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F. L. Templin, Ed.  
The Boeing Company  
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AERO/OMNI Base Specification Amendments (Volume 1)  
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## Abstract

The Automatic Extended Route Optimization (AERO) and Overlay Multilink Network (OMNI) Interface functional specifications have reached a level of maturity ready for advancement in the RFC publication process. Updates to the base specifications are documented in this first amendment and any additional future amendments as necessary.

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## 1. Introduction

The Automatic Extended Route Optimization (AERO) [I-D.templin-6man-aero3] and Overlay Multilink Network (OMNI) Interface [I-D.templin-6man-omni3] functional specifications have reached a level of maturity ready for advancement in the RFC publication process, while this and any other future amendments provide normative appendices that update the AERO/OMNI base specifications.

These amendments assume consistency with IPv4 [RFC0791], IPv6 [RFC8200] and the IPv6 neighbor discovery and autoconfiguration services [RFC4861][RFC4862][RFC9915]. The term "IP" refers universally to either the IPv4 or IPv6 protocol version.

## 2. AERO/OMNI: First Amendment

Amendments to the AERO/OMNI specifications appear in the following sections in the chronological order in which they were identified, formalized and recorded. Additional amendments may appear in future volumes.

## 2.1. Amendment 1.1: Prefix Delegation Administration

The AERO/OMNI base specifications include comprehensive instructions for Clients to request and receive Mobile Network Prefix (MNP) IP Prefix Delegations (PDs) from the mobility service. The specifications suggest that the Client should apply these MNP PDs on downstream-attached (or, "tethered") End User Network (EUN) interfaces but do not discuss specific MNP administrative procedures.

Per this amendment, when a Client receives an MNP PD it should provision the MNP over EUNs in a manner consistent with [RFC9663] and [RFC9762]. More specifically, the Client assigns some portions of the MNP to its EUN interfaces and optionally also sub-delegates other portions of the MNP to requesting EUN nodes. The Client can also use virtual interfaces (such as a loopback) as EUN interfaces. The Client should then assign an IP address taken from each EUN prefix to the corresponding EUN interface using standard IP address (auto)configuration procedures.

The Client then associates the IPv6 Subnet Router Anycast (SRA) address [RFC4291] corresponding to the MNP with the OMNI interface but does not assign it to the interface. For example, if the Client receives the IPv6 MNP PD 2001:db8:1::/48, it can either accept packets with an SRA address 2001:db8:1:\*/64 as the destination and respond with packets that use one of the Client's EUN addresses as the source or forward the packet to an EUN router that configures a more-specific sub-prefix of the ::/48. In the first case, the wildcard response would represent all sub-prefixes as reachable when in fact some may not be assigned to any EUN links; in the latter case, an adversary may be able to map the EUN internal subnets.

After the Client configures the SRA address and assigns EUN addresses it can operate as an IP host over the OMNI interface according to the weak end system model [RFC1122] while also serving as an IP router for its EUNs. The Client then engages host and router operations the same as per [RFC4861] and [RFC8200] except that the Client engages the OMNI interface as a combined host/router interface.

When the Client acts as a host over the OMNI interface, it can send Router Solicitations (RSs) to elicit Router Advertisements (RAs) from OMNI link Proxy/Servers. The Client can then use its EUN addresses for packets exchanged between its local applications and correspondents reached via OMNI link neighbors. (When the Client has no EUN addresses, it can instead use its OMNI interface Multilink Local Address (MLA) [I-D.templin-6man-mla] with the understanding that the packets may be routable only within the OMNI link limited domain.)

When the Client acts as a router over the OMNI interface, it forwards IP packets between EUN peers and correspondents reached via OMNI link neighbors but never sends RA messages over the OMNI interface. This may require the Client to enable IP forwarding on the OMNI interface but without representing itself as a router in OMNI link IPv6 Neighbor Discovery (IPv6 ND) messages. The Client instead sends RAs over its EUN interfaces that include EUN portions of the MNP in Prefix Information Options (PIOs) and also represents itself as a router in other EUN interface IPv6 ND messages.

Note that the Client could also optionally assign each EUN address it configures to the OMNI interface. This would give the outward appearance of strong end system support [RFC1122], albeit with added complexity and ambiguity for the Client to coordinate the same IP unicast address assigned to multiple interfaces.

Further details on MNP PD administrative options are beyond the scope of this amendment.

## 2.2. Amendment 1.2: AERO/OMNI MLA Addressing

In the addressing model supported under the current specifications, the MLAs of all nodes within the OMNI link limited domain (Clients, Proxy/Servers and others) should be reachable by all other nodes on the link. MLAs of nodes beyond the extent of the OMNI link will appear as unreachable destinations though they may be reachable within other OMNI links. This is due to the limited domain nature of OMNI link routing for MLAs and highlights why MLAs must appear as a lower preference than other GUAs in address selection policies.

In this addressing model, an MLA prefix (e.g., 2001:30::/28 [RFC9374]) is configured on-link on the OMNI interface and any MLA routes discovered by Mobile Ad-hoc NETworking (MANET) routing protocols are maintained in an alternate routing table instead of the main kernel routing table. The MANET routing protocol can then manage its multihop routes dynamically as necessary while the network layer forwards all packets with MLA destinations into the OMNI interface. The on-link nature of the MLA prefix will cause the network layer to invoke address resolution for destination MLAs within the limited domain. This will cause the OMNI Address Resolution Source (ARS) to either return an NA(AR) message locally for locally-known MLAs or propagate the NS(AR) message over the OMNI link to elicit an NA(AR) response from an Address Resolution Target (ART).

The ARS's NS(AR) uses the invoking packet's address or its local MLA as the Source, uses the MLA of the target as the Target and uses the solicited-node multicast address as the Destination. If the original

packet's source address is not on-link on the OMNI link, the OMNI interface also includes a Route Information Option (RIO) with a prefix that covers the source address as an OMNI sub-option. The ART's NA(AR) uses the NS(AR) target as both the Source and Target and uses the NS(AR) source as the Destination. AERO routing will cause these messages to traverse the OMNI link as OAL-encapsulated packets and return fresh reachability information.

### 2.3. Amendment 1.3: Address Resolution for Non-MLAs

Non-MLAs include MNP/FNP addresses and other GUA addresses matched only by "default". These prefixes must be configured as reachable (but not on-link) via the OMNI link. Clients therefore configure routes in the IPv6 routing system that cover MNPs and/or FNPs and with next hop set to the Link-Local Address (LLA) of the OMNI interface internal virtual router. This will cause all packets with destinations within these off-link prefixes to be delivered to the virtual router. The route(s) may include specific MNP/FNP prefixes or even the full Mobility Service Prefix and/or ::/0 (i.e., default).

The OMNI link virtual router then acts as an ARS to resolve adaptation layer addressing information for the packet's destination prefix internally within the adaptation layer and without disturbing the network layer. While address resolution is in progress, the virtual router maintains a short queue (possibly only a single entry) of packets destined to the ART prefix in the spirit of [RFC4861] (noting that many distinct destinations may match the same ART prefix). The virtual router should not attach subject packets awaiting address resolution to NS(AR) messages, as they may be produced by high-volume applications (e.g., "flood-pings") that send many unacknowledged packets without waiting for a response.

In this off-link model, the ARS's NS(AR) message uses the MLA assigned to the OMNI interface as the Source, a /64 Subnet Router Anycast address that covers the subject packet's destination address as the Target and the target's solicited-node multicast address as the Destination. If the original packet's source is not on-link on the OMNI interface, the NS(AR) also includes an OMNI RIO sub-option with a prefix that covers the source. The ART's responsive NA(AR) message uses its own MLA as the Source, the NS(AR) target as the Target and the NS(AR) source as the Destination. The NA(AR) also includes an RIO with a prefix that covers the NS(AR) target. The target and source OMNI interfaces then cache the RIO information as address resolution results.

This enhanced address resolution allows the ARS and ART to discover information for entire IPv6 prefix ranges without necessarily conveying reachability information for specific destinations (or even

sub-prefixes) within the prefix. The system therefore depends on the target network returning ICMPv6 Destination Unreachable messages for unreachable destinations within (reachable) prefixes the same as for any router.

#### 2.4. Amendment 1.4: OMNI Interface Virtual Router

The virtual router entity within the OMNI interface must present itself to the network layer as a minimally qualified IPv6 router according to IPv6 node requirements [RFC8504]. This includes using its internal LLA to send solicited and unsolicited Router Advertisements as well as respond to Neighbor Solicitations by returning solicited Neighbor Advertisements.

The virtual router entity uses its internal LLA as the Source or Destination Address for message exchanges with the network layer. The virtual router entity should also provide a configuration option allowing it to either respond to or ignore ICMPv6 Echo Request messages addressed to its internal LLA or the subnet router anycast address for its MLA prefix(es).

The virtual router can announce itself to the network layer proactively when an OMNI interface is first enabled, or it may instead wait for the network layer to generate a Router Solicitation (RS). In both cases, the virtual router is responsible for coordinating with its selected Proxy/Servers.

#### 2.5. Amendment 1.5: OMNI Interface Neighbor Cache

Each OMNI interface maintains a standard IPv6 network layer neighbor cache the same as for any IPv6 interface and also maintains an adaptation layer neighbor cache internally. The network layer neighbor cache maintains entries (NCEs) for the adaptation layer as a virtual router as well as for active on-link destinations only, while the adaptation layer neighbor cache maintains NCEs for both on-link destinations and off-link prefixes reached via the OMNI interface.

Each network layer NCE resolves to the singular OMNI interface internal link-layer address; this means that all NCE destinations would appear to belong to the same (singular) neighbor. The adaptation layer virtual router entity will then map the network layer NCE to the corresponding adaptation layer NCE by examining the IP source or destination address rather than the link-layer address. This relationship establishes a 1x1 mapping between the network layer as a virtual host and the adaptation layer as a virtual peer host/router on a shared link.

The network and adaptation layer neighbor caches are affected by the transmission and reception of IPv6 Neighbor Discovery (IPv6 ND) messages according to the base specifications. IPv6 ND messages affect both the network layer and adaptation layer caches for on-link addresses, while only the adaptation layer cache is affected for off-link addresses.

When the OMNI interface forwards an IPv6 ND message from the network layer to the adaptation layer, the adaptation layer removes the Source/Target Link Layer Address Option (S/TLLAO) and resets the IPv6 source address from the network layer Link-Local Address (LLA) to the node's MLA if necessary. The adaptation layer does not reset the ICMPv6 checksum before performing OAL encapsulation and transmission over an underlay interface since the OMNI option checksum protects integrity as an adaptation layer service. The ICMPv6 checksum will then appear simply as a random bit string over the wire to be ignored by the OAL destination as well as all OAL intermediate nodes.

When the underlay forwards an OAL-encapsulated IPv6 ND message to the adaptation layer, the OAL first verifies the OMNI checksum then processes any OMNI sub-options and performs decapsulation. The OAL then inserts a S/TLLAO that includes the MAC address assigned to the OMNI-internal virtual Ethernet interface and for RA messages only resets the IPv6 source address to the virtual router entity's LLA. The OAL then re-calculates/resets the ICMPv6 checksum and forwards the IPv6 ND message to the network layer via the OMNI interface. The network layer will then accept the message under the assumption that it originated from an on-link neighbor.

## 2.6. Amendment 1.6: Scalable Mapping

Scaling properties for the worldwide civil aviation airplane population are likely to remain within reasonable bounds for the pure BGP routing system discussed in [I-D.templin-6man-aero3] for the foreseeable future. (A single BGP system can presumably support  $O(10^6)$  routes when considering the scaling properties of the global public Internet BGP service.) However, the advent of unmanned air systems and all other manners of mobile nodes will soon present multiple orders of magnitude more mobility targets which may exceed the carrying capacity of a BGP-only service.

In order to support unbounded scaling, the BGP routing system can be limited to carry only the MLAs of all Proxy/Servers on the OMNI link (and possibly also the MNPs/FNPs/MLAs of a limited number of mobile nodes) without carrying the entire population of mobile node MNP/FNP/MLA information. Each MAP Proxy/Server then registers the MNP/FNP routes and MLA addresses of its dependent mobile nodes with a scalable mapping system that can be used to resolve a target address

based on longest prefix match into a MAP Proxy/Server MLA address. The Domain Name System (DNS) ip6.arpa reverse zone can be used for this purpose as suggested in [RFC9374].

Address resolution then becomes a two-phase operation where the address resolution request is first forwarded (e.g., via a default or more-specific route) to a Gateway which consults the DNS to determine the MLA of the current MAP Proxy/Server for the address resolution target. The mapping system agent then changes the OAL destination to the discovered MLA and forwards the address resolution request to the MAP which returns a fully qualified address resolution response.

By maintaining mobile node to MAP mappings in a scalable ancillary lookup directory database, the BGP routing system only needs to scale to the total population of Proxy/Servers and Gateways that make up the OMNI link (plus possibly also a limited number of mobile nodes). This is likely to remain within acceptable scaling limits even for extremely large mobile node populations for the foreseeable future.

Note that the Gateway performs these mapping system lookups only for subject prefixes associated with the OMNI link, e.g., those covered by MSPs or any well-known FNP. For other subject prefixes that match only "default" the Gateway returns an address resolution response with a Route Information Option (RIO) that includes a /64 prefix covering the target address while including its own MLA as the address resolution result.

Note also that MAP Proxy/Servers need only add or replace DNS resource records with the IP prefix mappings as they receive registration requests from new Clients. If the Client moves to a new MAP Proxy/Server, the new MAP simply replaces the old resource records with fresh information. If the resource records expire before a new MAP Proxy/Server supplies fresh information, the records are removed.

Global propagation delays for DNS resource record updates and the location privacy considerations for mobile node affiliations with MAP Proxy/Servers suggest that the OMNI link should configure a "two-faced" DNS service infrastructure maintained separately from the global public DNS. Such a service should be optimized for fast updates so that Gateways always receive fresh address resolution information.



## 2.7. Amendment 1.7: Address Duplication Implications

An implicit assumption in AERO/OMNI is that IP address duplication within the same OMNI link domain could result in an unresolvable and harmful interaction for any nodes affected. The AERO/OMNI routing system and neighbor discovery services are founded on an expectation of uniqueness of the MNPs/FNPs/MLAs claimed by nodes. The MLA in particular is carefully coordinated with a registration authority and bound to a public key identity to ensure uniqueness. MNP/FNP delegations are similarly bound to an MLA when delegated by AERO/OMNI infrastructure supporting nodes to prevent duplication.

On the other hand, link-layer address duplication (while presumably rare) would result in simply minor performance congestion since the IP stacks of the nodes with duplicate link-layer addresses would reject any mis-directed packets while the stacks of routers would be able to discern control messages based on their IPv6 MLA addresses as a unique node identifier. While link-layer address duplication is not desirable, it should have no harmful operational effects.

## 2.8. Amendment 1.8: Setting Auth Offset

The OMNI option trailer includes a 1-octet Auth Offset field that encodes the offset from the beginning of the OMNI sub-options to the first authentication (or "authentication helper") sub-option. This allows for more efficient authentication verification at OAL destinations since they need not wade through potentially long concatenations of leading non-authentication sub-options.

When an OMNI option does not assert an authentication/helper sub-option offset, the OAL source can set Auth Offset to any value no smaller than OMNI Length. For example, the OAL source can simply set the value 'ff' as an unambiguous indication that no offset is asserted.

## 2.9. Amendment 1.9: Surrogate Multilink Pilots (MPs)

The AERO/OMNI base specifications require that control messages (including IPv6 ND and Multilink Pilot (MP) messages) must be transmitted as whole packets not subject to OAL fragmentation. Very large original IP packets may therefore be unsuited to serve as MP messages.

In that case, the OAL source can continue to hold the large packet in a queue while sending unsolicited Neighbor Advertisement (uNA) messages that include Source, Destination and Flow Label information copied from the large packet as surrogate MPs.

Transmission of surrogate MPs will cause OAL intermediate systems to securely establish AFVI state, after which the OAL source can release the large packet (while applying fragmentation if necessary followed by header compression) to follow the newly-established AFVI path in the data plane.

## 2.10. Amendment 1.10: Extended AFVI TLVs

The OMNI specification defines a segment Routing Header (SRH) TLV termed the AERO Flow Vector Index (AFVI) TLV. This amendment defines an extended form of the AFVI TLV to include a Sequence Number and Window size as shown below:

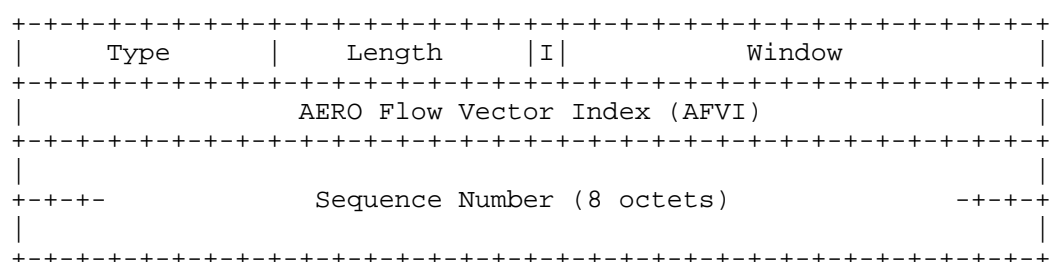


Figure 1: Extended AFVI TLV

In this extended form:

- \* Type is set the same as in the OMNI specification.
- \* Length is set to 14.
- \* I is an "Initialize" flag used for the same purpose as in the OMNI specification.
- \* Window is a 15-bit integer that encodes the size of the current send window in units of 512 Sequence Numbers. For example, if Window encodes the value 128 the current send window is  $(128 * 512) = 65536$  Sequence Numbers.
- \* AERO Flow Vector Index (AFVI) is a 32-bit field used for the same purpose as in the OMNI specification.
- \* Sequence Number is an 8-octet field that encodes the same value that would appear in the Extended Fragment Header (EFH). For unfragmented control messages, this value can therefore include a Sequence Number used to establish AFV state.

When the OAL source includes this extended form of the SRH AFVI TLV in unfragmented control messages, it should not also include an Extended Fragment Header (EFH) as it would only include redundant or conflicting information that could confuse OAL intermediate systems. The SRH AFVI TLV also has the distinct advantage that it is covered by the authentication signature included in the SRH HMAC TLV.

This amendment therefore deprecates inclusion of the EFH in unfragmented control messages and mandates inclusion of the SRH extended AFVI TLV in its place.

This amendment further deprecates inclusion of the OMNI Neighbor Synchronization sub-option, as all window synchronization will be unidirectional based on the SRH AFVI TLV and therefore no TCP-like bidirectional handshaking is necessary.

#### 2.11. Amendment 1.11: Path Change Mitigations

The AERO specification includes path change mitigations that permit an OAL intermediate node to revert to sending packets with uncompressed headers when the next hop in the AFV path has changed. The OAL destination is then responsible for returning ICMPv6 Parameter Problem messages with code "Compressed header expected".

In open Internetworks not protected by lower layer security, however, this arrangement could open a Denial of Service (DoS) vector in which an unauthorized source produces a flood of packets with uncompressed headers causing an OAL destination to return false path change reports.

The OAL intermediate node should therefore return an ICMP Parameter Problem message (subject to rate limiting) with code "Compressed header expected" (see: [I-D.templin-6man-aero3]) and then forward packets with uncompressed headers only if the underlay network is secured against DoS spoofing. In open Internetworks, the OAL intermediate node should instead simply drop the packets.

#### 2.12. Amendment 1.12: MAP Proxy/Servers

The OMNI specification implies that all First Hop Segment (FHS) Proxy/Servers should be eligible to also act as distributed Mobility Anchor Points (MAPs). For FHS Proxy/Servers positioned in highly dynamic environments, however, this might lead to undesirable interactions with the OMNI link routing system. These dynamic FHS Proxy/Servers should therefore not accept the MAP role themselves, but should instead act as transparent proxies to forward Client registration requests to MAPs located in more stable environments.

The Client discovers the list of eligible MAPs for the OMNI link by querying the Domain Name System (DNS) for the OMNI link Potential Router List (PRL). The PRL query returns a list of MAP Proxy/Server resource records that include the MLA, underlay IP address(es) and geographic positioning information for each MAP. Clients can then select specific MAPs by placing the MLA in an OMNI Router Solicitation (RS) Destination Address; the FHS Proxy/Server for the Client's link will in turn transparently proxy and forward the RS to the MAP.

Clients may selectively test connectivity to candidate MAPs before selecting one with the desired performance profile. The MAP should in turn defer its interactions with the OMNI link routing system until the Client indicates its intention to commit. This amendment therefore adds a new (C)ommit flag to the OMNI Proxy/Server Control sub-option as shown in Figure 2:

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| Sub-Type=15 | Sub-Length | M|P|N|A|R|C|   Reserved   |
+-----+-----+-----+-----+-----+-----+-----+-----+
~                                                                    ~

```

Figure 2: Proxy/Server Control With (C)ommit Flag

When the Client sends an RS to test a candidate MAP Proxy/Server's reachability and performance, it includes a Proxy/Server Control sub-option with the (C)ommit flag set to 0. The MAP Proxy/Server then returns a Router Advertisement (RA) message without committing to serve the Client. When the Client instead sets the (C)ommit flag to 1, the MAP Proxy/Server returns an RA with zero lifetimes if it is unable to commit. Otherwise, the MAP Proxy/Server creates a Neighbor Cache entry, delegates the Client's requested MNP(s) and injects the Client's MNP(s) and MLA into the OMNI link routing system. The MAP Proxy/Server then returns an RA with valid lifetimes.

### 3. IANA Considerations

This document includes no actions for IANA.

### 4. Security Considerations

The security considerations in the normative references apply.

### 5. Acknowledgements

This work is aligned with the Boeing/Virginia Tech National Security Institute (VTNSI) 5G MANET research program.

Honoring life, liberty and the pursuit of happiness.

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## Appendix A. Change Log

<< RFC Editor - remove prior to publication >>

Differences from -06 to -07:

- \* Clarified IPv6 ND message exchange requirements between network and adaptation layers.

Differences from -05 to -06:

- \* Subnet Router Anycast address for non-MLA NS/NA.

Differences from -04 to -05:

- \* Reverted to off-link model for non-MLAs.

Differences from -01 to -04:

- \* Further clarifications on on/off-link models.
- \* Added amendment 1.12 on MAP Proxy/Servers.

Differences from -00 to -01:

- \* Added amendments 1.2 through 1.11.

Differences from earlier versions:

- \* First draft publication.

#### Author's Address

Fred L. Templin (editor)  
The Boeing Company  
P.O. Box 3707  
Seattle, WA 98124  
United States of America  
Email: fltemplin@acm.org