPID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NLSP ID (6-octet system ID plus 1-octet pseudo-node
          ID) of this destination."
  ::= {nlspPathEntry 2}

nlspPathLinkIndex OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique value identifying this link within the
          destination node."
  ::= {nlspPathEntry 3}


-- Graph XRoutes Table
-  This table contains information about all of the XRoutes provided by
-  a node in the graph.

nlspGraphXRouteTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPGraphXRouteEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "This table contains the information about the XRoutes
          associated with a node in the graph."
  ::= {nlspGraph 4}

nlspGraphXRouteEntry OBJECT-TYPE
  SYNTAX     NLSPGraphXRouteEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry in the table contains the information for one
          XRoute associated with the node."
  INDEX     {
          nlspGraphXRouteSysInstance,
          nlspGraphXRouteNLSPID,
          nlspGraphXRouteNetNum
          }
  ::= {nlspGraphXRouteTable 1}

NLSPGraphXRouteEntry ::= SEQUENCE {
              nlspGraphXRouteSysInstance
                INTEGER,
              nlspGraphXRouteNLSPID
                NLSPID,
              nlspGraphXRouteNetNum
                NetNumber,
              nlspGraphXRouteCost
                INTEGER,
              nlspGraphXRouteHopCount
                INTEGER
              }

nlspGraphXRouteSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
          (via ipxSysInstance) to which this entry corresponds."
  ::= {nlspGraphXRouteEntry 1}

nlspGraphXRouteNLSPID OBJECT-TYPE
  SYNTAX     NLSPID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NLSP ID of the node."
  ::= {nlspGraphXRouteEntry 2}

nlspGraphXRouteNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number of the XRoute's destination."
  ::= {nlspGraphXRouteEntry 3}

nlspGraphXRouteCost OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The cost to reach the XRoute's destination."
  ::= {nlspGraphXRouteEntry 4}

nlspGraphXRouteHopCount OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of hops necessary to reach the XRoute's
```

```
          destination."
  ::= {nlspGraphXRouteEntry 5}


– Graph Services Table
–  This table contains information about all of the services provided by
–  a node in the graph.

nlspGraphServTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPGraphServEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "This table contains the information about the services
          associated with a node in the graph."
  ::= {nlspGraph 5}

nlspGraphServEntry OBJECT-TYPE
  SYNTAX     NLSPGraphServEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry in the table contains the information for one
          service associated with the node."
  INDEX      {
          nlspGraphServSysInstance,
          nlspGraphServNLSPID,
          nlspGraphServName,
          nlspGraphServTypeValue
          }
  ::= {nlspGraphServTable 1}

NLSPGraphServEntry ::= SEQUENCE {
                nlspGraphServSysInstance
                  INTEGER,
                nlspGraphServNLSPID
                  NLSPID,
                nlspGraphServName
                  OCTET STRING,
                nlspGraphServTypeValue
                  OCTET STRING,
                nlspGraphServType
                  INTEGER,
                nlspGraphServNetNum
                  NetNumber,
                nlspGraphServNode
                  OCTET STRING,
                nlspGraphServSocket
                  OCTET STRING
                }

nlspGraphServSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
          (via ipxSysInstance) to which this entry corresponds."
  ::= {nlspGraphServEntry 1}

nlspGraphServNLSPID OBJECT-TYPE
  SYNTAX     NLSPID
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The NLSP ID of the node."
  ::= {nlspGraphServEntry 2}

nlspGraphServName OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(1..48))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The service name."
  ::= {nlspGraphServEntry 3}

nlspGraphServTypeValue OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(2))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The service type's hexadecimal value."
  ::= {nlspGraphServEntry 4}

nlspGraphServType OBJECT-TYPE
  SYNTAX     INTEGER {
              unknown(1)
              }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The service type."
  ::= {nlspGraphServEntry 5}

nlspGraphServNetNum OBJECT-TYPE
  SYNTAX     NetNumber
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The IPX network number portion of the IPX address of
          the service."
  ::= {nlspGraphServEntry 6}

nlspGraphServNode OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(6))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The node portion of the IPX address of the service."
  ::= {nlspGraphServEntry 7}

nlspGraphServSocket OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(2))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The socket portion of the IPX address of the service."
  ::= {nlspGraphServEntry 8}


– LSP Group
–  The LSP group provides a representation of NLSP's LSP database.  This
–  group is optional.

– LSP Header Table
–  The LSP header table contains summary information about each LSP
–  in the database as well as an OCTET STRING containing the entire
–  LSP header.

nlspLSPTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPLSPEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The LSP header table."
  ::= {nlspLSP 1}

nlspLSPEntry OBJECT-TYPE
  SYNTAX     NLSPLSPEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one LSP's header."
  INDEX    {
           nlspLSPSysInstance,
           nlspLSPID
           }
  ::= {nlspLSPTable 1}

NLSPLSPEntry ::= SEQUENCE {
                nlspLSPSysInstance
                  INTEGER,
                nlspLSPID
                  OCTET STRING,
                nlspLSPLifetime
                  INTEGER,
                nlspLSPSeqNum
                  INTEGER,
                nlspLSPChecksum
                  INTEGER,
                nlspLSPRouterType
                  INTEGER,
                nlspLSPOverload
                  INTEGER,
                nlspLSPHeader
                  OCTET STRING
                }

nlspLSPSysInstance OBJECT-TYPE
  SYNTAX     INTEGER
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The unique identifier for the instance of NLSP and IPX
          (via ipxSysInstance) to which this entry corresponds."
  ::= {nlspLSPEntry 1}

nlspLSPID OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(8))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The value that uniquely identifies this LSP."
  ::= {nlspLSPEntry 2}

nlspLSPLifetime OBJECT-TYPE
  SYNTAX     INTEGER (0..65535)
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The number of seconds prior to the expiration of the
          LSP."
  ::= {nlspLSPEntry 3}

nlspLSPSeqNum OBJECT-TYPE
  SYNTAX     INTEGER (0..255)
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The sequence number of the LSP."
  ::= {nlspLSPEntry 4}

nlspLSPChecksum OBJECT-TYPE
  SYNTAX     INTEGER (0..65535)
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The checksum value of the LSP."
  ::= {nlspLSPEntry 5}

nlspLSPRouterType OBJECT-TYPE
  SYNTAX     INTEGER {
               unknown(1),
               nlspLevel1Router(2)
               }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The type of the router that sent the LSP."
  ::= {nlspLSPEntry 6}

nlspLSPOverload OBJECT-TYPE
  SYNTAX     INTEGER {
               no(1),
               yes(2)
               }
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "Indicates whether the sending router's LSP database is
          overloaded."
  ::= {nlspLSPEntry 7}

nlspLSPHeader OBJECT-TYPE
  SYNTAX     OCTET STRING (SIZE(27))
  ACCESS     read-only
  STATUS     mandatory
  DESCRIPTION "The complete LSP header."
  ::= {nlspLSPEntry 8}


-- LSP Options Table
--  The LSP options table is used to obtain each option contained in
--  an LSP.

nlspLSPOptTable OBJECT-TYPE
  SYNTAX     SEQUENCE OF NLSPLSPOptEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "The LSP Options table."
  ::= {nlspLSP 2}

nlspLSPOptEntry OBJECT-TYPE
  SYNTAX     NLSPLSPOptEntry
  ACCESS     not-accessible
  STATUS     mandatory
  DESCRIPTION "Each entry corresponds to one option from an LSP."
  INDEX    {
           nlspLSPOptSysInstance,
           nlspLSPOptLSPID,
           nlspLSPOptIndex
           }
  ::= {nlspLSPOptTable 1}

NLSPLSPOptEntry ::= SEQUENCE {
                nlspLSPOptSysInstance
                  INTEGER,
                nlspLSPOptLSPID
                  OCTET STRING,
                nlspLSPOptIndex
                  INTEGER,
                nlspLSPOptCode
                  INTEGER,
                nlspLSPOptLength
                  INTEGER,
                nlspLSPOptValue
                  OCTET STRING
                }
```

```
nlspLSPOptSysInstance OBJECT-TYPE
  SYNTAX      INTEGER
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The unique identifier of the instance of NLSP and IPX
            (via ipxSysInstance) to which this entry corresponds."
  ::= {nlspLSPOptEntry 1}

nlspLSPOptLSPID OBJECT-TYPE
  SYNTAX      OCTET STRING (SIZE(8))
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The value that uniquely identifies the LSP."
  ::= {nlspLSPOptEntry 2}

nlspLSPOptIndex OBJECT-TYPE
  SYNTAX      INTEGER
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The value that uniquely identifies this option within the
            LSP."
  ::= {nlspLSPOptEntry 3}

nlspLSPOptCode OBJECT-TYPE
  SYNTAX      INTEGER (0..255)
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The code that identifies the type of the option."
  ::= {nlspLSPOptEntry 4}

nlspLSPOptLength OBJECT-TYPE
  SYNTAX      INTEGER (0..255)
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The length of the option's value field."
  ::= {nlspLSPOptEntry 5}

nlspLSPOptValue OBJECT-TYPE
  SYNTAX      OCTET STRING (SIZE(0..255))
  ACCESS      read-only
  STATUS      mandatory
  DESCRIPTION "The option's value field."
  ::= {nlspLSPOptEntry 6}

END
```

11. Comparison with IS-IS

The basis of the NLSP™ design is the ISO OSI IS-IS standard (Reference [ISO92]). IS-IS was designed for ISO OSI CLNP, but NLSP is for the Novell® IPX™ protocol. This section summarizes the key differences between NLSP/IPX and IS-IS/CLNP. The current version of NLSP, as described in this document, is the basis for comparison.

11.1. Terminology in the Specification Document

IS-IS/CLNP	*NLSP/IPX*
Intermediate System.	Router.
End System.	End node. (Examples of end nodes are desktop client workstations and nonrouting servers.)
Protocol Data Unit.	Packet.
Subnetwork.	Network.
Network.	Internetwork.

11.2. Addressing Issues

IS-IS/CLNP	*NLSP/IPX*
The Network layer address, or NSAP, is variable in length, up to 20 bytes. For routing purposes, it has a variable-length Area Address, a one- to eight-byte ID field, and a one-byte Selector. The Selector identifies a software entity within the system.	The Network layer address is fixed at 12 bytes. It consists of a four-byte network number, a six-byte node number, and a two-byte socket field. The socket identifies a software entity within the system.
Each router has at least one area address. The maximum number of area addresses for an area is three or more (the number is configured uniformly in an area).	NLSP allows area addresses to be used. The maximum number of area addresses for an area is three. The default area address if all networks are in one area is (area = 0, mask = 0).
Each Manual Area Address is represented as a length-preceded NSAP prefix; that is, the leading bytes of the NSAP. It has one-byte granularity.	Each Manual Area Address is represented as pair of four-byte numbers. The first is an IPX network number; the second is a mask of leading one bits indicating how long the area identifier is. It is variable-length with one-bit granularity.

Each router has a unique system ID. The system ID is 1 to 8 bytes (the size is configured uniformly in an area).	Each router has a unique system ID. The system ID is 6 bytes. Each router also has a unique internal network number and a textual name.

11.3. Routing Issues

IS-IS/CLNP	*NLSP/IPX*
Systems use information about links to routers and end nodes to determine routes to routers and to end nodes.	Systems determine routes to IPX network numbers, and determine services reachable at those network numbers.
Includes Level 1 and Level 2 routing.	Includes specification of Level 1 routing and (for forward compatibility) supports routing to the nearest Level 2 router.
A router supports one to four routing metrics.	There is one routing metric: "Cost."
LSPs are sent only on LANs having adjacencies with the sending router.	LSPs are sent on a LAN even if there are no adjacencies on the circuit in question.
When a LAN circuit changes state to "Up," a system waits 2 × bcastHelloInt before electing a Designated Router on that circuit.	When a LAN circuit changes state to "Up," a system waits 2 × drBcastHelloInt before electing a Designated Router on that circuit. However, if in this time an adjacency is formed to a system on that LAN, and that system reports that it is the Designated Router itself, the Designated Router election process is run at once.
Priority is not affected by overload status.	Priority of becoming Designated Router is reduced when in LSP overload state.
The priority to become Designated Router on a LAN is configurable, per router per LAN attachment.	The priority to become Designated Router on a LAN is configurable, per router per LAN attachment. The default is 44. If a system elects itself Designated Router, it raises its priority by 20.
Level 1 LSPs describe links to other routers, and to end nodes.	Level 1 LSPs describe links to other routers, to external routes, and to services. NLSP also includes a management information field that contains the router's name and IPX internal network number.

Does not include extra measurements or management information.	Includes Throughput, Delay, MTU Size, and Media Type in LSPs. The first three of these also enter into load-splitting decisions.
Each LSP's IS Neighbors option can contain multiple neighbors.	Each LSP's Link Information option describes one neighbor and the link connecting to it.
The maximum size of sequence number packets and Hello packets is configurable.	The maximum size of sequence number packets and Hello packets is determined dynamically per circuit.
Comparison of LSPs for newness considers sequence number and remaining lifetime.	In addition to sequence number and remaining lifetime, comparison of LSPs for newness considers the checksum. The *preference of checksums* rule makes resolving LSP confusion operate the same way for equal and unequal sequence numbers.
On wraparound of an LSP sequence number, the router is disabled for a period.	On wraparound of an LSP sequence number, the specific LSP is purged for a period, but the router can (optionally) continue operation.
No backward compatibility needed.	Includes backward compatibility features for RIP and SAP. Includes WAN pseudonodes.
The originating lifetime of an LSP is 20 minutes.	The originating lifetime of an LSP is 120 minutes.

11.4. End Node Support

IS-IS/CLNP	*NLSP/IPX*
Uses the ES-IS protocol.	Uses RIP and SAP.
Can route data traffic reliably to an end node attached to a partitioned LAN.	Cannot route data traffic reliably to an end node attached to a partitioned LAN, because NLSP routes to IPX networks (not individual end nodes).

11.5. Data-Link Issues

IS-IS/CLNP	*NLSP/IPX*
Assumes that a router detects remote startup of a WAN link. Also assumes that failure of data delivery results in circuit disconnect.	Includes a state machine in establishing WAN circuits, to support unreliable datagram data links.

Hello messages are padded to maximum configured size (or one byte less) to ensure adjacencies are formed only between routers that can communicate fully.	MTU Size is included in Hello messages, enabling packets to be sent as large as possible, without overrunning the receiver's buffer.
Specifies pacing of packet transmissions to avoid overrunning receivers' capacity to handle traffic bursts.	Pacing of PDU transmissions vary in detail from IS-IS.
Uses multicast on a LAN.	Uses multicast on a LAN, with provision to revert to broadcast if there is a router that does not support multicast.
Includes specification of operation over X.25 and IEEE 802.x networks.	Includes specification of operation over X.25 and IEEE 802.x networks, but also operates over other LAN media, and over other WAN media using IW2 (of which X.25 support is one example).

11.6. System Integrity Issues

IS-IS/CLNP	*NLSP/IPX*
If a router receives an LSP with a bad checksum, it does an area-wide purge of the LSP.	If a router receives an LSP with a bad checksum, it generates an event and discards the LSP.
Includes optional authentication specification.	Does not include authentication.
Partial precomputation of LSP checksums is required.	Partial precomputation of LSP checksums is optional.

11.7. Packet Format and Framing

IS-IS/CLNP	*NLSP/IPX*
Routing packets are transmitted directly over the data-link layer.	Packets are transmitted with IPX headers.
Routing packets have a fixed part and a set of variable-length option fields.	Routing packet formats are very closely based on those of IS-IS. The fixed part of the NLSP packet is the same length as the IS-IS packet. Some fields that are reserved in IS-IS are used in NLSP; for example, the State field in the WAN Hello packet and the No Multicast bit in the LAN Hello packet. Some fields used in IS-IS are reserved in NLSP; for example, the IS-IS ID Length and Maximum Area Addresses fields do not apply to NLSP because these parameters are fixed.

LSP buffer size is 1492 bytes.	LSP buffer size is 512 bytes, but can be configured.

11.8. System Management

IS-IS/CLNP	*NLSP/IPX*
System Management is specified in GDMO notation.	System Management is specified in concise MIB form for SNMP.

12. LAN Frame Types

Standard LANs admit several frame formats. For the IPX™ protocol, the formats described in this section are all supported. The discussion here covers the three most common standard media: CSMA/CD, token ring, and FDDI.

Each standard medium has a default frame type, employed when the end user does not make an explicit choice. The default frame formats with NetWare® 4 software are (respectively) Ethernet 802.2 for CSMA/CD, Token Ring (without SNAP), and FDDI (without SNAP).

The subsections that follow illustrate the IPX encodings for the data-link header of each frame type. First, however, there is a discussion of address representation.

12.1. Universal Address Representation

The node number portion of IPX addresses is represented using the *Universal Address Representation* defined in Reference [IEEE91]. This is sometimes called the *canonical form* of the six-byte IEEE MAC address. Figure 12-1 illustrates the representation.

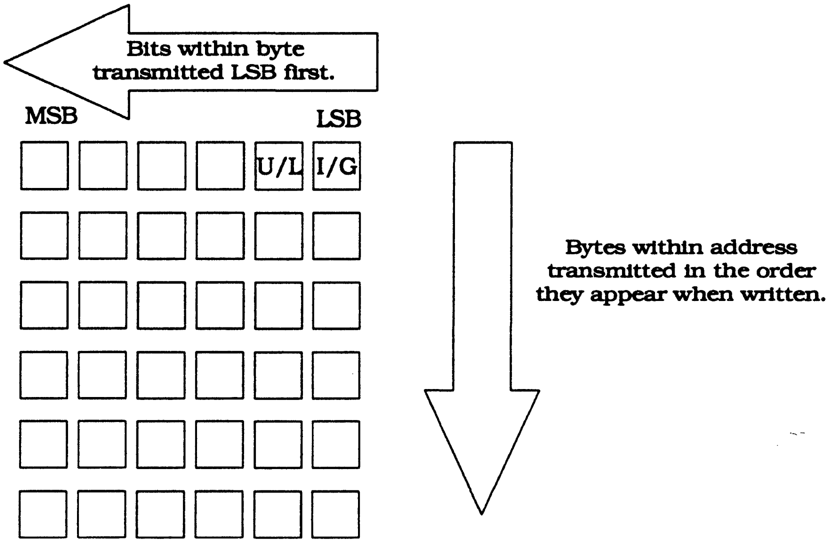

Bits within byte transmitted LSB first.
MSB
LSB
U/L
I/G
Bytes within address transmitted in the order they appear when written.

Figure 12-1: Universal Address Representation

The six-byte address is typically written in hyphenated hexadecimal notation; for example, AC-DE-48-00-00-80.

The least significant bit (LSB) of the first byte is called the *Individual/Group Address Bit* (I/G). When I/G is set to one, it indicates a broadcast or multicast address. Otherwise, the address belongs to an individual station.

The next bit of the first byte is called the *Universally or Locally Administered Address Bit* (U/L). When U/L is set to one, the address is assigned locally as part of LAN operation. Otherwise (the common case)

- The first three bytes are an *Organizationally Unique Identifier* assigned by IEEE, typically to an equipment vendor.
- The remaining three bytes are assigned by that vendor.

In the example of AC-DE-48-00-00-80, the I/G bit and the U/L bit are both zero. They are the two adjacent low-order zero bits of the "C".

As Figure 12-1 shows, bits within a byte are transmitted on a LAN with the least significant bit (LSB) first, and the bytes themselves are transmitted in the order they appear when written. In the example of AC-DE-48-00-00-80, the order of transmission on the wire is

Byte:	0xAC	0xDE	0x48	0x00	0x00	0x80
Time ⇨	0011 0101	0111 1011	0001 0010	0000 0000	0000 0000	0000 0001

⇧

First bit transmitted; also the I/G bit.

Figure 12-2: Standard Transmission of Universal Address

The discussion so far describes the standard view seen by the network layer and above, as well as by the IEEE 802.2 Logical Link Control (LLC) layer. LLC fits above different MAC media (CSMA/CD, token ring, FDDI), and is common for all the media. In the diagrams of the subsections to follow, the boundary between the MAC header and the LLC header is a double line (for those frame types using LLC). This boundary is the start of the MAC Information field. The MAC Information field extends to the end of the packet, up to but not including the frame check sequence. The other parts of the frame (before and after MAC Information) are called *MAC-specific* fields.

Notwithstanding the discussion so far, addresses in the MAC layer must be in the orientation required by the physical medium. In fact, different MACs differ in the bit order within a byte when actually transmitting on the wire (or fiber, as the case might be).

For CSMA/CD, transmission is LSB-first for the entire packet: the MAC-specific fields and the MAC Information field. An address' bit order on the wire is as shown in Figure 12-2 for both

- MAC Information; including the Node Number field in IPX addresses, and
- The MAC-specific fields; for example, the MAC Destination Address and Source Address fields in the subsections that follow.

For token ring and FDDI, by contrast,

- The MAC Information field is transmitted with the most significant bit (MSB) first, while
- The LAN MAC Destination Address and Source Address fields are still transmitted with the I/G bit first, as in Figure 12-2, but
- The MAC-specific fields are specified according to bit transmission order without indicating which is MSB or LSB

Note: Most implementations store nonaddress MAC-specific fields in memory with the first-transmitted bit as MSB. Therefore, from a software view, the entire packet is transmitted MSB first.

When viewed on a token ring or FDDI LAN, the Node Number field in IPX addresses actually appear on the wire as in Figure 12-3, as does, in fact, the entire IPX header and IPX Data.

Byte:	0xAC	0xDE	0x48	0x00	0x00	0x80
Time ⇨	1010 1100	1101 1110	0100 1000	0000 0000	0000 0000	1000 0000

⇧
First bit transmitted.

Figure 12-3: Addresses within Token Ring MAC Information

All effects of the differences of bit transmission order are contained in the MAC layer, below LLC. As viewed by the common, media-independent, LLC layer and above, the MAC Information arrives arranged in memory at the destination with the same bit orientation as it originated at the source. So, there is no problem with MAC Information.

However, in mapping to the physical medium, token ring and FDDI MAC implementations reverse the bit order of the MAC Destination Address and Source Address fields, so that each MAC address byte is transmitted in the MAC header as the mirror image of the same byte in an IPX Node Number of the same packet.

Note: This "mirror image" issue is a perennial source of compatibility problems. Different system designs differ in how and when bytes are reversed. Problems arise when, for example, software considers an address to be in the universal address representation when it is, in fact, the mirror image. When troubleshooting compatibility problems arise, implementors should keep in mind how (a) their system's internal design and (b) their diagnostic tools deal with the issue.

12.2. Ethernet 802.2

In Ethernet 802.2 packets, the Frame Length field contains a value less than or equal to 1500. The DSAP and SSAP values illustrated in the diagram indicate that the frame contains an IPX packet.

Ethernet 802.2	Number of Bytes	Value
Destination Address	6	
Source Address	6	
Frame Length	2	less than or equal to 1500
DSAP	1	0xE0
SSAP	1	0xE0
Control	1	0x03

12.3. Ethernet SNAP

In Ethernet SNAP packets, the Frame Length field contains a value less than or equal to 1500. The DSAP and SSAP values illustrated in the diagram indicate SNAP encapsulation. The Protocol Identification value illustrated in the diagram indicates that the frame contains an IPX packet.

Ethernet SNAP	Number of Bytes	Value
Destination Address	6	
Source Address	6	
Frame Length	2	less than or equal to 1500
DSAP	1	0xAA
SSAP	1	0xAA
Control	1	0x03
Protocol Identification	5	0x0000008137

12.4. Ethernet Raw 802.3

This is a historical frame format, supported for backward compatibility with certain installed systems. In Ethernet Raw 802.3 packets, the Frame Length field contains a value less than or equal to 1500. The IPX header immediately following the Frame Length field starts with 0xFFFF in the Checksum field. This frame format cannot be used with IPX checksums.

Ethernet Raw 802.3	Number of Bytes	Value
Destination Address	6	
Source Address	6	
Frame Length	2	less than or equal to 1500

12.5. Ethernet II

The Frame Type value illustrated in the diagram indicates that the frame contains an IPX packet. Note that the Frame Type value is greater than 1500, to discriminate the packet from previously described frame formats.

Ethernet II	Number of Bytes	Value
Destination Address	6	
Source Address	6	
Frame Type	2	0x8137

12.6. Token Ring

In token ring packets, the DSAP and SSAP values illustrated in the diagram indicate that the frame contains an IPX packet. Presence of the Route fields indicates the use of source route bridging.

Token Ring	Number of Bytes	Value
Access Control	1	
Frame Control	1	
Destination Address	6	
Source Address	6	
Route Control Broadcast / Length	1	
Route Control Direction	1	
Route Designator 1	2	
... ...	2	
Route Designator n	2	
DSAP	1	0xE0
SSAP	1	0xE0
Control	1	0x03

12.7. Token Ring SNAP

In token ring SNAP packets, the DSAP and SSAP values illustrated in the diagram indicate SNAP encapsulation. The Protocol Identification value illustrated in the diagram indicates that the frame contains an IPX packet. Presence of the Route fields indicates the use of source route bridging.

Token Ring SNAP	Number of Bytes	Value
Access Control	1	
Frame Control	1	
Destination Address	6	
Source Address	6	
Route Control Broadcast / Length	1	
Route Control Direction	1	
Route Designator 1	2	
... ...	2	
Route Designator n	2	
DSAP	1	0xAA
SSAP	1	0xAA
Control	1	0x03
Protocol Identification	5	0x0000008137

12.8. FDDI

In FDDI packets, the DSAP and SSAP values illustrated in the diagram indicate that the frame contains an IPX packet. Presence of the Route fields indicates the use of source route bridging.

FDDI	Number of Bytes	Value
FDDI Header	3	
Frame Control	1	
Destination Address	6	
Source Address	6	
Route Control Broadcast / Length	1	
Route Control Direction	1	
Route Designator 1	2	
... ...	2	
Route Designator n	2	
DSAP	1	0xE0
SSAP	1	0xE0
Control	1	0x03

12.9. FDDI SNAP

In FDDI SNAP packets, the DSAP and SSAP values illustrated in the diagram indicate SNAP encapsulation. The Protocol Identification value illustrated in the diagram indicates that the frame contains an IPX packet. Presence of the Route fields indicates the use of source route bridging.

FDDI SNAP	Number of Bytes	Value
FDDI Header	3	
Frame Control	1	
Destination Address	6	
Source Address	6	
Route Control Broadcast / Length	1	
Route Control Direction	1	
Route Designator 1	2	
... ...	2	
Route Designator n	2	
DSAP	1	0xAA
SSAP	1	0xAA
Control	1	0x03
Protocol Identification	5	0x0000008137

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Index