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# Deprecating ASM for Interdomain Multicast
draft-acg-mboned-multicast-models-02

## Abstract

This document provides a high-level overview of more commonly used multicast service models, principally the Any-Source Multicast (ASM) and Source-Specific Multicast (SSM) models, and discusses the applicability of the models to certain scenarios. As a result, this document recommends that ASM is not used for interdomain scenarios, and the use of SSM is strongly recommended for all multicast scenarios.

## Status of This Memo

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## 1. Introduction

IP Multicast has been deployed in various forms, both within private networks and on the wider Internet. While a number of service models have been published individually, and in many cases revised over time, there has been no strong recommendation made on the

appropriateness of the models to certain scenarios. This document aims to fill that gap, and includes a BCP-level recommendation to both deprecate the use of interdomain ASM and to promote the use of SSM for all multicast scenarios.

## 2. Multicast service models

The general IP multicast service model [RFC1112] is that senders send to a multicast IP group address, receivers express an interest in traffic sent to a given multicast address, and that routers figure out how to deliver traffic from the senders to the receivers.

The benefit of IP multicast is that it enables delivery of content such that any multicast packet sent from a source to a given multicast group address appears once and only once on any path between a sender and an interested receiver that has joined that multicast group. The principal advantage, in terms of bandwidth conservation will lie with the sender, i.e., at the head end.

A reserved range of IP multicast group addresses (for either IPv4 or IPv6) is used for multicast group communication, as described in Section 3.1.

Two high-level flavours of this service model have evolved over time. In Any-Source Multicast (ASM), any number of sources may transmit multicast packets, and those sources may come and go over the course of a multicast session without being known a priori. In ASM, receivers express interest only in a given multicast group address. In contrast, with Source-Specific Multicast (SSM) the specific source(s) that may send traffic to the group are known in advance. In SSM, receivers express interest both in a given multicast address and specific associated source address(es).

Senders transmit multicast packets without knowing where receivers are, or how many there are. Receivers are able to signal to on-link routers their desire to receive multicast content sent to a given multicast group, and in the case of SSM from a specific sender IP address. They may discover the group (and sender IP) information in a number of different ways. They are also able to signal their desire to no longer receive multicast traffic for a given group (and sender IP).

Multicast routing protocols are used to establish the multicast forwarding paths (tree) between a sender and a set of receivers. Each router would typically maintain multicast forwarding state for a given group (and potentially sender IP), such that it knows on which interfaces to forward (and where necessary replicate) multicast packets.

Multicast packet forwarding is generally not considered a reliable service. It is typically unidirectional, but a bidirectional multicast delivery mechanism also exists.

## 3. Multicast building blocks

In this section we describe general multicast building blocks that are applicable to both ASM and SSM deployment.

### 3.1. Multicast addressing

IANA has reserved specific ranges of IPv4 and IPv6 address space for multicast addressing.

Guidelines for IPv4 multicast address assignments can be found in [RFC5771]. IPv4 has no explicit multicast address format; a specific portion of the overall IPv4 address space is reserved for multicast use (224.0.0.0/4). As per Section 9 of RFC5771, domains with a 32-bit ASN MAY apply for space in AD-HOC Block III, or instead consider using IPv6 multicast addresses.

Guidelines for IPv6 multicast address assignments can be found in [RFC2375] and [RFC3307]. The IPv6 multicast address format is described in [RFC4291]. An IPv6 multicast group address will lie within ff00::/8.

### 3.2. Host signalling

A host wishing to signal interest in receiving (or no longer receiving) multicast to a given multicast group (and potentially from a specific sender IP) may do so by sending a packet using one of the protocols described below on an appropriate interface.

For IPv4, a host may use Internet Group Management Protocol Version 2 (IGMPv2) [RFC2236] to signal interest in a given group. IGMPv3 [RFC3376] has the added capability of specifying interest in receiving multicast packets from specific sources.

For IPv6, a host may use Multicast Listener Discovery Protocol (MLD) [RFC2710] to signal interest in a given group. MLDv2 [RFC3810] has the added capability of specifying interest in receiving multicast packets from specific sources.

Further guidance on IGMPv3 and MLDv2 is given in [RFC4604].

### 3.3. Multicast snooping

In some cases, it is desirable to limit the propagation of multicast messages in a layer 2 network, typically through a layer 2 switch device. In such cases multicast snooping can be used, by which the switch device observes the IGMP/MLD traffic passing through it, and then attempts to make intelligent decisions on which physical ports to forward multicast. Typically, ports that have not expressed an interest in receiving multicast for a given group would not have traffic for that group forwarded through them. There is further discussion in [RFC4541].

## 4. ASM service model protocols

### 4.1. Protocol Independent Multicast, Dense Mode (PIM-DM)

PIM-DM is detailed in [RFC3973]. It operates by flooding multicast messages to all routers within the network in which it is configured. This ensures multicast data packets reach all interested receivers behind edge routers. Prune messages are used by routers to tell upstream routers to (temporarily) stop forwarding multicast for groups for which they have no known receivers.

PIM-DM remains an Experimental protocol since its publication in 2005.

### 4.2. Protocol Independent Multicast, Sparse Mode (PIM-SM)

The most recent revision of PIM-SM is detailed in [RFC7761]. PIM-SM is, as the name suggests, was designed to be used in scenarios where the subnets with receivers are sparsely distributed throughout the network. PIM-SM supports any number of senders for a given multicast group, which do not need to be known in advance, and which may come and go through the session. PIM-SM does not use a flooding phase, making it more scalable and efficient than PIM-DM, but this means PIM-SM needs a mechanism to construct the multicast forwarding tree (and associated forwarding tables in the routers) without flooding the whole network.

To achieve this, PIM-SM introduces the concept of a Rendezvous Point (RP) for a PIM domain. All routers in a PIM-SM domain are then configured to use specific RP(s). Such configuration may be performed by a variety of methods, including Anycast-RP [RFC4610].

A sending host’s Designated Router encapsulates multicast packets to the RP, and a receiving host’s Designated Router can forward PIM JOIN messages to the RP, in so doing forming what is known as the Rendezvous Point Tree (RPT). Optimisation of the tree may then

happen once the receiving host's router is aware of the sender's IP, and a source-specific JOIN message may be sent towards it, in so doing forming the Shortest Path Tree (SPT). Unnecessary RPT paths are removed after the SPT is established.

#### 4.2.1. Interdomain PIM-SM, and MSDP

PIM-SM can in principle operate over any network in which the cooperating routers are configured with RPs. But in general, PIM-SM for a given domain will use an RP configured for that domain. There is thus a challenge in enabling PIM-SM to work between multiple domains, i.e. to allow an RP in one domain to learn the existence of a source in another domain, such that a receiver's router in one domain can know to forward a PIM JOIN towards a source's Designated Router in another domain. The solution to this problem is to use an inter-RP signalling protocol known as Multicast Source Discovery Protocol (MSDP). [RFC3618].

Deployment scenarios for MSDP are given in [RFC4611]. MSDP remains an Experimental protocol since its publication in 2003. MSDP was not replicated for IPv6.

### 4.3. Bidirectional PIM (PIM-BIDIR)

PIM-BIDIR is detailed in [RFC5015]. In contrast to PIM-SM, it can establish bi-directional multicast forwarding trees between multicast sources and receivers.

### 4.4. IPv6 PIM-SM with Embedded RP

Within a single PIM domain, PIM-SM for IPv6 works largely the same as it does for IPv4. However, the size of the IPv6 address (128 bits) allows a different mechanism for multicast routers to determine the RP for a given multicast group address. Embedded-RP [RFC3956] specifies a method to embed the unicast RP IP address in an IPv6 multicast group address, allowing routers supporting the protocol to determine the RP for the group without any prior configuration, simply by observing the RP address that is embedded (included) in the group address.

Embedded-RP allows PIM-SM operation across any IPv6 network in which there is an end-to-end path of routers supporting the protocol. By embedding the RP address in this way, multicast for a given group can operate interdomain without the need for an explicit source discovery protocol (i.e. without MSDP for IPv6). It would generally be desirable that the RP would be located close to the sender(s) in the group.

## 5. SSM service model protocols

### 5.1. Source Specific Multicast (PIM-SSM)

PIM-SSM is detailed in [RFC4607]. In contrast to PIM-SM, PIM-SSM benefits from assuming that source(s) are known about in advance, i.e. the source IP address is known (by some out of band mechanism), and thus the receiver's router can send a PIM JOIN directly towards the sender, without needing to use an RP.

IPv4 addresses in the 232/8 (232.0.0.0 to 232.255.255.255) range are designated as source-specific multicast (SSM) destination addresses and are reserved for use by source-specific applications and protocols. For IPv6, the address prefix FF3x::/32 is reserved for source-specific multicast use.

## 6. Discussion

In this section we discuss the applicability of the ASM and SSM models described above, and their associated protocols, to a range of deployment scenarios.

### 6.1. ASM Deployment

PIM-DM remains an Experimental protocol, that appears to be rarely used in campus or enterprise environments.

In enterprise and campus scenarios, PIM-SM is in relatively common use. The configuration and management of an RP within a single domain is not onerous. However, if interworking with external PIM domains in IPv4 multicast deployments is needed, MSDP is required to exchange information between domain RPs about sources. MSDP remains an Experimental protocol, and can be a complex and fragile protocol to administer and troubleshoot. MSDP is also specific to IPv4; it was not carried forward to IPv6, in no small part due to the complexity of operation and troubleshooting.

PIM-SM is a general purpose protocol that can handle all use cases. In particular, it was designed for cases where one or more sources may came and go during a multicast session. For cases where a single, persistent source is used, and receivers can be configured to know of that source, PIM-SM has unnecessary complexity.

As stated above, MSDP was not taken forward to IPv6. Instead, IPv6 has Embedded-RP, which allows the RP address for a multicast group to be embedded in the group address, making RP discovery automatic, if all routers on the path between a receiver and a sender support the protocol. Embedded-RP can support lightweight ad-hoc deployments.

However, it does rely on a single RP for an entire group. Embedded-RP was run successfully between European and US academic networks during the 6NET project in 2004/05. Its usage generally remains constrained to academic networks.

BIDIR-PIM is designed, as the name suggests, for bidirectional use cases.

### 6.2. SSM Deployment

As stated in RFC4607, SSM is particularly well-suited to dissemination-style applications with one or more senders whose identities are known (by some mechanism) before the application starts running. PIM-SSM is therefore very well-suited to applications such as classic linear broadcast TV over IP.

SSM requires hosts using it and (edge) routers with SSM receivers support the new(er) IGMPv3 and MLDv2 protocols. While delayed delivery of support in some OSes has meant that adoption of SSM has also been slower than might have been expected, or hoped, support for SSM is now widespread in common OSes.

## 7. Recommendations on ASM and SSM deployment

This document recommends that the use of interdomain ASM is deprecated, i.e., only SSM is to be used for interdomain multicast. Further, it also strongly recommends the use of SSM for all multicast scenarios, be they run inter or intradomain.

### 7.1. Rationale - advantages of SSM

A significant benefit of SSM is its reduced complexity through eliminating the network-based source discovery required in ASM. This means there are no RPs, shared trees, SPT switchover, PIM registers, MSDP or data-driven state creation elements to support. SSM is really just a small subset of PIM-SM, plus IGMPv3.

This reduced complexity makes SSM radically simpler to manage, troubleshoot and operate, particularly for network backbone operators; this is the main motivation for the recommendation to deprecate the use of ASM in interdomain scenarios. Interdomain ASM is widely viewed as complicated and fragile. By eliminating network-based source discovery for interdomain multicast, the vast majority of the complexity issues go away.

RFC 4607 includes details benefits of SSM, for example:

> "Elimination of cross-delivery of traffic when two sources simultaneously use the same source-specific destination address;
>
> Avoidance of the need for inter-host coordination when choosing source-specific addresses, as a consequence of the above;
>
> Avoidance of many of the router protocols and algorithms that are needed to provide the ASM service model."

Further discussion can also be found in [RFC3569].

SSM is considered more secure in that it supports access control, i.e. you only get packets from the sources you explicitly ask for, as opposed to ASM where anyone can decide to send traffic to a PIM-SM group address. This topic is expanded upon in [RFC4609].

### 7.2. On deprecating interdomain ASM

The recommendation to deprecate the use of interdomain ASM applies to the use of ASM between domains, where either MSDP (IPv4) or Embedded-RP (IPv6) is required for sharing knowledge of remote sources.

If an organisation, or AS, wishes to use multiple multicast domains within its own network border, that is a choice for that organisation to make, and it may then use MSDP or Embedded-RP internally within its own network.

MSDP is an Experimental level standard; this document does not propose making it Historic, given there may be such residual intra-organisation use cases.

By implication, it is thus strongly recommended that SSM be the multicast protocol of choice for interdomain multicast. Best current practices for deploying interdomain multicast using SSM are documented in [I-D.ietf-mboned-interdomain-peering-bcp].

### 7.3. Intradomain ASM

The use of ASM within a single multicast domain, such as an enterprise or campus, with an RP for the site, is relatively common today. The site may also choose to use Anycast-RP or MSDP for RP resilience, at the expense of the extra complexity in managing that configuration. Regardless, this document does not preclude continued use of ASM in the intradomain scenario.

However, it is strongly recommended that sites using ASM internally conduct an audit of the multicast applications used, and begin planning a migration to using SSM instead wherever possible.

### 7.4. IGMPv3/MLDv2 support

This document recommends that all host and router platforms supporting multicast also support IGMPv3 and MLDv2. The updated IPv6 Node Requirements RFC [I-D.ietf-6man-rfc6434-bis] states that MLDv2 support is a MUST in all implementations. Such support is already widespread in common host and router platforms.

### 7.5. Multicast addressing considerations

A key benefit of SSM is that the multicast application does not need to be allocated a specific multicast group by the network, rather as SSM is inherently source-specific, it can use any group address, G, in the reserved range of IPv4 or IPv6 SSM addresses for its own source address, S.

In principle, if interdomain ASM is deprecated, backbone operators could begin filtering the ranges of group addresses used by ASM. In practice, this is not recommended given there will be a transition period from ASM to SSM, as discussed in Section 7.7, where some form of ASM-SSM mappings may be used, and filtering may preclude such operations.

### 7.6. Application considerations

There will be a wide range of applications today that only support ASM, whether as software packages, or code embedded in devices such as set top boxes.

The strong recommendation in this document for use of SSM means that applications should instead use SSM, should operate correctly in an SSM environment, and thus trigger IGMPv3/MLDv2 messages to signal use of SSM.

It is often thought that ASM is required for multicast applications where there are multiple sources. However, RFC4607 also describes how SSM can be used instead of PIM-SM for multi-party applications:

> "SSM can be used to build multi-source applications where all participants' identities are not known in advance, but the multi-source "rendezvous" functionality does not occur in the network layer in this case. Just like in an application that uses unicast as the underlying transport, this functionality can be implemented by the application or by an application-layer library."

Thus, in theory, it should be possible to port ASM-only applications to be able to run using SSM, if an appropriate out-of-band mechanism can be chosen to convey the participant source addresses.

Given all common OSes support SSM, it is then down to the programming language and APIs used as to whether the necessary SSM APIs are available. SSM support is generally quite ubiquitous, with the current exception of websockets used in web-browser based applications.

It is desirable that applications also support appropriate congestion control, as described in [RFC8085], with appropriate codecs, to achieve the necessary rate adaption.

It is recommended that application developers choosing to use multicast, develop and engineer their applications to use SSM rather than ASM.

Some useful considerations for multicast applications can still be found in the relatively old [RFC3170].

### 7.7. ASM/SSM transition - protocol mapping

In the case of existing ASM applications that cannot readily be ported to SSM, it may be possible to use some form of protocol mapping, i.e., to have a mechanism to translate a (*,G) join or leave to a (S,G) join or leave, for a specific source, S. The general challenge in performing such mapping is determining where the configured source address, S, comes from.

There are some existing vendor-specific mechanisms to achieve this function, but none are documented in IETF standards. This may be an area for the IETF to work on, but it should be noted that any such effort would only be an interim transition mechanism, and such mappings do not remove the requirement for applications to be allocated ASM group addresses for the communications.

It is generally considered better to work towards using SSM, and thus pushing the source discovery problem from the network to the application.

## 8. Conclusions

This document recommends that the use of interdomain ASM is deprecated. It also recommends the use of SSM for all multicast scenarios. Specific implications and considerations for the recommendation are discussed.

## 9. Security Considerations

This document adds no new security considerations. RFC4609 describes the additional security benefits of using SSM instead of ASM.

## 10. IANA Considerations

This document currently makes no request of IANA.

Note to RFC Editor: this section may be removed upon publication as an RFC.

## 11. Acknowledgments

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# Mtrace Version 2: Traceroute Facility for IP Multicast
# draft-ietf-mboned-mtrace-v2-13

## 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.

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## 1. Introduction

Given a multicast distribution tree, tracing from a multicast source to a receiver is difficult, since we do not know which branch of the multicast tree the receiver lies. This means that we have to flood the whole tree to find the path from a source to a receiver. 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 a Mtrace2 client towards a specified source, or a Rendezvous Point (RP) if no source address is specified. RP is a special router where the source and receiver meet in PIM-SM [5]. Moreover, Mtrace2 provides

additional information such as the packet rates and losses, as well as other diagnosis information. Especially, Mtrace2 can be used 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., TTL threshold).

Figure 1 shows a typical case on 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. Source, Receiver and Mtrace2 client are typically a host on the Internet.

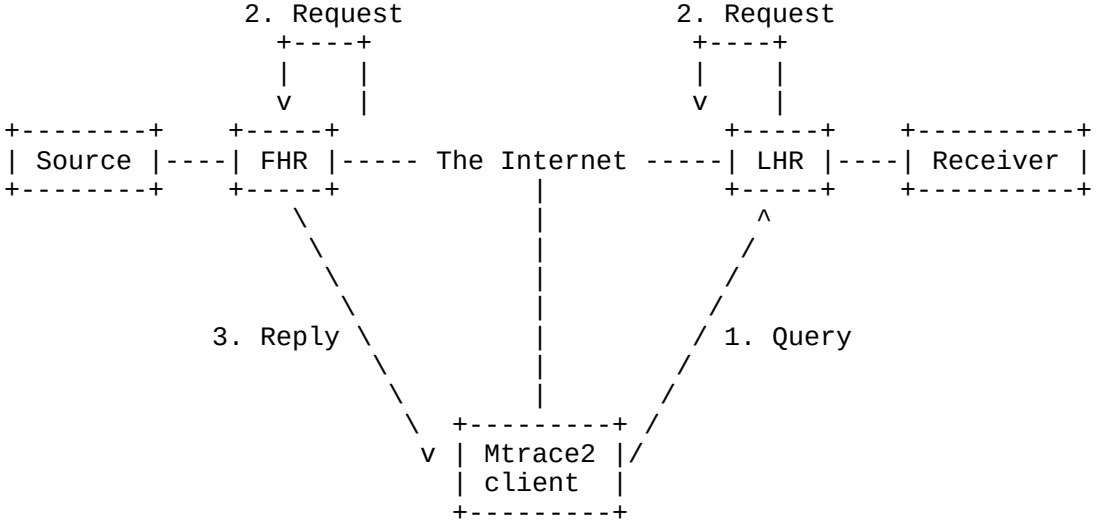



Figure 1

When an Mtrace2 client initiates a multicast trace anywhere on the Internet, it sends an Mtrace2 Query packet to the LHR or RP for a multicast group and a source address. The LHR/RP turns the Query packet into a Request, appends a standard response block containing its interface addresses and packet statistics to the Request packet, then forwards the packet towards the source. The Request packet is either unicasted to its upstream router towards the source, 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 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 if it reaches the RP first, or a fatal error condition such as "no route" is encountered along the path, or the hop count is exceeded.

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 Mtrace2 client specific, and it is 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 which 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 IGMP messages [8], 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.

## 2. Terminology

In this document, the key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" are to be interpreted as described in RFC 2119 [1], and 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
: The interface to which data from the source or RP is expected to transmit for the specified source and group. It is also the interface on which the Mtrace2 Request will be 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)
: The router that is directly connected to the receivers. It is also the router that receives the Mtrace2 Query from an Mtrace2 client.

Group state
: It is the state a shared-tree protocol, such as 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
: It is the state that is used to choose the path towards the source for the specified source and group.

ALL-[protocol]-ROUTERS.MCAST.NET
: It is a link-local multicast address for multicast routers to communicate with their adjacent routers that are running the same routing protocol. For instance, the address of ALL-PIM-ROUTERS.MCAST.NET [5] is ’224.0.0.13’ for IPv4 and ’ff02::d’ for IPv6.

## 3. Packet Formats

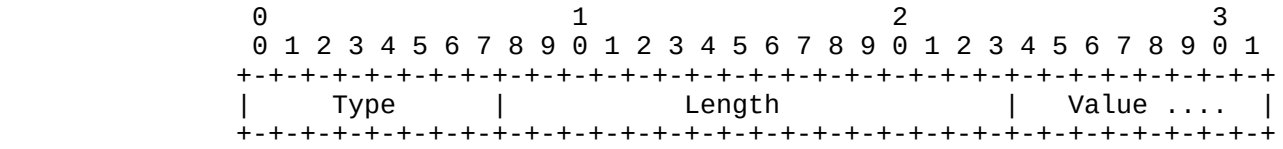
This section describes the details of the packet formats for Mtrace2 messages.

All Mtrace2 messages are encoded in TLV format (see Section 3.1). If an implementation receives an unknown TLV, it SHOULD ignored and silently discarded the unknown TLV. If the length of a TLV exceeds the length specified in the TLV, the TLV SHOULD be accepted; however, any additional data after the specified TLV length SHOULD be ignored.

All Mtrace2 messages are UDP packets. For IPv4, Mtrace2 Query and Request messages MUST NOT be fragmented. For IPv6, the packet size for the Mtrace2 messages MUST NOT exceed 1280 bytes, which is the smallest MTU for an IPv6 interface [2]. 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 mixed. For example, if an Mtrace2 Query or Request message arrives in as an IPv4 packet, all addresses specified in the Mtrace2 messages MUST be IPv4 as well. 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 6 octets. The maximum TLV length is not defined; however the entire Mtrace2 packet length should not exceed the available MTU.

Value: variable length

The format is based on the Type value. The length of the value field is 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 |
|---|---|
| 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, Request or 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 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 usually originated by an Mtrace2 client which sends an Mtrace2 Query message to the LHR. When tracing towards the source or the RP, the intermediate routers MUST NOT modify the Query message except the Type field.

An Mtrace2 Query message is shown as follows:

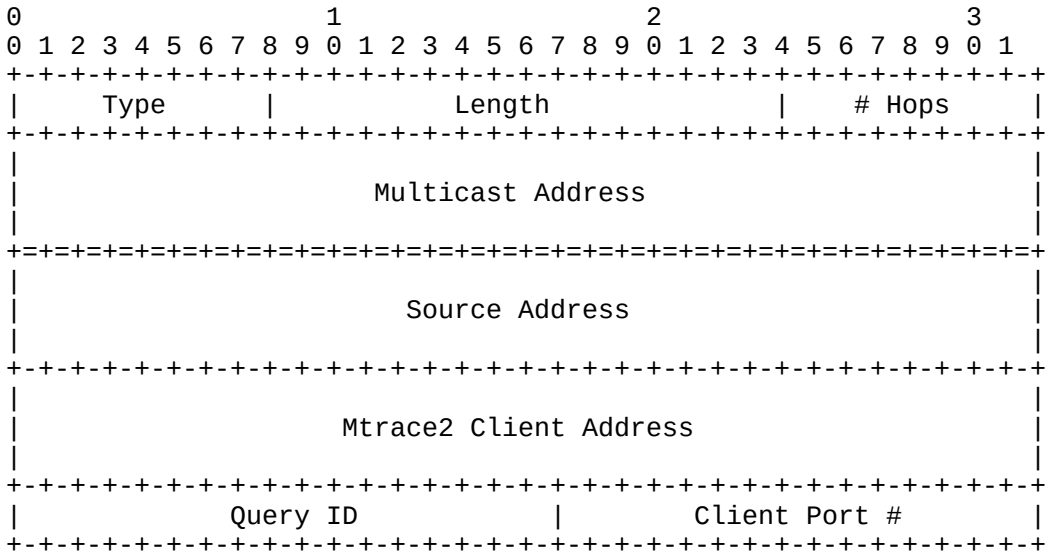



Figure 2

# 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 1's 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: an unicast address of the source to be traced; or,

s-2: all 1's 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, and therefore, MUST NOT be all 1's 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 format of an Mtrace2 Request message is similar to an Mtrace2 Query except the Type field is 0x02.

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

### 3.2.3. Mtrace2 Reply

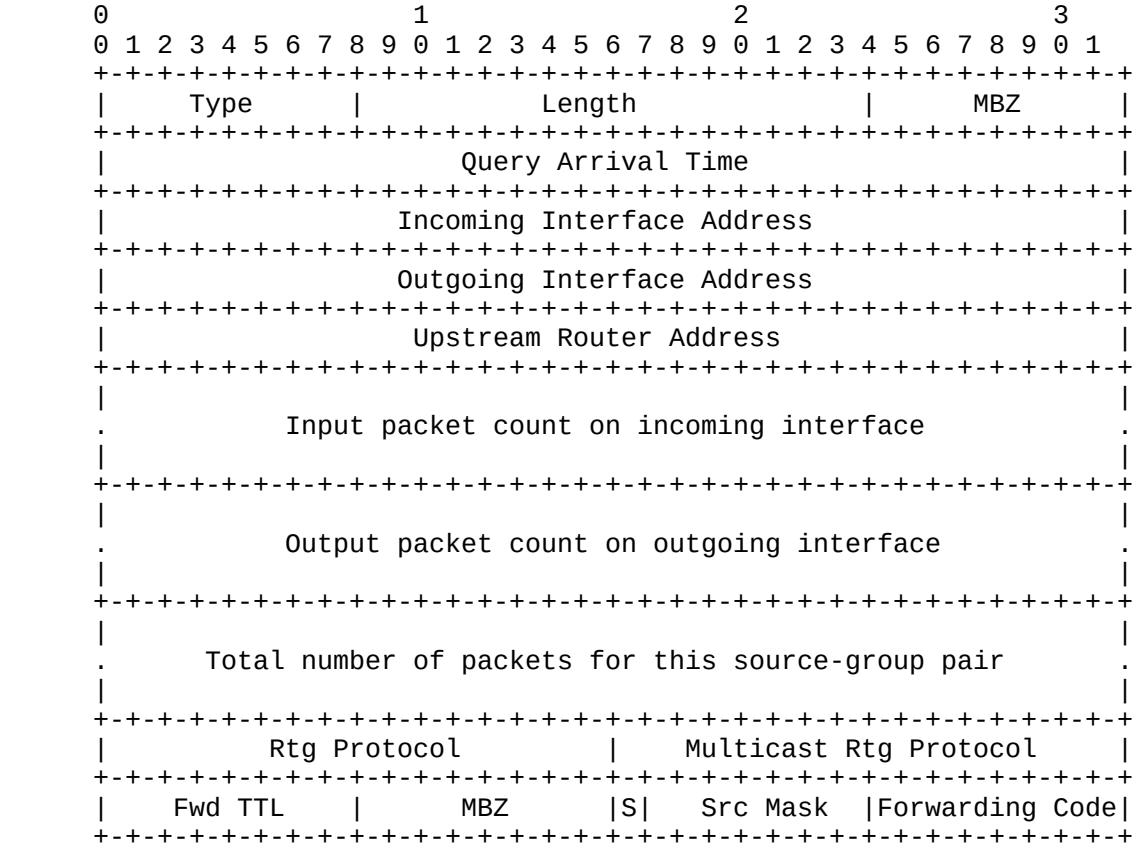
The format of an Mtrace2 Reply message is similar to an Mtrace2 Query except the Type field is 0x03.

When a FHR or a RP receives an Mtrace2 Request message which is destined to itself, it would append an Mtrace2 Standard Response Block (see Section 3.2.4) of its own to the Request message. Next, it would turn the Request message into a Reply by changing the Type field of the Request from 0x02 to 0x03. The Reply message would then be unicasted to the Mtrace2 client specified in the Mtrace2 Client Address field.

There are a number of cases an intermediate router might return a Reply before a Request reaches the FHR or the RP. See Section 4.1.1, Section 4.2.2, Section 4.3.3, and Section 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 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 UNIX timeval to a 32-bit NTP timestamp:

```
query_arrival_time
= (tv.tv_sec + 32384) << 16 + ((tv.tv_usec << 10) / 15625)
```

The constant 32384 is the number of seconds from Jan 1, 1900 to Jan 1, 1970 truncated to 16 bits. ((tv.tv_usec << 10) / 15625) is a reduction of ((tv.tv_usec / 100000000) << 16).

Note that Mtrace2 does not require all the routers on the path to have synchronized clocks in order to measure one-way latency.

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 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.MCAST.NET) if the upstream router is not known because of the workings of the multicast routing protocol. However, it should 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 1’s if no count can be reported. This counter may have the same value as ifHCInMulticastPkts from the IF-MIB [10] for this interface.

Output packet count on outgoing interface: 64 bit
: 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 1’s if no count can be reported. This counter may have the same value as ifHCOutMulticastPkts from the IF-MIB [10] 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 1's 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 IPMROUTE-STD-MIB [11] 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 RPF interface for the specified source or RP. This value should have the same value as ipMcastRouteRtProtocol from the IPMROUTE-STD-MIB [11] 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 IPMROUTE-STD-MIB [11] 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.

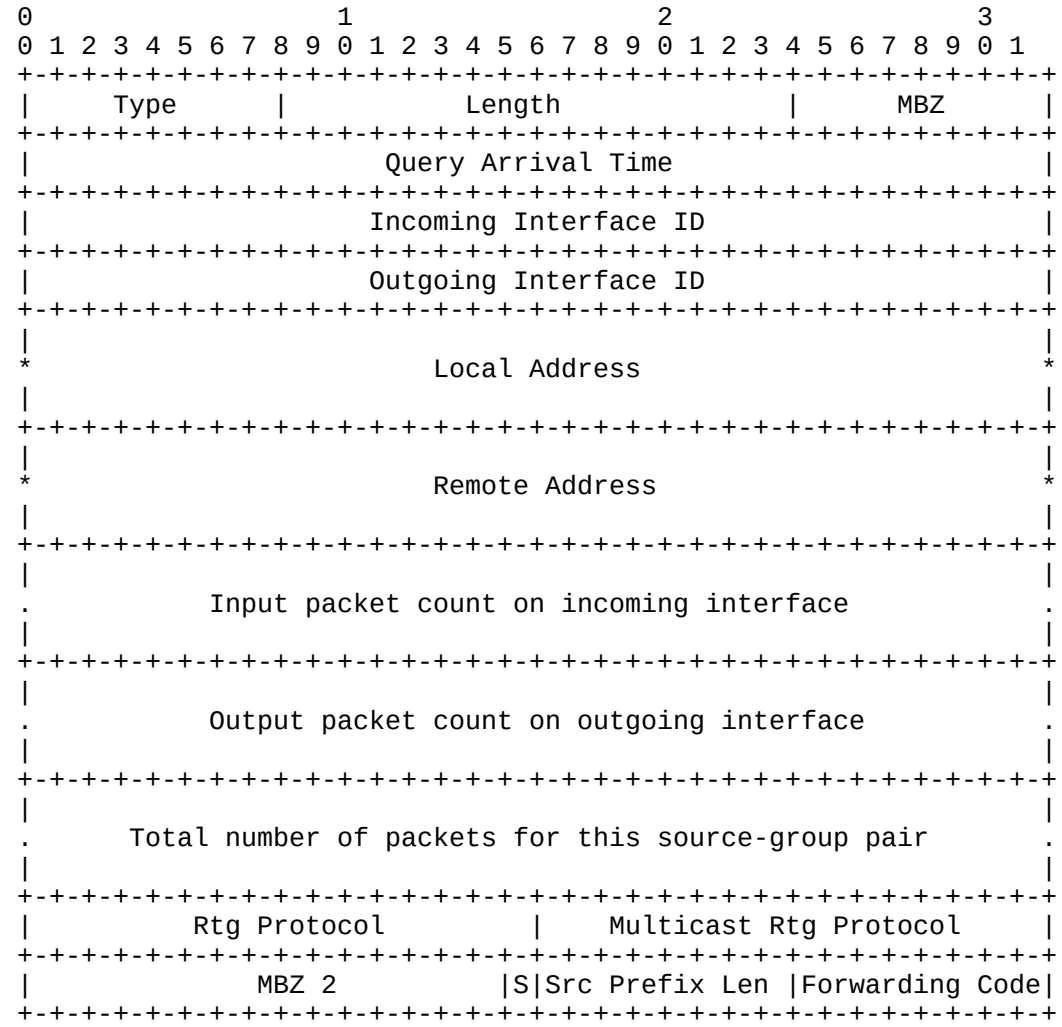
Src Mask: 7 bits
This field contains the number of 1's in the netmask the router has for the source (i.e. a value of 24 means the netmask is 0xffffff00). If the router is forwarding solely on group state, this field is set to 127 (0x7f).

Forwarding Code: 8 bits
This field contains a forwarding information/error code. Section 4.1 and Section 4.2 will 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 to which this router would not forward for the specified group towards the source or RP. |
| 0x02 | PRUNE_SENT | This router has sent a prune upstream which 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 which 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 which 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 [10] 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 [10] for this interface

Local Address: 128 bits
This field specifies a global IPv6 address that uniquely identifies the router. An unique local unicast address [9] 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 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.MCAST.NET) 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 IPMROUTE-STD-MIB [11] 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.

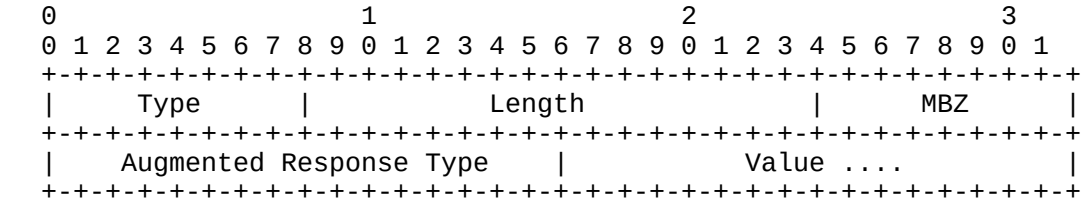
Src Prefix Len: 8 bits
This field contains the prefix length this router has for the source. If the router is forwarding solely on group state, this field is set to 255 (0xff).

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 |
|---|---|
| 0x01 | # 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 would add 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 would recognize the total number of hops the Request has been traced so far by adding this number and the number of the Standard Response Block in the current Request message.

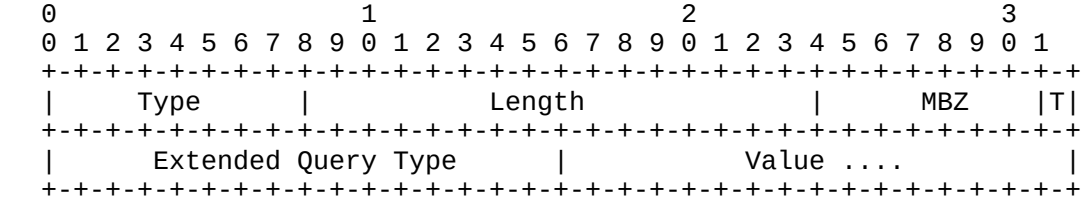
This document only defines one Augmented Response Type in the Augmented Response Block. The description on how to provide diagnosis information using the Augmented Response Block is out of the scope of this document, and will be addressed in separate documents.

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 which 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 Mtrace2 Query

An Mtrace2 Query message is an Mtrace2 message with no response blocks filled in, and uses 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 SHOULD, however, support a mechanism to filter out queries from clients beyond a specified administrative boundary. Such a boundary could, for example, be specified via a list of allowed/disallowed client addresses or subnets. If a query is received from beyond the specified administrative boundary, the Query MUST NOT be processed. The router MAY, however, perform rate limited logging of such events.

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, it turns the Query to a Request by changing the TLV type from 0x01 to 0x02, and performs the steps listed in Section 4.2.

### 4.2. Receiving Mtrace2 Request

An Mtrace2 Request is an Mtrace2 message that uses 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 which is not a link-scoped group (i.e. 224/24 for IPv4, FFx2::/16 [3] for IPv6), it MUST be silently ignored. GTSM [12] SHOULD be used by the router to determine whether the router is adjacent or not.

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".

1. Prepare a Standard Response Block to be appended to the packet and 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). Note that the Outgoing Interface is the one on which the Mtrace2 Request message arrives.

2. 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 1's for IPv4 or 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.

3. 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.

4. 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 by the step 2.

5. If Mtrace2 is administratively prohibited, note the Forwarding Code of ADMIN_PROHIB. If Mtrace2 is administratively prohibited and any of the fields as filled in the step 4 are considered private information, zero out the applicable fields.

6. 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.

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

8. 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.

9. 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.

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

11. 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 Forwarding Code of REACHED_GW. The router continues the processing as described in Section 4.5.

12. 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.MCAST.NET. It MUST be a link-scoped group (i.e. 224/24 for IPv4, FF02::/16 for IPv6), and MUST NOT be ALL-SYSTEMS.MCAST.NET (224.0.0.1) for IPv4 and All Nodes Address (FF02::1) for IPv6. It MAY also be ALL-ROUTERS.MCAST.NET (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 address 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 from the old Request excluding all the response blocks, followed by the previously prepared Standard Response Block, and an Augmented Response Block with Augmented Response Type of 0x01 and the number of the returned Standard Response Blocks as the value. The new Request is then forwarded upstream.

### 4.4. Sending Mtrace2 Reply

An Mtrace2 Reply MUST be returned to the client by a router if the total number of the traced routers is equal to the # Hops in the Request. The total number of the traced routers is the sum of the Standard Response Blocks in the Request (including the one just added) and the number of the returned blocks, if any.

#### 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 address 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, and turns the Query or Request as 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 makes the changes as follows:

- sets the RPF interface's address as the Mtrace2 Client Address;
- uses its own port number as the Client Port #; and,
- decreases # Hops by the number of the Standard Response Block that was just returned as a Reply.

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 the 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 1's. Additionally, the source-group packet count (see Section 3.2.4 and Section 3.2.5) within the domain may be all 1's 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.MCAST.NET (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 would be the Mtrace2 Client Address.

### 5.2. Determining the Path

An Mtrace2 client could send an initial Query messages 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, the hop count can continue past the non-responding hop, in the hopes that further hops may respond. These attempts should continue until 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 Section 7.3 and Section 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 ALL-ROUTERS.MCAST.NET (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, MTRACE.MCAST.NET 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 which is destined to itself, the router would return an ICMP port unreachable to the Mtrace2 client. On the other hand, when the router receives an Mtrace2 Request which is destined to itself, the router would return 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 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 can not 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 Section 4.5, Section 5.2, and Section 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 which 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.

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 (via mrinfo or SNMP [9][11]) a list of neighbors of the non-responding router. If desired, each of those neighbors could be probed to determine the remainder of the path. Unfortunately, this heuristic may end up with multiple paths, since there is no way of knowing what the non-responding router's algorithm for choosing an upstream router is. However, if all paths but one flow back towards the non-responding router, it is possible to be sure that this is the correct path.

## 6. Protocol-Specific Considerations

This section describes the Mtrace2 behavior with the present 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. Bi-Directional PIM

Bi-directional PIM [6] is a variant of PIM-SM that builds bi-directional shared trees connecting multicast sources and receivers. Along the bi-directional 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, Bi-directional 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 [13] 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 Dense Mode 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/MLD Proxy [7] 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 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 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 two traces, it is possible to find packet loss information by comparing the difference in input packet counts to the difference in output packet counts for the specified source-group address pair at the previous hop. On a point-to-point link, any difference in these numbers implies packet loss. Since the packet counts may be changing as the Mtrace2 Request is propagating, there may be small errors (off by 1 or 2 or more) in these statistics. However, these errors will not accumulate if multiple traces are taken to expand the measurement period. 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 time stamps 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 new assignments can only be made via a Standards Action as specified in [4].

### 8.1. Forwarding Codes

New Forwarding Codes must only be created by an RFC that modifies this document's Section 3.2.4 and Section 3.2.5, fully describing the conditions under which the new Forwarding Code is used. The IANA may act as a central repository so that there is a single place to look up Forwarding Codes and the document in which they are defined.

### 8.2. UDP Destination Port

The IANA should allocate UDP destination port for Mtrace2 upon publication of the first RFC.

## 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, source address, multicast address, and Mtrace2 client address. These addresses MUST be congruent with the definition defined in Section 3.2.1 and forwarding Mtrace2 messages having invalid addresses MUST be prohibited. For instance, if 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. Filtering of Clients

A router SHOULD support a mechanism to filter out queries from clients beyond a specified administrative boundary. Such a boundary could, for example, be specified via a list of allowed/disallowed client addresses or subnets. If a query is received from beyond the specified administrative boundary, the Query MUST NOT be processed. The router MAY, however, perform rate limited logging of such events.

### 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.

## 10. Acknowledgements

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