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Route Optimization in Mobile IP

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Status of This Memo

Abstract

Using the base Mobile IP protocol, all datagrams destined to a mobile node are routed through that mobile node's home agent, which then tunnels each datagram to the mobile node's current location. This document defines Route Optimization messages and extensions to the base protocol to optimize datagram routing to a mobile node. Using these protocol extensions, correspondent nodes may cache the binding of a mobile node, and then tunnel their datagrams for the mobile node directly to the care-of address, bypassing the mobile node's home agent. Extensions are also provided to allow datagrams in flight when a mobile node moves, and datagrams sent based on an out-of-date cached binding, to be forwarded directly to the mobile node's new binding.

Contents

1. Introduction

The base Mobile IP protocol [12], allows any mobile node to move about, changing its point of attachment to the Internet, while continuing to be identified by its home IP address. Correspondent nodes send IP datagrams to a mobile node at its home address in the same way as with any other destination. This scheme allows transparent interoperation between mobile nodes and their correspondent nodes, but forces all datagrams for a mobile node to be routed through its home agent. Thus, datagrams to the mobile node are often routed along paths that are significantly longer than optimal. For example, if a mobile node is visiting some subnet, even datagrams from a correspondent node on the same subnet must be routed through the Internet to the mobile node's home agent (on its home network), only then to be tunneled back to the original subnet for final delivery. This indirect routing delays the delivery of the datagrams to mobile nodes, and places an unnecessary burden on the networks and routers along their paths through the Internet.

In this document, we will define extensions to the operation of the base Mobile IP protocol to allow for better routing, so that datagrams can be routed from a correspondent node to a mobile node without going to the home agent first. We refer collectively to these extensions as Route Optimization.

Route Optimization extensions provide a means for nodes to cache the binding of a mobile node and to then tunnel their own datagrams directly to the care-of address indicated in that binding, bypassing the mobile node's home agent. Extensions are also provided to allow datagrams in flight when a mobile node moves, and datagrams sent based on an out-of-date cached binding, to be forwarded directly to the mobile node's new care-of address.

All operation of Route Optimization that changes the routing of IP datagrams to the mobile node is authenticated using the same type of mechanisms defined in the base Mobile IP protocol. This authentication generally relies on a mobility security association established in advance between the sender and receiver of such messages. The association can be created using ISAKMP [7], or any of the registration key establishment methods specified in [11].

After Section 2 gives some extra terminology, Section 3 provides an overview of the basic protocol operations associated with Route Optimization. Section 4 defines the message types used to update binding caches. Subsequent sections show the formats for the messages, explaining the function of fields within each message. Home agent considerations are given in Section 7, and foreign agent considerations in Section 8.

2. Terminology

This document introduces the following terminology, in addition to that used to describe the base Mobile IP protocol:

Binding cache

A cache of mobility bindings of mobile nodes, maintained by a node for use in tunneling datagrams to those mobile nodes.

Binding update

A message indicating a mobile node's current mobility binding, and in particular its care-of address.

Registration Lifetime

The registration lifetime is the time duration for which a binding is valid. The term remaining registration lifetime means the amount of time remaining for which a registration lifetime is still valid, at some time after the registration was approved by the home agent.

Security Parameters Index (SPI)

An index identifying a security context between a pair of nodes among the contexts available in the Mobility Security Association. SPI values 0 through 255 are reserved [2].

Triangle Routing

A situation in which a Correspondent Host's packets to a Mobile Host follow a path which is longer than the optimal path because the packets must be forwarded to the Mobile Host via a Home Agent.

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [1].

3. Route Optimization Overview

This section provides an overview of the protocols and operations of Route Optimization. These can be divided into two main parts:

1. Updating binding caches

2. Managing smooth handoffs between foreign agents

The first part of the document goes into detail about binding cache maintenance, and then smooth handoff is considered.

3.1. Binding Caches

Route Optimization provides a means for any node to maintain a binding cache containing the care-of address of one or more mobile nodes. When sending an IP datagram to a mobile node, if the sender has a binding cache entry for the destination mobile node, it MAY tunnel the datagram directly to the care-of address indicated in the cached mobility binding.

In the absence of any binding cache entry, datagrams destined for a mobile node will be routed to the mobile node's home network in the same way as any other IP datagram, and then tunneled to the mobile node's current care-of address by the mobile node's home agent. This is the only routing mechanism supported by the base Mobile IP protocol. With Route Optimization, as a side effect of this indirect routing of a datagram to a mobile node, the original sender of the datagram may be informed of the mobile node's current mobility binding, giving the sender an opportunity to cache the binding.

Any node may maintain a binding cache to optimize its own communication with mobile nodes. A node may create or update a binding cache entry for a mobile node only when it has received and authenticated the mobile node's mobility binding. As before, each binding in the binding cache also has an associated lifetime, specified in the Binding Update message in which the node obtained the binding. After the expiration of this time period, the binding is deleted from the cache. In addition, a node cache MAY use any reasonable strategy for managing the space within the binding cache. When a new entry needs to be added to the binding cache, the node MAY choose to drop any entry already in the cache, if needed, to make space for the new entry. For example, a least-recently used (LRU) strategy for cache entry replacement is likely to work well.

When a mobile node's home agent intercepts a datagram from the home network and tunnels it to the mobile node, the home agent may deduce that the original source of the datagram has no binding cache entry for the destination mobile node. The home agent SHOULD then send a Binding Update message to the original source node, informing it of the mobile node's current mobility binding. No acknowledgment for such a Binding Update message is needed, since additional future datagrams from this source node intercepted by the home agent for the mobile node will cause transmission of another Binding Update. For a Binding Update to be authenticated by the original source node, the source node and the home agent must have established a mobility

security association.

Similarly, when any node (e.g., a foreign agent) receives a tunneled datagram, if it has a binding cache entry for the destination mobile node (and thus has no visitor list entry for this mobile node), the node receiving this tunneled datagram may deduce that the tunneling node has an out-of-date binding cache entry for this mobile node. In this case, the receiving node SHOULD send a Binding Warning message to the mobile node's home agent, advising it to send a Binding Update message to the node that tunneled this datagram. A correspondent node can determine the mobile node's home agent from the binding cache entry, because the home agent address is learned from the Binding Update that established this cache entry. The address of the node that tunneled this datagram can be determined from the datagram's header, since the address of the node tunneling this datagram is the outer source address of the encapsulated datagram. As in the case of a Binding Update sent by the mobile node's home agent, no acknowledgment of this Binding Warning is needed, since additional future datagrams for the mobile node tunneled by the same node will cause the transmission of another Binding Warning. However, unlike the Binding Update message, no authentication of the Binding Warning message is necessary, since it does not directly affect the routing of IP datagrams to the mobile node.

When sending an IP datagram, if the sending node has a binding cache entry for the destination node, it SHOULD tunnel the datagram to the mobile node's care-of address using the encapsulation techniques used by home agents, and described in [9, 10, 3, 4].

3.2. Foreign Agent Smooth Handoff

When a mobile node moves and registers with a new foreign agent, the base Mobile IP protocol does not notify the mobile node's previous foreign agent. IP datagrams intercepted by the home agent after the new registration are tunneled to the mobile node's new care-of address, but datagrams in flight that had already been intercepted by the home agent and tunneled to the old care-of address when the mobile node moved are likely to be lost and are assumed to be retransmitted by higher-level protocols if needed. The old foreign agent eventually deletes its visitor list entry for the mobile node after the expiration of the registration lifetime.

Route Optimization provides a means for the mobile node's previous foreign agent to be reliably notified of the mobile node's new mobility binding, allowing datagrams in flight to the mobile node's previous foreign agent to be forwarded to its new care-of address. This notification also allows any datagrams tunneled to the mobile node's previous foreign agent, from correspondent nodes with out-of-date binding cache entries for the mobile node, to be

forwarded to its new care-of address. Finally, this notification

allows any resources consumed by the mobile node at the previous foreign agent (such as radio channel reservations) to be released immediately, rather than waiting for its registration lifetime to expire.

As part of the registration procedure, the mobile node MAY request that its new foreign agent attempt to notify its previous foreign agent on its behalf, by including a Previous Foreign Agent Notification extension in its Registration Request message sent to the new foreign agent. The new foreign agent then builds a Binding Update message and transmits it to the mobile node's previous foreign agent as part of registration, requesting an acknowledgment from the previous foreign agent. The extension includes only those values needed to construct the Binding Update message that are not already contained in the Registration Request message. The authenticator for the Binding Update message is computed by the mobile node using the security association shared with its previous foreign agent. This notification will typically include the mobile node's new care-of address, allowing the previous foreign agent to create a binding cache entry for the mobile node to serve as a forwarding pointer [5] to its new location. Any tunneled datagrams for the mobile node that arrive at its previous foreign agent after the forwarding pointer has been created can then be re-tunneled to the mobile node's new care-of address.

For this smooth handoff to be secure during registration with a new foreign agent, the mobile node and the previous foreign agent must have a security association. The security association is used to authenticate the notification sent to the previous foreign agent.

The Mobility Agent Advertisement extension of the agent advertisement message is revised under Route Optimization to include a bit indicating that the foreign agent supports smooth handoffs.

The mobile node is responsible for occasionally retransmitting a Binding Update message to its previous foreign agent until the matching Binding Acknowledge message is received, or until the mobile node can be sure that foreign agent has expired its binding. The mobile node is likely to select a small timeout value for the lifetime available to such bindings sent to previous foreign agents.

4. Route Optimization Message Formats

Route Optimization defines four message types used for management of binding cache entries. These message types fit in the numbering space defined in the base Mobile IP specification for messages sent to UDP port 434. Each of these messages begins with a one-octet

field indicating the type of the message. The binding cache

management messages in this section are carried by way of UDP, sent to port 434.

The following type codes are defined in this document:

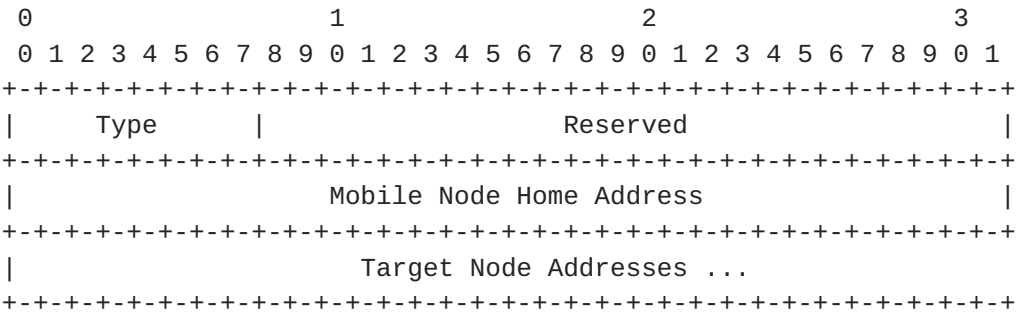
16	Binding Warning message
17	Binding Request message
18	Binding Update message
19	Binding Acknowledge message

Route Optimization also requires one minor change to existing Mobile IP messages: a new flag bit must be added to the Registration Request message, replacing a previously unused, reserved bit in the message.

This section describes each of the new Route Optimization messages and the change to Registration Request message.

4.1. Binding Warning Message

A Binding Warning message is used to transmit advice that a Binding Update is needed by one or more correspondent nodes or foreign agents. This happens when the suggested recipients are likely to have either no binding cache entry or an out-of-date binding cache entry for some mobile node. When any node detunnels a datagram destined for the mobile node, if it is not the current foreign agent for the destination mobile node, that foreign agent SHOULD send a Binding Warning message to the mobile node's home agent. If the foreign agent does not have any information about the mobile node's home agent, the foreign agent SHOULD send a Binding Warning message to the sender of the datagram (i.e., the correspondent node).



The format of the Binding Warning message is illustrated above, and contains the following fields:

Type 16

Reserved Sent as 0; ignored on reception.

Mobile Node Home Address
: The home address of the mobile node to which the Binding Warning message refers.

Target Node Addresses
: Zero or more addresses of nodes. Each address identifies a node that should be the target of a Binding Update message sent by the home agent. If no addresses are present, the recipient of the message is the intended target for the message.

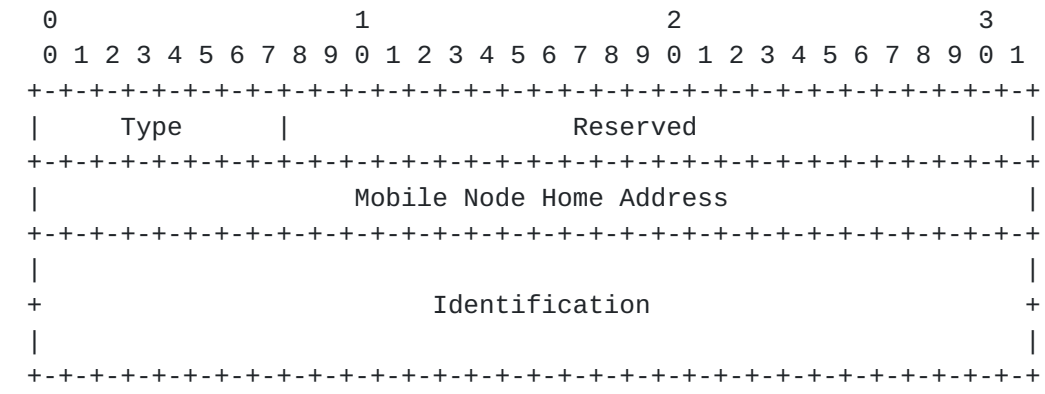
A home agent will receive a Binding Warning message if a node maintaining a binding cache entry for one of the home agent's mobile nodes uses an out-of-date entry. When a home agent receives a Binding Warning message, it SHOULD send a Binding Update message to each target node address identified in the Binding Warning, giving it the current binding for the mobile node identified in the mobile node home address field of the Binding Warning.

When a mobile node receives a new Care-of Address, it MAY send a Binding Warning message to its Home Agent, requesting that the home agent send Binding Update messages to one or more correspondent nodes. This feature MAY be used by the mobile node when it returns to its home network, so that the Home Agent will send out Binding Updates with zero lifetimes to all the mobile node's correspondent nodes. It is important for the correspondent nodes to delete their binding cache entries for the mobile node when the mobile node no longer has a Care-of Address.

If a foreign agent receives a packet for a mobile node for which there isn't any visitor list or binding cache information available, the foreign agent SHOULD send the Binding Warning to the correspondent node that transmitted the undeliverable message.

4.2. Binding Request Message

A Binding Request message is used by a node to request a mobile node's current mobility binding from a mobile node or the mobile node's home agent.



The format of the Binding Request message is illustrated above, and contains the following fields:

Type 17

Reserved Sent as 0; ignored on reception.

Mobile Node Home Address
The home address of the mobile node to which the Binding Request refers.

Identification
A 64-bit sequence number, assigned by the node sending the Binding Request message, used to assist in matching requests with replies, and in protecting against replay attacks.

When the home agent receives a Binding Request message, it consults its home list and determines the correct binding information to be sent to the requesting node. Before satisfying the request, the home agent is required to check whether or not the mobile node has allowed the information to be disseminated. If the mobile node specified the private (P) bit in its Registration Request message, then the home agent must make no further attempt to satisfy Binding Requests on behalf of that mobile node. In this case, the home agent SHOULD return a Binding Update in which both the care-of address is set equal to the mobile node's home address and the lifetime is set to zero. Such a Binding Update message indicates that the binding cache entry for the specified mobile node should be deleted.

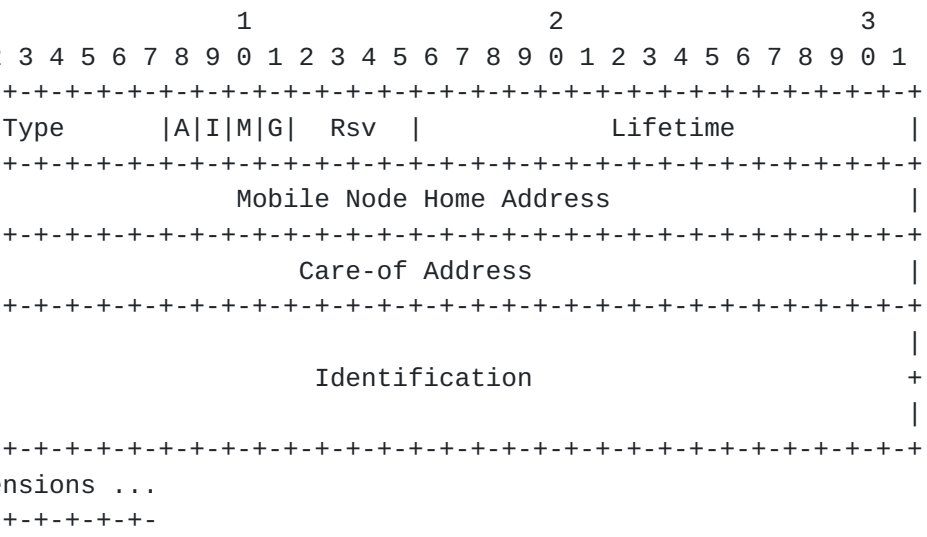
4.3. Binding Update Message

The Binding Update message is used for notification of a mobile node's current mobility binding. Subject to rate-limiting

provisions, it SHOULD be sent by the mobile node's home agent in the following situations:

- in response to a Binding Request message,
- in response to a Binding Warning message,
- in response to the reception of a Binding Warning extension to a Registration Request,
- in response to the reception of a packet destined for a mobile node.

A Binding Update SHOULD also be sent by a mobile node, or by the foreign agent with which the mobile node is registering, when notifying the mobile node's previous foreign agent that the mobile node has moved.



The format of the Binding Update message is illustrated above, and contains the following fields:

Type 18

A The 'A' (acknowledge) bit is set by the node sending the Binding Update message to request a Binding Acknowledge message be returned.

I The 'I' (identification present) bit is set by the node sending the Binding Update message if the identification field is present in the message.

M If the 'M' (minimal encapsulation) bit is set, datagrams MAY be tunneled to the mobile node using the minimal encapsulation protocol [10].

G If the 'G' (Generic Record Encapsulation, or GRE) bit is set, datagrams MAY be tunneled to the mobile node using GRE [3].

Rsv Reserved. Sent as 0; ignored on reception.

Lifetime The number of seconds remaining before the binding cache entry must be considered expired. A value of all ones indicates infinity. A value of zero indicates that no binding cache entry for the mobile node should be created and that any existing binding cache entry (and visitor list entry, in the case of a mobile node's previous foreign agent) for the mobile node should be deleted. The lifetime is typically equal to the remaining lifetime of the mobile node's registration.

Mobile Node Home Address
The home address of the mobile node to which the Binding Update message refers.

Care-of Address
The current care-of address of the mobile node. When set equal to the home address of the mobile node, the Binding Update message instead indicates that no binding cache entry for the mobile node should be created, and any existing binding cache entry (and visitor list entry, in the case of a mobile node's previous foreign agent) for the mobile node should be deleted.

Identification
If present, a 64-bit number, assigned by the node sending the Binding Request message, used to assist in matching requests with replies, and in protecting against replay attacks.

Each Binding Update message indicates the binding's maximum lifetime. When sending the Binding Update message, the home agent SHOULD set this lifetime to the remaining registration lifetime. A node wanting to provide continued service with a particular binding cache entry MAY attempt to reconfirm that mobility binding before the expiration of the registration lifetime. Such reconfirmation of a binding cache entry may be appropriate when the node has indications (such as an

open transport-level connection to the mobile node) that the binding

cache entry is still needed. This reconfirmation is performed by the node sending a Binding Request message to the mobile node's home agent, requesting it to reply with the mobile node's current mobility binding in a new Binding Update message. Note that the node maintaining the binding SHOULD also keep track of the home agent's address, to be able to fill in the destination IP address of future Binding Requests.

As stated in Section 4.2, if the home agent chooses to respond to a Binding Request for a mobile node that set the `P' bit in its registration, or which has returned home, it MUST send a Binding Update with the care-of address set to the mobile node's home address and with the lifetime set to zero. The home agent may also send such zero-lifetime Binding Updates to correspondent nodes named in a Binding Warning extension to a registration request that has the `P' bit set or which is effecting de-registration of the mobile node. Finally, the home agent MAY also send such zero-lifetime Binding Updates to foreign agents from which the mobile node was previously registered but which are no longer serving the mobile node. This would allow such foreign agents to immediately reclaim any state information that pertained to the mobile node without waiting for the requisite lifetime to expire.

When a node receives a Binding Update message, it is required to verify the authentication in the message, using the mobility security association it shares with the sender's home agent. In such cases, the authentication data is found in the Route Optimization or Smooth Handoff authentication extension (Section 5), which is required. If the authentication succeeds, then a binding cache entry SHOULD be updated for use in future transmissions of data to the mobile node. Otherwise, an authentication exception SHOULD be raised.

Under all circumstances, the sending of Binding Update messages is subject to the rate limiting restriction described in Section 7.1.

When using nonces for replay protection, the identification field in the Binding Update message is used differently, to still allow replay protection even though the Binding Update is not being sent in reply to a request directly from the target node. In this case, the home agent is required to set the high-order 32 bits of the identification field to the value of the nonce that will be used by the home agent in the next Binding Update message sent to this node. The low-order 32 bits of the identification field are required to be set to the value of the nonce being used for this message.

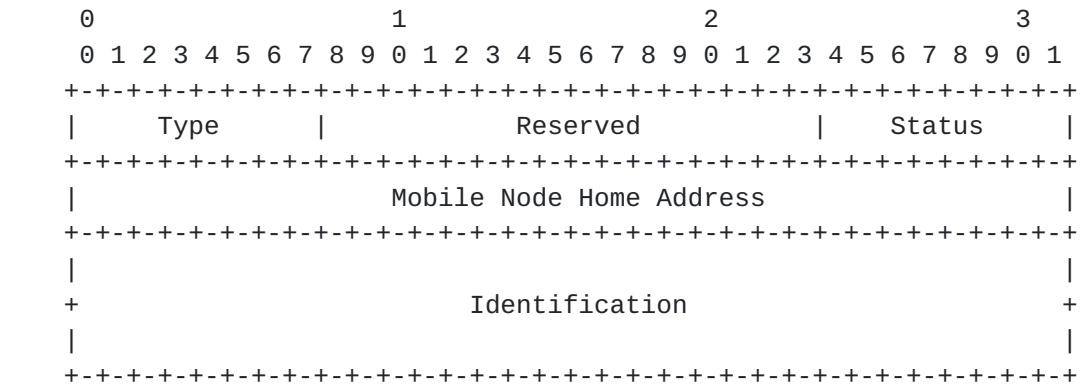
Thus, on each Binding Update message, the home agent communicates to the target node, the value of the nonce that will be used next time. If no Binding Updates are lost in the network, the home agent and the

target node can remain synchronized with respect to the nonces being

used. If, however, the target node receives a Binding Update with what it believes to be an incorrect nonce, it MAY resynchronize with the home agent by using a Binding Request message.

4.4. Binding Acknowledge Message

A Binding Acknowledge message is used to acknowledge receipt of a Binding Update message. It SHOULD be sent by a node receiving a Binding Update message in which the acknowledge (A) bit is set; if in addition that message also contains a valid authentication extension and Identification, the Binding Acknowledge MUST be sent.



The format of the Binding Acknowledge message is illustrated above, and contains the following fields:

Type 19

Status If the Status is nonzero, this acknowledgment is negative. For instance, if the Binding Update was not accepted, but the incoming datagram has the Acknowledge flag set, then the status code should be set appropriately in the Binding Acknowledge message.

Reserved Sent as 0; ignored on reception.

Mobile Node Home Address
Copied from the Binding Update message being acknowledged.

Identification
Copied from the Binding Update message being acknowledged, if present there.

Allowable values for the Status include:

128 reason unspecified
129 administratively prohibited
130 insufficient resources
131 sending node failed authentication
133 identification mismatch
134 poorly formed Binding Update

Up-to-date values of the Code field are specified in the most recent "Assigned Numbers" [13].

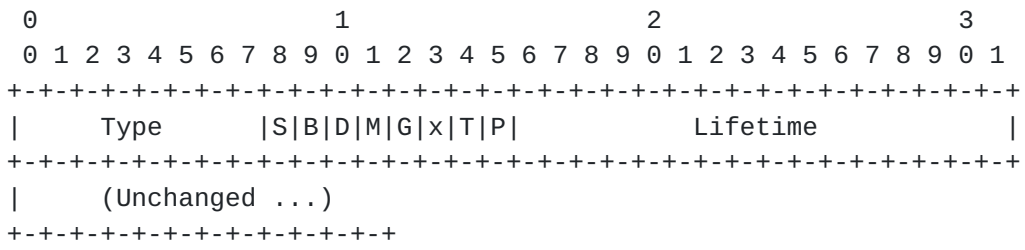
5. Route Optimization Authentication Extension

The Route Optimization Authentication extension is used to authenticate Route Optimization management messages sent with an SPI corresponding to the source IP address of the message. This extension is subtype TBD of the Generalized Authentication Extension [2]. The authenticator value is computed, as before, from the stream of bytes including the shared secret, the UDP payload (that is, the Route Optimization management message), all prior extensions in their entirety, and the type, subtype, length, and SPI of this extension, but not including the authenticator field itself nor the UDP header. This extension is required to be used in any Binding Update message sent by the Home Agent or the Mobile Node.

5.1. Modified Registration Request Message

One bit is added to the flag bits in the Registration Request message to indicate that the mobile node would like its home agent to keep its mobility binding private. Normally, the home agent sends Binding Update messages to correspondent nodes as needed to allow them to cache the mobile node's binding. If the mobile node sets the private (`P') bit in the Registration Request message, the home agent MUST NOT send the mobile node's binding in any Binding Update message. Instead, each Binding Update message SHOULD give the mobile node's care-of address equal to its home address, and SHOULD give a lifetime value of 0.

Thus, the Registration Request message under Route Optimization begins as shown below:



P The private (`P') bit is set by the node sending the Binding Update message to indicate that the home agent MUST keep its mobility binding private. In any Binding Update message sent by the mobile node's home agent, the care-of address SHOULD be set equal to the mobile node's home address, and the lifetime SHOULD be set equal to 0.

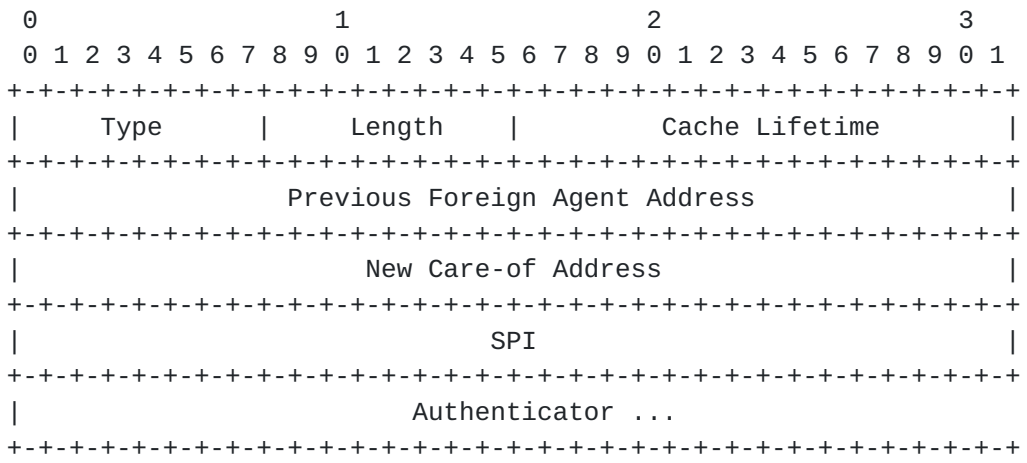
The other flag bits are as defined in the base Mobile IP specification [12] and for Reverse Tunneling [8].

6. Format of Smooth Handoff Extensions

This section specifies the format for messages which are used to enable smooth handoff from a mobile node's previous foreign agent to its new foreign agent when a mobile node initiates a new registration.

6.1. Previous Foreign Agent Notification Extension

The Previous Foreign Agent Notification extension MAY be included in a Registration Request message sent to a mobility agent (either a foreign agent or the mobile node's home agent). It instructs the mobility agent to send a Binding Update message to the mobile node's previous foreign agent on behalf of the mobile node, to notify it that the mobile node has moved. The previous foreign agent SHOULD then delete the mobile node's visitor list entry and, if a new care-of address is included in the Binding Update message, create a binding cache entry for the mobile node with its new care-of address. The Previous Foreign Agent Notification extension contains only those values not otherwise already contained in the Registration Request message that are needed for the new foreign agent to construct the Binding Update message.



Type 96

Length 14 plus the length of the authenticator

Cache Lifetime
The number of seconds remaining before the binding cache entry created by the previous foreign agent must be considered expired. A value of all ones indicates infinity. A value of zero indicates that the previous foreign agent MUST NOT create a binding cache entry for the mobile node once it has deleted the mobile node's visitor list entry. The cache lifetime value is copied into the lifetime field of the Binding Update message.

Previous Foreign Agent Address
The IP address of the mobile node's previous foreign agent to which the new foreign agent should send a Binding Update message on behalf of the mobile node.

New Care-of Address
The address for the new mobility agent to send in the Binding Update message to the previous foreign agent.

SPI Security Parameters Index (4 bytes). An opaque identifier. The SPI is copied over into the Smooth Handoff authentication extension by the new foreign agent.

Authenticator
The authenticator value to be used in the Route Optimization Authentication extension in the Binding Update message sent by the new foreign agent to the mobile node's previous foreign agent. This authenticator is calculated only over the Binding Update message body.

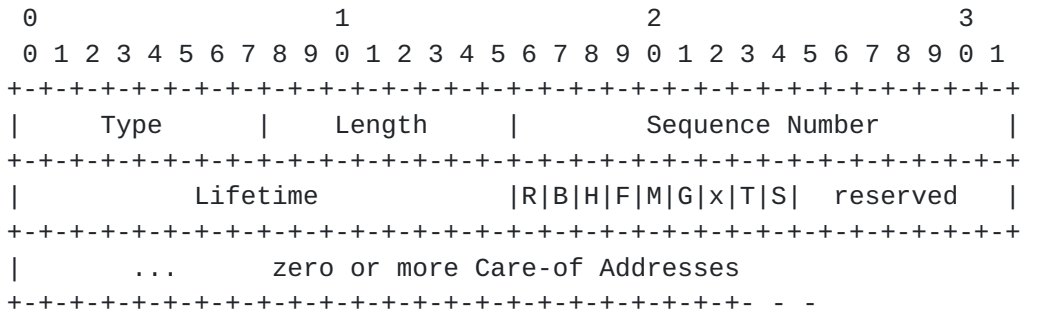
If a binding cache entry is created at the mobile node's previous foreign agent, it is treated in the same way as any other binding cache entry. The New Care-of Address in the extension SHOULD be either the care-of address being registered in the new registration (to cause IP datagrams from the previous foreign agent to be tunneled to the new foreign agent) or the mobile node's home address (to cause the previous foreign agent to delete its visitor list entry only for the mobile node, but not forward datagrams for it). This latter feature is especially valuable when a mobile node returns to its home network.

Mobile nodes SHOULD assign a small value to the Cache Lifetime, so that the binding created at the previous foreign agent will not take up space in the foreign agent's binding cache for very long.

The Binding Update sent by the mobility agent to the previous foreign agent MUST have the IP address of the foreign agent as the source address in the IP header. Conceptually, the mobility agent is ``forwarding'' a Binding Update to the previous foreign agent, albeit in a way that is specialized to the needs of the mobile node to reestablish connectivity with the fewest number of packet transmissions over its own link. The mobility agent MUST set the `A' bit in the Binding Update message, so that the previous foreign agent will know to send a Binding Acknowledge message back to the mobile node.

6.2. Modified Mobility Agent Advertisement Extension

Performing smooth handoffs requires one minor change to the existing Mobile IP Mobility Agent Advertisement extension [12]. A new flag bit, the 'S' bit, replaces a previously unused reserved bit in the extension, to indicate that the foreign agent supports smooth handoffs. By default, every foreign agent that supports smooth handoffs SHOULD support at least the establishment of a registration key by using elliptic curve key exchange [11].



Thus, the proposed modification to the Mobility Agent Advertisement

extension, illustrated above, keeps the advertisement almost the

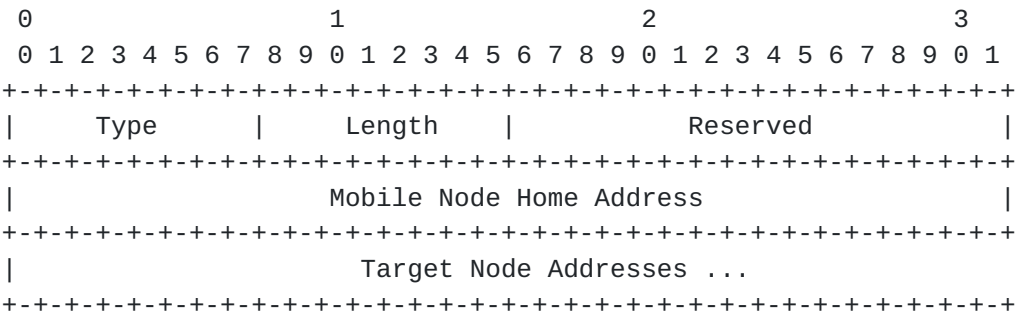
same as in the base Mobile IP specification, except for adding the following bit:

S The 'S' smooth handoff bit is set by the foreign agent sending the agent advertisement message to indicate that it supports the smooth handoffs, and thus the Registration Key Request extension [11].

More detailed information about the handling of this extension by foreign agents is deferred until Section 8.1.

6.3. Binding Warning Extension

A mobile node MAY append a Binding Warning Extension to a Registration Request. The Binding Warning extension is used to advise a mobile node's home agent that one or more correspondent nodes are likely to have either no binding cache entry or an out-of-date binding cache entry for the mobile node sending the Registration Request.



The format of the Binding Warning extension is illustrated above, and contains the following fields:

Type 16

Reserved Sent as 0; ignored on reception.

Mobile Node Home Address
The home address of the mobile node to which the Binding Warning message refers.

Target Node Addresses
One or more addresses of the correspondent nodes that need to receive Binding Update messages. Each node should be the target of a Binding Update message sent by the home agent.

When a home agent receives a Binding Warning extension as part of a valid Registration Request, it SHOULD send a Binding Update message to each target node address identified in the Binding Warning, giving it the current binding for the mobile node identified in the mobile node home address field of the Binding Warning.

When a mobile node returns to its home network, it SHOULD append a Binding Warning extension to the Registration Request message sent to its Home Agent, instructing its home agent to send Binding Update messages (naturally, with zero lifetimes) to one or more correspondent nodes. It is important for the correspondent nodes to delete their binding cache entries for the mobile node when the mobile node no longer has a Care-of Address.

7. Miscellaneous Home Agent Operations

7.1. Home Agent Rate Limiting

A home agent is required to provide some mechanism to limit the rate at which it sends Binding Update messages to to the same node about any given mobility binding. This rate limiting is especially important because it is expected that, within the short term, most Internet nodes will not support maintenance of a binding cache. In this case, continual transmissions of Binding Update messages will only waste processing resources at the home agent and correspondent node, and along the Internet path between these nodes.

7.2. Managing Binding Updates for Correspondent Nodes

The home agent MAY keep a list of correspondent nodes from which it has received Binding Acknowledgements for Binding Updates for active registrations (i.e., registrations which have not yet timed out). In this case, when the home agent receives a valid Registration Request, it MAY transmit new Binding Updates to each correspondent node that is on its list for the particular mobile node. In order to know which correspondent nodes correctly received the Binding Updates, the home agent SHOULD set the `A' bit in the Binding Update, requesting an acknowledgement.

Rate-limiting MUST be employed by a Home Agent offering this service, as specified in section 7.1.

8. Miscellaneous Foreign Agent Operations

This section details various operational considerations important for foreign agents wishing to support smooth handoff. This includes

processing Previous Foreign Agent Notification extensions, and the maintenance of up-to-date binding cache entries.

8.1. Previous Foreign Agent Notification

When a foreign agent receives a Previous Foreign Agent Notification extension, it creates a Binding Update for the previous foreign agent, using the specified SPI and precomputed authenticator sent to it by the mobile node.

When the previous foreign agent receives the Binding Update, it will authenticate the message using the mobility security association and SPI specified in the Binding Update. If the message authentication is correct, the visitor list entry for this mobile node at the previous foreign agent will be deleted and a Binding Acknowledge message returned to the sender. In addition, if a new care-of address was included in the Binding Update message, the previous foreign agent will create a binding cache entry for the mobile node; the previous foreign agent can then tunnel datagrams to the mobile node's new care-of address using that binding cache, just as any node maintaining a binding cache. The previous foreign agent is also expected to return a Binding Acknowledge message to the mobile node.

Note that this Binding Acknowledge is addressed to the mobile node, and SHOULD be tunneled using the new binding cache entry. The tunneled acknowledgment then SHOULD be delivered directly to the new foreign agent, without having to go to the home network. This creates an interesting problem for the new foreign agent when it receives the acknowledgment before the Registration Reply from the home agent. It is suggested that the new foreign agent deliver the acknowledgment to the mobile node anyway, even though the mobile node is technically unregistered. If there is concern that this provides a loophole for unauthorized traffic to the mobile node, the new foreign agent could limit the number of datagrams delivered to the unregistered mobile node to this single instance. Alternatively, a new extension to the Registration Reply message can be defined to carry along the acknowledgment from the previous foreign agent. This latter approach would have the benefit that fewer datagrams would be transmitted over bandwidth-constrained wireless media during registration.

When the Binding Acknowledge message from the previous foreign agent is received by the new foreign agent, it detunnels it and sends it to the mobile node. In this way, the mobile node can discover that its previous foreign agent has received the Binding Update message. The mobile node has to be certain that its previous foreign agent has been notified about its new care-of address, because

otherwise the previous foreign agent could become a "black hole"

for datagrams destined for the mobile node based on out-of-date binding cache entries at other nodes. The new foreign agent has no further responsibility for helping to update the binding cache at the previous foreign agent, and does not retransmit the message even if no acknowledgment is received.

If the acknowledgment has not been received after sufficient time, the mobile node is responsible for retransmitting another Binding Update message to its previous foreign agent. Although the previous foreign agent may have already received and processed the Binding Update message (the Binding Acknowledge message may have been lost in transit to the new foreign agent), the mobile node SHOULD continue to retransmit its Binding Update message until the previous foreign agent responds with a Binding Acknowledge.

8.2. Maintaining Binding Caches

The binding cache entry built by the previous foreign agent from the information in the Previous Foreign Agent Notification extension MAY be deleted from its Binding Cache at any time, and these cache entries are expected to be created with short lifetimes (see section 6.1). In this case, the previous foreign agent will be unable to find a current care-of address for subsequently arriving tunneled datagrams for the mobile node.

8.3. Rate Limiting

A foreign agent MUST provide some mechanism to limit the rate at which it sends Binding Warning messages to the same node about any given mobility binding. This rate limiting is especially important because it is expected that, within the short term, many Internet nodes will not support maintenance of a binding cache. In this case, continual transmissions of Binding Warning messages will only waste processing resources at the foreign agent and correspondent node, and along the Internet path between these nodes.

9. Security Considerations

The calculation of the authentication data supplied with the Route Optimization and Smooth Handoff authentication extensions in section 5 is specified to be the same as in the base Mobile IP document for ease of implementation. There is a better method available (HMAC), specified in RFC 2104 [6]. If the base Mobile IP specification is updated to use HMAC, then this route optimization specification SHOULD also be updated similarly.

10. Acknowledgement

Expanding the Binding Warning to allow a mobile node to send a list of correspondent nodes to the Home Agent was suggested by Mohamad Khalil, Emad Qaddoura, Haseeb Akhtar, and Liem Le of Nortel Networks. Pete McCann of Lucent also contributed text specifying additional considerations under which the home agent could send zero-lifetime Binding Updates in section 4.3.

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A. Mobility Security Association Management

One of the most difficult aspects of Route Optimization for Mobile IP in the Internet today is that of providing authentication for all messages that affect the routing of datagrams to a mobile node. In the base Mobile IP protocol, only the home agent is aware of the mobile node's mobility binding and only the home agent tunnels datagrams to the mobile node. Thus, all routing of datagrams to the mobile node while away from its home network is controlled by the home agent. Authentication is currently achieved based on a manually established mobility security association between the home agent and the mobile node. Since the home agent and the mobile node are both owned by the same organization (both are assigned IP addresses within the same IP subnet), this manual configuration is manageable, and (for example) can be performed while the mobile node is at home.

However, with Route Optimization, authentication is more difficult to manage, since a Binding Update may in general need to be sent to almost any node in the Internet. Since no authentication or key distribution protocol is generally available in the Internet today, the Route Optimization procedures defined in this document MAY make use of the same type of manual key distribution discussed in the base Mobile IP protocol. For use with Route Optimization, a mobility security association held by a correspondent node or a foreign agent must include the same parameters as required by base Mobile IP [12].

For a correspondent node to be able to create a binding cache entry for a mobile node, the correspondent node needs a mobility security association with either the mobile node or its home agent. This mobility security association, though, could be used in creating and updating binding cache entries at this correspondent node for all mobile nodes served by this home agent. Doing so places the correspondent node in a fairly natural relationship with respect to the mobile nodes served by this home agent. For example, the mobile nodes may represent different people affiliated with the same organization owning the home agent, with which the user of the correspondent node often collaborates. The effort of establishing such a mobility security association with the relevant home agent may be more manageable (appendix B) than the effort of doing so with each

mobile node. It is similarly possible for a home agent to have a

manually established mobility security association with the foreign agents often used by its mobile nodes, or for a particular mobile node to have a manually established mobility security association with the foreign agents serving the foreign networks that it often visits.

In general, if the movement and communication patterns of a mobile node or the group of mobile nodes served by the same home agent are sufficient to justify establishing a mobility security association with the mobile node's home agent, users or network administrators are likely to do so. Without establishing a mobility security association, nodes will not currently be able to authenticate the values transmitted in Route Optimization extensions.

B. Using a Master Key at the Home Agent

Rather than storing each mobility security association that it has established with many different correspondent nodes and foreign agents, a home agent MAY manage its mobility security associations so that each of them can be generated from a single master key. With the master key, the home agent could build a key for any given other node, for example by computing the node-specific key as

```
MD5(node-address | master-key | node-address)
```

where node-address is the IP address of the particular node for which the home agent is building a key, and master-key is the single master key held by the home agent for all mobility security associations it has established with correspondent nodes. The node-specific key is built by computing an MD5 hash over a string consisting of the master key with the node-address concatenated as a prefix and as a suffix.

Using this scheme, when establishing each mobility security association, the network administrator managing the home agent computes the node-specific key and communicates this key to the network administrator of the other node through some secure channel, such as over the telephone. The mobility security association is configured at this other node in the same way as any mobility security association. At the home agent, though, no record need be kept that this key has been given out. The home agent need only be configured to know that this scheme is in use for all of its mobility security associations (perhaps only for specific set of its mobile nodes).

When the home agent needs a mobility security association as part of Route Optimization, it builds the node-specific key based on the master key and the IP address of the other node with which it is

attempting to authenticate. If the other node knows the correct node-specific key, the authentication will succeed; otherwise, it will fail as it should.

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