

Automatic Multicast Tunneling

Abstract

This document describes Automatic Multicast Tunneling (AMT), a protocol for delivering multicast traffic from sources in a multicast-enabled network to receivers that lack multicast connectivity to the source network. The protocol uses UDP encapsulation and unicast replication to provide this functionality.

The AMT protocol is specifically designed to support rapid deployment by requiring minimal changes to existing network infrastructure.

Status of This Memo

This is an Internet Standards Track document.

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1. Introduction

The advantages and benefits provided by multicast technologies are well known. There are a number of application areas that are ideal candidates for the use of multicast, including media broadcasting, video conferencing, collaboration, real-time data feeds, data replication, and software updates. Unfortunately, many of these applications lack multicast connectivity to networks that carry traffic generated by multicast sources. The reasons for the lack of connectivity vary but are primarily the result of service provider policies and network limitations.

Automatic Multicast Tunneling (AMT) is a protocol that uses UDP-based encapsulation to overcome the aforementioned lack of multicast connectivity. AMT enables sites, hosts, or applications that do not have native multicast access to a network with multicast connectivity to a source, to request and receive Source-Specific Multicast (SSM) [RFC4607] and Any-Source Multicast (ASM) [RFC1112] traffic from a network that does provide multicast connectivity to that source.

2. Applicability

This document describes a protocol that may be used to deliver multicast traffic from a multicast-enabled network to sites that lack multicast connectivity to the source network. This document does not describe any methods for sourcing multicast traffic from isolated sites, as this topic is out of scope.

AMT is not intended to be used as a substitute for native multicast, especially in conditions or environments requiring high traffic flow. AMT uses unicast replication to reach multiple receivers, and the bandwidth cost for this replication will be higher than that required if the receivers were reachable via native multicast.

AMT is designed to be deployed at the border of networks possessing native multicast capabilities where access and provisioning can be managed by the AMT service provider.

3. Terminology

3.1. Requirements Notation

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3.2. Definitions

This document adopts the following definitions for use in describing the protocol:

Downstream:

A downstream interface or connection that faces away from the multicast distribution root or towards multicast receivers.

Upstream:

An upstream interface or connection that faces a multicast distribution root or source.

Non-Broadcast Multi-Access (NBMA):

An NBMA network or interface is one to which multiple network nodes (hosts or routers) are attached, but where packets are transmitted directly from one node to another node over a virtual circuit or physical link. NBMA networks do not support multicast or broadcast traffic -- a node that sources multicast traffic must replicate the multicast packets for separate transmission to each node that has requested the multicast traffic.

Multicast Receiver:

An entity that requests and receives multicast traffic. A receiver may be a router, host, application, or application component. The method by which a receiver transmits group membership requests and receives multicast traffic varies according to receiver type.

Group Membership Database:

A group membership database describes the current multicast subscription state (also referred to as "reception state") for an interface or system. See Section 3 of [RFC3376] for a detailed definition.

Reception State:

The multicast subscription state of a pseudo-interface, virtual interface, or physical network interface. Often synonymous with group membership database.

Subscription:

A group or state entry in a group membership database or reception state table. The presence of a subscription entry indicates membership in an IP multicast group.

Group Membership Protocol:

The term "group membership protocol" is used as a generic reference to the Internet Group Management Protocol (IGMP) [RFC1112] [RFC2236] [RFC3376] or the Multicast Listener Discovery protocol [RFC2710] [RFC3810].

Multicast Protocol:

The term "multicast protocol" is used as a generic reference to multicast routing protocols used to join or leave multicast distribution trees, such as Protocol Independent Multicast - Sparse Mode (PIM-SM) [RFC4601].

Network Address Translation (NAT):

Network Address Translation is the process of modifying the source IP address and port numbers carried by an IP packet while transiting a network node (see [RFC2663]). Intervening NAT devices may change the source address and port carried by messages sent from an AMT gateway to an AMT relay, possibly producing changes in protocol state and behavior.

Anycast:

A network addressing and routing method in which packets from a single sender are routed to the topologically nearest node in a group of potential receivers all identified by the same destination address. See [RFC4786].

3.3. Abbreviations

AMT - Automatic Multicast Tunneling protocol.

ASM - Any-Source Multicast.

DoS - Denial-of-Service (attack) and DDoS for distributed DoS.

IGMP - Internet Group Management Protocol (v1, v2, and v3).

IP - Internet Protocol (v4 and v6).

MAC - Message Authentication Code (or Cookie).

MLD - Multicast Listener Discovery protocol (v1 and v2).

NAT - Network Address Translation (or translation node).

NBMA - Non-Broadcast Multi-Access (network, interface, or mode).

PIM - Protocol Independent Multicast.

SSM - Source-Specific Multicast.

4. Protocol Overview

This section provides an informative description of the protocol. A normative description of the protocol and implementation requirements may be found in Section 5.

4.1. General Architecture

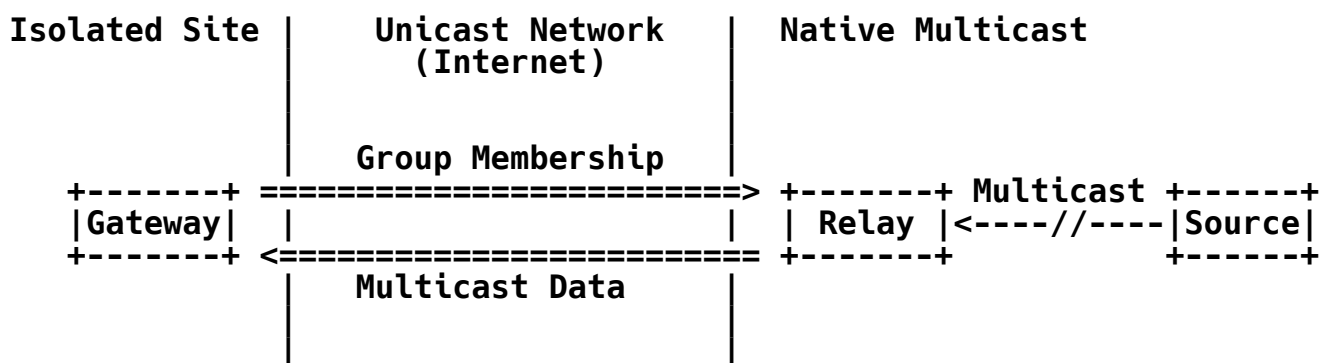


Figure 1: Basic AMT Architecture

The AMT protocol employs a client-server model in which a "gateway" sends requests to receive specific multicast traffic to a "relay" that responds by delivering the requested multicast traffic back to the gateway.

Gateways are generally deployed within networks that lack multicast support or lack connectivity to a multicast-enabled network containing multicast sources of interest.

Relays are deployed within multicast-enabled networks that contain, or have connectivity to, multicast sources.

4.1.1. Relationship to IGMP and MLD Protocols

AMT relies on the Internet Group Management Protocol (IGMP) [RFC3376] and the Multicast Listener Discovery (MLD) protocol [RFC3810] to provide the functionality required to manage, communicate, and act on changes in multicast group membership. A gateway or relay implementation does not necessarily require a fully functional, conforming implementation of IGMP or MLD to adhere to this

specification, but the protocol description that appears in this document assumes that this is the case. The minimum functional and behavioral requirements for the IGMP and MLD protocols are described in Sections 5.2.1 and 5.3.1.

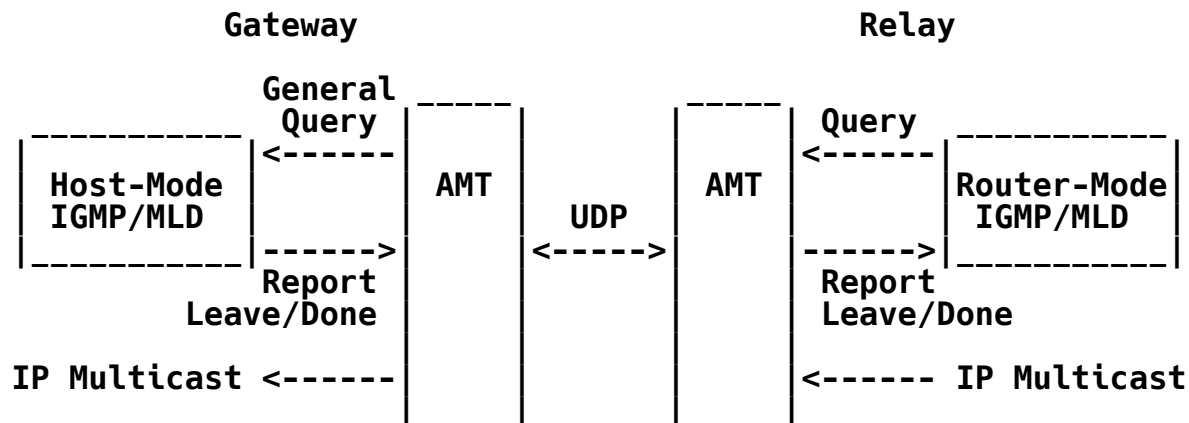


Figure 2: Multicast Reception State Managed by IGMP/MLD

A gateway runs the host portion of the IGMP and MLD protocols to generate group membership updates that are sent via AMT messages to a relay. A relay runs the router portion of the IGMP and MLD protocols to process the group membership updates to produce the required changes in multicast forwarding state. A relay uses AMT messages to send incoming multicast IP datagrams to gateways according to their current group membership state.

The primary function of AMT is to provide the handshaking, encapsulation, and decapsulation required to transport the IGMP and MLD messages and multicast IP datagrams between the gateways and relays. The IGMP and MLD messages that are exchanged between gateways and relays are encapsulated as complete IP datagrams within AMT control messages. Multicast IP datagrams are replicated and encapsulated in AMT data messages. All AMT messages are sent via unicast UDP/IP.

4.1.2. Gateways

The downstream side of a gateway services one or more receivers -- the gateway accepts group membership requests from receivers and forwards requested multicast traffic back to those receivers. The gateway functionality may be directly implemented in the host requesting the multicast service or within an application running on a host.

The upstream side of a gateway connects to relays. A gateway sends encapsulated IGMP and MLD messages to a relay to indicate an interest in receiving specific multicast traffic.

4.1.2.1. Architecture

Each gateway possesses a logical pseudo-interface:

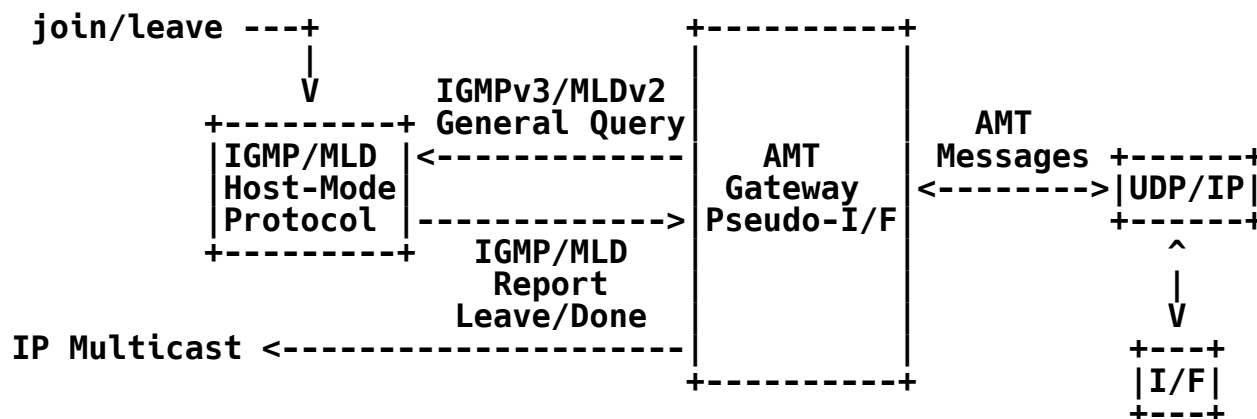


Figure 3: AMT Gateway Pseudo-Interface

The pseudo-interface is conceptually a network interface on which the gateway executes the host portion of the IPv4/IGMP (v2 or v3) and IPv6/MLD (v1 or v2) protocols. The multicast reception state of the pseudo-interface is manipulated using the IGMP or MLD service interface. The IGMP and MLD host protocols produce IP datagrams containing group membership messages that the gateway will send to the relay. The IGMP and MLD protocols also supply the retransmission and timing behavior required for protocol robustness.

All AMT encapsulation, decapsulation, and relay interaction are assumed to occur within the pseudo-interface.

A gateway host or application may create separate interfaces for IPv4/IGMP and IPv6/MLD. A gateway host or application may also require additional pseudo-interfaces for each source or domain-specific relay address.

Within this document, the term "gateway" may be used as a generic reference to an entity executing the gateway protocol, a gateway pseudo-interface, or a gateway device that has one or more interfaces connected to a unicast internetwork and one or more AMT gateway pseudo-interfaces.

The following diagram illustrates how an existing host IP stack implementation might be used to provide AMT gateway functionality to a multicast application:

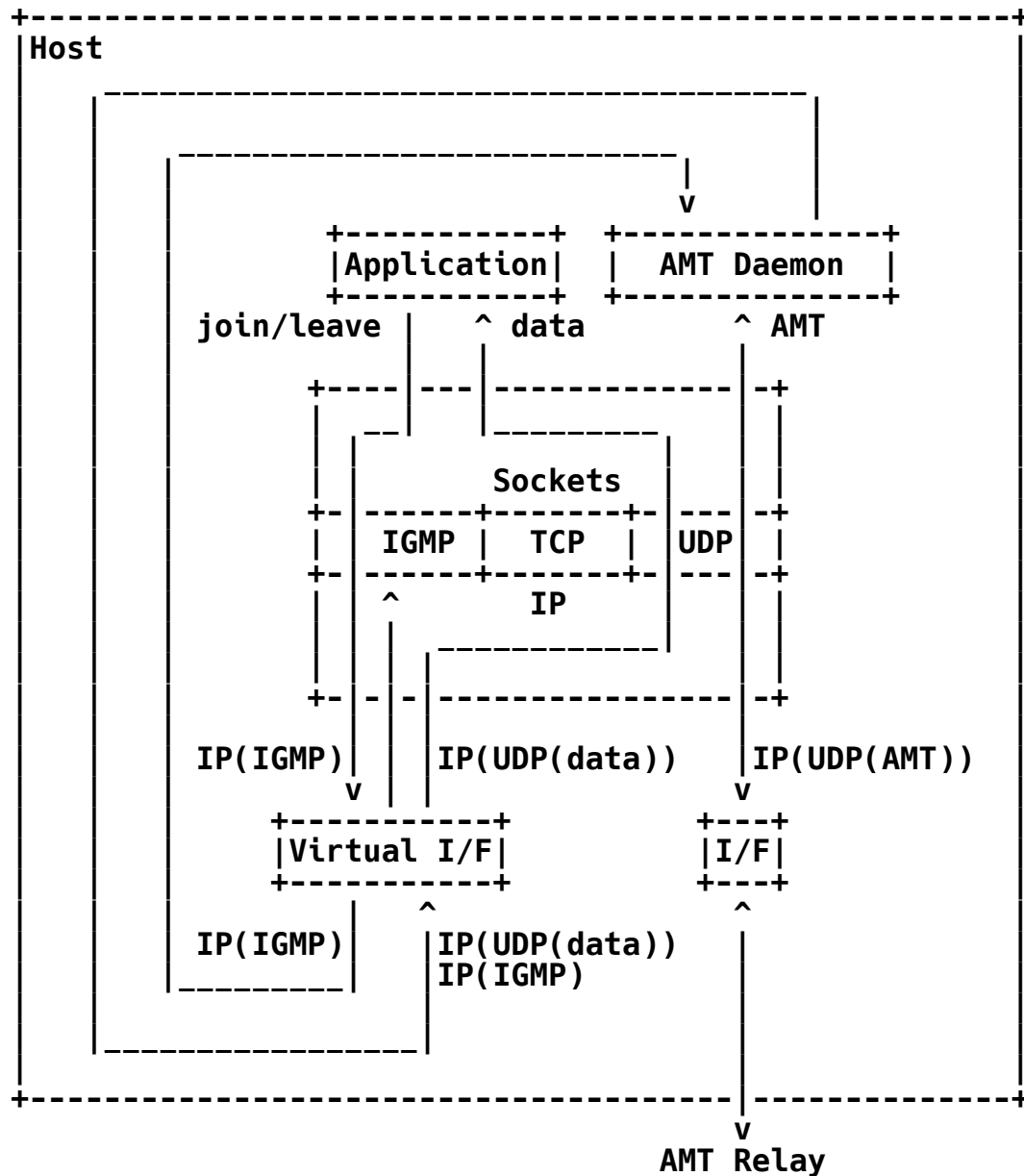


Figure 4: Virtual Interface Implementation Example

In this example, the host IP stack uses a virtual network interface to interact with a gateway pseudo-interface implementation.

4.1.2.2. Use Cases

Use cases for gateway functionality include the following:

IGMP/MLD Proxy

An IGMP/MLD proxy that runs AMT on an upstream interface and router-mode IGMP/MLD on downstream interfaces to provide host access to multicast traffic via the IGMP and MLD protocols.

Virtual Network Interface

A virtual network interface or pseudo-network device driver that runs AMT on a physical network interface to provide socket-layer access to multicast traffic via the IGMP/MLD service interface provided by the host IP stack.

Application

An application or application component that implements and executes IGMP/MLD and AMT internally to gain access to multicast traffic.

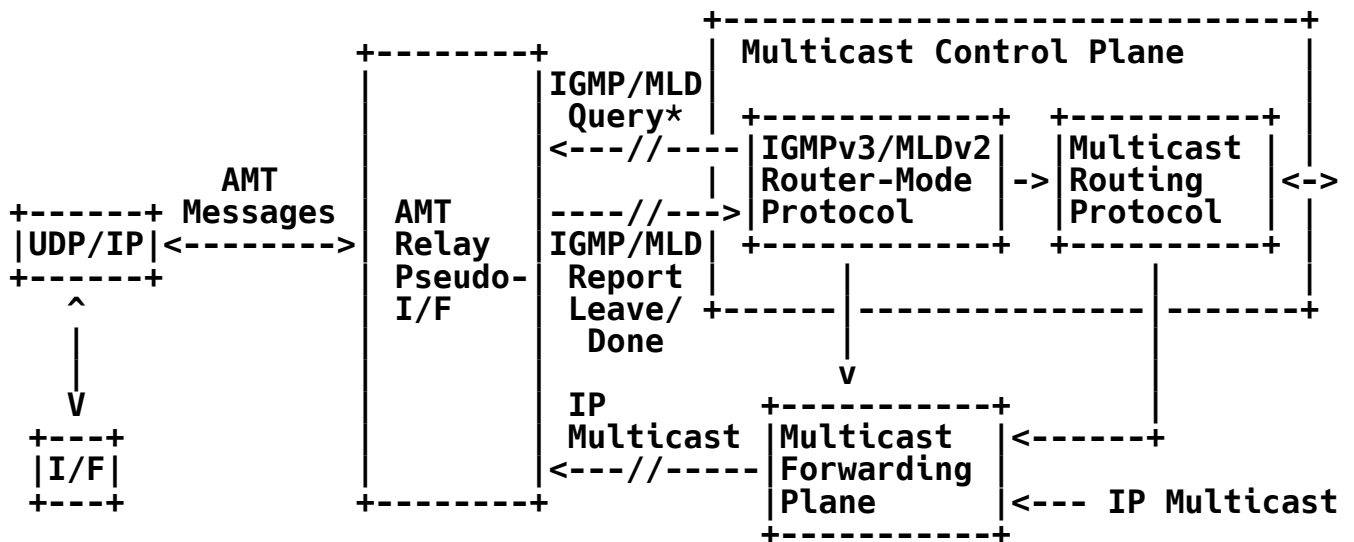
4.1.3. Relays

The downstream side of a relay services gateways -- the relay accepts encapsulated IGMP and MLD group membership messages from gateways and encapsulates and forwards the requested multicast traffic back to those gateways.

The upstream side of a relay communicates with a native multicast infrastructure -- the relay sends join and prune/leave requests towards multicast sources and accepts requested multicast traffic from those sources.

4.1.3.1. Architecture

Each relay possesses a logical pseudo-interface:



* Queries, if generated, are consumed by the pseudo-interface.

Figure 5: AMT Relay Pseudo-Interface (Router-Based)

The pseudo-interface is conceptually a network interface on which the relay runs the router portion of the IPv4/IGMPv3 and IPv6/MLDv2 protocols. Relays do not send unsolicited IGMPv3/MLDv2 query messages to gateways so relays must consume or discard any local queries normally generated by IGMPv3 or MLDv2. Note that the protocol mandates the use of IGMPv3 and MLDv2 for query messages. The AMT protocol is primarily intended for use in SSM applications and relies on several values provided by IGMPv3/MLDv2 to control gateway behavior.

A relay maintains group membership state for each gateway connected through the pseudo-interface as well as for the entire pseudo-interface (if multiple gateways are managed via a single interface). Multicast packets received on upstream interfaces on the relay are routed to the pseudo-interface where they are replicated, encapsulated, and sent to interested gateways. Changes in the pseudo-interface group membership state may trigger the transmission of multicast protocol requests upstream towards a given source or rendezvous point and cause changes in internal routing/forwarding state.

The relay pseudo-interface is an architectural abstraction used to describe AMT protocol operation. For the purposes of this document, the pseudo-interface is most easily viewed as an interface to a single gateway -- encapsulation, decapsulation, and other AMT-specific processing occurs "within" the pseudo-interface while forwarding and replication occur outside of it.

An alternative view is to treat the pseudo-interface as a non-broadcast multi-access (NBMA) network interface whose link layer is the unicast-only network over which AMT messages are exchanged with gateways. Individual gateways are conceptually treated as logical NBMA links on the interface. In this architectural model, group membership tracking, replication, and forwarding functions occur in the pseudo-interface.

This document does not specify any particular architectural solution -- a relay developer may choose to implement and distribute protocol functionality as required to take advantage of existing relay platform services and architecture.

Within this document, the term "relay" may be used as a generic reference to an entity executing the relay protocol, a relay pseudo-interface, or a relay device that has one or more network interfaces with multicast connectivity to a native multicast infrastructure, zero or more interfaces connected to a unicast internetwork, and one or more relay pseudo-interfaces.

4.1.3.2. Use Cases

Use cases for relay functionality include the following:

Multicast Router

A multicast router that runs AMT on a downstream interface to provide gateway access to multicast traffic. A "relay router" uses a multicast routing protocol (e.g., PIM-SM [RFC4601]) to construct a forwarding path for multicast traffic by sending join and prune messages to neighboring routers to join or leave multicast distribution trees for a given SSM source or ASM rendezvous point.

IGMP/MLD Proxy Router

An IGMP/MLD proxy that runs AMT on a downstream interface and host-mode IGMPv3/MLDv2 on an upstream interface. This "relay proxy" sends group membership reports to a local, multicast-enabled router to join and leave specific SSM or ASM groups.

4.1.4. Deployment

The AMT protocol calls for a relay deployment model that uses anycast addressing [RFC1546] [RFC4291] to pair gateways with relays.

Under this approach, one or more relays advertise a route for the same IP address prefix. To find a relay with which to communicate, a gateway sends a message to an anycast IP address within that prefix. This message is routed to the topologically nearest relay that has advertised the prefix. The relay that receives the message responds by sending its unicast address back to the gateway. The gateway uses this address as the destination address for any messages it subsequently sends to the relay.

The use of anycast addressing provides the following benefits:

- o Relays may be deployed at multiple locations within a single multicast-enabled network. Relays might be installed "near" gateways to reduce bandwidth requirements and latency and to limit the number of gateways that might be serviced by a single relay.
- o Relays may be added or removed at any time, thereby allowing staged deployment, scaling, and hot-swapping -- the relay discovery process will always return the nearest operational relay.
- o Relays may take themselves offline when they exhaust resources required to service additional gateways. Existing gateway connections may be preserved, but new gateway requests would be routed to the next-nearest relay.

4.1.4.1. Public versus Private

Ideally, the AMT protocol would provide a universal solution for connecting receivers to multicast sources, so that any gateway could be used to access any globally advertised multicast source via publicly accessible, widely deployed relays. Unfortunately, today's Internet does not yet allow this, because many relays will lack native multicast access to sources even though they may be globally accessible via unicast.

In these cases, a provider may deploy relays within their own source network to allow for multicast distribution within that network. Gateways that use these relays must use a provider-specific relay discovery mechanism or a private anycast address to obtain access to these relays.

4.1.4.2. Congestion Considerations

AMT relies on UDP to provide best-effort delivery of multicast data to gateways. Neither AMT nor UDP provides the congestion control mechanisms required to regulate the flow of data messages passing through a network. While congestion remediation might be provided by multicast receiver applications via multicast group selection or upstream reporting mechanisms, there are no means by which to ensure that such mechanisms are employed. To limit the possible congestion across a network or wider Internet, AMT service providers are expected to deploy AMT relays near the provider's network border and its interface with edge routers. The provider must limit relay address advertisements to those edges to prevent distant gateways from being able to access a relay and potentially generate flows that consume or exceed the capacity of intervening links.

4.1.5. Discovery

To execute the gateway portion of the protocol, a gateway requires a unicast IP address of an operational relay. This address may be obtained using a number of methods -- it may be statically assigned or dynamically chosen via some form of relay discovery process.

As described in the previous section, the AMT protocol provides a relay discovery method that relies on anycast addressing. Gateways are not required to use AMT relay discovery, but all relay implementations must support it.

The AMT protocol uses the following terminology when describing the discovery process:

Relay Discovery Address Prefix:

The anycast address prefix used to route discovery messages to a relay.

Relay Discovery Address:

The anycast destination address used when sending discovery messages.

Relay Address:

The unicast IP address obtained as a result of the discovery process.

4.1.5.1. Relay Discovery Address Selection

The selection of an anycast Relay Discovery Address may be source dependent, as a relay located via relay discovery must have multicast connectivity to a desired source.

Similarly, the selection of a unicast Relay Address may be source dependent, as a relay contacted by a gateway to supply multicast traffic must have native multicast connectivity to the traffic source.

Methods that might be used to perform source-specific or group-specific relay selection are highly implementation dependent and are not further addressed by this document. Possible approaches include the use of static lookup tables, DNS-based queries, or a provision of a service interface that accepts join requests on (S,G,relay-discovery-address) or (S,G,relay-address) tuples.

4.1.5.2. Relay Discovery Address Prefix

IANA has assigned IPv4 and IPv6 address prefixes for use in advertising and discovering publicly accessible relays.

A Relay Discovery Address is constructed from an address prefix by setting the low-order octet of the prefix address to 1 (for both IPv4 and IPv6). All remaining addresses within each prefix are reserved for future use.

Public relays must advertise a route to the address prefix (e.g., via BGP [RFC4271]) and configure an interface to respond to the Relay Discovery Address.

The discovery address prefixes are described in Section 7.

4.2. General Operation

4.2.1. Message Sequences

The AMT protocol defines the following messages for control and encapsulation. These messages are exchanged as UDP/IP datagrams, one message per datagram.

Relay Discovery:

Sent by gateways to solicit a Relay Advertisement from any relay.
Used to find a relay with which to communicate.

Relay Advertisement:

Sent by relays as a response to a Relay Discovery message. Used to deliver a Relay Address to a gateway.

Request:

Sent by gateways to solicit a Membership Query message from a relay.

Membership Query:

Sent by relays as a response to a Request message. Used to deliver an encapsulated IGMPv3 or MLDv2 query message to the gateway.

Membership Update:

Sent by gateways to deliver an encapsulated IGMP or MLD report/leave/done message to a relay.

Multicast Data:

Sent by relays to deliver an encapsulated IP multicast datagram or datagram fragment to a gateway.

Teardown:

Sent by gateways to stop the delivery of Multicast Data messages requested in an earlier Membership Update message.

The following sections describe how these messages are exchanged to execute the protocol.

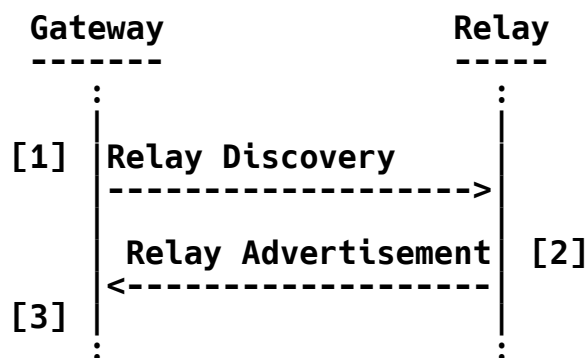
4.2.1.1. Relay Discovery Sequence

Figure 6: AMT Relay Discovery Sequence

The following sequence describes how the Relay Discovery and Relay Advertisement messages are used to find a relay with which to communicate:

1. The gateway sends a Relay Discovery message containing a random nonce to the Relay Discovery Address. If the Relay Discovery Address is an anycast address, the message is routed to the topologically nearest network node that advertises that address.
2. The node receiving the Relay Discovery message sends a Relay Advertisement message back to the source of the Relay Discovery message. The message carries a copy of the nonce contained in the Relay Discovery message and the unicast IP address of a relay.
3. When the gateway receives the Relay Advertisement message, it verifies that the nonce matches the one sent in the Relay Discovery message and, if it does, uses the Relay Address carried by the Relay Advertisement as the destination address for subsequent AMT messages.

Note that the responder need not be a relay -- the responder may obtain a Relay Address by some other means and return the result in the Relay Advertisement (i.e., the responder is a load-balancer or broker).

4.2.1.2. Membership Update Sequence

There exists a significant difference between normal IGMP and MLD behavior and that required by AMT. An IGMP/MLD router acting as a querier normally transmits query messages on a network interface to construct and refresh group membership state for the connected network. These query messages are multicast to all IGMP/MLD-enabled hosts on the network. Each host responds by multicasting report messages that describe their current multicast reception state.

However, AMT does not allow relays to send unsolicited query messages to gateways, as the set of active gateways may be unknown to the relay and potentially quite large. Instead, AMT requires each gateway to periodically send a message to a relay to solicit a query response. A gateway accomplishes this by sending a Request message to a relay. The relay responds by sending a Membership Query message back to the gateway. The Membership Query message carries an encapsulated query that is processed by the IGMP or MLD protocol implementation on the gateway to produce a membership/listener report. Each time the gateway receives a Membership Query message, it starts a timer whose expiration will trigger the start of a new Request->Membership Query message exchange. This timer-driven

sequence is used to mimic the transmission of a periodic query by an IGMP/MLD router. This query cycle may continue indefinitely once started by sending the initial Request message.

A membership update occurs when an IGMP or MLD report, leave, or done message is passed to the gateway pseudo-interface. These messages may be produced as a result of the aforementioned query processing or as a result of receiver interaction with the IGMP/MLD service interface. Each report is encapsulated and sent to the relay after the gateway has successfully established communication with the relay via a Request and Membership Query message exchange. If a report is passed to the pseudo-interface before the gateway has received a Membership Query message from the relay, the gateway may discard the report or queue the report for delivery after a Membership Query is received. Subsequent IGMP/MLD report/leave/done messages that are passed to the pseudo-interface are immediately encapsulated and transmitted to the relay.

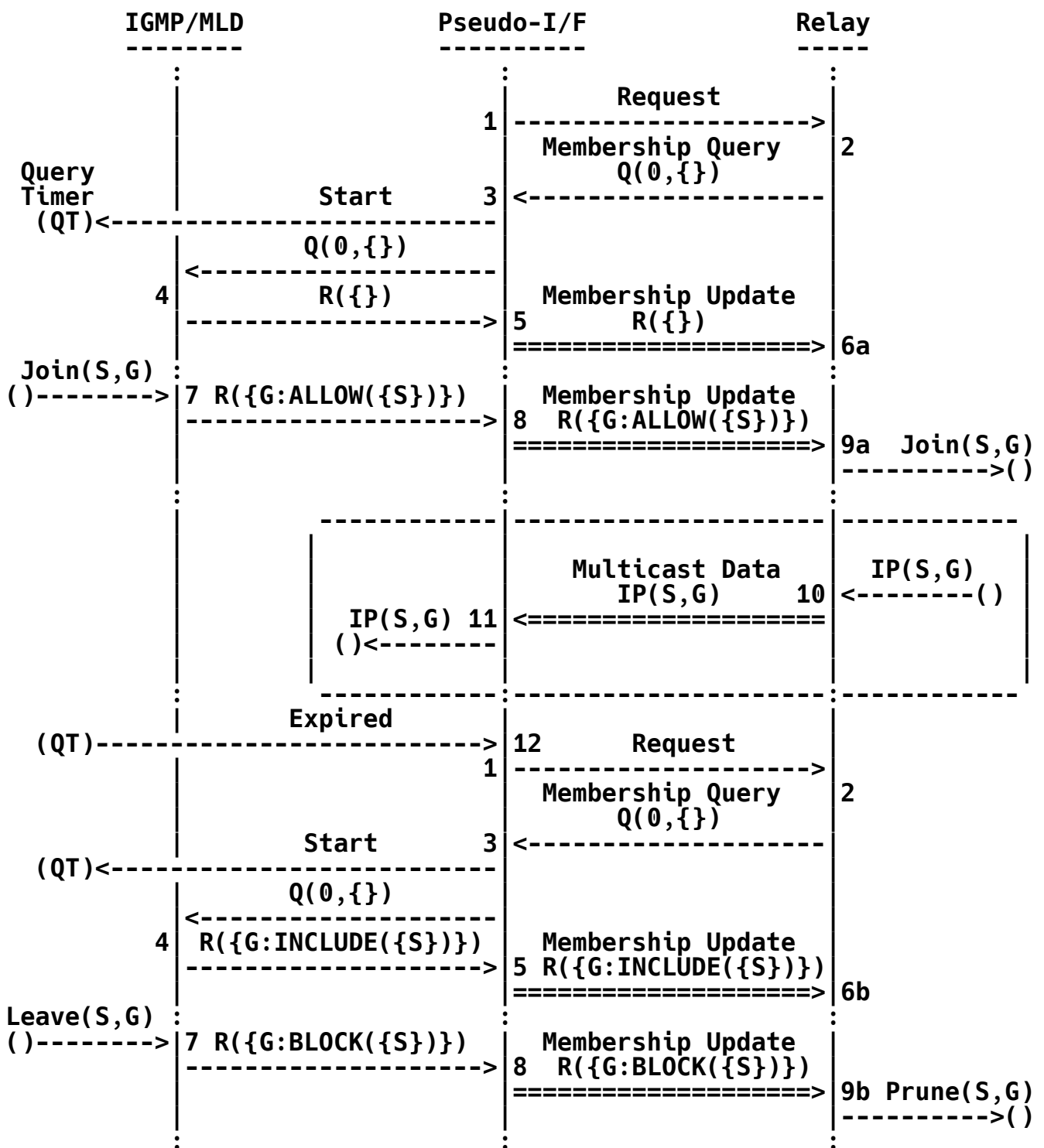


Figure 7: Membership Update Sequence (IGMPv3/MLDv2 Example)

The following sequence describes how the Request, Membership Query, and Membership Update messages are used to report current group membership state or changes in group membership state:

1. A gateway sends a Request message to the relay that contains a random nonce and a flag indicating whether the relay should return an IGMPv3 or MLDv2 General Query.
2. When the relay receives a Request message, it generates a message authentication code (MAC), typically, by computing a hash digest from the message source IP address, source UDP port, request nonce, and a private secret. The relay then sends a Membership Query message to the gateway that contains the request nonce, the MAC, and an IGMPv3 or MLDv2 General Query.
3. When the gateway receives a Membership Query message, it verifies that the request nonce matches the one sent in the last Request, and if it does, the gateway saves the request nonce and MAC for use in sending subsequent Membership Update messages. The gateway starts a timer whose expiration will trigger the transmission of a new Request message and extracts the encapsulated General Query message for processing by the IGMP or MLD protocol. The query timer duration is specified by the relay in the Querier's Query Interval Code (QQIC) field in the IGMPv3 or MLDv2 General Query. The QQIC field is defined in Section 4.1.7 of [RFC3376] and Section 5.1.9 of [RFC3810]).
4. The gateway's IGMP or MLD protocol implementation processes the General Query to produce a current-state report.
5. When an IGMP or MLD report is passed to the pseudo-interface, the gateway encapsulates the report in a Membership Update message and sends it to the relay. The request nonce and MAC fields in the Membership Update are assigned the values from the last Membership Query message received for the corresponding group membership protocol (IGMPv3 or MLDv2).
6. When the relay receives a Membership Update message, it computes a MAC from the message source IP address, source UDP port, request nonce, and a private secret. The relay accepts the Membership Update message if the received MAC matches the computed MAC; otherwise, the message is ignored. If the message is accepted, the relay may proceed to allocate, refresh, or modify tunnel state. This includes making any group membership,

routing, and forwarding state changes, and also issuing any upstream protocol requests required to satisfy the state change. The diagram illustrates two scenarios:

- A. The gateway has not previously reported any group subscriptions and the report does not contain any group subscriptions, so the relay takes no action.
 - B. The gateway has previously reported a group subscription, so the current-state report lists all current subscriptions. The relay responds by refreshing tunnel or group state and resetting any related timers.
7. A receiver indicates to the gateway that it wishes to join (allow) or leave (block) specific multicast traffic. This request is typically made using some form of IGMP/MLD service interface (as described in Section 2 of [RFC3376] and Section 3 of [RFC3810]). The IGMP/MLD protocol responds by generating an IGMP or MLD state-change message.
 8. When an IGMP or MLD report/leave/done message is passed to the pseudo-interface, the gateway encapsulates the message in a Membership Update message and sends it to the relay. The request nonce and MAC fields in the Membership Update are assigned the values from the last Membership Query message received for the corresponding group membership protocol (IGMP or MLD).

The IGMP and MLD protocols may generate multiple messages to provide robustness against packet loss -- each of these must be encapsulated in a new Membership Update message and sent to the relay. The Querier's Robustness Variable (QRV) field in the last IGMP/MLD query delivered to the IGMP/MLD protocol is typically used to specify the number of repetitions (i.e., the host adopts the QRV value as its own Robustness Variable value). The QRV field is defined in Section 4.1.6 of [RFC3376] and Section 5.1.8 of [RFC3810].
 9. When the relay receives a Membership Update message, it again computes a MAC from the message source IP address, source UDP port, request nonce, and a private secret. The relay accepts the Membership Update message if the received MAC matches the computed MAC; otherwise, the message is ignored. If the message is accepted, the relay processes the encapsulated IGMP/MLD and allocates, modifies, or deletes tunnel state accordingly. This includes making any group membership, routing, and forwarding

state changes, and also issuing any upstream protocol requests required to satisfy the state change. The diagram illustrates two scenarios:

- A. The gateway wishes to add a group subscription.
 - B. The gateway wishes to delete a previously reported group subscription.
10. Multicast datagrams transmitted from a source travel through the native multicast infrastructure to the relay. When the relay receives a multicast IP datagram that carries a source and destination address for which a gateway has expressed an interest in receiving (via the Membership Update message), it encapsulates the datagram into a Multicast Data message and sends it to the gateway using the source IP address and UDP port carried by the Membership Update message as the destination address.
 11. When the gateway receives a Multicast Data message, it extracts the multicast packet from the message and passes it on to the appropriate receivers.
 12. When the query timer expires, the gateway sends a new Request message to the relay to start a new membership update cycle.

The MAC-based source-authentication mechanism described above provides a simple defense against malicious attempts to exhaust relay resources via source-address spoofing. Flooding a relay with spoofed Request or Membership Update messages may consume computational resources and network bandwidth but will not result in the allocation of state, because the Request message is stateless and spoofed Membership Update messages will fail source authentication and be rejected by the relay.

A relay will only allocate new tunnel state if the IGMP/MLD report carried by the Membership Update message creates one or more group subscriptions.

A relay deallocates tunnel state after one of the following events: the gateway sends a Membership Update message containing a report that results in the deletion of all remaining group subscriptions, the IGMP/MLD state expires (due to lack of refresh by the gateway), or the relay receives a valid Teardown message from the gateway (see Section 4.2.1.3).

A gateway that accepts or reports group subscriptions for both IPv4 and IPv6 addresses will send separate Request and Membership Update messages for each protocol (IPv4/IGMP and IPv6/MLD).

4.2.1.3. Teardown Sequence

A gateway sends a Teardown message to a relay to request that it stop delivering Multicast Data messages to a tunnel endpoint created by an earlier Membership Update message. This message is intended to be used following a gateway address change (see Section 4.2.2.1) to stop the transmission of undeliverable or duplicate Multicast Data messages. Gateway support for the Teardown message is RECOMMENDED. Gateways are not required to send them and may instead rely on group membership to expire on the relay.

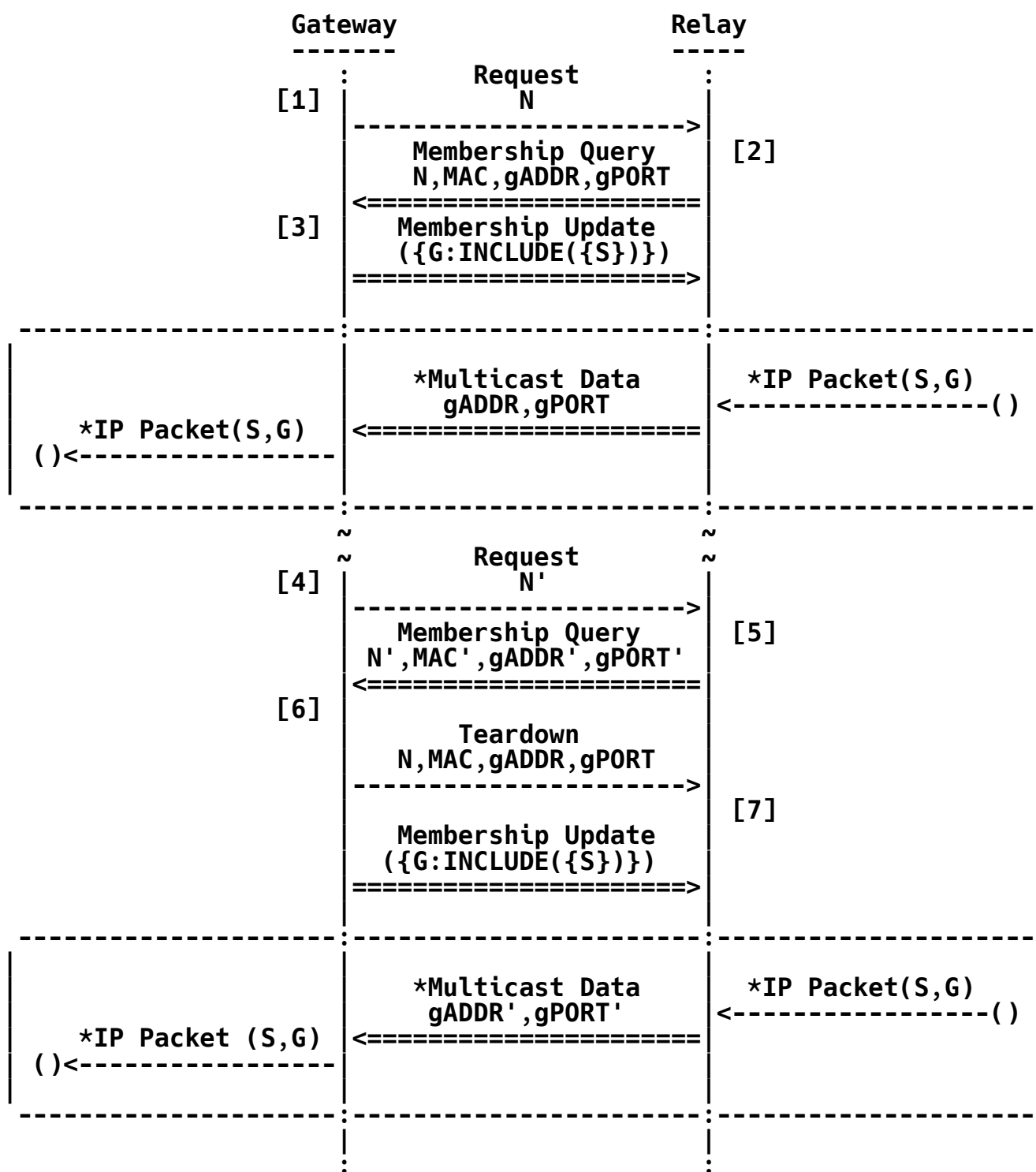


Figure 8: Teardown Message Sequence (IGMPv3/MLDv2 Example)

The following sequence describes how the Membership Query and Teardown messages are used to detect an address change and stop the delivery of Multicast Data messages to an address:

1. A gateway sends a Request message containing a random nonce to the relay.
2. The relay sends a Membership Query message to the gateway that contains the source IP address (gADDR) and source UDP port (gPORT) values from the Request message. These values will be used to identify the tunnel should one be created by a subsequent Membership Update message.
3. When the gateway receives a Membership Query message that carries the gateway address fields, it compares the gateway IP address and UDP port number values with those received in the previous Membership Query (if any). If these values do not match, this indicates that the Request message arrived at the relay carrying a different source address than the one sent previously. At this point in the sequence, no change in source address or port has occurred.
4. The gateway sends a new Request message to the relay. However, this Request message arrives at the relay carrying a different source address than that of the previous Request due to some change in network interface, address assignment, network topology, or NAT mapping.
5. The relay again responds by sending a Membership Query message to the gateway that contains the new source IP address (gADDR') and source UDP port (gPORT') values from the Request message.
6. When the gateway receives the Membership Query message, it compares the gateway address and port number values against those returned in the previous Membership Query message.
7. If the reported address or port has changed, the gateway sends a Teardown message to the relay that contains the request nonce, MAC, gateway IP address, and gateway port number returned in the earlier Membership Query message. The gateway may send the Teardown message multiple times where the number of repetitions is governed by the Querier's Robustness Variable (QRV) value contained in the IGMPv3/MLDv2 General Query carried by the original Membership Query (see Section 4.1.6 of [RFC3376] and Section 5.1.8 of [RFC3810]). The gateway continues to process the new Membership Query message as usual.

8. When the relay receives a Teardown message, it computes a MAC from the message source IP address, source UDP port, request nonce, and a private secret. The relay accepts the Teardown message if the received MAC matches the computed MAC; otherwise, the message is ignored. If the message is accepted, the relay makes any group membership, routing, and forwarding state changes required to stop the transmission of Multicast Data messages to that address.

4.2.1.4. Timeout and Retransmission

The AMT protocol does not establish any requirements regarding what actions a gateway should take if it fails to receive a response from a relay. A gateway implementation may wait for an indefinite period of time to receive a response, may set a time limit on how long to wait for a response, may retransmit messages should the time limit be reached, may limit the number of retransmissions, or may simply report an error.

For example, a gateway may retransmit a Request message if it fails to receive a Membership Query or expected Multicast Data messages within some time period. If the gateway fails to receive any response to a Request after several retransmissions or within some maximum period of time, it may reenter the relay discovery phase in an attempt to find a new relay. This topic is addressed in more detail in Section 5.2.

4.2.2. Tunneling

From the standpoint of a relay, an AMT "tunnel" is identified by the IP address and UDP port pair used as the destination address for sending encapsulated multicast IP datagrams to a gateway. In this document, we refer to this address as the tunnel endpoint address.

A gateway sends a Membership Update message to a relay to add or remove group subscriptions to a tunnel endpoint. The tunnel endpoint is identified by the source IP address and source UDP port carried by the Membership Update message when it arrives at a relay (this address may differ from that carried by the message when it exited the gateway as a result of network address translation).

The Membership Update messages sent by a single gateway host may originate from several source addresses or ports -- each unique combination represents a unique tunnel endpoint. A single gateway host may legitimately create and accept traffic on multiple tunnel endpoints, e.g., the gateway may use separate ports for the IPv4/IGMP and IPv6/MLD protocols.

A tunnel is "created" when a gateway sends a Membership Update message containing an IGMP or MLD membership report that creates one or more group subscriptions when none currently existed for that tunnel endpoint address.

A tunnel ceases to exist when all group subscriptions for a tunnel endpoint are deleted. This may occur as a result of the following events:

- o The gateway sends an IGMP or MLD report, leave, or done message to the relay that deletes the last group subscription linked to the tunnel endpoint.
- o The gateway sends a Teardown message to the relay that causes it to delete any and all subscriptions bound to the tunnel endpoint.
- o The relay stops receiving updates from the gateway until such time that per-group or per-tunnel timers expire, causing the relay to delete the subscriptions.

The tunneling approach described above conceptually transforms a unicast-only internetwork into an NBMA link layer, over which multicast traffic may be delivered. Each relay, plus the set of all gateways using the relay, together may be thought of as being on a separate logical NBMA link, where the "link layer" address is a UDP/IP address-port pair provided by the Membership Update message.

4.2.2.1. Address Roaming

As described above, each time a relay receives a Membership Update message from a new source address-port pair, the group subscriptions described by that message apply to the tunnel endpoint identified by that address.

This can cause problems for a gateway if the address carried by the messages it sends to a relay changes unexpectedly. These changes may cause the relay to transmit duplicate, undeliverable, or unrequested traffic back towards the gateway or an intermediate device. This may create congestion and have negative consequences for the gateway, its network, or multicast receivers and in some cases may also produce a significant amount of ICMP traffic directed back towards the relay by a NAT, router, or gateway host.

There are several scenarios in which the address carried by messages sent by a gateway may change without that gateway's knowledge -- for example, when:

- o The message originates from a different interface on a gateway that possesses multiple interfaces.
- o The DHCP assignment for a gateway interface changes.
- o The gateway roams to a different wireless network.
- o The address mapping applied by an intervening network-translation device (NAT) changes as a result of mapping expiration or routing changes in a multihomed network.

In the case where the address change occurs between the transmission of a Request message and subsequent Membership Update messages, the relay will simply ignore any Membership Update messages from the new address because MAC authentication will fail (see Section 4.2.1.2). The relay may continue to transmit previously requested traffic, but no duplication will occur, i.e., the possibility for the delivery of duplicate traffic does not arise until a Request message is received from the new address.

The protocol provides a method for a gateway to detect an address change and explicitly request that the relay stop sending traffic to a previous address. This process involves the Membership Query and Teardown messages and is described in Section 4.2.1.3.

4.2.2.2. Network Address Translation

The messages sent by a gateway to a relay may be subject to network address translation (NAT) -- the source IP address and UDP port carried by an IP packet sent by the gateway may be modified multiple times before arriving at the relay. In the most restrictive form of NAT, the NAT device will create a new mapping for each combination of source and destination IP address and UDP port. In this case, bidirectional communication can only be conducted by sending outgoing packets to the source address and port carried by the last incoming packet.

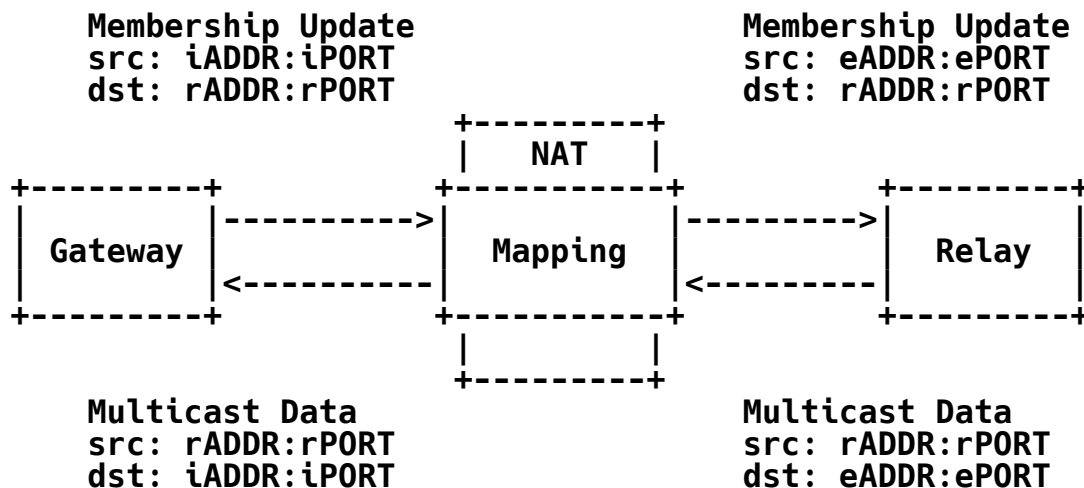


Figure 9: Network Address Translation in AMT

AMT provides automatic NAT traversal by using the source IP address and UDP port carried by the Membership Update message as received at the relay as the destination address for any Multicast Data messages the relay sends back as a result.

The NAT mapping created by a Membership Update message will eventually expire unless it is refreshed by a passing message. This refresh will occur each time the gateway performs the periodic update required to refresh group state within the relay (see Section 4.2.1.2).

4.2.2.3. UDP Encapsulation

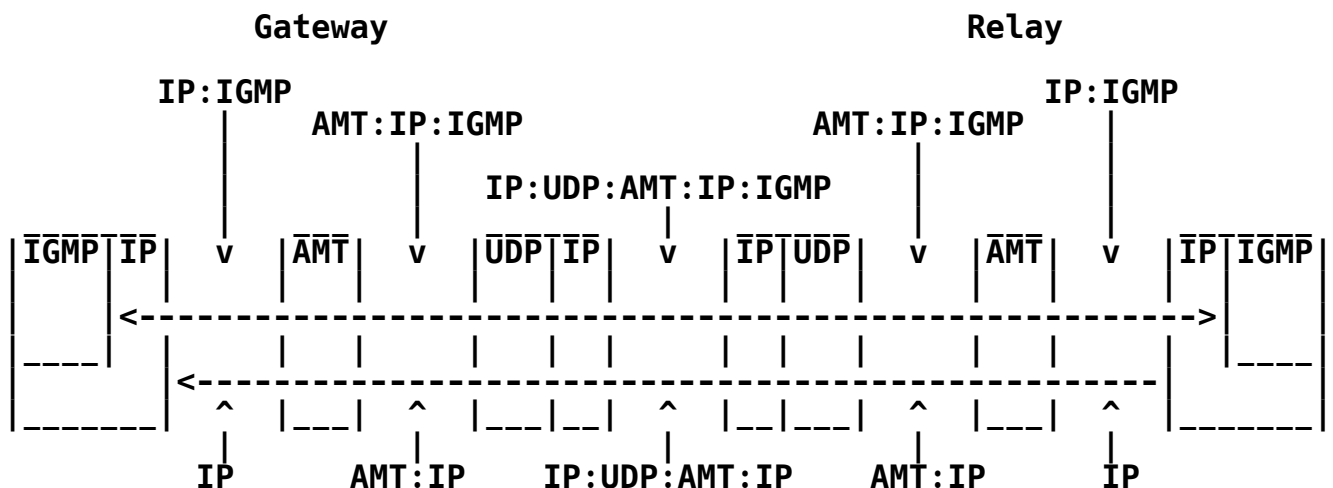


Figure 10: AMT Encapsulation

The IGMP and MLD messages used in AMT are exchanged as complete IP datagrams. These IP datagrams are encapsulated in AMT messages that are transmitted using UDP. The same holds true for multicast traffic -- each multicast IP datagram or datagram fragment that arrives at the relay is encapsulated in an AMT message and transmitted to one or more gateways via UDP.

The IP protocol of the encapsulated packets need not match the IP protocol used to send the AMT messages. AMT messages sent via IPv4 may carry IPv6/MLD packets, and AMT messages sent via IPv6 may carry IPv4/IGMP packets.

The Checksum field contained in the UDP header of the messages requires special consideration. Of primary concern is the cost of computing a checksum on each replicated multicast packet after it is encapsulated for delivery to a gateway. Many routing/forwarding platforms do not possess the capability to compute checksums on UDP-encapsulated packets, as they may not have access to the entire datagram.

To avoid placing an undue burden on the relay platform, the protocol specifically allows zero-valued UDP checksums on the Multicast Data messages. This is not an issue in UDP over IPv4, as the UDP Checksum field may be set to zero. However, this is a problem for UDP over IPv6, as that protocol requires a valid, non-zero checksum in UDP datagrams [RFC2460]. Messages sent over IPv6 with a UDP checksum of zero may fail to reach the gateway. This is a well-known issue for UDP-based tunneling protocols and is described in [RFC6936]. A recommended solution is described in [RFC6935].

4.2.2.4. UDP Fragmentation

Naive encapsulation of multicast IP datagrams within AMT data messages may produce UDP datagrams that might require fragmentation if their size exceeds the MTU of the network path between the relay and a gateway. Many multicast applications, especially those related to media streaming, are designed to deliver independent data samples in separate packets, without fragmentation, to ensure that some number of complete samples can be delivered even in the presence of packet loss. To prevent or reduce undesirable fragmentation, the AMT protocol describes specific procedures for handling multicast datagrams whose encapsulation might exceed the Path MTU. These procedures are described in Section 5.3.3.6.

5. Protocol Description

This section provides a normative description of the AMT protocol.

5.1. Protocol Messages

The AMT protocol defines seven message types for control and encapsulation. These messages are assigned the following names and numeric identifiers:

| Message Type | Message Name |
|--------------|---------------------|
| 1 | Relay Discovery |
| 2 | Relay Advertisement |
| 3 | Request |
| 4 | Membership Query |
| 5 | Membership Update |
| 6 | Multicast Data |
| 7 | Teardown |

These messages are exchanged as IPv4 or IPv6 UDP datagrams.

5.1.1. Relay Discovery

A Relay Discovery message is used to solicit a response from a relay in the form of a Relay Advertisement message.

The UDP/IP datagram containing this message **MUST** carry a valid, non-zero UDP checksum and carry the following IP address and UDP port values:

Source IP Address - The IP address of the gateway interface on which the gateway will listen for a relay response. Note: The value of this field may be changed as a result of network address translation before arriving at the relay.

Source UDP Port - The UDP port number on which the gateway will listen for a relay response. Note: The value of this field may be changed as a result of network address translation before arriving at the relay.

Destination IP Address - An anycast or unicast IP address, i.e., the Relay Discovery Address advertised by a relay.

Destination UDP Port - The AMT port number (see Section 7.2).

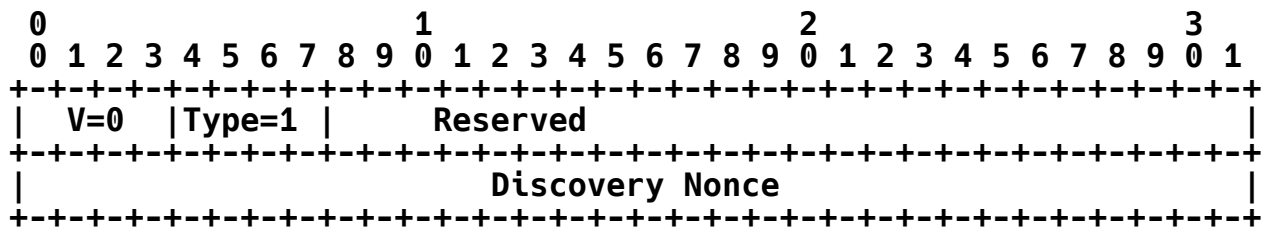


Figure 11: Relay Discovery Message Format

5.1.1.1. Version (V)

The protocol version number for this message is 0.

5.1.1.2. Type

The type number for this message is 1.

5.1.1.3. Reserved

Reserved bits that **MUST** be set to zero by the gateway and ignored by the relay.

5.1.1.4. Discovery Nonce

A 32-bit random value generated by the gateway and echoed by the relay in a Relay Advertisement message. This value is used by the gateway to correlate Relay Advertisement messages with Relay Discovery messages. Discovery nonce generation is described in Section 5.2.3.4.5.

5.1.2. Relay Advertisement

The Relay Advertisement message is used to supply a gateway with a unicast IP address of a relay. A relay sends this message to a gateway when it receives a Relay Discovery message from that gateway.

The UDP/IP datagram containing this message **MUST** carry a valid, non-zero UDP checksum and carry the following IP address and UDP port values:

Source IP Address - The destination IP address carried by the Relay Discovery message (i.e., the Relay Discovery Address advertised by the relay).

Source UDP Port - The destination UDP port carried by the Relay Discovery message (i.e., the AMT port number).

Destination IP Address - The source IP address carried by the Relay Discovery message. Note: The value of this field may be changed as a result of network address translation before arriving at the gateway.

Destination UDP Port - The source UDP port carried by the Relay Discovery message. Note: The value of this field may be changed as a result of network address translation before arriving at the gateway.

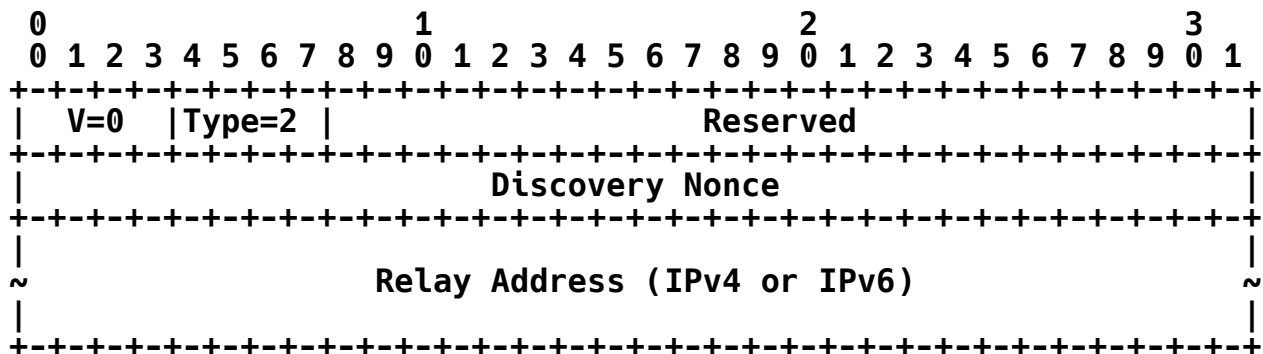


Figure 12: Relay Advertisement Message Format

5.1.2.1. Version (V)

The protocol version number for this message is 0.

5.1.2.2. Type

The type number for this message is 2.

5.1.2.3. Reserved

Reserved bits that MUST be set to zero by the relay and ignored by the gateway.

5.1.2.4. Discovery Nonce

A 32-bit value copied from the Discovery Nonce field (Section 5.1.1.4) contained in the Relay Discovery message. The gateway uses this value to match a Relay Advertisement to a Relay Discovery message.

5.1.2.5. Relay Address

The unicast IPv4 or IPv6 address of the relay. A gateway uses the length of the UDP datagram containing the Relay Advertisement message to determine the address family, i.e., $\text{length} - 8 = 4$ (IPv4) or 16 (IPv6). The relay returns an IP address for the protocol used to send the Relay Discovery message, i.e., an IPv4 address for an IPv4 Relay Discovery Address or an IPv6 address for an IPv6 Relay Discovery Address.

5.1.3. Request

A gateway sends a Request message to a relay to solicit a Membership Query response.

The successful delivery of this message marks the start of the first stage in the three-way handshake used to create or update state within a relay.

The UDP/IP datagram containing this message **MUST** carry a valid, non-zero UDP checksum and carry the following IP address and UDP port values:

Source IP Address - The IP address of the gateway interface on which the gateway will listen for a response from the relay. Note: The value of this field may be changed as a result of network address translation before arriving at the relay.

Source UDP Port - The UDP port number on which the gateway will listen for a response from the relay. Note: The value of this field may be changed as a result of network address translation before arriving at the relay.

Destination IP Address - The unicast IP address of the relay.

Destination UDP Port - The AMT port number.

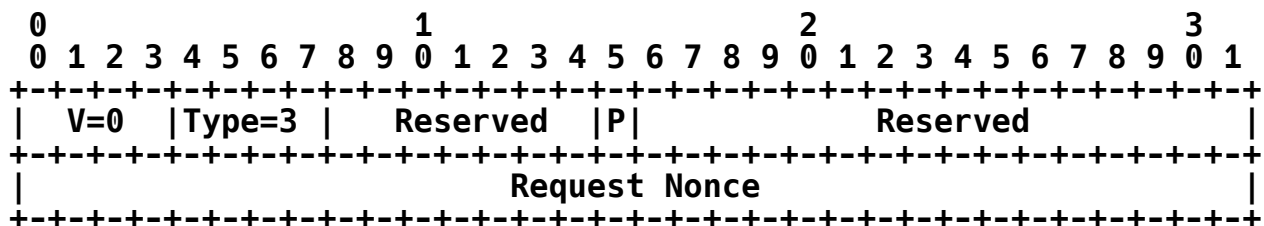


Figure 13: Request Message Format

5.1.3.1. Version (V)

The protocol version number for this message is 0.

5.1.3.2. Type

The type number for this message is 3.

5.1.3.3. Reserved

Reserved bits that **MUST** be set to zero by the gateway and ignored by the relay.

5.1.3.4. P Flag

The P flag is set to indicate which group membership protocol the gateway wishes the relay to use in the Membership Query response:

| Value | Meaning |
|-------|--|
| 0 | The relay MUST respond with a Membership Query message that contains an IPv4 packet carrying an IGMPv3 General Query message. |
| 1 | The relay MUST respond with a Membership Query message that contains an IPv6 packet carrying an MLDv2 General Query message. |

5.1.3.5. Request Nonce

A 32-bit random value generated by the gateway and echoed by the relay in a Membership Query message. This value is used by the relay to compute the Response MAC value and is used by the gateway to correlate Membership Query messages with Request messages. Request Nonce generation is described in Section 5.2.3.5.6.

5.1.4. Membership Query

A relay sends a Membership Query message to a gateway to solicit a Membership Update response, but only after receiving a Request message from the gateway.

The successful delivery of this message to a gateway marks the start of the second stage in the three-way handshake used to create or update tunnel state within a relay.

The UDP/IP datagram containing this message **MUST** carry a valid, non-zero UDP checksum and carry the following IP address and UDP port values:

Source IP Address - The destination IP address carried by the Request message (i.e., the unicast IP address of the relay).

Source UDP Port - The destination UDP port carried by the Request message (i.e., the AMT port number).

Destination IP Address - The source IP address carried by the Request message. Note: The value of this field may be changed as a result of network address translation before arriving at the gateway.

Destination UDP Port - The source UDP port carried by the Request message. Note: The value of this field may be changed as a result of network address translation before arriving at the gateway.

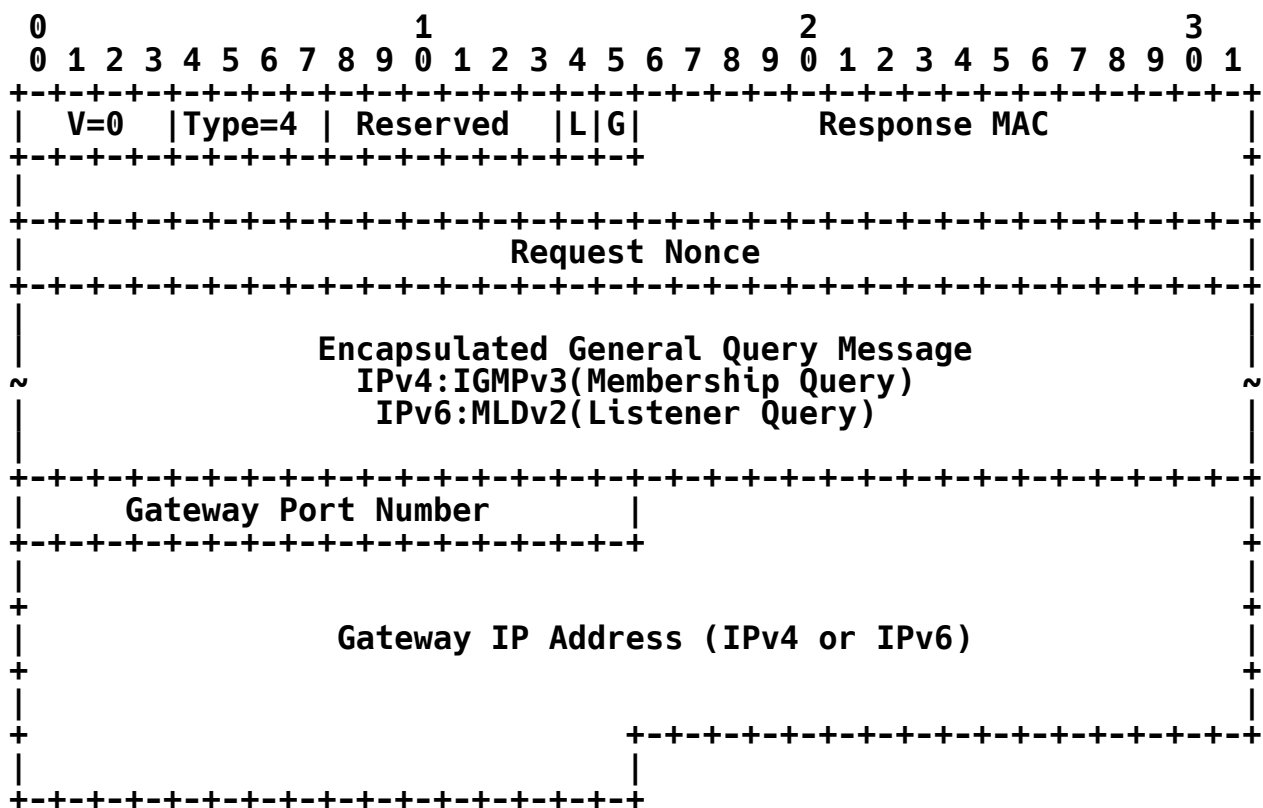


Figure 14: Membership Query Message Format

5.1.4.1. Version (V)

The protocol version number for this message is 0.

5.1.4.2. Type

The type number for this message is 4.

5.1.4.3. Reserved

Reserved bits that **MUST** be set to zero by the relay and ignored by the gateway.

5.1.4.4. Limit (L) Flag

A 1-bit flag set to 1 to indicate that the relay is **NOT** accepting Membership Update messages from new gateway tunnel endpoints and that it will ignore any that are. A value of 0 has no special significance -- the relay may or may not be accepting Membership Update messages from new gateway tunnel endpoints. A gateway checks this flag before attempting to create new group subscription state on the relay to determine whether it should restart relay discovery. A gateway that has already created group subscriptions on the relay may ignore this flag. Support for this flag is **RECOMMENDED**.

5.1.4.5. Gateway Address (G) Flag

A 1-bit flag set to 0 to indicate that the message does **NOT** carry the Gateway Port Number and Gateway IP Address fields, and 1 to indicate that it does. A relay implementation that supports the optional teardown procedure (see Section 5.3.3.5) **SHOULD** set this flag as well as the Gateway Port Number and Gateway IP Address field values. If a relay sets this flag, it **MUST** also include the Gateway Port Number and Gateway IP Address fields in the message. A gateway implementation that does not support the optional teardown procedure (see Section 5.2.3.7) **MAY** ignore this flag and the Gateway Address fields if they are present.

5.1.4.6. Response MAC

A 48-bit source authentication value generated by the relay as described in Section 5.3.5. The gateway echoes this value in subsequent Membership Update messages to allow the relay to verify that the sender of a Membership Update message was the intended receiver of a Membership Query sent by the relay.

5.1.4.7. Request Nonce

A 32-bit value copied from the Request Nonce field (Section 5.1.3.5) carried by a Request message. The relay will have included this value in the Response MAC computation. The gateway echoes this value in subsequent Membership Update messages. The gateway also uses this value to match a Membership Query to a Request message.

5.1.4.8. Encapsulated General Query Message

An IP-encapsulated IGMP or MLD message generated by the relay. This field will contain one of the following IP datagrams:

IPv4:IGMPv3 Membership Query

IPv6:MLDv2 Listener Query

The source address carried by the query message should be set as described in Section 5.3.3.3.

The Querier's Query Interval Code (QQIC) field in the General Query is used by a relay to specify the time offset a gateway should use to schedule a new three-way handshake to refresh the group membership state within the relay (current time + Query Interval). The QQIC field is defined in Section 4.1.7 of [RFC3376] and Section 5.1.9 of [RFC3810].

The Querier's Robustness Variable (QRV) field in the General Query is used by a relay to specify the number of times a gateway should retransmit unsolicited membership reports, encapsulated within Membership Update messages, and, optionally, the number of times to send a Teardown message. The QRV field is defined in Section 4.1.6 of [RFC3376] and Section 5.1.8 of [RFC3810].

5.1.4.9. Gateway Address Fields

The Gateway Port Number and Gateway Address fields are present in the Membership Query message if, and only if, the G flag is set.

A gateway need not parse the encapsulated IP datagram to determine the position of these fields within the UDP datagram containing the Membership Query message -- if the G flag is set, the gateway may simply subtract the total length of the fields (18 bytes) from the total length of the UDP datagram to obtain the offset.

5.1.4.9.1. Gateway Port Number

A 16-bit UDP port number containing a UDP port value.

The relay sets this field to the value of the UDP source port of the Request message that triggered the Query message.

5.1.4.9.2. Gateway IP Address

A 16-byte IP address that, when combined with the value contained in the Gateway Port Number field, forms the gateway endpoint address that the relay will use to identify the tunnel instance, if any, created by a subsequent Membership Update message. This field may contain an IPv6 address or an IPv4 address stored as an IPv4-compatible IPv6 address, where the IPv4 address is prefixed with 96 bits set to zero (see [RFC4291]). This address must match that used by the relay to compute the value stored in the Response MAC field.

5.1.5. Membership Update

A gateway sends a Membership Update message to a relay to report a change in group membership state, or to report the current group membership state in response to receiving a Membership Query message. The gateway encapsulates the IGMP or MLD message as an IP datagram within a Membership Update message and sends it to the relay, where it may (see below) be decapsulated and processed by the relay to update group membership and forwarding state.

A gateway cannot send a Membership Update message until it receives a Membership Query from a relay, because the gateway must copy the Request Nonce and Response MAC values carried by a Membership Query into any subsequent Membership Update messages it sends back to that relay. These values are used by the relay to verify that the sender of the Membership Update message was the recipient of the Membership Query message from which these values were copied.

The successful delivery of this message to the relay marks the start of the final stage in the three-way handshake. This stage concludes when the relay successfully verifies that the sender of the Membership Update message was the recipient of a Membership Query message sent earlier. At this point, the relay may proceed to process the encapsulated IGMP or MLD message to create or update group membership and forwarding state on behalf of the gateway.

The UDP/IP datagram containing this message **MUST** carry a valid, non-zero UDP checksum and carry the following IP address and UDP port values:

Source IP Address - The IP address of the gateway interface on which the gateway will listen for Multicast Data messages from the relay. The address must be the same address used to send the initial Request message, or the message will be ignored. Note: The value of this field may be changed as a result of network address translation before arriving at the relay.

Source UDP Port - The UDP port number on which the gateway will listen for Multicast Data messages from the relay. This port must be the same port used to send the initial Request message, or the message will be ignored. Note: The value of this field may be changed as a result of network address translation before arriving at the relay.

Destination IP Address - The unicast IP address of the relay.

Destination UDP Port - The AMT port number.

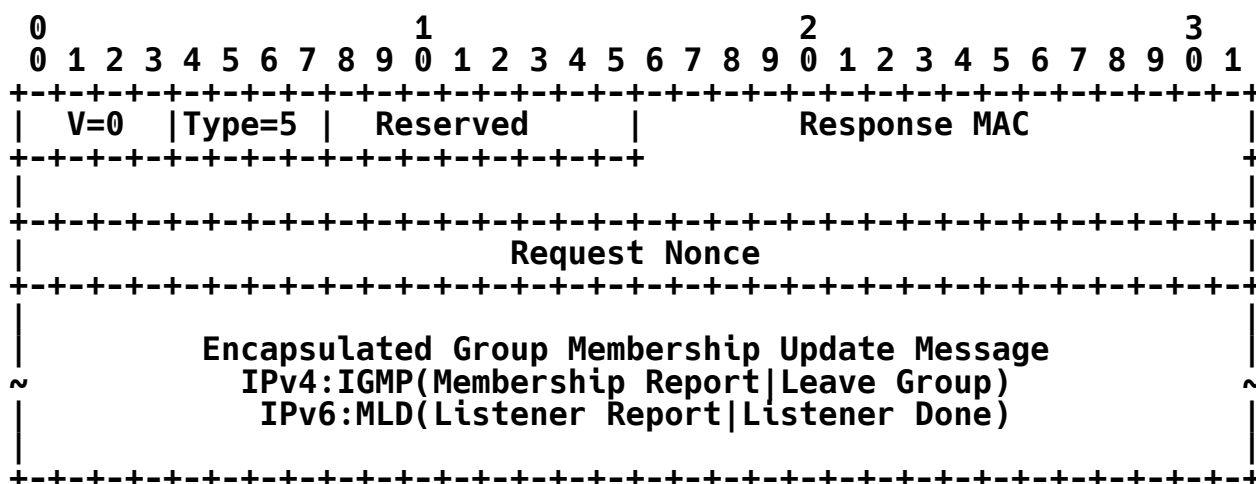


Figure 15: Membership Update Message Format

5.1.5.1. Version (V)

The protocol version number for this message is 0.

5.1.5.2. Type

The type number for this message is 5.

5.1.5.3. Reserved

Reserved bits that **MUST** be set to zero by the gateway and ignored by the relay.

5.1.5.4. Response MAC

A 48-bit value copied from the Response MAC field (Section 5.1.4.6) in a Membership Query message. Used by the relay to perform source authentication.

5.1.5.5. Request Nonce

A 32-bit value copied from the Request Nonce field in a Request or Membership Query message. Used by the relay to perform source authentication.

5.1.5.6. Encapsulated Group Membership Update Message

An IP-encapsulated IGMP or MLD message produced by the host-mode IGMP or MLD protocol running on a gateway pseudo-interface. This field will contain one of the following IP datagrams:

IPv4:IGMPv2 Membership Report

IPv4:IGMPv2 Leave Group

IPv4:IGMPv3 Membership Report

IPv6:MLDv1 Multicast Listener Report

IPv6:MLDv1 Multicast Listener Done

IPv6:MLDv2 Multicast Listener Report

The source address carried by the message should be set as described in Section 5.2.1.

5.1.6. Multicast Data

A relay sends a Multicast Data message to deliver a multicast IP datagram or datagram fragment to a gateway.

The Checksum field in the UDP header of this message **MAY** contain a value of zero when sent over IPv4 but **SHOULD**, if possible, contain a valid, non-zero value when sent over IPv6 (see Section 4.2.2.3).

The UDP/IP datagram containing this message **MUST** carry the following IP address and UDP port values:

Source IP Address - The unicast IP address of the relay.

Source UDP Port - The AMT port number.

Destination IP Address - A tunnel endpoint IP address, i.e., the source IP address carried by the Membership Update message sent by a gateway to indicate an interest in receiving the multicast packet. Note: The value of this field may be changed as a result of network address translation before arriving at the gateway.

Destination UDP Port - A tunnel endpoint UDP port, i.e., the source UDP port carried by the Membership Update message sent by a gateway to indicate an interest in receiving the multicast packet. Note: The value of this field may be changed as a result of network address translation before arriving at the gateway.

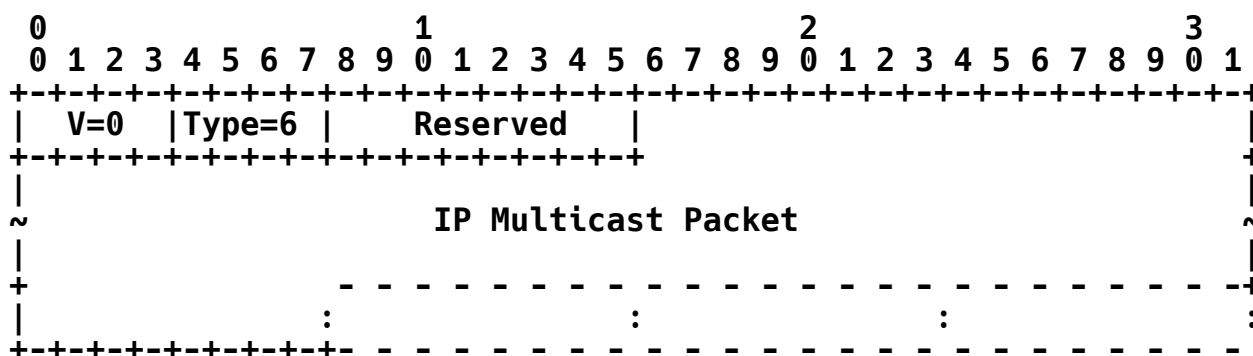


Figure 16: Multicast Data Message Format

5.1.6.1. Version (V)

The protocol version number for this message is 0.

5.1.6.2. Type

The type number for this message is 6.

5.1.6.3. Reserved

Reserved bits that **MUST** be set to zero by the relay and ignored by the gateway.

5.1.6.4. IP Multicast Data

A complete IPv4 or IPv6 multicast datagram or datagram fragment.

5.1.7. Teardown

A gateway sends a Teardown message to a relay to request that it stop sending Multicast Data messages to a tunnel endpoint created by an earlier Membership Update message. A gateway sends this message when it detects that a Request message sent to the relay carries an address that differs from that carried by a previous Request message. The gateway uses the Gateway IP Address and Gateway Port Number fields in the Membership Query message to detect these address changes.

To provide backwards compatibility with early implementations of the AMT protocol, support for this message and associated procedures is considered OPTIONAL -- gateways are not required to send this message, and relays are not required to act upon it.

The UDP/IP datagram containing this message MUST carry a valid, non-zero UDP checksum and carry the following IP address and UDP port values:

Source IP Address - The IP address of the gateway interface used to send the message. This address may differ from that used to send earlier messages. Note: The value of this field may be changed as a result of network address translation before arriving at the relay.

Source UDP Port - The UDP port number. This port number may differ from that used to send earlier messages. Note: The value of this field may be changed as a result of network address translation before arriving at the relay.

Destination IP Address - The unicast IP address of the relay.

Destination UDP Port - The AMT port number.

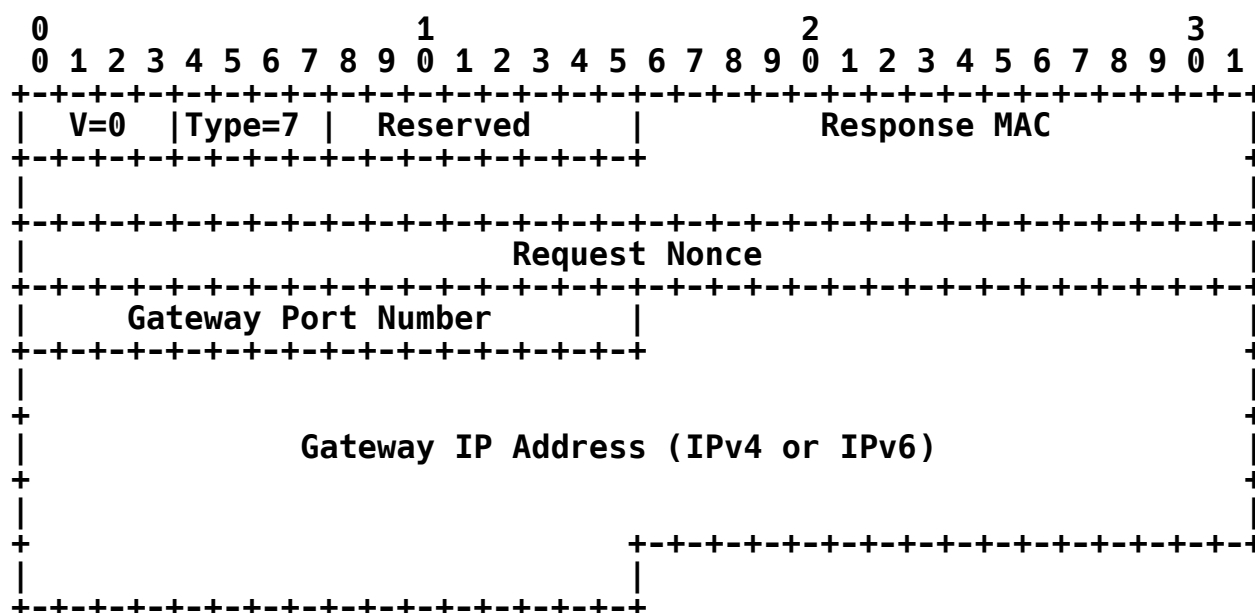


Figure 17: Membership Teardown Message Format

5.1.7.1. Version (V)

The protocol version number for this message is 0.

5.1.7.2. Type

The type number for this message is 7.

5.1.7.3. Reserved

Reserved bits that MUST be set to zero by the gateway and ignored by the relay.

5.1.7.4. Response MAC

A 48-bit value copied from the Response MAC field (Section 5.1.4.6) in the last Membership Query message the relay sent to the gateway endpoint address of the tunnel to be torn down. The gateway endpoint address is provided by the Gateway IP Address and Gateway Port Number fields carried by the Membership Query message. The relay validates the Teardown message by comparing this value with one computed from the Gateway IP Address field, Gateway Port Number field, Request Nonce field, and a private secret (just as it does in the Membership Update message).

5.1.7.5. Request Nonce

A 32-bit value copied from the Request Nonce field (Section 5.1.4.7) in the last Membership Query message the relay sent to the gateway endpoint address of the tunnel to be torn down. The gateway endpoint address is provided by the Gateway IP Address and Gateway Port Number fields carried by the Membership Query message. This value must match that used by the relay to compute the value stored in the Response MAC field.

5.1.7.6. Gateway Port Number

A 16-bit UDP port number that, when combined with the value contained in the Gateway IP Address field, forms the tunnel endpoint address that the relay will use to identify the tunnel instance to tear down. The relay provides this value to the gateway using the Gateway Port Number field (Section 5.1.4.9.1) in a Membership Query message. This port number must match that used by the relay to compute the value stored in the Response MAC field.

5.1.7.7. Gateway IP Address

A 16-byte IP address that, when combined with the value contained in the Gateway Port Number field, forms the tunnel endpoint address that the relay will use to identify the tunnel instance to tear down. The relay provides this value to the gateway using the Gateway IP Address field (Section 5.1.4.9.2) in a Membership Query message. This field may contain an IPv6 address or an IPv4 address stored as an IPv4-compatible IPv6 address, where the IPv4 address is prefixed with 96 bits set to zero (see [RFC4291]). This address must match that used by the relay to compute the value stored in the Response MAC field.

5.2. Gateway Operation

The following sections describe gateway implementation requirements. A non-normative discussion of gateway operation may be found in Section 4.2.

5.2.1. IP/IGMP/MLD Protocol Requirements

Gateway operation requires a subset of host-mode IPv4/IGMP and IPv6/MLD functionality to provide group membership tracking, query processing, and report generation. A gateway MAY use IGMPv2 (ASM), IGMPv3 (ASM and SSM), MLDv1 (ASM), or MLDv2 (ASM and SSM).

An application with embedded gateway functionality must provide its own implementation of this subset of the IPv4/IGMP and IPv6/MLD protocols. The service interface used to manipulate group membership state need not match that described in the IGMP and MLD specifications, but the actions taken as a result **SHOULD** be similar to those described in Section 5.1 of [RFC3376] and Section 6.1 of [RFC3810]. The gateway application will likely need to implement many of the same functions as a host IP stack, including checksum verification, dispatching, datagram filtering and forwarding, and IP encapsulation/decapsulation.

The encapsulated IGMP datagrams generated by a gateway **MUST** conform to the descriptions found in Section 4 of [RFC3376]. These datagrams **MUST** possess the IP headers, header options, and header values called for in [RFC3376], with the following exception: a gateway **MAY** use any source address value in an IGMP report datagram, including the "unspecified" address (all octets are zero). This exception is made because a gateway pseudo-interface might not possess a valid IPv4 address, and even if an address has been assigned to the interface, that address might not be a valid link-local source address on any relay interface. It is for this reason that a relay must accept encapsulated IGMP reports regardless of the source address they carry. See Section 5.3.1.

The encapsulated MLD messages generated by a gateway **MUST** conform to the description found in Section 5 of [RFC3810]. These datagrams **MUST** possess the IP headers, header options, and header values called for in [RFC3810], with the following exception: a gateway **MAY** use any source address value in an MLD report datagram, including the "unspecified" address (all octets are zero). This exception is made because a gateway pseudo-interface might not possess a valid IPv6 address, and even if an address has been assigned to the interface, that address might not be a valid link-local source address on any relay interface. As with IGMP, it is for this reason that a relay must accept encapsulated MLD reports regardless of the source address they carry. See Section 5.3.1.

The gateway IGMP/MLD implementation **SHOULD** retransmit unsolicited membership state-change reports and merge new state-change reports with pending reports as described in Section 5.1 of [RFC3376] and Section 6.1 of [RFC3810]. The number of retransmissions is specified by the relay in the Querier's Robustness Variable (QRV) field in the last General Query forwarded by the pseudo-interface. See Section 4.1.6 of [RFC3376] and Section 5.1.8 of [RFC3810].

The gateway IGMP/MLD implementation **SHOULD** handle General Query messages as described in Section 5.2 of [RFC3376] and Section 6.2 of [RFC3810] but **MAY** ignore the Max Resp Code (Maximum Response Code) field value and generate a current-state report without any delay.

An IPv4 gateway implementation **MUST** accept IPv4 datagrams that carry the General Query variant of the IGMPv3 Membership Query message, as described in Section 4 of [RFC3376]. The gateway **MUST** accept the IGMP datagram regardless of the IP source address carried by that datagram.

An IPv6 gateway implementation **MUST** accept IPv6 datagrams that carry the General Query variant of the MLDv2 Multicast Listener Query message, as described in Section 5 of [RFC3810]. The gateway **MUST** accept the MLD datagram regardless of the IP source address carried by that datagram.

5.2.2. Pseudo-Interface Configuration

A gateway host may possess or create multiple gateway pseudo-interfaces, each with a unique configuration that describes a binding to a specific IP protocol, Relay Address, Relay Discovery Address, or upstream network interface.

5.2.2.1. Relay Discovery Address

If a gateway implementation uses AMT relay discovery to obtain a Relay Address, it must first be supplied with a Relay Discovery Address. The Relay Discovery Address may be an anycast or unicast address. A gateway implementation may rely on a static address assignment or some form of dynamic address discovery. This specification does not require that a gateway implementation use any particular method to obtain a Relay Discovery Address -- an implementation may employ any method that returns a suitable Relay Discovery Address.

5.2.2.2. Relay Address

Before a gateway implementation can execute the AMT protocol to request and receive multicast traffic, it must be supplied with a unicast Relay Address. A gateway implementation may rely on static address assignment or support some form of dynamic address discovery. This specification does not require the use of any particular method to obtain a Relay Address -- an implementation may employ any method that returns a suitable Relay Address.

5.2.2.3. Upstream Interface Selection

A gateway host that possesses multiple network interfaces or addresses may allow for an explicit selection of the interface to use when communicating with a relay. The selection might be made to satisfy connectivity, tunneling, or IP protocol requirements.

5.2.2.4. Optional Retransmission Parameters

A gateway implementation that supports retransmission MAY require the following information:

Discovery Timeout

Initial time to wait for a response to a Relay Discovery message.

Maximum Relay Discovery Retransmission Count

Maximum number of Relay Discovery retransmissions to allow before terminating relay discovery and reporting an error.

Request Timeout

Initial time to wait for a response to a Request message.

Maximum Request Retransmission Count

Maximum number of Request retransmissions to allow before abandoning a relay and restarting relay discovery or reporting an error.

Maximum Retries Count for "Destination Unreachable"

The maximum number of times a gateway should attempt to send the same Request or Membership Update message after receiving an ICMP Destination Unreachable message.

5.2.3. Gateway Service

In the following descriptions, a gateway pseudo-interface is treated as a passive entity managed by a gateway service. The gateway pseudo-interface provides the state, and the gateway service provides the processing. The term "gateway" is used when describing service behavior with respect to a single pseudo-interface.

5.2.3.1. Startup

When a gateway pseudo-interface is started, the gateway service begins listening for AMT messages sent to the UDP endpoint(s) associated with the pseudo-interface and for any locally generated IGMP/MLD messages passed to the pseudo-interface. The handling of these messages is described below.

When the pseudo-interface is enabled, the gateway service MAY:

- o Optionally execute the relay discovery procedure described in Section 5.2.3.4.
- o Optionally execute the membership query procedure described in Section 5.2.3.5 to start the periodic membership update cycle.

5.2.3.2. Handling AMT Messages

A gateway MUST ignore any datagram it receives that cannot be interpreted as a Relay Advertisement, Membership Query, or Multicast Data message. The handling of Relay Advertisement, Membership Query, and Multicast Data messages is addressed in the sections that follow.

A gateway that conforms to this specification MUST ignore any message with a Version field value other than zero.

While listening for AMT messages, a gateway may be notified that an ICMP Destination Unreachable message was received as a result of an AMT message transmission. Handling of ICMP Destination Unreachable messages is described in Section 5.2.3.9.

5.2.3.3. Handling Multicast Data Messages

A gateway may receive Multicast Data messages after it sends a Membership Update message to a relay that adds a group subscription. The gateway may continue to receive Multicast Data messages long after the gateway sends a Membership Update message that deletes existing group subscriptions. The gateway MUST be prepared to receive these messages at any time but MAY ignore them or discard their contents if the gateway no longer has any interest in receiving the multicast datagrams contained within them.

A gateway MUST ignore a Multicast Data message if it fails to satisfy any of the following requirements:

- o The source IP address and UDP port carried by the Multicast Data message MUST be equal to the destination IP address and UDP port carried by the matching Membership Update message (i.e., the current Relay Address).
- o The destination address carried by the encapsulated IP datagram MUST fall within the multicast address allocation assigned to the relevant IP protocol, i.e., 224.0.0.0/4 for IPv4 and ff00::/8 for IPv6.

The gateway extracts the encapsulated IP datagram and forwards it to the local IP protocol implementation for checksum verification, fragmented datagram reassembly, source and group filtering, and transport-layer protocol processing.

Because AMT uses UDP encapsulation to deliver multicast datagrams to gateways, it qualifies as a tunneling protocol subject to the limitations described in [RFC6936]. If supported, a gateway **SHOULD** employ the solution described in [RFC6936] to ensure that the local IP stack does not discard IPv6 datagrams with zero checksums. If Multicast Data message datagrams are processed directly within the gateway (instead of the host IP stack), the gateway **MUST NOT** discard any of these datagrams because they carry a UDP checksum of zero.

5.2.3.4. Relay Discovery Procedure

This section describes gateway requirements related to the relay discovery message sequence described in Section 4.2.1.1.

5.2.3.4.1. Starting Relay Discovery

A gateway may start or restart the relay discovery procedure in response to the following events:

- o When a gateway pseudo-interface is started (enabled).
- o When the gateway wishes to report a group subscription when none currently exist.
- o Before sending the next Request message in a membership update cycle, i.e., each time the query timer expires (see below).
- o After the gateway fails to receive a response to a Request message.
- o After the gateway receives a Membership Query message with the L flag set to 1.

5.2.3.4.2. Sending a Relay Discovery Message

A gateway sends a Relay Discovery message to a relay to start the relay discovery process.

The gateway **MUST** send the Relay Discovery message using the current Relay Discovery Address and AMT port number as the destination. The Discovery Nonce value in the Relay Discovery message **MUST** be computed as described in Section 5.2.3.4.5.

The gateway **MUST** save a copy of the Relay Discovery message or save the Discovery Nonce value for possible retransmission and verification of a Relay Advertisement response.

When a gateway sends a Relay Discovery message, it may be notified that an ICMP Destination Unreachable message was received as a result of an earlier AMT message transmission. Handling of ICMP Destination Unreachable messages is described in Section 5.2.3.9.

5.2.3.4.3. Waiting for a Relay Advertisement Message

A gateway **MAY** retransmit a Relay Discovery message if it does not receive a matching Relay Advertisement message within some timeout period. If the gateway retransmits the message multiple times, the timeout period **SHOULD** be adjusted to provide a random exponential back-off. The **RECOMMENDED** timeout is a random value in the range $[\text{initial_timeout}, \text{MIN}(\text{initial_timeout} * 2^{\text{retry_count}}, \text{maximum_timeout})]$, with a **RECOMMENDED** initial timeout of 1 second and a **RECOMMENDED** maximum timeout of 120 seconds (which is the recommended minimum NAT mapping timeout described in [RFC4787]).

5.2.3.4.4. Handling a Relay Advertisement Message

When a gateway receives a Relay Advertisement message, it must first determine whether it should accept or ignore the message. A gateway **MUST** ignore a Relay Advertisement message if it fails to satisfy any of the following requirements:

- o The gateway **MUST** be waiting for a Relay Advertisement message.
- o The Discovery Nonce value contained in the Relay Advertisement message **MUST** be equal to the Discovery Nonce value contained in the Relay Discovery message.
- o The source IP address and UDP port of the Relay Advertisement message **MUST** be equal to the destination IP address and UDP port of the matching Relay Discovery message.

Once a gateway receives a Relay Advertisement response to a Relay Discovery message, it **SHOULD** ignore any other Relay Advertisements that arrive on the AMT interface until it sends a new Relay Discovery message.

If a gateway executes the relay discovery procedure at the start of each membership update cycle and the Relay Address returned in the latest Relay Advertisement message differs from the address returned in a previous Relay Advertisement message, then the gateway **SHOULD** send a Teardown message (if supported) to the old Relay Address,

using information from the last Membership Query message received from that relay, as described in Section 5.2.3.7. This behavior is illustrated in the following diagram.

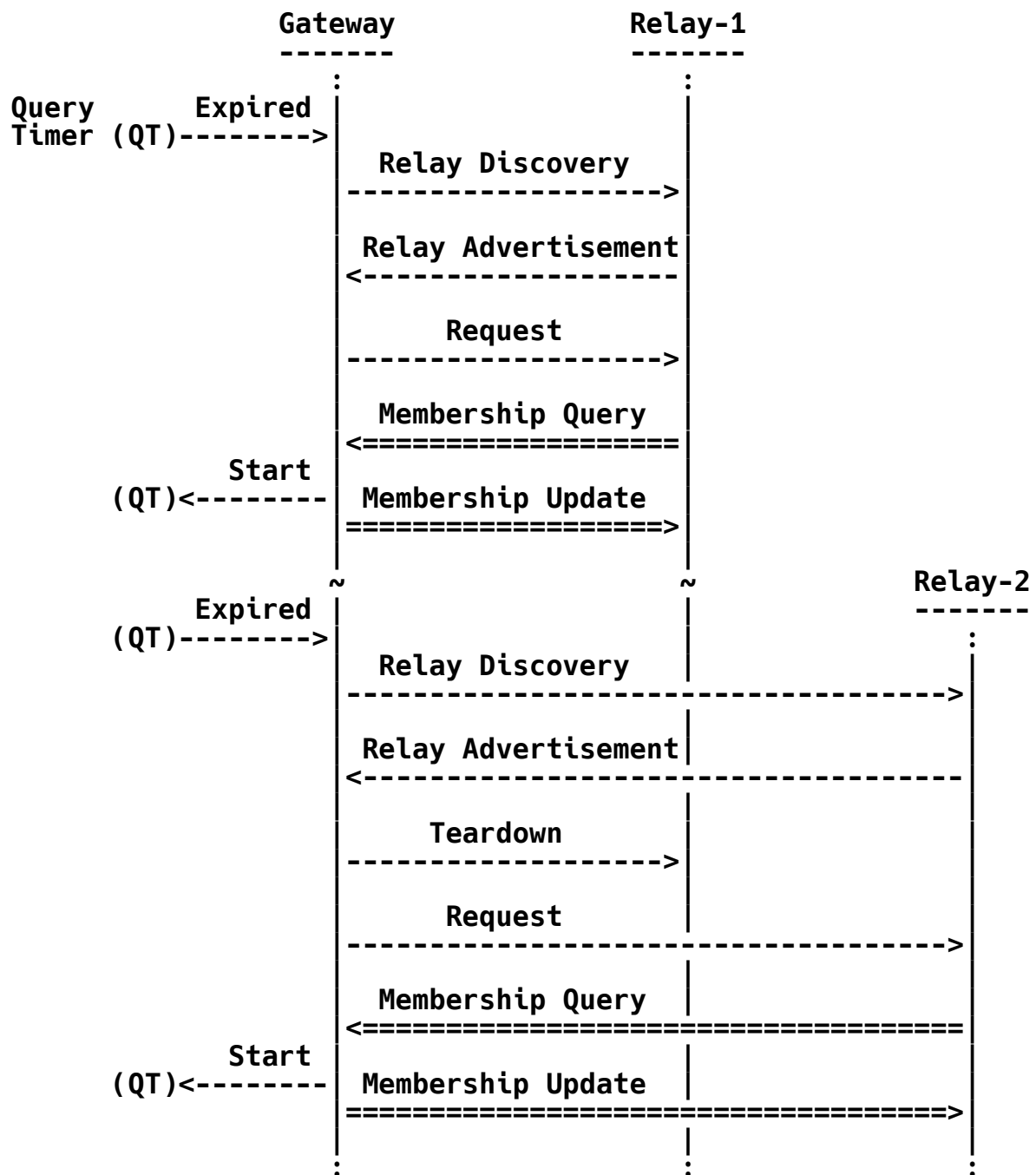


Figure 18: Teardown after Relay Address Change

5.2.3.4.5. Discovery Nonce Generation

The discovery nonce **MUST** be a random, non-zero 32-bit value and, if possible, **SHOULD** be computed using a cryptographically secure pseudorandom number generator. A new nonce **SHOULD** be generated each time the gateway restarts the relay discovery process. The same nonce **SHOULD** be used when retransmitting a Relay Discovery message.

5.2.3.5. Membership Query Procedure

This section describes gateway requirements related to the membership update message sequence described in Section 4.2.1.2.

5.2.3.5.1. Starting the Membership Update Cycle

A gateway may send a Request message to start a membership update cycle (following the optional relay discovery procedure) in response to the following events:

- o When the gateway pseudo-interface is activated.
- o When the gateway wishes to report a group subscription when none currently exist.

Starting the membership update cycle when a gateway pseudo-interface is started provides several benefits:

- o Better performance by allowing state-change reports to be sent as they are generated, thus minimizing the time to join.
- o More robustness by relying on unsolicited state-change reports to update group membership state rather than the current-state reports generated by the membership update cycle. Unsolicited state-change reports are typically retransmitted multiple times while current-state reports are not.
- o Simplified implementation by eliminating any need to queue IGMP/MLD messages for delivery after a Membership Query is received, since the IGMP/MLD state-change messages may be sent as they are generated.

However, this approach places an additional load on relays, as a gateway will send periodic requests even when it has no multicast subscriptions. To reduce load on a relay, a gateway **SHOULD** only send a Membership Update message while it has active group subscriptions. A relay will still need to compute a Response MAC for each Request

but will not be required to recompute it a second time to authenticate a Membership Update message that contains no subscriptions.

5.2.3.5.2. Sending a Request Message

A gateway sends a Request message to a relay to solicit a Membership Query response and start the membership update cycle.

A gateway constructs a Request message containing a Request Nonce value computed as described in Section 5.2.3.5.6. The gateway **MUST** set the P flag in the Request message to identify the protocol the gateway wishes the relay to use for the General Query response.

A gateway **MUST** send a Request message using the current Relay Address and AMT port number as the destination.

A gateway **MUST** save a copy of the Request message or save the Request Nonce and P flag values for possible retransmission and verification of a Membership Query response.

When a gateway sends a Request message, it may be notified that an ICMP Destination Unreachable message was received as a result of an earlier AMT message transmission. Handling of ICMP Destination Unreachable messages is described in Section 5.2.3.9.

5.2.3.5.3. Waiting for a Membership Query Message

A gateway **MAY** retransmit a Request message if it does not receive a matching Membership Query message within some timeout period. If the gateway retransmits the message multiple times, the timeout period **SHOULD** be adjusted to provide a random exponential back-off. The **RECOMMENDED** timeout is a random value in the range [initial_timeout, MIN(initial_timeout * 2^retry_count, maximum_timeout)], with a **RECOMMENDED** initial_timeout of 1 second and a **RECOMMENDED** maximum_timeout of 120 seconds (which is the recommended minimum NAT mapping timeout described in [RFC4787]).

If a gateway that uses relay discovery does not receive a Membership Query within a specified time period or after a specified number of retries, the gateway **SHOULD** stop waiting for a Membership Query message and restart relay discovery to locate another relay.

5.2.3.5.4. Handling a Membership Query Message

When a gateway receives a Membership Query message, it must first determine whether it should accept or ignore the message. A gateway **MUST** ignore a Membership Query message, or the encapsulated IP datagram within it, if the message fails to satisfy any of the following requirements:

- o The gateway **MUST** be waiting for a Membership Query message.
- o The Request Nonce value contained in the Membership Query **MUST** equal the Request Nonce value contained in the Request message.
- o The source IP address and UDP port of the Membership Query **MUST** equal the destination IP address and UDP port of the matching Request message (i.e., the current Relay Address).
- o The encapsulated IP datagram **MUST** carry an IGMPv3 or MLDv2 message. The protocol **MUST** match the protocol identified by the P flag in the Request message.
- o The IGMPv3 or MLDv2 message **MUST** be a General Query message.
- o The total length of the encapsulated IP datagram as computed from the lengths contained in the datagram header(s) **MUST NOT** exceed the available field length within the Membership Query message.

Once a gateway receives a Membership Query response to a Request message, it **SHOULD** ignore any other Membership Query messages that arrive on the AMT interface until it sends a new Request message.

The gateway **MUST** save the Membership Query message, or the Request Nonce, Response MAC, Gateway IP Address, and Gateway Port Number fields for use in sending subsequent Membership Update and Teardown messages.

The gateway extracts the encapsulated IP datagram and forwards it to the local IP protocol implementation for checksum verification and dispatching to the IGMP or MLD implementation running on the pseudo-interface. The gateway **MUST NOT** forward any octets that might exist between the encapsulated IP datagram and the end of the message or Gateway Address fields.

The MLD protocol specification indicates that senders should use a link-local source IP address in message datagrams. This requirement must be relaxed for AMT because gateways and relays do not normally share a common subnet. For this reason, a gateway implementation **MUST** accept MLD (and IGMP) query message datagrams regardless of the

source IP address they carry. This may require additional processing on the part of the gateway that might be avoided if the relay and gateway use the IPv4 and IPv6 addresses allocated for use in AMT-encapsulated control packets as described in Section 5.2.1.

The gateway **MUST** start a timer that will trigger the next iteration of the membership update cycle by executing the membership query procedure. The gateway **SHOULD** compute the timer duration from the Querier's Query Interval Code carried by the General Query. A gateway **MAY** use a smaller timer duration if required to refresh a NAT mapping that would otherwise time out. A gateway **MAY** use a larger timer duration if it has no group subscriptions to report.

If the gateway supports the Teardown message and the G flag is set in the Membership Query message, the gateway **MUST** compare the Gateway IP Address and Gateway Port Number on the new Membership Query message with the values carried by the previous Membership Query message. If either value has changed, the gateway **MUST** send a Teardown message to the relay as described in Section 5.2.3.7.

If the L flag is set in the Membership Query message, the relay is reporting that it is **NOT** accepting Membership Update messages that create new tunnel endpoints and will simply ignore any that do. If the L flag is set and the gateway is not currently reporting any group subscriptions to the relay, the gateway **SHOULD** stop sending periodic Request messages and restart the relay discovery procedure (if discovery is enabled) to find a new relay with which to communicate. Even if the L flag is set, the gateway **MAY** continue to send updates if it has previously reported group subscriptions to the relay, one or more subscriptions still exist, and the gateway endpoint address has not changed since the last Membership Query was received (see previous paragraph).

5.2.3.5.5. Handling Query Timer Expiration

When the query timer (started in the previous step) expires, the gateway should execute the membership query procedure again to continue the membership update cycle.

5.2.3.5.6. Request Nonce Generation

The Request Nonce **MUST** be a random value and, if possible, **SHOULD** be computed using a cryptographically secure pseudorandom number generator. A new nonce **MUST** be generated each time the gateway starts the membership query process. The same nonce **SHOULD** be used when retransmitting a Request message.

5.2.3.6. Membership Update Procedure

This section describes gateway requirements related to the membership update message sequence described in Section 4.2.1.2.

The membership update process is primarily driven by the host-mode IGMP or MLD protocol implementation running on the gateway pseudo-interface. The IGMP and MLD protocols produce current-state reports in response to General Query messages generated by the pseudo-interface via AMT and produce state-change reports in response to receiver requests made using the IGMP or MLD service interface.

5.2.3.6.1. Handling an IGMP/MLD IP Datagram

The gateway pseudo-interface **MUST** accept the following IP datagrams from the IPv4/IGMP and IPv6/MLD protocols running on the pseudo-interface:

- o IPv4 datagrams that carry an IGMPv2 or IGMPv3 Membership Report or an IGMPv2 Leave Group message as described in Section 4 of [RFC3376].
- o IPv6 datagrams that carry an MLDv1 or MLDv2 Multicast Listener Report or an MLDv1 Multicast Listener Done message as described in Section 5 of [RFC3810].

The gateway must be prepared to receive these messages any time the pseudo-interface is running. The gateway **MUST** ignore any datagrams not listed above.

A gateway that waits to start a membership update cycle until after it receives a datagram containing an IGMP/MLD state-change message **MAY**:

- o Discard IGMP or MLD datagrams until it receives a Membership Query message, at which time it processes the Membership Query message as normal to eventually produce a current-state report on the pseudo-interface, which describes the end state (RECOMMENDED).
- o Insert IGMP or MLD datagrams into a queue for transmission after it receives a Membership Query message.

If and when a gateway receives a Membership Query message (for IGMP or MLD), it sends any queued or incoming IGMP or MLD datagrams to the relay as described in the next section.

5.2.3.6.2. Sending a Membership Update Message

A gateway cannot send a Membership Update message to a relay until it has received a Membership Query message from a relay. If the gateway has not yet located a relay with which to communicate, it **MUST** first execute the relay discovery procedure described in Section 5.2.3.4 to obtain a Relay Address. If the gateway has a Relay Address but has not yet received a Membership Query message, it **MUST** first execute the membership query procedure described in Section 5.2.3.5 to obtain a Request Nonce and Response MAC that can be used to send a Membership Update message.

Once a gateway possesses a valid Relay Address, Request Nonce, and Response MAC, it may encapsulate the IP datagram containing the IGMP/MLD message into a Membership Update message. The gateway **MUST** copy the Request Nonce and Response MAC values from the last Membership Query received from the relay into the corresponding fields in the Membership Update. The gateway **MUST** send the Membership Update message using the Relay Address and AMT port number as the destination.

When a gateway sends a Membership Update message, it may be notified that an ICMP Destination Unreachable message was received as a result of an earlier AMT message transmission. Handling of ICMP Destination Unreachable messages is described in Section 5.2.3.9.

5.2.3.7. Teardown Procedure

This section describes gateway requirements related to the teardown message sequence described in Section 4.2.1.3.

Gateway support for the Teardown message is **RECOMMENDED**.

A gateway that supports Teardown **SHOULD** make use of Teardown functionality if it receives a Membership Query message from a relay that has the G flag set to indicate that it contains valid Gateway Address fields.

5.2.3.7.1. Handling a Membership Query Message

As described in Section 5.2.3.5.4, if a gateway supports the Teardown message, has reported active group subscriptions, and receives a Membership Query message with the G flag set, the gateway **MUST** compare the Gateway IP Address and Gateway Port Number on the new Membership Query message with the values carried by the previous Membership Query message. If either value has changed, the gateway **MUST** send a Teardown message as described in the next section.

5.2.3.7.2. Sending a Teardown Message

A gateway sends a Teardown message to a relay to request that it stop delivering Multicast Data messages to the gateway and delete any group memberships created by the gateway.

When a gateway constructs a Teardown message, it **MUST** copy the Request Nonce, Response MAC, Gateway IP Address, and Gateway Port Number fields from the Membership Query message that provided the Response MAC for the last Membership Update message sent, into the corresponding fields of the Teardown message.

A gateway **MUST** send the Teardown message using the Relay Address and AMT port number as the destination. A gateway **MAY** send the Teardown message multiple times for robustness. The gateway **SHOULD** use the Querier's Robustness Variable (QRV) field contained in the query encapsulated within the last Membership Query to set the limit on the number of retransmissions (see Section 4.1.6 of [RFC3376] and Section 5.1.8 of [RFC3810]). If the gateway sends the Teardown message multiple times, it **SHOULD** insert a delay between each transmission using the timing algorithm employed in IGMP/MLD for transmitting unsolicited state-change reports. The **RECOMMENDED** default delay value is 1 second.

When a gateway sends a Teardown message, it may be notified that an ICMP Destination Unreachable message was received as a result of an earlier AMT message transmission. Handling of ICMP Destination Unreachable messages is described in Section 5.2.3.9.

5.2.3.8. Shutdown

When a gateway pseudo-interface is stopped and the gateway has existing group subscriptions, the gateway **SHOULD** either:

- o Send a Teardown message to the relay as described in Section 5.2.3.7, but only if the gateway supports the Teardown message and the current relay is returning Gateway Address fields in Membership Query messages, or
- o Send a Membership Update message to the relay that will delete existing group subscriptions.

5.2.3.9. Handling ICMP Destination Unreachable Responses

A gateway may receive an ICMP Destination Unreachable message [RFC0792] after sending an AMT message. Whether the gateway is notified that an ICMP message was received is highly dependent on firewall and gateway IP stack behavior and gateway implementation.

If the reception of an ICMP Destination Unreachable message is reported to the gateway while waiting to receive an AMT message, the gateway may respond as follows, depending on platform capabilities and which outgoing message triggered the ICMP response:

1. The gateway MAY simply abandon the current relay and restart relay discovery (if used). This is the least desirable approach, as it does not allow for transient network changes.
2. If the last message sent was a Relay Discovery or Request message, the gateway MAY simply ignore the ICMP response and continue waiting for incoming AMT messages. If the gateway is configured to retransmit Relay Discovery or Request messages, the normal retransmission behavior for those messages is preserved to prevent the gateway from prematurely abandoning a relay.
3. If the last message sent was a Membership Update message, the gateway MAY start a new membership update and associated Request retransmission cycle.

If the reception of an ICMP Destination Unreachable message is reported to the gateway when attempting to transmit a new AMT message, the gateway may respond as follows, depending on platform capabilities and which outgoing message triggered the ICMP response:

1. The gateway MAY simply abandon the current relay and restart relay discovery (if used). This is the least desirable approach, as it does not allow for transient network changes.
2. If the last message sent was a Relay Discovery, Request, or Teardown message, the gateway MAY attempt to transmit the new message. If the gateway is configured to retransmit Relay Discovery, Request, or Teardown messages, the normal retransmission behavior for those messages is preserved to prevent the gateway from prematurely abandoning a relay.
3. If the last message sent was a Membership Update message, the gateway SHOULD start a new membership update and associated Request retransmission cycle.

5.3. Relay Operation

The following sections describe relay implementation requirements. A non-normative discussion of relay operation may be found in Section 4.2.

5.3.1. IP/IGMP/MLD Protocol Requirements

A relay requires a subset of router-mode IGMP and MLD functionality to provide group membership tracking and report processing.

A relay accessible via IPv4 **MUST** support IPv4/IGMPv3 and **MAY** support IPv6/MLDv2. A relay accessible via IPv6 **MUST** support IPv6/MLDv2 and **MAY** support IPv4/IGMPv3.

A relay **MUST** apply the forwarding rules described in Section 6.3 of [RFC3376] and Section 7.3 of [RFC3810].

A relay **MUST** handle incoming reports as described in Section 6.4 of [RFC3376] and Section 7.4 of [RFC3810], with the exception that actions that lead to queries **MAY** be modified to eliminate query generation. A relay **MUST** accept IGMP and MLD report datagrams regardless of the IP source address carried by those datagrams.

All other aspects of IGMP/MLD router behavior, such as the handling of queries, querier election, etc., are not used or required for relay operation.

5.3.2. Startup

If a relay is deployed for anycast discovery, the relay **MUST** advertise an anycast Relay Discovery Address Prefix into the unicast routing system of the anycast domain. An address within that prefix, i.e., a Relay Discovery Address, **MUST** be assigned to a relay interface.

A unicast IPv4 and/or IPv6 address **MUST** be assigned to the relay interface that will be used to send and receive AMT control and data messages. This address or addresses are returned in Relay Advertisement messages.

The remaining details of relay "startup" are highly implementation dependent and are not addressed in this document.

5.3.3. Running

When a relay is started, it begins listening for AMT messages on the interface to which the unicast Relay Address(es) has been assigned, i.e., the address returned in Relay Advertisement messages.

5.3.3.1. Handling AMT Messages

A relay **MUST** ignore any message other than a Relay Discovery, Request, Membership Update, or Teardown message. The handling of Relay Discovery, Request, Membership Update, and Teardown messages is addressed in the sections that follow.

Support for the Teardown message is **OPTIONAL**. If a relay does not support the Teardown message, it **MUST** also ignore this message.

A relay that conforms to this specification **MUST** ignore any message with a Version field value other than zero.

5.3.3.2. Handling a Relay Discovery Message

This section describes relay requirements related to the relay discovery message sequence described in Section 4.2.1.1.

A relay **MUST** accept and respond to Relay Discovery messages sent to an anycast Relay Discovery Address or the unicast Relay Address. If a relay receives a Relay Discovery message sent to its unicast address, it **MUST** respond just as it would if the message had been sent to its anycast Relay Discovery Address.

When a relay receives a Relay Discovery message, it responds by sending a Relay Advertisement message back to the source of the Relay Discovery message.

The relay **MUST** use the source IP address and UDP port number of the Relay Discovery message as the destination IP address and UDP port number for the Relay Advertisement message. The source IP address and UDP port number carried by the Relay Advertisement message **MUST** match the destination IP address and UDP port number of the Relay Discovery message to ensure successful NAT traversal.

The relay **MUST** copy the value contained in the Discovery Nonce field of the Relay Discovery message into the Discovery Nonce field in the Relay Advertisement message.

If the Relay Discovery message was received as an IPv4 datagram, the relay MUST return an IPv4 address in the Relay Address field of the Relay Advertisement message. If the Relay Discovery message was received as an IPv6 datagram, the relay MUST return an IPv6 address in the Relay Address field.

5.3.3.3. Handling a Request Message

This section describes relay requirements related to the membership query portion of the message sequence described in Section 4.2.1.2.

When a relay receives a Request message, it responds by sending a Membership Query message back to the source of the Request message.

The relay MUST use the source IP address and UDP port of the Request message as the destination IP address and UDP port for the Membership Query message. The source IP address and UDP port carried by the Membership Query MUST match the destination IP address and UDP port of the Request to ensure successful NAT traversal.

The relay MUST return the value contained in the Request Nonce field of the Request message in the Request Nonce field of the Membership Query message. The relay MUST compute a MAC value, as described in Section 5.3.5, and return that value in the Response MAC field of the Membership Query message.

If a relay supports the Teardown message, it MUST set the G flag in the Membership Query message and return the source IP address and UDP port carried by the Request message in the corresponding Gateway IP Address and Gateway Port Number fields. If the relay does not support the Teardown message, it SHOULD NOT set these fields, as this may cause the gateway to generate unnecessary Teardown messages.

If the P flag in the Request message is 0, the relay MUST return an IPv4-encapsulated IGMPv3 General Query in the Membership Query message. If the P flag is 1, the relay MUST return an IPv6-encapsulated MLDv2 General Query in the Membership Query message.

If the relay is not accepting Membership Update messages that create new tunnel endpoints due to resource limitations, it SHOULD set the L flag in the Membership Query message to notify the gateway of this state. Support for the L flag is OPTIONAL. See Section 5.3.3.8.

The encapsulated IGMPv3 General Query datagrams generated by a relay MUST conform to the descriptions found in Section 4.1 of [RFC3376]. These datagrams MUST possess the IP headers, header options, and header values called for in [RFC3376], with the following exception: a relay MAY use any source IP address for an IGMP General Query datagram, including the "unspecified" address (all octets are zero). This exception is made because any source address that a relay might normally send may not be a valid link-local address on any gateway interface. It is for this reason that a gateway must accept encapsulated IGMP queries regardless of the source address they carry. See Section 5.2.1.

The encapsulated MLDv2 General Query datagrams generated by a relay MUST conform to the descriptions found in Section 5.1 of [RFC3810]. These datagrams MUST possess the IP headers, header options, and header values called for in [RFC3810], with the following exception: a relay MAY use any source IP address for an MLD General Query datagram, including the "unspecified" address (all octets are zero). This exception is made because any source address that a relay might normally send may not be a valid link-local address on any gateway interface. As with IGMP, it is for this reason that a gateway must accept encapsulated MLD queries regardless of the source address they carry. See Section 5.2.1.

A relay MUST set the Querier's Query Interval Code (QQIC) field in the General Query to supply the gateway with a suggested time duration to use for the membership query timer. The QQIC field is defined in Section 4.1.7 of [RFC3376] and Section 5.1.9 of [RFC3810]. A relay MAY adjust this value to affect the rate at which the Request messages are sent from a gateway. However, a gateway is allowed to use a shorter duration than the duration specified in the QQIC field, so a relay may be limited in its ability to spread out Requests coming from a gateway.

A relay MUST set the Querier's Robustness Variable (QRV) field in the General Query to a non-zero value. This value SHOULD be greater than one. If a gateway retransmits membership state-change messages, it will retransmit them (Robustness Variable - 1) times. The QRV field is defined in Section 4.1.6 of [RFC3376] and Section 5.1.8 of [RFC3810].

A relay SHOULD set the Maximum Response Code field in the General Query to a value of 1 to trigger an immediate response from the gateway (some host IGMP/MLD implementations may not accept a value of zero). A relay SHOULD NOT use the IGMPv3/MLDv2 Query Response Interval variable, if available, to generate the Maximum Response Code field value, as the Query Response Interval variable is used in setting the duration of group state timers and must not be set to

such a small value. The Maximum Response Code field is defined in Section 4.1.1 of [RFC3376] and Section 5.1.3 of [RFC3810]. See Section 5.3.3.7.

5.3.3.4. Handling a Membership Update Message

This section describes relay requirements related to the membership update portion of the message sequence described in Section 4.2.1.2.

When a relay receives a Membership Update message, it must first determine whether it should accept or ignore the message. A relay **MUST NOT** make any changes to group membership and forwarding state if the message fails to satisfy any of the following requirements:

- o The IP datagram encapsulated within the message **MUST** be one of the following:
 - * IPv4 datagram carrying an IGMPv2 or IGMPv3 Membership Report message.
 - * IPv4 datagram carrying an IGMPv2 Leave Group message.
 - * IPv6 datagram carrying an MLDv1 or MLDv2 Multicast Listener Report message.
 - * IPv6 datagram carrying MLDv1 Multicast Listener Done message.
- o The encapsulated IP datagram **MUST** satisfy the IP header requirements for the IGMP or MLD message type as described in Section 4 of [RFC3376], Section 2 of [RFC2236], Section 5 of [RFC3810], and Section 3 of [RFC2710], with the following exception: a relay **MUST** accept an IGMP or MLD message regardless of the IP source address carried by the datagram.
- o The total length of the encapsulated IP datagram as computed from the lengths contained in the datagram header(s) **MUST NOT** exceed the available field length within the Membership Update message.
- o The computed checksums for the encapsulated IP datagram and its payload **MUST** match the values contained therein. Checksum computation and verification vary by protocol; see [RFC0791] for IPv4, [RFC3376] for IGMPv3, and [RFC4443] for MLD (ICMPv6).
- o If processing of the encapsulated IGMP or MLD message would result in an allocation of new state or a modification of existing state, the relay **MUST** authenticate the source of the message by verifying that the value contained in the Response MAC field equals the MAC value computed from the fields in the Membership Update message

datagram. If a time-varying private secret is used in the computation of a Response MAC, the relay **MUST** retain the previous version of the private secret for use in authenticating Membership Updates sent during the subsequent query interval. If the first attempt at Response MAC authentication fails, the relay **MUST** attempt to authenticate the Response MAC using the previous private secret value unless $2 * \text{query_interval}$ time has elapsed since the private secret change. See Section 5.3.5.

A relay **MAY** skip source authentication to reduce the computational cost of handling Membership Update messages if the relay can make a trivial determination that the IGMP/MLD message carried by the Membership Update message will produce no changes in group membership or forwarding state. The relay does not need to compute and compare MAC values if it finds there are no group subscriptions for the source of the Membership Update message and either of the following is true:

- o The encapsulated IP datagram is an IGMPv3 Membership Report or MLDv2 Multicast Listener Report message that contains no group records. This may often be the case for gateways that continuously repeat the membership update cycle even though they have no group subscriptions to report.
- o The encapsulated IP datagram is an IGMPv2 Leave Group or MLDv1 Multicast Listener Done message.

The IGMP and MLD protocol specifications indicate that senders **SHOULD** use a link-local source IP address in message datagrams. This requirement must be relaxed for AMT because gateways and relays do not share a common subnet. For this reason, a relay implementation **MUST** accept IGMP and MLD datagrams regardless of the source IP address they carry.

Once a relay has determined that the Membership Update message is valid, it processes the encapsulated IGMP or MLD message to update group membership state and communicates with the multicast protocol to update forwarding state and possibly send multicast protocol messages towards upstream routers. The relay **MUST** ignore any octets that might exist between the encapsulated IP datagram and the end of the Membership Update message.

As described in Section 4.2.2, a relay uses the source IP address and source UDP port carried by a Membership Update message to identify a tunnel endpoint. A relay uses the tunnel endpoint as the destination address for any Multicast Data messages it sends as a result of the

group membership and forwarding state created by processing the IGMP/MLD messages contained in Membership Update messages received from the endpoint.

If a Membership Update message originates from a new endpoint, the relay **MUST** determine whether it can accept updates from a new endpoint. If a relay has been configured with a limit on the total number of endpoints, or a limit on the total number of endpoints for a given source address, then the relay **MAY** ignore the Membership Update message and possibly withdraw any Relay Discovery Address Prefix announcement that it might have made. See Section 5.3.3.8.

A relay **MUST** maintain some form of group membership database for each endpoint. The per-endpoint databases are used to update a forwarding table containing entries that map a (*,G) or (S,G) subscription to a list of tunnel endpoints.

A relay **MUST** maintain some form of group membership database representing a merger of the group membership databases of all endpoints. The merged group membership database is used to update upstream multicast forwarding state.

A relay **MUST** maintain a forwarding table that maps each unique (*,G) and (S,G) subscription to a list of tunnel endpoints. A relay uses this forwarding table to provide the destination address when performing UDP/IP encapsulation of the incoming multicast IP datagrams to form Multicast Data messages.

If a group filter mode for a group entry on a tunnel endpoint is **EXCLUDE**, the relay **SHOULD NOT** forward datagrams that originate from sources in the filter source list unless the relay architecture does not readily support source filtering. A relay **MAY** ignore the source list if necessary because gateways are expected to do their own source filtering.

5.3.3.5. Handling a Teardown Message

This section describes relay requirements related to the teardown message sequence described in Section 4.2.1.3.

When a relay (that supports the Teardown message) receives a Teardown message, it **MUST** first authenticate the source of the Teardown message by verifying that the Response MAC carried by the Teardown message is equal to a MAC value computed from the fields carried by the Teardown message. The method used to compute the MAC differs from that used to generate and validate the Membership Query and Membership Update messages in that the source IP address and source UDP port number used to compute the MAC are taken from the Gateway IP

Address and Gateway Port Number fields in the Teardown message rather than from the IP and UDP headers in the datagram that carries the Teardown message. The MAC computation is described in Section 5.3.5. A relay **MUST** ignore a Teardown message if the computed MAC does not equal the value of the Response MAC field.

If a relay determines that a Teardown message is authentic, it **MUST** immediately stop transmitting Multicast Data messages to the endpoint identified by the Gateway IP Address and Gateway Port Number fields in the message. The relay **MUST** eventually delete any group membership and forwarding state associated with the endpoint but **MAY** delay doing so to allow a gateway to recreate group membership state on a new endpoint and thereby avoid making unnecessary (temporary) changes in upstream routing/forwarding state.

The state changes made by a relay when processing a Teardown message **MUST** be identical to those that would be made if the relay had received an IGMP/MLD report that would cause the IGMP or MLD protocol to delete all existing group records in the group membership database associated with the endpoint. The processing of the Teardown message should trigger or mimic the normal interaction between IGMP or MLD and a multicast protocol to produce required changes in forwarding state and possibly send prune/leave messages towards upstream routers.

5.3.3.6. Handling Multicast IP Datagrams

When a multicast IP datagram is forwarded to the relay pseudo-interface, the relay **MUST**, for each gateway that has expressed an interest in receiving the datagram, encapsulate the IP datagram into a Multicast Data message or messages and send that message or messages to the gateway. This process is highly implementation dependent but conceptually requires the following steps:

- o Use the IP datagram source and destination address to look up the appropriate (*,G) or (S,G) entry in the endpoint forwarding table created for the pseudo-interface as a result of IGMP/MLD processing.
- o Possibly replicate the datagram for each gateway endpoint listed for that (*,G) or (S,G) entry.

- o If the multicast IP datagram size exceeds the Tunnel MTU as determined according to the procedure described in Section 5.3.3.6.1, the relay must execute the procedure described in Section 5.3.3.6.2.
- o Encapsulate and transmit the IP datagram according to the procedure described in Section 5.3.3.6.3.

The relay pseudo-interface **MUST** ignore any other IP datagrams forwarded to the pseudo-interface.

5.3.3.6.1. Path and Tunnel MTU

A relay **MUST** compute a Tunnel MTU (TMTU) value for each AMT tunnel that originates on the relay. A relay will use the TMTU value to determine whether an incoming multicast IP datagram can be delivered downstream in a Membership Data message without fragmentation. A relay **MUST** compute the TMTU by subtracting the size of the Membership Data message headers (IP, UDP, and AMT) from the current Path MTU (PMTU) associated with each AMT tunnel. The relay **MUST** maintain a PMTU value on a per-tunnel or per-relay basis. A relay **MUST** support one or both of the following methods for determining the PMTU value:

- o The relay **MAY** provide a configuration option that establishes a fixed PMTU that will be applied to all AMT tunnels originating at the relay.
- o The relay **MAY** dynamically adjust PMTU value(s) in response to receipt of ICMP/ICMPv6 Datagram Too Big messages as described in [RFC1191] and [RFC1981].

If a relay supports dynamic adjustment of per-tunnel or per-relay PMTU values in response to ICMP messages, the relay **MUST** provide a configuration option that disables this feature and also provide a configuration option that establishes a minimum PMTU for all tunnels. These configuration options may be used to mitigate certain types of denial-of-service attacks (see Section 6). When dynamic PMTU adjustments are disabled, the PMTU for all tunnels **MUST** default to the Link MTU (first hop) on the downstream interface.

5.3.3.6.2. MTU Filtering Procedure

This section defines procedures that a relay must execute when it receives a multicast datagram whose size is greater than the Tunnel MTU of the tunnel or tunnels through which it must be delivered.

5.3.3.6.2.1. IPv4 Multicast IP Datagrams

If the DF bit in the multicast datagram header is set to 1 (Don't Fragment), the relay **MUST** discard the packet and, if the datagram originated from an SSM source, send an ICMPv4 [RFC0792] Destination Unreachable message to the source, with code 4 (fragmentation needed and DF set). The ICMP Destination Unreachable message **MUST** contain a Next-Hop MTU (as specified by [RFC1191]), and the relay **MUST** set the Next-Hop MTU to the TMTU associated with the tunnel or tunnels. If the DF bit in the multicast datagram header is set to 0 (May Fragment), the relay **MUST** fragment the datagram and encapsulate each fragment within Multicast Data messages for transmission through the tunnel or tunnels. This ensures that gateways will receive complete, non-fragmented Multicast Data messages, containing fragmented multicast datagram payloads. The relay **SHOULD** avoid generating a separate ICMP message for each tunnel but instead send a single ICMP message with a Next-Hop MTU equal to the smallest TMTU of all tunnels to which the datagram was to be forwarded.

5.3.3.6.2.2. IPv6 Multicast IP Datagrams

The relay **MUST** discard the packet and, if the datagram originated from an SSM source, send an ICMPv6 [RFC4443] Packet Too Big message to the payload source. The MTU specified in the Packet Too Big message **MUST** be equal to the TMTU associated with the tunnel or tunnels. The relay **SHOULD** avoid generating a separate ICMPv6 message for each tunnel but instead send a single ICMPv6 message with a Next-Hop MTU equal to the smallest TMTU of all tunnels to which the datagram was to be forwarded.

5.3.3.6.3. Encapsulation Procedure

A relay encapsulates a multicast IP datagram in a UDP/IP Membership Data message, using the tunnel endpoint UDP/IP address as the destination address and the unicast Relay Address and port number as the source UDP/IP address. To ensure successful NAT traversal, the source address and port **MUST** match the destination address and port carried by the Membership Update message sent by the gateway to create the forwarding table entry.

If possible, the relay **SHOULD** compute a valid, non-zero checksum for the UDP datagram carrying the Multicast Data message. See Section 4.2.2.3.

The following sections describe additional requirements related to the IP protocol of the tunnel and that of the multicast IP datagram.

5.3.3.6.3.1. Tunneling over IPv4

When a relay delivers an IPv4 payload over an IPv4 tunnel and the DF bit in the payload header is set to 1 (Don't Fragment), the relay **MUST** set the DF bit in the Multicast Data IP header to 1. When a relay delivers an IPv4 payload over an IPv4 tunnel and the DF bit in the payload header is set to 0 (May Fragment), by default, the relay **MUST** set the DF bit in the Multicast Data IP header to 1. However, a relay **MAY** provide a configuration option that allows the DF bit to be copied from the payload header to the Multicast Data IP header to allow downstream fragmentation of the Multicast Data message. When a relay delivers an IPv6 payload over an IPv4 tunnel, the relay **MUST** set the DF bit in the Multicast Data IP header to 1. The relay **MUST NOT** transmit a Multicast Data message with an IP header in which the MF (More Fragments) bit is set to 1.

5.3.3.6.3.2. Tunneling over IPv6

When tunneling over IPv6, a relay **MUST NOT** emit a Multicast Data message datagram containing an IPv6 fragment header.

5.3.3.6.4. Handling Destination Unreachable Messages

If a relay receives a sequence of ICMP or ICMPv6 Destination Unreachable messages (excluding ICMP code 4; see below) in response to transmission of a sequence of AMT Multicast Data messages to a gateway, the relay **SHOULD** discontinue sending messages to that gateway and shut down the tunnel for that gateway.

Handling of ICMP Destination Unreachable messages with code 4, "fragmentation needed and DF set" (i.e., "Datagram Too Big") is covered in Section 5.3.3.6.1. If a relay provides this capability, it **MUST** provide a configuration option that indicates what number of sequential Destination Unreachable messages can be received and ignored before the relay will automatically shut down a tunnel.

5.3.3.7. State Timers

A relay **MUST** maintain a timer or timers whose expiration will trigger the removal of any group subscriptions and forwarding state previously created for a gateway endpoint should the gateway fail to refresh the group membership state within a specified time interval.

A relay **MAY** use a variant of the IGMPv3/MLDv2 state management protocol described in Section 6 of [RFC3376] or Section 7 of [RFC3810] or may maintain a per-endpoint timer to trigger the deletion of group membership state.

If a per-endpoint timer is used, the relay **MUST** restart this timer each time it receives a new Membership Update message from the gateway endpoint.

The endpoint timer duration **MAY** be computed from tunable IGMP/MLD variables as follows:

$$((\text{Robustness_Variable}) * (\text{Query_Interval})) + \text{Query_Response_Interval}$$

If IGMP/MLD default values are used for these variables, the gateway will time out after $125s * 2 + 10s = 260s$. The timer duration **MUST** be greater than the query interval suggested in the last Membership Query message sent to the gateway endpoint.

Regardless of the timers used (IGMPv3/MLDv2 or endpoint), the Query_Response_Interval value **SHOULD** be greater than or equal to 10s to allow for packet loss and round-trip time in the Request/Membership Query message exchange.

5.3.3.8. Relay Resource Management

A relay may be configured with various service limits to ensure a minimum level of performance for gateways that connect to it.

If a relay has determined that it has reached or exceeded maximum allowable capacity or has otherwise exhausted resources required to support additional gateways, it **SHOULD** withdraw any Relay Discovery Address Prefix it has advertised into the unicast internetwork and **SHOULD** set the L flag in any Membership Query messages it returns to gateways while in this state.

If the relay receives an update from a gateway that adds group membership or forwarding state for an endpoint that has already reached maximum allowable state entries, the relay **SHOULD** continue to accept updates from the gateway but ignore any group membership/forwarding state additions requested by that gateway.

If the relay receives an update from a gateway that would create a new tunnel endpoint for a source IP address that has already reached the maximum allowable number of endpoints (maximum UDP ports), it should simply ignore the Membership Update.

5.3.4. Shutdown

The following steps should be treated as an abstract description of the shutdown procedure for a relay:

- o Withdraw the Relay Discovery Address Prefix advertisement (if used).
- o Stop listening for Relay Discovery messages.
- o Stop listening for control messages from gateways.
- o Stop sending data messages to gateways.
- o Delete all AMT group membership and forwarding state created on the relay, coordinating with the multicast routing protocol to update the group membership state on upstream interfaces as required.

5.3.5. Response MAC Generation

A Response MAC value is computed by the relay. A Response MAC computation is required in the following situations:

- o To generate a Response MAC value from a Request message for inclusion in a Membership Query message.
- o To generate a Response MAC value from a Membership Update message for use in authenticating the Response MAC carried within that message.
- o To generate a Response MAC value from a Teardown message to authenticate the Response MAC carried within that message.

Gateways treat the Response MAC field as an opaque value, so a relay implementation may generate the MAC using any method available to it. The RECOMMENDED method for computing the Response MAC is to compute a cryptographically secure hash or keyed-hash digest from the following values:

- o The source IP address of the message (or Teardown Gateway IP Address field).

- o The source UDP port of the message (or Teardown Gateway Port Number field).
- o The Request Nonce contained in the message.
- o A private secret or key known only to the relay.

5.3.6. Private Secret Generation

If the relay implementation uses a private secret (or key) to compute the Response MAC value, the relay **SHOULD** periodically compute a new private secret. The **RECOMMENDED** maximum interval is 2 hours. A relay **MUST** retain the prior secret for use in verifying MAC values that were sent to gateways just prior to the use of the new secret.

6. Security Considerations

AMT is not intended to be a strongly secure protocol. In general, the protocol provides the same level of security and robustness as is provided by the UDP, IGMP, and MLD protocols on which it relies. The lack of strong security features can be largely attributed to the desire to make the protocol lightweight by minimizing the state and computation required to service a single gateway, thereby allowing a relay to service a larger number of gateways.

Many of the threats and vectors described in [RFC3552] may be employed against the protocol to launch various types of denial-of-service attacks that can affect the functioning of gateways or their ability to locate and communicate with a relay. These scenarios are described below.

As is the case for UDP, IGMP, and MLD, the AMT protocol provides no mechanisms for ensuring message delivery or integrity. The protocol does not provide confidentiality -- multicast groups, sources, and streams requested by a gateway are sent in the clear.

The protocol does use a three-way handshake to provide trivial source authentication for state allocation and updates (see below). The protocol also requires gateways and relays to ignore malformed messages and those messages that do not carry expected address values, protocol payload types, or content.

6.1. Relays

The three-way handshake provided by the membership update message sequence (see Section 4.2.1.2) provides a defense against source-spoofing-based resource-exhaustion attacks on a relay by requiring source authentication before state allocation. However, in an effort

to consume computational resources, attackers may still attempt to flood a relay with Request and Membership Update messages to force the relay to make the MAC authentication computations. Implementations may choose to limit the frequency with which a relay responds to Request messages sent from a single IP address or IP address and UDP port pair, but support for this functionality is not required. The three-way handshake provides no defense against an eavesdropping or man-in-the-middle attacker.

Attackers that execute the gateway protocol may consume relay resources by instantiating a large number of tunnels or joining a large number of multicast streams. A relay implementation should provide a mechanism for limiting the number of tunnels (Multicast Data message destinations) that can be created for a single gateway source address. Relays should also provide a means for limiting the number of joins per tunnel instance as a defense against these attacks.

Relays may withdraw their AMT anycast prefix advertisement when they reach configured maximum capacity or exhaust required resources. This behavior allows gateways to use the relay discovery process to find the next topologically nearest relay that has advertised the prefix. This behavior also allows a successful resource-exhaustion attack to propagate from one relay to the next until all relays reachable using the anycast address have effectively been taken offline. This behavior may also be used to acquire the unicast addresses for individual relays that can then be used to launch a DDoS attack on all of the relays without using the relay discovery process. To prevent wider disruption of AMT-based distribution networks, relay anycast address advertisements can be limited to specific administrative routing domains. This will isolate such attacks to a single domain.

The Path and Tunnel MTU adjustment (discovery) procedure described in Section 5.3.3.6.1 is vulnerable to two denial-of-service attacks (see Section 8 of [RFC1191] for details). Both attacks are based on a malicious party sending forged ICMPv4 Destination Unreachable or ICMPv6 Packet Too Big messages to a host. In the first attack, the forged message indicates an inordinately small Path MTU. In the second attack, the forged message indicates an inordinately large Path MTU. In both cases, throughput is adversely affected. In order to mitigate such attacks, relay implementations MUST include a configuration option to disable Path MTU adjustments on AMT tunnels.

6.2. Gateways

A passive eavesdropper may launch a denial-of-service attack on a gateway by capturing a Membership Query or Membership Update message and using the Request Nonce and message authentication code carried by the captured message to send a spoofed Membership Update or Teardown message to the relay. The spoofed messages may be used to modify or destroy group membership state associated with the gateway, thereby changing or interrupting the multicast traffic flows.

A passive eavesdropper may also spoof Multicast Data messages in an attempt to overload the gateway or to disrupt or supplant existing traffic flows. A properly implemented gateway will filter Multicast Data messages that do not originate from the expected Relay Address and should filter non-multicast packets and multicast IP packets whose group or source addresses are not included in the current reception state for the gateway pseudo-interface.

An active eavesdropper may launch a man-in-the-middle attack in which messages normally exchanged between a gateway and relay are intercepted, modified, spoofed, or discarded by the attacker. The attacker may deny access to, modify, or replace requested multicast traffic. The AMT protocol provides no means for detecting or defending against a man-in-the-middle attack -- any such functionality must be provided by multicast receiver applications through independent detection and validation of incoming multicast datagrams.

The anycast discovery technique for finding relays (see Section 4.1.4) introduces a risk that a rogue router or a rogue Autonomous System (AS) could introduce a bogus route to a specific Relay Discovery Address Prefix and thus divert or absorb Relay Discovery messages sent by gateways. Network managers must guarantee the integrity of their routing to a particular Relay Discovery Address Prefix in much the same way that they guarantee the integrity of all other routes.

6.3. Encapsulated IP Packets

An attacker forging or modifying a Membership Query or Membership Update message may attempt to embed something other than an IGMP or MLD message within the encapsulated IP packet carried by these messages in an effort to introduce these into the recipient's IP stack. A properly implemented gateway or relay will ignore any such messages and may further choose to ignore Membership Query messages that do not contain IGMP/MLD General Query or Membership Update messages that do not contain IGMP/MLD membership reports.

Properly implemented gateways and relays will also filter encapsulated IP packets that appear corrupted or truncated by verifying packet length and checksums.

7. IANA Considerations

7.1. IPv4 and IPv6 Anycast Prefix Allocation

The following unicast prefixes have been assigned to provide anycast routing of Relay Discovery messages to public AMT relays as described in Section 4.1.4. Address assignments within these prefixes are described in Section 4.1.5.2.

7.1.1. IPv4

IANA has assigned 192.52.193.0/24 from the "IANA IPv4 Special-Purpose Address Registry". The block has been registered as follows:

| Attribute | Value |
|----------------------|-----------------|
| Address Block | 192.52.193.0/24 |
| Name | AMT |
| RFC | [RFC7450] |
| Allocation Date | 2014-12 |
| Termination Date | N/A |
| Source | True |
| Destination | True |
| Forwardable | True |
| Global | True |
| Reserved-by-Protocol | False |

7.1.2. IPv6

IANA has registered the following special-purpose address block for IPv6 anycast AMT relay discovery.

| Attribute | Value |
|----------------------|-------------|
| Address Block | 2001:3::/32 |
| Name | AMT |
| RFC | [RFC7450] |
| Allocation Date | 2014-12 |
| Termination Date | N/A |
| Source | True |
| Destination | True |
| Forwardable | True |
| Global | True |
| Reserved-by-Protocol | False |

7.2. UDP Port Number

The UDP port number 2268 has been reserved with IANA for use in the implementation and deployment of AMT. The protocol described by this document continues to use this port number according to the intent of the original request. IANA has updated the assignee, contact, and reference fields for this port number in accordance with this document.

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