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Transmission of IPv6 Packets over Aeronautical ("aero") Interfaces
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Abstract

Mobile nodes (e.g., aircraft of various configurations) communicate with networked correspondents over multiple access network data links and configure mobile routers to connect their on-board networks. Mobile nodes connect to access networks using either the classic or mobility service-enabled link model. This document specifies the transmission of IPv6 packets over aeronautical ("aero") interfaces.

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1. Introduction

Mobile Nodes (MNs) such as aircraft of various configurations may have multiple data links for communicating with networked correspondents. These data links often have differing performance, cost and availability characteristics that can change dynamically according to mobility patterns, flight phases, proximity to infrastructure, etc.

Each MN receives an IPv6 Mobile Network Prefix (MNP) that can be used by on-board networks regardless of the access network data links selected for data transport. The MN performs router discovery the same as for customer edge routers [RFC7084], and acts as a mobile router on behalf of its on-board networks. The MN connects to access networks using either the classic [RFC4861] or Mobility Service (MS)-enabled link model.

In the classic model, all IPv6 Neighbor Discovery (IPv6 ND) messaging is directly over native access network interfaces managed according

to the weak end system model. The MN discovers neighbors on the link through link-scoped multicast and/or unicast transmissions that map to their corresponding link layer addresses per standard address resolution / mapping procedures. The MN then coordinates with mobility agents located in the larger Internetwork beyond the first-hop access links according the on-board mobility function. This arrangement requires the MN to engage in active mobility messaging on its own behalf and with no assistance from the access network.

In the MS-enabled model, a virtual interface (termed the "aero interface") is configured as a thin layer over the underlying access network interfaces. The aero interface is therefore the only interface abstraction exposed to the IPv6 layer and behaves according to the Non-Broadcast, Multiple Access (NBMA) interface principle, while underlying access network interfaces appear as link layer communication channels in the architecture. The aero interface connects to a virtual overlay cloud service known as the "aero link".

Each aero link has one or more associated Mobility Service Prefixes (MSPs) that identify the link. An MSP is an aggregated IPv6 prefix from which aero link MNPs are derived. If the MN connects to multiple aero links, then it configures a separate aero interface for each link.

The aero interface interacts with the ground-domain MS through IPv6 ND control message exchanges [RFC4861]. The MS tracks MN movements and represents their MNPs in a global routing or mapping system.

The aero interface provides a traffic engineering nexus for guiding inbound and outbound traffic to the correct underlying interface(s). The IPv6 layer sees the aero interface as a point of connection to the aero link; if there are multiple aero links (i.e., multiple MS's), the IPv6 layer will see multiple aero interfaces.

This document specifies the transmission of IPv6 packets [RFC8200] and MN/MS control messaging over aeronautical ("aero") interfaces in the MS-enabled link model, but also includes all necessary details for MN operation in the classic link model.

2. Terminology

The terminology in the normative references applies; especially, the terms "link" and "interface" are the same as defined in the IPv6 [RFC8200] and IPv6 Neighbor Discovery (ND) [RFC4861] specifications.

The following terms are defined within the scope of this document:

Access Network (ANET)

a data link service network (e.g., an aviation radio access network, satellite service provider network, cellular operator network, etc.) protected by physical and/or link layer security. Each ANET connects to outside Internetworks via border security devices such as proxys, firewalls, packet filtering gateways, etc.

ANET interface
a node's attachment to a link in an ANET.

Internetwork (INET)
a connected network region with a coherent IP addressing plan that provides transit forwarding services for ANET mobile nodes and INET correspondents. Examples include private enterprise networks, aviation networks and the global public Internet itself.

INET interface
a node's attachment to a link in an INET.

aero link
a virtual overlay cloud service configured over one or more INETs and their connected ANETs. An aero link may comprise multiple segments joined by bridges the same as for any link; the addressing plans in each segment may be mutually exclusive and managed by different administrative entities.

aero interface
a node's attachment to an aero link, and configured over one or more underlying ANET/INET interfaces.

aero address
an IPv6 link-local address constructed as specified in Section 7, and assigned to an aero interface.

3. Requirements

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.

4. Aeronautical ("aero") Interface Model

An aero interface is a MN virtual interface configured over one or more ANET interfaces, which may be physical (e.g., an aeronautical radio link) or virtual (e.g., an Internet or higher-layer "tunnel"). The MN coordinates with the MS through IPv6 ND message exchanges.

The aero interface architectural layering model is the same as in [RFC7847], and augmented as shown in Figure 1. The IPv6 layer therefore sees the aero interface as a single network layer interface with multiple underlying ANET interfaces that appear as link layer communication channels in the architecture.

```
                                  +----------------------------+
                                  |          TCP/UDP           |
          Session-to-IP     +---->|                            |
          Address Binding   |     +----------------------------+
                            +---->|            IPv6            |
          IP Address        +---->|                            |
          Binding           |     +----------------------------+
                            +---->|       aero Interface       |
          Logical-to-       +---->|       (aero address)       |
          Physical          |     +----------------------------+
          Interface         +---->|  L2  |  L2  |       |  L2  |
          Binding                 |(IF#1)|(IF#2)| ..... |(IF#n)|
                                  +------+------+       +------+
                                  |  L1  |  L1  |       |  L1  |
                                  |      |      |       |      |
                                  +------+------+       +------+
```

Figure 1: Aero Interface Architectural Layering Model

The aero virtual interface model gives rise to a number of opportunities:

o since aero interface link-local addresses are uniquely derived from an MNP (see: Section 7, no Duplicate Address Detection (DAD) messaging is necessary over the aero interface.

o ANET interfaces can remain unnumbered in environments where communications are coordinated entirely over the aero interface.

o as ANET interface properties change (e.g., link quality, cost, availability, etc.), any active ANET interface can be used to update the profiles of multiple additional ANET interfaces in a single message. This allows for timely adaptation and service continuity under dynamically changing conditions.

o coordinating ANET interfaces in this way allows them to be represented in a unified MS profile with provisions for mobility and multilink operations.

o exposing a single virtual interface abstraction to the IPv6 layer allows for traffic engineering (including QoS based link selection, packet replication, load balancing, etc.) at the link

layer while still permitting queuing at the IPv6 layer based on, e.g., traffic class, flow label, etc.

- the IPv6 layer sees the aero interface as a point of connection to the aero link; if there are multiple aero links (i.e., multiple MS's), the IPv6 layer will see multiple aero interfaces.

Other opportunities are discussed in [RFC7847].

5. Maximum Transmission Unit

The aero interface and all underlying ANET interfaces MUST configure an MTU of at least 1280 bytes as required for all IPv6 interfaces [RFC8200]. The aero interface SHOULD configure an MTU based on the largest MTU among all ANET interfaces. If the aero interface receives a IPv6 ND Router Advertisement (RA) message with an MTU option, it configures this new value regardless of any ANET interface MTUs.

The aero interface can return internally-generated ICMPv6 "Packet Too Big" messages for packets that fit within the aero interface MTU but are too large for the selected underlying ANET interface. This ensures that the MTU is adaptive and reflects the ANET interface used for a given data flow.

Underlying ANET interfaces can employ link-layer fragmentation at a layer below IPv6 so that packets as large as the aero interface MTU can be accommodated. This ensures that no packets are lost due to a size restriction in either the uplink or downlink direction.

6. Frame Format

The aero interface transmits IPv6 packets according to the native frame format of each underlying ANET interface. For example, for Ethernet-compatible interfaces the frame format is specified in [RFC2464], for aeronautical radio interfaces the frame format is specified in standards such as ICAO Doc 9776 (VDL Mode 2 Technical Manual), for tunnels over IPv6 the frame format is exactly as specified in [RFC2473], etc.

7. Link-Local Addresses

A MN "aero address" is an IPv6 link-local address with an interface identifier based on its assigned MNP. MN aero addresses begin with the prefix fe80::/64 followed by a 64-bit prefix taken from the MNP (see: Appendix B). For example, for the MNP:

    2001:db8:1000:2000::/56

the corresponding aero addresses are:

fe80::2001:db8:1000:2000

fe80::2001:db8:1000:2001

fe80::2001:db8:1000:2002

... etc. ...

fe80::2001:db8:1000:20ff

When the MN configures aero addresses from its MNP, it assigns them to each ANET interface (and also to the Aero interface in the MS-enabled model). The lowest-numbered aero address serves as the "base" address (for example, for the MNP 2001:db8:1000:2000::/56 the base aero address is fe80::2001:db8:1000:2000). The MN uses the base aero address for IPv6 ND messaging, but accepts packets destined to all aero addresses equally (i.e., the same as for any multi-addressed IPv6 interface).

In the MS-enabled link model, MS endpoint (MSE) aero addresses are allocated from the range fe80::/96, and MUST be managed for uniqueness by the collective aero link administrative authorities. The lower 32 bits of the address includes a unique integer value, e.g., fe80::1, fe80::2, fe80::3, etc. The address fe80:: is reserved as the IPv6 link-local Subnet Router Anycast address [RFC4291], and the address fe80::ffff:ffff is reserved as the MSE discovery address; hence, these values are not available for general assignment.

In the classic link model, ANET link devices number their interface from the range fe80::/96 the same as above except that these addresses need not be managed for uniqueness outside of the local ANET link. It is therefore possible that different ANET links could reuse numbers from the fe80::/96 space since the addresses are link-scope only.

In a mixed model, both the classic and MS-enabled numbering schemes can be used without conflict within the same ANET, as the two services would be conducted as ships in the night. A mix of MNs operating according to classic and MS-enabled models could then operate within the same ANETs without interference.

Since MN aero addresses are guaranteed unique by the nature of the unique MNP delegation, aero interfaces set the autoconfiguration variable DupAddrDetectTransmits to 0 [RFC4862].

8. Address Mapping - Unicast

Aero interfaces maintain a neighbor cache for tracking per-neighbor state the same as for any IPv6 interface and use the link-local address format specified in Section 7. IPv6 Neighbor Discovery (ND) [RFC4861] messages on aero interfaces use the native Source/Target Link-Layer Address Option (S/TLLAO) formats of the underlying ANET interfaces (e.g., for Ethernet the S/TLLAO is specified in [RFC2464]).

MNs such as aircraft typically have many wireless data link types (e.g. satellite-based, cellular, terrestrial, air-to-air directional, etc.) with diverse performance, cost and availability properties. The aero interface would therefore appear to have multiple link layer connections, and may include information for multiple ANET interfaces in a single message exchange.

Aero interfaces use a new IPv6 ND options called the "Aero Registration (AR)" option (type TBD). MNs include the AR option in Router Solicitation (RS) and/or unsolicited Neighbor Advertisement (uNA) messages to request registration/deregistration, and the MS includes the AR option in Router Advertisement (RA) messages to acknowledge the MN's registration/deregistration.

MNs send RS/uNA messages that include AR options formatted as shown in Figure 2:

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |      Type     |     Length    | Prefix Length |R|  Reserved   |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                             Nonce                             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |           ifIndex [1]         |P00|P01|P02|P03|P04|P05|P06|P07|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P08|P09|P10|P11|P12|P13|P14|P15|P16|P17|P18|P19|P20|P21|P22|P23|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P24|P25|P26|P27|P28|P29|P30|P31|P32|P33|P34|P35|P36|P37|P38|P39|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P40|P41|P42|P43|P44|P45|P46|P47|P48|P49|P50|P51|P52|P53|P54|P55|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P56|P57|P58|P59|P60|P61|P62|P63|           ifIndex [2]         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P00|P01|P02|P03|P04|P05|P06|P07|P08|P09|P10|P11|P12|P13|P14|P15|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P16|P17|P18|P19|P20|P21|P22|P23|P24|P25|P26|P27|P28|P29|P30|P31|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P32|P33|P34|P35|P36|P37|P38|P39|P40|P41|P42|P43|P44|P45|P46|P47|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P48|P49|P50|P51|P52|P53|P54|P55|P56|P57|P58|P59|P60|P61|P62|P63|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   ...
   ...                             +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   ...                             |           ifIndex [N]         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P00|P01|P02|P03|P04|P05|P06|P07|P08|P09|P10|P11|P12|P13|P14|P15|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P16|P17|P18|P19|P20|P21|P22|P23|P24|P25|P26|P27|P28|P29|P30|P31|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P32|P33|P34|P35|P36|P37|P38|P39|P40|P41|P42|P43|P44|P45|P46|P47|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |P48|P49|P50|P51|P52|P53|P54|P55|P56|P57|P58|P59|P60|P61|P62|P63|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
           ... (0 - 6 octets of trailing zero padding) ...
```

Figure 2: Aero Registration (AR) Option Format in RS/uNA Messages

In this format:

- o Type is set to TBD.

- o Length is set to the value (2.25*N + 1), where N is the number of ifIndex tuples. Length is incremented to the next highest integer

value, and 0-6 octets of trailing zero padding are added to the end of the option to produce an integral number of 8-octet units.

o Prefix Length is set to the length of the MNP embedded in the MN's aero address.

o R is set to '1' to request registration or set to '0' to request de-registration.

o Reserved is set to the value '0' on transmission.

o Nonce is set to a (pseudo)-random 32-bit value selected by the MN, and used to correlate received confirmations.

o A list of N (ifIndex[i], P[i])-tuples are included as follows:

  * ifIndex[i] [RFC2863] is set to a 16-bit integer value corresponding to a specific underlying ANET interface. The first ifIndex MUST correspond to the ANET interface over which the message is sent. Once the MN has assigned an ifIndex to an ANET interface, the assignment MUST remain unchanged until the MN disables the interface. MNs MUST number each ifIndex with a value between '1' and '0xffff'.

  * P[i] is a per-ifIndex set of Preferences that correspond to the 64 Differentiated Service Code Point (DSCP) values [RFC2474] pertaining to the ANET interface. Each (P00 - P63) field is set to the value '0' ("disabled"), '1' ("low"), '2' ("medium") or '3' ("high") to indicate a QoS preference level for ANET interface selection purposes.

The MS sends corresponding RA messages with AR options formatted as shown in Figure 3:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Type     |  Length = 2   | Prefix Length |R|  Reserved   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                             Nonce                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Prefix Lifetime                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Reserved                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: Aero Registration (AR) Option Format in RA messages

In this format:

- o Type is set to TBD.
- o Length is set to the constant value '2' (i.e., 2 units of 8 octets).
- o Prefix Length is set to the length included in the AR option of the RS message that triggered the RA response.
- o R is set to '1' to confirm registration or set to '0' to release/ decline registration.
- o Reserved is set to the value '0' on transmission.
- o Nonce echoes the 32 bit value received in the AR option of the corresponding RS message.
- o Prefix Lifetime is set to the time in seconds that the MSE will maintain the Prefix registration.

9. Address Mapping - Multicast

The multicast address mapping of the native underlying ANET interface applies. The mobile router on board the aircraft also serves as an IGMP/MLD Proxy for its EUNs and/or hosted applications per [RFC4605] while using the link layer address of the router as the link layer address for all multicast packets.

10. Address Mapping for IPv6 Neighbor Discovery Messages

As discussed in [RFC4861], IPv6 ND messages may be sent to either a multicast or unicast link-scoped IPv6 destination address. For aero interfaces in the MS-enabled model, however, IPv6 ND messaging must be coordinated between the MN and MS only without invoking other nodes on the ANET.

For this reason, each ANET link type is required to reserve a fixed unicast link-layer address ("MSADDR") for the purpose of supporting MN/MS IPv6 ND messaging the same as in [RFC6543]. For Ethernet-compatible ANETs, this specification reserves one Ethernet unicast address 00-00-5E-00-52-14. For non-Ethernet ANETs, MSADDR is reserved per the assigned numbers authority for the ANET addressing space.

MNs operating according to the MS-enabled model map all IPv6 ND messages they send (i.e., both multicast and unicast) to MSADDR instead of to an ordinary unicast or multicast link-layer address.

In this way, all of the MN's IPv6 ND messages will be received by MS devices that are configured to accept packets destined to MSADDR (i.e., a point-to-point neighbor model). Note that multiple MS devices on the link could be configured to accept packets destinted to MSADDR. Though out of scope for this document, such an arrangement could provide basis for virtual router redundancy.

Therefore, ANET MS devices MUST accept and process packets destined to MSADDR, while all other devices MUST NOT process packets destined to MSADDR. In this arrangement MNs operating according to the MS-enabled model have assurance that their IPv6 ND messages will be handled only by the MS, and will not corrupt the neighbor caches of classic devices and/or MNs on the link. This model has a well-established operational experience in Proxy Mobile IPv6 (PMIP) [RFC5213].

11. Conceptual Sending Algorithm

The MN's IPv6 layer selects the outbound aero interface according to standard IPv6 requirements. The aero interface maintains default routes and neighbor cache entries for MSEs, and may also include additional neighbor cache entries created through other means (e.g., Address Resolution, static configuration, etc.).

When the MN sends packets, it may receive a Redirect message the same as for any IPv6 interface. When the MN uses Address Resolution, the aero interface forwards NS messages to an MSE (see: Section 12) which acts as a link-layer forwarding agent according to the NBMA link model. The resulting NA message will provide link-layer address information for the neighbor. When Neighbor Unreachability Detection is used, the NS/NA exchange confirms reachability the same as for any IPv6 interface.

After a packet enters the aero interface, an outbound ANET interface is selected based on traffic engineering information such as DSCP, application port number, cost, performance, etc. Aero interface traffic engineering could also be configured to perform replication across multiple ANET interfaces for increased reliability at the expense of packet duplication.

When a target neighbor has multiple link-layer addresses (each with a different traffic engineering profile), the aero interface selects ANET interfaces and neighbor link-layer addresses according to both its own outbound preferences and the inbound preferences of the target neighbor.

11.1. Multiple Aero Interfaces

MNs may associate with multiple MS instances concurrently. Each MS instance represents a distinct aero link distinguished by its associated MSPs. The MN configures a separate aero interface for each link so that multiple interfaces (e.g., aero0, aero1, aero2, etc.) are exposed to the IPv6 layer.

Depending on local policy and configuration, an MN may choose between alternative active aero interfaces using a packet's DSCP, routing information or static configuration. In particular, the MN can add the MSPs received in Prefix Information Options (PIOs) [RFC4861] [RFC8028] as guidance for aero interface selection based on per-packet source addresses.

Each aero interface can be configured over the same or different sets of ANET interfaces. Each ANET distinguishes between the different aero links based on the MSPs represented in per-packet IPv6 addresses.

Multiple distinct aero links can therefore be used to support fault tolerance, load balancing, reliability, etc. The architectural model parallels Layer 2 Virtual Local Area Networks (VLANs), where the MSPs serve as (virtual) VLAN tags.

12. Router Discovery and Prefix Assertion

ANET access routers accept packets destined to the link-local Subnet Router Anycast Address (fe80::). ANET access routers that support the classic link model configure link-local addresses that are guaranteed not to conflict with MN link-local addresses as discussed in Section 7. ANET access routers that support the MS-enabled model configure the link-layer address MSADDR (see: Section 10) and act as proxies for all MSEs from the range fe80::1 through fe80::ffff:fffe.

MNs that support the classic model perform ordinary RS/RA exchanges over each ANET the same as for ordinary IPv6 links. ANET access routers send RAs with an IPv6 link-local source address from the range fe80::1 through fe80::ffff:fffe that is guaranteed not to conflict with the MN's aero address nor the address of any other routers on the link. The MNs are then responsible for coordinating their ANET interfaces on their own behalf and for coordinating with any INET-based mobility agents. No further support from the ANET is needed.

MNs that support the MS-enabled model instead interface with the MS via RS/RA message exchanges that include AR options. For each ANET interface, the MN sends initial RS messages with AR options with

link-layer address set to MSADDR and with network-layer address set to a specific MSE address (or to fe80::ffff:ffff to request the ANET to select an MSE). The ANET access router receives the RS messages and contacts the corresponding MSE. When the MSE responds, the ANET access router returns RA messages with AR options and with any information for the link that would normally be delivered in a solicited RA message.

MNs configure aero interfaces that observe the properties discussed in the previous section. The aero interface and its underlying interfaces are said to be in either the "UP" or "DOWN" state according to administrative actions in conjunction with the interface connectivity status. An aero interface transitions to UP or DOWN through administrative action and/or through state transitions of the underlying interfaces. When a first underlying interface transitions to UP, the aero interface also transitions to UP. When all underlying interfaces transition to DOWN, the aero interface also transitions to DOWN.

When an aero interface transitions to UP, the MN sends initial RS messages to register its MNP and an initial set of underlying ANET interfaces that are also UP. The MN sends additional RS messages to refresh lifetimes and to register/deregister underlying ANET interfaces as they transition to UP or DOWN.

MS-enabled ANET access routers send RA messages with configuration information in response to a MN's RS messages. The RA includes a Router Lifetime value and PIOs with (A; L=0) that include MSPs for the link. The configuration information may also include Route Information Options (RIO) options [RFC4191] with more-specific routes, and an MTU option that specifies the maximum acceptable packet size for the link. The ANET access router sends immediate unicast RA responses without delay; therefore, the 'MAX_RA_DELAY_TIME' and 'MIN_DELAY_BETWEEN_RAS' constants for multicast RAs do not apply. The ANET access router MAY send periodic and/or event-driven unsolicited RA messages, but is not required to do so for unicast advertisements [RFC4861].

The MN sends RS messages from within the aero interface while using an UP underlying ANET interface as the outbound interface. Each RS message is formatted as though it originated from the IPv6 layer, but the process is coordinated wholly from within the aero interface and is therefore opaque to the IPv6 layer. The MN sends initial RS messages over an UP underlying interface with its aero address as the source and the address of an MSE as the destination. The RS messages include AR options with a valid Prefix Length as well as ifIndex and P(i) values appropriate for underlying ANET interfaces. The MS-

enabled ANET access router processes RS message and forwards the information in the AR option to the MSE.

When the MSE processes the AR information, if the prefix registration was accepted the MSE injects the MNP into the routing/mapping system then caches the new Prefix Length, MNP, ifIndex and P(i) values. The MSE then returns a non-zero Prefix Lifetime if the prefix assertion was acceptable; otherwise, with a zero Prefix Lifetime. The ANET access router then returns an RA message to the MN.

When the MN receives the RA message, it creates a default route with next hop address set to the MSE found in the RA source address and with link-layer address set to MSADDR. The ANET access router will then forward packets acting as a proxy between the MN and the actual MSE.

The MN then manages its underlying ANET interfaces according to their states as follows:

o When an underlying ANET interface transitions to UP, the MN sends an RS over the ANET interface with an AR option. The AR option contains a first ifIndex-tuple with values appropriate for this ANET interface, and may contain additional ifIndex-tuples appropriate for other ANET interfaces.

o When an underlying ANET interface transitions to DOWN, the MN sends an RS/uNA message over any UP ANET interface with an AR option containing an ifIndex-tuple for the DOWN ANET interface with all P(i) values set to '0'. The MN sends an RS when an acknowledgement is required, or an uNA when reliability is not thought to be a concern (e.g., if redundant transmissions are sent on multiple ANET interfaces).

o When a MN wishes to release from the current MSE, it sends an RS message over any UP ANET interface with an AR option with R set to 0. The corresponding MSE then withdraws the MNP from the routing/mapping system and returns an RA message with an AR option with Prefix Lifetime set to 0.

o When all of a MNs underlying interfaces have transitioned to DOWN, the MSE withdraws the MNP the same as if it had received a message with an AR option with R set to 0.

The MN is responsible for retrying each RS exchange up to MAX_RTR_SOLICITATIONS times separated by RTR_SOLICITATION_INTERVAL seconds until an RA is received. If no RA is received over multiple UP ANET interfaces, the MN declares this MSE unreachable and tries a different MSE.

The IPv6 layer sees the aero interface as an ordinary IPv6 interface. Therefore, when the IPv6 layer sends an RS message the aero interface returns an internally-generated RA message as though the message originated from an IPv6 router. The internally-generated RA message contains configuration information (such as Router Lifetime, MTU, etc.) that is consistent with the information received from the RAs generated by the MS.

Whether the aero interface IPv6 ND messaging process is initiated from the receipt of an RS message from the IPv6 layer is an implementation matter. Some implementations may elect to defer the IPv6 ND messaging process until an RS is received from the IPv6 layer, while others may elect to initiate the process independently of any IPv6 layer messaging.

13. IANA Considerations

The IANA is instructed to allocate an official number from the IPv6 Neighbor Discovery Option Formats registry for the Aero Registration (TBD) option. Implementations set TBD to 253 as an interim value [RFC4727].

The IANA is instructed to allocate one Ethernet unicast address, 00-00-5E-00-52-14 [RFC5214] in the registry "IANA Ethernet Address Block - Unicast Use".

14. Security Considerations

Security considerations are the same as defined for the specific access network interface types, and readers are referred to the appropriate interface specifications.

IPv6 and IPv6 ND security considerations also apply, and are specified in the normative references.

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16. References

16.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC2474] Nichols, K., Blake, S., Baker, F., and D. Black, "Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers", RFC 2474, DOI 10.17487/RFC2474, December 1998, <https://www.rfc-editor.org/info/rfc2474>.

[RFC4191] Draves, R. and D. Thaler, "Default Router Preferences and More-Specific Routes", RFC 4191, DOI 10.17487/RFC4191, November 2005, <https://www.rfc-editor.org/info/rfc4191>.

[RFC4291] Hinden, R. and S. Deering, "IP Version 6 Addressing Architecture", RFC 4291, DOI 10.17487/RFC4291, February 2006, <https://www.rfc-editor.org/info/rfc4291>.

[RFC4727] Fenner, B., "Experimental Values In IPv4, IPv6, ICMPv4, ICMPv6, UDP, and TCP Headers", RFC 4727, DOI 10.17487/RFC4727, November 2006, <https://www.rfc-editor.org/info/rfc4727>.

[RFC4861] Narten, T., Nordmark, E., Simpson, W., and H. Soliman, "Neighbor Discovery for IP version 6 (IPv6)", RFC 4861, DOI 10.17487/RFC4861, September 2007, <https://www.rfc-editor.org/info/rfc4861>.

[RFC4862] Thomson, S., Narten, T., and T. Jinmei, "IPv6 Stateless Address Autoconfiguration", RFC 4862, DOI 10.17487/RFC4862, September 2007, <https://www.rfc-editor.org/info/rfc4862>.

[RFC8028] Baker, F. and B. Carpenter, "First-Hop Router Selection by Hosts in a Multi-Prefix Network", RFC 8028, DOI 10.17487/RFC8028, November 2016, <https://www.rfc-editor.org/info/rfc8028>.

[RFC8200] Deering, S. and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", STD 86, RFC 8200, DOI 10.17487/RFC8200, July 2017, <https://www.rfc-editor.org/info/rfc8200>.

16.2. Informative References

[RFC2464] Crawford, M., "Transmission of IPv6 Packets over Ethernet Networks", RFC 2464, DOI 10.17487/RFC2464, December 1998, <https://www.rfc-editor.org/info/rfc2464>.

[RFC2473] Conta, A. and S. Deering, "Generic Packet Tunneling in IPv6 Specification", RFC 2473, DOI 10.17487/RFC2473, December 1998, <https://www.rfc-editor.org/info/rfc2473>.

[RFC2863] McCloghrie, K. and F. Kastenholz, "The Interfaces Group MIB", RFC 2863, DOI 10.17487/RFC2863, June 2000, <https://www.rfc-editor.org/info/rfc2863>.

[RFC4605] Fenner, B., He, H., Haberman, B., and H. Sandick, "Internet Group Management Protocol (IGMP) / Multicast Listener Discovery (MLD)-Based Multicast Forwarding ("IGMP/MLD Proxying")", RFC 4605, DOI 10.17487/RFC4605, August 2006, <https://www.rfc-editor.org/info/rfc4605>.

[RFC5213] Gundavelli, S., Ed., Leung, K., Devarapalli, V., Chowdhury, K., and B. Patil, "Proxy Mobile IPv6", RFC 5213, DOI 10.17487/RFC5213, August 2008, <https://www.rfc-editor.org/info/rfc5213>.

[RFC5214] Templin, F., Gleeson, T., and D. Thaler, "Intra-Site Automatic Tunnel Addressing Protocol (ISATAP)", RFC 5214, DOI 10.17487/RFC5214, March 2008, <https://www.rfc-editor.org/info/rfc5214>.

[RFC6543] Gundavelli, S., "Reserved IPv6 Interface Identifier for Proxy Mobile IPv6", RFC 6543, DOI 10.17487/RFC6543, May 2012, <https://www.rfc-editor.org/info/rfc6543>.

[RFC7084] Singh, H., Beebee, W., Donley, C., and B. Stark, "Basic Requirements for IPv6 Customer Edge Routers", RFC 7084, DOI 10.17487/RFC7084, November 2013, <https://www.rfc-editor.org/info/rfc7084>.

[RFC7421] Carpenter, B., Ed., Chown, T., Gont, F., Jiang, S., Petrescu, A., and A. Yourtchenko, "Analysis of the 64-bit Boundary in IPv6 Addressing", RFC 7421, DOI 10.17487/RFC7421, January 2015, <https://www.rfc-editor.org/info/rfc7421>.

[RFC7847] Melia, T., Ed. and S. Gundavelli, Ed., "Logical-Interface Support for IP Hosts with Multi-Access Support", RFC 7847, DOI 10.17487/RFC7847, May 2016, <https://www.rfc-editor.org/info/rfc7847>.

Appendix A. Aero Option Extensions for Special-Purpose Links

The aero option format specified in Section 8 includes a Length value of 3 (i.e., 3 units of 8 octets). However, special-purpose aero links may extend the basic format to include additional fields and a Length value larger than 3.

For example, adaptation of the aero interface to the Aeronautical Telecommunications Network with Internet Protocol Services (ATN/IPS) includes link selection preferences based on transport port numbers in addition to the existing DSCP-based preferences. ATN/IPS nodes maintain a map of transport port numbers to 64 possible preference fields, e.g., TCP port 22 maps to preference field 8, TCP port 443 maps to preference field 20, UDP port 8060 maps to preference field 34, etc. The extended aero option format for ATN/IPS is shown in Figure 4, where the Length value is 7 and the 'Q(i)' fields provide link preferences for the corresponding transport port number.

```
        0                   1                   2                   3
        0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |      Type     |  Length = 5   | Prefix Length |S|R|D| Reserved|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |            ifIndex            |           Reserved            |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |P00|P01|P02|P03|P04|P05|P06|P07|P08|P09|P10|P11|P12|P13|P14|P15|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |P16|P17|P18|P19|P20|P21|P22|P23|P24|P25|P26|P27|P28|P29|P30|P31|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |P32|P33|P34|P35|P36|P37|P38|P39|P40|P41|P42|P43|P44|P45|P46|P47|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |P48|P49|P50|P51|P52|P53|P54|P55|P56|P57|P58|P59|P60|P61|P62|P63|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |Q00|Q01|Q02|Q03|Q04|Q05|Q06|Q07|Q08|Q09|Q10|Q11|Q12|Q13|Q14|Q15|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |Q16|Q17|Q18|Q19|Q20|Q21|Q22|Q23|Q24|Q25|Q26|Q27|Q28|Q29|Q30|Q31|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |Q32|Q33|Q34|Q35|Q36|Q37|Q38|Q39|Q40|Q41|Q42|Q43|Q44|Q45|Q46|Q47|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |Q48|Q49|Q50|Q51|Q52|Q53|Q54|Q55|Q56|Q57|Q58|Q59|Q60|Q61|Q62|Q63|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4: ATN/IPS Extended Aero Option Format

Appendix B. Prefix Length Considerations

The IPv6 addressing architecture [RFC4291] reserves the prefix ::/8; this assures that MNPs will not begin with ::32 so that MN and MS aero addresses cannot overlap. Additionally, this specification currently observes the 64-bit boundary in IPv6 addresses [RFC7421].

MN aero addresses insert the most-significant 64 MNP bits into the least-significant 64 bits of the prefix fe80::/64, however [RFC4291] defines the link-local prefix as fe80::/10 meaning "fe80" followed by 54 unused bits followed by the least-significant 64 bits of the address. Future versions of this specification may adapt the 54 unused bits for extended coding of MNP prefixes of /65 or longer (up to /118).

Appendix C. Change Log

<< RFC Editor - remove prior to publication >>

Differences from draft-templin-atn-aero-interface-04 to draft-templin-atn-aero-interface-05:

o Introduced RFC6543 precedent for focusing IPv6 ND messaging to a reserved unicast link-layer address

o Introduced new IPv6 ND option for Aero Registration

o Specification of MN-to-MSE message exchanges via the ANET access router as a proxy

o IANA Considerations updated to include registration requests and set interim RFC4727 option type value.

Differences from draft-templin-atn-aero-interface-03 to draft-templin-atn-aero-interface-04:

o Removed MNP from aero option format - we already have RIOs and PIOs, and so do not need another option type to include a Prefix.

o Clarified that the RA message response must include an aero option to indicate to the MN that the ANET provides a MS.

o MTU interactions with link adaptation clarified.

Differences from draft-templin-atn-aero-interface-02 to draft-templin-atn-aero-interface-03:

o Sections re-arranged to match RFC4861 structure.

o Multiple aero interfaces

o Conceptual sending algorithm

Differences from draft-templin-atn-aero-interface-01 to draft-templin-atn-aero-interface-02:

o Removed discussion of encapsulation (out of scope)

o Simplified MTU section

o Changed to use a new IPv6 ND option (the "aero option") instead of S/TLLAO

o Explained the nature of the interaction between the mobility management service and the air interface

Differences from draft-templin-atn-aero-interface-00 to draft-templin-atn-aero-interface-01:

- o Updates based on list review comments on IETF 'atn' list from 4/29/2019 through 5/7/2019 (issue tracker established)

- o added list of opportunities afforded by the single virtual link model

- o added discussion of encapsulation considerations to Section 6

- o noted that DupAddrDetectTransmits is set to 0

- o removed discussion of IPv6 ND options for prefix assertions. The aero address already includes the MNP, and there are many good reasons for it to continue to do so. Therefore, also including the MNP in an IPv6 ND option would be redundant.

- o Significant re-work of "Router Discovery" section.

- o New Appendix B on Prefix Length considerations

First draft version (draft-templin-atn-aero-interface-00):

- o Draft based on consensus decision of ICAO Working Group I Mobility Subgroup March 22, 2019.

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