Network Working Group
Internet-Draft
Obsoletes: rfc5320, rfc5558, rfc5720, rfc6179, rfc6706 (if approved)
Intended status: Standards Track
Expires: April 8, 2019

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October 5, 2018

Asymmetric Extended Route Optimization (AERO)
draft-templin-intarea-6706bis-02.txt

Abstract

This document specifies the operation of IP over tunnel virtual links using Asymmetric Extended Route Optimization (AERO). Nodes attached to AERO links can exchange packets via trusted intermediate routers that provide forwarding services to reach off-link destinations and route optimization services for improved performance. AERO provides an IPv6 link-local address format that supports operation of the IPv6 Neighbor Discovery (ND) protocol and links ND to IP forwarding. Dynamic link selection, mobility management, quality of service (QoS) signaling and route optimization are naturally supported through dynamic neighbor cache updates, while IPv6 Prefix Delegation (PD) is supported by network services such as the Dynamic Host Configuration Protocol for IPv6 (DHCPv6). AERO is a widely-applicable tunneling solution especially well-suited to aviation services, mobile Virtual Private Networks (VPNs) and other applications as described in this document.

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1. Introduction

This document specifies the operation of IP over tunnel virtual links using Asymmetric Extended Route Optimization (AERO). The AERO link can be used for tunneling between neighboring nodes over either IPv6 or IPv4 networks, i.e., AERO views the IPv6 and IPv4 networks as equivalent links for tunneling. Nodes attached to AERO links can

exchange packets via trusted intermediate routers that provide forwarding services to reach off-link destinations and route optimization services for improved performance [RFC5522].

AERO provides an IPv6 link-local address format that supports operation of the IPv6 Neighbor Discovery (ND) [RFC4861] protocol and links ND to IP forwarding. Dynamic link selection, mobility management, quality of service (QoS) signaling and route optimization are naturally supported through dynamic neighbor cache updates, while IPv6 Prefix Delegation (PD) is supported by network services such as the Dynamic Host Configuration Protocol for IPv6 (DHCPv6) [RFC3315][RFC3633].

A node's AERO interface can be configured over multiple underlying interfaces. From the standpoint of ND, AERO interface neighbors therefore may appear to have multiple link-layer addresses (i.e., the IP addresses assigned to underlying interfaces). Each link-layer address is subject to change due to mobility and/or QoS fluctuations, and link-layer address changes are signaled by ND messaging the same as for any IPv6 link.

AERO is applicable to a wide variety of use cases. For example, it can be used to coordinate the Virtual Private Network (VPN) links of mobile nodes (e.g., cellphones, tablets, laptop computers, etc.) that connect into a home enterprise network via public access networks using services such as OpenVPN [OVPN]. AERO is also applicable to aviation services for both manned and unmanned aircraft where the aircraft is treated as a mobile node that can connect an Internet of Things (IoT). Other applicable use cases are also in scope.

The remainder of this document presents the AERO specification.

2. Terminology

The terminology in the normative references applies; the following terms are defined within the scope of this document:

IPv6 Neighbor Discovery (ND)
: an IPv6 control message service for coordinating neighbor relationships between nodes connected to a common link. The ND service used by AERO is specified in [RFC4861].

IPv6 Prefix Delegation (PD)
: a networking service for delegating IPv6 prefixes to nodes on the link. The nominal PD service is DHCPv6 [RFC3315] [RFC3633], however alternate services (e.g., based on ND messaging) are also in scope [I-D.templin-v6ops-pdhost][I-D.templin-6man-dhcpv6-ndopt].

(native) Internetwork
: a connected IP network topology over which the AERO link virtual overlay is configured and native peer-to-peer communications are supported. Example Internetworks include the global public Internet, private enterprise networks, aviation networks, etc.

AERO link
: a Non-Broadcast, Multiple Access (NBMA) tunnel virtual overlay configured over an underlying Internetwork. All nodes on the AERO link appear as single-hop neighbors from the perspective of the virtual overlay even though they may be separated by many underlying Internetwork hops. The AERO mechanisms can also operate over native link types (e.g., Ethernet, WiFi etc.) when a tunnel virtual overlay is not needed.

AERO interface
: a node's attachment to an AERO link. Since the addresses assigned to an AERO interface are managed for uniqueness, AERO interfaces do not require Duplicate Address Detection (DAD) and therefore set the administrative variable DupAddrDetectTransmits to zero [RFC4862].

AERO address
: an IPv6 link-local address constructed as specified in Section 3.4.

AERO node
: a node that is connected to an AERO link.

AERO Client ("Client")
: a node that requests IP PDs from one or more AERO Servers. Following PD, the Client assigns an AERO address to the AERO interface for use in ND exchanges with other AERO nodes. A node that acts as an AERO Client on one AERO interface can also act as an AERO Server on a different AERO interface.

AERO Server ("Server")
: a node that configures an AERO interface to provide default forwarding services for AERO Clients. The Server assigns an administratively-provisioned IPv6 link-local address to the AERO interface to support the operation of the ND/PD services. An AERO Server can also act as an AERO Relay.

AERO Relay ("Relay")
: an IP router that can relay IP packets between AERO Servers and/or forward IP packets between the AERO link and the native Internetwork. Relays are standard IP routers that can be purchased from any major network equipment supplier.

AERO Proxy ("Proxy")
: a node that provides proxying services for Clients that cannot associate directly with Servers, e.g., when the Client is located in a secured internal enclave and the Server is located in the external Internetwork. The AERO Proxy is a conduit between the secured enclave and the external Internetwork in the same manner as for common web proxies, and behaves in a similar fashion as for ND proxies [RFC4389].

ingress tunnel endpoint (ITE)
: an AERO interface endpoint that injects encapsulated packets into an AERO link.

egress tunnel endpoint (ETE)
: an AERO interface endpoint that receives encapsulated packets from an AERO link.

underlying network
: the same as defined for Internetwork.

underlying link
: a link that connects an AERO node to the underlying network.

underlying interface
: an AERO node's interface point of attachment to an underlying link.

link-layer address
: an IP address assigned to an AERO node's underlying interface. When UDP encapsulation is used, the UDP port number is also considered as part of the link-layer address. Packets transmitted over an AERO interface use link-layer addresses as encapsulation header source and destination addresses. Destination link-layer addresses can be either "reachable" or "unreachable" based on dynamically-changing network conditions.

network layer address
: the source or destination address of an encapsulated IP packet.

end user network (EUN)
: an internal virtual or external edge IP network that an AERO Client connects to the rest of the network via the AERO interface. The Client sees each EUN as a "downstream" network and sees the AERO interface as its point of attachment to the "upstream" network.

AERO Service Prefix (ASP)

an IP prefix associated with the AERO link and from which more-specific AERO Client Prefixes (ACPs) are derived.

AERO Client Prefix (ACP)
an IP prefix derived from an ASP and delegated to a Client, where the ACP prefix length must be no shorter than the ASP prefix length and must be no longer than 64 for IPv6 or 32 for IPv4.

base AERO address
the lowest-numbered AERO address from the first ACP delegated to the Client (see Section 3.4).

Throughout the document, the simple terms "Client", "Server", "Relay" and "Proxy" refer to "AERO Client", "AERO Server", "AERO Relay" and "AERO Proxy", respectively. Capitalization is used to distinguish these terms from DHCPv6 client/server/relay [RFC3315].

The terminology of DHCPv6 [RFC3315][RFC3633] and IPv6 ND [RFC4861] (including the names of node variables, messages and protocol constants) is used throughout this document. Also, the term "IP" is used to generically refer to either Internet Protocol version, i.e., IPv4 [RFC0791] or IPv6 [RFC8200].

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119]. Lower case uses of these words are not to be interpreted as carrying RFC2119 significance.

3. Asymmetric Extended Route Optimization (AERO)

The following sections specify the operation of IP over Asymmetric Extended Route Optimization (AERO) links:

3.1. AERO Link Reference Model

Figure 1: AERO Link Reference Model

Figure 1 presents the AERO link reference model. In this model:

- AERO Relay R1 aggregates AERO Service Prefix (ASP) A1, acts as a default router for its associated Servers (S1 and S2), and connects the AERO link to the rest of the Internetwork.

- AERO Servers S1 and S2 associate with Relay R1 and also act as default routers for their associated Clients C1 and C2.

- AERO Clients C1 and C2 associate with Servers S1 and S2, respectively. They receive AERO Client Prefix (ACP) delegations X1 and X2, and also act as default routers for their associated physical or internal virtual EUNs. Simple hosts H1 and H2 attach to the EUNs served by Clients C1 and C2, respectively.

- AERO Proxy P1 provides proxy services for AERO Clients in secured enclaves that cannot associate directly with other AERO link neighbors.

Each node on the AERO link maintains an AERO interface neighbor cache and an IP forwarding table the same as for any link. Although the figure shows a limited deployment, in common operational practice there may be many additional Relays, Servers, Clients and Proxies.

3.2. AERO Node Types

AERO Relays are standard IP routers that provide default forwarding services to AERO Servers. Each Relay also peers with Servers and other Relays in a dynamic routing protocol instance to discover the list of active ACPs (see Section 3.3). Relays forward packets between neighbors connected to the same AERO link and also forward packets between the AERO link and the native Internetwork. Relays present the AERO link to the native Internetwork as a set of one or more AERO Service Prefixes (ASPs) and serve as a gateway between the AERO link and the Internetwork. Relays maintain tunnels with neighboring Servers, and maintain an IP forwarding table entry for each AERO Client Prefix (ACP).

AERO Servers provide default forwarding services to AERO Clients. Each Server also peers with Relays in a dynamic routing protocol instance to advertise its list of associated ACPs (see Section 3.3). Servers facilitate PD exchanges with Clients, where each delegated prefix becomes an ACP taken from an ASP. Servers forward packets between AERO interface neighbors, and maintain AERO interface neighbor cache entries for Relays. They also maintain both neighbor cache entries and IP forwarding table entries for each of their associated Clients.

AERO Clients act as requesting routers to receive ACPs through PD exchanges with AERO Servers over the AERO link. Each Client can associate with a single Server or with multiple Servers, e.g., for fault tolerance, load balancing, etc. Each IPv6 Client receives at least a /64 IPv6 ACP, and may receive even shorter prefixes. Similarly, each IPv4 Client receives at least a /32 IPv4 ACP (i.e., a singleton IPv4 address), and may receive even shorter prefixes. Clients maintain an AERO interface neighbor cache entry for each of their associated Servers as well as for each of their correspondent Clients.

AERO Proxies provide a transparent conduit for AERO Clients connected to secured enclaves to associate with AERO link Servers. The Client sends all of its control plane messages to the Server's link-layer address and the Proxy intercepts them before they leave the secured enclave. The Proxy forwards the Client's control and data plane messages to and from the Client's current Server(s). The Proxy may also discover a more direct route toward a target destination via AERO route optimization, in which case future outbound data packets

would be forwarded via the more direct route. The Proxy function is specified in Section 4.

3.3. AERO Routing System

The AERO routing system comprises a private instance of the Border Gateway Protocol (BGP) [RFC4271] that is coordinated between Relays and Servers and does not interact with either the public Internet BGP routing system or the native Internetwork routing system. Relays advertise only a small and unchanging set of ASPs to the native Internetwork routing system instead of the full dynamically changing set of ACPs.

In a reference deployment, each AERO Server is configured as an Autonomous System Border Router (ASBR) for a stub Autonomous System (AS) using an AS Number (ASN) that is unique within the BGP instance, and each Server further uses eBGP to peer with one or more Relays but does not peer with other Servers. All Relays are members of the same hub AS using a common ASN, and use iBGP to maintain a consistent view of all active ACPs currently in service.

Each Server maintains a working set of associated ACPs, and dynamically announces new ACPs and withdraws departed ACPs in its eBGP updates to Relays. Clients are expected to remain associated with their current Servers for extended timeframes, however Servers SHOULD selectively suppress updates for impatient Clients that repeatedly associate and disassociate with them in order to dampen routing churn.

Each Relay configures a black-hole route for each of its ASPs. By black-holing the ASPs, the Relay will maintain forwarding table entries only for the ACPs that are currently active, and packets destined to all other ACPs will correctly incur Destination Unreachable messages due to the black hole route. Relays do not send eBGP updates for ACPs to Servers, but instead only originate a default route. In this way, Servers have only partial topology knowledge (i.e., they know only about the ACPs of their directly associated Clients) and they forward all other packets to Relays which have full topology knowledge.

Scaling properties of the AERO routing system are limited by the number of BGP routes that can be carried by Relays. As of 2015, the global public Internet BGP routing system manages more than 500K routes with linear growth and no signs of router resource exhaustion [BGP]. More recent network emulation studies have also shown that a single Relay can accommodate at least 1M dynamically changing BGP routes even on a lightweight virtual machine, i.e., and without requiring high-end dedicated router hardware.

Therefore, assuming each Relay can carry 1M or more routes, this means that at least 1M Clients can be serviced by a single set of Relays. A means of increasing scaling would be to assign a different set of Relays for each set of ASPs. In that case, each Server still peers with one or more Relays, but the Server institutes route filters so that it only sends BGP updates to the specific set of Relays that aggregate the ASP. For example, if the ASP for the AERO link is 2001:db8::/32, a first set of Relays could service the ASP segment 2001:db8::/40, a second set of Relays could service 2001:db8:0100::/40, a third set could service 2001:db8:0200::/40, etc.

Assuming up to 1K sets of Relays, the AERO routing system can then accommodate 1B or more ACPs with no additional overhead for Servers and Relays (for example, it should be possible to service 1B /64 ACPs taken from a /34 ASP and even more for shorter prefixes). In this way, each set of Relays services a specific set of ASPs that they advertise to the native Internetwork routing system, and each Server configures ASP-specific routes that list the correct set of Relays as next hops. This arrangement also allows for natural incremental deployment, and can support small scale initial deployments followed by dynamic deployment of additional Clients, Servers and Relays without disturbing the already-deployed base.

Note that in an alternate routing arrangement each set of Relays could advertise an aggregated ASP for the link into the native Internetwork routing system even though each Relay services only smaller segments of the ASP. In that case, a Relay upon receiving a packet with a destination address covered by the ASP segment of another Relay can simply tunnel the packet to the other Relay. The tradeoff then is the penalty for Relay-to-Relay tunneling compared with reduced routing information in the native routing system.

A full discussion of the BGP-based routing system used by AERO is found in [I-D.templin-atn-bgp].

3.4. AERO Interface Addresses

AERO interface link-local address types include administratively-provisioned addresses and AERO addresses.

Administratively-provisioned addresses are allocated from the range fe80::/96 and assigned to Relay and Server AERO interfaces. Administratively-provisioned addresses MUST be managed for uniqueness by the administrative authority for the AERO link. The address fe80:: is reserved as the IPv6 link-local Subnet Router Anycast address (i.e., the same as for any IPv6 link), and the address fe80::ffff:ffff is reserved as the "prefix-solicitation" address used

by Clients to bootstrap AERO address autoconfiguration. These reserved addresses are therefore not available for general assignment.

An AERO address is an IPv6 link-local address with an embedded prefix based on an ACP and associated with a Client's AERO interface. AERO addresses remain stable as the Client moves between topological locations, i.e., even if its link-layer addresses change.

For IPv6, AERO addresses begin with the prefix fe80::/64 and include in the interface identifier (i.e., the lower 64 bits) a 64-bit prefix taken from one of the Client's IPv6 ACPs. For example, if the AERO Client receives the IPv6 ACP:

   2001:db8:1000:2000::/56

it constructs its corresponding AERO addresses as:

   fe80::2001:db8:1000:2000

   fe80::2001:db8:1000:2001

   fe80::2001:db8:1000:2002

   ... etc. ...

   fe80::2001:db8:1000:20ff

For IPv4, AERO addresses are based on an IPv4-mapped IPv6 address formed from an IPv4 ACP and with a Prefix Length of 96 plus the ACP prefix length. For example, for the IPv4 ACP 192.0.2.32/28 the IPv4-mapped IPv6 ACP is:

   0:0:0:0:0:FFFF:192.0.2.16/124

The Client then constructs its AERO addresses with the prefix fe80::/64 and with the lower 64 bits of the IPv4-mapped IPv6 address in the interface identifier as:

   fe80::FFFF:192.0.2.16

   fe80::FFFF:192.0.2.17

   fe80::FFFF:192.0.2.18

   ... etc. ...

   fe80:FFFF:192.0.2.31

When the Server delegates ACPs to the Client, both the Server and Client use the lowest-numbered AERO address from the first ACP delegation as the "base" AERO address (for example, for the ACP 2001:db8:1000:2000::/56 the base AERO address is fe80::2001:db8:1000:2000). The Client then assigns the base AERO address to the AERO interface and uses it for the purpose of maintaining the neighbor cache entry. The Server likewise uses the AERO address as its index into the neighbor cache for this Client.

If the Client has multiple AERO addresses (i.e., when there are multiple ACPs and/or ACPs with short prefix lengths), the Client originates ND messages using the base AERO address as the source address and accepts and responds to ND messages destined to any of its AERO addresses as equivalent to the base AERO address. In this way, the Client maintains a single neighbor cache entry that may be indexed by multiple AERO addresses.

AERO addresses that embed an IPv6 prefix can be statelessly transformed into an IPv6 Subnet Router Anycast address and vice-versa. For example, for the AERO address fe80::2001:db8:2000:3000 the corresponding Subnet Router Anycast address is 2001:db8:2000:3000::. In the same way, for the IPv6 Subnet Router Anycast address 2001:db8:1:2:: the corresponding AERO address is fe80::2001:db8:1:2. In other words, the low-order 64 bits of an AERO address can be used as the high-order 64 bits of a Subnet Router Anycast address, and vice-versa.

AERO interfaces additionally reserve an IPv6 prefix to support IPv6 ND message exchanges between Servers. A Unique Local Address (ULA) prefix [RFC4389] would be a good candidate for the reserved prefix, since it is not routable outside of the AERO link. An address with interface identifier set to 0 taken from the reserved prefix is used as the AERO Server Subnet Router Anycast address. For example, if the reserved prefix is the ULA prefix fd00:db8::/64 the AERO Server Subnet Router Anycast Address is fd00:db8::.

3.5. AERO Interface Characteristics

AERO interfaces use encapsulation (see: Section 3.9) to exchange packets with neighbors attached to the AERO link.

AERO interfaces maintain a neighbor cache for tracking per-neighbor state the same as for any interface. AERO interfaces use ND messages including Router Solicitation (RS), Router Advertisement (RA), Neighbor Solicitation (NS) and Neighbor Advertisement (NA) for neighbor cache management.

AERO interface ND messages include one or more Source/Target Link-Layer Address Options (S/TLLAOs) formatted as shown in Figure 2:

Figure 2: AERO Source/Target Link-Layer Address Option (S/TLLAO) Format

In this format:

- Type is set to '1' for SLLAO or '2' for TLLAO.
- Length is set to the constant value '5' (i.e., 5 units of 8 octets).
- Reserved is set to the value '0' on transmission and ignored on receipt.
- Interface ID is set to a 16-bit integer value corresponding to an underlying interface of the AERO node.
- UDP Port Number and IP Address are set to the addresses used by the AERO node when it sends encapsulated packets over the specified underlying interface (or to '0' when the addresses are left unspecified). When UDP is not used as part of the encapsulation, UDP Port Number is set to '0'. When the

encapsulation IP address family is IPv4, IP Address is formed as an IPv4-mapped IPv6 address as specified in Section 3.4.

- P(i) is a set of 64 Preference values that correspond to the 64 Differentiated Service Code Point (DSCP) values [RFC2474]. Each P(i) is set to the value '0' ("disabled"), '1' ("low"), '2' ("medium") or '3' ("high") to indicate a QoS preference level for packet forwarding purposes.

AERO interfaces may be configured over multiple underlying interface connections to underlying links. For example, common mobile handheld devices have both wireless local area network ("WLAN") and cellular wireless links. These links are typically used "one at a time" with low-cost WLAN preferred and highly-available cellular wireless as a standby. In a more complex example, aircraft frequently have many wireless data link types (e.g. satellite-based, cellular, terrestrial, air-to-air directional, etc.) with diverse performance and cost properties.

A Client's underlying interfaces are classified as follows:

- Native interfaces connect to the open Internetwork, and have a global IP address that is reachable from any open Internetwork correspondent.

- NATed interfaces connect to a closed network that is separated from the open Internetwork by a Network Address Translator (NAT). The NAT does not participate in any AERO control message signaling, but the AERO Server can issue AERO control messages on behalf of the Client.

- VPNed interfaces use security encapsulation over the Internetwork to a Virtual Private Network (VPN) gateway that also acts as an AERO Server. As with NATed links, the AERO Server can issue control messages on behalf of the Client.

- Proxyed interfaces connect to a closed network that is separated from the open Internetwork by an AERO Proxy. Unlike NATed and VPNed interfaces, the AERO Proxy (rather than the Server) can issue control message on behalf of the Client.

- Direct interfaces connect the Client directly to a neighbor without crossing any networked paths. An example is a line-of-sight link between a remote pilot and an unmanned aircraft.

If a Client's multiple underlying interfaces are used "one at a time" (i.e., all other interfaces are in standby mode while one interface is active), then ND messages include only a single S/TLLAO with

Interface ID set to a constant value. In that case, the Client would appear to have a single underlying interface but with a dynamically changing link-layer address.

If the Client has multiple active underlying interfaces, then from the perspective of ND it would appear to have multiple link-layer addresses. In that case, ND messages MAY include multiple S/TLLAOs -- each with an Interface ID that corresponds to a specific underlying interface of the AERO node.

When the Client includes an S/TLLAO for an underlying interface for which it is aware that there is a NAT or Proxy on the path to the Server, or when a node includes an S/TLLAO solely for the purpose of announcing new QoS preferences, the node sets both UDP Port Number and IP Address to 0 to indicate that the addresses are unspecified.

When an ND message includes multiple S/TLLAOs, the first S/TLLAO MUST correspond to the AERO node's underlying interface used to transmit the message.

3.6. AERO Interface Initialization

3.6.1. AERO Relay Behavior

When a Relay enables an AERO interface, it first assigns an administratively-provisioned link-local address fe80::ID to the interface. Each fe80::ID address MUST be unique among all AERO nodes on the link. The Relay then engages in a dynamic routing protocol session with one or more Servers and all other Relays on the link (see: Section 3.3), and advertises its assigned ASPs into the native Internetwork. Each Relay subsequently maintains an IP forwarding table entry for each active ACP covered by its ASP(s).

3.6.2. AERO Server Behavior

When a Server enables an AERO interface, it assigns an administratively-provisioned link-local address fe80::ID the same as for Relays. The Server further configures a service to facilitate ND/PD exchanges with AERO Clients. The Server maintains neighbor cache entries for one or more Relays on the link, and manages per-Client neighbor cache entries and IP forwarding table entries based on control message exchanges. Each Server also engages in a dynamic routing protocol with their neighboring Relays (see: Section 3.3).

When the Server receives an NS/RS message on the AERO interface it authenticates the message and returns an NA/RA message. The Server further provides a simple link-layer conduit between AERO interface neighbors. In particular, when a packet sent by a source Client

arrives on the Server's AERO interface and is destined to another AERO node, the Server forwards the packet from within the AERO interface driver at the link layer without ever disturbing the network layer.

3.6.3. AERO Client Behavior

When a Client enables an AERO interface, it sends RS messages with ND/PD parameters over an underlying interface to one or more AERO Servers, which return RA messages with corresponding PD parameters. See [I-D.templin-6man-dhcpv6-ndopt] for the types of ND/PD parameters that can be included in the RS/RA message exchanges.

After the initial ND/PD message exchange, the Client can register additional underlying interfaces with the Server by sending a simple RS message (i.e., one with no PD parameters) over each underlying interface using its base AERO address as the source network layer address. The Server will update its neighbor cache entry for the Client and return a simple RA message.

The Client maintains a neighbor cache entry for each of its Servers and each of its active correspondent Clients. When the Client receives ND messages on the AERO interface it updates or creates neighbor cache entries, including link-layer address and QoS preferences.

3.6.4. AERO Proxy Behavior

When a Proxy enables an AERO interface, it maintains per-Client proxy neighbor cache entries based on control message exchanges. Proxies forward packets between their associated Clients and the Clients' associated Servers.

When the Proxy receives an RS message from a Client in the secured enclave, it creates an incomplete proxy neighbor cache entry and sends a corresponding RS message to a Server selected by the Client while using its own link-layer address as the source address. When the Server returns an RA message, the Proxy completes the proxy neighbor cache entry based on autoconfiguration information in the RA and sends a corresponding RA to the Client while using its own link-layer address as the source address. The Client, Server and Proxy will then have the necessary state for managing the proxy neighbor association.

3.7. AERO Interface Neighbor Cache Maintenance

Each AERO interface maintains a conceptual neighbor cache that includes an entry for each neighbor it communicates with on the AERO link, the same as for any IPv6 interface [RFC4861]. AERO interface neighbor cache entries are said to be one of "permanent", "static", "proxy" or "dynamic".

Permanent neighbor cache entries are created through explicit administrative action; they have no timeout values and remain in place until explicitly deleted. AERO Relays maintain permanent neighbor cache entries for their associated Relays and Servers on the link, and AERO Servers maintain permanent neighbor cache entries for their associated Relays. Each entry maintains the mapping between the neighbor's fe80::ID network-layer address and corresponding link-layer address.

Static neighbor cache entries are created and maintained through ND/PD exchanges as specified in Section 3.14, and remain in place for durations bounded by ND/PD lifetimes. AERO Servers maintain static neighbor cache entries for each of their associated Clients, and AERO Clients maintain static neighbor cache entries for each of their associated Servers.

Proxy neighbor cache entries are created and maintained by AERO Proxies when they process Client/Server ND/PD exchanges, and remain in place for durations bounded by ND/PD lifetimes. AERO Proxies maintain proxy neighbor cache entries for each of their associated Clients.

Dynamic neighbor cache entries are created or updated based on receipt of route optimization messages as specified in Section 3.15, and are garbage-collected when keepalive timers expire. AERO nodes maintain dynamic neighbor cache entries for each of their active correspondents with lifetimes based on ND messaging constants.

When a target AERO node receives a valid NS message used for route optimization, it returns an NA message and also creates or updates a dynamic neighbor cache entry for the source network-layer and link-layer addresses. The node then sets a "ReportTime" variable in the neighbor cache entry to REPORT_TIME seconds. The node resets ReportTime when it receives a new NS message, and otherwise decrements ReportTime while no NS messages have been received. It is RECOMMENDED that REPORT_TIME be set to the default constant value 40 seconds to allow a 10 second window so that the AERO route optimization procedure can converge before ReportTime decrements below FORWARD_TIME (see below).

When a source AERO node receives a valid NA message that matches its NS message, it creates or updates a dynamic neighbor cache entry for the target network-layer and link-layer addresses. The node then sets a "ForwardTime" variable in the neighbor cache entry to FORWARD_TIME seconds and uses this value to determine whether packets can be forwarded directly to the correspondent, i.e., instead of via a default route. The node resets ForwardTime when it receives a new NA, and otherwise decrements ForwardTime while no further NA messages arrive. It is RECOMMENDED that FORWARD_TIME be set to the default constant value 30 seconds to match the default REACHABLE_TIME value specified in [RFC4861].

The node also sets a "MaxRetry" variable to MAX_RETRY to limit the number of keepalives sent when a correspondent may have gone unreachable. It is RECOMMENDED that MAX_RETRY be set to 3 the same as described for address resolution in Section 7.3.3 of [RFC4861].

Different values for REPORT_TIME, FORWARD_TIME and MAX_RETRY MAY be administratively set; however, if different values are chosen, all nodes on the link MUST consistently configure the same values. Most importantly, REPORT_TIME SHOULD be set to a value that is sufficiently longer than FORWARD_TIME to allow the AERO route optimization procedure to converge.

When there may be a NAT or Proxy between the Client and the Server, or if the path from the Client to the Server should be tested for reachability, the Client can send periodic RS messages to the Server without PD parameters to receive RA replies. The RS/RA messaging will keep NAT/Proxy state alive and test Server reachability without disturbing the PD service.

3.8. AERO Interface Forwarding Algorithm

IP packets enter a node's AERO interface either from the network layer (i.e., from a local application or the IP forwarding system) or from the link layer (i.e., from the AERO tunnel virtual link). Packets that enter the AERO interface from the network layer are encapsulated and forwarded into the AERO link, i.e., they are tunneled to an AERO interface neighbor. Packets that enter the AERO interface from the link layer are either re-admitted into the AERO link or forwarded to the network layer where they are subject to either local delivery or IP forwarding. In all cases, the AERO interface itself MUST NOT decrement the network layer TTL/Hop-count since its forwarding actions occur below the network layer.

AERO interfaces may have multiple underlying interfaces and/or neighbor cache entries for neighbors with multiple Interface ID registrations (see Section 3.5). The AERO node uses each packet's

DSCP value to select an outgoing underlying interface based on the node's own QoS preferences, and also to select a destination link-layer address based on the neighbor's underlying interface with the highest preference. If multiple outgoing interfaces and/or neighbor interfaces have a preference of "high", the AERO node sends one copy of the packet via each of the (outgoing / neighbor) interface pairs; otherwise, the node sends a single copy of the packet via the interface with the highest preference. AERO nodes keep track of which underlying interfaces are currently "reachable" or "unreachable", and only use "reachable" interfaces for forwarding purposes.

The following sections discuss the AERO interface forwarding algorithms for Clients, Proxies, Servers and Relays. In the following discussion, a packet's destination address is said to "match" if it is a non-link-local address with a prefix covered by an ASP/ACP, or if it is an AERO address that embeds an ACP, or if it is the same as an administratively-provisioned link-local address.

3.8.1. Client Forwarding Algorithm

When an IP packet enters a Client's AERO interface from the network layer the Client searches for a dynamic neighbor cache entry that matches the destination. If there is a match, the Client uses one or more "reachable" link-layer addresses in the entry as the link-layer addresses for encapsulation and admits the packet into the AERO link. Otherwise, the Client uses the link-layer address in a static neighbor cache entry for a Server as the encapsulation address (noting that there may be a Proxy on the path to the real Server).

When an IP packet enters a Client's AERO interface from the link-layer, if the destination matches one of the Client's ACPs or link-local addresses the Client decapsulates the packet and delivers it to the network layer. Otherwise, the Client drops the packet and MAY return a network-layer ICMP Destination Unreachable message subject to rate limiting (see: Section 3.13).

3.8.2. Proxy Forwarding Algorithm

When the Proxy receives a packet from a Client within the secured enclave, the Proxy searches for a dynamic neighbor cache entry that matches the destination. If there is a match, the Proxy uses one or more "reachable" link-layer addresses in the entry as the link-layer addresses for encapsulation and admits the packet into the AERO link. Otherwise, the Proxy uses the link-layer address for one of the Client's Servers as the encapsulation address.

When the Proxy receives a packet from an AERO interface neighbor, it searches for a proxy neighbor cache entry for a Client within the secured enclave that matches the destination. If there is a match, the Proxy forwards the packet to the Client. Otherwise, the Proxy returns the packet to the neighbor, i.e., by reversing the source and destination link-layer addresses and re-admitting the packet into the AERO link.

3.8.3. Server Forwarding Algorithm

When an IP packet enters a Server's AERO interface from the network layer, the Server searches for a static neighbor cache entry for a Client that matches the destination. If there is a match, the Server uses one or more link-layer addresses in the entry as the link-layer addresses for encapsulation and admits the packet into the AERO link. Otherwise, the Server uses the link-layer address in a permanent neighbor cache entry for a Relay (selected through longest-prefix match) as the link-layer address for encapsulation.

When an IP packet enters a Server's AERO interface from the link layer, the Server processes the packet according to the network-layer destination address as follows:

- if the destination matches one of the Server's own addresses the Server decapsulates the packet and forwards it to the network layer for local delivery.

- else, if the destination matches a static neighbor cache entry for a Client the Server first determines whether the neighbor is the same as the one it received the packet from. If so, the Server drops the packet silently to avoid looping; otherwise, the Server uses the neighbor's link-layer address(es) as the destination for encapsulation and re-admits the packet into the AERO link.

- else, the Server uses the link-layer address in a neighbor cache entry for a Relay (selected through longest-prefix match) as the link-layer address for encapsulation.

3.8.4. Relay Forwarding Algorithm

When an IP packet enters a Relay's AERO interface from the network layer, the Relay searches its IP forwarding table for an ACP entry that matches the destination the same as for any IP router. If there is a match, the Relay uses the link-layer address in the corresponding neighbor cache entry as the link-layer address for encapsulation and forwards the packet to the AERO neighbor. Otherwise, the Relay drops the packet and returns a network-layer

ICMP Destination Unreachable message subject to rate limiting (see: Section 3.13).

When an IP packet enters a Relay's AERO interface from the link-layer, (i.e., when it receives a packet from a Server via a tunnel) the Relay processes the packet as follows:

- if the destination does not match an ASP, or if the destination matches one of the Relay's own addresses, the Relay decapsulates the packet and forwards it to the network layer where it will be subject to either IP forwarding or local delivery.

- else, if the destination matches an ACP entry in the IP forwarding table the Relay first determines whether the neighbor is the same as the one it received the packet from. If so the Relay MUST drop the packet silently to avoid looping; otherwise, the Relay uses the neighbor's link-layer address as the destination for encapsulation and re-admits the packet into the AERO link.

- else, the Relay drops the packet and returns an ICMP Destination Unreachable message subject to rate limiting (see: Section 3.13).

3.8.5. Processing Return Packets

When an AERO Server receives a return packet from an AERO Proxy (see Section 3.8.2), it proceeds according to the AERO link trust basis. Namely, the return packets have the same trust profile as for link-layer Destination Unreachable messages. If the Server has sufficient trust basis to accept link-layer Destination Unreachable messages, it can then process the return packet by searching for a dynamic neighbor cache entry that matches the destination. If there is a match, the Server marks the corresponding link-layer address as "unreachable", selects the next-highest priority "reachable" link-layer address in the entry as the link-layer address for encapsulation then (re)admits the packet into the AERO link. If there are no "reachable" link-layer addresses, the Server instead sets ForwardTime in the dynamic neighbor cache entry to 0 (noting that ReportTime may still be non-zero). Otherwise, the Server SHOULD drop the packet and treat it as an indication that a path may be failing, and MAY use Neighbor Unreachability Detection (NUD) (see: Section 3.13) to test the path for reachability.

When an AERO Relay receives a return packet from an AERO Server, it searches its routing table for an entry that matches the inner destination address. If there is a routing table entry that lists a different Server as the next hop, the Relay forwards the packet to the different Server; otherwise, the Relay drops the packet.

3.9. AERO Interface Encapsulation and Re-encapsulation

AERO interfaces encapsulate IP packets according to whether they are entering the AERO interface from the network layer or if they are being re-admitted into the same AERO link they arrived on. This latter form of encapsulation is known as "re-encapsulation".

The AERO interface encapsulates packets per the Generic UDP Encapsulation (GUE) procedures in [I-D.ietf-intarea-gue][I-D.ietf-intarea-gue-extensions], or through an alternate encapsulation format (e.g., see: Appendix A). For packets entering the AERO interface from the network layer, the AERO interface copies the "TTL/Hop Limit", "Type of Service/Traffic Class" [RFC2983], "Flow Label"[RFC6438] (for IPv6) and "Congestion Experienced" [RFC3168] values in the packet's IP header into the corresponding fields in the encapsulation IP header. For packets undergoing re-encapsulation, the AERO interface instead copies these values from the original encapsulation IP header into the new encapsulation header, i.e., the values are transferred between encapsulation headers and *not* copied from the encapsulated packet's network-layer header. (Note especially that by copying the TTL/Hop Limit between encapsulation headers the value will eventually decrement to 0 if there is a (temporary) routing loop.) For IPv4 encapsulation/re-encapsulation, the AERO interface sets the DF bit as discussed in Section 3.12.

When GUE encapsulation is used, the AERO interface next sets the UDP source port to a constant value that it will use in each successive packet it sends, and sets the UDP length field to the length of the encapsulated packet plus 8 bytes for the UDP header itself plus the length of the GUE header (or 0 if GUE direct IP encapsulation is used). For packets sent to a Server or Relay, the AERO interface sets the UDP destination port to 8060, i.e., the IANA-registered port number for AERO. For packets sent to a Client, the AERO interface sets the UDP destination port to the port value stored in the neighbor cache entry for this Client. The AERO interface then either includes or omits the UDP checksum according to the GUE specification.

Clients normally use the IP address of the underlying interface as the encapsulation source address. If the underlying interface does not have an IP address, however, the Client uses an IP address taken from an ACP as the encapsulation source address (assuming the node has some way of injecting the ACP into the underlying network routing system). For IPv6 addresses, the Client normally uses the ACP Subnet Router Anycast address [RFC4291].

Encapsulation between Servers and Relays can use standard mechanisms such as Generic Routing Encapsulation (GRE) [RFC2784] and IPSec [RFC4301] so that Relays can be standard IP routers with no AERO-specific mechanisms.

3.10. AERO Interface Decapsulation

AERO interfaces decapsulate packets destined either to the AERO node itself or to a destination reached via an interface other than the AERO interface the packet was received on. Decapsulation is per the procedures specified for the appropriate encapsulation format.

3.11. AERO Interface Data Origin Authentication

AERO nodes employ simple data origin authentication procedures for encapsulated packets they receive from other nodes on the AERO link. In particular:

- AERO Relays and Servers accept encapsulated packets with a link-layer source address that matches a permanent neighbor cache entry.

- AERO Servers accept authentic encapsulated ND messages from Clients (either directly or via a Proxy), and create or update a static neighbor cache entry for the Client based on the specific message type.

- AERO Clients and Servers accept encapsulated packets if there is a static neighbor cache entry with a link-layer address that matches the packet's link-layer source address.

- AERO Proxies accept encapsulated packets if there is a proxy neighbor cache entry that matches the packet's network-layer address.

Each packet should include a signature that the recipient can use to authenticate the message origin, e.g., as for common VPN systems such as OpenVPN [OVPN]. In environments where source address spoofing is not considered a threat, however, it may be sufficient to require signatures only for ND control plane messages and omit signatures for data plane messages.

3.12. AERO Interface Packet Size Issues

The AERO interface is the node's attachment to the AERO link. The AERO interface acts as a tunnel ingress when it sends a packet to an AERO link neighbor and as a tunnel egress when it receives a packet from an AERO link neighbor. AERO interfaces observe the packet

sizing considerations for tunnels discussed in [I-D.ietf-intarea-tunnels] and as specified below.

The Internet Protocol expects that IP packets will either be delivered to the destination or a suitable Packet Too Big (PTB) message returned to support the process known as IP Path MTU Discovery (PMTUD) [RFC1191][RFC1981]. However, PTB messages may be crafted for malicious purposes such as denial of service, or lost in the network [RFC2923]. This can be especially problematic for tunnels, where a condition known as a PMTUD "black hole" can result. For these reasons, AERO interfaces employ operational procedures that avoid interactions with PMTUD, including the use of fragmentation when necessary.

AERO interfaces observe two different types of fragmentation. Source fragmentation occurs when the AERO interface (acting as a tunnel ingress) fragments the encapsulated packet into multiple fragments before admitting each fragment into the tunnel. Network fragmentation occurs when an encapsulated packet admitted into the tunnel by the ingress is fragmented by an IPv4 router on the path to the egress. Note that a packet that incurs source fragmentation may also incur network fragmentation.

IPv6 specifies a minimum link Maximum Transmission Unit (MTU) of 1280 bytes [RFC8200]. Although IPv4 specifies a smaller minimum link MTU of 68 bytes [RFC0791], AERO interfaces also observe the IPv6 minimum for IPv4 even if encapsulated packets may incur network fragmentation.

IPv6 specifies a minimum Maximum Reassembly Unit (MRU) of 1500 bytes [RFC8200], while the minimum MRU for IPv4 is only 576 bytes [RFC1122] (note that common IPv6 over IPv4 tunnels already assume a larger MRU than the IPv4 minimum).

AERO interfaces therefore configure an MTU that MUST NOT be smaller than 1280 bytes, MUST NOT be larger than the minimum MRU among all nodes on the AERO link minus the encapsulation overhead ("ENCAPS"), and SHOULD NOT be smaller than 1500 bytes. AERO interfaces also configure a Maximum Segment Unit (MSU) as the maximum-sized encapsulated packet that the ingress can inject into the tunnel without source fragmentation. The MSU value MUST NOT be larger than (MTU+ENCAPS) and MUST NOT be larger than 1280 bytes unless there is operational assurance that a larger size can traverse the link along all paths.

All AERO nodes MUST configure the same MTU/MSU values for reasons cited in [RFC3819][RFC4861]; in particular, multicast support requires a common MTU value among all nodes on the link. All AERO

nodes MUST configure an MRU large enough to reassemble packets up to (MTU+ENCAPS) bytes in length; nodes that cannot configure a large-enough MRU MUST NOT enable an AERO interface.

The network layer proceeds as follow when it presents an IP packet to the AERO interface. For each IPv4 packet that is larger than the AERO interface MTU and with the DF bit set to 0, the network layer uses IPv4 fragmentation to break the packet into a minimum number of non-overlapping fragments where the first fragment is no larger than the MTU and the remaining fragments are no larger than the first. For all other IP packets, if the packet is larger than the AERO interface MTU, the network layer drops the packet and returns a PTB message to the original source. Otherwise, the network layer admits each IP packet or fragment into the AERO interface.

For each IP packet admitted into the AERO interface, the interface (acting as a tunnel ingress) encapsulates the packet. If the encapsulated packet is larger than the AERO interface MSU the ingress source-fragments the encapsulated packet into a minimum number of non-overlapping fragments where the first fragment is no larger than the MSU and the remaining fragments are no larger than the first. The ingress then admits each encapsulated packet or fragment into the tunnel, and for IPv4 sets the DF bit to 0 in the IP encapsulation header in case any network fragmentation is necessary. The encapsulated packets will be delivered to the egress, which reassembles them into a whole packet if necessary.

Several factors must be considered when fragmentation is needed. For AERO links over IPv4, the IP ID field is only 16 bits in length, meaning that fragmentation at high data rates could result in data corruption due to reassembly misassociations [RFC6864][RFC4963]. For AERO links over both IPv4 and IPv6, studies have also shown that IP fragments are dropped unconditionally over some network paths [I-D.taylor-v6ops-fragdrop]. In environments where IP fragmentation issues could result in operational problems, the ingress SHOULD employ intermediate-layer source fragmentation (see: [RFC2764] and [I-D.ietf-intarea-gue-extensions]) before appending the outer encapsulation headers to each fragment. Since the encapsulation fragment header reduces the room available for packet data, but the original source has no way to control its insertion, the ingress MUST include the fragment header length in the ENCAPS length even for packets in which the header is absent.

3.13. AERO Interface Error Handling

When an AERO node admits encapsulated packets into the AERO interface, it may receive link-layer or network-layer error indications.

A link-layer error indication is an ICMP error message generated by a router in the underlying network on the path to the neighbor or by the neighbor itself. The message includes an IP header with the address of the node that generated the error as the source address and with the link-layer address of the AERO node as the destination address.

The IP header is followed by an ICMP header that includes an error Type, Code and Checksum. Valid type values include "Destination Unreachable", "Time Exceeded" and "Parameter Problem" [RFC0792][RFC4443]. (AERO interfaces ignore all link-layer IPv4 "Fragmentation Needed" and IPv6 "Packet Too Big" messages since they only emit packets that are guaranteed to be no larger than the IP minimum link MTU as discussed in Section 3.12.)

The ICMP header is followed by the leading portion of the packet that generated the error, also known as the "packet-in-error". For ICMPv6, [RFC4443] specifies that the packet-in-error includes: "As much of invoking packet as possible without the ICMPv6 packet exceeding the minimum IPv6 MTU" (i.e., no more than 1280 bytes). For ICMPv4, [RFC0792] specifies that the packet-in-error includes: "Internet Header + 64 bits of Original Data Datagram", however [RFC1812] Section 4.3.2.3 updates this specification by stating: "the ICMP datagram SHOULD contain as much of the original datagram as possible without the length of the ICMP datagram exceeding 576 bytes".

The link-layer error message format is shown in Figure 3 (where, "L2" and "L3" refer to link-layer and network-layer, respectively):

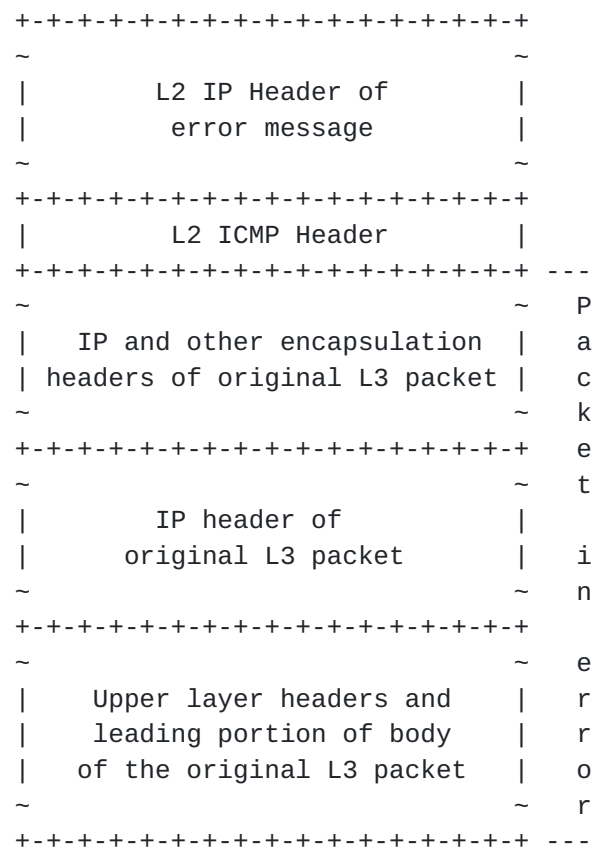

Figure 3: AERO Interface Link-Layer Error Message Format

The AERO node rules for processing these link-layer error messages are as follows:

- When an AERO node receives a link-layer Parameter Problem message, it processes the message the same as described as for ordinary ICMP errors in the normative references [RFC0792][RFC4443].

- When an AERO node receives persistent link-layer Time Exceeded messages, the IP ID field may be wrapping before earlier fragments awaiting reassembly have been processed. In that case, the node SHOULD begin including integrity checks and/or institute rate limits for subsequent packets.

- When an AERO node receives persistent link-layer Destination Unreachable messages in response to encapsulated packets that it sends to one of its dynamic neighbor correspondents, the node SHOULD process the message as an indication that a path may be failing, and MAY initiate NUD over that path. If it receives Destination Unreachable messages on many or all paths, the node SHOULD set ForwardTime for the corresponding dynamic neighbor

cache entry to 0 and allow future packets destined to the correspondent to flow through a default route.

- When an AERO Client receives persistent link-layer Destination Unreachable messages in response to encapsulated packets that it sends to one of its static neighbor Servers, the Client SHOULD mark the path as unusable and use another path. If it receives Destination Unreachable messages on many or all paths, the Client SHOULD associate with a new Server and release its association with the old Server as specified in Section 3.17.6.

- When an AERO Server receives persistent link-layer Destination Unreachable messages in response to encapsulated packets that it sends to one of its static neighbor Clients, the Server SHOULD mark the underlying path as unusable and use another underlying path. If it receives Destination Unreachable messages on multiple paths, the Server should take no further actions unless it receives a receives an explicit ND/PD release message or if the PD lifetime expires. In that case, the Server MUST release the Client's delegated ACP, withdraw the ACP from the AERO routing system and delete the neighbor cache entry.

- When an AERO Relay or Server receives link-layer Destination Unreachable messages in response to an encapsulated packet that it sends to one of its permanent neighbors, it treats the messages as an indication that the path to the neighbor may be failing. However, the dynamic routing protocol should soon reconverge and correct the temporary outage.

When an AERO Relay receives a packet for which the network-layer destination address is covered by an ASP, if there is no more-specific routing information for the destination the Relay drops the packet and returns a network-layer Destination Unreachable message subject to rate limiting. The Relay writes the network-layer source address of the original packet as the destination address and uses one of its non link-local addresses as the source address of the message.

When an AERO node receives an encapsulated packet for which the reassembly buffer it too small, it drops the packet and returns a network-layer Packet Too Big (PTB) message. The node first writes the MRU value into the PTB message MTU field, writes the network-layer source address of the original packet as the destination address and writes one of its non link-local addresses as the source address.

3.14. AERO Router Discovery, Prefix Delegation and Autoconfiguration

AERO Router Discovery, Prefix Delegation and Autoconfiguration are coordinated as discussed in the following Sections.

3.14.1. AERO ND/PD Service Model

Each AERO Server configures a PD service to facilitate Client requests. Each Server is provisioned with a database of ACP-to-Client ID mappings for all Clients enrolled in the AERO system, as well as any information necessary to authenticate each Client. The Client database is maintained by a central administrative authority for the AERO link and securely distributed to all Servers, e.g., via the Lightweight Directory Access Protocol (LDAP) [RFC4511], via static configuration, etc. Therefore, no Server-to-Server PD state synchronization is necessary, and Clients can optionally hold separate PDs for the same ACPs from multiple Servers. In this way, Clients can associate with multiple Servers, and can receive new PDs from new Servers before releasing PDs received from existing Servers. This provides the Client with a natural fault-tolerance and/or load balancing profile.

AERO Clients and Servers use ND messages to maintain neighbor cache entries. AERO Servers configure their AERO interfaces as advertising interfaces, and therefore send unicast RA messages with configuration information in response to a Client's RS message. Thereafter, Clients send additional RS messages to the Server's unicast address to refresh prefix and/or router lifetimes.

AERO Clients and Servers include PD parameters in the RS/RA messages they exchange (see: [I-D.templin-6man-dhcpv6-ndopt]). The unified ND/PD messages are exchanged between Client and Server according to the prefix management schedule required by the PD service.

On Some AERO links, PD arrangements may be through some out-of-band service such as network management, static configuration, etc. In those cases, AERO nodes can use simple RS/RA message exchanges with no explicit PD options. Instead, the RS/RA messages use AERO addresses as a means of representing the delegated prefixes, e.g., if a message includes a source address of "fe80::2001:db8:1:2" then the recipient can infer that the sender holds the prefix delegation "2001:db8:1:2::/N" (where 'N' is the prefix length common to all ACPs for the link).

The following sections specify the Client and Server behavior.

3.14.2. AERO Client Behavior

AERO Clients discover the link-layer addresses of AERO Servers via static configuration (e.g., from a flat-file map of Server addresses and locations), or through an automated means such as Domain Name System (DNS) name resolution [RFC1035]. In the absence of other information, the Client resolves the DNS Fully-Qualified Domain Name (FQDN) "linkupnetworks.[domainname]" where "linkupnetworks" is a constant text string and "[domainname]" is a DNS suffix for the Client's underlying interface (e.g., "example.com"). After discovering the link-layer addresses, the Client associates with one or more of the corresponding Servers.

To associate with a Server, the Client acts as a requesting router to request ACPs through an ND/PD message exchange. The Client sends an RS message with PD parameters and with all-routers multicast as the IPv6 destination address, the address of the Client's underlying interface as the link-layer source address and the link-layer address of the Server as the link-layer destination address. If the Client already knows its own AERO address, it uses the AERO address as the IPv6 source address; otherwise, it uses the prefix-solicitation address as the source address. If the Client's underlying interface connects to a subnetwork that supports ACP injection, the Client can use the ACP's Subnet Router Anycast address as the link-layer source address.

The Client next includes one or more SLLAOs in the RS message formatted as described in Section 3.5 to register its link-layer address(es) with the Server. The first SLLAO MUST correspond to the underlying interface over which the Client will send the RS message. The Client MAY include additional SLLAOs specific to other underlying interfaces, but if so it sets the UDP Port Number and IP Address fields to 0. The Client can instead register additional link-layer addresses with the Server by sending additional RS messages including SLLAOs via other underlying interfaces after the initial RS/RA exchange.

The Client then sends the RS message to the AERO Server and waits for an RA message reply (see Section 3.14.3) while retrying MAX_RETRY times until an RA is received. If the Client receives no RAs, or if it receives an RA with Router Lifetime set to 0 and/or with no ACP PD parameters, the Client SHOULD discontinue autoconfiguration attempts through this Server and try another Server. Otherwise, the Client processes the ACPs found in the RA message.

Next, the Client creates a static neighbor cache entry with the Server's link-local address as the network-layer address and the Server's encapsulation source address as the link-layer address. The

Client then autoconfigures AERO addresses for each of the delegated ACPs and assigns them to the AERO interface.

The Client next examines the P bit in the RA message flags field [RFC5175]. If the P bit value was 1, the Client infers that there is a NAT or Proxy on the path to the Server via the interface over which it sent the RS message. In that case, the Client sets UDP Port Number and IP Address to 0 in the S/TLLAOs of any subsequent ND messages it sends to the Server over that link.

The Client also caches any ASPs included in Route Information Options (RIOs) [RFC4191] as ASPs to associate with the AERO link, and assigns the MTU/MSU values in the MTU options to its AERO interface while configuring an appropriate MRU. This configuration information applies to the AERO link as a whole, and all AERO nodes will receive the same values.

Following autoconfiguration, the Client sub-delegates the ACPs to its attached EUNs and/or the Client's own internal virtual interfaces as described in [I-D.templin-v6ops-pdhost] to support the Client's downstream attached "Internet of Things (IoT)". The Client subsequently maintains its ACP delegations through each of its Servers by sending RS messages with PD parameters to receive corresponding RA messages.

After the Client registers its Interface IDs and their associated UDP/IP addresses and 'P(i)' values, it may wish to change one or more Interface ID registrations, e.g., if an underlying interface changes address or becomes unavailable, if QoS preferences change, etc. To do so, the Client prepares an unsolicited NA message to send over any available underlying interface. The target address of the NA message is set to the Client's link-local address, and the destination address is set to all-nodes multicast. The NA MUST include a TLLAO specific to the selected available underlying interface as the first TLLAO and MAY include any additional TLLAOs specific to other underlying interfaces. The Client includes fresh 'P(i)' values in each TLLAO to update the Server's neighbor cache entry. If the Client wishes to update 'P(i)' values without updating the link-layer address, it sets the UDP Port Number and IP Address fields to 0. If the Client wishes to disable the interface, it sets all 'P(i)' values to '0' ("disabled").

If the Client wishes to discontinue use of a Server it issues an RS message with PD parameters that will cause the Server to release the Client. When the Server processes the message, it releases the ACP, deletes its neighbor cache entry for the Client, withdraws the IP route from the routing system and returns an RA reply containing any necessary PD parameters.

3.14.3. AERO Server Behavior

AERO Servers act as IPv6 routers and support a PD service for Clients. AERO Servers arrange to add their encapsulation layer IP addresses (i.e., their link-layer addresses) to a static map of Server addresses for the link and/or the DNS resource records for the FQDN "linkupnetworks.[domainname]" before entering service.

When an AERO Server receives a prospective Client's RS message with PD parameters on its AERO interface, and the Server is too busy, it SHOULD return an immediate RA reply with no ACPs and with Router Lifetime set to 0. Otherwise, the Server authenticates the RS message and processes the PD parameters. The Server first determines the correct ACPs to delegate to the Client by searching the Client database. When the Server delegates the ACPs, it also creates an IP forwarding table entry for each ACP so that the AERO BGP-based routing system will propagate the ACPs to the Relays that aggregate the corresponding ASP (see: Section 3.3).

Next, the Server prepares an RA message that includes the delegated ACPs and any other PD parameters. The Server then returns the RA message using its link-local address as the network-layer source address, the network-layer source address of the RS message as the network-layer destination address, the Server's link-layer address as the source link-layer address, and the source link-layer address of the RS message as the destination link-layer address. The Server next sets the P flag in the RA message flags field [RFC5175] to 1 if the source link-layer address in the RS message was different than the address in the first SLLAO to indicate that there is a NAT or Proxy on the path; otherwise it sets P to 0. The Server then includes one or more RIOs that encode the ASPs for the AERO link. The Server also includes two MTU options - the first MTU option includes the MTU for the link and the second MTU option includes the MSU for the link (see Section 3.12). The Server finally sends the RA message to the Client.

The Server next creates a static neighbor cache entry for the Client using the base AERO address as the network-layer address and with lifetime set to no more than the smallest PD lifetime. Next, the Server updates the neighbor cache entry link-layer address(es) by recording the information in each SLLAO option indexed by the Interface ID and including the UDP port number, IP address and P(i) values. For the first SLLAO in the list, however, the Server records the actual encapsulation source UDP and IP addresses instead of those that appear in the SLLAO in case there was a NAT or Proxy in the path.

After the initial RS/RA exchange, the AERO Server maintains the neighbor cache entry for the Client until the PD lifetimes expire. If the Client issues additional RS messages with PD renewal parameters, the Server extends the PD lifetimes. If the Client issues an RS with PD release parameters, or if the Client does not issue a renewal before the lifetime expires, the Server deletes the neighbor cache entry for the Client and withdraws the IP routes from the AERO routing system. The Server processes these and any other Client PD messages, and returns an RA reply. The Server may also issue an unsolicited RA message with PD reconfigure parameters to inform the Client that it needs to renegotiate its PDs.

3.14.3.1. Lightweight DHCPv6 Relay Agent (LDRA)

When DHCPv6 is used as the ND/PD service back end, AERO Clients and Servers are always on the same link (i.e., the AERO link) from the perspective of DHCPv6. However, in some implementations the DHCPv6 server and ND function may be located in separate modules. In that case, the Server's AERO interface driver module can act as a Lightweight DHCPv6 Relay Agent (LDRA)[RFC6221] to relay PD messages to and from the DHCPv6 server module.

When the LDRA receives an authentic RS message, it extracts the PD message parameters and uses them to fabricate an IPv6/UDP/DHCPv6 message. It sets the IPv6 source address to the source address of the RS message, sets the IPv6 destination address to 'All_DHCP_Relay_Agents_and_Servers' and sets the UDP fields to values that will be understood by the DHCPv6 server.

The LDRA then wraps the message in a Relay-Forward message header and includes an Interface-ID option that includes enough information to allow the LDRA to forward the resulting Reply message back to the Client (e.g., the Client's link-layer addresses, a security association identifier, etc.). The LDRA also wraps the information in all of the SLLAO options from the RS message into the Interface-ID option, then forwards the message to the DHCPv6 server.

When the DHCPv6 server prepares a Reply message, it wraps the message in a Relay-Reply message and echoes the Interface-ID option. The DHCPv6 server then delivers the Relay-Reply message to the LDRA, which discards the Relay-Reply wrapper and IPv6/UDP headers, then uses the DHCPv6 message to fabricate an RA response to the Client. The Server uses the information in the Interface ID option to prepare the RA message and to cache the link-layer addresses taken from the SLLAOs echoed in the Interface-ID option.

3.15. AERO Interface Route Optimization

When a source Client forwards packets to a prospective correspondent Client within the same AERO link domain (i.e., one for which the packet's destination address is covered by an ASP), the source Client MAY initiate an AERO link route optimization procedure. The procedure is based on an exchange of IPv6 ND messages using a chain of AERO Servers and Relays as a trust basis.

Although the Client is responsible for initiating route optimization, the Server is the policy enforcement point that determines whether route optimization is permitted. For example, on some AERO links route optimization would allow traffic to circumvent critical network-based traffic inspection points. In those cases, the Server can simply discard any route optimization messages instead of forwarding them.

The following sections specify the AERO link route optimization procedure.

3.15.1. Reference Operational Scenario

Figure 4 depicts the AERO link route optimization reference operational scenario, using IPv6 addressing as the example (while not shown, a corresponding example for IPv4 addressing can be easily constructed). The figure shows an AERO Relay ('R1'), two AERO Servers ('S1', 'S2'), two AERO Clients ('C1', 'C2') and two ordinary IPv6 hosts ('H1', 'H2'):

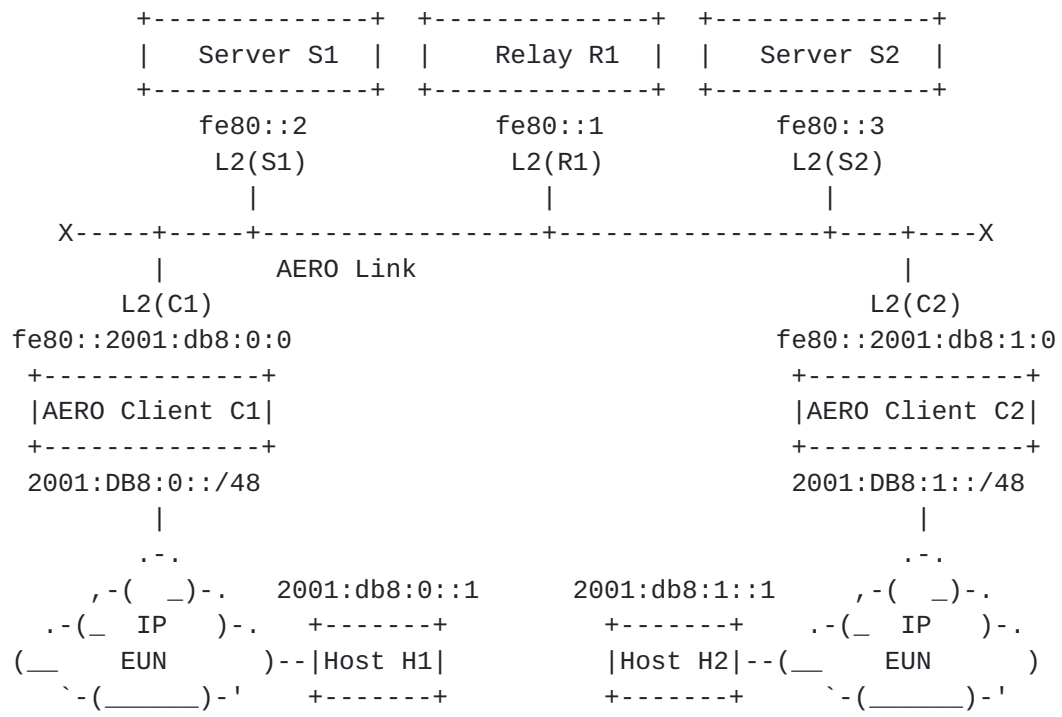

Figure 4: AERO Reference Operational Scenario

In Figure 4, Relay ('R1') assigns the administratively-provisioned link-local address fe80::1 to its AERO interface with link-layer address L2(R1), Server ('S1') assigns the address fe80::2 with link-layer address L2(S1), and Server ('S2') assigns the address fe80::3 with link-layer address L2(S2). Servers ('S1') and ('S2') next arrange to add their link-layer addresses to a published list of valid Servers for the AERO link.

AERO Client ('C1') receives the ACP 2001:db8:0::/48 in an ND/PD exchange via AERO Server ('S1') then assigns the address fe80::2001:db8:0:0 to its AERO interface with link-layer address L2(C1). Client ('C1') configures a default route and neighbor cache entry via the AERO interface with next-hop address fe80::2 and link-layer address L2(S1), then sub-delegates the ACP to its attached EUNs. IPv6 host ('H1') connects to the EUN, and configures the address 2001:db8:0::1.

AERO Client ('C2') receives the ACP 2001:db8:1::/48 in an ND/PD exchange via AERO Server ('S2') then assigns the address fe80::2001:db8:1:0 to its AERO interface with link-layer address L2(C2). Client ('C2') configures a default route and neighbor cache entry via the AERO interface with next-hop address fe80::3 and link-layer address L2(S2), then sub-delegates the ACP to its attached EUNs. IPv6 host ('H2') connects to the EUN, and configures the address 2001:db8:1::1.

3.15.2. Concept of Operations

Again, with reference to Figure 4, when source host ('H1') sends a packet to destination host ('H2'), the packet is first forwarded over the source host's attached EUN to Client ('C1'). Client ('C1') then forwards the packet via its AERO interface to Server ('S1') and also sends an NS message toward Client ('C2') via Server ('S1').

Server ('S1') then forwards both the packet and the NS message out the same AERO interface toward Client ('C2') via Relay ('R1'). When Relay ('R1') receives the packet and NS message, it consults its forwarding table to discover Server ('S2') as the next hop toward Client ('C2'). Relay ('R1') then forwards both the packet and the NS message to Server ('S2'), which then forwards them to Client ('C2').

After Client ('C2') receives the NS message, it process the message and creates or updates a dynamic neighbor cache entry for Client ('C1'), then sends the NA response to the link-layer address of Client ('C1').

After Client ('C1') receives the NA message, it processes the message and creates or updates a dynamic neighbor cache entry for Client ('C2'). Thereafter, forwarding of packets from Client ('C1') to Client ('C2') without involving any intermediate nodes is enabled. The mechanisms that support this exchange are specified in the following sections.

3.15.3. Sending NS Messages

When a Client forwards a packet with a source address from one of its ACPs toward a destination address covered by an ASP (i.e., toward another AERO Client connected to the same AERO link), the source Client MAY send an NS message forward toward the destination Client via the Server.

In the reference operational scenario, when Client ('C1') forwards a packet toward Client ('C2'), it MAY also send an NS message forward toward Client ('C2'), subject to rate limiting (see Section 8.2 of [RFC4861]). Client ('C1') prepares the NS message as follows:

- the link-layer source address is set to 'L2(C1)' (i.e., the link-layer address of Client ('C1')).
- the link-layer destination address is set to 'L2(S1)' (i.e., the link-layer address of Server ('S1')).
- the network-layer source address is set to fe80::2001:db8:0:0 (i.e., the base AERO address of Client ('C1')).

- the network-layer destination address is set to the AERO address corresponding to the destination address of Client ('C2').

- the Type is set to 135.

- the Target Address is set to the destination address of the packet that triggered route optimization.

- the message includes SLLAOs set to appropriate values for the Client ('C1')'s underlying interfaces The first SLLAO serves as the "Report-To" address for the Client, which is the address to which the target will announce mobility events and/or other dynamic updates.

- the message includes one or more RIOs that include Client ('C1')'s ACPs [I-D.templin-6man-rio-redirect].

- the message SHOULD include a Timestamp option and a Nonce option.

Note that the act of sending NS messages is cited as "MAY", since Client ('C1') may have advanced knowledge that the direct path to Client ('C2') would be unusable or otherwise undesirable. If the direct path later becomes unusable after the initial route optimization, Client ('C1') simply allows packets to again flow through Server ('S1').

3.15.4. Re-encapsulating and Relaying the NS

When Server ('S1') receives an NS message from Client ('C1'), it first verifies that the SLLAOs in the NS are a proper subset of the link-layer addresses in Client ('C1')'s neighbor cache entry. If the Client's SLLAOs are not acceptable, Server ('S1') discards the message.

Server ('S1') then examines the network-layer destination address of the NS to determine the next hop toward Client ('C2') by searching for the AERO address in the neighbor cache. Since Client ('C2') is not one of its neighbors, Server ('S1') then inserts an additional layer of encapsulation between the outer IP header and the NS message proper. This mid-layer IP header uses the AERO Server Subnet Router Anycast address as the source address and the Subnet Router Anycast address corresponding to Client ("C2")'s AERO address as the destination address (in this case, C2's Subnet Router Anycast address is 2001:db8:1:0::). The Server then forwards this double-encapsulated NS message to Relay ('R1') by changing the link-layer source address of the message to 'L2(S1)' and changing the link-layer destination address to 'L2(R1)'. Server ('S1') finally forwards the

message to Relay ('R1') without decrementing the network-layer TTL/ Hop Limit field.

When Relay ('R1') receives the double-encapsulated NS message from Server ('S1') it discards the outer IP header and determines that Server ('S2') is the next hop toward Client ('C2') by consulting its standard IP forwarding table for the Client Subnet Router Anycast destination address. Relay ('R1') then encapsulates and forwards the message to Server ('S2') the same as for any IP router.

When Server ('S2') receives the double-encapsulated NS message from Relay ('R1') it removes the mid-layer IP header and determines that Client ('C2') is a neighbor on a native underlying interface by consulting its neighbor cache for Client ('C2')'s AERO address. Server ('S2') then re-encapsulates the NS while changing the link-layer source address to 'L2(S2)' and changing the link-layer destination address to 'L2(C2)'. Server ('S2') then forwards the message to Client ('C2').

3.15.5. Processing NSs and Sending NAs

When Client ('C2') receives the NS message, it accepts the NS only if the message has a link-layer source address of one of its Servers (e.g., L2(S2)). Client ('C2') further accepts the message only if it is willing to serve as a route optimization target.

In the reference operational scenario, when Client ('C2') receives a valid NS message, it either creates or updates a dynamic neighbor cache entry that stores the source address of the message as the network-layer address of Client ('C1') and stores the link-layer addresses found in the SLLAOs as the link-layer addresses of Client ('C1'). Client ('C2') then sets ReportTime for the neighbor cache entry to REPORT_TIME.

After processing the message, Client ('C2') prepares an NA message response as follows:

- the link-layer source address is set to 'L2(C2)' (i.e., the link-layer address of Client ('C2')).
- the link-layer destination address is set to 'L2(C1)' (i.e., the link-layer address of Client ('C1')).
- the network-layer source address is set to fe80::2001:db8:1:0 (i.e., the base AERO address of Client ('C2')).
- the network-layer destination address is set to fe80::2001:db8:0:0 (i.e., the base AERO address of Client ('C1')).

- the Type is set to 136.
- The Target Address is set to the Target Address field in the NS message.
- the message includes one or more TLLAOs set to appropriate values for Client ('C2')'s native underlying interfaces.
- the message includes one or more RIOs that include Client ('C2')'s ACPs [I-D.templin-6man-rio-redirect].
- the message SHOULD include a Timestamp option and MUST echo the Nonce option received in the NS (i.e., if a Nonce option was present).

Client ('C2') then sends the NA message to Client ('C1').

3.15.6. Processing NAs

When Client ('C1') receives the NA message, it first verifies that the NA matches the original NS message. Client ('C1') then processes the message as follows.

In the reference operational scenario, when Client ('C1') receives the NA message, it either creates or updates a dynamic neighbor cache entry that stores the source address of the message as the network-layer address of Client ('C2'), stores the link-layer addresses found in the TLLAOs as the link-layer addresses of Client ('C2') and stores the ACPs encoded in the RIOs of the NA as the ACPs for Client ('C2'). Client ('C1') then sets ForwardTime for the neighbor cache entry to FORWARD_TIME.

Now, Client ('C1') has a neighbor cache entry with a valid ForwardTime value, while Client ('C2') has a neighbor cache entry with a valid ReportTime value. Thereafter, Client ('C1') may forward ordinary network-layer data packets directly to Client ('C2') without involving any intermediate nodes, and Client ('C2') can dynamically report any changes in link-layer information by sending unsolicited NA messages. (In order for Client ('C2') to forward packets to Client ('C1'), a corresponding NS/NA message exchange is required in the reverse direction; hence, the mechanism is asymmetric.)

3.15.7. Server-Based Route Optimization

The source Client itself may initiate route optimization if the Client has only native interfaces. If the source Client has Direct, NATed, Proxyed or VPNed interfaces, route optimization must instead be initiated by the source Server. The source Server MUST include an

SLLAO with a "Report-To" address in the route optimization NS messages it sends. The "Report-To" address must be one of the source Server's globally routable IP addresses.

In the same way, the target Client may serve as a route optimization target if it has only native interfaces. If some or all of the target Client's underlying interfaces are Direct, NATed, Proxyed or VPNed the target Server must instead serve as the route optimization target. In that case, when the source Server sends an NS message the target Server prepares an NA response the same as if it were the target Client (see: Section 3.15.5).

When the target Server sends an NA response to a route optimization NS, it includes a Timestamp option, any necessary security options, and TLLAOs corresponding to the target Client's underlying interfaces. The target Server writes the link-layer address of the Client in TLLAOs corresponding to native underlying interfaces, writes the link-layer address of the Proxy in TLLAOs corresponding to Proxyed underlying interfaces and writes its own link-layer address in TLLAOs corresponding to other interfaces. The Interface ID and QoS Preference values in the TLLAOs are those supplied by the target Client during ND exchanges with the target Server. The target Server then establishes a dynamic neighbor cache entry for the source with ReportTime set to REPORT_TIME seconds and with a "Report-To" address set to the address of the source.

When the source Server receives the NA response, it creates or updates a dynamic neighbor cache entry for the target with ForwardTime set to FORWARD_TIME seconds and with the information provided in the TLLAOs as the link-layer addresses and preference values for the Client. The source Server then translates the solicited NA message into an unsolicited NA message by changing the source address to its own link-local address, changing the destination address to all-nodes multicast, recalculating checksums and any security options, and including the Timestamp option as it appeared in the original solicited NA. The source Server then retains this message for subsequent transmission to any source neighbors that send packets to the target within the current ForwardTime window.

While ForwardTime is greater than 0, the source Server sends unsolicited NA messages (subject to rate limiting) in response to data packets from source Clients or Proxies that are destined to the target Client. The unsolicited NA messages update source Client and Proxy dynamic neighbor cache entries with ForwardTime set to FORWARD_TIME minus the difference between the current time and the NA Timestamp. Subsequent packets from the source destined to the target

Client then travel via the route-optimized path instead of through the dogleg path through Servers and Relays.

Following route optimization, when the target Client (or Proxy) sends unsolicited NA messages to the target Server to update link-layer addresses and/or QoS preferences, the target Server translates the messages the same as described above and repeats them to any of its neighbors with non-zero ReportTime. The source Server in turn translates the messages and repeats them to any of their source Clients or Proxys to which they recently sent NAs.

If the target Client moves to a new Server, the old Server sends immediate unsolicited NA messages with no TLLAOs to any of its dynamic neighbors with non-zero ReportTime, and retains the dynamic neighbor cache entry until ReportTime expires. While ReportTime is non-zero, the old Server sends unsolicited NA messages with no TLLAOs (subject to rate limiting) back to the source in response to data packets received from a correspondent node while forwarding the packets themselves to a Relay. The Relay will then either forward the packets to the new Server if the target Client has moved, or drop the packets if the target Client is no longer in the network. When the source receives the unsolicited NAs with no TLLAOs, it allows future packets destined to the target Client to again flow through its own Server (or Relay).

3.16. Neighbor Unreachability Detection (NUD)

AERO nodes perform Neighbor Unreachability Detection (NUD) by sending NS messages to elicit solicited NA messages from neighbors the same as described in [RFC4861]. NUD is performed either reactively in response to persistent link-layer errors (see Section 3.13) or proactively to update neighbor cache entry timers and/or link-layer address information. (NS messages may include SLLAOs and NA messages may include TLLAOs in order to update link-layer address information.)

When an AERO node sends an NS/NA message, it uses one of its link-local addresses as the IPv6 source address and a link-local address of the neighbor as the IPv6 destination address. When route optimization directs a source AERO node to a target AERO node, the source node SHOULD proactively test the direct path by sending an initial NS message to elicit a solicited NA response. While testing the path, the source node can optionally continue sending packets via its default router, maintain a small queue of packets until target reachability is confirmed, or (optimistically) allow packets to flow directly to the target.

While data packets are still flowing, the source node thereafter periodically tests the direct path to the target node (see Section 7.3 of [RFC4861]) in order to keep dynamic neighbor cache entries alive. When the target node receives a valid NS message, it resets ReportTime to REPORT_TIME and updates its cached link-layer addresses (if necessary). When the source node receives a corresponding NA message, it resets ForwardTime to FORWARD_TIME and updates its cached link-layer addresses (if necessary). If the source node is unable to elicit an NA response from the target node after MaxRetry attempts, it SHOULD set ForwardTime to 0. Otherwise, the source node considers the path usable and SHOULD thereafter process any link-layer errors as an indication that the direct path to the target node may be failing.

When ForwardTime for a dynamic neighbor cache entry expires, the source node resumes sending any subsequent packets via a Server (or Relay) and may (eventually) attempt to re-initiate the AERO route optimization process. When ReportTime for a dynamic neighbor cache entry expires, the target node ceases to send dynamic mobility and QoS updates to the source node. When both ForwardTime and ReportTime for a dynamic neighbor cache entry expire, the node deletes the neighbor cache entry.

Note that an AERO node may have multiple underlying interface paths toward the target neighbor. In that case, the node SHOULD perform NUD over each underlying interface and only consider the neighbor unreachable if NUD fails over multiple underlying interface paths.

3.17. Mobility Management and Quality of Service (QoS)

AERO is an example of a Distributed Mobility Management (DMM) service. Each AERO Server is responsible for only a subset of the Clients on the AERO link, as opposed to a Centralized Mobility Management (CMM) service where there is a single network mobility service for all Clients. AERO Clients coordinate with their regional Servers via RS/RA exchanges to maintain the DMM profile, and the AERO routing system tracks the current AERO Client/Server peering relationships.

AERO interfaces accommodate mobility management by sending unsolicited NA messages the same as for announcing link-layer address changes for any interface that implements IPv6 ND [RFC4861]. (In environments where reliability is a concern, AERO interfaces can send immediate NS messages to receive solicited NA messages, i.e., they can skip the unreliable unsolicited NA messaging step and move directly to a reliable NS/NA exchange. This comes at a penalty of at least one round trip.)

When a node sends an unsolicited NA message, it sets the IPv6 source to its own link-local address, sets the IPv6 destination address to all-nodes multicast, sets the link-layer source address to its own address and sets the link-layer destination address to either a multicast address or the unicast link-layer address of a neighbor. If the unsolicited NA message must be received by multiple neighbors, the node sends multiple copies of the NA using a different unicast link-layer destination address for each neighbor. Mobility management considerations are specified in the following sections.

3.17.1. Forwarding Packets on Behalf of Departed Clients

When a Server receives packets with destination addresses that do not match one of its static neighbor cache Clients, it forwards the packets to a Relay and also returns an unsolicited NA message to the sender with no TLLAOs. The packets will be delivered to the target Client's new location, and the sender will realize that it needs to delete its routing information that associated the target with this Server.

3.17.2. Announcing Link-Layer Address and QoS Preference Changes

When a Client needs to change its link-layer addresses, e.g., due to a mobility event, it sends unsolicited NAs to its neighbors using the new link-layer address as the source address and with TLLAOs that include the new Client UDP Port Number, IP Address and P(i) values. (For neighbors that are Servers, the Client can instead initiate an RS/RA exchange.) If the Client sends the NA solely for the purpose of updating QoS preferences without updating the link-layer address, the Client sets the UDP Port Number and IP Address to 0.

The Client MAY send up to MaxRetry unsolicited NA messages in parallel with sending actual data packets in case one or more NAs are lost. If all NAs are lost, the neighbor will eventually invoke NUD by sending NS messages that include SLLAOs.

3.17.3. Bringing New Links Into Service

When a Client needs to bring new underlying interfaces into service (e.g., when it activates a new data link), it sends unsolicited NAs to its neighbors using the new link-layer address as the source address and with TLLAOs that include the new Client link-layer information. (For neighbors that are Servers, the Client can instead initiate an RS/RA exchange.)

3.17.4. Removing Existing Links from Service

When a Client needs to remove existing underlying interfaces from service (e.g., when it de-activates an existing data link), it sends unsolicited NAs to its neighbors with TLLAOs with all P(i) values set to 0. (For neighbors that are Servers, the Client can instead initiate an RS/RA exchange.)

If the Client needs to send ND messages over an underlying interface other than the one being removed from service, it MUST include a current TLLAO for the sending interface as the first TLLAO and include TLLAOs for any underlying interface being removed from service as additional TLLAOs.

3.17.5. Implicit Mobility Management

AERO interface neighbors MAY provide a configuration option that allows them to perform implicit mobility management in which no ND messaging is used. In that case, the Client only transmits packets over a single interface at a time, and the neighbor always observes packets arriving from the Client from the same link-layer source address.

If the Client's underlying interface address changes (either due to a readdressing of the original interface or switching to a new interface) the neighbor immediately updates the neighbor cache entry for the Client and begins accepting and sending packets to the Client's new link-layer address. This implicit mobility method applies to use cases such as cellphones with both WiFi and Cellular interfaces where only one of the interfaces is active at a given time, and the Client automatically switches over to the backup interface if the primary interface fails.

3.17.6. Moving to a New Server

When a Client associates with a new Server, it performs the Client procedures specified in Section 3.14.2. The Client then sends RS messages with PD release parameters to the old Server to release itself from that Server's domain. If the Client does not receive an RA reply after MaxRetry attempts, the old Server may have failed and the Client should discontinue its release attempts.

Clients SHOULD NOT move rapidly between Servers in order to avoid causing excessive oscillations in the AERO routing system. Such oscillations could result in intermittent reachability for the Client itself, while causing no harm to the network. Examples of when a Client might wish to change to a different Server include a Server

that has gone unreachable, topological movements of significant distance, etc.

3.18. Multicast Considerations

When the underlying network does not support multicast, AERO Clients map link-scoped multicast addresses to the link-layer address of a Server, which acts as a multicast forwarding agent. The AERO Client also serves as an IGMP/MLD Proxy for its EUNs and/or hosted applications per [RFC4605] while using the link-layer address of the Server as the link-layer address for all multicast packets.

When the underlying network supports multicast, AERO nodes use the multicast address mapping specification found in [RFC2529] for IPv4 underlying networks and use a TBD site-scoped multicast mapping for IPv6 underlying networks. In that case, border routers must ensure that the encapsulated site-scoped multicast packets do not leak outside of the site spanned by the AERO link.

4. The AERO Proxy

In some environments, AERO Clients may be located in secured subnetwork enclaves (e.g., corporate enterprise networks, radio access networks, cellular service provider networks, etc.) that do not allow direct communications from the Client to a Server in the outside Internetwork. In that case, the secured enclave can employ an AERO Proxy.

The AERO Proxy is located at the secured enclave perimeter and listens for RS messages originating from or RA messages destined to AERO Clients located within the enclave. The Proxy acts on these control messages as follows:

- when the Proxy receives an RS message from a Client within the secured enclave, it first authenticates the message then creates a proxy neighbor cache entry for the Client in the INCOMPLETE State and caches the Client and Server link-layer address along with any identifying information including Transaction IDs, Client Identifiers, Nonce values, etc. The Proxy then creates a new RS message using its own link-local address as the source and with an RIO that includes the Client's ACP. The Proxy then forwards the message to the Server indicated by the destination link-layer address in the original RS while using its own external address as the source link-layer address.

- when the Server receives the RS message, it authenticates the message then creates a static neighbor cache entry for the Client

with the Proxy's address as the link-layer address. The Server then sends an RA message back to the Proxy.

- when the Proxy receives the RA message, it matches the message with the RS that created the (INCOMPLETE) proxy neighbor cache entry. The Proxy then caches the route information in the message as a mapping from the Client's ACPs to the Client's address within the secured enclave, and sets the neighbor cache entry state to REACHABLE. The Proxy then creates a new RA message using the cached Client information and forwards it to the Client.

After the initial RS/RA handshake, the Proxy forwards data packets between the Client and Server with the Server acting as the Client's default router. The Proxy can send ND messages to the Client's Server(s) to update Server neighbor cache entries on behalf of the Client. (For example, the Proxy can send unsolicited NA messages with a TLLAO with UDP Port Number and IP Address set to 0 and with valid P(i) values to update the Server(s) with the Client's new QoS preferences for that link). The Proxy also forwards any control and data messages originating from the Client to the Client's primary Server.

At some time after data packets have been flowing from the Client to the Server, the Proxy may receive unsolicited NA messages from the Server with TLLAOs corresponding to a target Client. The Proxy establishes a dynamic neighbor cache entry for the target with ForwardTime set to FORWARD_TIME and allows future data packets destined to the target to flow directly according to the link-layer address information instead of through the Server. The Proxy may at some later point receive additional NA messages with TLLAOs, and if so resets ForwardTime and updates its cached link-layer address information. If the Proxy receives no further NA messages, or if it receives NA messages with no TLLAOs, it deletes the dynamic neighbor cache entry.

In some subnetworks that employ a Proxy, the Client's ACP can be injected into the underlying network routing system. In that case, the Client can send data messages without encapsulation so that the native underlying network routing system transports the unencapsulated packets to the Proxy. This can be very beneficial, e.g., if the Client connects to the network via low-end data links such as some aviation wireless links. In that case, however, the Client's control message are still sent encapsulated so as to supply the Proxy with the address of the Server and to transport IPv6 ND messages without decrementing the hop-count. In summary, the interface becomes one where control messages are encapsulated while data messages are either unencapsulated or encapsulated according to the specific use case. This encapsulation avoidance can be seen as a

form of "header compression", meaning that the MTU should be sized based on the size of full encapsulated messages even if most messages are sent unencapsulated.

5. Direct Underlying Interfaces

When a Client's AERO interface is configured over a Direct underlying interface, the neighbor at the other end of the Direct link can receive packets without any encapsulation. In that case, the Client sends packets over the Direct link according to the QoS preferences associated with its underling interfaces. If the Direct underlying interface has the highest QoS preference, then the Client's IP packets are transmitted directly to the peer without going through an underlying network. If other underlying interfaces have higher QoS preferences, then the Client's IP packets are transmitted via a different underlying interface, which may result in the inclusion of AERO Proxies, Servers and Relays in the communications path. Direct underlying interfaces must be tested periodically for reachability, e.g., via NUD, via periodic unsolicited NAs, etc.

6. Operation on AERO Links with /64 ASPs

IPv6 AERO links typically have ASPs that cover many candidate ACPs of length /64 or shorter. However, in some cases it may be desirable to use AERO over links that have only a /64 ASP. This can be accommodated by treating all Clients on the AERO link as simple hosts that receive /128 prefix delegations.

In that case, the Client sends an RS message to the Server the same as for ordinary AERO links. The Server responds with an RA message that includes one or more /128 prefixes (i.e., singleton addresses) that include the /64 ASP prefix along with an interface identifier portion to be assigned to the Client. The Client and Server then configure their AERO addresses based on the interface identifier portions of the /128s (i.e., the lower 64 bits) and not based on the /64 prefix (i.e., the upper 64 bits).

For example, if the ASP for the host-only IPv6 AERO link is 2001:db8:1000:2000::/64, each Client will receive one or more /128 IPv6 prefix delegations such as 2001:db8:1000:2000::1/128, 2001:db8:1000:2000::2/128, etc. When the Client receives the prefix delegations, it assigns the AERO addresses fe80::1, fe80::2, etc. to the AERO interface, and assigns the global IPv6 addresses (i.e., the /128s) to either the AERO interface or an internal virtual interface such as a loopback. In this arrangement, the Client conducts route optimization in the same sense as discussed in Section 3.15.

This specification has applicability for nodes that act as a Client on an "upstream" AERO link, but also act as a Server on "downstream" AERO links. More specifically, if the node acts as a Client to receive a /64 prefix from the upstream AERO link it can then act as a Server to provision /128s to Clients on downstream AERO links.

7. Implementation Status

An AERO implementation based on OpenVPN (https://openvpn.net/) was announced on the v6ops mailing list on January 10, 2018. The latest version is available at: http://linkupnetworks.net/aero/AERO-OpenVPN-1.2.tgz.

An initial public release of the AERO proof-of-concept source code was announced on the intarea mailing list on August 21, 2015. The latest version is available at: http://linkupnetworks.net/aero/aero-4.0.0.tgz.

8. IANA Considerations

The IANA has assigned a 4-octet Private Enterprise Number "45282" for AERO in the "enterprise-numbers" registry.

The IANA has assigned the UDP port number "8060" for an earlier experimental version of AERO [RFC6706]. This document obsoletes [RFC6706] and claims the UDP port number "8060" for all future use.

No further IANA actions are required.

9. Security Considerations

AERO link security considerations are the same as for standard IPv6 Neighbor Discovery [RFC4861] except that AERO improves on some aspects. In particular, AERO uses a trust basis between Clients and Servers, where the Clients only engage in the AERO mechanism when it is facilitated by a trusted Server.

NS and NA messages SHOULD include a Timestamp option (see Section 5.3 of [RFC3971]) that other AERO nodes can use to verify the message time of origin. NS and RS messages SHOULD include a Nonce option (see Section 5.3 of [RFC3971]) that recipients echo back in corresponding NA and RA responses.

In cases where spoofing cannot be mitigated through other means, AERO IPv6 ND messages should employ SEcure Neighbor Discovery (SEND) [RFC3971], which also protects the PD information embedded in RS/RA message options. In order to apply SEND, AERO nodes use

Cryptographically Generated Addresses (CGAs) [RFC3972] as the source addresses of secured ND messages.

AERO links must be protected against link-layer address spoofing attacks in which an attacker on the link pretends to be a trusted neighbor. Links that provide link-layer securing mechanisms (e.g., IEEE 802.1X WLANs) and links that provide physical security (e.g., enterprise network wired LANs) provide a first line of defense, however AERO nodes SHOULD also use securing services such as SEND for authentication and network admission control.

AERO Clients MUST ensure that their connectivity is not used by unauthorized nodes on their EUNs to gain access to a protected network, i.e., AERO Clients that act as routers MUST NOT provide routing services for unauthorized nodes. (This concern is no different than for ordinary hosts that receive an IP address delegation but then "share" the address with other nodes via some form of Internet connection sharing such as tethering.)

AERO Clients, Servers and Relays on the open Internet are susceptible to the same attack profiles as for any Internet nodes. For this reason, IP security SHOULD be used when AERO is employed over unmanaged/unsecured links using securing mechanisms such as IPsec [RFC4301], IKE [RFC5996] and/or TLS [RFC5246]. In some environments, however, the use of application-layer security from Clients to correspondent nodes (i.e., other Clients and/or Internet nodes) could obviate the need for IP security between AERO Clients, Servers and Relays.

AERO Servers and Relays present targets for traffic amplification DoS attacks. This concern is no different than for widely-deployed VPN security gateways in the Internet, where attackers could send spoofed packets to the gateways at high data rates. This can be mitigated by connecting Relays and Servers over dedicated links with no connections to the Internet and/or when connections to the Internet are only permitted through well-managed firewalls.

Traffic amplification DoS attacks can also target an AERO Client's low data rate links. This is a concern not only for Clients located on the open Internet but also for Clients in secured enclaves. AERO Servers can institute rate limits that protect Clients from receiving packet floods that could DoS low data rate links.

AERO Relays and Servers MUST discard packets with AERO Server Subnet Router Anycast as the source address originating from any node other than a permanent neighbor. This is to avoid a message injection spoofing attack from an off-link attacker.

Security considerations for accepting link-layer ICMP messages and reflected packets are discussed throughout the document.

10. Acknowledgements

Discussions in the IETF, aviation standards communities and private exchanges helped shape some of the concepts in this work. Individuals who contributed insights include Mikael Abrahamsson, Mark Andrews, Fred Baker, Bob Braden, Stewart Bryant, Brian Carpenter, Wojciech Dec, Ralph Droms, Adrian Farrel, Nick Green, Sri Gundavelli, Brian Haberman, Bernhard Haindl, Joel Halpern, Tom Herbert, Sascha Hlusiak, Lee Howard, Andre Kostur, Ted Lemon, Andy Malis, Satoru Matsushima, Tomek Mrugalski, Alexandru Petrescu, Behcet Saikaya, Michal Skorepa, Joe Touch, Bernie Volz, Ryuji Wakikawa, Tony Whyman, Lloyd Wood and James Woodyatt. Members of the IESG also provided valuable input during their review process that greatly improved the document. Special thanks go to Stewart Bryant, Joel Halpern and Brian Haberman for their shepherding guidance during the publication of the AERO first edition.

This work has further been encouraged and supported by Boeing colleagues including Kyle Bae, M. Wayne Benson, Dave Bernhardt, Cam Brodie, Balaguruna Chidambaram, Irene Chin, Bruce Cornish, Claudiu Danilov, Wen Fang, Anthony Gregory, Jeff Holland, Ed King, Gene MacLean III, Rob Muszkiewicz, Sean O'Sullivan, Kent Shuey, Brian Skeen, Mike Slane, Carrie Spiker, Brendan Williams, Julie Wulff, Yueli Yang, Eric Yeh and other members of the BR&T and BIT mobile networking teams. Kyle Bae, Wayne Benson and Eric Yeh are especially acknowledged for implementing the AERO functions as extensions to the public domain OpenVPN distribution.

Earlier works on NBMA tunneling approaches are found in [RFC2529][RFC5214][RFC5569].

Many of the constructs presented in this second edition of AERO are based on the author's earlier works, including:

- The Internet Routing Overlay Network (IRON) [RFC6179][I-D.templin-ironbis]

- Virtual Enterprise Traversal (VET) [RFC5558][I-D.templin-intarea-vet]

- The Subnetwork Encapsulation and Adaptation Layer (SEAL) [RFC5320][I-D.templin-intarea-seal]

- AERO, First Edition [RFC6706]

Note that these works cite numerous earlier efforts that are not also cited here due to space limitations. The authors of those earlier works are acknowledged for their insights.

This work is aligned with the NASA Safe Autonomous Systems Operation (SASO) program under NASA contract number NNA16BD84C.

This work is aligned with the FAA as per the SE2025 contract number DTFAWA-15-D-00030.

This work is aligned with the Boeing Information Technology (BIT) MobileNet program.

This work is aligned with the Boeing Research and Technology (BR&T) autonomous systems networking program.

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Appendix A. AERO Alternate Encapsulations

When GUE encapsulation is not needed, AERO can use common encapsulations such as IP-in-IP [RFC2003][RFC2473][RFC4213], Generic Routing Encapsulation (GRE) [RFC2784][RFC2890] and others. The encapsulation is therefore only differentiated from non-AERO tunnels through the application of AERO control messaging and not through, e.g., a well-known UDP port number.

As for GUE encapsulation, alternate AERO encapsulation formats may require encapsulation layer fragmentation. For simple IP-in-IP encapsulation, an IPv6 fragment header is inserted directly between the inner and outer IP headers when needed, i.e., even if the outer header is IPv4. The IPv6 Fragment Header is identified to the outer IP layer by its IP protocol number, and the Next Header field in the IPv6 Fragment Header identifies the inner IP header version. For GRE encapsulation, a GRE fragment header is inserted within the GRE header [I-D.templin-intarea-grefrag].

Figure 5 shows the AERO IP-in-IP encapsulation format before any fragmentation is applied:

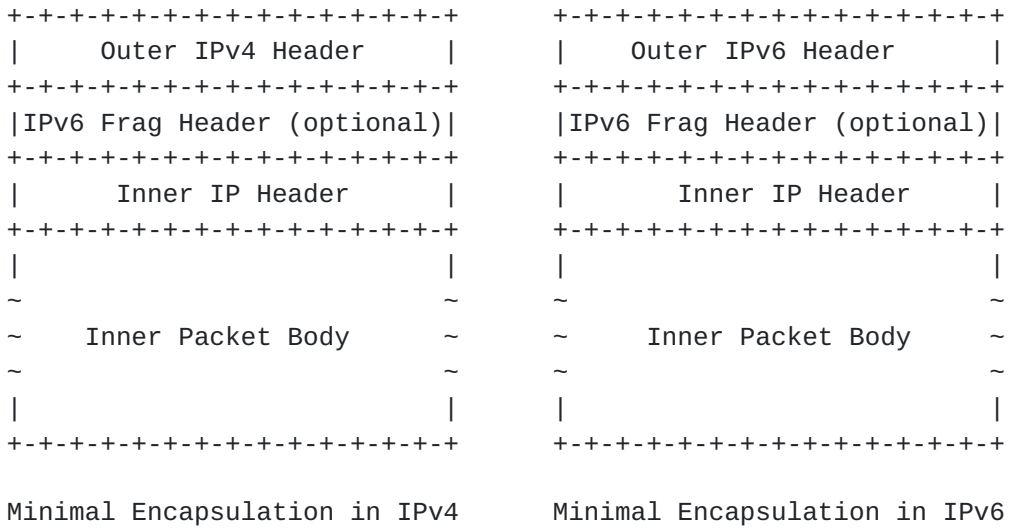

Figure 5: Minimal Encapsulation Format using IP-in-IP

Figure 6 shows the AERO GRE encapsulation format before any fragmentation is applied:

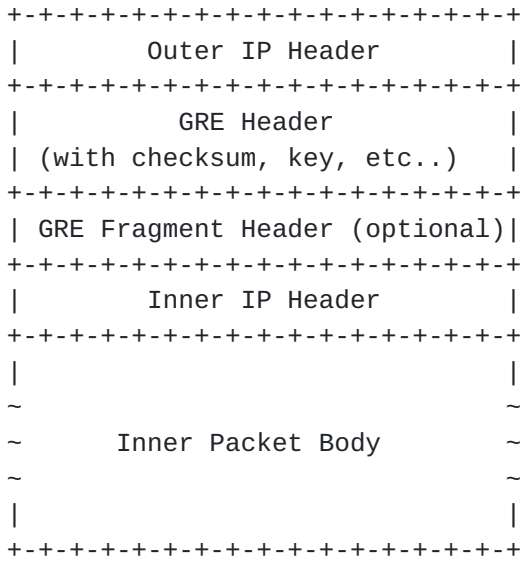

Figure 6: Minimal Encapsulation Using GRE

Alternate encapsulation may be preferred in environments where GUE encapsulation would add unnecessary overhead. For example, certain low-bandwidth wireless data links may benefit from a reduced encapsulation overhead.

GUE encapsulation can traverse network paths that are inaccessible to non-UDP encapsulations, e.g., for crossing Network Address Translators (NATs). More and more, network middleboxes are also being configured to discard packets that include anything other than a well-known IP protocol such as UDP and TCP. It may therefore be necessary to determine the potential for middlebox filtering before enabling alternate encapsulation in a given environment.

In addition to IP-in-IP, GRE and GUE, AERO can also use security encapsulations such as IPsec and SSL/TLS. In that case, AERO control messaging and route determination occur before security encapsulation is applied for outgoing packets and after security decapsulation is applied for incoming packets.

AERO is especially well suited for use with VPN system encapsulations such as OpenVPN [OVPN].

Appendix B. When to Insert an Encapsulation Fragment Header

An encapsulation fragment header is inserted when the AERO tunnel ingress needs to apply fragmentation to accommodate packets that must be delivered without loss due to a size restriction. Fragmentation is performed on the inner packet while encapsulating each inner packet fragment in outer IP and encapsulation layer headers that differ only in the fragment header fields.

The fragment header can also be inserted in order to include a coherent Identification value with each packet, e.g., to aid in Duplicate Packet Detection (DPD). In this way, network nodes can cache the Identification values of recently-seen packets and use the cached values to determine whether a newly-arrived packet is in fact a duplicate. The Identification value within each packet could further provide a rough indicator of packet reordering, e.g., in cases when the tunnel egress wishes to discard packets that are grossly out of order.

In some use cases, there may be operational assurance that no fragmentation of any kind will be necessary, or that only occasional large control messages will require fragmentation. In that case, the encapsulation fragment header can be omitted and ordinary fragmentation of the outer IP protocol version can be applied when necessary.

Appendix C. Autoconfiguration for Constrained Platforms

On some platforms (e.g., popular cell phone operating systems), the act of assigning a default IPv6 route and/or assigning an address to an interface may not be permitted from a user application due to security policy. Typically, those platforms include a TUN/TAP interface [TUNTAP] that acts as a point-to-point conduit between user applications and the AERO interface. In that case, the Client can instead generate a "synthesized RA" message. The message conforms to [RFC4861] and is prepared as follows:

- the IPv6 source address is the Client's AERO address
- the IPv6 destination address is all-nodes multicast
- the Router Lifetime is set to a time that is no longer than the ACP DHCPv6 lifetime
- the message does not include a Source Link Layer Address Option (SLLAO)

- the message includes a Prefix Information Option (PIO) with a /64 prefix taken from the ACP as the prefix for autoconfiguration

The Client then sends the synthesized RA message via the TUN/TAP interface, where the operating system kernel will interpret it as though it were generated by an actual router. The operating system will then install a default route and use StateLess Address AutoConfiguration (SLAAC) to configure an IPv6 address on the TUN/TAP interface. Methods for similarly installing an IPv4 default route and IPv4 address on the TUN/TAP interface are based on synthesized DHCPv4 messages [RFC2131].

Appendix D. Operational Deployment Alternatives

AERO can be used in many different variations based on the specific use case. The following sections discuss variations that adhere to the AERO principles while allowing selective application of AERO components.

D.1. Operation on AERO Links Without DHCPv6 Services

When Servers on the AERO link do not provide DHCPv6 services, operation can still be accommodated through administrative configuration of ACPs on AERO Clients. In that case, administrative configurations of AERO interface neighbor cache entries on both the Server and Client are also necessary. However, this may interfere with the ability for Clients to dynamically change to new Servers, and can expose the AERO link to misconfigurations unless the administrative configurations are carefully coordinated.

D.2. Operation on Server-less AERO Links

In some AERO link scenarios, there may be no Servers on the link and/or no need for Clients to use a Server as an intermediary trust anchor. In that case, each Client acts as a Server unto itself to establish neighbor cache entries by performing direct Client-to-Client IPv6 ND message exchanges, and some other form of trust basis must be applied so that each Client can verify that the prospective neighbor is authorized to use its claimed ACP.

When there is no Server on the link, Clients must arrange to receive ACPs and publish them via a secure alternate PD authority through some means outside the scope of this document.

D.3. Operation on Client-less AERO Links

In some environments, the AERO service may be useful for mobile nodes that do not implement the AERO Client function and do not perform encapsulation. For example, if the mobile node has a way of injecting its ACP into the access subnetwork routing system an AERO Server connected to the same access network can accept the ACP prefix injection as an indication that a new mobile node has come onto the subnetwork. The Server can then inject the ACP into the BGP routing system the same as if an AERO Client/Server PD exchange had occurred. If the mobile node subsequently withdraws the ACP from the access network routing system, the Server can then withdraw the ACP from the BGP routing system.

In this arrangement, AERO Servers and Relays are used in exactly the same ways as for environments where DHCPv6 Client/Server exchanges are supported. However, the access subnetwork routing systems must be capable of accommodating rapid ACP injections and withdrawals from mobile nodes with the understanding that the information must be propagated to all routers in the system. Operational experience has shown that this kind of routing system "churn" can lead to overall instability and routing system inconsistency.

D.4. Manually-Configured AERO Tunnels

In addition to the dynamic neighbor discovery procedures for AERO link neighbors described above, AERO encapsulation can be applied to manually-configured tunnels. In that case, the tunnel endpoints use an administratively-provisioned link-local address and exchange NS/NA messages the same as for dynamically-established tunnels.

D.5. Encapsulation Avoidance on Relay-Server Dedicated Links

In some environments, AERO Servers and Relays may be connected by dedicated point-to-point links, e.g., high speed fiberoptic leased lines. In that case, the Servers and Relays can participate in the AERO link the same as specified above but can avoid encapsulation over the dedicated links. In that case, however, the links would be dedicated for AERO and could not be multiplexed for both AERO and non-AERO communications.

D.6. Encapsulation Protocol Version Considerations

A source Client may connect only to an IPvX underlying network, while the target Client connects only to an IPvY underlying network. In that case, the target and source Clients have no means for reaching each other directly (since they connect to underlying networks of

different IP protocol versions) and so must ignore any route optimization messages and continue to send packets via their Servers.

D.7. Extending AERO Links Through Security Gateways

When an enterprise mobile node moves from a campus LAN connection to a public Internet link, it must re-enter the enterprise via a security gateway that has both a physical interface connection to the Internet and a physical interface connection to the enterprise internetwork. This most often entails the establishment of a Virtual Private Network (VPN) link over the public Internet from the mobile node to the security gateway. During this process, the mobile node supplies the security gateway with its public Internet address as the link-layer address for the VPN. The mobile node then acts as an AERO Client to negotiate with the security gateway to obtain its ACP.

In order to satisfy this need, the security gateway also operates as an AERO Server with support for AERO Client proxying. In particular, when a mobile node (i.e., the Client) connects via the security gateway (i.e., the Server), the Server provides the Client with an ACP in a PD exchange the same as if it were attached to an enterprise campus access link. The Server then replaces the Client's link-layer source address with the Server's enterprise-facing link-layer address in all AERO messages the Client sends toward neighbors on the AERO link. The AERO messages are then delivered to other nodes on the AERO link as if they were originated by the security gateway instead of by the AERO Client. In the reverse direction, the AERO messages sourced by nodes within the enterprise network can be forwarded to the security gateway, which then replaces the link-layer destination address with the Client's link-layer address and replaces the link-layer source address with its own (Internet-facing) link-layer address.

After receiving the ACP, the Client can send IP packets that use an address taken from the ACP as the network layer source address, the Client's link-layer address as the link-layer source address, and the Server's Internet-facing link-layer address as the link-layer destination address. The Server will then rewrite the link-layer source address with the Server's own enterprise-facing link-layer address and rewrite the link-layer destination address with the target AERO node's link-layer address, and the packets will enter the enterprise network as though they were sourced from a node located within the enterprise. In the reverse direction, when a packet sourced by a node within the enterprise network uses a destination address from the Client's ACP, the packet will be delivered to the security gateway which then rewrites the link-layer destination address to the Client's link-layer address and rewrites the link-layer source address to the Server's Internet-facing link-layer

address. The Server then delivers the packet across the VPN to the AERO Client. In this way, the AERO virtual link is essentially extended *through* the security gateway to the point at which the VPN link and AERO link are effectively grafted together by the link-layer address rewriting performed by the security gateway. All AERO messaging services (including route optimization and mobility signaling) are therefore extended to the Client.

In order to support this virtual link grafting, the security gateway (acting as an AERO Server) must keep static neighbor cache entries for all of its associated Clients located on the public Internet. The neighbor cache entry is keyed by the AERO Client's AERO address the same as if the Client were located within the enterprise internetwork. The neighbor cache is then managed in all ways as though the Client were an ordinary AERO Client. This includes the AERO IPv6 ND messaging signaling for Route Optimization and Neighbor Unreachability Detection.

Note that the main difference between a security gateway acting as an AERO Server and an enterprise-internal AERO Server is that the security gateway has at least one enterprise-internal physical interface and at least one public Internet physical interface. Conversely, the enterprise-internal AERO Server has only enterprise-internal physical interfaces. For this reason security gateway proxying is needed to ensure that the public Internet link-layer addressing space is kept separate from the enterprise-internal link-layer addressing space. This is afforded through a natural extension of the security association caching already performed for each VPN client by the security gateway.

Appendix E. Change Log

Changes from draft-templin-intarea-6706bis-01 to draft-templin-intrea-6706bis-02:

- Note on encapsulation avoidance in Section 4.

Changes from draft-templin-intarea-6706bis-00 to draft-templin-intrea-6706bis-01:

- Remove DHCPv6 Server Release procedures that leveraged the old way Relays used to "route" between Server link-local addresses

- Remove all text relating to Relays needing to do any AERO-specific operations

- Proxy sends RS and receives RA from Server using SEND. Use CGAs as source addresses, and destination address of RA reply is to the AERO address corresponding to the Client's ACP.

- Proxy uses SEND to protect RS and authenticate RA (Client does not use SEND, but rather relies on subnetwork security. When the Proxy receives an RS from the Client, it creates a new RS using its own addresses as the source and uses SEND with CGAs to send a new RS to the Server.

- Emphasize distributed mobility management

- AERO address-based RS injection of ACP into underlying routing system.

Changes from draft-templin-aerolink-82 to draft-templin-intarea-6706bis-00:

- Document use of NUD (NS/NA) for reliable link-layer address updates as an alternative to unreliable unsolicited NA. Consistent with Section 7.2.6 of RFC4861.

- Server adds additional layer of encapsulation between outer and inner headers of NS/NA messages for transmission through Relays that act as vanilla IPv6 routers. The messages include the AERO Server Subnet Router Anycast address as the source and the Subnet Router Anycast address corresponding to the Client's ACP as the destination.

- Clients use Subnet Router Anycsat address as the encapsulation source address when the access network does not provide a topologically-fixed address.

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