Internet Engineering Task Force (IETF)
Request for Comments: 8487
Category: Standards Track
ISSN: 2070-1721

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October 2018

Mtrace Version 2: Traceroute Facility for IP Multicast

Abstract

This document describes the IP multicast traceroute facility, named Mtrace version 2 (Mtrace2). Unlike unicast traceroute, Mtrace2 requires special implementations on the part of routers. This specification describes the required functionality in multicast routers, as well as how an Mtrace2 client invokes a Query and receives a Reply.

Status of This Memo

This is an Internet Standards Track document.

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Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at https://www.rfc-editor.org/info/rfc8487.

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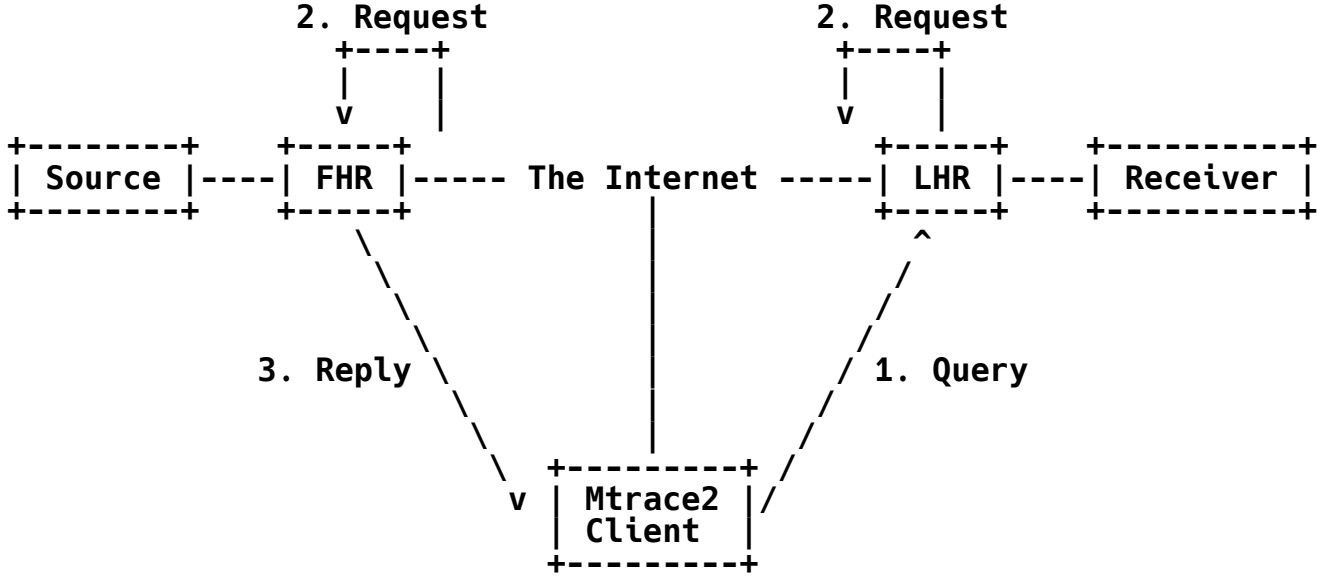
1. Introduction

Given a multicast distribution tree, tracing hop-by-hop downstream from a multicast source to a given multicast receiver is difficult because there is no efficient and deterministic way to determine the branch of the multicast routing tree on which that receiver lies. On the other hand, walking up the tree from a receiver to a source is easy, as most existing multicast routing protocols know the upstream router for each source. Tracing from a receiver to a source can involve only the routers on the direct path.

This document specifies the multicast traceroute facility named Mtrace version 2 or Mtrace2, which allows the tracing of an IP multicast routing path. Mtrace2 is usually initiated from an Mtrace2 client by sending an Mtrace2 Query to a Last-Hop Router (LHR) or to a Rendezvous Point (RP). The RP is a special router where sources and receivers meet in Protocol Independent Multicast - Sparse Mode (PIM-SM) [5]. From the LHR/RP receiving the Query, the tracing is directed towards a specified source if a source address is specified and a source-specific state exists on the receiving router. If no source address is specified or if no source-specific state exists on a receiving LHR, the tracing is directed toward the RP for the specified group address. Moreover, Mtrace2 provides additional information such as the packet rates and losses, as well as other diagnostic information. Mtrace2 is primarily intended for the following purposes:

- To trace the path that a packet would take from a source to a receiver.
- To isolate packet-loss problems (e.g., congestion).
- To isolate configuration problems (e.g., Time to live (TTL) threshold).

The following figure shows a typical case of how Mtrace2 is used. FHR represents the first-hop router, LHR represents the last-hop router, and the arrow lines represent the Mtrace2 messages that are sent from one node to another. The numbers before the Mtrace2 messages represent the sequence of the messages that would happen. The source, receiver, and Mtrace2 client are typically hosts.



When an Mtrace2 client initiates a multicast trace, it sends an Mtrace2 Query packet to an LHR or RP for a multicast group and, optionally, a source address. The LHR/RP turns the Query packet into a Request. The Request message type enables each of the upstream routers processing the message to apply different packet and message validation rules than those required for the handling of a Query message. The LHR/RP then appends a Standard Response Block containing its interface addresses and packet statistics to the Request packet, then forwards the packet towards the source/RP. The Request packet is either unicasted to its upstream router towards the source/RP or multicasted to the group if the upstream router's IP address is not known. In a similar fashion, each router along the path to the source/RP appends a Standard Response Block to the end of the Request packet before forwarding it to its upstream router. When the FHR receives the Request packet, it appends its own Standard Response Block, turns the Request packet into a Reply, and unicasts the Reply back to the Mtrace2 client.

The Mtrace2 Reply may be returned before reaching the FHR under some circumstances. This can happen if a Request packet is received at an RP or gateway, or when any of several types of error or exception conditions occur that prevent the sending of a Request to the next upstream router.

The Mtrace2 client waits for the Mtrace2 Reply message and displays the results. When not receiving an Mtrace2 Reply message due to network congestion, a broken router (see Section 5.6), or a non-responding router (see Section 5.7), the Mtrace2 client may resend another Mtrace2 Query with a lower hop count (see Section 3.2.1) and

repeat the process until it receives an Mtrace2 Reply message. The details are specific to the Mtrace2 client and outside the scope of this document.

Note that when a router's control plane and forwarding plane are out of sync, the Mtrace2 Requests might be forwarded based on the control states instead. In this case, the traced path might not represent the real path the data packets would follow.

Mtrace2 supports both IPv4 and IPv6. Unlike the previous version of Mtrace, which implements its query and response as Internet Group Management Protocol (IGMP) messages [10], all Mtrace2 messages are UDP based. Although the packet formats of IPv4 and IPv6 Mtrace2 are different because of the address families, the syntax between them is similar.

This document describes the base specification of Mtrace2 that can serve as a basis for future proposals such as Mtrace2 for Automatic Multicast Tunneling (AMT) [16] and Mtrace2 for Multicast in MPLS/BGP IP VPNs (known as Multicast VPN (MVPN)) [15]. They are, therefore, out of the scope of this document.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [1] [7] when, and only when, they appear in all capitals, as shown here. The key words indicate requirement levels for compliant Mtrace2 implementations.

2.1. Definitions

Since Mtrace2 Queries and Requests flow in the opposite direction to the data flow, we refer to "upstream" and "downstream" with respect to data, unless explicitly specified.

Incoming Interface:
: The interface on which data is expected to arrive from the specified source and group.

Outgoing Interface:
: This is one of the interfaces to which data from the source or RP is expected to be transmitted for the specified source and group. It is also the interface on which the Mtrace2 Request was received.

Upstream router:
The router, connecting to the Incoming Interface of the current router, which is responsible for forwarding data for the specified source and group to the current router.

First-Hop Router (FHR):
The router that is directly connected to the source the Mtrace2 Query specifies.

Last-Hop Router (LHR):
A router that is directly connected to a receiver. It is also the router that receives the Mtrace2 Query from an Mtrace2 client.

Group state:
The state a shared-tree protocol, such as Protocol Independent Multicast - Sparse Mode (PIM-SM) [5], uses to choose the upstream router towards the RP for the specified group. In this state, source-specific state is not available for the corresponding group address on the router.

Source-specific state:
The state that is used to choose the path towards the source for the specified source and group.

ALL-[protocol]-ROUTERS group:
Link-local multicast address for multicast routers to communicate with their adjacent routers that are running the same routing protocol. For instance, the IPv4 'ALL-PIM-ROUTERS' group is '224.0.0.13', and the IPv6 'ALL-PIM-ROUTERS' group is 'ff02::d' [5].

3. Packet Formats

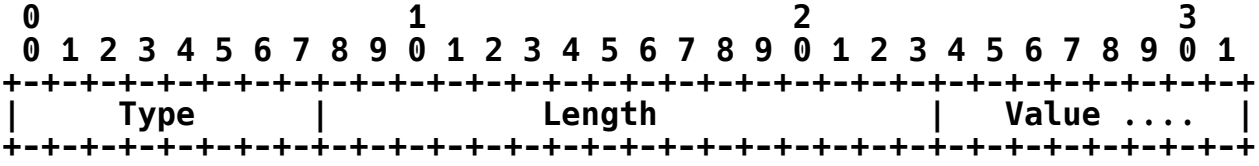
This section describes the details of the packet formats for Mtrace2 messages.

All Mtrace2 messages are encoded in the Type/Length/Value (TLV) format (see Section 3.1). The first TLV of a message is a message header TLV specifying the type of message and additional context information required for processing of the message and for parsing of subsequent TLVs in the message. Subsequent TLVs in a message, referred to as Blocks, are appended after the header TLV to provide additional information associated with the message. If an implementation receives an unknown TLV Type for any TLV in a message, it SHOULD ignore and silently discard the entire packet. If the length of a TLV exceeds the available space in the containing packet, the implementation MUST ignore and silently discard the TLV and any remaining portion of the containing packet.

All Mtrace2 messages are UDP packets. For IPv4, Mtrace2 Query/Request/Reply messages MUST NOT be fragmented. Therefore, Mtrace2 clients and LHRs/RPs MUST set the IP header do-not-fragment (DF) bit for all Mtrace2 messages. For IPv6, the packet size for the Mtrace2 messages MUST NOT exceed 1280 bytes, which is the smallest Maximum Transmission Unit (MTU) for an IPv6 interface [8]. The source port is uniquely selected by the local host operating system. The destination port is the IANA-reserved Mtrace2 port number (see Section 8). All Mtrace2 messages MUST have a valid UDP checksum.

Additionally, Mtrace2 supports both IPv4 and IPv6, but not when mixed. For example, if an Mtrace2 Query or Request message arrives as an IPv4 packet, all addresses specified in the Mtrace2 messages MUST be IPv4 as well. The same rule applies to IPv6 Mtrace2 messages.

3.1. Mtrace2 TLV Format



Type: 8 bits

Describes the format of the Value field. For all the available types, please see Section 3.2.

Length: 16 bits

Length of Type, Length, and Value fields in octets. Minimum length required is 4 octets. The length MUST be a multiple of 4 octets. The maximum TLV length is not defined; however, the entire Mtrace2 packet length MUST NOT exceed the available MTU.

Value: variable length

The format is based on the Type value. The length of the Value field is the Length field minus 3. All reserved fields in the Value field MUST be transmitted as zeros and ignored on receipt.

3.2. Defined TLVs

The following TLV Types are defined:

Code	Type
0x00	Reserved
0x01	Mtrace2 Query
0x02	Mtrace2 Request
0x03	Mtrace2 Reply
0x04	Mtrace2 Standard Response Block
0x05	Mtrace2 Augmented Response Block
0x06	Mtrace2 Extended Query Block

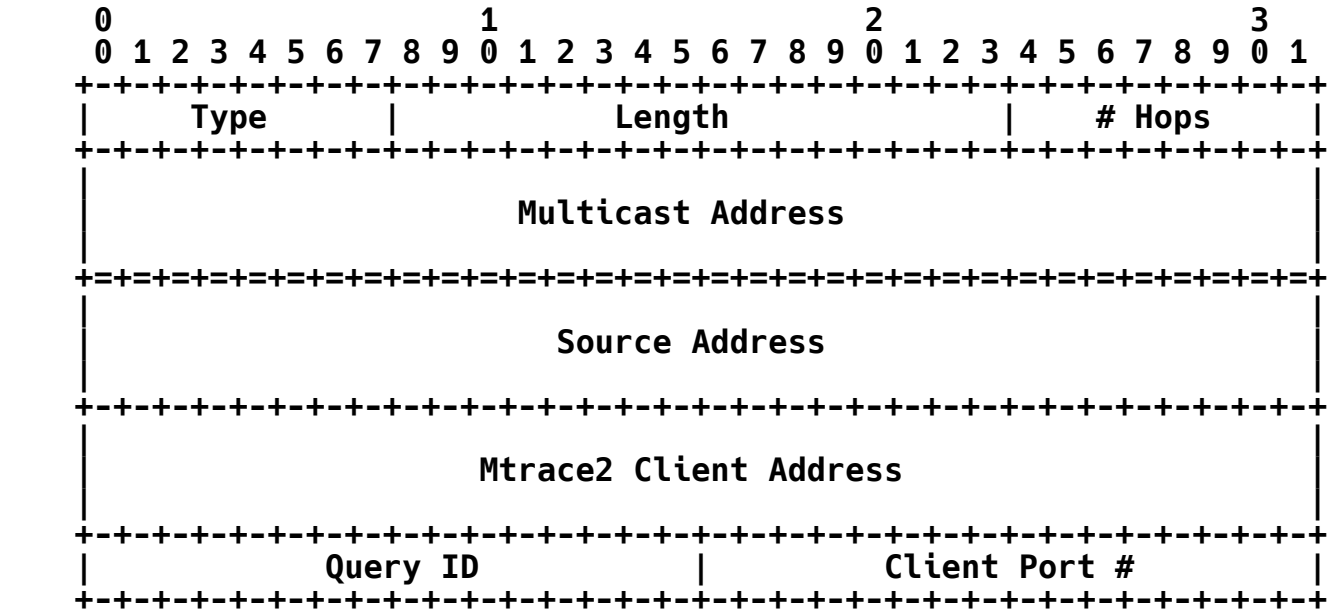
Each Mtrace2 message MUST begin with either a Query, a Request, or a Reply TLV. The first TLV determines the type of each Mtrace2 message. Following a Query TLV, there can be a sequence of optional Extended Query Blocks. In the case of a Request or a Reply TLV, it is then followed by a sequence of Standard Response Blocks, each from a multicast router on the path towards the source or the RP. In the case where more information is needed, a Standard Response Block can be followed by one or multiple Augmented Response Blocks.

We will describe each message type in detail in the next few sections.

3.2.1. Mtrace2 Query

An Mtrace2 Query is originated by an Mtrace2 client, which sends an Mtrace2 Query message to the LHR. The LHR modifies only the Type field of the Query TLV (to turn it into a "Request") before appending a Standard Response Block and forwarding it upstream. The LHR and intermediate routers handling the Mtrace2 message when tracing upstream MUST NOT modify any other fields within the Query/Request TLV. Additionally, intermediate routers handling the message after the LHR has converted the Query into a Request MUST NOT modify the Type field of the Request TLV. If the actual number of hops is not known, an Mtrace2 client could send an initial Query message with a large # Hops (e.g., 0xff), in order to try to trace the full path.

An Mtrace2 Query message is shown as follows:



Length: 16 bits
The Length field MUST be either 20 (i.e., 8 + 3 * 4 (IPv4 addresses)) or 56 (i.e., 8 + 3 * 16 (IPv6 addresses)); if the length is 20, then IPv4 addresses MUST be assumed, and if the length is 56, then IPv6 addresses MUST be assumed.

Hops: 8 bits
This field specifies the maximum number of hops that the Mtrace2 client wants to trace. If there are some error conditions in the middle of the path that prevent an Mtrace2 Reply from being received by the client, the client MAY issue another Mtrace2 Query with a lower number of hops until it receives a Reply.

Multicast Address: 32 bits or 128 bits
This field specifies an IPv4 or IPv6 address, which can be either:

m-1: a multicast group address to be traced or

m-2: all ones in case of IPv4 or the unspecified address (::) in case of IPv6 if no group-specific information is desired.

Source Address: 32 bits or 128 bits
This field specifies an IPv4 or IPv6 address, which can be either:

s-1: a unicast address of the source to be traced or

s-2: all ones in case of IPv4 or the unspecified address (::) in case of IPv6 if no source-specific information is desired. For example, the client is tracing a (*,g) group state.

Note that it is invalid to have a source-group combination of (s-2, m-2). If a router receives such combination in an Mtrace2 Query, it MUST silently discard the Query.

Mtrace2 Client Address: 32 bits or 128 bits
This field specifies the Mtrace2 client's IPv4 address or IPv6 global address. This address MUST be a valid unicast address; therefore, it MUST NOT be all ones or an unspecified address. The Mtrace2 Reply will be sent to this address.

Query ID: 16 bits
This field is used as a unique identifier for this Mtrace2 Query so that duplicate or delayed Reply messages may be detected.

Client Port #: 16 bits
This field specifies the destination UDP port number for receiving the Mtrace2 Reply packet.

3.2.2. Mtrace2 Request

The Mtrace2 Request TLV is exactly the same as an Mtrace2 Query except for identifying the Type field of 0x02.

When an LHR receives an Mtrace2 Query message, it turns the Query into a Request by changing the Type field of the Query from 0x01 to 0x02. The LHR then appends an Mtrace2 Standard Response Block (see Section 3.2.4) of its own to the Request message before sending it upstream. The upstream routers do the same without changing the Type field until one of them is ready to send a Reply.

3.2.3. Mtrace2 Reply

The Mtrace2 Reply TLV is exactly the same as an Mtrace2 Query except for identifying the Type field of 0x03.

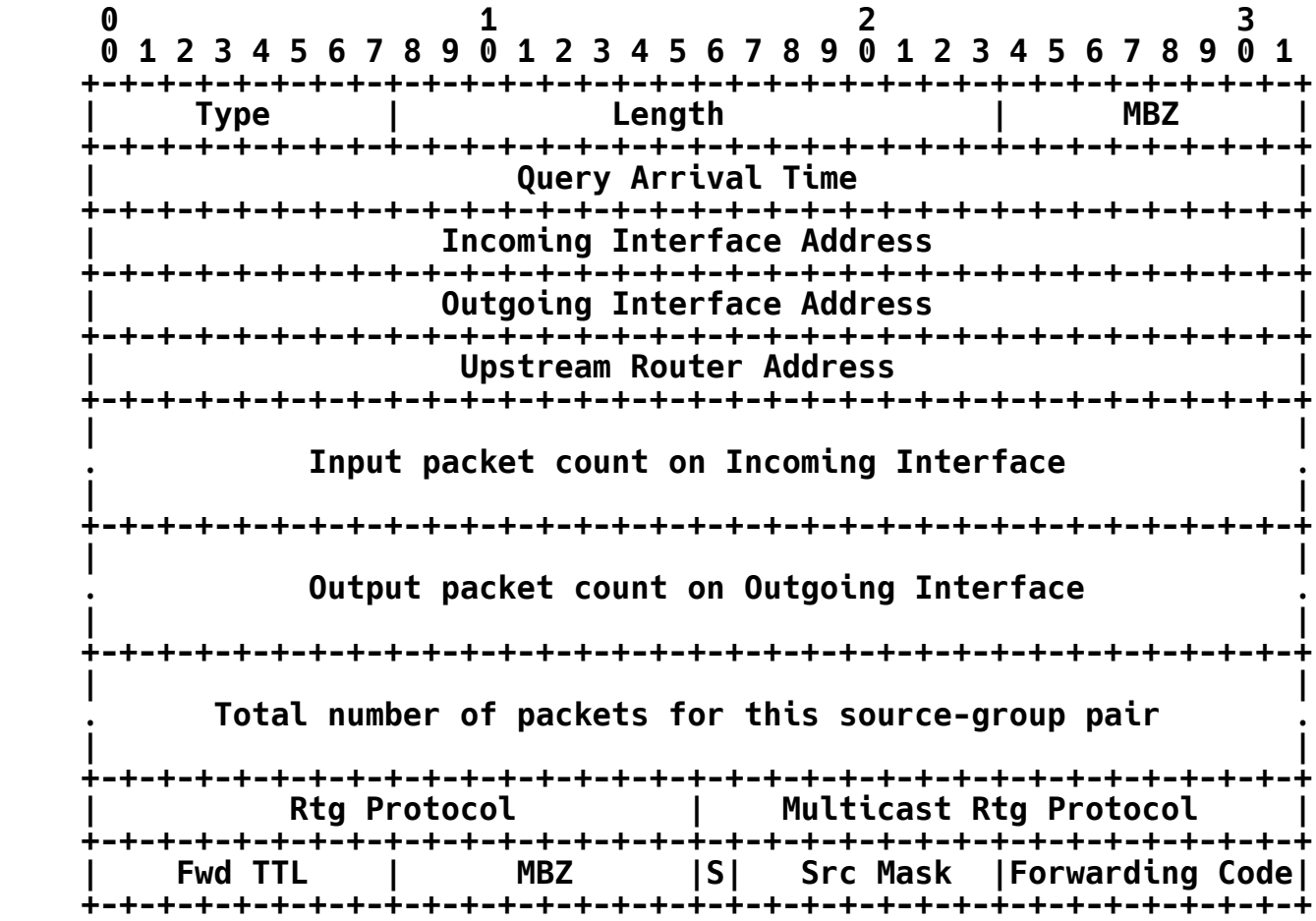
When an FHR or an RP receives an Mtrace2 Request message that is destined to itself, it appends an Mtrace2 Standard Response Block (see Section 3.2.4) of its own to the Request message. Next, it turns the Request message into a Reply by changing the Type field of

the Request from 0x02 to 0x03 and by changing the UDP destination port to the port number specified in the Client Port Number field in the Request. It then unicasts the Reply message to the Mtrace2 client specified in the Mtrace2 Client Address field.

There are a number of cases in which an intermediate router might return a Reply before a Request reaches the FHR or the RP. See Sections 4.1.1, 4.2.2, 4.3.3, and 4.5 for more details.

3.2.4. IPv4 Mtrace2 Standard Response Block

This section describes the message format of an IPv4 Mtrace2 Standard Response Block. The Type field is 0x04.



MBZ: 8 bits
This field MUST be zeroed on transmission and ignored on reception.

Query Arrival Time: 32 bits
The Query Arrival Time is a 32-bit Network Time Protocol (NTP) timestamp specifying the arrival time of the Mtrace2 Query or Request packet at this router. The 32-bit form of an NTP timestamp consists of the middle 32 bits of the full 64-bit form; that is, the low 16 bits of the integer part and the high 16 bits of the fractional part.

The following formula converts from a timespec (fractional part in nanoseconds) to a 32-bit NTP timestamp:

```
query_arrival_time
= ((tv.tv_sec + 32384) << 16) + ((tv.tv_nsec << 7) / 1953125)
```

The constant 32384 is the number of seconds from Jan 1, 1900 to Jan 1, 1970 truncated to 16 bits. ((tv.tv_nsec << 7) / 1953125) is a reduction of ((tv.tv_nsec / 1000000000) << 16), where "<<" denotes a logical left shift.

Note that synchronized clocks are required on the traced routers to estimate propagation and queuing delays between successive hops. Nevertheless, even without this synchronization, an application can still estimate an upper bound on cumulative one-way latency by measuring the time between sending a Query and receiving a Reply.

Additionally, Query Arrival Time is useful for measuring the packet rate. For example, suppose that a client issues two Queries, and the corresponding Requests R1 and R2 arrive at router X at time T1 and T2, then the client would be able to compute the packet rate on router X by using the packet-count information stored in the R1 and R2 and using the time T1 and T2.

Incoming Interface Address: 32 bits
This field specifies the address of the interface on which packets from the source or the RP are expected to arrive, or 0 if unknown or unnumbered.

Outgoing Interface Address: 32 bits
This field specifies the address of the interface on which packets from the source or the RP are expected to transmit towards the receiver, or 0 if unknown or unnumbered. This is also the address of the interface on which the Mtrace2 Query or Request arrives.

Upstream Router Address: 32 bits
This field specifies the address of the upstream router from which this router expects packets from this source. This MAY be a multicast group (e.g., ALL-[protocol]-ROUTERS group) if the upstream router is not known because of the workings of the multicast routing protocol. However, it MUST be 0 if the Incoming Interface address is unknown or unnumbered.

Input packet count on Incoming Interface: 64 bits
This field contains the number of multicast packets received for all groups and sources on the Incoming Interface, or all ones if no count can be reported. This counter may have the same value as ifHCInMulticastPkts from the Interfaces Group MIB (IF-MIB) [9] for this interface.

Output packet count on Outgoing Interface: 64 bits
This field contains the number of multicast packets that have been transmitted or queued for transmission for all groups and sources on the Outgoing Interface, or all ones if no count can be reported. This counter may have the same value as ifHCOutMulticastPkts from the IF-MIB [9] for this interface.

Total number of packets for this source-group pair: 64 bits
This field counts the number of packets from the specified source forwarded by the router to the specified group, or all ones if no count can be reported. If the S bit is set (see below), the count is for the source network, as specified by the Src Mask field (see below). If the S bit is set and the Src Mask field is 127, indicating no source-specific state, the count is for all sources sending to this group. This counter should have the same value as ipMcastRoutePkts from the IP Multicast MIB [14] for this forwarding entry.

Rtg Protocol: 16 bits
This field describes the unicast routing protocol running between this router and the upstream router, and it is used to determine the Reverse Path Forwarding (RPF) interface for the specified source or RP. This value should have the same value as ipMcastRouteRtProtocol from the IP Multicast MIB [14] for this entry. If the router is not able to obtain this value, all 0's must be specified.

Multicast Rtg Protocol: 16 bits
This field describes the multicast routing protocol in use between the router and the upstream router. This value should have the same value as ipMcastRouteProtocol from the IP Multicast MIB [14] for this entry. If the router cannot obtain this value, all 0's must be specified.

Fwd TTL: 8 bits
This field contains the configured multicast TTL threshold, if any, of the Outgoing Interface.

S: 1 bit
If this bit is set, it indicates that the packet count for the source-group pair is for the source network, as determined by masking the source address with the Src Mask field.

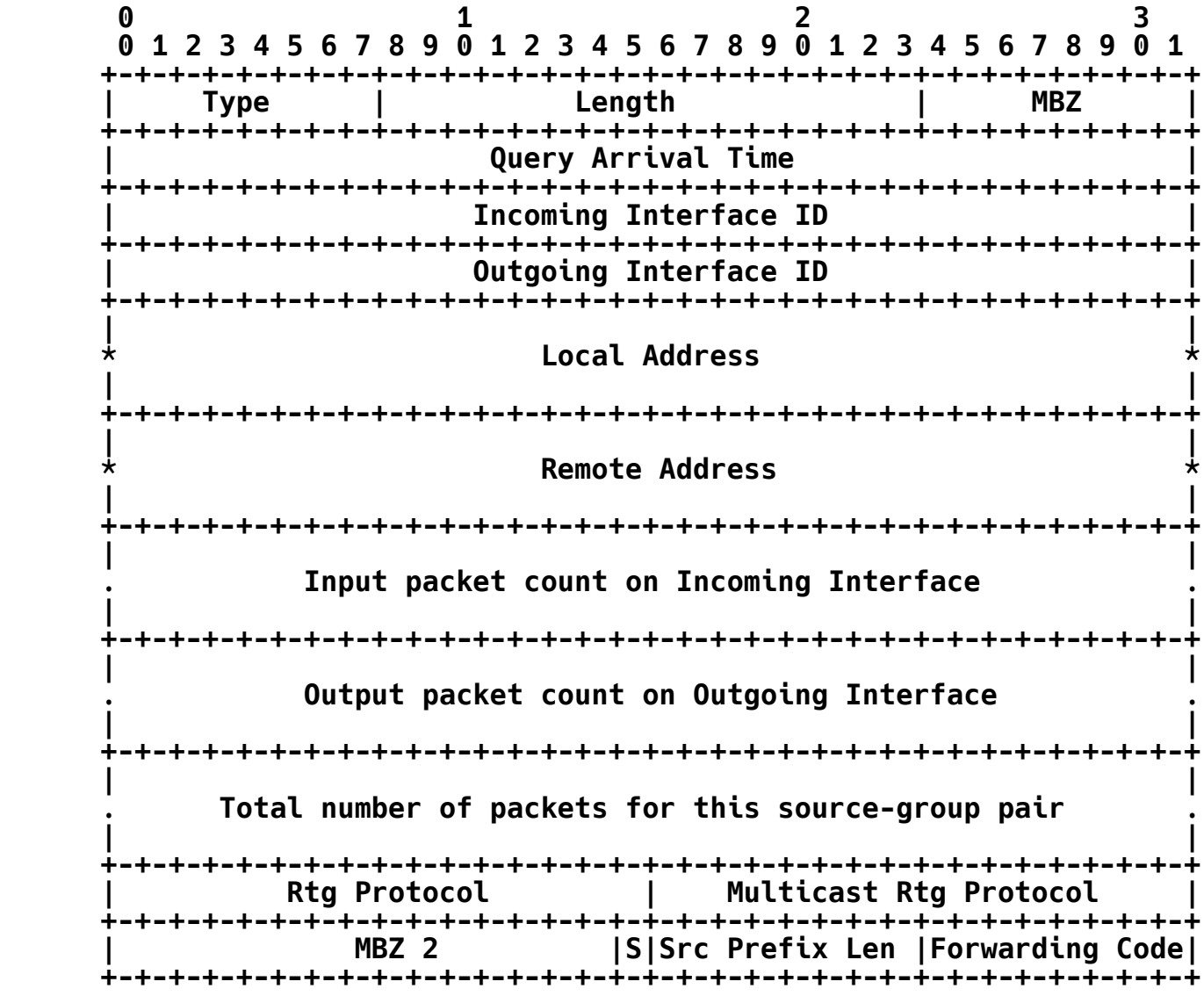
Src Mask: 7 bits
This field contains the number of 1's in the netmask the router has for the source (i.e., a value of 24 means the netmask is 0xffffff00). If the router is forwarding solely on group state, this field is set to 127 (0x7f).

Forwarding Code: 8 bits
This field contains a forwarding information/error code. Values with the high-order bit set (0x80-0xff) are intended for use with conditions that are transitory or automatically recovered. Other Forwarding Code values indicate a need to fix a problem in the Query or a need to redirect the Query. Sections 4.1 and 4.2 explain how and when the Forwarding Code is filled. Defined values are as follows:

Value	Name	Description
0x00	NO_ERROR	No error.
0x01	WRONG_IF	Mtrace2 Request arrived on an interface for which this router does not perform forwarding for the specified group to the source or RP.
0x02	PRUNE_SENT	This router has sent a prune upstream that applies to the source and group in the Mtrace2 Request.
0x03	PRUNE_RCVD	This router has stopped forwarding for this source and group in response to a Request from the downstream router.
0x04	SCOPED	The group is subject to administrative scoping at this router.
0x05	NO_ROUTE	This router has no route for the source or group and no way to determine a potential route.
0x06	WRONG_LAST_HOP	This router is not the proper LHR.
0x07	NOT_FORWARDING	This router is not forwarding this source and group out the Outgoing Interface for an unspecified reason.
0x08	REACHED_RP	Reached the Rendezvous Point.
0x09	RPF_IF	Mtrace2 Request arrived on the expected RPF interface for this source and group.
0x0A	NO_MULTICAST	Mtrace2 Request arrived on an interface that is not enabled for multicast.
0x0B	INFO_HIDDEN	One or more hops have been hidden from this trace.
0x0C	REACHED_GW	Mtrace2 Request arrived on a gateway (e.g., a NAT or firewall) that hides the information between this router and the Mtrace2 client.
0x0D	UNKNOWN_QUERY	A non-transitive Extended Query Type was received by a router that does not support the type.
0x80	FATAL_ERROR	A fatal error is one where the router may know the upstream router but cannot forward the message to it.
0x81	NO_SPACE	There was not enough room to insert another Standard Response Block in the packet.
0x83	ADMIN_PROHIB	Mtrace2 is administratively prohibited.

3.2.5. IPv6 Mtrace2 Standard Response Block

This section describes the message format of an IPv6 Mtrace2 Standard Response Block. The Type field is also 0x04.



MBZ: 8 bits
This field MUST be zeroed on transmission and ignored on reception.

Query Arrival Time: 32 bits
Same definition as in IPv4.

Incoming Interface ID: 32 bits
This field specifies the interface ID on which packets from the source or RP are expected to arrive, or 0 if unknown. This ID should be the value taken from InterfaceIndex of the IF-MIB [9] for this interface.

Outgoing Interface ID: 32 bits
This field specifies the interface ID to which packets from the source or RP are expected to transmit, or 0 if unknown. This ID should be the value taken from InterfaceIndex of the IF-MIB [9] for this interface.

Local Address: 128 bits
This field specifies a global IPv6 address that uniquely identifies the router. A unique local unicast address [12] SHOULD NOT be used unless the router is only assigned link-local and unique local addresses. If the router is only assigned link-local addresses, its link-local address can be specified in this field.

Remote Address: 128 bits
This field specifies the address of the upstream router, which, in most cases, is a link-local unicast address for the upstream router.

Although a link-local address does not have enough information to identify a node, it is possible to detect the upstream router with the assistance of the Incoming Interface ID and the current router address (i.e., Local Address).

Note that this may be a multicast group (e.g., ALL-[protocol]-ROUTERS group) if the upstream router is not known because of the workings of a multicast routing protocol. However, it should be the unspecified address (::) if the Incoming Interface address is unknown.

Input packet count on Incoming Interface: 64 bits
Same definition as in IPv4.

Output packet count on Outgoing Interface: 64 bits
Same definition as in IPv4.

Total number of packets for this source-group pair: 64 bits
Same definition as in IPv4, except if the S bit is set (see below), the count is for the source network, as specified by the Src Prefix Len field. If the S bit is set and the Src Prefix Len field is 255, indicating no source-specific state, the count is

for all sources sending to this group. This counter should have the same value as ipMcastRoutePkts from the IP Multicast MIB [14] for this forwarding entry.

Rtg Protocol: 16 bits
Same definition as in IPv4.

Multicast Rtg Protocol: 16 bits

Same definition as in IPv4.

MBZ 2: 15 bits
This field MUST be zeroed on transmission and ignored on reception.

S: 1 bit
Same definition as in IPv4, except the Src Prefix Len field is used to mask the source address.

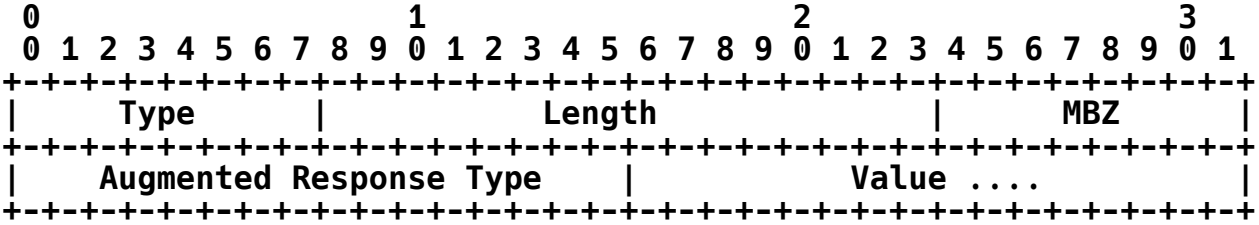
Src Prefix Len: 8 bits
This field contains the prefix length this router has for the source. If the router is forwarding solely on group state, this field is set to 255 (0xff).

Forwarding Code: 8 bits
Same definition as in IPv4.

3.2.6. Mtrace2 Augmented Response Block

In addition to the Standard Response Block, a multicast router on the traced path can optionally add one or multiple Augmented Response Blocks before sending the Request to its upstream router.

The Augmented Response Block is flexible for various purposes such as providing diagnosis information (see Section 7) and protocol verification. Its Type field is 0x05, and its format is as follows:



MBZ: 8 bits
This field MUST be zeroed on transmission and ignored on reception.

Augmented Response Type: 16 bits
This field specifies the type of various responses from a multicast router that might need to communicate back to the Mtrace2 client as well as the multicast routers on the traced path.

The Augmented Response Type is defined as follows:

Code	Type
0x0001	# of the returned Standard Response Blocks

When the NO_SPACE error occurs on a router, the router should send the original Mtrace2 Request received from the downstream router as a Reply back to the Mtrace2 client and continue with a new Mtrace2 Request. In the new Request, the router adds a Standard Response Block followed by an Augmented Response Block with 0x01 as the Augmented Response Type, and the number of the returned Mtrace2 Standard Response Blocks as the Value.

Each upstream router recognizes the total number of hops the Request has traced so far by adding this number and the number of the Standard Response Block in the current Request message.

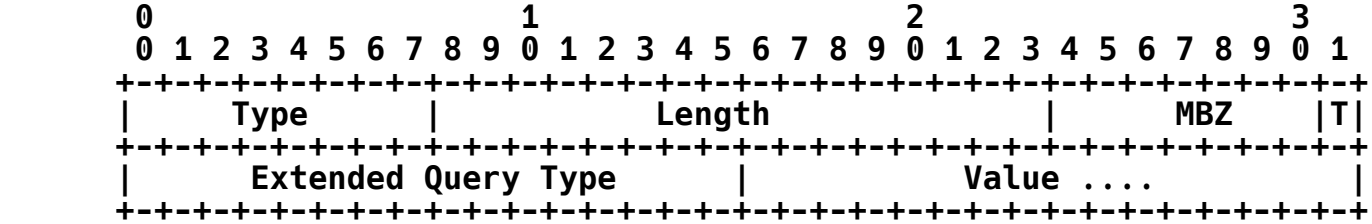
This document only defines one Augmented Response Type in the Augmented Response Block. The description on how to provide diagnosis information using the Augmented Response Block is out of the scope of this document and will be addressed in separate documents.

Value: variable length
The format is based on the Augmented Response Type value. The length of the Value field is Length field minus 6.

3.2.7. Mtrace2 Extended Query Block

There may be a sequence of optional Extended Query Blocks that follow an Mtrace2 Query to further specify any information needed for the Query. For example, an Mtrace2 client might be interested in tracing the path the specified source and group would take based on a certain topology. In this case, the client can pass in the multi-topology ID as the value for an Extended Query Type (see below). The Extended Query Type is extensible, and the behavior of the new types will be addressed by separate documents.

The Mtrace2 Extended Query Block's Type field is 0x06 and is formatted as follows:



MBZ: 7 bits
This field MUST be zeroed on transmission and ignored on reception.

T-bit (Transitive Attribute): 1 bit
If the TLV Type is unrecognized by the receiving router, then this TLV is either discarded or forwarded along with the Query, depending on the value of this bit. If this bit is set, then the router MUST forward this TLV. If this bit is clear, the router MUST send an Mtrace2 Reply with an UNKNOWN_QUERY error.

Extended Query Type: 16 bits
This field specifies the type of the Extended Query Block.

Value: 16 bits
This field specifies the value of this Extended Query.

4. Router Behavior

This section describes the router behavior in the context of Mtrace2 in detail.

4.1. Receiving an Mtrace2 Query

An Mtrace2 Query message is an Mtrace2 message with no response blocks filled in and uses a TLV Type of 0x01.

4.1.1. Query Packet Verification

Upon receiving an Mtrace2 Query message, a router MUST examine whether the Multicast Address and the Source Address are a valid combination as specified in Section 3.2.1, and whether the Mtrace2 Client Address is a valid IP unicast address. If either one is invalid, the Query MUST be silently ignored.

Mtrace2 supports a non-local client to the LHR/RP. A router MUST, however, support a mechanism to drop Queries from clients beyond a specified administrative boundary. The potential approaches are described in Section 9.2.

In the case where a local LHR client is required, the router must then examine the Query to see if it is the proper LHR/RP for the destination address in the packet. It is the proper local LHR if it has a multicast-capable interface on the same subnet as the Mtrace2 Client Address and is the router that would forward traffic from the given (S,G) or (*,G) onto that subnet. It is the proper RP if the multicast group address specified in the Query is 0 and if the IP header destination address is a valid RP address on this router.

If the router determines that it is not the proper LHR/RP, or it cannot make that determination, it does one of two things depending on whether the Query was received via multicast or unicast. If the Query was received via multicast, then it MUST be silently discarded. If it was received via unicast, the router turns the Query into a Reply message by changing the TLV Type to 0x03 and appending a Standard Response Block with a Forwarding Code of WRONG_LAST_HOP. The rest of the fields in the Standard Response Block MUST be zeroed. The router then sends the Reply message to the Mtrace2 Client Address on the Client Port # as specified in the Mtrace2 Query.

Duplicate Query messages as identified by the tuple (Mtrace2 Client Address, Query ID) SHOULD be ignored. This MAY be implemented using a cache of previously processed Queries keyed by the Mtrace2 Client Address and Query ID pair. The duration of the cached entries is implementation specific. Duplicate Request messages MUST NOT be ignored in this manner.

4.1.2. Query Normal Processing

When a router receives an Mtrace2 Query and it determines that it is the proper LHR/RP, it turns the Query to a Request by changing the TLV Type from 0x01 to 0x02, and it performs the steps listed in Section 4.2.

4.2. Receiving an Mtrace2 Request

An Mtrace2 Request is an Mtrace2 message that uses the TLV Type of 0x02. With the exception of the LHR, whose Request was just converted from a Query, each Request received by a router should have at least one Standard Response Block filled in.

4.2.1. Request Packet Verification

If the Mtrace2 Request does not come from an adjacent router, or if the Request is not addressed to this router, or if the Request is addressed to a multicast group that is not a link-scoped group (i.e., 224.0.0.0/24 for IPv4 and FFx2::/16 for IPv6 [2]), it MUST be silently ignored. The Generalized TTL Security Mechanism (GTSM) [13] SHOULD be used by the router to determine whether the router is adjacent or not. Source verification specified in Section 9.2 is also considered.

If the sum of the number of the Standard Response Blocks in the received Mtrace2 Request and the value of the Augmented Response Type of 0x01, if any, is equal or more than the # Hops in the Mtrace2 Request, it MUST be silently ignored.

4.2.2. Request Normal Processing

When a router receives an Mtrace2 Request message, it performs the following steps. Note that it is possible to have multiple situations covered by the Forwarding Codes. The first one encountered is the one that is reported, i.e., all "note Forwarding Code N" should be interpreted as "if Forwarding Code is not already set, set Forwarding Code to N". Note that in the steps described below, the "Outgoing Interface" is the one on which the Mtrace2 Request message arrives.

1. Prepare a Standard Response Block to be appended to the packet, setting all fields to an initial default value of zero.

2. If Mtrace2 is administratively prohibited, note the Forwarding Code of ADMIN_PROHIB and skip to step 4.

3. In the Standard Response Block, fill in the Query Arrival Time, Outgoing Interface Address (for IPv4) or Outgoing Interface ID (for IPv6), Output Packet Count, and Fwd TTL (for IPv4).

4. Attempt to determine the forwarding information for the specified source and group, using the same mechanisms as would be used when a packet is received from the source destined for the group. A state need not be instantiated, it can be a "phantom" state created only for the purpose of the trace, such as "dry-run".

   If using a shared-tree protocol and there is no source-specific state, or if no source-specific information is desired (i.e., all ones for IPv4 or an unspecified address (::) for IPv6), group state should be used. If there is no group state or no

group-specific information is desired, potential source state (i.e., the path that would be followed for a source-specific "join") should be used.

5. If no forwarding information can be determined, the router notes a Forwarding Code of NO_ROUTE, sets the remaining fields that have not yet been filled in to zero, and then sends an Mtrace2 Reply back to the Mtrace2 client.

6. If a Forwarding Code of ADMIN_PROHIB has been set, skip to step 7. Otherwise, fill in the Incoming Interface Address (or Incoming Interface ID and Local Address for IPv6), Upstream Router Address (or Remote Address for IPv6), Input Packet Count, Total Number of Packets, Routing Protocol, S, and Src Mask (or Src Prefix Len for IPv6) using the forwarding information determined in step 4.

7. If the Outgoing Interface is not enabled for multicast, note Forwarding Code of NO_MULTICAST. If the Outgoing Interface is the interface from which the router would expect data to arrive from the source, note Forwarding Code RPF_IF. If the Outgoing Interface is not one to which the router would forward data from the source or RP to the group, a Forwarding Code of WRONG_IF is noted. In the above three cases, the router will return an Mtrace2 Reply and terminate the trace.

8. If the group is subject to administrative scoping on either the Outgoing or Incoming Interfaces, a Forwarding Code of SCOPED is noted.

9. If this router is the RP for the group for a non-source-specific Query, note a Forwarding Code of REACHED_RP. The router will send an Mtrace2 Reply and terminate the trace.

10. If this router is directly connected to the specified source or source network on the Incoming Interface, it sets the Upstream Router Address (for IPv4) or the Remote Address (for IPv6) of the response block to zero. The router will send an Mtrace2 Reply and terminate the trace.

11. If this router has sent a prune upstream that applies to the source and group in the Mtrace2 Request, it notes a Forwarding Code of PRUNE_SENT. If the router has stopped forwarding downstream in response to a prune sent by the downstream router, it notes a Forwarding Code of PRUNE_RCVD. If the router should normally forward traffic downstream for this source and group but is not, it notes a Forwarding Code of NOT_FORWARDING.

12. If this router is a gateway (e.g., a NAT or firewall) that hides the information between this router and the Mtrace2 client, it notes a Forwarding Code of REACHED_GW. The router continues the processing as described in Section 4.5.

13. If the total number of the Standard Response Blocks, including the newly prepared one, and the value of the Augmented Response Type of 0x01, if any, is less than the # Hops in the Request, the packet is then forwarded to the upstream router as described in Section 4.3; otherwise, the packet is sent as an Mtrace2 Reply to the Mtrace2 client as described in Section 4.4.

4.3. Forwarding Mtrace2 Request

This section describes how an Mtrace2 Request should be forwarded.

4.3.1. Destination Address

If the upstream router for the Mtrace2 Request is known for this Request, the Mtrace2 Request is sent to that router. If the Incoming Interface is known but the upstream router is not, the Mtrace2 Request is sent to an appropriate multicast address on the Incoming Interface. The multicast address SHOULD depend on the multicast routing protocol in use, such as ALL-[protocol]-ROUTERS group. It MUST be a link-scoped group (i.e., 224.0.0.0/24 for IPv4 and FF02::/16 for IPv6) and MUST NOT be the all-systems multicast group (224.0.0.1) for IPv4 and All Nodes Address (FF02::1) for IPv6. It MAY also be the all-routers multicast group (224.0.0.2) for IPv4 or All Routers Address (FF02::2) for IPv6 if the routing protocol in use does not define a more appropriate multicast address.

4.3.2. Source Address

An Mtrace2 Request should be sent with the address of the Incoming Interface. However, if the Incoming Interface is unnumbered, the router can use one of its numbered interface addresses as the source address.

4.3.3. Appending Standard Response Block

An Mtrace2 Request MUST be sent upstream towards the source or the RP after appending a Standard Response Block to the end of the received Mtrace2 Request. The Standard Response Block includes the multicast states and statistics information of the router described in Section 3.2.4.

If appending the Standard Response Block would make the Mtrace2 Request packet longer than the MTU of the Incoming Interface, or, in the case of IPv6, longer than 1280 bytes, the router MUST change the Forwarding Code in the last Standard Response Block of the received Mtrace2 Request into NO_SPACE. The router then turns the Request into a Reply and sends the Reply as described in Section 4.4.

The router will continue with a new Request by copying the old Request, excluding all the response blocks, followed by the previously prepared Standard Response Block and an Augmented Response Block with 0x01 as the Augmented Response Type, and the number of the returned Standard Response Blocks as the Value.

4.4. Sending Mtrace2 Reply

An Mtrace2 Reply MUST be returned to the client by a router if any of the following conditions occur:

1. The total number of the traced routers are equal to the # Hops in the Request (including the one just added) plus the number of the returned blocks, if any.

2. Appending the Standard Response Block would make the Mtrace2 Request packet longer than the MTU of the Incoming Interface. (In case of IPv6, not more than 1280 bytes; see Section 4.3.3 for additional details on the handling of this case.)

3. The Request has reached the RP for a non-source-specific Query or has reached the first-hop router for a source-specific Query (see Section 4.2.2, items 9 and 10, for additional details).

4.4.1. Destination Address

An Mtrace2 Reply MUST be sent to the address specified in the Mtrace2 Client Address field in the Mtrace2 Request.

4.4.2. Source Address

An Mtrace2 Reply SHOULD be sent with the address of the router's Outgoing Interface. However, if the Outgoing Interface address is unnumbered, the router can use one of its numbered interface addresses as the source address.

4.4.3. Appending Standard Response Block

An Mtrace2 Reply MUST be sent with the prepared Standard Response Block appended at the end of the received Mtrace2 Request except in the case of NO_SPACE Forwarding Code.

4.5. Proxying Mtrace2 Query

When a gateway (e.g., a NAT or firewall), which needs to block unicast packets to the Mtrace2 client, or hide information between the gateway and the Mtrace2 client, receives an Mtrace2 Query from an adjacent host or Mtrace2 Request from an adjacent router, it appends a Standard Response Block with REACHED_GW as the Forwarding Code. It turns the Query or Request into a Reply and sends the Reply back to the client.

At the same time, the gateway originates a new Mtrace2 Query message by copying the original Mtrace2 header (the Query or Request without any of the response blocks) and making the following changes:

- setting the RPF interface's address as the Mtrace2 Client Address;
- using its own port number as the Client Port #; and,
- decreasing # Hops by ((number of the Standard Response Blocks that were just returned in a Reply) - 1). The "- 1" in this expression accounts for the additional Standard Response Block appended by the gateway router.

The new Mtrace2 Query message is then sent to the upstream router or to an appropriate multicast address on the RPF interface.

When the gateway receives an Mtrace2 Reply whose Query ID matches the one in the original Mtrace2 header, it MUST relay the Mtrace2 Reply back to the Mtrace2 client by replacing the Reply's header with the original Mtrace2 header. If the gateway does not receive the corresponding Mtrace2 Reply within the [Mtrace Reply Timeout] period (see Section 5.8.4), then it silently discards the original Mtrace2 Query or Request message and terminates the trace.

4.6. Hiding Information

Information about a domain's topology and connectivity may be hidden from Mtrace2 Requests. The Forwarding Code of INFO_HIDDEN may be used to note that. For example, the Incoming Interface address and packet count on the ingress router of a domain, and the Outgoing Interface address and packet count on the egress router of the domain, can be specified as all ones. Additionally, the source-group packet count (see Sections 3.2.4 and 3.2.5) within the domain may be all ones if it is hidden.

5. Client Behavior

This section describes the behavior of an Mtrace2 client in detail.

5.1. Sending Mtrace2 Query

An Mtrace2 client initiates an Mtrace2 Query by sending the Query to the LHR of interest.

5.1.1. Destination Address

If an Mtrace2 client knows the proper LHR, it unicasts an Mtrace2 Query packet to that router; otherwise, it MAY send the Mtrace2 Query packet to the all-routers multicast group (224.0.0.2) for IPv4 or All Routers Address (FF02::2) for IPv6. This will ensure that the packet is received by the LHR on the subnet.

See also Section 5.4 on determining the LHR.

5.1.2. Source Address

An Mtrace2 Query MUST be sent with the client's interface address, which is the Mtrace2 Client Address.

5.2. Determining the Path

An Mtrace2 client could send an initial Query message with a large # Hops, in order to try to trace the full path. If this attempt fails, one strategy is to perform a linear search (as the traditional unicast traceroute program does); set the # Hops field to 1 and try to get a Reply, then 2, and so on. If no Reply is received at a certain hop, this hop is identified as the probable cause of forwarding failures on the path. Nevertheless, the sender may attempt to continue tracing past the non-responding hop by further increasing the hop count in the hope that further hops may respond. Each of these attempts MUST NOT be initiated before the previous attempt has terminated either because of successful reception of a Reply or because the [Mtrace Reply Timeout] timeout has occurred.

See also Section 5.6 on receiving the results of a trace.

5.3. Collecting Statistics

After a client has determined that it has traced the whole path or as much as it can expect to (see Section 5.8), it might collect statistics by waiting a short time and performing a second trace. If the path is the same in the two traces, statistics can be displayed as described in Sections 7.3 and 7.4.

5.4. Last-Hop Router (LHR)

The Mtrace2 client may not know which is the last-hop router, or that router may be behind a firewall that blocks unicast packets but passes multicast packets. In these cases, the Mtrace2 Request should be multicasted to the all-routers multicast group (224.0.0.2) for IPv4 or All Routers Address (FF02::2) for IPv6. All routers except the correct last-hop router SHOULD ignore any Mtrace2 Request received via multicast.

5.5. First-Hop Router (FHR)

The IANA assigned 224.0.1.32 as the default multicast group for old IPv4 mtrace (v1) responses, in order to support mtrace clients that are not unicast reachable from the first-hop router. Mtrace2, however, does not require any IPv4/IPv6 multicast addresses for the Mtrace2 Replies. Every Mtrace2 Reply is sent to the unicast address specified in the Mtrace2 Client Address field of the Mtrace2 Reply.

5.6. Broken Intermediate Router

A broken intermediate router might simply not understand Mtrace2 packets and drop them. The Mtrace2 client will get no Reply at all as a result. It should then perform a hop-by-hop search by setting the # Hops field until it gets an Mtrace2 Reply. The client may use linear or binary search; however, the latter is likely to be slower because a failure requires waiting for the [Mtrace Reply Timeout] period.

5.7. Non-supported Router

When a non-supported router receives an Mtrace2 Query or Request message whose destination address is a multicast address, the router will silently discard the message.

When the router receives an Mtrace2 Query that is destined to itself, the router returns an Internet Control Message Protocol (ICMP) port unreachable to the Mtrace2 client. On the other hand, when the router receives an Mtrace2 Request that is destined to itself, the router returns an ICMP port unreachable to its adjacent router from which the Request receives. Therefore, the Mtrace2 client needs to terminate the trace when the [Mtrace Reply Timeout] timeout has occurred, and it may then issue another Query with a lower number of # Hops.

5.8. Mtrace2 Termination

When performing an expanding hop-by-hop trace, it is necessary to determine when to stop expanding.

5.8.1. Arriving at Source

A trace can be determined to have arrived at the source if the Incoming Interface of the last router in the trace is non-zero, but the upstream router is zero.

5.8.2. Fatal Error

A trace has encountered a fatal error if the last Forwarding Error in the trace has the 0x80 bit set.

5.8.3. No Upstream Router

A trace cannot continue if the last upstream router in the trace is set to 0.

5.8.4. Reply Timeout

This document defines the [Mtrace Reply Timeout] value, which is used to time out an Mtrace2 Reply as seen in Sections 4.5, 5.2, and 5.7. The default [Mtrace Reply Timeout] value is 10 (seconds) and can be manually changed on the Mtrace2 client and routers.

5.9. Continuing after an Error

When the NO_SPACE error occurs, as described in Section 4.2, a router will send back an Mtrace2 Reply to the Mtrace2 client and continue with a new Request (see Section 4.3.3). In this case, the Mtrace2 client may receive multiple Mtrace2 Replies from different routers along the path. When this happens, the client MUST treat them as a single Mtrace2 Reply message by collating the Augmented Response Blocks of subsequent Replies sharing the same Query ID, sequencing each cluster of Augmented Response Blocks based on the order in which they are received.

If a trace times out, it is very likely that a router in the middle of the path does not support Mtrace2. That router's address will be in the Upstream Router field of the last Standard Response Block in the last received Reply. A client may be able to determine a list of neighbors of the non-responding router (e.g., by using the Simple Network Management Protocol (SNMP) [12] [14]). The neighbors obtained in this way could then be probed (via the multicast MIB [14]) to determine which one is the upstream neighbor (i.e., an RPF

neighbor) of the non-responding router. This algorithm can identify the upstream neighbor because, even though there may be multiple neighbors, the non-responding router should only have sent a "join" to the one neighbor corresponding to its selected RPF path. Because of this, only the RPF neighbor should contain the non-responding router as a multicast next hop in its MIB output list for the affected multicast route.

6. Protocol-Specific Considerations

This section describes the Mtrace2 behavior with the presence of different multicast protocols.

6.1. PIM-SM

When an Mtrace2 reaches a PIM-SM RP, and the RP does not forward the trace on, it means that the RP has not performed a source-specific join, so there is no more state to trace. However, the path that traffic would use if the RP did perform a source-specific join can be traced by setting the trace destination to the RP, the trace source to the traffic source, and the trace group to 0. This Mtrace2 Query may be unicasted to the RP, and the RP takes the same actions as an LHR.

6.2. Bidirectional PIM

Bidirectional PIM [4] is a variant of PIM-SM that builds bidirectional shared trees that connect multicast sources and receivers. Along the bidirectional shared trees, multicast data is natively forwarded from the sources to the Rendezvous Point Link (RPL), and from which, to receivers without requiring source-specific state. In contrast to PIM-SM, Bidirectional PIM always has the state to trace.

A Designated Forwarder (DF) for a given Rendezvous Point Address (RPA) is in charge of forwarding downstream traffic onto its link and forwarding upstream traffic from its link towards the RPL that the RPA belongs to. Hence, Mtrace2 Reply reports DF addresses or RPA along the path.

6.3. PIM-DM

Routers running PIM - Dense Mode (PIM-DM) [11] do not know the path packets would take unless traffic is flowing. Without some extra protocol mechanism, this means that in an environment with multiple possible paths with branch points on shared media, Mtrace2 can only trace existing paths, not potential paths. When there are multiple

possible paths but the branch points are not on shared media, the upstream router is known, but the LHR may not know that it is the appropriate last hop.

When traffic is flowing, PIM-DM routers know whether or not they are the LHR for the link (because they won or lost an Assert battle) and know who the upstream router is (because it won an Assert battle). Therefore, Mtrace2 is always able to follow the proper path when traffic is flowing.

6.4. IGMP/MLD Proxy

When an IGMP or Multicast Listener Discovery (MLD) Proxy [3] receives an Mtrace2 Query packet on an Incoming Interface, it notes a WRONG_IF in the Forwarding Code of the last Standard Response Block (see Section 3.2.4) and sends the Mtrace2 Reply back to the Mtrace2 client. On the other hand, when an Mtrace2 Query packet reaches an Outgoing Interface of the IGMP/MLD proxy, it is forwarded onto its Incoming Interface towards the upstream router.

7. Problem Diagnosis

This section describes different scenarios in which Mtrace2 can be used to diagnose the multicast problems.

7.1. Forwarding Inconsistencies

The Forwarding Error code can tell if a group is unexpectedly pruned or administratively scoped.

7.2. TTL or Hop-Limit Problems

By taking the maximum of hops from the source and forwarding the TTL threshold over all hops, it is possible to discover the TTL or hop limit required for the source to reach the destination.

7.3. Packet Loss

By taking multiple traces, it is possible to find packet-loss information by tracking the difference between the output packet count for the specified source-group address pair at a given upstream router and the input packet count on the next-hop downstream router. On a point-to-point link, any steadily increasing difference in these counts implies packet loss. Although the packet counts will differ due to Mtrace2 Request propagation delay, the difference should remain essentially constant (except for jitter caused by differences in propagation time among the trace iterations). However, this difference will display a steady increase if packet loss is

occurring. On a shared link, the count of input packets can be larger than the number of output packets at the previous hop, due to other routers or hosts on the link injecting packets. This appears as "negative loss", which may mask real packet loss.

In addition to the counts of input and output packets for all multicast traffic on the interfaces, the Standard Response Block includes a count of the packets forwarded by a node for the specified source-group pair. Taking the difference in this count between two traces and then comparing those differences between two hops gives a measure of packet loss just for traffic from the specified source to the specified receiver via the specified group. This measure is not affected by shared links.

On a point-to-point link that is a multicast tunnel, packet loss is usually due to congestion in unicast routers along the path of that tunnel. On native multicast links, loss is more likely in the output queue of one hop, perhaps due to priority dropping, or in the input queue at the next hop. The counters in the Standard Response Block do not allow these cases to be distinguished. Differences in packet counts between the Incoming and Outgoing Interfaces on one node cannot generally be used to measure queue overflow in the node.

7.4. Link Utilization

Again, with two traces, you can divide the difference in the input or output packet counts at some hop by the difference in timestamps from the same hop to obtain the packet rate over the link. If the average packet size is known, then the link utilization can also be estimated to see whether packet loss may be due to the rate limit or the physical capacity on a particular link being exceeded.

7.5. Time Delay

If the routers have synchronized clocks, it is possible to estimate propagation and queuing delay from the differences between the timestamps at successive hops. However, this delay includes control processing overhead, so is not necessarily indicative of the delay that data traffic would experience.

8. IANA Considerations

The following registries have been created and are maintained under the "Specification Required" registry policy as specified in [6].

8.1. "Mtrace2 Forwarding Codes" Registry

This registry holds integers in the range 0-255. Assignment of a Forwarding Code requires specification of a value and a name for the Forwarding Code. Initial values for the Forwarding Codes are given in the table at the end of Section 3.2.4. Additional values (specific to IPv6) may also be specified at the end of Section 3.2.5. Any additions to this registry are required to fully describe the conditions under which the new Forwarding Code is used.

8.2. "Mtrace2 TLV Types" Registry

Assignment of a TLV Type requires specification of an integer value "Code" in the range 0-255 and a name ("Type"). Initial values for the TLV Types are given in the table at the beginning of Section 3.2.

8.3. UDP Destination Port

IANA has assigned UDP user port 33435 (mtrace) for use by this protocol as the Mtrace2 UDP destination port.

9. Security Considerations

This section addresses some of the security considerations related to Mtrace2.

9.1. Addresses in Mtrace2 Header

An Mtrace2 header includes three addresses: a source address, a multicast address, and an Mtrace2 Client Address. These addresses MUST be congruent with the definition defined in Section 3.2.1, and forwarding Mtrace2 messages that have invalid addresses MUST be prohibited. For instance, if the Mtrace2 Client Address specified in an Mtrace2 header is a multicast address, then a router that receives the Mtrace2 message MUST silently discard it.

9.2. Verification of Clients and Peers

A router providing Mtrace2 functionality MUST support a source-verification mechanism to drop Queries from clients and Requests from peer router or client addresses that are unauthorized or that are beyond a specified administrative boundary. This verification could, for example, be specified via a list of allowed/disallowed clients and peer addresses or subnets for a given Mtrace2 message type sent to the Mtrace2 protocol port. If a Query or Request is received from an unauthorized address or one beyond the specified administrative boundary, the Query/Request MUST NOT be processed. The router MAY, however, perform rate-limited logging of such events.

The required use of source verification on the participating routers minimizes the possible methods for introduction of spoofed Query/Request packets that would otherwise enable DoS amplification attacks targeting an authorized "query" host. The source verification mechanisms provide this protection by allowing Query messages from an authorized host address to be received only by the router(s) connected to that host and only on the interface to which that host is attached. For protection against spoofed Request messages, the source-verification mechanisms allow Request messages only from a directly connected routing peer and allow these messages to be received only on the interface to which that peer is attached.

Note that the following vulnerabilities cannot be covered by the source verification methods described here. These methods can, nevertheless, prevent attacks launched from outside the boundaries of a given network as well as from any hosts within the network that are not on the same LAN as an intended authorized query client.

- A server/router "B" other than the server/router "A" that actually "owns" a given IP address could, if it is connected to the same LAN, send an Mtrace2 Query or Request with the source address set to the address for server/router "A". This is not a significant threat, however, if only trusted servers and routers are connected to that LAN.

- A malicious application running on a trusted server or router could send packets that might cause an amplification problem. It is beyond the scope of this document to protect against a DoS attack launched from the same host that is the target of the attack or from another "on path" host, but this is not a likely threat scenario. In addition, routers on the path MAY rate-limit the packets as specified in Sections 9.5 and 9.6.

9.3. Topology Discovery

Mtrace2 can be used to discover any actively used topology. If your network topology is a secret, Mtrace2 may be restricted at the border of your domain, using the ADMIN_PROHIB Forwarding Code.

9.4. Characteristics of Multicast Channel

Mtrace2 can be used to discover what sources are sending to what groups and at what rates. If this information is a secret, Mtrace2 may be restricted at the border of your domain, using the ADMIN_PROHIB Forwarding Code.

9.5. Limiting Query/Request Rates

A router may limit Mtrace2 Queries and Requests by ignoring some of the consecutive messages. The router MAY randomly ignore the received messages to minimize the processing overhead, i.e., to keep fairness in processing Queries or prevent traffic amplification. The rate limit is left to the router's implementation.

9.6. Limiting Reply Rates

The proxying and NO_SPACE behaviors may result in one Query returning multiple Reply messages. In order to prevent abuse, the routers in the traced path MAY need to rate-limit the Replies. The rate-limit function is left to the router's implementation.

9.7. Specific Security Concerns

9.7.1. Request and Response Bombardment

A malicious sender could generate invalid and undesirable Mtrace2 traffic to hosts and/or routers on a network by eliciting responses to spoofed or multicast client addresses. This could be done via forged or multicast client/source addresses in Mtrace2 Query or Request messages. The recommended protections against this type of attack are described in Sections 9.1, 9.2, 9.5, and 9.6.

9.7.2. Amplification Attack

Because an Mtrace2 Query results in Mtrace2 Request and Mtrace2 Reply messages that are larger than the original message, the potential exists for an amplification attack from a malicious sender. This threat is minimized by restricting the set of addresses from which Mtrace2 messages can be received on a given router as specified in Section 9.2.

In addition, for a router running a PIM protocol (PIM-SM, PIM-DM, PIM - Source-Specific Multicast (PIM-SSM), or Bidirectional PIM), the router SHOULD drop any Mtrace2 Request or Reply message that is received from an IP address that does not correspond to an authenticated PIM neighbor on the interface from which the packet is received. The intent of this text is to prevent non-router endpoints from injecting Request messages. Implementations of non-PIM protocols SHOULD employ some other mechanism to prevent this attack.

9.7.3. Leaking of Confidential Topology Details

Mtrace2 Queries are a potential mechanism for obtaining confidential topology information for a targeted network. Sections 9.2 and 9.4 describe required and optional methods for ensuring that information delivered with Mtrace2 messages is not disseminated to unauthorized hosts.

9.7.4. Delivery of False Information (Forged Reply Messages)

Forged Reply messages could potentially provide a host with invalid or incorrect topology information. They could also provide invalid or incorrect information regarding multicast traffic statistics, multicast stream propagation delay between hops, multicast and unicast protocols in use between hops and other information used for analyzing multicast traffic patterns, and troubleshooting multicast traffic problems. This threat is mitigated by the following factors:

- The required source verification of permissible source addresses specified in Section 9.2 eliminates the origination of forged Replies from addresses that have not been authorized to send Mtrace2 messages to routers on a given network. This mechanism can block forged Reply messages sent from any "off path" source.

- To forge a Reply, the sender would need to somehow know (or guess) the associated 2-byte Query ID for an extant Query and the dynamically allocated source port number. Because "off path" sources can be blocked by a source verification mechanism, the scope of this threat is limited to "on path" attackers.

- The required use of source verification (Section 9.2) and recommended use of PIM neighbor authentication (Section 9.7.2) for messages that are only valid when sent by a multicast routing peer (Request and Reply messages) eliminate the possibility of reception of a forged Reply from an authorized host address that does not belong to a multicast peer router.

- The use of encryption between the source of a Query and the endpoint of the trace would provide a method to protect the values of the Query ID and the dynamically allocated client (source) port (see Section 3.2.1). These are the values needed to create a forged Reply message that would pass validity checks at the querying client. This type of cryptographic protection is not practical, however, because the primary reason for executing an Mtrace2 is that the destination endpoint (and path to that endpoint) are not known by the querying client. While it is not practical to provide cryptographic protection between a client and the Mtrace2 endpoints (destinations), it may be possible to

prevent forged responses from "off path" nodes attached to any Mtrace2 transit LAN by devising a scheme to encrypt the critical portions of an Mtrace2 message between each valid sender/receiver pair at each hop to be used for multicast/Mtrace2 transit. The use of encryption protection between nodes is, however, out of the scope of this document.

10. References

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Acknowledgements

This specification started largely as a transcription of Van Jacobson's slides from the 30th IETF meeting and the implementation in mrouted 3.3 by Ajit Thyagarajan. Van's original slides credit Steve Casner, Steve Deering, Dino Farinacci, and Deb Agrawal. The original multicast traceroute client, mtrace (version 1), has been implemented by Ajit Thyagarajan, Steve Casner, and Bill Fenner. The idea of the S bit to allow statistics for a source subnet is due to Tom Pusateri.

For the Mtrace version 2 specification, the authors would like to give special thanks to Tatsuya Jinmei, Bill Fenner, and Steve Casner. Also, extensive comments were received from David L. Black, Ronald Bonica, Yiqun Cai, Liu Hui, Bharat Joshi, Robert Kebler, John Kristoff, Mankamana Mishra, Heidi Ou, Eric Rescorla, Pekka Savola, Shinsuke Suzuki, Dave Thaler, Achmad Husni Thamrin, Stig Venaas, Cao Wei, and the MBONED Working Group members.

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