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NBMA Next Hop Resolution Protocol (NHRP)

Status of this Memo

This document specifies an Internet standards track protocol for the Internet community, and requests discussion and suggestions for improvements. Please refer to the current edition of the "Internet Official Protocol Standards" (STD 1) for the standardization state and status of this protocol. Distribution of this memo is unlimited.

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Abstract

This document describes the NBMA Next Hop Resolution Protocol (NHRP). NHRP can be used by a source station (host or router) connected to a Non-Broadcast, Multi-Access (NBMA) subnetwork to determine the internetworking layer address and NBMA subnetwork addresses of the "NBMA next hop" towards a destination station. If the destination is connected to the NBMA subnetwork, then the NBMA next hop is the destination station itself. Otherwise, the NBMA next hop is the egress router from the NBMA subnetwork that is "nearest" to the destination station. NHRP is intended for use in a multiprotocol internetworking layer environment over NBMA subnetworks.

Note that while this protocol was developed for use with NBMA subnetworks, it is possible, if not likely, that it will be applied to BMA subnetworks as well. However, this usage of NHRP is for further study.

This document is intended to be a functional superset of the NBMA Address Resolution Protocol (NARP) documented in [1].

Operation of NHRP as a means of establishing a transit path across an NBMA subnetwork between two routers will be addressed in a separate document (see [13]).

1. Introduction

The keywords MUST, MUST NOT, REQUIRED, SHALL, SHALL NOT, SHOULD, SHOULD NOT, RECOMMENDED, MAY, and OPTIONAL, when they appear in this document, are to be interpreted as described in [15].

The NBMA Next Hop Resolution Protocol (NHRP) allows a source station (a host or router), wishing to communicate over a Non-Broadcast, Multi-Access (NBMA) subnetwork, to determine the internetworking layer addresses and NBMA addresses of suitable "NBMA next hops" toward a destination station. A subnetwork can be non-broadcast either because it technically doesn't support broadcasting (e.g., an X.25 subnetwork) or because broadcasting is not feasible for one reason or another (e.g., an SMDS multicast group or an extended Ethernet would be too large). If the destination is connected to the NBMA subnetwork, then the NBMA next hop is the destination station itself. Otherwise, the NBMA next hop is the egress router from the NBMA subnetwork that is "nearest" to the destination station.

One way to model an NBMA network is by using the notion of logically independent IP subnets (LISs). LISs, as defined in [3] and [4], have the following properties:

- 1) All members of a LIS have the same IP network/subnet number and address mask.
- 2) All members of a LIS are directly connected to the same NBMA subnetwork.
- 3) All hosts and routers outside of the LIS are accessed via a router.
- 4) All members of a LIS access each other directly (without routers).

Address resolution as described in [3] and [4] only resolves the next hop address if the destination station is a member of the same LIS as the source station; otherwise, the source station must forward packets to a router that is a member of multiple LIS's. In multi-LIS

configurations, hop-by-hop address resolution may not be sufficient to resolve the "NBMA next hop" toward the destination station, and IP packets may have multiple IP hops through the NBMA subnetwork.

Another way to model NBMA is by using the notion of Local Address Groups (LAGs) [10]. The essential difference between the LIS and the LAG models is that while with the LIS model the outcome of the "local/remote" forwarding decision is driven purely by addressing information, with the LAG model the outcome of this decision is decoupled from the addressing information and is coupled with the Quality of Service and/or traffic characteristics. With the LAG model any two entities on a common NBMA network could establish a direct communication with each other, irrespective of the entities' addresses.

Support for the LAG model assumes the existence of a mechanism that allows any entity (i.e., host or router) connected to an NBMA network to resolve an internetworking layer address to an NBMA address for any other entity connected to the same NBMA network. This resolution would take place regardless of the address assignments to these entities. Within the parameters described in this document, NHRP describes such a mechanism. For example, when the internetworking layer address is of type IP, once the NBMA next hop has been resolved, the source may either start sending IP packets to the destination (in a connectionless NBMA subnetwork such as SMDS) or may first establish a connection to the destination with the desired bandwidth (in a connection-oriented NBMA subnetwork such as ATM).

Use of NHRP may be sufficient for hosts doing address resolution when those hosts are directly connected to an NBMA subnetwork, allowing for straightforward implementations in NBMA stations. NHRP also has the capability of determining the egress point from an NBMA subnetwork when the destination is not directly connected to the NBMA subnetwork and the identity of the egress router is not learned by other methods (such as routing protocols). Optional extensions to NHRP provide additional robustness and diagnosability.

Address resolution techniques such as those described in [3] and [4] may be in use when NHRP is deployed. ARP servers and services over NBMA subnetworks may be required to support hosts that are not capable of dealing with any model for communication other than the LIS model, and deployed hosts may not implement NHRP but may continue to support ARP variants such as those described in [3] and [4]. NHRP is intended to reduce or eliminate the extra router hops required by the LIS model, and can be deployed in a non-interfering manner with existing ARP services [14].

The operation of NHRP to establish transit paths across NBMA subnetworks between two routers requires additional mechanisms to avoid stable routing loops, and will be described in a separate document (see [13]).

2. Overview

2.1 Terminology

The term "network" is highly overloaded, and is especially confusing in the context of NHRP. We use the following terms:

Internetwork layer--the media-independent layer (IP in the case of TCP/IP networks).

Subnetwork layer--the media-dependent layer underlying the internetwork layer, including the NBMA technology (ATM, X.25, SMDS, etc.)

The term "server", unless explicitly stated to the contrary, refers to a Next Hop Server (NHS). An NHS is an entity performing the Next Hop Resolution Protocol service within the NBMA cloud. An NHS is always tightly coupled with a routing entity (router, route server or edge device) although the converse is not yet guaranteed until ubiquitous deployment of this functionality occurs. Note that the presence of intermediate routers that are not coupled with an NHS entity may preclude the use of NHRP when source and destination stations on different sides of such routers and thus such routers may partition NHRP reachability within an NBMA network.

The term "client", unless explicitly stated to the contrary, refers to a Next Hop Resolution Protocol client (NHC). An NHC is an entity which initiates NHRP requests of various types in order to obtain access to the NHRP service.

The term "station" generally refers to a host or router which contains an NHRP entity. Occasionally, the term station will describe a "user" of the NHRP client or service functionality; the difference in usage is largely semantic.

2.2 Protocol Overview

In this section, we briefly describe how a source S (which potentially can be either a router or a host) uses NHRP to determine the "NBMA next hop" to destination D.

For administrative and policy reasons, a physical NBMA subnetwork may be partitioned into several, disjoint "Logical NBMA subnetworks". A Logical NBMA subnetwork is defined as a collection of hosts and routers that share unfiltered subnetwork connectivity over an NBMA subnetwork. "Unfiltered subnetwork connectivity" refers to the absence of closed user groups, address screening or similar features that may be used to prevent direct communication between stations connected to the same NBMA subnetwork. (Hereafter, unless otherwise specified, we use the term "NBMA subnetwork" to mean *logical* NBMA subnetwork.)

Placed within the NBMA subnetwork are one or more entities that implement the NHRP protocol. Such stations which are capable of answering NHRP Resolution Requests are known as "Next Hop Servers" (NHSs). Each NHS serves a set of destination hosts, which may or may not be directly connected to the NBMA subnetwork. NHSs cooperatively resolve the NBMA next hop within their logical NBMA subnetwork. In addition to NHRP, NHSs may support "classical" ARP service; however, this will be the subject of a separate document [14].

An NHS maintains a cache which contains protocol layer address to NBMA subnetwork layer address resolution information. This cache can be constructed from information obtained from NHRP Register packets (see Section 5.2.3 and 5.2.4), from NHRP Resolution Request/Reply packets, or through mechanisms outside the scope of this document (examples of such mechanisms might include ARP[3] and pre-configured tables). Section 6.2 further describes cache management issues.

For a station within a given LIS to avoid providing NHS functionality, there must be one or more NHSs within the NBMA subnetwork which are providing authoritative address resolution information on its behalf. Such an NHS is said to be "serving" the station. A station on a LIS that lacks NHS functionality and is a client of the NHRP service is known as NHRP Client or just NHCs. If a serving NHS is to be able to supply the address resolution information for an NHC then NHSs must exist at each hop along all routed paths between the NHC making the resolution request and the destination NHC. The last NHRP entity along the routed path is the serving NHS; that is, NHRP Resolution Requests are not forwarded to destination NHCs but rather are processed by the serving NHS.

An NHC also maintains a cache of protocol address to NBMA address resolution information. This cache is populated through information obtained from NHRP Resolution Reply packets, from manual configuration, or through mechanisms outside the scope of this document.

The protocol proceeds as follows. An event occurs triggering station S to want to resolve the NBMA address of a path to D. This is most likely to be when a data packet addressed to station D is to be emitted from station S (either because station S is a host, or station S is a transit router), but the address resolution could also be triggered by other means (a routing protocol update packet, for example). Station S first determines the next hop to station D through normal routing processes (for a host, the next hop may simply be the default router; for routers, this is the "next hop" to the destination internetwork layer address). If the destination's address resolution information is already available in S's cache then that information is used to forward the packet. Otherwise, if the next hop is reachable through one of its NBMA interfaces, S constructs an NHRP Resolution Request packet (see Section 5.2.1) containing station D's internetwork layer address as the (target) destination address, S's own internetwork layer address as the source address (Next Hop Resolution Request initiator), and station S's NBMA addressing information. Station S may also indicate that it prefers an authoritative NHRP Resolution Reply (i.e., station S only wishes to receive an NHRP Resolution Reply from an NHS serving the destination NHC). Station S emits the NHRP Resolution Request packet towards the destination.

If the NHRP Resolution Request is triggered by a data packet then S may, while awaiting an NHRP Resolution Reply, choose to dispose of the data packet in one of the following ways:

- (a) Drop the packet
- (b) Retain the packet until the NHRP Resolution Reply arrives and a more optimal path is available
- (c) Forward the packet along the routed path toward D

The choice of which of the above to perform is a local policy matter, though option (c) is the recommended default, since it may allow data to flow to the destination while the NBMA address is being resolved. Note that an NHRP Resolution Request for a given destination MUST NOT be triggered on every packet.

When the NHS receives an NHRP Resolution Request, a check is made to see if it serves station D. If the NHS does not serve D, the NHS forwards the NHRP Resolution Request to another NHS. Mechanisms for determining how to forward the NHRP Resolution Request are discussed in Section 3.

If this NHS serves D, the NHS resolves station D's NBMA address information, and generates a positive NHRP Resolution Reply on D's behalf. NHRP Resolution Replies in this scenario are always marked as "authoritative". The NHRP Resolution Reply packet contains the

address resolution information for station D which is to be sent back to S. Note that if station D is not on the NBMA subnetwork, the next hop internetwork layer address will be that of the egress router through which packets for station D are forwarded.

A transit NHS receiving an NHRP Resolution Reply may cache the address resolution information contained therein. To a subsequent NHRP Resolution Request, this NHS may respond with the cached, "non-authoritative" address resolution information if the NHS is permitted to do so (see Sections 5.2.2 and 6.2 for more information on non-authoritative versus authoritative NHRP Resolution Replies). Non-authoritative NHRP Resolution Replies are distinguished from authoritative NHRP Resolution Replies so that if a communication attempt based on non-authoritative information fails, a source station can choose to send an authoritative NHRP Resolution Request. NHSs MUST NOT respond to authoritative NHRP Resolution Requests with cached information.

If the determination is made that no NHS in the NBMA subnetwork can reply to the NHRP Resolution Request for D then a negative NHRP Resolution Reply (NAK) is returned. This occurs when (a) no next-hop resolution information is available for station D from any NHS, or (b) an NHS is unable to forward the NHRP Resolution Request (e.g., connectivity is lost).

NHRP Registration Requests, NHRP Purge Requests, NHRP Purge Replies, and NHRP Error Indications follow a routed path in the same fashion that NHRP Resolution Requests and NHRP Resolution Replies do. Specifically, "requests" and "indications" follow the routed path from Source Protocol Address (which is the address of the station initiating the communication) to the Destination Protocol Address. "Replies", on the other hand, follow the routed path from the Destination Protocol Address back to the Source Protocol Address with the following exceptions: in the case of a NHRP Registration Reply and in the case of an NHC initiated NHRP Purge Request, the packet is always returned via a direct VC (see Sections 5.2.4 and 5.2.5); if one does not exist then one MUST be created.

NHRP Requests and NHRP Replies do NOT cross the borders of a NBMA subnetwork however further study is being done in this area (see Section 7). Thus, the internetwork layer data traffic out of and into an NBMA subnetwork always traverses an internetwork layer router at its border.

NHRP optionally provides a mechanism to send a NHRP Resolution Reply which contains aggregated address resolution information. For example, suppose that router X is the next hop from station S to station D and that X is an egress router for all stations sharing an

internetwork layer address prefix with station D. When an NHRP Resolution Reply is generated in response to a NHRP Resolution Request, the responder may augment the internetwork layer address of station D with a prefix length (see Section 5.2.0.1). A subsequent (non-authoritative) NHRP Resolution Request for some destination that shares an internetwork layer address prefix (for the number of bits specified in the prefix length) with D may be satisfied with this cached information. See section 6.2 regarding caching issues.

To dynamically detect subnetwork-layer filtering in NBMA subnetworks (e.g., X.25 closed user group facility, or SMDS address screens), to trace the routed path that an NHRP packet takes, or to provide loop detection and diagnostic capabilities, a "Route Record" may be included in NHRP packets (see Sections 5.3.2 and 5.3.3). The Route Record extensions are the NHRP Forward Transit NHS Record Extension and the NHRP Reverse Transit NHS Record Extension. They contain the internetwork (and subnetwork layer) addresses of all intermediate NHSs between source and destination and between destination and source respectively. When a source station is unable to communicate with the responder (e.g., an attempt to open an SVC fails), it may attempt to do so successively with other subnetwork layer addresses in the NHRP Forward Transit NHS Record Extension until it succeeds (if authentication policy permits such action). This approach can find a suitable egress point in the presence of subnetwork-layer filtering (which may be source/destination sensitive, for instance, without necessarily creating separate logical NBMA subnetworks) or subnetwork-layer congestion (especially in connection-oriented media).

3. Deployment

NHRP Resolution Requests traverse one or more hops within an NBMA subnetwork before reaching the station that is expected to generate a response. Each station, including the source station, chooses a neighboring NHS to which it will forward the NHRP Resolution Request. The NHS selection procedure typically involves applying a destination protocol layer address to the protocol layer routing table which causes a routing decision to be returned. This routing decision is then used to forward the NHRP Resolution Request to the downstream NHS. The destination protocol layer address previously mentioned is carried within the NHRP Resolution Request packet. Note that even though a protocol layer address was used to acquire a routing decision, NHRP packets are not encapsulated within a protocol layer header but rather are carried at the NBMA layer using the encapsulation described in Section 5.

Each NHS/router examines the NHRP Resolution Request packet on its way toward the destination. Each NHS which the NHRP packet traverses on the way to the packet's destination might modify the packet (e.g., updating the Forward Record extension). Ignoring error situations, the NHRP Resolution Request eventually arrives at a station that is to generate an NHRP Resolution Reply. This responding station "serves" the destination. The responding station generates an NHRP Resolution Reply using the source protocol address from within the NHRP packet to determine where the NHRP Resolution Reply should be sent.

Rather than use routing to determine the next hop for an NHRP packet, an NHS may use other applicable means (such as static configuration information) in order to determine to which neighboring NHSs to forward the NHRP Resolution Request packet as long as such other means would not cause the NHRP packet to arrive at an NHS which is not along the routed path. The use of static configuration information for this purpose is beyond the scope of this document.

The NHS serving a particular destination must lie along the routed path to that destination. In practice, this means that all egress routers must double as NHSs serving the destinations beyond them, and that hosts on the NBMA subnetwork are served by routers that double as NHSs. Also, this implies that forwarding of NHRP packets within an NBMA subnetwork requires a contiguous deployment of NHRP capable routers. It is important that, in a given LIS/LAG which is using NHRP, all NHSs within the LIS/LAG have at least some portion of their resolution databases synchronized so that a packet arriving at one router/NHS in a given LIS/LAG will be forwarded in the same fashion as a packet arriving at a different router/NHS for the given LIS/LAG. One method, among others, is to use the Server Cache Synchronization Protocol (SCSP) [12]. It is RECOMMENDED that SCSP be the method used when a LIS/LAG contains two or more router/NHSs.

During migration to NHRP, it cannot be expected that all routers within the NBMA subnetwork are NHRP capable. Thus, NHRP traffic which would otherwise need to be forwarded through such routers can be expected to be dropped due to the NHRP packet not being recognized. In this case, NHRP will be unable to establish any transit paths whose discovery requires the traversal of the non-NHRP speaking routers. If the client has tried and failed to acquire a cut through path then the client should use the network layer routed path as a default.

If an NBMA technology offers a group, an anycast, or a multicast addressing feature then the NHC may be configured with such an address (appropriate to the routing realm it participates in) which would be assigned to all NHS serving that routing realm. This

address can then be used for establishing an initial connection to an NHS to transmit a registration request. This address may not be used for sending NHRP requests. The resulting VC may be used for NHRP requests if and only if the registration response is received over that VC, thereby indicating that one happens to have anycast connected to an NHS serving the LIS/LAG. In the case of non-connection oriented networks, or of multicast (rather than anycast) addresses, the address MUST NOT be used for sending NHRP resolution requests.

When an NHS "serves" an NHC, the NHS MUST send NHRP messages destined for the NHC directly to the NHC. That is, the NHRP message MUST NOT transit through any NHS which is not serving the NHC when the NHRP message is currently at an NHS which does serve the NHC (this, of course, assumes the NHRP message is destined for the NHC). Further, an NHS which serves an NHC SHOULD have a direct NBMA level connection to that NHC (see Section 5.2.3 and 5.2.4 for examples).

With the exception of NHRP Registration Requests (see Section 5.2.3 and 5.2.4 for details of the NHRP Registration Request case), an NHC MUST send NHRP messages over a direct NBMA level connection between the serving NHS and the served NHC.

It may not be desirable to maintain semi-permanent NBMA level connectivity between the NHC and the NHS. In this case, when NBMA level connectivity is initially setup between the NHS and the NHC (as described in Section 5.2.4), the NBMA address of the NHS should be obtained through the NBMA level signaling technology. This address should be stored for future use in setting up subsequent NBMA level connections. A somewhat more information rich technique to obtain the address information (and more) of the serving NHS would be for the NHC to include the Responder Address extension (see Section 5.3.1) in the NHRP Registration Request and to store the information returned to the NHC in the Responder Address extension which is subsequently included in the NHRP Registration Reply. Note also that, in practice, a client's default router should also be its NHS; thus a client may be able to know the NBMA address of its NHS from the configuration which was already required for the client to be able to communicate. Further, as mentioned in Section 4, NHCs may be configured with the addressing information of one or more NHSs.

4. Configuration

Next Hop Clients

An NHC connected to an NBMA subnetwork MAY be configured with the Protocol address(es) and NBMA address(es) of its NHS(s). The NHS(s) will likely also represent the NHC's default or peer

routers, so their NBMA addresses may be obtained from the NHC's existing configuration. If the NHC is attached to several subnetworks (including logical NBMA subnetworks), the NHC should also be configured to receive routing information from its NHS(s) and peer routers so that it can determine which internetwork layer networks are reachable through which subnetworks.

Next Hop Servers

An NHS is configured with knowledge of its own internetwork layer and NBMA addresses. An NHS MAY also be configured with a set of internetwork layer address prefixes that correspond to the internetwork layer addresses of the stations it serves. The NBMA addresses of the stations served by the NHS may be learned via NHRP Registration packets.

If a served NHC is attached to several subnetworks, the router/route-server coresident with the serving NHS may also need to be configured to advertise routing information to such NHCs.

If an NHS acts as an egress router for stations connected to other subnetworks than the NBMA subnetwork, the NHS must, in addition to the above, be configured to exchange routing information between the NBMA subnetwork and these other subnetworks.

In all cases, routing information is exchanged using conventional intra-domain and/or inter-domain routing protocols.

5. NHRP Packet Formats

This section describes the format of NHRP packets. In the following, unless otherwise stated explicitly, the unqualified term "request" refers generically to any of the NHRP packet types which are "requests". Further, unless otherwise stated explicitly, the unqualified term "reply" refers generically to any of the NHRP packet types which are "replies".

An NHRP packet consists of a Fixed Part, a Mandatory Part, and an Extensions Part. The Fixed Part is common to all NHRP packet types. The Mandatory Part MUST be present, but varies depending on packet type. The Extensions Part also varies depending on packet type, and need not be present.

The length of the Fixed Part is fixed at 20 octets. The length of the Mandatory Part is determined by the contents of the extensions offset field (ar\$extoff). If ar\$extoff=0x0 then the mandatory part length is equal to total packet length (ar\$pktsz) minus 20 otherwise the mandatory part length is equal to ar\$extoff minus 20. The length

of the Extensions Part is implied by `ar$pktsz` minus `ar$extoff`. NHSSs may increase the size of an NHRP packet as a result of extension processing, but not beyond the offered maximum packet size of the NBMA network.

NHRP packets are actually members of a wider class of address mapping and management protocols being developed by the IETF. A specific encapsulation, based on the native formats used on the particular NBMA network over which NHRP is carried, indicates the generic IETF mapping and management protocol. For example, SMDS networks always use LLC/SNAP encapsulation at the NBMA layer [4], and an NHRP packet is preceded by the following LLC/SNAP encapsulation:

```
[0xAA-AA-03] [0x00-00-5E] [0x00-03]
```

The first three octets are LLC, indicating that SNAP follows. The SNAP OUI portion is the IANA's OUI, and the SNAP PID portion identifies the mapping and management protocol. A field in the Fixed Header following the encapsulation indicates that it is NHRP.

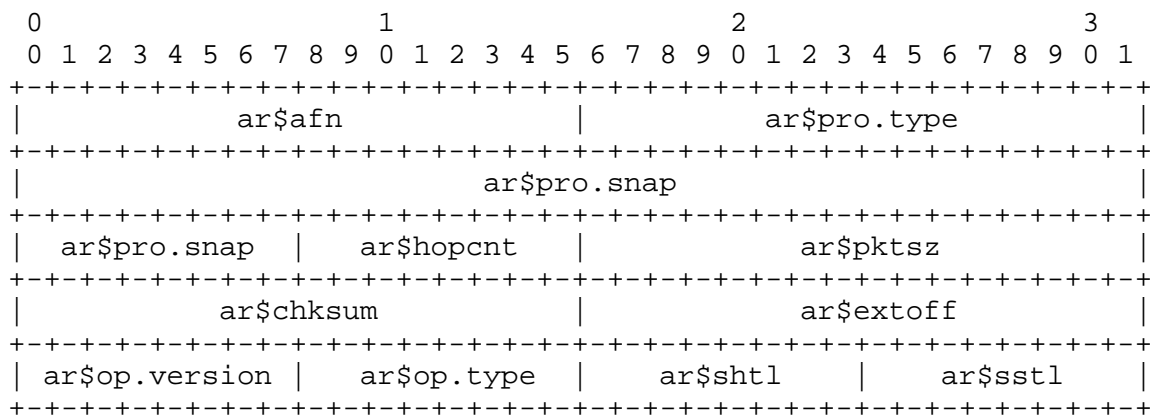
ATM uses either LLC/SNAP encapsulation of each packet (including NHRP), or uses no encapsulation on VCs dedicated to a single protocol (see [7]). Frame Relay and X.25 both use NLPID/SNAP encapsulation or identification of NHRP, using a NLPID of 0x0080 and the same SNAP contents as above (see [8], [9]).

Fields marked "unused" MUST be set to zero on transmission, and ignored on receipt.

Most packet types (`ar$op.type`) have both internetwork layer protocol-independent fields and protocol-specific fields. The protocol type/snap fields (`ar$pro.type/snap`) qualify the format of the protocol-specific fields.

5.1 NHRP Fixed Header

The Fixed Part of the NHRP packet contains those elements of the NHRP packet which are always present and do not vary in size with the type of packet.

**ar\$afn**

Defines the type of "link layer" addresses being carried. This number is taken from the 'address family number' list specified in [6]. This field has implications to the coding of ar\$shtl and ar\$sstl as described below.

ar\$pro.type

field is a 16 bit unsigned integer representing the following number space:

0x0000 to 0x00FF	Protocols defined by the equivalent NLPIDs.
0x0100 to 0x03FF	Reserved for future use by the IETF.
0x0400 to 0x04FF	Allocated for use by the ATM Forum.
0x0500 to 0x05FF	Experimental/Local use.
0x0600 to 0xFFFF	Protocols defined by the equivalent Ethertypes.

(based on the observations that valid Ethertypes are never smaller than 0x600, and NLPIDs never larger than 0xFF.)

ar\$pro.snap

When ar\$pro.type has a value of 0x0080, a SNAP encoded extension is being used to encode the protocol type. This snap extension is placed in the ar\$pro.snap field. This is termed the 'long form' protocol ID. If ar\$pro != 0x0080 then the ar\$pro.snap field MUST be zero on transmit and ignored on receive. The ar\$pro.type field itself identifies the protocol being referred to. This is termed the 'short form' protocol ID.

In all cases, where a protocol has an assigned number in the ar\$pro.type space (excluding 0x0080) the short form MUST be used when transmitting NHRP messages; i.e., if Ethertype or NLPID codings exist then they are used on transmit rather than the

ethertype. If both Ethertype and NLPID codings exist then when transmitting NHRP messages, the Ethertype coding MUST be used (this is consistent with RFC 1483 coding). So, for example, the following codings exist for IP:

```
SNAP:      ar$pro.type = 0x00-80, ar$pro.snap = 0x00-00-00-08-00
NLPID:     ar$pro.type = 0x00-CC, ar$pro.snap = 0x00-00-00-00-00
Ethertype: ar$pro.type = 0x08-00, ar$pro.snap = 0x00-00-00-00-00
```

and thus, since the Ethertype coding exists, it is used in preference.

ar\$hopcnt

The Hop count indicates the maximum number of NHSs that an NHRP packet is allowed to traverse before being discarded. This field is used in a similar fashion to the way that a TTL is used in an IP packet and should be set accordingly. Each NHS decrements the TTL as the NHRP packet transits the NHS on the way to the next hop along the routed path to the destination. If an NHS receives an NHRP packet which it would normally forward to a next hop and that packet contains an ar\$hopcnt set to zero then the NHS sends an error indication message back to the source protocol address stating that the hop count has been exceeded (see Section 5.2.7) and the NHS drops the packet in error; however, an error indication is never sent as a result of receiving an error indication. When a responding NHS replies to an NHRP request, that NHS places a value in ar\$hopcnt as if it were sending a request of its own.

ar\$pktsz

The total length of the NHRP packet, in octets (excluding link layer encapsulation).

ar\$chksum

The standard IP checksum over the entire NHRP packet starting at the fixed header. If the packet is an odd number of bytes in length then this calculation is performed as if a byte set to 0x00 is appended to the end of the packet.

ar\$extoff

This field identifies the existence and location of NHRP extensions. If this field is 0 then no extensions exist otherwise this field represents the offset from the beginning of the NHRP packet (i.e., starting from the ar\$afn field) of the first extension.

`ar$op.version`

This field indicates what version of generic address mapping and management protocol is represented by this message.

0	MARS protocol [11].
1	NHRP as defined in this document.
0x02 - 0xEF	Reserved for future use by the IETF.
0xF0 - 0xFE	Allocated for use by the ATM Forum.
0xFF	Experimental/Local use.

`ar$op.type`

When `ar$op.version == 1`, this is the NHRP packet type: NHRP Resolution Request(1), NHRP Resolution Reply(2), NHRP Registration Request(3), NHRP Registration Reply(4), NHRP Purge Request(5), NHRP Purge Reply(6), or NHRP Error Indication(7). Use of NHRP packet Types in the range 128 to 255 are reserved for research or use in other protocol development and will be administered by IANA as described in Section 9.

`ar$shtl`

Type & length of source NBMA address interpreted in the context of the 'address family number'[6] indicated by `ar$afn`. See below for more details.

`ar$sstl`

Type & length of source NBMA subaddress interpreted in the context of the 'address family number'[6] indicated by `ar$afn`. When an NBMA technology has no concept of a subaddress, the subaddress length is always coded `ar$sstl = 0` and no storage is allocated for the subaddress in the appropriate mandatory part. See below for more details.

Subnetwork layer address type/length fields (e.g., `ar$shtl`, `Cli Addr T/L`) and subnetwork layer subaddresses type/length fields (e.g., `ar$sstl`, `Cli SAddr T/L`) are coded as follows:

```

  7 6 5 4 3 2 1 0
+---+---+---+---+
|0|x| length  |
+---+---+---+---+
```

The most significant bit is reserved and MUST be set to zero. The second most significant bit (x) is a flag indicating whether the address being referred to is in:

- NSAP format (x = 0).
- Native E.164 format (x = 1).

For NBMA technologies that use neither NSAP nor E.164 format addresses, x = 0 SHALL be used to indicate the native form for the particular NBMA technology.

If the NBMA network is ATM and a subaddress (e.g., Source NBMA SubAddress, Client NBMA SubAddress) is to be included in any part of the NHRP packet then ar\$afn MUST be set to 0x000F; further, the subnetwork layer address type/length fields (e.g., ar\$shtl, Cli Addr T/L) and subnetwork layer subaddress type/length fields (e.g., ar\$sstl, Cli SAddr T/L) MUST be coded as in [11]. If the NBMA network is ATM and no subaddress field is to be included in any part of the NHRP packet then ar\$afn MAY be set to 0x0003 (NSAP) or 0x0008 (E.164) accordingly.

The bottom 6 bits is an unsigned integer value indicating the length of the associated NBMA address in octets. If this value is zero the flag x is ignored.

5.2.0 Mandatory Part

The Mandatory Part of the NHRP packet contains the operation specific information (e.g., NHRP Resolution Request/Reply, etc.) and variable length data which is pertinent to the packet type.

5.2.0.1 Mandatory Part Format

Sections 5.2.1 through 5.2.6 have a very similar mandatory part. This mandatory part includes a common header and zero or more Client Information Entries (CIEs). Section 5.2.7 has a different format which is specified in that section.

The common header looks like the following:

0								1								2								3							
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
Src Proto Len								Dst Proto Len								Flags															
Request ID																															
Source NBMA Address (variable length)																															
Source NBMA Subaddress (variable length)																															
Source Protocol Address (variable length)																															
Destination Protocol Address (variable length)																															

And the CIEs have the following format:

0										1										2										3									
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1								
Code										Prefix Length										unused																			
Maximum Transmission Unit										Holding Time																													
Cli Addr T/L										Cli SAddr T/L										Cli Proto Len										Preference									
										Client NBMA Address (variable length)																													
										Client NBMA Subaddress (variable length)																													
										Client Protocol Address (variable length)																													
.....																																							
Code										Prefix Length										unused																			
Maximum Transmission Unit										Holding Time																													
Cli Addr T/L										Cli SAddr T/L										Cli Proto Len										Preference									
										Client NBMA Address (variable length)																													
										Client NBMA Subaddress (variable length)																													
										Client Protocol Address (variable length)																													

The meanings of the fields are as follows:

Src Proto Len

This field holds the length in octets of the Source Protocol Address.

Dst Proto Len

This field holds the length in octets of the Destination Protocol Address.

Flags

These flags are specific to the given message type and they are explained in each section.

Request ID

A value which, when coupled with the address of the source, provides a unique identifier for the information contained in a "request" packet. This value is copied directly from an "request" packet into the associated "reply". When a sender of a "request" receives "reply", it will compare the Request ID and source address information in the received "reply" against that found in its outstanding "request" list. When a match is found then the "request" is considered to be acknowledged.

The value is taken from a 32 bit counter that is incremented each time a new "request" is transmitted. The same value MUST be used when resending a "request", i.e., when a "reply" has not been received for a "request" and a retry is sent after an appropriate interval.

It is RECOMMENDED that the initial value for this number be 0. A node MAY reuse a sequence number if and only if the reuse of the sequence number is not precluded by use of a particular method of synchronization (e.g., as described in Appendix A).

The NBMA address/subaddress form specified below allows combined E.164/NSAPA form of NBMA addressing. For NBMA technologies without a subaddress concept, the subaddress field is always ZERO length and ar\$stl = 0.

Source NBMA Address

The Source NBMA address field is the address of the source station which is sending the "request". If the field's length as specified in ar\$shtl is 0 then no storage is allocated for this address at all.

Source NBMA SubAddress

The Source NBMA subaddress field is the address of the source station which is sending the "request". If the field's length as specified in ar\$sstl is 0 then no storage is allocated for this address at all.

For those NBMA technologies which have a notion of "Calling Party Addresses", the Source NBMA Addresses above are the addresses used when signaling for an SVC.

"Requests" and "indications" follow the routed path from Source Protocol Address to the Destination Protocol Address. "Replies", on the other hand, follow the routed path from the Destination Protocol Address back to the Source Protocol Address with the following

exceptions: in the case of a NHRP Registration Reply and in the case of an NHC initiated NHRP Purge Request, the packet is always returned via a direct VC (see Sections 5.2.4 and 5.2.5).

Source Protocol Address

This is the protocol address of the station which is sending the "request". This is also the protocol address of the station toward which a "reply" packet is sent.

Destination Protocol Address

This is the protocol address of the station toward which a "request" packet is sent.

Code

This field is message specific. See the relevant message sections below. In general, this field is a NAK code; i.e., when the field is 0 in a reply then the packet is acknowledging a request and if it contains any other value the packet contains a negative acknowledgment.

Prefix Length

This field is message specific. See the relevant message sections below. In general, however, this field is used to indicate that the information carried in an NHRP message pertains to an equivalence class of internetwork layer addresses rather than just a single internetwork layer address specified. All internetwork layer addresses that match the first "Prefix Length" bit positions for the specific internetwork layer address are included in the equivalence class. If this field is set to 0x00 then this field MUST be ignored and no equivalence information is assumed (note that 0x00 is thus equivalent to 0xFF).

Maximum Transmission Unit

This field gives the maximum transmission unit for the relevant client station. If this value is 0 then either the default MTU is used or the MTU negotiated via signaling is used if such negotiation is possible for the given NBMA.

Holding Time

The Holding Time field specifies the number of seconds for which the Next Hop NBMA information specified in the CIE is considered to be valid. Cached information SHALL be discarded when the holding time expires. This field must be set to 0 on a NAK.

Cli Addr T/L

Type & length of next hop NBMA address specified in the CIE. This field is interpreted in the context of the 'address family number'[6] indicated by ar\$afn (e.g., ar\$afn=0x0003 for ATM).

Cli SAddr T/L

Type & length of next hop NBMA subaddress specified in the CIE. This field is interpreted in the context of the 'address family number'[6] indicated by ar\$afn (e.g., ar\$afn=0x0015 for ATM makes the address an E.164 and the subaddress an ATM Forum NSAP address). When an NBMA technology has no concept of a subaddress, the subaddress is always null with a length of 0. When the address length is specified as 0 no storage is allocated for the address.

Cli Proto Len

This field holds the length in octets of the Client Protocol Address specified in the CIE.

Preference

This field specifies the preference for use of the specific CIE relative to other CIEs. Higher values indicate higher preference. Action taken when multiple CIEs have equal or highest preference value is a local matter.

Client NBMA Address

This is the client's NBMA address.

Client NBMA SubAddress

This is the client's NBMA subaddress.

Client Protocol Address

This is the client's internetworking layer address specified.

Note that an NHS may cache source address binding information from an NHRP Resolution Request if and only if the conditions described in Section 6.2 are met for the NHS. In all other cases, source address binding information appearing in an NHRP message MUST NOT be cached.

5.2.1 NHRP Resolution Request

The NHRP Resolution Request packet has a Type code of 1. Its mandatory part is coded as described in Section 5.2.0.1 and the message specific meanings of the fields are as follows:

Flags - The flags field is coded as follows:

```

      0                               1
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+---+---+---+---+---+---+---+---+---+---+
|Q|A|D|U|S|           unused           |
+---+---+---+---+---+---+---+---+---+---+

```

Q
Set if the station sending the NHRP Resolution Request is a router; clear if the it is a host.

A
This bit is set in a NHRP Resolution Request if only authoritative next hop information is desired and is clear otherwise. See the NHRP Resolution Reply section below for further details on the "A" bit and its usage.

D
Unused (clear on transmit)

U
This is the Uniqueness bit. This bit aids in duplicate address detection. When this bit is set in an NHRP Resolution Request and one or more entries exist in the NHS cache which meet the requirements of the NHRP Resolution Request then only the CIE in the NHS's cache with this bit set will be returned. Note that even if this bit was set at registration time, there may still be multiple CIEs that might fulfill the NHRP Resolution Request because an entire subnet can be registered through use of the Prefix Length in the CIE and the address of interest might be within such a subnet. If the "uniqueness" bit is set and the responding NHS has one or more cache entries which match the request but no such cache entry has the "uniqueness" bit set, then the NHRP Resolution Reply returns with a NAK code of "13 - Binding Exists But Is Not Unique" and no CIE is included. If a client wishes to receive non-unique Next Hop Entries, then the client must have the "uniqueness" bit set to zero in its NHRP Resolution Request. Note that when this bit is set in an NHRP Registration Request, only a single CIE may be specified in the NHRP Registration Request and that CIE must have the Prefix Length field set to 0xFF.

S
Set if the binding between the Source Protocol Address and the Source NBMA information in the NHRP Resolution Request is guaranteed to be stable and accurate (e.g., these addresses are those of an ingress router which is connected to an ethernet stub network or the NHC is an NBMA attached host).

Zero or one CIEs (see Section 5.2.0.1) may be specified in an NHRP Resolution Request. If one is specified then that entry carries the pertinent information for the client sourcing the NHRP Resolution Request. Usage of the CIE in the NHRP Resolution Request is described below:

Prefix Length

If a CIE is specified in the NHRP Resolution Request then the Prefix Length field may be used to qualify the widest acceptable prefix which may be used to satisfy the NHRP Resolution Request. In the case of NHRP Resolution Request/Reply, the Prefix Length specifies the equivalence class of addresses which match the first "Prefix Length" bit positions of the Destination Protocol Address. If the "U" bit is set in the common header then this field MUST be set to 0xFF.

Maximum Transmission Unit

This field gives the maximum transmission unit for the source station. A possible use of this field in the NHRP Resolution Request packet is for the NHRP Resolution Requester to ask for a target MTU.

Holding Time

The Holding Time specified in the one CIE permitted to be included in an NHRP Resolution Request is the amount of time which the source address binding information in the NHRP Resolution Request is permitted to be cached by transit and responding NHSSs. Note that this field may only have a non-zero value if the S bit is set.

All other fields in the CIE MUST be ignored and SHOULD be set to 0.

The Destination Protocol Address in the common header of the Mandatory Part of this message contains the protocol address of the station for which resolution is desired. An NHC MUST send the NHRP Resolution Request directly to one of its serving NHSSs (see Section 3 for more information).

5.2.2 NHRP Resolution Reply

The NHRP Resolution Reply packet has a Type code of 2. CIEs correspond to Next Hop Entries in an NHS's cache which match the criteria in the NHRP Resolution Request. Its mandatory part is coded as described in Section 5.2.0.1. The message specific meanings of the fields are as follows:

Flags - The flags field is coded as follows:

```

      0                               1
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+---+---+---+---+---+---+---+---+---+---+
|Q|A|D|U|S|           unused           |
+---+---+---+---+---+---+---+---+---+

```

Q

Copied from the NHRP Resolution Request. Set if the NHRP Resolution Requester is a router; clear if it is a host.

A

Set if the next hop CIE in the NHRP Resolution Reply is authoritative; clear if the NHRP Resolution Reply is non-authoritative.

When an NHS receives a NHRP Resolution Request for authoritative information for which it is the authoritative source, it MUST respond with a NHRP Resolution Reply containing all and only those next hop CIEs which are contained in the NHS's cache which both match the criteria of the NHRP Resolution Request and are authoritative cache entries. An NHS is an authoritative source for a NHRP Resolution Request if the information in the NHS's cache matches the NHRP Resolution Request criteria and that information was obtained through a NHRP Registration Request or through synchronization with an NHS which obtained this information through a NHRP Registration Request. An authoritative cache entry is one which is obtained through a NHRP Registration Request or through synchronization with an NHS which obtained this information through a NHRP Registration Request.

An NHS obtains non-authoritative CIEs through promiscuous listening to NHRP packets other than NHRP Registrations which are directed at it. A NHRP Resolution Request which indicates a request for non-authoritative information should cause a NHRP Resolution Reply which contains all entries in the replying NHS's cache (i.e., both authoritative and non-authoritative) which match the criteria specified in the request.

D

Set if the association between destination and the associate next hop information included in all CIEs of the NHRP Resolution Reply is guaranteed to be stable for the lifetime of the information (the holding time). This is the case if the Next Hop protocol address in a CIE identifies the destination (though it may be different in value than the Destination address if the destination system has multiple addresses) or if the destination is not connected directly to the NBMA subnetwork but the egress router to that destination is guaranteed to be stable (such as

when the destination is immediately adjacent to the egress router through a non-NBMA interface).

U

This is the Uniqueness bit. See the NHRP Resolution Request section above for details. When this bit is set, only one CIE is included since only one unique binding should exist in an NHS's cache.

S

Copied from NHRP Resolution Request message.

One or more CIEs are specified in the NHRP Resolution Reply. Each CIE contains NHRP next hop information which the responding NHS has cached and which matches the parameters specified in the NHRP Resolution Request. If no match is found by the NHS issuing the NHRP Resolution Reply then a single CIE is enclosed with the a CIE Code set appropriately (see below) and all other fields MUST be ignored and SHOULD be set to 0. In order to facilitate the use of NHRP by minimal client implementations, the first CIE MUST contain the next hop with the highest preference value so that such an implementation need parse only a single CIE.

Code

If this field is set to zero then this packet contains a positively acknowledged NHRP Resolution Reply. If this field contains any other value then this message contains an NHRP Resolution Reply NAK which means that an appropriate internetworking layer to NBMA address binding was not available in the responding NHS's cache. If NHRP Resolution Reply contains a Client Information Entry with a NAK Code other than 0 then it MUST NOT contain any other CIE. Currently defined NAK Codes are as follows:

4 - Administratively Prohibited

An NHS may refuse an NHRP Resolution Request attempt for administrative reasons (due to policy constraints or routing state). If so, the NHS MUST send an NHRP Resolution Reply which contains a NAK code of 4.

5 - Insufficient Resources

If an NHS cannot serve a station due to a lack of resources (e.g., can't store sufficient information to send a purge if routing changes), the NHS MUST reply with a NAKed NHRP Resolution Reply which contains a NAK code of 5.

12 - No Internetworking Layer Address to NBMA Address Binding Exists

This code states that there were absolutely no internetworking layer address to NBMA address bindings found in the responding NHS's cache.

13 - Binding Exists But Is Not Unique

This code states that there were one or more internetworking layer address to NBMA address bindings found in the responding NHS's cache, however none of them had the uniqueness bit set.

Prefix Length

In the case of NHRP Resolution Reply, the Prefix Length specifies the equivalence class of addresses which match the first "Prefix Length" bit positions of the Destination Protocol Address.

Holding Time

The Holding Time specified in a CIE of an NHRP Resolution Reply is the amount of time remaining before the expiration of the client information which is cached at the replying NHS. It is not the value which was registered by the client.

The remainder of the fields for the CIE for each next hop are filled out as they were defined when the next hop was registered with the responding NHS (or one of the responding NHS's synchronized servers) via the NHRP Registration Request.

Load-splitting may be performed when more than one Client Information Entry is returned to a requester when equal preference values are specified. Also, the alternative addresses may be used in case of connectivity failure in the NBMA subnetwork (such as a failed call attempt in connection-oriented NBMA subnetworks).

Any extensions present in the NHRP Resolution Request packet MUST be present in the NHRP Resolution Reply even if the extension is non-Compulsory.

If an unsolicited NHRP Resolution Reply packet is received, an Error Indication of type Invalid NHRP Resolution Reply Received SHOULD be sent in response.

When an NHS that serves a given NHC receives an NHRP Resolution Reply destined for that NHC then the NHS must MUST send the NHRP Resolution Reply directly to the NHC (see Section 3).

5.2.3 NHRP Registration Request

The NHRP Registration Request is sent from a station to an NHS to notify the NHS of the station's NBMA information. It has a Type code of 3. Each CIE corresponds to Next Hop information which is to be cached at an NHS. The mandatory part of an NHRP Registration Request is coded as described in Section 5.2.0.1. The message specific meanings of the fields are as follows:

Flags - The flags field is coded as follows:

```

      0                               1
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|U|               unused               |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

U

This is the Uniqueness bit. When set in an NHRP Registration Request, this bit indicates that the registration of the protocol address is unique within the confines of the set of synchronized NHSs. This "uniqueness" qualifier MUST be stored in the NHS/NHC cache. Any attempt to register a binding between the protocol address and an NBMA address when this bit is set MUST be rejected with a Code of "14 - Unique Internetworking Layer Address Already Registered" if the replying NHS already has a cache entry for the protocol address and the cache entry has the "uniqueness" bit set. A registration of a CIE's information is rejected when the CIE is returned with the Code field set to anything other than 0x00. See the description of the uniqueness bit in NHRP Resolution Request section above for further details. When this bit is set only, only one CIE MAY be included in the NHRP Registration Request.

Request ID

The request ID has the same meaning as described in Section 5.2.0.1. However, the request ID for NHRP Registrations which is maintained at each client MUST be kept in non-volatile memory so that when a client crashes and reregisters there will be no inconsistency in the NHS's database. In order to reduce the overhead associated with updating non-volatile memory, the actual updating need not be done with every increment of the Request ID but could be done, for example, every 50 or 100 increments. In this scenario, when a client crashes and reregisters it knows to add 100 to the value of the Request ID in the non-volatile memory before using the Request ID for subsequent registrations.

One or more CIEs are specified in the NHRP Registration Request. Each CIE contains next hop information which a client is attempting to register with its servers. Generally, all fields in CIEs enclosed in NHRP Registration Requests are coded as described in Section 5.2.0.1. However, if a station is only registering itself with the NHRP Registration Request then it MAY code the Cli Addr T/L, Cli SAddr T/L, and Cli Proto Len as zero which signifies that the client address information is to be taken from the source information in the common header (see Section 5.2.0.1). Below, further clarification is given for some fields in a CIE in the context of a NHRP Registration Request.

Code

This field is set to 0x00 in NHRP Registration Requests.

Prefix Length

This field may be used in a NHRP Registration Request to register equivalence information for the Client Protocol Address specified in the CIE of an NHRP Registration Request. In the case of NHRP Registration Request, the Prefix Length specifies the equivalence class of addresses which match the first "Prefix Length" bit positions of the Client Protocol Address. If the "U" bit is set in the common header then this field MUST be set to 0xFF.

The NHRP Registration Request is used to register an NHC's NHRP information with its NHSS. If an NHC is configured with the protocol address of a serving NHS then the NHC may place the NHS's protocol address in the Destination Protocol Address field of the NHRP Registration Request common header otherwise the NHC must place its own protocol address in the Destination Protocol Address field.

When an NHS receives an NHRP Registration Request which has the Destination Protocol Address field set to an address which belongs to a LIS/LAG for which the NHS is serving then if the Destination Protocol Address field is equal to the Source Protocol Address field (which would happen if the NHC put its protocol address in the Destination Protocol Address) or the Destination Protocol Address field is equal to the protocol address of the NHS then the NHS processes the NHRP Registration Request after doing appropriate error checking (including any applicable policy checking).

When an NHS receives an NHRP Registration Request which has the Destination Protocol Address field set to an address which does not belong to a LIS/LAG for which the NHS is serving then the NHS forwards the packet down the routed path toward the appropriate LIS/LAG.

When an NHS receives an NHRP Registration Request which has the Destination Protocol Address field set to an address which belongs to a LIS/LAG for which the NHS is serving then if the Destination Protocol Address field does not equal the Source Protocol Address field and the Destination Protocol Address field does not equal the protocol address of the NHS then the NHS forwards the message to the appropriate NHS within the LIS/LAG as specified by Destination Protocol Address field.

It is possible that a misconfigured station will attempt to register with the wrong NHS (i.e., one that cannot serve it due to policy constraints or routing state). If this is the case, the NHS MUST reply with a NAK-ed Registration Reply of type Can't Serve This Address.

If an NHS cannot serve a station due to a lack of resources, the NHS MUST reply with a NAK-ed Registration Reply of type Registration Overflow.

In order to keep the registration entry from being discarded, the station MUST re-send the NHRP Registration Request packet often enough to refresh the registration, even in the face of occasional packet loss. It is recommended that the NHRP Registration Request packet be sent at an interval equal to one-third of the Holding Time specified therein.

5.2.4 NHRP Registration Reply

The NHRP Registration Reply is sent by an NHS to a client in response to that client's NHRP Registration Request. If the Code field of a CIE in the NHRP Registration Reply has anything other than zero in it then the NHRP Registration Reply is a NAK otherwise the reply is an ACK. The NHRP Registration Reply has a Type code of 4.

An NHRP Registration Reply is formed from an NHRP Registration Request by changing the type code to 4, updating the CIE Code field, and filling in the appropriate extensions if they exist. The message specific meanings of the fields are as follows:

Attempts to register the information in the CIEs of an NHRP Registration Request may fail for various reasons. If this is the case then each failed attempt to register the information in a CIE of an NHRP Registration Request is logged in the associated NHRP Registration Reply by setting the CIE Code field to the appropriate error code as shown below:

CIE Code

0 - Successful Registration

The information in the CIE was successfully registered with the NHS.

4 - Administratively Prohibited

An NHS may refuse an NHRP Registration Request attempt for administrative reasons (due to policy constraints or routing state). If so, the NHS MUST send an NHRP Registration Reply which contains a NAK code of 4.

5 - Insufficient Resources

If an NHS cannot serve a station due to a lack of resources, the NHS MUST reply with a NAKed NHRP Registration Reply which contains a NAK code of 5.

14 - Unique Internetworking Layer Address Already Registered

If a client tries to register a protocol address to NBMA address binding with the uniqueness bit on and the protocol address already exists in the NHS's cache then if that cache entry also has the uniqueness bit on then this NAK Code is returned in the CIE in the NHRP Registration Reply.

Due to the possible existence of asymmetric routing, an NHRP Registration Reply may not be able to merely follow the routed path back to the source protocol address specified in the common header of the NHRP Registration Reply. As a result, there MUST exist a direct NBMA level connection between the NHC and its NHS on which to send the NHRP Registration Reply before NHRP Registration Reply may be returned to the NHC. If such a connection does not exist then the NHS must setup such a connection to the NHC by using the source NBMA information supplied in the common header of the NHRP Registration Request.

5.2.5 NHRP Purge Request

The NHRP Purge Request packet is sent in order to invalidate cached information in a station. The NHRP Purge Request packet has a type code of 5. The mandatory part of an NHRP Purge Request is coded as described in Section 5.2.0.1. The message specific meanings of the fields are as follows:

Flags - The flags field is coded as follows:

```

      0                               1
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+---+---+---+---+---+---+---+---+---+
|N|               unused               |
+---+---+---+---+---+---+---+---+---+

```

N

When set, this bit tells the receiver of the NHRP Purge Request that the requester does not expect to receive an NHRP Purge Reply. If an unsolicited NHRP Purge Reply is received by a station where that station is identified in the Source Protocol Address of the packet then that packet must be ignored.

One or more CIEs are specified in the NHRP Purge Request. Each CIE contains next hop information which is to be purged from an NHS/NHC cache. Generally, all fields in CIEs enclosed in NHRP Purge Requests are coded as described in Section 5.2.0.1. Below, further clarification is given for some fields in a CIE in the context of a NHRP Purge Request.

Code

This field is set to 0x00 in NHRP Purge Requests.

Prefix Length

In the case of NHRP Purge Requests, the Prefix Length specifies the equivalence class of addresses which match the first "Prefix Length" bit positions of the Client Protocol Address specified in the CIE. All next hop information which contains a protocol address which matches an element of this equivalence class is to be purged from the receivers cache.

The Maximum Transmission Unit and Preference fields of the CIE are coded as zero. The Holding Time should be coded as zero but there may be some utility in supplying a "short" holding time to be applied to the matching next hop information before that information would be purged; this usage is for further study. The Client Protocol Address field and the Cli Proto Len field MUST be filled in. The Client Protocol Address is filled in with the protocol address to be purged from the receiving station's cache while the Cli Proto Len is set the length of the purged client's protocol address. All remaining fields in the CIE MAY be set to zero although the client NBMA information (and associated length fields) MAY be specified to narrow the scope of the NHRP Purge Request if requester desires. However, the receiver of an NHRP Purge Request may choose to ignore the Client NBMA information if it is supplied.

An NHRP Purge Request packet is sent from an NHS to a station to cause it to delete previously cached information. This is done when the information may be no longer valid (typically when the NHS has previously provided next hop information for a station that is not directly connected to the NBMA subnetwork, and the egress point to that station may have changed).

An NHRP Purge Request packet may also be sent from an NHC to an NHS with which the NHC had previously registered. This allows for an NHC to invalidate its registration with NHRP before it would otherwise expire via the holding timer. If an NHC does not have knowledge of a protocol address of a serving NHS then the NHC must place its own protocol address in the Destination Protocol Address field and forward the packet along the routed path. Otherwise, the NHC must place the protocol address of a serving NHS in this field.

Serving NHSs may need to send one or more new NHRP Purge Requests as a result of receiving a purge from one of their served NHCs since the NHS may have previously responded to NHRP Resolution Requests for that NHC's NBMA information. These purges are "new" in that they are sourced by the NHS and not the NHC; that is, for each NHC that previously sent a NHRP Resolution Request for the purged NHC NBMA information, an NHRP Purge Request is sent which contains the Source Protocol/NBMA Addresses of the NHS and the Destination Protocol Address of the NHC which previously sent an NHRP Resolution Request prior to the purge.

The station sending the NHRP Purge Request MAY periodically retransmit the NHRP Purge Request until either NHRP Purge Request is acknowledged or until the holding time of the information being purged has expired. Retransmission strategies for NHRP Purge Requests are a local matter.

When a station receives an NHRP Purge Request, it MUST discard any previously cached information that matches the information in the CIEs.

An NHRP Purge Reply MUST be returned for the NHRP Purge Request even if the station does not have a matching cache entry assuming that the "N" bit is off in the NHRP Purge Request.

If the station wishes to reestablish communication with the destination shortly after receiving an NHRP Purge Request, it should make an authoritative NHRP Resolution Request in order to avoid any stale cache entries that might be present in intermediate NHSs (See section 6.2.2.). It is recommended that authoritative NHRP Resolution Requests be made for the duration of the holding time of the old information.

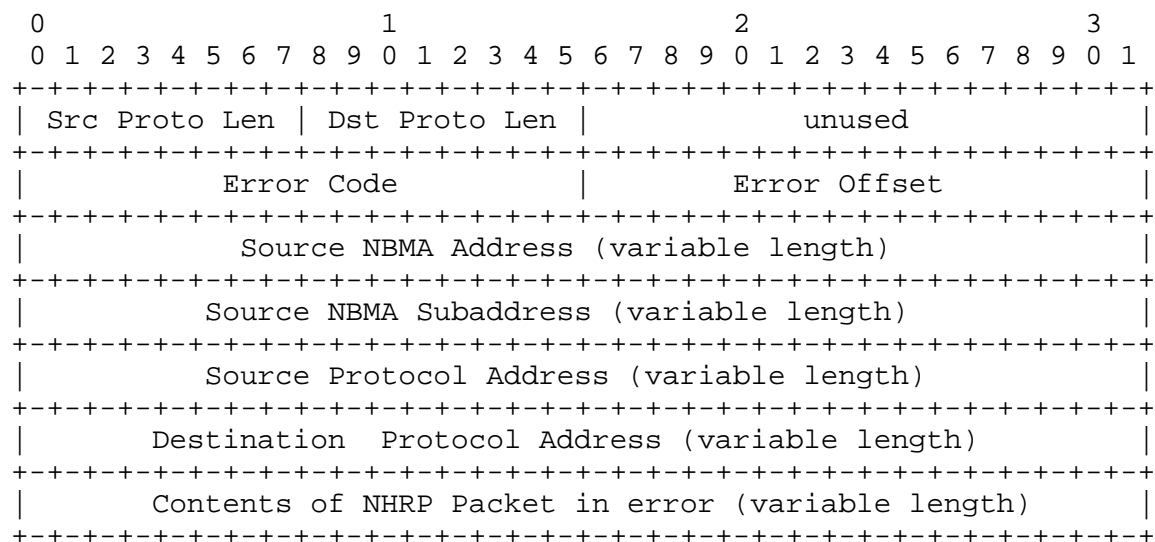
5.2.6 NHRP Purge Reply

The NHRP Purge Reply packet is sent in order to assure the sender of an NHRP Purge Request that all cached information of the specified type has been purged from the station sending the reply. The NHRP Purge Reply has a type code of 6.

An NHRP Purge Reply is formed from an NHRP Purge Request by merely changing the type code in the request to 6. The packet is then returned to the requester after filling in the appropriate extensions if they exist.

5.2.7 NHRP Error Indication

The NHRP Error Indication is used to convey error indications to the sender of an NHRP packet. It has a type code of 7. The Mandatory Part has the following format:



Src Proto Len

This field holds the length in octets of the Source Protocol Address.

Dst Proto Len

This field holds the length in octets of the Destination Protocol Address.

Error Code

An error code indicating the type of error detected, chosen from the following list:

1 - Unrecognized Extension

When the Compulsory bit of an extension in NHRP packet is set, the NHRP packet cannot be processed unless the extension has been processed. The responder MUST return an NHRP Error Indication of type Unrecognized Extension if it is incapable of processing the extension. However, if a transit NHS (one which is not going to generate a reply) detects an unrecognized extension, it SHALL ignore the extension.

3 - NHRP Loop Detected

A Loop Detected error is generated when it is determined that an NHRP packet is being forwarded in a loop.

6 - Protocol Address Unreachable

This error occurs when a packet is moving along the routed path and it reaches a point such that the protocol address of interest is not reachable.

7 - Protocol Error

A generic packet processing error has occurred (e.g., invalid version number, invalid protocol type, failed checksum, etc.)

8 - NHRP SDU Size Exceeded

If the SDU size of the NHRP packet exceeds the MTU size of the NBMA network then this error is returned.

9 - Invalid Extension

If an NHS finds an extension in a packet which is inappropriate for the packet type, an error is sent back to the sender with Invalid Extension as the code.

10 - Invalid NHRP Resolution Reply Received

If a client receives a NHRP Resolution Reply for a Next Hop Resolution Request which it believes it did not make then an error packet is sent to the station making the reply with an error code of Invalid Reply Received.

11 - Authentication Failure

If a received packet fails an authentication test then this error is returned.

15 - Hop Count Exceeded

The hop count which was specified in the Fixed Header of an NHRP message has been exceeded.

Error Offset

The offset in octets into the original NHRP packet in which an error was detected. This offset is calculated starting from the NHRP Fixed Header.

Source NBMA Address

The Source NBMA address field is the address of the station which observed the error.

Source NBMA SubAddress

The Source NBMA subaddress field is the address of the station which observed the error. If the field's length as specified in `ar$stl` is 0 then no storage is allocated for this address at all.

Source Protocol Address

This is the protocol address of the station which issued the Error packet.

Destination Protocol Address

This is the protocol address of the station which sent the packet which was found to be in error.

An NHRP Error Indication packet SHALL NEVER be generated in response to another NHRP Error Indication packet. When an NHRP Error Indication packet is generated, the offending NHRP packet SHALL be discarded. In no case should more than one NHRP Error Indication packet be generated for a single NHRP packet.

If an NHS sees its own Protocol and NBMA Addresses in the Source NBMA and Source Protocol address fields of a transiting NHRP Error Indication packet then the NHS will quietly drop the packet and do nothing (this scenario would occur when the NHRP Error Indication packet was itself in a loop).

Note that no extensions may be added to an NHRP Error Indication.

5.3 Extensions Part

The Extensions Part, if present, carries one or more extensions in {Type, Length, Value} triplets.

Extensions have the following format:

```

      0               1               2               3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-----+-----+-----+-----+-----+-----+-----+-----+
|C|u|          Type          |          Length          |
+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Value...                   |
+-----+-----+-----+-----+-----+-----+-----+-----+

```

C

"Compulsory." If clear, and the NHS does not recognize the type code, the extension may safely be ignored. If set, and the NHS does not recognize the type code, the NHRP "request" is considered to be in error. (See below for details.)

u

Unused and must be set to zero.

Type

The extension type code (see below). The extension type is not qualified by the Compulsory bit, but is orthogonal to it.

Length

The length in octets of the value (not including the Type and Length fields; a null extension will have only an extension header and a length of zero).

When extensions exist, the extensions list is terminated by the Null TLV, having Type = 0 and Length = 0.

Extensions may occur in any order, but any particular extension type may occur only once in an NHRP packet unless explicitly stated to the contrary in the extensions definition. For example, the vendor-private extension may occur multiple times in a packet in order to allow for extensions which do not share the same vendor ID to be represented. It is RECOMMENDED that a given vendor include no more than one Vendor Private Extension.

An NHS MUST NOT change the order of extensions. That is, the order of extensions placed in an NHRP packet by an NHC (or by an NHS when an NHS sources a packet) MUST be preserved as the packet moves between NHSs. Minimal NHC implementations MUST only recognize, but

not necessarily parse, the Vendor Private extension and the End Of Extensions extension. Extensions are only present in a "reply" if they were present in the corresponding "request" with the exception of Vendor Private extensions. The previous statement is not intended to preclude the creation of NHS-only extensions which might be added to and removed from NHRP packets by the same NHS; such extensions MUST not be propagated to NHCs.

The Compulsory bit provides for a means to add to the extension set. If the bit is set in an extension then the station responding to the NHRP message which contains that extension MUST be able to understand the extension (in this case, the station responding to the message is the station that would issue an NHRP reply in response to a NHRP request). As a result, the responder MUST return an NHRP Error Indication of type Unrecognized Extension. If the Compulsory bit is clear then the extension can be safely ignored; however, if an ignored extension is in a "request" then it MUST be returned, unchanged, in the corresponding "reply" packet type.

If a transit NHS (one which is not going to generate a "reply") detects an unrecognized extension, it SHALL ignore the extension. If the Compulsory bit is set, the transit NHS MUST NOT cache the information contained in the packet and MUST NOT identify itself as an egress router (in the Forward Record or Reverse Record extensions). Effectively, this means, if a transit NHS encounters an extension which it cannot process and which has the Compulsory bit set then that NHS MUST NOT participate in any way in the protocol exchange other than acting as a forwarding agent.

The NHRP extension Type space is subdivided to encourage use outside the IETF.

0x0000 - 0x0FFF	Reserved for NHRP.
0x1000 - 0x11FF	Allocated to the ATM Forum.
0x1200 - 0x37FF	Reserved for the IETF.
0x3800 - 0x3FFF	Experimental use.

IANA will administer the ranges reserved for the IETF as described in Section 9. Values in the 'Experimental use' range have only local significance.

5.3.0 The End Of Extensions

Compulsory = 1
Type = 0
Length = 0

When extensions exist, the extensions list is terminated by the End Of Extensions/Null TLV.

5.3.1 Responder Address Extension

Compulsory = 1
Type = 3
Length = variable

This extension is used to determine the address of the NHRP responder; i.e., the entity that generates the appropriate "reply" packet for a given "request" packet. In the case of an NHRP Resolution Request, the station responding may be different (in the case of cached replies) than the system identified in the Next Hop field of the NHRP Resolution Reply. Further, this extension may aid in detecting loops in the NHRP forwarding path.

This extension uses a single CIE with the extension specific meanings of the fields set as follows:

The Prefix Length fields MUST be set to 0 and ignored.

CIE Code

5 - Insufficient Resources

If the responder to an NHRP Resolution Request is an egress point for the target of the address resolution request (i.e., it is one of the stations identified in the list of CIEs in an NHRP Resolution Reply) and the Responder Address extension is included in the NHRP Resolution Request and insufficient resources to setup a cut-through VC exist at the responder then the Code field of the Responder Address Extension is set to 5 in order to tell the client that a VC setup attempt would in all likelihood be rejected; otherwise this field MUST be coded as a zero. NHCs MAY use this field to influence whether they attempt to setup a cut-through to the egress router.

Maximum Transmission Unit

This field gives the maximum transmission unit preferred by the responder. If this value is 0 then either the default MTU is used or the MTU negotiated via signaling is used if such negotiation is possible for the given NBMA.

Holding Time

The Holding Time field specifies the number of seconds for which the NBMA information of the responder is considered to be valid. Cached information SHALL be discarded when the holding time expires.

"Client Address" information is actually "Responder Address" information for this extension. Thus, for example, Cli Addr T/L is the responder NBMA address type and length field.

If a "requester" desires this information, the "requester" SHALL include this extension with a value of zero. Note that this implies that no storage is allocated for the Holding Time and Type/Length fields until the "Value" portion of the extension is filled out.

If an NHS is generating a "reply" packet in response to a "request" containing this extension, the NHS SHALL include this extension, containing its protocol address in the "reply". If an NHS has more than one protocol address, it SHALL use the same protocol address consistently in all of the Responder Address, Forward Transit NHS Record, and Reverse Transit NHS Record extensions. The choice of which of several protocol address to include in this extension is a local matter.

If an NHRP Resolution Reply packet being forwarded by an NHS contains a protocol address of that NHS in the Responder Address Extension then that NHS SHALL generate an NHRP Error Indication of type "NHRP Loop Detected" and discard the NHRP Resolution Reply.

If an NHRP Resolution Reply packet is being returned by an intermediate NHS based on cached data, it SHALL place its own address in this extension (differentiating it from the address in the Next Hop field).

5.3.2 NHRP Forward Transit NHS Record Extension

Compulsory = 1
Type = 4
Length = variable

The NHRP Forward Transit NHS record contains a list of transit NHSs through which a "request" has traversed. Each NHS SHALL append to the extension a Forward Transit NHS element (as specified below) containing its Protocol address. The extension length field and the ar\$chksum fields SHALL be adjusted appropriately.

The responding NHS, as described in Section 5.3.1, SHALL NOT update this extension.

In addition, NHSs that are willing to act as egress routers for packets from the source to the destination SHALL include information about their NBMA Address.

This extension uses a single CIE per NHS Record element with the extension specific meanings of the fields set as follows:

The Prefix Length fields MUST be set to 0 and ignored.

CIE Code

5 - Insufficient Resources

If an NHRP Resolution Request contains an NHRP Forward Transit NHS Record Extension and insufficient resources to setup a cut-through VC exist at the current transit NHS then the CIE Code field for NHRP Forward Transit NHS Record Extension is set to 5 in order to tell the client that a VC setup attempt would in all likelihood be rejected; otherwise this field MUST be coded as a zero. NHCs MAY use this field to influence whether they attempt to setup a cut-through as described in Section 2.2. Note that the NHRP Reverse Transit NHS Record Extension MUST always have this field set to zero.

Maximum Transmission Unit

This field gives the maximum transmission unit preferred by the transit NHS. If this value is 0 then either the default MTU is used or the MTU negotiated via signaling is used if such negotiation is possible for the given NBMA.

Holding Time

The Holding Time field specifies the number of seconds for which the NBMA information of the transit NHS is considered to be valid. Cached information SHALL be discarded when the holding time expires.

"Client Address" information is actually "Forward Transit NHS Address" information for this extension. Thus, for example, Cli Addr T/L is the transit NHS NBMA address type and length field.

If a "requester" wishes to obtain this information, it SHALL include this extension with a length of zero. Note that this implies that no storage is allocated for the Holding Time and Type/Length fields until the "Value" portion of the extension is filled out.

If an NHS has more than one Protocol address, it SHALL use the same Protocol address consistently in all of the Responder Address, Forward NHS Record, and Reverse NHS Record extensions. The choice of which of several Protocol addresses to include in this extension is a local matter.

If a "request" that is being forwarded by an NHS contains the Protocol Address of that NHS in one of the Forward Transit NHS elements then the NHS SHALL generate an NHRP Error Indication of type "NHRP Loop Detected" and discard the "request".

5.3.3 NHRP Reverse Transit NHS Record Extension

Compulsory = 1
Type = 5
Length = variable

The NHRP Reverse Transit NHS record contains a list of transit NHSs through which a "reply" has traversed. Each NHS SHALL append a Reverse Transit NHS element (as specified below) containing its Protocol address to this extension. The extension length field and ar\$chksum SHALL be adjusted appropriately.

The responding NHS, as described in Section 5.3.1, SHALL NOT update this extension.

In addition, NHSs that are willing to act as egress routers for packets from the source to the destination SHALL include information about their NBMA Address.

This extension uses a single CIE per NHS Record element with the extension specific meanings of the fields set as follows:

The CIE Code and Prefix Length fields MUST be set to 0 and ignored.

Maximum Transmission Unit

This field gives the maximum transmission unit preferred by the transit NHS. If this value is 0 then either the default MTU is used or the MTU negotiated via signaling is used if such negotiation is possible for the given NBMA.

Holding Time

The Holding Time field specifies the number of seconds for which the NBMA information of the transit NHS is considered to be valid. Cached information SHALL be discarded when the holding time expires.

"Client Address" information is actually "Reverse Transit NHS Address" information for this extension. Thus, for example, Cli Addr T/L is the transit NHS NBMA address type and length field.

If a "requester" wishes to obtain this information, it SHALL include this extension with a length of zero. Note that this implies that no storage is allocated for the Holding Time and Type/Length fields until the "Value" portion of the extension is filled out.

If an NHS has more than one Protocol address, it SHALL use the same Protocol address consistently in all of the Responder Address, Forward NHS Record, and Reverse NHS Record extensions. The choice of which of several Protocol addresses to include in this extension is a local matter.

If a "reply" that is being forwarded by an NHS contains the Protocol Address of that NHS in one of the Reverse Transit NHS elements then the NHS SHALL generate an NHRP Error Indication of type "NHRP Loop Detected" and discard the "reply".

Note that this information may be cached at intermediate NHSs; if so, the cached value SHALL be used when generating a reply.

5.3.4 NHRP Authentication Extension

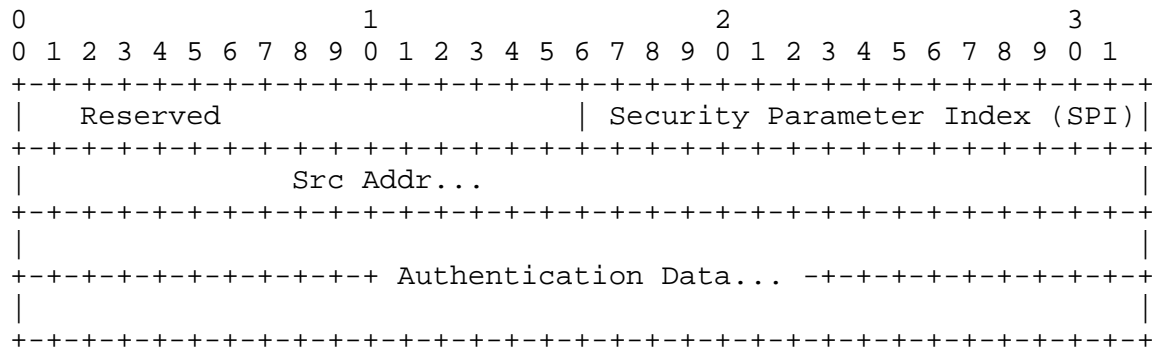
Compulsory = 1 Type = 7 Length = variable

The NHRP Authentication Extension is carried in NHRP packets to convey authentication information between NHRP speakers. The Authentication Extension may be included in any NHRP "request" or "reply" only.

The authentication is always done pairwise on an NHRP hop-by-hop basis; i.e., the authentication extension is regenerated at each hop. If a received packet fails the authentication test, the station SHALL generate an Error Indication of type "Authentication Failure" and discard the packet. Note that one possible authentication failure is the lack of an Authentication Extension; the presence or absence of the Authentication Extension is a local matter.

5.3.4.1 Header Format

The authentication header has the following format:



Security Parameter Index (SPI) can be thought of as an index into a table that maintains the keys and other information such as hash algorithm. Src and Dst communicate either offline using manual keying or online using a key management protocol to populate this table. The sending NHRP entity always allocates the SPI and the parameters associated with it.

Src Addr a variable length field is the address assigned to the outgoing interface. The length of the addr is obtained from the source protocol length field in the mandatory part of the NHRP header. The tuple <spi, src addr> uniquely identifies the key and other parameters that are used in authentication.

The length of the authentication data field is dependent on the hash algorithm used. The data field contains the keyed hash calculated over the entire NHRP payload. The authentication data field is zeroed out before the hash is calculated.

5.3.4.2 SPI and Security Parameters Negotiation

SPI's can be negotiated either manually or using an Internet Key Management protocol. Manual keying MUST be supported. The following parameters are associated with the tuple <SPI, src>- lifetime, Algorithm, Key. Lifetime indicates the duration in seconds for which the key is valid. In case of manual keying, this duration can be infinite. Also, in order to better support manual keying, there may be multiple tuples active at the same time (Dst being the same).

Algorithm specifies the hash algorithm agreed upon by the two entities. HMAC-MD5-128 [16] is the default algorithm. Other algorithms MAY be supported by defining new values. IANA will assign the numbers to identify the algorithm being used as described in Section 9.

Any Internet standard key management protocol MAY so be used to negotiate the SPI and parameters.

5.3.4.3 Message Processing

At the time of adding the authentication extension header, src looks up in a table to fetch the SPI and the security parameters based on the outgoing interface address. If there are no entries in the table and if there is support for key management, the src initiates the key management protocol to fetch the necessary parameters. The src constructs the Authentication Extension payload and calculates the hash by zeroing authentication data field. The result replaces in the zeroed authentication data field. The src address field in the payload is the IP address assigned to the outgoing interface.

If key management is not supported and authentication is mandatory, the packet is dropped and this information is logged.

On the receiving end, dst fetches the parameters based on the SPI and the ip address in the authentication extension payload. The authentication data field is extracted before zeroing out to calculate the hash. It computes the hash on the entire payload and if the hash does not match, then an "abnormal event" has occurred.

5.3.4.4 Security Considerations

It is important that the keys chosen are strong as the security of the entire system depends on the keys being chosen properly and the correct implementation of the algorithms.

The security is performed on a hop by hop basis. The data received can be trusted only so much as one trusts all the entities in the path traversed. A chain of trust is established amongst NHRP entities in the path of the NHRP Message . If the security in an NHRP entity is compromised, then security in the entire NHRP domain is compromised.

Data integrity covers the entire NHRP payload. This guarantees that the message was not modified and the source is authenticated as well. If authentication extension is not used or if the security is compromised, then NHRP entities are liable to both spoofing attacks, active attacks and passive attacks.

There is no mechanism to encrypt the messages. It is assumed that a standard layer 3 confidentiality mechanism will be used to encrypt and decrypt messages. It is recommended to use an Internet standard key management protocol to negotiate the keys between the neighbors. Transmitting the keys in clear text, if other methods of negotiation is used, compromises the security completely.

Any NHS is susceptible to Denial of Service (DOS) attacks that cause it to become overloaded, preventing legitimate packets from being acted upon properly. A rogue host can send request and registration packets to the first hop NHS. If the authentication option is not used, the registration packet is forwarded along the routed path requiring processing along each NHS. If the authentication option is used, then only the first hop NHS is susceptible to DOS attacks (i.e., unauthenticated packets will be dropped rather than forwarded on). If security of any host is compromised (i.e., the keys it is using to communicate with an NHS become known), then a rogue host can send NHRP packets to the first hop NHS of the host whose keys were compromised, which will then forward them along the routed path as in the case of unauthenticated packets. However, this attack requires that the rogue host to have the same first hop NHS as that of the compromised host. Finally, it should be noted that denial of service attacks that cause routers on the routed path to expend resources processing NHRP packets are also susceptible to attacks that flood packets at the same destination as contained in an NHRP packet's Destination Protocol Address field.

5.3.5 NHRP Vendor-Private Extension

Compulsory = 0
 Type = 8
 Length = variable

The NHRP Vendor-Private Extension is carried in NHRP packets to convey vendor-private information or NHRP extensions between NHRP speakers.

```

      0                               1                               2                               3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|                               Vendor ID                               | Data.... |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

Vendor ID

802 Vendor ID as assigned by the IEEE [6]

Data

The remaining octets after the Vendor ID in the payload are vendor-dependent data.

This extension may be added to any "request" or "reply" packet and it is the only extension that may be included multiple times. If the receiver does not handle this extension, or does not match the Vendor

ID in the extension then the extension may be completely ignored by the receiver. If a Vendor Private Extension is included in a "request" then it must be copied to the corresponding "reply".

6. Protocol Operation

In this section, we discuss certain operational considerations of NHRP.

6.1 Router-to-Router Operation

In practice, the initiating and responding stations may be either hosts or routers. However, there is a possibility under certain conditions that a stable routing loop may occur if NHRP is used between two routers. In particular, attempting to establish an NHRP path across a boundary where information used in route selection is lost may result in a routing loop. Such situations include the loss of BGP path vector information, the interworking of multiple routing protocols with dissimilar metrics (e.g, RIP and OSPF), etc. In such circumstances, NHRP should not be used. This situation can be avoided if there are no "back door" paths between the entry and egress router outside of the NBMA subnetwork. Protocol mechanisms to relax these restrictions are under investigation.

In general it is preferable to use mechanisms, if they exist, in routing protocols to resolve the egress point when the destination lies outside of the NBMA subnetwork, since such mechanisms will be more tightly coupled to the state of the routing system and will probably be less likely to create loops.

6.2 Cache Management Issues

The management of NHRP caches in the source station, the NHS serving the destination, and any intermediate NHSS is dependent on a number of factors.

6.2.1 Caching Requirements

Source Stations

Source stations MUST cache all received NHRP Resolution Replies that they are actively using. They also must cache "incomplete" entries, i.e., those for which a NHRP Resolution Request has been sent but those for which an NHRP Resolution Reply has not been received. This is necessary in order to preserve the Request ID

for retries, and provides the state necessary to avoid triggering NHRP Resolution Requests for every data packet sent to the destination.

Source stations MUST purge expired information from their caches. Source stations MUST purge the appropriate cached information upon receipt of an NHRP Purge Request packet.

When a station has a co-resident NHC and NHS, the co-resident NHS may reply to NHRP Resolution Requests from the co-resident NHC with information which the station cached as a result of the co-resident NHC making its own NHRP Resolution Requests as long as the co-resident NHS follows the rules for Transit NHSS as seen below.

Serving NHSS

The NHS serving the destination (the one which responds authoritatively to NHRP Resolution Requests) SHOULD cache protocol address information from all NHRP Resolution Requests to which it has responded if the information in the NHRP Resolution Reply has the possibility of changing during its lifetime (so that an NHRP Purge Request packet can be issued). The internetworking to NBMA binding information provided by the source station in the NHRP Resolution Request may also be cached if and only if the "S" bit is set, the NHRP Resolution Request has included a CIE with the Holding Time field set greater than zero (this is the valid Holding Time for the source binding), and only for non-authoritative use for a period not to exceed the Holding Time.

Transit NHSS

A Transit NHS (lying along the NHRP path between the source station and the responding NHS) may cache source binding information contained in NHRP Resolution Request packets that it forwards if and only if the "S" bit is set, the NHRP Resolution Request has included a CIE with the Holding Time field set greater than zero (this is the valid Holding Time for the source binding), and only for non-authoritative use for a period not to exceed the Holding Time.

A Transit NHS may cache destination information contained in NHRP Resolution Reply CIE if only if the D bit is set and then only for non-authoritative use for a period not to exceed the Holding Time value contained in the CIE. A Transit NHS MUST NOT cache source binding information contained in an NHRP Resolution Reply.

Further, a transit NHS MUST discard any cached information when the prescribed time has expired. It may return cached information in response to non-authoritative NHRP Resolution Requests only.

6.2.2 Dynamics of Cached Information

NBMA-Connected Destinations

NHRP's most basic function is that of simple NBMA address resolution of stations directly attached to the NBMA subnetwork. These mappings are typically very static, and appropriately chosen holding times will minimize problems in the event that the NBMA address of a station must be changed. Stale information will cause a loss of connectivity, which may be used to trigger an authoritative NHRP Resolution Request and bypass the old data. In the worst case, connectivity will fail until the cache entry times out.

This applies equally to information marked in NHRP Resolution Replies as being "stable" (via the "D" bit).

Destinations Off of the NBMA Subnetwork

If the source of an NHRP Resolution Request is a host and the destination is not directly attached to the NBMA subnetwork, and the route to that destination is not considered to be "stable," the destination mapping may be very dynamic (except in the case of a subnetwork where each destination is only singly homed to the NBMA subnetwork). As such the cached information may very likely become stale. The consequence of stale information in this case will be a suboptimal path (unless the internetwork has partitioned or some other routing failure has occurred).

6.3 Use of the Prefix Length field of a CIE

A certain amount of care needs to be taken when using the Prefix Length field of a CIE, in particular with regard to the prefix length advertised (and thus the size of the equivalence class specified by it). Assuming that the routers on the NBMA subnetwork are exchanging routing information, it should not be possible for an NHS to create a black hole by advertising too large of a set of destinations, but suboptimal routing (e.g., extra internetwork layer hops through the NBMA) can result. To avoid this situation an NHS that wants to send the Prefix Length MUST obey the following rule:

The NHS examines the Network Layer Reachability Information (NLRI) associated with the route that the NHS would use to forward towards the destination (as specified by the Destination internetwork layer

address in the NHRP Resolution Request), and extracts from this NLRI the shortest address prefix such that: (a) the Destination internetwork layer address (from the NHRP Resolution Request) is covered by the prefix, (b) the NHS does not have any routes with NLRI which form a subset of what is covered by the prefix. The prefix may then be used in the CIE.

The Prefix Length field of the CIE should be used with restraint, in order to avoid NHRP stations choosing suboptimal transit paths when overlapping prefixes are available. This document specifies the use of the prefix length only when all the destinations covered by the prefix are "stable". That is, either:

- (a) All destinations covered by the prefix are on the NBMA network, or
- (b) All destinations covered by the prefix are directly attached to the NHRP responding station.

Use of the Prefix Length field of the CIE in other circumstances is outside the scope of this document.

6.4 Domino Effect

One could easily imagine a situation where a router, acting as an ingress station to the NBMA subnetwork, receives a data packet, such that this packet triggers an NHRP Resolution Request. If the router forwards this data packet without waiting for an NHRP transit path to be established, then when the next router along the path receives the packet, the next router may do exactly the same - originate its own NHRP Resolution Request (as well as forward the packet). In fact such a data packet may trigger NHRP Resolution Request generation at every router along the path through an NBMA subnetwork. We refer to this phenomena as the NHRP "domino" effect.

The NHRP domino effect is clearly undesirable. At best it may result in excessive NHRP traffic. At worst it may result in an excessive number of virtual circuits being established unnecessarily. Therefore, it is important to take certain measures to avoid or suppress this behavior. NHRP implementations for NHSs MUST provide a mechanism to address this problem. One possible strategy to address this problem would be to configure a router in such a way that NHRP Resolution Request generation by the router would be driven only by the traffic the router receives over its non-NBMA interfaces (interfaces that are not attached to an NBMA subnetwork). Traffic received by the router over its NBMA-attached interfaces would not trigger NHRP Resolution Requests. Such a router avoids the NHRP domino effect through administrative means.

7. NHRP over Legacy BMA Networks

There would appear to be no significant impediment to running NHRP over legacy broadcast subnetworks. There may be issues around running NHRP across multiple subnetworks. Running NHRP on broadcast media has some interesting possibilities; especially when setting up a cut-through for inter-ELAN inter-LIS/LAG traffic when one or both end stations are legacy attached. This use for NHRP requires further research.

8. Discussion

The result of an NHRP Resolution Request depends on how routing is configured among the NHSSs of an NBMA subnetwork. If the destination station is directly connected to the NBMA subnetwork and the routed path to it lies entirely within the NBMA subnetwork, the NHRP Resolution Replies always return the NBMA address of the destination station itself rather than the NBMA address of some egress router. On the other hand, if the routed path exits the NBMA subnetwork, NHRP will be unable to resolve the NBMA address of the destination, but rather will return the address of the egress router. For destinations outside the NBMA subnetwork, egress routers and routers in the other subnetworks should exchange routing information so that the optimal egress router may be found.

In addition to NHSSs, an NBMA station could also be associated with one or more regular routers that could act as "connectionless servers" for the station. The station could then choose to resolve the NBMA next hop or just send the packets to one of its connectionless servers. The latter option may be desirable if communication with the destination is short-lived and/or doesn't require much network resources. The connectionless servers could, of course, be physically integrated in the NHSSs by augmenting them with internetwork layer switching functionality.

9. IANA Considerations

IANA will take advice from the Area Director appointed designated subject matter expert, in order to assign numbers from the various number spaces described herein. In the event that the Area Director appointed designated subject matter expert is unavailable, the relevant IESG Area Director will appoint another expert. Any and all requests for value assignment within a given number space will be accepted when the usage of the value assignment documented. Possible forms of documentantion include, but is not limited to, RFCs or the product of another cooperative standards body (e.g., the MPOA and LANE subworking group of the ATM Forum).

References

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