IETF Mobile IP Working Group
INTERNET-DRAFT

David B. Johnson
Carnegie Mellon University
Charles Perkins
Sun Microsystems
13 March 1998

Mobility Support in IPv6

<draft-ietf-mobileip-ipv6-05.txt>

Status of This Memo

Abstract

This document specifies the operation of mobile computers using IPv6. Each mobile node is always identified by its home address, regardless of its current point of attachment to the Internet. While situated away from its home, a mobile node is also associated with a care-of address, which provides information about the mobile node's current location. IPv6 packets addressed to a mobile node's home address are transparently routed to its care-of address. The protocol enables IPv6 nodes to cache the binding of a mobile node's home address with its care-of address, and to then send any packets destined for the mobile node directly to it at this care-of address.

Contents

1. Introduction

This document specifies the operation of mobile computers using Internet Protocol Version 6 (IPv6) [5]. Without specific support for mobility in IPv6, packets destined to a mobile node (host or router) would not be able to reach it while the mobile node is away from its home link (the link on which its home IPv6 subnet prefix is in use), since routing is based on the subnet prefix in a packet's destination IP address. In order to continue communication in spite of its movement, a mobile node could change its IP address each time it moves to a new link, but the mobile node would then not be able to maintain transport and higher-layer connections when it changes location. Mobility support in IPv6 is particularly important, as mobile computers are likely to account for a majority or at least a substantial fraction of the population of the Internet during the lifetime of IPv6.

The protocol operation defined here, known as Mobile IPv6, allows a mobile node to move from one link to another without changing the mobile node's IP address. A mobile node is always addressable by its "home address", an IP address assigned to the mobile node within its home subnet prefix on its home link. Packets may be routed to the mobile node using this address regardless of the mobile node's current point of attachment to the Internet, and the mobile node may continue to communicate with other nodes (stationary or mobile) after moving to a new link. The movement of a mobile node away from its home link is thus transparent to transport and higher-layer protocols and applications.

The Mobile IPv6 protocol is just as suitable for mobility across homogeneous media as for mobility across heterogeneous media. For example, Mobile IPv6 facilitates node movement from one Ethernet segment to another as well as it facilitates node movement from an Ethernet segment to a wireless LAN cell, with the mobile node's IP address remaining unchanged in spite of such movement.

One can think of the Mobile IPv6 protocol as solving the "macro" mobility management problem. More "micro" mobility management applications -- for example, handoff among wireless transceivers, each of which covers only a very small geographic area -- are possibly more suited to other solutions. For example, in many current wireless LAN products, link-layer mobility mechanisms allow a "handoff" of a mobile node from one cell to another, reestablishing link-layer connectivity to the node in each new location. As long as such handoff occurs only within cells of the mobile node's home link, such link-layer mobility mechanisms are likely to offer faster convergence and lower overhead than Mobile IPv6. Extensions to the Mobile IPv6 protocol are also possible to support a more local,

hierarchical form of mobility management, but such extensions are beyond the scope of this document.

The protocol specified in this document solves the problem of transparently routing packets to and from mobile nodes while away from home. However, it does not attempt to solve all general problems related to the use of mobile computers or wireless networks. In particular, this protocol does not attempt to solve:

- Handling links with partial reachability, such as typical wireless networks. Some aspects of this problem are addressed by the movement detection procedure described in Section 10.2, but no attempt has been made to fully solve this problem in its general form. Most aspects of this problem can be solved by the workaround of restricting such networks to only one router per link, although there are still possible hidden terminal problems when two nodes on the same link (on opposite sides of the router) attempt to communicate directly.

- Access control on a link being visited by a mobile node. This is a general problem any time an untrusted node is allowed to connect to any link layer. It is independent whether the connecting node uses Mobile IP, DHCP [2], or just "borrows" an IP address on the link.

2. Comparison with Mobile IP for IPv4

[This section will include a comparison between the Mobile IPv6 protocol and the Mobile IPv4 protocol [13, 12, 14]. However, this comparison has not yet been written. It will be filled in with the next revision to this draft.]

3. Terminology

3.1. General Terms

IP

Internet Protocol Version 6 (IPv6).

node

A device that implements IP.

router

A node that forwards IP packets not explicitly addressed to itself.

host

Any node that is not a router.

link

A communication facility or medium over which nodes can communicate at the link layer, such as an Ethernet (simple or bridged). A link is the layer immediately below IP.

interface

A node's attachment to a link.

subnet prefix

A bit string that consists of some number of initial bits of an IP address.

interface identifier

A number used to identify a node's interface on a link. The interface identifier is the remaining low-order bits in the node's IP address after the subnet prefix.

link-layer address

A link-layer identifier for an interface, such as IEEE 802 addresses on Ethernet links.

packet

An IP header plus payload.

3.2. Mobile IPv6 Terms

home address

An IP address assigned to a mobile node within its home link.

home subnet prefix

The IP subnet prefix corresponding to a mobile node's home address.

home link

The link on which a mobile node's home subnet prefix is defined. Standard IP routing mechanisms will deliver packets destined for a mobile node's home address to its home link.

mobile node

A node that can change its point of attachment from one link to another, while still being reachable via its home address.

movement

A change in a mobile node's point of attachment to the Internet such that it is no longer connected to the same link as it was previously. If a mobile node is not currently attached to its home link, the mobile node is said to be "away from home".

correspondent node

A peer node with which a mobile node is communicating. The correspondent node may be either mobile or stationary.

foreign subnet prefix

Any IP subnet prefix other than the mobile node's home subnet prefix.

foreign link

Any link other than the mobile node's home link.

home agent

A router on a mobile node's home link with which the mobile node has registered its current care-of address. While the mobile node is away from home, the home agent intercepts packets on the home link destined to the mobile node's home

address, encapsulates them, and tunnels them to the mobile node's registered care-of address.

care-of address

An IP address associated with a mobile node while visiting a foreign link; the subnet prefix of this IP address is a foreign subnet prefix. Among the multiple care-of addresses that a mobile node may have at a time (e.g., with different subnet prefixes), the one registered with the mobile node's home agent is called its "primary" care-of address.

binding

The association of the home address of a mobile node with a care-of address for that mobile node, along with the remaining lifetime of that association.

3.3. Specification Language

The keywords "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [3].

4. Overview of Mobile IPv6

4.1. Basic Operation

A mobile node is always addressable by its home address, whether it is currently attached to its home link or is away from home. While a mobile node is at home, packets addressed to its home address are routed to it using conventional Internet routing mechanisms in the same way as if the node were never mobile. Since the subnet prefix of a mobile node's home address is the subnet prefix (or one of the subnet prefixes) on the mobile node's home link (it is the mobile node's home subnet prefix), packets addressed to it will be routed to its home link.

While a mobile node is attached to some foreign link away from home, it is also addressable by one or more care-of addresses, in addition to its home address. A care-of address is an IP address associated with a mobile node while visiting a particular foreign link. The subnet prefix of a mobile node's care-of address is the subnet prefix (or one of the subnet prefixes) on the foreign link being visited by the mobile node; if the mobile node is connected to this foreign link while using that care-of address, packets addressed to this care-of address will be routed to the mobile node in its location away from home. The association between a mobile node's home address and care-of address is known as a "binding" for the mobile node. A mobile node typically acquires its care-of address through stateless [18] or stateful (e.g., DHCPv6 [2]) address autoconfiguration, according to the methods of IPv6 Neighbor Discovery [11]. Other methods of acquiring a care-of address are also possible, but such methods are beyond the scope of this document.

While away from home, the mobile node registers one of its bindings with a router on its home link, requesting this router to function as the "home agent" for the mobile node. This binding registration is done by the mobile node sending a packet with a "Binding Update" destination option to the home agent; the home agent then replies by returning a packet containing a "Binding Acknowledgement" destination option to the mobile node. The care-of address in this binding registered with its home agent is known as the mobile node's "primary care-of address". The mobile node's home agent thereafter uses proxy Neighbor Discovery to intercept any IPv6 packets addressed to the mobile node's home address (or home addresses) on the home link, and tunnels each intercepted packet to the mobile node's primary care-of address. To tunnel each intercepted packet, the home agent encapsulates the packet using IPv6 encapsulation [4], with the outer IPv6 header addressed to the mobile node's primary care-of address.

Section 10.12 discusses the reasons why it may be desirable for a mobile node to use more than one care-of address at the same

time. However, a mobile node's primary care-of address is distinct among these in that the home agent maintains only a single care-of address registered for each mobile node, and always tunnels a mobile node's packets intercepted from its home link to this mobile node's registered primary care-of address. The home agent thus need not implement any policy to determine which of possibly many care-of addresses to which to tunnel each intercepted packet, leaving the mobile node entirely in control of this policy by which of its care-of addresses it registers with its home agent.

It is possible that while a mobile node is away from home, some nodes on its home link may be reconfigured, such that the router that was operating as the mobile node's home agent is replaced by a different router serving this role. In this case, the mobile node may not know the IP address of its own home agent. Mobile IPv6 provides a mechanism, known as "dynamic home agent address discovery", that allows a mobile node to dynamically discover the IP address of a home agent on its home link with which it may register its care-of address while away from home. The mobile node sends a Binding Update to the "Home-Agents anycast address" for its home subnet prefix and thus reaches one of the (possibly many) routers on its home link currently operating as a home agent. This home agent rejects the mobile node's Binding Update, but returns in the Binding Acknowledgement in response a list of all home agents on the home link. This list of home agents is maintained by each home agent on the home link through use of the Home Agent (H) bit in each home agent's periodic unsolicited multicast Router Advertisements.

The Binding Update and Binding Acknowledgement destination options, together with a "Binding Request" destination option, are also used to allow IPv6 nodes communicating with a mobile node, to dynamically learn and cache the mobile node's binding. When sending a packet to any IPv6 destination, a node checks its cached bindings for an entry for the packet's destination address. If a cached binding for this destination address is found, the node uses an IPv6 Routing header [5] (instead of IPv6 encapsulation) to route the packet to the mobile node by way of the care-of address indicated in this binding. If, instead, the sending node has no cached binding for this destination address, the node sends the packet normally (with no Routing header), and the packet is subsequently intercepted and tunneled by the mobile node's home agent as described above. A node communicating with a mobile node is referred to in this document as a "correspondent node" of the mobile node.

Since a Binding Update, Binding Acknowledgement, and Binding Request are each represented in a packet as an IPv6 destination option [5], they may be included in any IPv6 packet. Any of these options can be sent in either of two ways:

- A Binding Update, Binding Acknowledgement, or Binding Request can be included within any IPv6 packet carrying any payload such as TCP [16] or UDP [15].

- A Binding Update, Binding Acknowledgement, or Binding Request can be sent as a separate IPv6 packet containing no payload. In this case, the Next Header field in the last extension header in the packet is set to the value 59, to indicate "No Next Header" [5].

Mobile IPv6 also defines one additional IPv6 destination option. When a mobile node sends a packet while away from home, it will generally set the Source Address in the packet's IPv6 header to one of its current care-of addresses, and will also include a "Home Address" destination option in the packet, giving the mobile node's home address. Many routers implement security policies such as "ingress filtering" [6] that do not allow forwarding of packets that appear to have a Source Address that is not topologically correct. By using the care-of address as the IPv6 header Source Address, the packet will be able to pass normally through such routers, yet ingress filtering rules will still be able to locate the true physical source of the packet in the same way as packets from non-mobile nodes. By also including the Home Address option, the sending mobile node can communicate its home address to the correspondent node receiving this packet, allowing the use of the care-of address to be transparent above the Mobile IPv6 support level (e.g., at the transport layer). The inclusion of a Home Address option in a packet affects only the correspondent node's receipt of this single packet; no state is created or modified in the correspondent node as a result of receiving a Home Address option in a packet.

4.2. New IPv6 Destination Options

As discussed in general in Section 4.1, the following four new IPv6 destination options are defined for Mobile IPv6:

Binding Update

A Binding Update option is used by a mobile node to notify a correspondent node or the mobile node's home agent of its current binding. The Binding Update sent to the mobile node's home agent to register its primary care-of address is marked as a "home registration". Any packet that includes a Binding Update option MUST also include either an AH [7] or ESP [8] header providing sender authentication, data integrity protection, and replay protection. The Binding Update option is described in detail in Section 5.1.

Binding Acknowledgement

A Binding Acknowledgement option is used to acknowledge receipt of a Binding Update, if an acknowledgement was requested in the Binding Update. Any packet that includes a Binding Acknowledgement option MUST also include either an AH [7] or ESP [8] header providing sender authentication, data integrity protection, and replay protection. The Binding Acknowledgement option is described in detail in Section 5.2.

Binding Request

A Binding Request option is used to request a mobile node to send a Binding Update to the requesting node, containing the mobile node's current binding. This option is typically used by a correspondent node to refresh a cached binding for a mobile node, when the cached binding is in active use but the binding's lifetime is close to expiration. No special authentication is required for the Binding Request option. The Binding Request option is described in detail in Section 5.3.

Home Address

A Home Address option is used in a packet sent by a mobile node to inform the recipient of that packet of the mobile node's home address. For packets sent by a mobile node while away from home, the mobile node generally uses one of its care-of addresses as the Source Address in the packet's IPv6 header. By including a Home Address option in the packet, the correspondent node receiving the packet is able to substitute the mobile node's home address for this care-of address when processing the packet, thus making the use of the care-of address transparent to the correspondent node. If the IP header of a packet carrying a Home Address option is covered by authentication, then the Home Address option MUST also be covered by this authentication, but no other special authentication is required for the Home Address option. The Home Address option is described in detail in Section 5.4.

Extensions to the format of these options MAY be included after the fixed portion of the option data specified in this document. The presence of such extensions will be indicated by the Option Length field within the option. When the Option Length is greater than the length required for the option specified here, the remaining octets are interpreted as extensions. Currently, no extensions have been defined.

4.3. Conceptual Data Structures

This document describes the Mobile IPv6 protocol in terms of the following three conceptual data structures used in the maintenance of cached bindings:

Binding Cache

A cache, maintained by each IPv6 node, of bindings for other nodes. The Binding Cache MAY be implemented in any manner consistent with the external behavior described in this document, for example by being combined with the node's Destination Cache as maintained through Neighbor Discovery [11]. When sending a packet, the Binding Cache MUST be searched before the Neighbor Discovery conceptual Destination Cache [11]. Each Binding Cache entry conceptually contains the following fields:

- The home address of the mobile node for which this is the Binding Cache entry. This field is used as the key for searching the Binding Cache for the destination address of a packet being routed. If the destination address of the packet matches the home address in the Binding Cache entry, this entry SHOULD be used in routing that packet.

- The care-of address for the mobile node indicated by the home address field in this Binding Cache entry. If the destination address of a packet being routed by a node matches the home address in this entry, the packet SHOULD be routed to this care-of address, as described in Section 8.9, for packets originated by this node, or in Section 9.5, if this node is the mobile node's home agent and the packet was intercepted by it on the home link.

- A lifetime value, indicating the remaining lifetime for this Binding Cache entry. The lifetime value is initialized from the Lifetime field in the Binding Update that created or last modified this Binding Cache entry. Once the lifetime on this entry expires, the entry MUST be deleted from the Binding Cache.

- A flag indicating whether or not this Binding Cache entry is a "home registration" entry.

- The value of the Prefix Length field received in the Binding Update that created or last modified this Binding Cache entry.

- The maximum value of the Sequence Number field received in

previous Binding Updates for this mobile node home address.

All comparisons between Sequence Number values MUST be performed modulo 2**16.

- Recent usage information for this Binding Cache entry, as needed for the cache replacement policy in use in the Binding Cache and to assist in determining whether a Binding Request should be sent when the lifetime on this entry nears expiration.

- The time at which a Binding Request was last sent for this entry, as needed to implement the rate limiting restriction for sending Binding Requests.

An entry in a node's Binding Cache for which the node is serving as a home agent is marked as a "home registration" entry and SHOULD NOT be deleted by the home agent until the expiration of its binding lifetime. Other Binding Cache entries MAY be replaced at any time by any reasonable local cache replacement policy but SHOULD NOT be unnecessarily deleted. Any node's Binding Cache may contain at most one entry for each mobile node home address. The contents of a node's Binding Cache MUST NOT be changed in response to a Home Address option in a received packet.

Binding Update List

A list, maintained by each mobile node, recording information for each Binding Update sent by this mobile node, for which the Lifetime sent in that Binding Update has not yet expired. The Binding Update List includes all bindings sent by the mobile node: those to correspondent nodes, to the mobile node's home agent, and to a previous default router of the mobile node. The Binding Update List MAY be implemented in any manner consistent with the external behavior described in this document. Each Binding Update List entry conceptually contains the following fields:

- The IP address of the node to which a Binding Update was sent. This node might still have a Binding Cache entry derived from this Binding Update, if the Binding Update was successfully received by that node (e.g., not lost by the network) and if that node has not deleted the entry before its expiration (e.g., to reclaim space in its Binding Cache for other entries).

- The home address for which that Binding Update was sent. This will be the mobile node's home address for most Binding Updates (Sections 10.4 and 10.5), but will be

the mobile node's previous care-of address for Binding

Updates sent to the mobile node's previous default router (Section 10.6).

- The care-of address sent in that Binding Update. This value is necessary for determining if the mobile node has sent a Binding Update giving its new care-of address to this destination after changing its care-of address.

- The remaining lifetime of that binding. This lifetime is initialized from the Lifetime value sent in the Binding Update and is decremented until it reaches zero, at which time this entry MUST be deleted from the Binding Update List.

- The maximum value of the Sequence Number field sent in previous Binding Updates to this destination. All comparisons between Sequence Number values MUST be performed modulo 2**16.

- The state of any retransmissions needed for this Binding Update, if the Acknowledge (A) bit was set in this Binding Update. This state includes the time remaining until the next retransmission attempt for the Binding Update, and the current state of the exponential back-off process for retransmissions.

- The time at which a Binding Update was last sent to this destination, as needed to implement the rate limiting restriction for sending Binding Updates.

- A flag that, when set, indicates that future Binding Updates should not be sent to this destination. The mobile node sets this flag in the Binding Update List entry when it receives an ICMP Parameter Problem, Code 2, error message in response to a Binding Update sent to that destination, as described in Section 10.9.

Home Agents List

A list, maintained by each home agent, recording the IP address of each other home agent on a link on which this node is serving as a home agent; the home agent maintains a separate Home Agents List for each such link on which it is serving. This list is used in the dynamic home agent address discovery mechanism. The information for the list is learned through receipt of periodic unsolicited multicast Router Advertisements from each other home agent on the link, in which the Home Agent (H) bit is set, in a manner similar to the Default Router List conceptual data structure maintained by each host

for Neighbor Discovery [11]. The Home Agents List MAY be

implemented in any manner consistent with the external behavior described in this document. Each Home Agents List entry conceptually contains the following fields:

- The IP address of another router on the home link that this node currently believes is operating as a home agent for this link. A new entry is created or an existing entry is updated in the Home Agents List in response to receipt of a valid Router Advertisement in which the Home Agent (H) bit is set.

- The remaining lifetime of this Home Agents List entry. The lifetime is initialized from the Router Lifetime field in the received Router Advertisement and is decremented until it reaches zero, at which time this entry MUST be deleted from the Home Agents List.

4.4. Binding Management

When a mobile node configures a new care-of address and decides to use this new address as its primary care-of address, the mobile node registers this new binding with its home agent by sending the home agent a Binding Update. The mobile node indicates that an acknowledgement is needed for this Binding Update and continues to periodically retransmit it until acknowledged. The home agent acknowledges the Binding Update by returning a Binding Acknowledgement to the mobile node.

When a mobile node receives a packet tunneled to it from its home agent, the mobile node assumes that the original sending correspondent node has no Binding Cache entry for the mobile node, since the correspondent node would otherwise have sent the packet directly to the mobile node using a Routing header. The mobile node thus returns a Binding Update to the correspondent node, allowing it to cache the mobile node's binding for routing future packets. Although the mobile node may request an acknowledgement for this Binding Update, it need not, since subsequent packets from the correspondent node will continue to be intercepted and tunneled by the mobile node's home agent, effectively causing any needed Binding Update retransmission.

A correspondent node with a Binding Cache entry for a mobile node may refresh this binding, for example if the binding's lifetime is near expiration, by sending a Binding Request to the mobile node. Normally, a correspondent node will only refresh a Binding Cache entry in this way if it is actively communicating with the mobile node and has indications, such as an open TCP connection to

the mobile node, that it will continue this communication in the

future. When a mobile node receives a Binding Request, it replies by returning a Binding Update to the node sending the Binding Request.

A mobile node may use more than one care-of address at the same time, although only one care-of address may be registered for it at its home agent as its primary care-of address. The mobile node's home agent will tunnel all intercepted packets for the mobile node to its (single) registered primary care-of address, but the mobile node will accept packets that it receives at any of its current care-of addresses. Use of more than one care-of address by a mobile node may be useful, for example, to improve smooth handoff when the mobile node moves from one wireless link to another. If each of these wireless links is connected to the Internet through a separate base station, such that the wireless transmission range from the two base stations overlap, the mobile node may be able to remain connected to both links while in the area of overlap. In this case, the mobile node could acquire a new care-of address on the new link before moving out of transmission range and disconnecting from the old link. The mobile node may thus still accept packets at its old care-of address while it works to update its home agent and correspondent nodes, notifying them of its new care-of address on the new link.

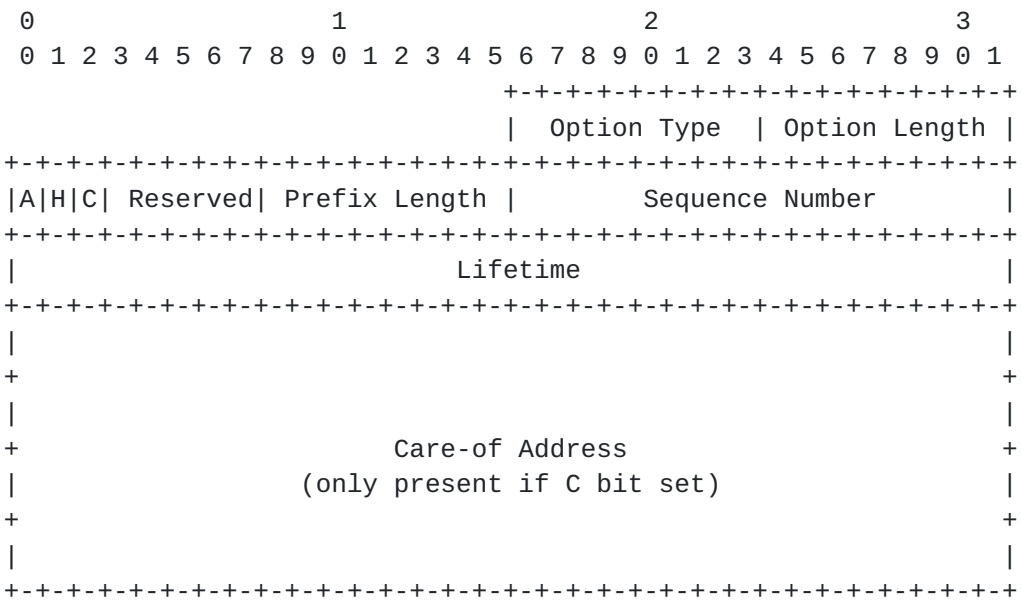
Since correspondent nodes cache bindings, it is expected that correspondent nodes usually will route packets directly to the mobile node's care-of address, so that the home agent is rarely involved with packet transmission to the mobile node. This is essential for scalability and reliability, and for minimizing overall network load. By caching the care-of address of a mobile node, optimal routing of packets can be achieved from the correspondent node to the mobile node. Routing packets directly to the mobile node's care-of address also eliminates congestion at the mobile node's home agent and home link. In addition, the impact of any possible failure of the home agent, the home link, or intervening networks leading to or from the home link is reduced, since these nodes and links are not involved in the delivery of most packets to the mobile node.

5. New IPv6 Destination Options

5.1. Binding Update Option Format

The Binding Update destination option is used by a mobile node to notify other nodes of a new care-of address.

The Binding Update option is encoded in type-length-value (TLV) format as follows:



Option Type

195 ???

Option Length

8-bit unsigned integer. Length of the option, in octets, excluding the Option Type and Option Length fields. For the current definition of the Binding Update option, the minimum value for this field is 8; the length is 24 if the Care-of Address Present (C) bit is set.

Acknowledge (A)

The Acknowledge (A) bit is set by the sending node to request a Binding Acknowledgement (Section 5.2) be returned upon receipt of the Binding Update option.

Home Registration (H)

The Home Registration (H) bit is set by the sending mobile node

to request the receiving node to act as this node's home agent.

The Destination Address in the IP header of the packet carrying this option MUST be that of a router sharing the same subnet prefix as the home address of the mobile node in the binding (given by the Home Address field in the Home Address option in the packet).

Care-of Address Present (C)

The Care-of Address Present (C) bit indicates the presence of the Care-of Address field in the Binding Update. The care-of address for this binding is either the address in the Care-of Address field in the Binding Update, if this bit is set, or the Source Address in the packet's IPv6 header, if this bit is not set.

Reserved

Sent as 0; ignored on reception.

Prefix Length

The Prefix Length field is valid only for a "home registration" Binding Update. This field MUST be zero if the Home Registration (H) bit is not set in the Binding Update. The Prefix Length field is set by the sending mobile node to the (nonzero) length of its subnet prefix in its home address (given in the Home Address option in the packet) to request its home agent to use the interface identifier in the mobile node's home address (the remaining low-order bits after the indicated subnet prefix) to form all other appropriate home addresses for the mobile node. The home agent becomes the home agent not only for the individual home address given in this binding, but also for all other home addresses for this mobile node formed from this interface identifier. That is, for each on-link prefix on the home link, the home agent uses the interface identifier to form other valid addresses for the mobile node on the home link, and acts as a home agent also for those addresses. In addition, the home agent forms the link-local address and site-local address corresponding to this interface identifier, and defends each for purposes of Duplicate Address Detection. Details of this operation are described in Section 9.3.

Sequence Number

Used by the receiving node to sequence Binding Updates and by the sending node to match a returned Binding Acknowledgement with this Binding Update. Each Binding Update sent by a mobile node MUST use a Sequence Number greater than the Sequence

Number value sent in the previous Binding Update (if any) to

the same destination address (modulo 2**16). There is no requirement, however, that the Sequence Number value strictly increase by 1 with each new Binding Update sent or received.

Lifetime

32-bit unsigned integer. The number of seconds remaining before the binding must be considered expired. A value of all one bits (0xffffffff) indicates infinity. A value of zero indicates that the Binding Cache entry for the mobile node should be deleted.

Care-of Address

This field in the Binding Update is optional and is only present when the Care-of Address Present (C) bit is set. If present, it gives the care-of address of the mobile node for this binding. For most Binding Updates sent, it is expected that this field will not be present, and instead that the care-of address for the binding will be given by the Source Address field in the packet's IPv6 header.

Any packet including a Binding Update option MUST also include a Home Address option. The home address of the mobile node in the binding given in the Binding Update option is indicated by the Home Address field in the Home Address option in the packet.

Any packet that includes a Binding Update option MUST also include either an AH [7] or ESP [8] header providing sender authentication, data integrity protection, and replay protection.

If the care-of address in the binding (either the Care-of Address field in the Binding Update option or the Source Address field in the packet's IPv6 header) is equal to the home address of the mobile node, the Binding Update option indicates that any existing binding for the mobile node should be deleted. Likewise, if the Lifetime field in the Binding Update option is equal to 0, the Binding Update option indicates that any existing binding for the mobile node should be deleted. In each of these cases, no Binding Cache entry for the mobile node should be created in response to receiving the Binding Update.

The last Sequence Number value sent to a destination is stored by the mobile node in the Binding Update List entry for that destination; the last Sequence Number value received from a mobile node is stored by a correspondent node in the Binding Cache entry for that mobile node. Thus, the mobile node's and the correspondent node's knowledge of the last sequence number expire at the same time. If the sending mobile node has no Binding Update List entry, the Sequence Number

may start at any value; if the receiving correspondent node has no

Binding Cache entry, it should accept a Binding Update with any Sequence Number value.

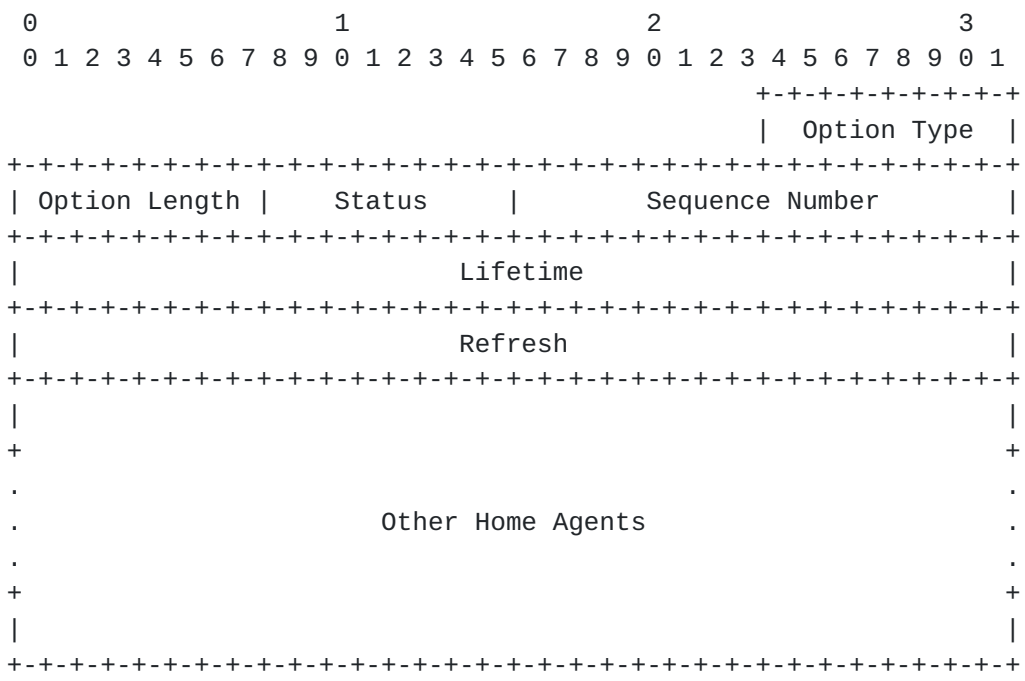
The three highest-order bits of the Option Type are encoded to indicate specific processing of the option [5]. For the Binding Update option, these three bits are set to 110, indicating that any IPv6 node processing this option that does not recognize the Option Type must discard the packet and, only if the packet's Destination Address was not a multicast address, return an ICMP Parameter Problem, Code 2, message to the packet's Source Address; and that the data within the option cannot change en-route to the packet's final destination.

Extensions to the Binding Update option format may be included after the fixed portion of the Binding Update option specified above. The presence of such extensions will be indicated by the Option Length field. When the Option Length is greater than the length defined above, the remaining octets are interpreted as extensions. Currently, no extensions have been defined.

5.2. Binding Acknowledgement Option Format

The Binding Acknowledgement destination option is used to acknowledge receipt of a Binding Update option (Section 5.1). When a node receives a packet containing a Binding Update option, with this node being the destination node of the packet (only the destination node processes the option since it is a destination option), this node MUST return a Binding Acknowledgement to the source of the packet, if the Acknowledge (A) bit is set in the Binding Update.

The Binding Acknowledgement option is encoded in type-length-value (TLV) format as follows:



Option Type

2 ???

Option Length

8-bit unsigned integer. Length of the option, in octets, excluding the Option Type and Option Length fields. This field MUST be set to 11 + 16 * (the number of IP addresses included in the Other Home Agents field). The number of addresses included in the Other Home Agents field MUST be zero (Option Length then MUST be set to 11), unless the Status field is set to 135 (dynamic home agent address discovery response).

Status

8-bit unsigned integer indicating the disposition of the Binding Update. Values of the Status field less than 128 indicate that the Binding Update was accepted by the receiving node. The following such Status values are currently defined:

0 Binding Update accepted

Values of the Status field greater than or equal to 128 indicate that the Binding Update was rejected by the receiving node. The following such Status values are currently defined:

128 Reason unspecified
129 Poorly formed Binding Update
130 Administratively prohibited
131 Insufficient resources
132 Home registration not supported
133 Not home subnet
134 Sequence Number field value too small
135 Dynamic home agent address discovery response
136 Incorrect interface identifier length

Up-to-date values of the Status field are to be specified in the most recent "Assigned Numbers" [17].

Sequence Number

The Sequence Number in the Binding Acknowledgement is copied from the Sequence Number field in the Binding Update option, for use by the mobile node in matching this Acknowledgement with an outstanding Binding Update.

Lifetime

The granted lifetime for which this node will attempt to retain the entry for this mobile node in its Binding Cache. If the node sending the Binding Acknowledgement is serving as the mobile node's home agent, the Lifetime period also indicates the period for which this node will continue this service; if the mobile node requires home agent service from this node beyond this period, the mobile node MUST send a new Binding Update to it before the expiration of this period, in order to extend the lifetime. The value of this field is undefined if the Status field indicates that the Binding Update was rejected.

Refresh

The recommended period at which the mobile node SHOULD send a new Binding Update to this node in order to "refresh" the mobile node's binding in this node's Binding Cache. This refreshing of the binding is useful in case the node fails and loses its cache state. The Refresh period is determined by the node sending the Binding Acknowledgement (the node caching the binding). If this node is serving as the mobile node's home agent, the Refresh value may be set, for example, based on whether the node stores the mobile node's binding in volatile storage or in nonvolatile storage. If the node sending the Binding Acknowledgement is not serving as the mobile node's home agent, the Refresh period SHOULD be set equal to the Lifetime period in the Binding Acknowledgement; even if this node loses this cache entry due to a failure of the node, packets from it can still reach the mobile node through the mobile node's home agent, causing a new Binding Update to this node to allow it to recreate this cache entry. The value of this field is undefined if the Status field indicates that the Binding Update was rejected.

Other Home Agents

A list of other home agents on the home link for the mobile node to which this Binding Acknowledgement is sent. This field MUST NOT be present (zero addresses listed) unless the Binding Acknowledgement is sent in response to an anycast Binding Update sent by this mobile node attempting dynamic home agent address discovery. In this case, the Status field MUST be set to 135 (dynamic home agent address discovery response). The list of home agents in the Other Home Agents field MUST NOT include this home agent's own unicast IP address, which is returned instead to the mobile node in the Source Address field in the IPv6 header of the packet in which this Binding Acknowledgement is sent.

Any packet that includes a Binding Acknowledgement option MUST also include either an AH [7] or ESP [8] header providing sender authentication, data integrity protection, and replay protection.

If the node returning the Binding Acknowledgement accepted the Binding Update for which the Acknowledgement is being returned (the value of the Status field in the Acknowledgement is less than 128), this node will have an entry for the mobile node in its Binding Cache and MUST use this entry (which includes the care-of address received in the Binding Update) in sending the packet containing the Binding Acknowledgement to the mobile node. The details of sending this

packet to the mobile node are the same as for sending any packet to a mobile node using a binding, and are described in Section 8.9. The

packet is sent using a Routing header, routing the packet to the mobile node by way of its care-of address recorded in the Binding Cache entry.

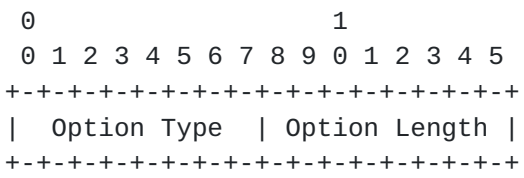
If the node returning the Binding Acknowledgement instead rejected the Binding Update (the value of the Status field in the Acknowledgement is greater than or equal to 128), this node MUST similarly use a Routing header in sending the packet containing the Binding Acknowledgement, as described in Section 8.9, but MUST NOT use its Binding Cache in forming the IP header or Routing header in this packet. Rather, the care-of address used by this node in sending the packet containing the Binding Acknowledgement MUST be copied from the care-of address received in the rejected Binding Update; this node MUST NOT modify its Binding Cache in response to receiving this rejected Binding Update and MUST ignore its Binding Cache in sending the packet in which it returns this Binding Acknowledgement. The packet is sent using a Routing header, routing the packet to the home address of the rejected Binding Update by way of the care-of address indicated in the packet containing the Binding Update. When sending a Binding Acknowledgement to reject a Binding Update, the Binding Acknowledgement MUST be sent in an IPv6 packet containing no payload (with the Next Header field in the last extension header in the packet set to indicate "No Next Header" [5]).

The three highest-order bits of the Option Type are encoded to indicate specific processing of the option [5]. For the Binding Acknowledgement option, these three bits are set to 000, indicating that any IPv6 node processing this option that does not recognize the Option Type must skip over this option and continue processing the header, and that the data within the option cannot change en-route to the packet's final destination.

5.3. Binding Request Option Format

The Binding Request destination option is used to request a mobile node's binding from the mobile node. When a mobile node receives a packet containing a Binding Request option, it SHOULD return a Binding Update (Section 5.1) to the source of the Binding Request.

The Binding Request option is encoded in type-length-value (TLV) format as follows:



Option Type

3 ???

Option Length

8-bit unsigned integer. Length of the option, in octets, excluding the Option Type and Option Length fields. For the current definition of the Binding Request option, this field MUST be set to 0.

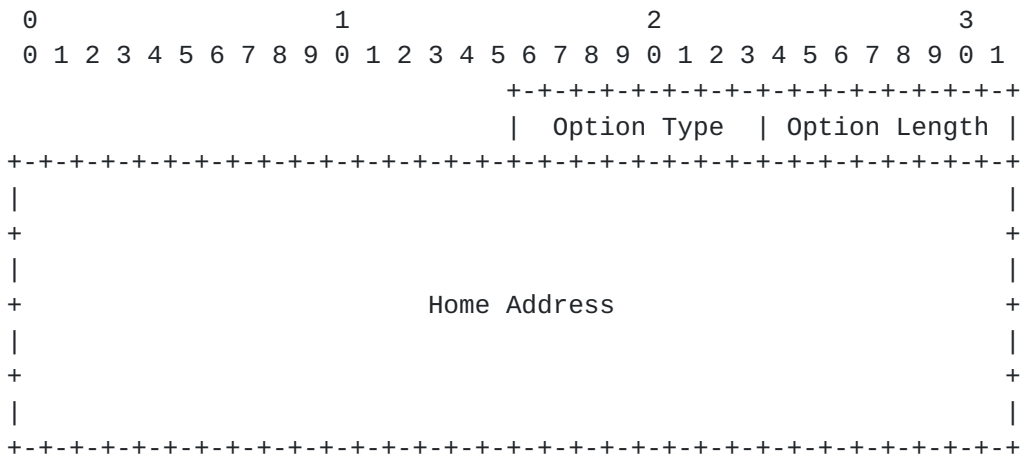
The three highest-order bits of the Option Type are encoded to indicate specific processing of the option [5]. For the Binding Request option, these three bits are set to 000, indicating that any IPv6 node processing this option that does not recognize the Option Type must skip over this option and continue processing the header, and that the data within the option cannot change en-route to the packet's final destination.

Extensions to the Binding Request option format may be included after the fixed portion of the Binding Request option specified above. The presence of such extensions will be indicated by the Option Length field. When the Option Length is greater than 0 octets, the remaining octets are interpreted as extensions. Currently, no extensions have been defined.

5.4. Home Address Option Format

The Home Address destination option is used in a packet sent by a mobile node to inform the recipient of that packet of the mobile node's home address. For packets sent by a mobile node while away from home, the mobile node generally uses one of its care-of addresses as the Source Address in the packet's IPv6 header. By including a Home Address option in the packet, the correspondent node receiving the packet is able to substitute the mobile node's home address for this care-of address when processing the packet, thus making the use of the care-of address transparent to the correspondent node.

The Home Address option is encoded in type-length-value (TLV) format as follows:



Option Type

196 ???

Option Length

8-bit unsigned integer. Length of the option, in octets, excluding the Option Type and Option Length fields. For the current definition of the Home Address option, this field MUST be set to 16.

Home Address

The home address of the mobile node sending the packet.

The inclusion of a Home Address option in a packet affects only the correspondent node's receipt of this single packet; no state is created or modified in the correspondent node as a result of receiving a Home Address option in a packet. In particular, the

receipt of a packet containing a Home Address option MUST NOT alter

the contents of the receiver's Binding Cache due to the presence of the Home Address option, and the mapping between the home address and care-of address indicated by the Home Address option MUST NOT be used as a basis for routing subsequent packets sent by this receiving node.

No special authentication of the Home Address option is required, except that if the IPv6 header of a packet is covered by authentication, then that authentication MUST also cover the Home Address option; this coverage is achieved automatically by the definition of the Option Type code for the Home Address option, since it indicates that the option is included in the authentication computation. If the packet carries no IP authentication, then the contents of the Home Address option, as well as the Source Address field or any other field in the IPv6 header, may have been forged or altered during transit. Upon receipt of a packet containing a Home Address option, the receiving node replaces the Source Address in the IPv6 header with the Home Address in the Home Address option. By requiring that any authentication of the IPv6 header also cover the Home Address option, the security of the Source Address field in the IPv6 header is not compromised by the presence of a Home Address option. Security issues related to the Home Address option are discussed further in Section 13.

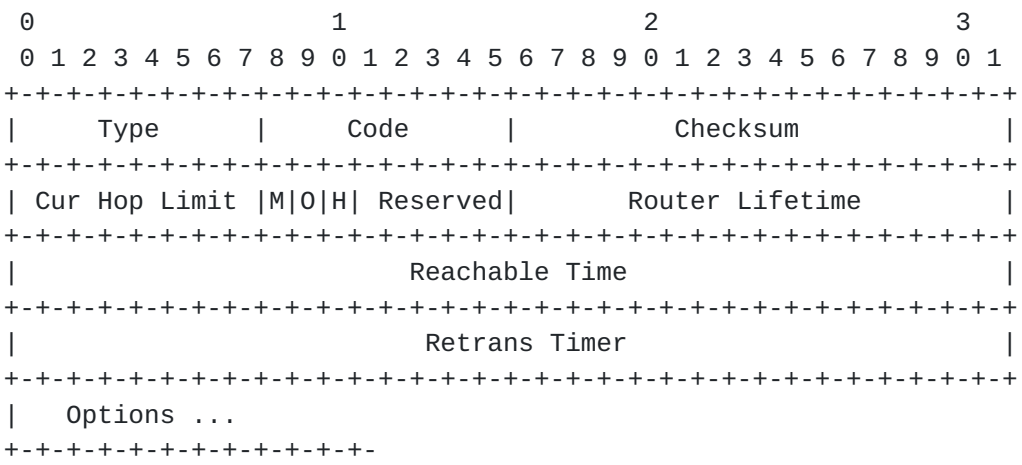
The three highest-order bits of the Option Type are encoded to indicate specific processing of the option [5]. For the Home Address option, these three bits are set to 110, indicating that any IPv6 node processing this option that does not recognize the Option Type must discard the packet and, only if the packet's Destination Address was not a multicast address, return an ICMP Parameter Problem, Code 2, message to the packet's Source Address; and that the data within the option cannot change en-route to the packet's final destination.

Extensions to the Home Address option format may be included after the fixed portion of the Home Address option specified above. The presence of such extensions will be indicated by the Option Length field. When the Option Length is greater than 8 octets, the remaining octets are interpreted as extensions. Currently, no extensions have been defined.

6. Modifications to IPv6 Neighbor Discovery

6.1. Router Advertisement Message Format

Mobile IPv6 requires the addition of a single flag bit to the format of a Router Advertisement message [11], for use in the dynamic home agent address discovery mechanism (Sections 9.2 and 10.4). The Router Advertisement message format is thus modified as follows:



This format represents the following changes over that specified for Neighbor Discovery [11]:

Home Agent (H)

The Home Agent (H) bit is set in a Router Advertisement to indicate that the router sending this Router Advertisement is also functioning as a Mobile IP home agent.

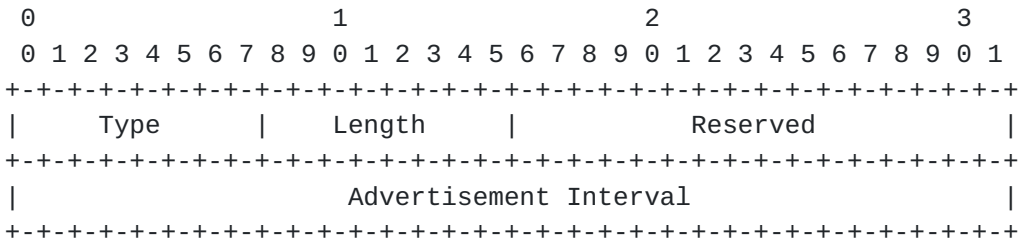
Reserved

Reduced from a 6-bit field to a 5-bit field to account for the addition of the Home Agent (H) bit.

6.2. Advertisement Interval Option Format

The Advertisement Interval option is used in Router Advertisement messages to advertise the interval at which this router sends unsolicited multicast Router Advertisements. Routers operating as Mobile IP home agents MAY include this option in their Router Advertisements. A mobile node receiving a Router Advertisement containing this option SHOULD utilize the specified Advertisement Interval for that home agent in its movement detection algorithm, as described in Section 10.2.

This option MUST be silently ignored for other Neighbor Discovery messages.



Type

6 ???

Length

1

Reserved

This field is unused. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.

Advertisement Interval

32-bit unsigned integer. The maximum time, in milliseconds, between successive unsolicited router Router Advertisement messages sent by this router on this network interface. Using the conceptual router configuration variables defined by Neighbor Discovery [11], this field MUST be equal to the value MaxRtrAdvInterval, expressed in milliseconds.

6.3. Changes to MinRtrAdvInterval Limits

The Neighbor Discovery protocol specification [11] limits routers to a minimum interval of 3 seconds between sending unsolicited multicast Router Advertisement messages from any given network interface (MinRtrAdvInterval), stating that:

> "Routers generate Router Advertisements frequently enough that hosts will learn of their presence within a few minutes, but not frequently enough to rely on an absence of advertisements to detect router failure; a separate Neighbor Unreachability Detection algorithm provides failure detection."

This limitation, however, is not suitable to providing timely movement detection for mobile nodes. Mobile nodes detect their own movement by learning the presence of new routers as the mobile node moves into wireless transmission range of them (or physically connects to a new wired network), and by learning that previous routers are no longer reachable. Mobile nodes MUST be able to quickly detect when they move to a link served by a new router, so that they can acquire a new care-of address and send Binding Updates to register this care-of address with their home agent and to notify correspondent nodes as needed.

Thus, routers serving as Mobile IP home agents MAY send unsolicited multicast Router Advertisements more frequently than this limit. In particular, on network interfaces where the home agent is expecting to provide service to visiting mobile nodes (e.g., wireless network interfaces), the home agent SHOULD be configured with a smaller MinRtrAdvInterval value to allow sending of unsolicited multicast Router Advertisements more often. A recommended maximum rate is once per second, although specific knowledge of the type of network interface in use SHOULD be taken into account in configuring this limit for each network interface.

7. Requirements for IPv6 Nodes

Mobile IPv6 places some special requirements on the functions provided by different IPv6 nodes. This section summarizes those requirements, identifying the functionality each requirement is intended to support. Further details on this functionality is provided in the following sections.

7.1. Requirements for All IPv6 Hosts and Routers

Since any IPv6 node may at any time be a correspondent node of a mobile node, either sending a packet to a mobile node or receiving a packet from a mobile node, the following requirements pertain to ALL IPv6 nodes (whether host or router, whether mobile or stationary):

- Every IPv6 node MUST be able to process a Home Address option received in a packet.

- Every IPv6 node SHOULD be able to process a Binding Update option received in a packet, and to return a Binding Acknowledgement option if requested.

- Every IPv6 node SHOULD be able to maintain a Binding Cache of the bindings received in accepted Binding Updates.

7.2. Requirements for IPv6 Home Agents

In order for a mobile node to operate correctly while away from home, at least one IPv6 router in the mobile node's home link must function as a home agent for the mobile node. The following special requirements pertain to all IPv6 routers capable of serving as a home agent:

- Every home agent MUST be able to maintain an entry in its Binding Cache for each mobile node for which it is serving as the home agent. Each such Binding Cache entry records the mobile node's binding with its primary care-of address and is marked as a "home registration".

- Every home agent MUST be able to intercept packets (using proxy Neighbor Discovery) on the local subnet addressed to a mobile node for which it is currently serving as the home agent while that mobile node is away from home.

- Every home agent MUST be able to encapsulate such intercepted packets in order to tunnel them to the primary care-of address for the mobile node indicated in its binding.

- Every home agent MUST be able to return a Binding Acknowledgement in response to a Binding Update received with the Acknowledge (A) bit set.

- Every home agent MUST be able to accept packets addressed to the Home-Agents anycast address for the subnet on which it is serving as a home agent, and MUST be able to participate in dynamic home agent address discovery (Section 9.2).

7.3. Requirements for IPv6 Mobile Nodes

Finally, the following requirements pertain all IPv6 nodes capable of functioning as mobile nodes:

- Every IPv6 mobile node MUST be able to perform IPv6 decapsulation [4].

- Every IPv6 mobile node MUST support sending Binding Updates, as specified in Sections 10.4, 10.5, and 10.6; and MUST be able to receive and process Binding Acknowledgements, as specified in Section 10.10.

- Every IPv6 mobile node MUST maintain a Binding Update List in which it records the IP address of each other node to which it has sent a Binding Update, for which the Lifetime sent in that binding has not yet expired.

- Every IPv6 mobile node MUST support receiving a Binding Request by responding with a Binding Update.

- Every IPv6 mobile node MUST support sending packets containing a Home Address option; this option MUST be included in all packets sent while away from home, if the packet would otherwise have been sent with the mobile node's home address as the IP Source Address.

8. Correspondent Node Operation

A correspondent node is any node communicating with a mobile node. The correspondent node, itself, may be stationary or mobile, and may possibly also be functioning as a home agent for Mobile IPv6. The procedures in this section thus apply to all IPv6 nodes.

8.1. Receiving Packets from a Mobile Node

Packets sent by a mobile node while away from home generally include a Home Address option. When any node receives a packet containing a Home Address option, it MUST process the option in a manner consistent with copying the Home Address field from the Home Address option into the IPv6 header, replacing the original value of the Source Address field there. Further processing of the packet (e.g., at the transport layer) thus need not know that the original Source Address was a care-of address, or that the Home Address option was used in the packet. Since the sending mobile node uses its home address at the transport layer when sending such a packet, the use of the care-of address and Home Address option is thus transparent to both the mobile node and the correspondent node above the level of the Home Address option generation and processing.

8.2. Receiving Binding Updates

Upon receiving a Binding Update option in some packet, the receiving node MUST validate the Binding Update according to the following tests:

- The packet MUST contain a valid Home Address option. The home address for the binding is specified by the Home Address field of the Home Address option.

- The Option Length field in the Binding Update option is greater than or equal to the length specified in Section 5.1.

- The packet contains a valid AH [7] or ESP [8] header that provides sender authentication, integrity protection, and replay protection.

- The Sequence Number field in the Binding Update option is greater than the Sequence Number received in the previous Binding Update for this home address, if any. The Sequence Number comparison is performed modulo 2**16.

Any Binding Update not satisfying all of these tests MUST be silently ignored, and the packet carrying the Binding Update MUST be

discarded.

If the Binding Update is valid according to the tests above, then the Binding Update is processed further as follows:

- If the Destination Address in the packet's IPv6 header is the Home-Agents anycast address for a local subnet and this address is assigned to one of this node's network interfaces, then the mobile node sending this Binding Update is attempting dynamic home agent address discovery. Processing for this type of received Binding Update is described in Section 9.2. (If the Destination Address is not assigned to one of this node's network interfaces, then the packet would have been forwarded as a normal packet and the Binding Update, as a destination option, would not be processed in any way by this node.)

- If the Lifetime specified in the Binding Update is nonzero and the specified Care-of Address is not equal to the home address for the binding (as given in the Home Address option in the packet), then this is a request to cache a binding for the mobile node. Processing for this type of received Binding Update is described in Section 8.3.

- If the Lifetime specified in the Binding Update is zero or the specified Care-of Address matches the home address for the binding, then this is a request to delete the mobile node's cached binding. Processing for this type of received Binding Update is described in Section 8.4.

8.3. Requests to Cache a Binding

If a node receives a valid Binding Update requesting it to cache a binding for a mobile node, as specified in Section 8.2, then the node MUST examine the Home Registration (H) bit in the Binding Update to determine how to further process the Binding Update. If the Home Registration (H) bit is set, the Binding Update is processed according to the procedure specified in Section 9.3.

If the Home Registration (H) bit is not set, then the receiving node SHOULD create a new entry in its Binding Cache for this mobile node (or update its existing Binding Cache entry for this mobile node, if such an entry already exists). The home address of the mobile node is taken from the Home Address field in the packet's Home Address option. The new Binding Cache entry records the association between this home address and the care-of address for the binding, as specified in either the Care-of Address field of the Binding Update or in the Source Address field in the packet's IPv6 header. Any Binding Cache entry created or updated in response to processing this Binding Update MUST be deleted after the expiration of the Lifetime

period specified in the Binding Update.

8.4. Requests to Delete a Binding

If a node receives a valid Binding Update requesting it to delete a cached binding for a mobile node, as specified in Section 8.2, then the node MUST examine the Home Registration (H) bit in the Binding Update to determine how to further process the Binding Update. If the Home Registration (H) bit is set, the Binding Update is processed according to the procedure specified in Section 9.4.

If the Home Registration (H) bit is not set, then the receiving node MUST delete any existing entry in its Binding Cache for this mobile node. The home address of the mobile node is taken from the Home Address field in the packet's Home Address option.

8.5. Sending Binding Acknowledgements

When any node receives a packet containing a Binding Update option in which the Acknowledge (A) bit is set, it SHOULD return a Binding Acknowledgement option acknowledging receipt of the Binding Update. If the node accepts the Binding Update and creates or updates an entry in its Binding Cache for this binding, the Status field in the Binding Acknowledgement MUST be set to a value less than 128; if the node rejects the Binding Update and does not create or update an entry for this binding, the Status field in the Binding Acknowledgement MUST be set to a value greater than or equal to 128. Specific values for the Status field are described in Section 5.2 and in the most recent "Assigned Numbers" [17].

As described in Section 5.2, the packet in which the Binding Acknowledgement is returned MUST include either an AH [7] or ESP [8] header providing sender authentication, data integrity protection, and replay protection; and the packet MUST be sent using a Routing header in the same way as any other packet sent to a mobile node using a care-of address (even if the binding was rejected), as described in Section 8.9. The packet is routed first to the care-of address contained in the Binding Update being acknowledged, and then to the mobile node's home address. This use of the Routing header ensures that the Binding Acknowledgement will be routed to the current location of the node sending the Binding Update, whether the Binding Update was accepted or rejected.

8.6. Sending Binding Requests

Entries in a node's Binding Cache MUST be deleted when their lifetime expires. If such an entry is still in active use in sending packets to a mobile node, the next packet sent to the mobile node will be routed normally, to the mobile node's home link, where it will be

intercepted and tunneled to the mobile node. The mobile node will

then return a Binding Update to the sender, allowing it to create a new Binding Cache entry for sending future packets to the mobile node. Communication with the mobile node continues uninterrupted, but the forwarding of this packet through the mobile node's home agent creates additional overhead and latency in delivering packets to the mobile node.

If the sender knows that the Binding Cache entry is still in active use, it MAY send a Binding Request to the mobile node in an attempt to avoid this overhead and latency due to deleting and recreating the Binding Cache entry. Since a Binding Request is a destination option, it may, for example, be included in any packet already being sent to the mobile node, such as a packet that is part of ongoing TCP communication with the mobile node. When the mobile node receives a packet from some sender containing a Binding Request, it returns a Binding Update to that sender, giving its current binding and a new lifetime.

8.7. Cache Replacement Policy

Any entry in a node's Binding Cache MUST be deleted after the expiration of the Lifetime specified in the Binding Update from which the entry was created or was last updated. Conceptually, a node maintains a separate timer for each entry in its Binding Cache. When creating or updating a Binding Cache entry in response to a received and accepted Binding Update, the node sets the timer for this entry to the specified Lifetime period. When a Binding Cache entry's timer expires, the node deletes the entry.

Each node's Binding Cache will, by necessity, have a finite size. A node MAY use any reasonable local policy for managing the space within its Binding Cache, except that any entry marked as a "home registration" (Section 9.3) MUST NOT be deleted from the cache until the expiration of its lifetime period. When attempting to add a new "home registration" entry in response to a Binding Update with the Home Registration (H) bit set, if insufficient space exists (or can be reclaimed) in the node's Binding Cache, the node MUST reject the Binding Update and SHOULD return a Binding Acknowledgement to the sending mobile node, in which the Status field is set to 131 (insufficient resources). When otherwise attempting to add a new entry to its Binding Cache, a node MAY, if needed, choose to drop any entry already in its Binding Cache, other than a "home registration" entry, in order to make space for the new entry. For example, a "least-recently used" (LRU) strategy for cache entry replacement among entries not marked as a "home registration" is likely to work well.

Any binding dropped from a node's Binding Cache due to lack of cache space will be rediscovered and a new cache entry created, if the

binding is still in active use by the node for sending packets. If the node sends a packet to a destination for which it has dropped the entry from its Binding Cache, the packet will be routed normally, leading to the mobile node's home link. There, the packet will be intercepted by the mobile node's home agent and tunneled to the mobile node's current primary care-of address. As when a Binding Cache entry is initially created, this indirect routing to the mobile node through its home agent will result in the mobile node sending a Binding Update to this sending node when it receives the tunneled packet, allowing it to add an entry again for this destination to its Binding Cache.

8.8. Receiving ICMP Error Messages

When a correspondent node sends a packet to a mobile node, if the correspondent node has a Binding Cache entry for the destination address of the packet, then the correspondent node uses a Routing header to deliver the packet to the mobile node through the care-of address in the binding recorded in the Binding Cache entry. Any ICMP error message caused by the packet on its way to the mobile node will be returned normally to the correspondent node.

On the other hand, if the correspondent node has no Binding Cache entry for the mobile node, the packet will be routed to the mobile node's home link, where it will be intercepted by the mobile node's home agent, encapsulated, and tunneled to the mobile node's primary care-of address. Any ICMP error message caused by the packet on its way to the mobile node while in the tunnel, will be returned to the mobile node's home agent (the source of the tunnel). By the definition of IPv6 encapsulation [4], this encapsulating node MUST relay certain ICMP error messages back to the original sender of the packet, which in this case is the correspondent node.

Likewise, if a packet for a mobile node arrives at the mobile node's previous default router (e.g., the mobile node moved after the packet was sent), the router will encapsulate and tunnel the packet to the mobile node's new care-of address (if it has a Binding Cache entry for the mobile node). As above, any ICMP error message caused by the packet while in this tunnel will be returned to the previous default router (the source of the tunnel), which MUST relay certain ICMP error messages back to the correspondent node [4].

Thus, in all cases, any meaningful ICMP error messages caused by packets from a correspondent node to a mobile node will be returned to the correspondent node. If the correspondent node receives persistent ICMP Destination Unreachable messages after sending packets to a mobile node based on an entry in its Binding

Cache, the correspondent node SHOULD delete this Binding Cache entry. If the correspondent node subsequently transmits another

packet to the mobile node, the packet will be routed to the mobile node's home link, intercepted by the mobile node's home agent, and tunneled to the mobile node's primary care-of address using IPv6 encapsulation. The mobile node will then return a Binding Update to the correspondent node, allowing it to recreate a (correct) Binding Cache entry for the mobile node.

8.9. Sending Packets to a Mobile Node

Before sending any packet, the sending node SHOULD examine its Binding Cache for an entry for the destination address to which the packet is being sent. If the sending node has a Binding Cache entry for this address, the sending node SHOULD use a Routing header to route the packet to this mobile node (the destination node) by way of the care-of address in the binding recorded in that Binding Cache entry. For example, assuming use of a Type 0 Routing header [5], if no other use of a Routing header is involved in the routing of this packet, the mobile node sets the fields in the packet's IPv6 header and Routing header as follows:

- The Destination Address in the packet's IPv6 header is set to the mobile node's care-of address copied from the Binding Cache entry.

- The Routing header is initialized to contain a single route segment, with an Address of the mobile node's home address (the original destination address to which the packet was being sent).

Following the definition of a Type 0 Routing header [5], this packet will be routed to the mobile node's care-of address, where it will be delivered to the mobile node (the mobile node has associated the care-of address with its network interface). Normal processing of the Routing header by the mobile node will then proceed as follows:

- The mobile node swaps the Destination Address in the packet's IPv6 header and the Address specified in the Routing header. This results in the packet's IP Destination Address being set to the mobile node's home address.

- The mobile node then resubmits the packet to its IPv6 module for further processing. Since the mobile node recognizes its own home address as one if its current IP addresses, the packet is processed further within the mobile node, in the same way then as if the mobile node was at home.

If, instead, the sending node has no Binding Cache entry for the destination address to which the packet is being sent, the sending node simply sends the packet normally, with no Routing header. If

the destination node is not a mobile node (or is a mobile node that

is currently at home), the packet will be delivered directly to this node and processed normally by it. If, however, the destination node is a mobile node that is currently away from home, the packet will be intercepted by the mobile node's home agent and tunneled (using IPv6 encapsulation [4]) to the mobile node's current primary care-of address, as described in Section 9.5. The mobile node will then send a Binding Update to the sending node, as described in Section 10.5, allowing the sending node to create a Binding Cache entry for its use in sending subsequent packets to this mobile node.

9. Home Agent Operation

9.1. Receiving Router Advertisement Messages

For each link on which a router provides service as a home agent, the router maintains a Home Agents List recording the IP address of all other home agents that link. This list is used in the dynamic home agent address discovery mechanism, described in Section 9.2. The information for the list is learned through receipt of periodic unsolicited multicast Router Advertisements from each other home agent on the link, in which the Home Agent (H) bit is set, in a manner similar to the Default Router List conceptual data structure maintained by each host for Neighbor Discovery [11].

On receipt of a valid Router Advertisement, as defined in the processing algorithm specified for Neighbor Discovery [11], the home agent extracts the Source Address of the packet and performs the following steps, in addition to any steps already required of it by Neighbor Discovery:

- If the address is not already present in the home agent's Home Agents List, and the advertisement's Router Lifetime is non-zero, create a new entry in the list, and initialize its lifetime from the advertisement's Router Lifetime field.

- If the address is already present in the home agent's Home Agents List as a result of a previously-received advertisement, reset its lifetime to the Router Lifetime value in the newly-received advertisement.

- If the address is already present in the home agent's Home Agents List and the received Router Lifetime value is zero, immediately delete this entry in the Home Agents List

A home agent SHOULD maintain an entry in its Home Agents List for each such valid home agent address until that entry's lifetime expires, after which time the entry MUST be deleted.

9.2. Dynamic Home Agent Address Discovery

If a received Binding Update indicates that the mobile node sending it is attempting dynamic home agent address discovery, as described in Section 8.2, then the receiving node MUST process the Binding Update as specified in this section.

A mobile node attempts dynamic home agent address discovery by sending its "home registration" Binding Update to the Home-Agents anycast address for its home IP subnet prefix (the packet MUST also

include a Home Address option, as described in Section 10.4). A home

agent receiving such a Binding Update that is serving this subnet (the home agent is configured with this anycast address on one of its network interfaces) MUST reject the Binding Update and SHOULD return a Binding Acknowledgement indicating this rejection, with the Source Address of the packet carrying the Binding Acknowledgement set to one of the unicast addresses of the home agent. The Status field in the Binding Acknowledgement MUST be set to 135 (dynamic home agent address discovery response).

In this Binding Acknowledgement rejecting the dynamic home agent address discovery Binding Update, this home agent SHOULD include the IP address of all other home agents currently listed in its Home Agents List. To include this list in the Binding Acknowledgement, the Option Length field MUST be set to 11 + 16 * (the number of IP addresses included in the Other Home Agents field in the Binding Acknowledgement). The mobile node, upon receiving this Binding Acknowledgement, MAY then resend its Binding Update to the unicast home agent address given as the IP Source Address of the packet carrying the Binding Acknowledgement or to any of the unicast IP addresses listed in the Other Home Agents field in the Acknowledgement. For example, the mobile node may re-attempt its home registration with each of these home agents in turn, by sending each a Binding Update and waiting for the matching Binding Acknowledgement, until its registration is accepted by one of these home agents.

9.3. Primary Care-of Address Registration

General processing of a received Binding Update that requests a binding to be cached, is described in Section 8.3. However, if the Home Registration (H) bit is set in the Binding Update, then after following the step outlined for all Binding Update options in Section 8.2, the receiving node MUST process the Binding Update as specified in this section rather than following the general procedure for requests to cache a binding specified in Section 8.3.

To begin processing the Binding Update, the home agent MUST perform the following sequence of tests:

- If the node is not a router that implements home agent functionality, then the node MUST reject the Binding Update and SHOULD return a Binding Acknowledgement to the mobile node, in which the Status field is set to 132 (home registration not supported).

- Else, if the home address for the binding (the Home Address field in the packet's Home Address option) is not an on-link IPv6

address with respect to the home agent's current Prefix List, then the home agent MUST reject the Binding Update and SHOULD

return a Binding Acknowledgement to the mobile node, in which the Status field is set to 133 (not home subnet).

- Else, if the Prefix Length field is nonzero in the Binding Update and this length differs from the length of the home agent's own knowledge of the corresponding subnet prefix on the home link, then the home agent MUST reject the Binding Update and SHOULD return a Binding Acknowledgement to the mobile node, in which the Status field is set to 136 (incorrect subnet prefix length).

- Else, if the home agent chooses to reject the Binding Update for any other reason (e.g., insufficient resources to serve another mobile node as a home agent), then the home agent SHOULD return a Binding Acknowledgement to the mobile node, in which the Status field is set to an appropriate value to indicate the reason for the rejection.

If the home agent does not reject the Binding Update as described above, then it becomes the home agent for the mobile node. The new home agent (the receiving node) MUST then create a new entry or update the existing entry in its Binding Cache for this mobile node's home address (given in the Home Address option in the packet), as described in Section 8.3. In addition, the home agent MUST mark this Binding Cache entry as a "home registration" to indicate that the node is serving as a home agent for this binding. Binding Cache entries marked as a "home registration" MUST be excluded from the normal cache replacement policy used for the Binding Cache (Section 8.7) and MUST NOT be removed from the Binding Cache until the expiration of the Lifetime period.

If the home agent was not already serving as a home agent for this mobile node (the home agent did not already have a Binding Cache entry for this home address marked as a "home registration"), then the home agent MUST multicast onto the home link a "gratuitous" Neighbor Advertisement message [11] on behalf of the mobile node, in order to begin intercepting packets addressed to it while it is away from home. Specifically, the home agent follows the following steps:

- The home agent examines the value of the Prefix Length field in the Binding Update. If this value is zero, the following step is carried out only for the individual home address specified (in the Home Address option in the packet) for this binding. If, instead, this field is nonzero, then the following step is carried out for each address for the mobile node formed from the interface identifier in the mobile node's home address in this Binding Update (the remaining low-order bits in the address after the indicated subnet prefix), together with each one of the subnet prefixes currently considered by the home agent to be

on-link (including both the link-local and site-local prefix).

- For each specific IP address for the mobile node determined in the first step above, the home agent multicast onto the home link (to the all-nodes multicast address) a Neighbor Advertisement message [11] on behalf of the mobile node, to advertise the home agent's own link-layer address for this IP address. The Target Address in the Neighbor Advertisement message MUST be set to this IP address for the mobile node, and the Advertisement MUST include a Target Link-layer Address option specifying the home agent's link-layer address. The Solicited Flag (S) in the Advertisement MUST NOT be set, since it was not solicited by any Neighbor Solicitation message. The Override Flag (O) in the Advertisement MUST be set, indicating that the Advertisement SHOULD override any existing Neighbor Cache entry at any node receiving it.

Any node on the home link receiving one of the Neighbor Advertisement messages described above will thus update its Neighbor Cache to associate the mobile node's address with the home agent's link layer address, causing it to transmit any future packets for the mobile node normally destined to this address instead to the mobile node's home agent. Since multicasts on the local link (such as Ethernet) are typically not guaranteed to be reliable, the home agent MAY retransmit this Neighbor Advertisement message up to MAX_ADVERT_REXMIT times to increase its reliability. It is still possible that some nodes on the home link will not receive any of these Neighbor Advertisements, but these nodes will eventually be able to detect the link-layer address change for the mobile node's home address, through use of Neighbor Unreachability Detection [11].

In addition, while this node is serving as a home agent for this mobile node (it still has a "home registration" entry for this mobile node in its Binding Cache), it MUST act as a proxy for this mobile node to reply to any received Neighbor Solicitation messages for it. When a home agent receives a Neighbor Solicitation message, it MUST check if the Target Address specified in the message matches the home address of any mobile node for which it has a Binding Cache entry marked as a "home registration". This check MUST include all possible home addresses for the mobile node, based on the subnet prefixes currently considered to be on-link by the home agent (including the corresponding link-local address and site-local address), if the Prefix Length field was nonzero in the Binding Update that created this "home registration" binding at the home agent. If such an entry exists in the home agent's Binding Cache, the home agent MUST reply to the Neighbor Solicitation message with a Neighbor Advertisement message, giving the home agent's own link-layer address as the link-layer address for the specified Target Address. Acting as a proxy in this way allows other nodes on the mobile node's home link to resolve the mobile node's IPv6 home

address, and allows the home agent to to defend these addresses on the home link for Duplicate Address Detection [11].

Any packet addressed to the mobile node's home address (including addresses formed from other on-link prefixes, if the Prefix Length field was nonzero in the Binding Update) will thus be received by the mobile node's home agent while the mobile node is registered away from home. For any such packet received by the home agent for the mobile node, the home agent SHOULD tunnel the packet to the mobile node at its primary care-of address, as described in Section 9.5.

However, packets addressed to the mobile node's link-local address MUST NOT be tunneled to the mobile node. Instead, such a packet MUST be discarded, and the home agent SHOULD return an ICMP Destination Unreachable, Code 3, message to the packet's Source Address (unless this Source Address is a multicast address).

Similarly, packets addressed to the mobile node's site-local address MUST NOT be tunneled to the mobile node, unless the mobile node's registered primary care-of address is within the same site as the mobile node's home address. For any such packet not forwarded to the mobile node for this reason, the packet MUST be discarded, and the home agent SHOULD return an ICMP Destination Unreachable, Code 3, message to the packet's Source Address (unless this Source Address is a multicast address). Currently, however, the exact definition and semantics of a "site" are undefined in IPv6, and the mechanism for a home agent to determine if the care-of address is within the same site as the home address is outside the scope of this document.

9.4. Primary Care-of Address De-registration

General processing of a received Binding Update that requests a binding to be deleted, is described in Section 8.4. However, if the Home Registration (H) bit is set in the Binding Update, then after following the step outlined for all Binding Update options in Section 8.2, the receiving node MUST process the Binding Update as specified in this section rather than following the general procedure for requests to delete a cache binding specified in Section 8.4.

To begin processing the Binding Update, the home agent MUST perform the following sequence of tests:

- If the node is not a router that implements home agent functionality, then the node MUST reject the Binding Update and SHOULD return a Binding Acknowledgement to the mobile node, in which the Status field is set to 132 (home registration not supported).

- Else, if the home address for the binding (the Home Address field in the packet's Home Address option) is not an on-link IPv6 address with respect to the home agent's current Prefix

List, then it MUST reject the Binding Update and SHOULD return a

Binding Acknowledgement to the mobile node, in which the Status field is set to 133 (not home subnet).

If the home agent does not reject the Binding Update as described above, then it MUST delete any existing entry in its Binding Cache for this mobile node.

9.5. Tunneling Intercepted Packets to a Mobile Node

For any packet sent to a mobile node from the mobile node's home agent (for which the home agent is the original sender of the packet), the home agent is operating as a correspondent node of the mobile node for this packet and the procedures described in Section 8.9 apply. The home agent (as a correspondent node) uses a Routing header to route the packet to the mobile node by way of the care-of address in the home agent's Binding Cache (the mobile node's primary care-of address, in this case).

In addition, while the mobile node is away from home and this node is acting as the mobile node's home agent, the home agent intercepts any packets on the home link addressed to the mobile node's home address, as described in Section 9.3. The home agent cannot use a Routing header to forward these intercepted packets to the mobile node, since it cannot modify the packet in flight without invalidating any existing IPv6 Authentication header present in the packet [7].

For forwarding each intercepted packet to the mobile node, the home agent MUST tunnel the packet to the mobile node using IPv6 encapsulation [4]; the tunnel entry point node is the home agent, and the tunnel exit point node is the mobile node itself (using its primary care-of address as registered with the home agent). When a home agent encapsulates an intercepted packet for forwarding to the mobile node, the home agent sets the Source Address in the prepended tunnel IP header to the home agent's own IP address, and sets the Destination Address in the tunnel IP header to the mobile node's primary care-of address. When received by the mobile node (using its primary care-of address), normal processing of the tunnel header [4] will result in decapsulation and processing of the original packet by the mobile node.

9.6. Renumbering the Home Subnet

Neighbor Discovery [11] specifies a mechanism by which all nodes on a subnet can gracefully autoconfigure new addresses, say by each node combining a new subnet prefix with its existing link-layer address. As currently specified, this mechanism works when the nodes are on the same link as the router issuing the necessary multicast packets

to advertise the new subnet prefix(es) appropriate for the link.

However, for mobile nodes away from home, special care must be taken to allow the mobile nodes to renumber gracefully. The most direct method of ensuring this is for the home agent to encapsulate and tunnel the multicast packets to the primary care-of address of each mobile node for which it is serving as the home agent. The rules for this are as follows:

- A mobile node assumes that its subnet prefix has not changed unless it receives an authenticated Router Advertisement message from its home agent that the prefix has changed.

- When the mobile node is at home, the home agent does not tunnel Router Advertisements to it.

- The mobile node's home agent serves as a proxy for the mobile node's home address and link-local address, including defending these addresses for Duplicate Address Detection, while the mobile node is registered with the home agent away from home.

- When a home subnet prefix changes, the home agent tunnels Router Advertisement packets to each mobile node registered with it that is currently away from home and using a home address with the affected subnet prefix. Such tunneled Router Advertisements MUST be authenticated [7].

- When a mobile node receives a tunneled Router Advertisement containing a new subnet prefix, it MUST perform the standard autoconfiguration operation to create its new address.

- When a mobile node returns to its home link, it must again perform Duplicate Address Detection at the earliest possible moment after it has deleted its "home registration" binding with its home agent.

- A mobile node MAY send a Router Solicitation to its home agent at any time, within the constraints imposed by rate control defined by Neighbor Discovery [11].

10. Mobile Node Operation

10.1. Sending Packets While Away from Home

While a mobile node is away from home, it continues to use its home address as well as also using one or more care-of addresses. When sending a packet while away from home, a mobile node MAY choose among these in selecting the address that it will use as the source of the packet, as follows:

- From the point of view of protocol layers and applications above Mobile IP (e.g., transport protocols), the mobile node will generally use its home address as the source of the packet for most packets, even while away from home, since Mobile IP is designed to make mobility transparent to such software. Doing so also makes the node's mobility and the fact that it is currently away from home transparent to the correspondent nodes with which it communicates. For packets sent that are part of transport-level connections established while the mobile node was at home, the mobile node MUST use its home address in this way. Likewise, for packets sent that are part of transport-level connections that the mobile node may still be using after moving to a new location, the mobile node SHOULD use its home address in this way. When sending such packets, Mobile IP will modify the packet to move the home address into a Home Address option and will set the IPv6 header's Source Address field to one of the mobile node's care-of address; these modifications to the packet are then reversed in the node receiving the packet, restoring the mobile node's home address to be the packet's Source Address before processing by higher protocols layers and applications.

- For short-term communication, particularly for communication that may easily be retried if it fails, the mobile node MAY choose to directly use one of its care-of addresses as the source of the packet, thus not requiring the use of a Home Address option in the packet. An example of this type of communication might be DNS queries sent by the mobile node [9, 10]. Using the mobile node's care-of address as the source for such queries will generally have a lower overhead than using the mobile node's home address, since no extra options need be used in either the query or its reply, and all packets can be routed normally, directly between their source and destination without relying on Mobile IP. If the mobile node has no particular knowledge that the communication being sent fits within this type of communication, however, the mobile node SHOULD NOT use its care-of address as the source of the packet in this way.

If the mobile node uses one of its care-of addresses as the source

of some packet while away from home, no special Mobile IP processing is required for sending this packet. The packet is simply addressed

and transmitted in the same way as any normal IPv6 packet, setting the Source Address field in the packet's IPv6 header to this care-of address.

On the other hand, if while away from home, the mobile node uses its home address as the source of a packet from the point of view of higher protocol layers or applications as described above, special Mobile IP processing of this packet is required for the insertion of the Home Address option. Specifically:

- Since Mobile IP is transparent to higher protocol layers (e.g., to TCP), the packet is initially constructed using the mobile node's home address as the packet's Source Address, in the same way as if the mobile node were at home.

- If the mobile node is at home, no special Mobile IP processing for this packet is required. The packet is sent normally and the following additional steps are not performed.

- Likewise, if the Source Address field in the packet's IPv6 header is not the mobile node's home address, no special Mobile IP processing for this packet is required. The packet is sent normally and the following additional steps are not performed.

- Otherwise, insert a Home Address option into the packet, with the Home Address field copied from the original value of the Source Address field in the packet.

- Change the Source Address field in the packet's IPv6 header to one of the mobile node's care-of addresses. This will typically be the mobile node's current primary care-of address, but MUST be a care-of address with a subnet prefix that is on-link on the network interface on which the mobile node will transmit the packet.

This addition of the Home Address option to a packet MUST be performed before outgoing IPsec processing, such as the addition of an AH [7] or ESP [8] header to the packet, is performed. Likewise, IPsec processing for a received packet containing a Home Address option MUST be performed before the packet is possibly modified as part of processing the Home Address option. By using the care-of address as the Source Address in the IPv6 header, with the mobile node's home address instead in the Home Address option, the packet will be able to safely pass through any router implementing ingress filtering [6].

10.2. Movement Detection

A mobile node MAY use any combination of mechanisms available to it to detect when it has moved from one link to another. The primary movement detection mechanism for Mobile IPv6 defined here uses the facilities of IPv6 Neighbor Discovery, including Router Discovery and Neighbor Unreachability Detection. The description here is based on the conceptual model of the organization and data structures defined by Neighbor Discovery [11].

Mobile nodes SHOULD use Router Discovery to discover new routers and on-link subnet prefixes; a mobile node MAY send Router Solicitation messages, or MAY wait for unsolicited (periodic) Router Advertisement messages, as specified for Router Discovery [11]. Based on received Router Advertisement messages, a mobile node (in the same way as any other node) maintains an entry in its Default Router List for each router, and an entry in its Prefix List for each subnet prefix, that it currently considers to be on-link. Each entry in these lists has an associated invalidation timer value (extracted from the Router Advertisement) used to expire the entry when it becomes invalid.

While away from home, a mobile node SHOULD select one router from its Default Router List to use as its default router, and one subnet prefix advertised by that router from its Prefix List to use as the subnet prefix in its primary care-of address. A mobile node MAY also have associated additional care-of addresses, using other subnet prefixes from its Prefix List. The method by which a mobile node selects and forms a care-of address from the available subnet prefixes is described in Section 10.3. The mobile node registers its primary care-of address with its home agent, as described in Section 10.4.

While a mobile node is away from home and using some router as its default router, it is important for the mobile node to be able to quickly detect when that router becomes unreachable, so that it can switch to a new default router and to a new primary care-of address. Since some links (notably wireless) do not necessarily work equally well in both directions, it is likewise important for the mobile node to detect when it becomes unreachable to packets sent from its default router, so that the mobile node can take steps to ensure that any correspondent nodes attempting to communicate with it can still reach it through some other route.

To detect when its default router becomes unreachable, a mobile node SHOULD use Neighbor Unreachability Detection. As specified in Neighbor Discovery [11], while the mobile node is actively sending packets to (or through) its default router, the mobile node can detect that the router (as its neighbor) is still reachable either

through indications from upper layer protocols on the mobile node that a connection is making "forward progress" (e.g., receipt of TCP

acknowledgements for new data transmitted), or through receipt of a Neighbor Advertisement message from its default router in response to an explicit Neighbor Solicitation messages to it. Note that although this mechanism only detects that the mobile node's default router has become unreachable to the mobile node while the mobile node is actively sending packets to it, this is the only time that this direction of reachability confirmation is needed. Confirmation that the mobile node is still reachable from the router is handled separately, as described below.

For a mobile node to detect when it has become unreachable to its default router, however, the mobile node cannot efficiently rely on Neighbor Unreachability Detection alone, since the network overhead would be prohibitively high in many cases for a mobile node to continually probe its default router with Neighbor Solicitation messages even when it is not otherwise actively sending packets to it. Instead, a mobile node SHOULD consider receipt of any IPv6 packets from its current default router as an indication that it is still reachable from the router. Both packets from the router's IP address and (IPv6) packets from its link-layer address (e.g., those forwarded but not originated by the router) SHOULD be considered.

Since the router SHOULD be sending periodic multicast Router Advertisement messages, the mobile node will have frequent opportunity to check if it is still reachable from its default router, even in the absence of other packets to it from the router. If Router Advertisements that the mobile node receives include an Advertisement Interval option, the mobile node MAY use its Advertisement Interval field as an indication of the frequency with which it should expect to continue to receive future Advertisements from that router. This field specifies the minimum rate (the maximum amount of time between successive Advertisements) that the mobile node should expect. If this amount of time elapses without the mobile node receiving any Advertisement from this router, the mobile node can be sure that at least one Advertisement sent by the router has been lost. It is thus possible for the mobile node to implement its own policy for determining the number of Advertisements from its current default router it is willing to tolerate losing before deciding to switch to a different router from which it may currently be correctly receiving Advertisements.

On some types of network interfaces, the mobile node MAY also supplement this monitoring of Router Advertisements, by setting its network interface into "promiscuous" receive mode, so that it is able to receive all packets on the link, including those not link-level addressed to it. The mobile node will then be able to detect any packets sent by the router, in order to to detect reachability from the router. This use of promiscuous mode may be useful on very low

bandwidth (e.g., wireless) links, but its use MUST be configurable on the mobile node.

If the above means do not provide indication that the mobile node is still reachable from its current default router (i.e., the mobile node receives no packets from the router for a period of time), then the mobile node SHOULD actively probe the router with Neighbor Solicitation messages, even if it is not otherwise actively sending packets to the router. If it receives a solicited Neighbor Advertisement message in response from the router, then the mobile node can deduce that it is still reachable. It is expected that the mobile node will in most cases be able to determine its reachability from the router by listening for packets from the router as described above, and thus, such extra Neighbor Solicitation probes should rarely be necessary.

With some types of networks, it is possible that additional indications about link-layer mobility can be obtained from lower-layer protocol or device driver software within the mobile node. However, a mobile node MUST NOT assume that all link-layer mobility indications from lower layers indicate a movement of the mobile node to a new link, such that the mobile node would need to switch to a new default router and primary care-of address. For example, movement of a mobile node from one cell to another in many wireless LANs can be made transparent to the IP level through use of a link-layer "roaming" protocol, as long as the different wireless LAN cells all operate as part of the same IP link with the same subnet prefix. Upon lower-layer indication of link-layer mobility, the mobile node MAY send Router Solicitation messages to determine if new routers (and new on-link subnet prefixes) are present on its new link.

Such lower-layer information might also be useful to a mobile node in deciding to switch its primary care-of address to one of the other care-of addresses it has formed from the on-link subnet prefixes currently available through different routers from which the mobile node is reachable. For example, a mobile node MAY use signal strength or signal quality information (with suitable hysteresis) for its link with the available routers to decide when to switch to a new primary care-of address using that router rather than its current default router (and current primary care-of address). Even though the mobile node's current default router may still be reachable in terms of Neighbor Unreachability Detection, the mobile node MAY use such lower-layer information to determine that switching to a new default router would provide a better connection.

10.3. Forming New Care-of Addresses

After detecting that it has moved from one link to another (i.e., its current default router has become unreachable and it has discovered a

new default router), a mobile node SHOULD form a new primary care-of address using one of the on-link subnet prefixes advertised by the

new router. A mobile node MAY form a new primary care-of address at any time, except that it MUST NOT do so too frequently (not more often than once per MAX_UPDATE_RATE seconds).

In addition, after discovering a new on-link subnet prefix, a mobile node MAY form a new (non-primary) care-of address using that subnet prefix, even when it has not switched to a new default router. A mobile node can have only one primary care-of address at a time (which is registered with its home agent), but it MAY have an additional care-of address for any or all of the subnet prefixes on its current link. Furthermore, since a wireless network interface may actually allow a mobile node to be reachable on more than one link at a time (i.e., within wireless transmitter range of routers on more than one separate link), a mobile node MAY have care-of addresses on more than one link at a time. The use of more than one care-of address at a time is described in Section 10.12.

As described in Section 4, in order to form a new care-of address, a mobile node MAY use either stateless [18] or stateful (e.g., DHCPv6 [2]) address autoconfiguration. If a mobile node needs to send packets as part of the method of address autoconfiguration, it MUST use an IPv6 link-local address rather than its own IPv6 home address as the Source Address in the IPv6 header of each such autoconfiguration packet.

In some cases, a mobile node may already know a (constant) IPv6 address that has been assigned to it for its use only while visiting a specific foreign link. For example, a mobile node may be statically configured with an IPv6 address assigned by the system administrator of some foreign link, for its use while visiting that link. If so, rather than using address autoconfiguration to form a new care-of address using this subnet prefix, the mobile node MAY use its own pre-assigned address as its care-of address on this link.

10.4. Sending Binding Updates to the Home Agent

After deciding to change its primary care-of address as described in Sections 10.2 and 10.3, a mobile node MUST register this care-of address with its home agent in order to make this its primary care-of address. To do so, the mobile node sends a packet to its home agent containing a Binding Update option, with the packet constructed as follows:

- The Home Registration (H) bit MUST be set in the Binding Update.
- The Acknowledge (A) bit MUST be set in the Binding Update.
- The packet MUST contain a Home Address option, giving the mobile

node's home address for the binding.

- The care-of address for the binding MUST be used as the Source Address in the packet's IPv6 header, or the Care-of Address Present (C) bit MUST be set in the Binding Update and the care-of address for the binding MUST be specified in the Care-of Address field in the Binding Update.

- The Prefix Length field SHOULD be set to the length of the mobile node's subnet prefix in its home address, to request the mobile node's home agent to serve as a home agent for all home addresses for the mobile node based on all on-link subnet prefixes on the home link. Otherwise, this field MUST be set to zero.

The Acknowledge (A) bit in the Binding Update requests the home agent to return a Binding Acknowledgement in response to this Binding Update. As described in Section 5.2, the mobile node SHOULD retransmit this Binding Update to its home agent until it receives a matching Binding Acknowledgement. Once reaching a retransmission timeout period of MAX_BINDACK_TIMEOUT, the mobile node SHOULD continue to periodically retransmit the Binding Update at this rate until acknowledged (or until it begins attempting to register a different primary care-of address).

The Prefix Length field in the Binding Update allows the mobile node to request its home agent to serve all home addresses for the mobile node, as indicated by the interface identifier in the mobile node's home address (the remaining low-order bits after the indicated subnet prefix), together with each on-link subnet prefix on the home link. If the mobile node has additional home addresses using a different interface identifier, then the mobile node SHOULD send an additional Binding Update to its home agent to register the care-of address for each such other home address (or set of home addresses sharing an interface identifier).

It is possible that when the mobile node needs to send such a Binding Update to its home agent, that the mobile node does not know the address of any router on its home link that can serve as a home agent for it. In this case, the mobile node SHOULD use the dynamic home agent address discovery procedure to find the address of a suitable home agent on its home link. To do so, the mobile node sends the packet, as described above, with the Destination Address in the packet's IPv6 header set to the Home-Agents anycast address for its home subnet prefix. As described in Section 9.2, the home agent on its home link that receives this Binding Update will reject the Update, returning to the mobile node the home agent's own unicast IP address along with a list of the unicast IP addresses of each other home agent operating on the home link. The mobile node SHOULD then retransmit its Binding Update to one of these homes agent using the provided unicast address; the mobile node MAY re-attempt

this home registration with each of these home agents in turn, by sending each a Binding Update and waiting for the matching Binding

Acknowledgement, until its registration is accepted by one of these home agents.

If the mobile node has a current registration with some home agent on its home link (the Lifetime for that registration has not yet expired), then the mobile node MUST attempt any new registration first with that home agent. If that registration attempt fails (e.g., times out or is rejected), the mobile node SHOULD then reattempt this registration with another home agent on its home link. If the mobile node knows of no other suitable home agent, then it MAY attempt the dynamic home agent address discovery procedure described above.

10.5. Sending Binding Updates to Correspondent Nodes

A mobile node MAY send a Binding Update to any correspondent node at any time to allow it to cache its current care-of address (subject to the rate limiting defined in Section 10.8). In any Binding Update sent by a mobile node, the care-of address (either the Source Address in the packet's IPv6 header or the Care-of Address field in the Binding Update) MUST be set to one of the care-of addresses currently in use by the mobile node or to the mobile node's home address. If set to one of the mobile node's current care-of addresses (the care-of address given MAY differ from the mobile node's primary care-of address), the Binding Update requests the correspondent node to create or update an entry for the mobile node in the correspondent node's Binding Cache to record this care-of address for use in sending future packets to the mobile node. If, instead, the care-of address is set to the mobile node's home address, the Binding Update requests the correspondent node to delete any existing Binding Cache entry that it has for the mobile node. A mobile node MAY set the care-of address differently for sending Binding Updates to different correspondent nodes.

When sending any Binding Update, the mobile node MUST record in its Binding Update List the following fields from the Binding Update:

- The IP address of the node to which the Binding Update was sent.
- The home address for which the Binding Update was sent,
- The remaining lifetime of the binding, initialized from the Lifetime field sent in the Binding Update.

The mobile node MUST retain in its Binding Update List information about all Binding Updates sent, for which the lifetime of the binding has not yet expired. When sending a Binding Update, if an entry already exists in the mobile node's Binding Update List for

an earlier Binding Update sent to that same destination node, the

existing Binding Update List entry is updated to reflect the new Binding Update rather than creating a new Binding Update List entry.

In general, when a mobile node sends a Binding Update to its home agent to register a new primary care-of address (as described in Section 10.4), the mobile node will also send a Binding Update to each correspondent node for which an entry exists in the mobile node's Binding Update List. Thus, correspondent nodes are generally kept updated about the mobile node's binding and can send packets directly to the mobile node using the mobile node's current care-of address.

The mobile node, however, need not send these Binding Updates immediately after configuring a new care-of address. For example, since the Binding Update is a destination option and can be included in any packet sent by a mobile node, the mobile node MAY delay sending a new Binding Update to any correspondent node for a short period of time, in hopes that the needed Binding Update can be included in some packet that the mobile node sends to that correspondent node for some other reason (for example, as part of some TCP connection in use). In this case, when sending a packet to some correspondent node, the mobile node SHOULD check in its Binding Update List to determine if a new Binding Update to this correspondent node is needed, and SHOULD include the new Binding Update in this packet as necessary.

In addition, when a mobile node receives a packet for which the mobile node can deduce that the original sender of the packet has no Binding Cache entry for the mobile node, or for which the mobile node can deduce that the original sender of the packet has an out-of-date care-of address for the mobile node in its Binding Cache, the mobile node SHOULD return a Binding Update to the sender giving its current care-of address. In particular, the mobile node SHOULD return a Binding Update in response to receiving a packet that meets all of the following tests:

- The packet was tunneled using IPv6 encapsulation.

- The Destination Address in the tunnel (outer) IPv6 header is equal to any of the mobile node's care-of addresses.

- The Destination Address in the original (inner) IPv6 header is equal to the mobile node's home address. If the original packet contains a Routing header, the final Address indicated in the Routing header should be used in this comparison rather than the Destination Address in the original IPv6 header.

- The Source Address in the tunnel (outer) IPv6 header differs from

the Source Address in the original (inner) IPv6 header.

The destination address to which the Binding Update should be sent in response to receiving a packet meeting all of the tests above, is the Source Address in the original (inner) IPv6 header of the packet.

Binding Updates sent to correspondent nodes are not generally required to be acknowledged. However, if the mobile node wants to be sure that its new care-of address has been added to a correspondent node's Binding Cache, the mobile node MAY request an acknowledgement by setting the Acknowledge (A) bit in the Binding Update. In this case, however, the mobile node SHOULD NOT continue to retransmit the Binding Update once the retransmission timeout period has reached MAX_BINDACK_TIMEOUT.

A mobile node MAY choose to keep its location private from certain correspondent nodes, and thus need not send new Binding Updates to those correspondents. A mobile node MAY also send a Binding Update to such a correspondent node to instruct it to delete any existing binding for the mobile node from its Binding Cache, as described in Section 5.1. No other IPv6 nodes are authorized to send Binding Updates on behalf of a mobile node.

10.6. Sending Binding Updates to the Previous Default Router

After switching to a new default router (and thus also changing its primary care-of address), a mobile node MAY send a Binding Update to its previous default router, giving its new care-of address. If the mobile node sends such a Binding Update, the home address for the binding, specified in the Home Address option included in the packet carrying this Binding Update, MUST be set the mobile node's old primary care-of address (that it used while using this default router), and the care-of address for the binding (either the Source Address in the packet's IPv6 header or the Care-of Address field in the Binding Update) MUST be set to the mobile node's new primary care-of address. In addition, the Home Registration (H) bit MUST also be set in this Binding Update, to request the mobile node's previous default router to temporarily act as a home agent for the mobile node's old primary care-of address. The previous default router will thus tunnel packets for the mobile node to its new care-of address. All of the procedures defined for home agent operation must be followed by this previous default router for this registration. Note that the previous router does not necessarily know the mobile node's (permanent) home address as part of this registration.

10.7. Retransmitting Binding Updates

If, after sending a Binding Update in which the Acknowledge (A) bit

is set, a mobile node fails to receive a Binding Acknowledgement

within INITIAL_BINDACK_TIMEOUT seconds, the mobile node SHOULD retransmit the Binding Update until a Binding Acknowledgement is received. Such a retransmitted Binding Update MUST use he same Sequence Number value as the original transmission. The retransmissions by the mobile node MUST use an exponential back-off process, in which the timeout period is doubled upon each retransmission until either the node receives a Binding Acknowledgement or the timeout period reaches the value MAX_BINDACK_TIMEOUT.

10.8. Rate Limiting for Sending Binding Updates

A mobile node MUST NOT send Binding Updates more often than once per MAX_UPDATE_RATE seconds to any node. After sending MAX_FAST_UPDATES consecutive Binding Updates to a particular node with the same care-of address, the mobile node SHOULD reduce its rate of sending Binding Updates to that node, to the rate of SLOW_UPDATE_RATE per second. The mobile node MAY continue to send Binding Updates at the slower rate indefinitely, in hopes that the node will eventually be able to process a Binding Update and begin to route its packets directly to the mobile node at its new care-of address.

10.9. Receiving ICMP Error Messages

The Option Type value for a Binding Update option specifies that any node receiving this option that does not recognize the Option Type SHOULD return an ICMP Parameter Problem, Code 2, message to the sender of the packet containing the Binding Update option. If a node sending a Binding Update receives such an ICMP error message in response, it should record in its Binding Update List that future Binding Updates should not be sent to this destination.

Likewise, although ALL IPv6 nodes (whether host or router, whether mobile or stationary) MUST implement the ability to receive packets containing a Home Address option, all Option Type values in IPv6 include a specification of the behavior that a node receiving a packet containing this option performs if it does not implement receipt of that type of option. For the Home Address option, the Option Type value specifies that any node receiving this option that does not recognize the Option Type SHOULD return an ICMP Parameter Problem, Code 2, message to the sender of the packet containing the Home Address option. If a mobile node receives such an ICMP error message from some node indicating that it does not recognize the mobile node's Home Address option, the mobile node SHOULD log the error and then discard the ICMP message; this error message indicates that the node to which the original packet was addressed (the node

returning the ICMP error message) does not correctly implement this required part of the IPv6 protocol.

10.10. Receiving Binding Acknowledgements

Upon receiving a packet carrying a Binding Acknowledgement, a mobile node MUST validate the packet according to the following tests:

- The packet contains either an AH [7] or ESP [8] header providing sender authentication, data integrity protection, and replay protection.

- The Option Length field in the option is greater than or equal to 11 octets.

- The Sequence Number field matches the Sequence Number sent by the mobile node to this destination address in an outstanding Binding Update.

Any Binding Acknowledgement not satisfying all of these tests MUST be silently ignored, although the remainder of the packet (i.e., other options, extension headers, or payload) SHOULD be processed normally according to any procedure defined for that part of the packet.

When a mobile node receives a packet carrying a valid Binding Acknowledgement, the mobile node MUST examine the Status field as follows:

- If the Status field indicates that the Binding Update was accepted (the Status field is less than 128), then the mobile node MUST update the corresponding entry in its Binding Update List to indicate that the Binding Update has been acknowledged. The mobile node MUST thus stop retransmitting the Binding Update.

- If the Status field indicates that the Binding Update was rejected (the Status field is greater than or equal to 128), then the mobile node MUST delete the corresponding Binding Update List entry (and MUST also stop retransmitting the Binding Update). Optionally, the mobile node MAY then take steps to correct the cause of the error and retransmit the Binding Update (with a new Sequence Number value), subject to the rate limiting restriction specified in Section 10.8. In particular, if the Status field is equal to 135 (dynamic home agent address discovery response), then the mobile node MAY reattempt its home registration with any of the home agent IP addresses listed in the Other Home Agents field in the Binding Acknowledgement or with the home agent address given in the Source Address field of the packet carrying the Binding Acknowledgement. If any of these addresses is not unicast a address or does not have a subnet prefix equal to the mobile node's own subnet prefix, then that particular address MUST be ignored and the mobile node MUST NOT reattempt its home registration with that home agent.

10.11. Receiving Binding Requests

When a mobile node receives a packet containing a Binding Request, it SHOULD return to the sender a packet containing a Binding Update. The Lifetime field in this Binding Update SHOULD be set to a new lifetime, extending any current lifetime remaining from a previous Binding Update sent to this node (as indicated in any existing Binding Update List entry for this node). When sending this Binding Update, the mobile node MUST update its Binding Update List in the same way as for any other Binding Update sent by the mobile node.

Note, however, that the mobile node MAY choose to keep its current binding private from the sender of the Binding Request. In this case, the mobile node instead SHOULD returns a Binding Update to the sender, in which the Lifetime field is set to zero.

10.12. Using Multiple Care-of Addresses

As described in Section 10.3, a mobile node MAY use more than one care-of address at a time. Particularly in the case of many wireless networks, a mobile node effectively might be reachable through multiple links at the same time (e.g., with overlapping wireless cells), on which different on-link subnet prefixes may exist. A mobile node SHOULD select a primary care-of address from among those care-of addresses it has formed using any of these subnet prefixes, based on the movement detection mechanism in use, as described in Section 10.2. When the mobile node selects a new primary care-of address, it MUST register it with its home agent through a Binding Update with the Home Registration (H) and Acknowledge (A) bits set, as described in Section 10.4.

To assist with smooth handoffs, a mobile node SHOULD retain its previous primary care-of address as a (non-primary) care-of address, and SHOULD still accept packets at this address, even after registering its new primary care-of address with its home agent. This is reasonable, since the mobile node could only receive packets at its previous primary care-of address if it were indeed still connected to that link. If the previous primary care-of address was allocated using stateful address autoconfiguration [2], the mobile node may not wish to release the address immediately upon switching to a new primary care-of address.

10.13. Routing Multicast Packets

A mobile node that is connected to its home link functions in the same way as any other (stationary) node. Thus, when it is at home, a mobile node functions identically to other multicast senders and

receivers. This section therefore describes the behavior of a mobile node that is not on its home link.

In order to receive packets sent to some multicast group, a mobile node must join that multicast group. One method by which a mobile node MAY join the group is via a (local) multicast router on the foreign link being visited. The mobile node SHOULD use its care-of address sharing a subnet prefix with the multicast router, as the source IPv6 address of its multicast group membership control messages.

Alternatively, a mobile node MAY join multicast groups via a bi-directional tunnel to its home agent. The mobile node tunnels the appropriate multicast group membership control packets to its home agent, and the home agent forwards multicast packets down the tunnel to the mobile node.

A mobile node that wishes to send packets to a multicast group also has two options: (1) send directly on the foreign link being visited; or (2) send via a tunnel to its home agent. Because multicast routing in general depends upon the Source Address used in the IPv6 header of the multicast packet, a mobile node that tunnels a multicast packet to its home agent MUST use its home address as the IPv6 Source Address of the inner multicast packet.

10.14. Returning Home

A mobile node detects that it has returned to its home link through the movement detection algorithm in use (Section 10.2), when the mobile node detects that its home subnet prefix is again on-link. The mobile node SHOULD then send a Binding Update to its home agent, to instruct its home agent to no longer intercept or tunnel packets for it. In this Binding Update, the mobile node MUST set the care-of address for the binding (the Source Address field in the packet's IPv6 header) to the mobile node's own home address. As with other Binding Updates sent to register with its home agent, the mobile node MUST set the Acknowledge (A) and Home Registration (H) bits, and SHOULD retransmit the Binding Update until a matching Binding Acknowledgement is received.

In addition, the mobile node MUST multicast onto the home link (to the all-nodes multicast address) a Neighbor Advertisement message [11], to advertise the mobile node's own link-layer address for its own home address. The Target Address in this Neighbor Advertisement message MUST be set to the mobile node's home address, and the Advertisement MUST include a Target Link-layer Address option specifying the mobile node's link-layer address. The mobile node

MUST multicast such a Neighbor Advertisement message for each of its home addresses, as defined by the current on-link prefixes, including

its link-local address and site-local address. The Solicited Flag (S) in these Advertisements MUST NOT be set, since they were not solicited by any Neighbor Solicitation message. The Override Flag (O) in these Advertisements MUST be set, indicating that the Advertisements SHOULD override any existing Neighbor Cache entries at any node receiving them.

Since multicasts on the local link (such as Ethernet) are typically not guaranteed to be reliable, the mobile node MAY retransmit these Neighbor Advertisement messages up to MAX_ADVERT_REXMIT times to increase their reliability. It is still possible that some nodes on the home link will not receive any of these Neighbor Advertisements, but these nodes will eventually be able to recover through use of Neighbor Unreachability Detection [11].

11. Constants

INITIAL_BINDACK_TIMEOUT	1 second
MAX_BINDACK_TIMEOUT	256 seconds
MAX_UPDATE_RATE	once per second
SLOW_UPDATE_RATE	once per 10 seconds
MAX_FAST_UPDATES	5
MAX_ADVERT_REXMIT	3

12. IANA Considerations

This document defines four new types of IPv6 destination options, each of which must be assigned an Option Type value:

- The Binding Update option, described in Section 5.1
- The Binding Acknowledgement option, described in Section 5.2
- The binding Request option, described in Section 5.3
- The Home Address option, described in Section 5.4

In addition, this document defines a new Neighbor Discovery [11] option, which must be assigned an Option Type value within the option numbering space for Neighbor Discovery messages:

- The Advertisement Interval option, described in Section 6.2.

Finally, this document defines a new type of anycast address, which must be assigned a reserved interface identifier value for use with any subnet prefix to define this anycast address on each subnet:

- The Home-Agents anycast address, used in the dynamic home agent address discovery procedure described in Sections 9.2 and 10.4.

13. Security Considerations

13.1. Binding Updates, Acknowledgements, and Requests

The Binding Update option described in this document will result in packets addressed to a mobile node being delivered instead to its care-of address. This ability to change the routing of these packets could be a significant vulnerability if any packet containing a Binding Update option was not authenticated. Such use of "remote redirection", for instance as performed by the Binding Update option, is widely understood to be a security problem in the current Internet if not authenticated [1].

The Binding Acknowledgement option also requires authentication, since, for example, an attacker could otherwise trick a mobile node into believing a different outcome from a registration attempt with its home agent.

No authentication is required for the Binding Request option, since the use of this option does not modify or create any state in either the sender or the receiver. The Binding Request option does open some issues with binding privacy, but those issues can be dealt with either through existing IPsec encryption mechanisms or through use of firewalls.

The existing IPsec replay protection mechanisms allow a "replay protection window" to support receiving packets out of order. Although appropriate for many forms of communication, Binding Updates MUST be applied only in the order sent. The Binding Update option thus includes a Sequence Number field to provide this necessary sequencing. The use of this Sequence Number together with IPsec replay protection is similar in many ways, for example, to the the sequence number in TCP. IPsec provides strong replay protection but no ordering, and the sequence number provides ordering but need not worry about replay protection such as through the sequence number wrapping around.

13.2. Home Address Options

No special authentication of the Home Address option is required, except that if the IPv6 header of a packet is covered by authentication, then that authentication MUST also cover the Home Address option; this coverage is achieved automatically by the definition of the Option Type code for the Home Address option (Section 5.4), since it indicates that the option is included in the authentication computation. Thus, even when authentication is used in the IPv6 header, the security of the Source Address field in the IPv6 header is not compromised by the presence of a Home Address

option. Without authentication of the packet, then any field in the

IPv6 header, including the Source Address field, and any other parts of the packet, including the Home Address option, can be forged or modified in transit. In this case, the contents of the Home Address option is no more suspect than any other part of the packet.

The use of the Home Address option allows packets sent by a mobile node to pass normally through routers implementing ingress filtering [6]. Since the care-of address used in the Source Address field of the packet's IPv6 header is topologically correct for the sending location of the mobile node, ingress filtering can trace the location of the mobile node in the same way as can be done with any sender when ingress filtering is in use.

However, if a node receiving a packet that includes a Home Address option implements the processing of this option by physically copying the Home Address field from the option into the IPv6 header, replacing the Source Address field there, then the ability to trace the true location of the sender is removed once this step in the processing is performed. This diminishing of the power of ingress filtering only occurs once the packet has been received at its ultimate destination, and does not affect the capability of ingress filtering while the packet is in transit. Furthermore, this diminishing can be entirely eliminated by appropriate implementation techniques in the receiving node. For example, the original contents of the Source Address field (the sending care-of address) could be saved elsewhere in memory with the packet, until all processing of the packet is completed.

13.3. General Mobile Computing Issues

The mobile computing environment is potentially very different from the ordinary computing environment. In many cases, mobile computers will be connected to the network via wireless links. Such links are particularly vulnerable to passive eavesdropping, active replay attacks, and other active attacks. Furthermore, mobile computers are more susceptible to loss or theft than stationary computers. Any secrets such as authentication or encryption keys stored on the mobile computer are thus subject to compromise in ways generally not common in the non-mobile environment.

Users who have sensitive data that they do not wish others to have access to should use additional mechanisms (such as encryption) to provide privacy protection, but such mechanisms are beyond the scope of this document. Users concerned about traffic analysis should consider appropriate use of link encryption. If stronger location privacy is desired, the mobile node can create a tunnel to its home agent. Then, packets destined for correspondent nodes will appear

to emanate from the home subnet, and it may be more difficult to

pinpoint the location of the mobile node. Such mechanisms are all beyond the scope of this document.

Changes from Previous Draft

This appendix briefly lists some of the major changes in this draft relative to the previous version of this same draft, draft-ietf-mobileip-ipv6-04.txt:

- Replaced the ID Length field in the Binding Update with the Prefix Length field.

- Added a definition of "interface identifier" in Section 3.1.

- Added a description of dynamic home agent address discovery to the basic operation overview in Section 4.1.

- Added a description of the new Home Agents List conceptual data structure in Section 4.3. This list is used in the dynamic home agent address discovery mechanism.

- Added the Other Home Agents field to the Binding Acknowledgement option format, and modified the description of the setting for the Option Length field in the Binding Acknowledgement to accommodate the Other Home Agents field. This field is used in the dynamic home agent address discovery mechanism.

- Added Section 9.1, describing the processing performed by a home agent to maintain its Home Agents List when the home agent receives a valid Router Advertisement message in which the Home Agent (H) bit is set.

- Revised the description of dynamic home agent address discovery in Section 9.2 to include use of the new Home Agents List and the return of the IP addresses from this list in the Other Home Agents field of the Binding Acknowledgement that rejects the anycast Binding Update.

- Revised Section 10.10 to include a description of the Other Home Agents field in the received Binding Acknowledgement.

- Added Section 6, listing modifications to IPv6 Neighbor Discovery: The Router Advertisement message is changed to include the Home Agent (H) bit, a new Advertisement Interval option is defined for Router Advertisement messages, and the value of MinRtrAdvInterval for home agents is allowed to be less than the generic limit for routers of 3 seconds [11].

- Added a description in the IANA Considerations in Section 12, of the need to assign an Option Type value for the new Advertisement Interval option that can appear on Router Advertisement messages.

- Changed the rule in Section 9.3 dealing with forwarding site-local-addressed packets to a mobile node while the mobile nodes is away from home. Such packets now MUST NOT be tunneled to the mobile node, unless the mobile node's registered primary care-of address is within the same site as the mobile node's home address.

- Added a description in Section 10.9 of what a mobile node should do if it receives an ICMP Parameter Problem error message in response to the Home Address option in some packet that it sent. Although ALL IPv6 nodes MUST implement receipt of packets containing a Home Address option, the encoding of an Option Type value in IPv6 always specifies some behavior for the case in which the receiver does not recognize that type of option.

- In Section 10.2, changed SHOULD to MAY in specifying that upon lower-layer indication of link-layer mobility, the mobile node MAY send Router Solicitation messages to determine if new routers are present on its new link.

- Also in Section 10.2, added a description of how the value specified in the Advertisement Interval option in received Router Advertisements MAY be used in the mobile node's movement detection algorithm.

- Moved the section on routing multicast packets to and from a mobile host while away from home, to now be Section 10.13, a subsection of the description of mobile node operation (Section 10), rather than being a separate section on its own. This better integrates this operation into the document.

- Corrected the specification of the length of the Binding Update option. The correct length is 24, not 16, if the Care-of Address Present (C) bit is set.

- Corrected the specification of the length of the Binding Acknowledgement option. The correct length is 11, not 12 (plus 16 times the number of addresses listed in the Other Home Agents field in the Acknowledgement).

- Other minor clarifications and correction of typographical errors throughout.

Acknowledgements

We would like to thank the members of the Mobile IP and IPng Working Groups for their comments and suggestions on this work. We would particularly like to thank Josh Broch, Thomas Narten, Erik Nordmark, and Jim Solomon for their detailed reviews of earlier versions of this draft. Their suggestions have helped to improve both the design and presentation of the protocol.

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Chair's Address

The Working Group can be contacted via its current chairs:

Jim Solomon
Motorola, Inc.
1301 E. Algonquin Rd.
Schaumburg, IL 60196
USA

Phone: +1 847 576-2753
E-mail: solomon@comm.mot.com

Erik Nordmark
Sun Microsystems, Inc.
2550 Garcia Avenue
Mt. View, CA 94041
USA

Phone: +1 415 786-5166
Fax: +1 415 786-5896
E-mail: nordmark@sun.com

Authors' Addresses

Questions about this document can also be directed to the authors:

David B. Johnson
Carnegie Mellon University
Computer Science Department
5000 Forbes Avenue
Pittsburgh, PA 15213-3891
USA

Phone: +1 412 268-7399
Fax: +1 412 268-5576
E-mail: dbj@cs.cmu.edu

Charles Perkins
Sun Microsystems, Inc.
Technology Development Group
Mail Stop MPK15-214
Room 2682
901 San Antonio Road
Palo Alto, CA 94303
USA

Phone: +1 415 786-6464
Fax: +1 415 786-6445
E-mail: cperkins@eng.sun.com