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Transmission of IPv6 Packets over Overlay Multilink Network (OMNI) Interfaces
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Abstract

Mobile nodes (e.g., aircraft of various configurations, terrestrial vehicles, seagoing vessels, mobile enterprise devices, etc.) communicate with networked correspondents over multiple access network data links and configure mobile routers to connect end user networks. A multilink interface specification is therefore needed for coordination with the network-based mobility service. This document specifies the transmission of IPv6 packets over Overlay Multilink Network (OMNI) Interfaces.

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1. Introduction

Mobile Nodes (MNs) (e.g., aircraft of various configurations, terrestrial vehicles, seagoing vessels, mobile enterprise devices, etc.) often have multiple data links for communicating with networked correspondents. These data links may have diverse performance, cost and availability properties that can change dynamically according to mobility patterns, flight phases, proximity to infrastructure, etc. MNs coordinate their data links in a discipline known as "multilink", in which a single virtual interface is configured over the underlying data link interfaces.

The MN configures a virtual interface (termed the "Overlay Multilink Network (OMNI) interface") as a thin layer over the underlying access network interfaces. The OMNI 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 OMNI interface connects to a virtual overlay service known as the "OMNI link". The OMNI link spans a worldwide Internetwork that may include private-use infrastructures and/or the global public Internet itself.

Each MN receives a Mobile Network Prefix (MNP) for numbering downstream-attached End User Networks (EUNs) independently of the access network data links selected for data transport. The MN performs router discovery over the OMNI interface (i.e., similar to IPv6 customer edge routers [RFC7084]) and acts as a mobile router on behalf of its EUNs. The router discovery process is iterated over each of the OMNI interface's underlying access network data links in order to register per-link parameters (see Section 12).

The OMNI interface provides a multilink nexus for exchanging inbound and outbound traffic via the correct underlying Access Network (ANET) interface(s). The IPv6 layer sees the OMNI interface as a point of connection to the OMNI link. Each OMNI link has one or more associated Mobility Service Prefixes (MSPs) from which OMNI link MNPs are derived. If there are multiple OMNI links, the IPv6 layer will see multiple OMNI interfaces.

The OMNI interface interacts with a network-based Mobility Service (MS) through IPv6 Neighbor Discovery (ND) control message exchanges [RFC4861]. The MS provides Mobility Service Endpoints (MSEs) that track MN movements and represent their MNPs in a global routing or mapping system.

This document specifies the transmission of IPv6 packets [RFC8200] and MN/MS control messaging over OMNI interfaces.

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. Also, the Protocol Constants defined in Section 10 of [RFC4861] are used in their same format and meaning in this document.

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

Mobile Node (MN)

an end system with multiple distinct upstream data link connections that are managed together as a single logical unit. The MN's data link connection parameters can change over time due to, e.g., node mobility, link quality, etc. The MN further connects a downstream-attached End User Network (EUN). The term MN used here is distinct from uses in other documents, and does not imply a particular mobility protocol.

End User Network (EUN)
a simple or complex downstream-attached mobile network that travels with the MN as a single logical unit. The IPv6 addresses assigned to EUN devices remain stable even if the MN's upstream data link connections change.

Mobility Service (MS)
a mobile routing service that tracks MN movements and ensures that MNs remain continuously reachable even across mobility events. Specific MS details are out of scope for this document.

Mobility Service Prefix (MSP)
an aggregated IPv6 prefix (e.g., 2001:db8::/32) advertised to the rest of the Internetwork by the MS, and from which more-specific Mobile Network Prefixes (MNPs) are derived.

Mobile Network Prefix (MNP)
a longer IPv6 prefix taken from the MSP (e.g., 2001:db8:1000:2000::/56) and assigned to a MN. MNs sub-delegate the MNP to devices located in EUNs.

Access Network (ANET)
a data link service network (e.g., an aviation radio access network, satellite service provider network, cellular operator network, etc.) that provides an Access Router (AR) for connecting MNs to correspondents in outside Internetworks. Physical and/or data link level security between the MN and AR are assumed.

ANET interface
a MN'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 MNs and INET correspondents. Examples include private enterprise networks, ground domain aviation service networks and the global public Internet itself.

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

OMNI link
a virtual overlay configured over one or more INETs and their connected ANETs. An OMNI link can comprise multiple INET 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.

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

OMNI link local address (LLA)
an IPv6 link-local address constructed as specified in Section 7, and assigned to an OMNI interface.

Multilink
an OMNI interface's manner of managing diverse underlying data link interfaces as a single logical unit. The OMNI interface provides a single unified interface to upper layers, while underlying data link selections are performed on a per-packet basis considering factors such as DSCP, flow label, application policy, signal quality, cost, etc. Multilinking decisions are coordinated in both the outbound (i.e. MN to correspondent) and inbound (i.e., correspondent to MN) directions.

L2
The second layer in the OSI network model. Also known as "layer-2", "link-layer", "sub-IP layer", "data link layer", etc.

L3
The third layer in the OSI network model. Also known as "layer-3", "network-layer", "IPv6 layer", etc.

3. Requirements

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119][RFC8174] when, and only when, they appear in all capitals, as shown here.

4. Overlay Multilink Network (OMNI) Interface Model

An OMNI 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 receives a MNP from the MS, and coordinates with the MS through IPv6 ND message exchanges. The MN uses the MNP to construct

a unique OMNI LLA through the algorithmic derivation specified in Section 7 and assigns the LLA to the OMNI interface.

The OMNI interface architectural layering model is the same as in [RFC7847], and augmented as shown in Figure 1. The IP layer (L3) therefore sees the OMNI interface as a single network layer interface with multiple underlying ANET interfaces that appear as L2 communication channels in the architecture.

```
                                  +----------------------------+
                                  |    Upper Layer Protocol    |
           Session-to-IP    +---->|                            |
           Address Binding  |     +----------------------------+
                            +---->|           IP (L3)          |
           IP Address       +---->|                            |
           Binding          |     +----------------------------+
                            +---->|       OMNI Interface       |
           Logical-to-      +---->|         (OMNI LLA)         |
           Physical         |     +----------------------------+
           Interface        +---->|  L2  |  L2  |       |  L2  |
           Binding                |(IF#1)|(IF#2)| ..... |(IF#n)|
                                  +------+------+       +------+
                                  |  L1  |  L1  |       |  L1  |
                                  |      |      |       |      |
                                  +------+------+       +------+
```

Figure 1: OMNI Interface Architectural Layering Model

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

o since OMNI LLAs are uniquely derived from an MNP, no Duplicate Address Detection (DAD) messaging is necessary over the OMNI interface.

o ANET interfaces do not require any L3 addresses (i.e., not even link-local) in environments where communications are coordinated entirely over the OMNI 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 multilink operation (including QoS based link selection, packet replication, load balancing, etc.) at L2 while still permitting queuing at the L3 based on, e.g., DSCP, flow label, etc.

- o L3 sees the OMNI interface as a point of connection to the OMNI link; if there are multiple OMNI links (i.e., multiple MS's), L3 will see multiple OMNI interfaces.

Other opportunities are discussed in [RFC7847].

Figure 2 depicts the architectural model for a MN connecting to the MS via multiple independent ANETs. When an ANET interface becomes active, the MN's OMNI interface sends native (i.e., unencapsulated) IPv6 ND messages via the underlying ANET interface. IPv6 ND messages traverse the ground domain ANETs until they reach an Access Router (AR#1, AR#2, .., AR#n). The AR then coordinates with a Mobility Service Endpoint (MSE#1, MSE#2, ..., MSE#m) in the INET and returns an IPv6 ND message response to the MN. IPv6 ND messages traverse the ANET at layer 2; hence, the Hop Limit is not decremented.

```
                           +--------------+
                           |      MN      |
                           +--------------+
                           |OMNI interface|
                           +----+----+----+
                  +--------|IF#1|IF#2|IF#n|------ +
                 /         +----+----+----+        \
                /                 |                 \
               /    <---- Native  |  IP ---->        \
              v                   v                   v
           (:::)-.              (:::)-.              (:::)-.
      .-(::ANET:::)        .-(::ANET:::)        .-(::ANET:::)
        `-(::::)-'           `-(::::)-'           `-(::::)-'
          +----+               +----+               +----+
    ...   |AR#1|  ..........   |AR#2|   .........   |AR#n|  ...
   .      +-|--+               +-|--+               +-|--+     .
   .        |                    |                    |
   .        v                    v                    v        .
   .               <-----  Encapsulation ----->                .
   .                                                           .
   .      +-----+               (:::)-.                        .
   .      |MSE#2|          .-(::::::::)          +-----+      .
   .      +-----+       .-(:::   INET  :::)-.     |MSE#m|      .
   .                 (:::::    Routing  ::::)    +-----+      .
   .                    `-(::: System :::)-'                   .
   .  +-----+               `-(:::::::-'                       .
   .  |MSE#1|          +-----+               +-----+           .
   .  +-----+          |MSE#3|               |MSE#4|           .
   .                   +-----+               +-----+           .
   .                                                           .
   .                                                           .
   .       <----- Worldwide Connected Internetwork ---->       .
    ...........................................................
```

Figure 2: MN/MS Coordination via Multiple ANETs

After the initial IPv6 ND message exchange, the MN can send and receive unencapsulated IPv6 data packets over the OMNI interface. OMNI interface multilink services will forward the packets via ARs in the correct underlying ANETs. The AR encapsulates the packets according to the capabilities provided by the MS and forwards them to the next hop within the worldwide connected Internetwork via optimal routes.

5. Maximum Transmission Unit

All IPv6 interfaces MUST configure an MTU of at least 1280 bytes [RFC8200]. The OMNI interface configures its MTU based on the largest MTU among all underlying ANET interfaces. The value MAY be overridden if an RA message with an MTU option is received.

The OMNI interface returns internally-generated IPv6 Path MTU Discovery (PMTUD) Packet Too Big (PTB) messages [RFC8201] for packets admitted into the OMNI interface that are too large for the outbound underlying ANET interface. Similarly, the OMNI interface performs PMTUD even if the destination appears to be on the same link since a proxy on the path could return a PTB message. PMTUD therefore ensures that the OMNI interface MTU is adaptive and reflects the current path used for a given data flow.

Applications that cannot tolerate loss due to MTU restrictions SHOULD refrain from sending packets larger than 1280 bytes, since dynamic path changes can reduce the path MTU at any time. Applications that may benefit from sending larger packets even though the path MTU may change dynamically MAY use larger sizes.

6. Frame Format

The OMNI 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 specified in [RFC2473], etc.

7. Link-Local Addresses

OMNI interfaces assign IPv6 Link-Local Addresses (i.e., "OMNI LLAs") using the following constructs:

o IPv6 MN OMNI LLAs encode the most-significant 64 bits of a MNP within the least-significant 64 bits (i.e., the interface ID) of a Link-Local IPv6 Unicast Address (see: [RFC4291], Section 2.5.6). For example, for the MNP 2001:db8:1000:2000::/56 the corresponding LLA is fe80::2001:db8:1000:2000.

o IPv4-compatible MN OMNI LLAs are assigned as fe80::ffff:[v4addr], i.e., the most significant 10 bits of the prefix fe80::/10, followed by 70 '0' bits, followed by 16 '1' bits, followed by a 32bit IPv4 address. For example, the IPv4-Compatible MN OMNI LLA

for 192.0.2.1 is fe80::ffff:192.0.2.1 (also written as fe80::ffff:c000:0201).

o MSE OMNI LLAs are assigned from the range fe80::/96, and MUST be managed for uniqueness. The lower 32 bits of the LLA includes a unique integer value between '1' and 'fffffffe', e.g., as in fe80::1, fe80::2, fe80::3, etc., fe80::ffff:fffe. The address fe80:: is the link-local Subnet-Router anycast address [RFC4291] and the address fe80::ffff:ffff is reserved. (Note that distinct OMNI link segments can avoid overlap by assignig MSE OMNI LLAs from unique fe80::/96 sub-prefixes. For example, a first segment could assign from fe80::1000/116, a second from fe80::2000/116, a third from fe80::3000/116, etc.)

Since the prefix 0000::/8 is "Reserved by the IETF" [RFC4291], no MNPs can be allocated from that block ensuring that there is no possibility for overlap between the above OMNI LLA constructs.

Since MN OMNI LLAs are based on the distribution of administratively assured unique MNPs, and since MSE OMNI LLAs are guaranteed unique through administrative assignment, OMNI interfaces set the autoconfiguration variable DupAddrDetectTransmits to 0 [RFC4862].

8. Address Mapping - Unicast

OMNI interfaces maintain a neighbor cache for tracking per-neighbor state and use the link-local address format specified in Section 7. IPv6 Neighbor Discovery (ND) [RFC4861] messages on MN OMNI interfaces observe 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 OMNI interface would therefore appear to have multiple L2 connections, and may include information for multiple ANET interfaces in a single IPv6 ND message exchange.

OMNI interfaces use an IPv6 ND option called the "OMNI option" 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    | Prefix Length |R|N|  Reserved |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   ifIndex[1]  |   ifType[1]   | Reserved [1]  |Link[1]|QoS[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]  |   ifType[2]   | Reserved [2]  |Link[2]|QoS[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]  |   ifType[N]   | Reserved [N]  |Link[N]|QoS[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|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    zero-padding (if necessary)                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|               Notification ID (present only if N=1)           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: OMNI Option Format

In this format:

o Type is set to TBD.

- Length is set to the number of 8 octet blocks in the option.

- Prefix Length is set according to the IPv6 source LLA type. For MN OMNI LLAs, the value is set to the length of the embedded MNP. For MSE OMNI LLAs, the value is set to 128.

- R (the "Register/Release" bit) is set to '1' to register an MNP or set to '0' to release a registration.

- N (the "Notify" bit) is set to '1' if the option includes a trailing 4 byte "Notification ID" (see below); set to '0' otherwise.

- Reserved is set to the value '0' on transmission and ignored on reception.

- A set of N ANET interface "ifIndex-tuples" are included as follows:

  * ifIndex[i] is set to an 8-bit integer value corresponding to a specific underlying ANET interface. The first ifIndex-tuple MUST correspond to the ANET interface over which the message is sent. IPv6 ND messages originating from a MN may include multiple ifIndex-tuples, and MUST number each with a distinct ifIndex value between '1' and '255' that represents a MN-specific 8-bit mapping for the actual ifIndex value assigned to the ANET interface by network management [RFC2863]. IPv6 ND messages originating from the MS include a single ifIndex-tuple with ifIndex set to the value '0'.

  * ifType[i] is set to an 8-bit integer value corresponding to the underlying ANET interface identified by ifIndex. The value represents an OMNI interface-specific 8-bit mapping for the actual IANA ifType value registered in the 'IANAifType-MIB' registry [http://www.iana.org].

  * Reserved[i] is set to the value '0' on transmission and ignored on reception.

  * Link[i] encodes a 4-bit link metric. The value '0' means the link is DOWN, and the remaining values mean the link is UP with metric ranging from '1' ("lowest") to '15' ("highest").

  * QoS[i] encodes the number of 4-byte blocks (between '0' and '15') of two-bit P[*] values that follow. The first 4 blocks correspond to the 64 Differentiated Service Code Point (DSCP) values P00 - P63 [RFC2474]. If additional 4-byte P[i] blocks follow, their values correspond to "pseudo-DSCP" values P64,

P65, P66, etc. numbered consecutively. The pseudo-DSCP values correspond to ancillary QoS information defined for the specific OMNI interface (e.g., see Appendix A).

* P[*] includes zero or more per-ifIndex 4-byte blocks of two-bit Preferences. Each P[*] 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 first four blocks always correspond to the 64 DSCP values in consecutive order. If one or more of the blocks are absent (e.g., for QoS values 0,1,2,3) the P[*] values for the missing blocks default to "medium".

o Zero-padding added if necessary to produce an integral number of 8 octet blocks.

o Notification ID (present only if N = '1') contains the least-significant 32 bits of an MSE OMNI LLA to notify. For example, for the LLA fe80::face:cafe the field contains 0xfacecafe.

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 L2 address of the router as the L2 address for all multicast packets.

10. Address Mapping for IPv6 Neighbor Discovery Messages

Per [RFC4861], IPv6 ND messages may be sent to either a multicast or unicast link-scoped IPv6 destination address. However, IPv6 ND messaging is coordinated between the MN and MS only without invoking other nodes on the ANET.

For this reason, ANET links maintain unicast L2 addresses ("MSADDR") for the purpose of supporting MN/MS IPv6 ND messaging. For Ethernet-compatible ANETs, this specification reserves one Ethernet unicast address TBD2. For non-Ethernet statically-addressed ANETs, MSADDR is reserved per the assigned numbers authority for the ANET addressing space. For still other ANETs, MSADDR may be dynamically discovered through other means, e.g., L2 beacons.

MNs map the L3 addresses of all IPv6 ND messages they send (i.e., both multicast and unicast) to an MSADDR instead of to an ordinary unicast or multicast L2 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. Note that multiple MS devices on

the link could be configured to accept packets destined to MSADDR, e.g., as a basis for supporting redundancy.

Therefore, ARs MUST accept and process packets destined to MSADDR, while all other devices MUST NOT process packets destined to MSADDR. This model has well-established operational experience in Proxy Mobile IPv6 (PMIP) [RFC5213][RFC6543].

11. Conceptual Sending Algorithm

The MN's IPv6 layer selects the outbound OMNI interface according to standard IPv6 requirements when forwarding data packets from local or EUN applications to external correspondents. The OMNI 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.).

After a packet enters the OMNI interface, an outbound ANET interface is selected based on multilink parameters such as DSCP, application port number, cost, performance, message size, etc. OMNI interface multilink selections could also be configured to perform replication across multiple ANET interfaces for increased reliability at the expense of packet duplication.

OMNI interface multilink service designers MUST observe the BCP guidance in Section 15 [RFC3819] in terms of implications for reordering when packets from the same flow may be spread across multiple ANET interfaces having diverse properties.

11.1. Multiple OMNI Interfaces

MNs may associate with multiple MS instances concurrently. Each MS instance represents a distinct OMNI link distinguished by its associated MSPs. The MN configures a separate OMNI interface for each link so that multiple interfaces (e.g., omni0, omni1, omni2, etc.) are exposed to the IPv6 layer.

Depending on local policy and configuration, an MN may choose between alternative active OMNI interfaces using a packet's DSCP, routing information or static configuration. Interface selection based on per-packet source addresses is also enabled when the MSPs for each OMNI interface are known (e.g., discovered through Prefix Information Options (PIOs) and/or Route Information Options (RIOs)).

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

Multiple distinct OMNI 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 Registration

ARs process IPv6 ND messages destined to All-Routers multicast (ff02::2), Subnet-Router anycast (fe80::) and unicast IPv6 LLAs [RFC4291]. ARs configure the L2 address MSADDR (see: Section 10) and act as a proxy for MSE OMNI LLAs.

MNs interface with the MS by sending RS messages with OMNI options. For each ANET interface, the MN sends an RS message with an OMNI option, with L2 destination address set to MSADDR and with L3 destination address set to either a specific MSE OMNI LLA, link-local Subnet-Router anycast, or All-Routers multicast. The MN discovers MSE OMNI LLAs either through an RA message response to an initial anycast/multicast RS or before sending an initial RS message. [RFC5214] provides example MSE address discovery methods, including information conveyed during data link login, name service lookups, static configuration, etc.

The AR receives the RS messages and coordinates with the corresponding MSE in a manner outside the scope of this document. The AR returns an RA message with source address set to the MSE OMNI LLA, with an OMNI option and with any information for the link that would normally be delivered in a solicited RA message. (Note that if all MSEs share common state, the AR can instead return an RA with source address set to link-local Subnet-Router anycast.)

MNs configure OMNI interfaces that observe the properties discussed in the previous section. The OMNI 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 OMNI 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 OMNI interface also transitions to UP. When all underlying interfaces transition to DOWN, the OMNI interface also transitions to DOWN.

When an OMNI 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.

ARs return RA messages with configuration information in response to a MN's RS messages. The RAs include a Router Lifetime value and any necessary options, such as:

o PIOs with (A; L=0) that include MSPs for the link [RFC8028].

o RIOs [RFC4191] with more-specific routes.

o an MTU option that specifies the maximum acceptable packet size for the OMNI link

The AR coordinates with the MSE and sends immediate unicast RA responses without delay; therefore, the IPv6 ND MAX_RA_DELAY_TIME and MIN_DELAY_BETWEEN_RAS constants for multicast RAs do not apply. The AR 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 OMNI 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 OMNI interface and is therefore opaque to the IPv6 layer. The MN sends initial RS messages over an UP underlying interface with its OMNI LLA as the source. The RS messages include an OMNI option with a valid Prefix Length as well as ifIndex-tuples appropriate for underlying ANET interfaces. The AR processes RS message and conveys the OMNI option information to the MSE.

When the MSE processes the OMNI information, it first validates the prefix registration information. If the prefix registration was valid, the MSE injects the MNP into the routing/mapping system then caches the new Prefix Length, MNP and ifIndex-tuples. The MSE then directs the AR to return an RA message to the MN with an OMNI option and with a non-zero Router Lifetime if the prefix registration was successful; otherwise, with a zero Router Lifetime. If the MN's OMNI option included a Notification ID, the new MSE also notifies the former MSE.

When the MN receives the RA message, it creates a default route with L3 next hop address set to the address found in the RA source address and with L2 address set to MSADDR. The AR will then forward packets between the MN and the MS.

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 OMNI option. The OMNI

option contains a first ifIndex-tuple with values specific to this ANET interface, and may contain additional ifIndex-tuples specific to other ANET interfaces.

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

- When a MN wishes to release from a current MSE, it sends an RS or unsolicited NA message over any UP ANET interfaces with an OMNI option with R set to 0. The corresponding MSE then withdraws the MNP from the routing/mapping system and (for RS responses) returns an RA message with an OMNI option and with Router Lifetime set to 0.

- When a MN wishes to transition to a new MSE, it sends an RS or unsolicited NA message over any UP ANET interfaces with an OMNI option with R set to 1, with the new MSE OMNI LLA set in the destination address, and (optionally) with N set to 1 and a Notification ID included for the former MSE.

- When all of a MNs underlying interfaces have transitioned to DOWN (or if no further MN RS messages are received before Router Lifetime expires) the MSE withdraws the MNP the same as if it had received a message with an OMNI 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 OMNI interface as an ordinary IPv6 interface. Therefore, when the IPv6 layer sends an RS message the OMNI 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 OMNI 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 proactively.

13. AR and MSE Resilience

ANETs SHOULD deploy ARs in Virtual Router Redundancy Protocol (VRRP) [RFC5798] configurations so that service continuity is maintained even if one or more ARs fail. Using VRRP, the MN is unaware which of the (redundant) ARs is currently providing service, and any service discontinuity will be limited to the failover time supported by VRRP. Widely deployed public domain implementations of VRRP are available.

MSEs SHOULD use high availability clustering services so that multiple redundant systems can provide coordinated response to failures. As with VRRP, widely deployed public domain implementations of high availability clustering services are available. Note that special-purpose and expensive dedicated hardware is not necessary, and public domain implementations can be used even between lightweight virtual machines in cloud deployments.

14. Detecting and Responding to MSE Failures

In environments where fast recovery from MSE failure is required, ARs SHOULD use proactive Neighbor Unreachability Detection (NUD) in a manner that parallels Bidirectional Forwarding Detection (BFD) [RFC5880] to track MSE reachability. ARs can then quickly detect and react to failures so that cached information is re-established through alternate paths. Proactive NUD control messaging is carried only over well-connected ground domain networks (i.e., and not low-end aeronautical radio links) and can therefore be tuned for rapid response.

ARs perform proactive NUD for MSEs for which there are currently active ANET MNs. If an MSE fails, ARs can quickly inform MNs of the outage by sending multicast RA messages on the ANET interface. The AR sends RA messages to the MN via the ANET interface with source address set to the MSEs OMNI LLA, destination address set to All-Nodes multicast (ff02::1) [RFC4291], and Router Lifetime set to 0.

The AR SHOULD send MAX_FINAL_RTR_ADVERTISEMENTS RA messages separated by small delays [RFC4861]. Any MNs on the ANET interface that have been using the (now defunct) MSE will receive the RA messages and associate with a new MSE.

15. IANA Considerations

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

The IANA is instructed to allocate one Ethernet unicast address TBD2 (suggest 00-00-5E-00-52-14 [RFC5214]) in the registry "IANA Ethernet Address Block - Unicast Use".

16. Security Considerations

Security considerations for IPv6 [RFC8200] and IPv6 Neighbor Discovery [RFC4861] apply. OMNI interface IPv6 ND messages SHOULD include Nonce and Timestamp options [RFC3971] when synchronized transaction confirmation is needed.

Security considerations for specific access network interface types are covered under the corresponding IP-over-(foo) specification (e.g., [RFC2464]).

17. Acknowledgements

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

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Appendix A. OMNI Option Extensions for Pseudo-DSCP Mappings

Adaptation of the OMNI interface to specific Internetworks such as 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 additional "pseudo-DSCP" P[*] preference fields beyond the first 64. For example, TCP port 22 maps to pseudo-DSCP value P67, TCP port 443 maps to P70, UDP port 8060 maps to P76, etc. Figure 4 shows an example OMNI option with extended P[*] values beyond the base 64 used for DSCP mapping (i.e., for QoS values 5 or greater):

```
        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|N| Reserved  |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |    ifIndex    |    ifType     |     Flags     | Link  |QoS=5+ |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |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|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |P64|P65|P66|P67|P68|P69|P70|P71|P72|P73|P74|P75|P76|P77|P78|P79|
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       ...
```

Figure 4: ATN/IPS Extended OMNI Option Format

Appendix B. Prefix Length Considerations

The 64-bit boundary in IPv6 addresses [RFC7421] determines the MN OMNI LLA format for encoding the most-significant 64 MNP bits into the least-significant 64 bits of the prefix fe80::/64 as discussed in Section 7.

[RFC4291] defines the link-local address format as the most significant 10 bits of the prefix fe80::/10, followed by 54 unused bits, followed by the least-significant 64 bits of the address. If the 64-bit boundary is relaxed through future standards activity, then the 54 unused bits can be employed for extended coding of MNPs of length /65 up to /118.

The extended coding format would continue to encode MNP bits 0-63 in bits 64-127 of the OMNI LLA, while including MNP bits 64-117 in bits 10-63. For example, the OMNI LLA corresponding to the MNP 2001:db8:1111:2222:3333:4444:5555::/112 would be fe8c:ccd1:1115:5540:2001:db8:1111:2222, and would still be a valid IPv6 LLA per [RFC4291].

Appendix C. VDL Mode 2 Considerations

ICAO Doc 9776 is the "Technical Manual for VHF Data Link Mode 2" (VDLM2) that specifies an essential radio frequency data link service for aircraft and ground stations in worldwide civil aviation air traffic management. The VDLM2 link type is "multicast capable"

[RFC4861], but with considerable differences from common multicast links such as Ethernet and IEEE 802.11.

First, the VDLM2 link data rate is only 31.5Kbps - multiple orders of magnitude less than most modern wireless networking gear. Second, due to the low available link bandwidth only VDLM2 ground stations (i.e., and not aircraft) are permitted to send broadcasts, and even so only as compact layer 2 "beacons". Third, aircraft employ the services of ground stations by performing unicast RS/RA exchanges upon receipt of beacons instead of listening for multicast RA messages and/or sending multicast RS messages.

This beacon-oriented unicast RS/RA approach is necessary to conserve the already-scarce available link bandwidth. Moreover, since the numbers of beaconing ground stations operating within a given spatial range must be kept as sparse as possible, it would not be feasible to have different classes of ground stations within the same region observing different protocols. It is therefore highly desirable that all ground stations observe a common language of RS/RA as specified in this document.

Note that links of this nature may benefit from compression techniques that reduce the bandwidth necessary for conveying the same amount of data. The IETF lpwan working group is considering possible alternatives: [https://datatracker.ietf.org/wg/lpwan/documents].

Appendix D. Change Log

<< RFC Editor - remove prior to publication >>

Differences from draft-templin-atn-aero-interface-15 to draft-templin-atn-aero-interface-16:

o New note on MSE OMNI LLA uniqueness assurance.

o General cleanup.

Differences from draft-templin-atn-aero-interface-14 to draft-templin-atn-aero-interface-15:

o General cleanup.

Differences from draft-templin-atn-aero-interface-13 to draft-templin-atn-aero-interface-14:

o General cleanup.

Differences from draft-templin-atn-aero-interface-12 to draft-templin-atn-aero-interface-13:

o Minor re-work on "Notify-MSE" (changed to Notification ID).

Differences from draft-templin-atn-aero-interface-11 to draft-templin-atn-aero-interface-12:

o Removed "Request/Response" OMNI option formats. Now, there is only one OMNI option format that applies to all ND messages.

o Added new OMNI option field and supporting text for "Notify-MSE".

Differences from draft-templin-atn-aero-interface-10 to draft-templin-atn-aero-interface-11:

o Changed name from "aero" to "OMNI"

o Resolved AD review comments from Eric Vyncke (posted to atn list)

Differences from draft-templin-atn-aero-interface-09 to draft-templin-atn-aero-interface-10:

o Renamed ARO option to AERO option

o Re-worked Section 13 text to discuss proactive NUD.

Differences from draft-templin-atn-aero-interface-08 to draft-templin-atn-aero-interface-09:

o Version and reference update

Differences from draft-templin-atn-aero-interface-07 to draft-templin-atn-aero-interface-08:

o Removed "Classic" and "MS-enabled" link model discussion

o Added new figure for MN/AR/MSE model.

o New Section on "Detecting and responding to MSE failure".

Differences from draft-templin-atn-aero-interface-06 to draft-templin-atn-aero-interface-07:

o Removed "nonce" field from AR option format. Applications that require a nonce can include a standard nonce option if they want to.

o Various editorial cleanups.

Differences from draft-templin-atn-aero-interface-05 to draft-templin-atn-aero-interface-06:

o New Appendix C on "VDL Mode 2 Considerations"

o New Appendix D on "RS/RA Messaging as a Single Standard API"

o Various significant updates in Section 5, 10 and 12.

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:

- Removed discussion of encapsulation (out of scope)
- Simplified MTU section
- Changed to use a new IPv6 ND option (the "aero option") instead of S/TLLAO
- 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:

- Updates based on list review comments on IETF 'atn' list from 4/29/2019 through 5/7/2019 (issue tracker established)
- added list of opportunities afforded by the single virtual link model
- added discussion of encapsulation considerations to Section 6
- noted that DupAddrDetectTransmits is set to 0
- 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.
- Significant re-work of "Router Discovery" section.
- New Appendix B on Prefix Length considerations

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

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

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