Internet Group Management Protocol, Version 3

Status of this Memo

   This document specifies an Internet standards track protocol for the
   Internet community, and requests discussion and suggestions for
   improvements. Please refer to the current edition of the "Internet
   Official Protocol Standards" (STD 1) for the standardization state
   and status of this protocol. Distribution of this memo is unlimited.

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Abstract

   This document specifies Version 3 of the Internet Group Management
   Protocol, IGMPv3. IGMP is the protocol used by IPv4 systems to
   report their IP multicast group memberships to neighboring multicast
   routers. Version 3 of IGMP adds support for "source filtering", that
   is, the ability for a system to report interest in receiving packets
   only from specific source addresses, or from *all but* specific
   source addresses, sent to a particular multicast address. That
   information may be used by multicast routing protocols to avoid
   delivering multicast packets from specific sources to networks where
   there are no interested receivers.

   This document obsoletes RFC 2236.

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1. Introduction

   The Internet Group Management Protocol (IGMP) is used by IPv4 systems
   (hosts and routers) to report their IP multicast group memberships to
   any neighboring multicast routers. Note that an IP multicast router
   may itself be a member of one or more multicast groups, in which case
   it performs both the "multicast router part" of the protocol (to
   collect the membership information needed by its multicast routing
   protocol) and the "group member part" of the protocol (to inform
   itself and other, neighboring multicast routers of its memberships).

   IGMP is also used for other IP multicast management functions, using
   message types other than those used for group membership reporting.
   This document specifies only the group membership reporting functions
   and messages.

   This document specifies Version 3 of IGMP. Version 1, specified in
   [RFC-1112], was the first widely-deployed version and the first
   version to become an Internet Standard. Version 2, specified in
   [RFC-2236], added support for "low leave latency", that is, a
   reduction in the time it takes for a multicast router to learn that
   there are no longer any members of a particular group present on an
   attached network. Version 3 adds support for "source filtering",
   that is, the ability for a system to report interest in receiving
   packets *only* from specific source addresses, as required to support
   Source-Specific Multicast [SSM], or from *all but* specific source
   addresses, sent to a particular multicast address. Version 3 is
   designed to be interoperable with Versions 1 and 2.

   Multicast Listener Discovery (MLD) is used in a similar way by IPv6
   systems. MLD version 1 [MLD] implements the functionality of IGMP
   version 2; MLD version 2 [MLDv2] implements the functionality of IGMP
   version 3.

   The capitalized key words "MUST", "MUST NOT", "REQUIRED", "SHALL",
   "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and
   "OPTIONAL" in this document are to be interpreted as described in
   [RFC-2119]. Due to the lack of italics, emphasis is indicated herein
   by bracketing a word or phrase in "*" characters.

2. The Service Interface for Requesting IP Multicast Reception

   Within an IP system, there is (at least conceptually) a service
   interface used by upper-layer protocols or application programs to
   ask the IP layer to enable and disable reception of packets sent to
   specific IP multicast addresses. In order to take full advantage of
   the capabilities of IGMPv3, a system's IP service interface must
   support the following operation:

      IPMulticastListen (socket, interface, multicast-address,
                          filter-mode, source-list)

   where:

   o "socket" is an implementation-specific parameter used to
     distinguish among different requesting entities (e.g., programs or
     processes) within the system; the socket parameter of BSD Unix
     system calls is a specific example.

   o "interface" is a local identifier of the network interface on which
     reception of the specified multicast address is to be enabled or
     disabled. Interfaces may be physical (e.g., an Ethernet interface)
     or virtual (e.g., the endpoint of a Frame Relay virtual circuit or
     the endpoint of an IP-in-IP "tunnel"). An implementation may allow
     a special "unspecified" value to be passed as the interface
     parameter, in which case the request would apply to the "primary"
     or "default" interface of the system (perhaps established by system
     configuration). If reception of the same multicast address is
     desired on more than one interface, IPMulticastListen is invoked
     separately for each desired interface.

   o "multicast-address" is the IP multicast address, or group, to which
     the request pertains. If reception of more than one multicast
     address on a given interface is desired, IPMulticastListen is
     invoked separately for each desired multicast address.

   o "filter-mode" may be either INCLUDE or EXCLUDE. In INCLUDE mode,
     reception of packets sent to the specified multicast address is
     requested *only* from those IP source addresses listed in the
     source-list parameter. In EXCLUDE mode, reception of packets sent
     to the given multicast address is requested from all IP source
     addresses *except* those listed in the source-list parameter.

   o "source-list" is an unordered list of zero or more IP unicast
     addresses from which multicast reception is desired or not desired,
     depending on the filter mode. An implementation MAY impose a limit
     on the size of source lists, but that limit MUST NOT be less than
     64 addresses per list. When an operation causes the source list
     size limit to be exceeded, the service interface MUST return an
     error.

   For a given combination of socket, interface, and multicast address,
   only a single filter mode and source list can be in effect at any one
   time. However, either the filter mode or the source list, or both,
   may be changed by subsequent IPMulticastListen requests that specify
   the same socket, interface, and multicast address. Each subsequent
   request completely replaces any earlier request for the given socket,
   interface and multicast address.

   Previous versions of IGMP did not support source filters and had a
   simpler service interface consisting of Join and Leave operations to
   enable and disable reception of a given multicast address (from *all*
   sources) on a given interface. The equivalent operations in the new
   service interface follow:

   The Join operation is equivalent to

      IPMulticastListen (socket, interface, multicast-address,
                          EXCLUDE, {})

   and the Leave operation is equivalent to:

      IPMulticastListen (socket, interface, multicast-address,
                          INCLUDE, {})

   where {} is an empty source list.

   An example of an API providing the capabilities outlined in this
   service interface is in [FILTER-API].

3. Multicast Reception State Maintained by Systems

3.1. Socket State

   For each socket on which IPMulticastListen has been invoked, the
   system records the desired multicast reception state for that socket.
   That state conceptually consists of a set of records of the form:

      (interface, multicast-address, filter-mode, source-list)

   The socket state evolves in response to each invocation of
   IPMulticastListen on the socket, as follows:

   o If the requested filter mode is INCLUDE *and* the requested source
     list is empty, then the entry corresponding to the requested
     interface and multicast address is deleted if present. If no such
     entry is present, the request is ignored.

   o If the requested filter mode is EXCLUDE *or* the requested source
     list is non-empty, then the entry corresponding to the requested
     interface and multicast address, if present, is changed to contain
     the requested filter mode and source list. If no such entry is
     present, a new entry is created, using the parameters specified in
     the request.

3.2. Interface State

   In addition to the per-socket multicast reception state, a system
   must also maintain or compute multicast reception state for each of
   its interfaces. That state conceptually consists of a set of
   records of the form:

      (multicast-address, filter-mode, source-list)

   At most one record per multicast-address exists for a given
   interface. This per-interface state is derived from the per-socket
   state, but may differ from the per-socket state when different
   sockets have differing filter modes and/or source lists for the
   same multicast address and interface. For example, suppose one
   application or process invokes the following operation on socket
   s1:

      IPMulticastListen (s1, i, m, INCLUDE, {a, b, c})

   requesting reception on interface i of packets sent to multicast
   address m, *only* if they come from source a, b, or c. Suppose
   another application or process invokes the following operation on
   socket s2:

       IPMulticastListen (s2, i, m, INCLUDE, {b, c, d})

   requesting reception on the same interface i of packets sent to the
   same multicast address m, *only* if they come from sources b, c, or
   d. In order to satisfy the reception requirements of both sockets,
   it is necessary for interface i to receive packets sent to m from
   any one of the sources a, b, c, or d. Thus, in this example, the
   reception state of interface i for multicast address m has filter
   mode INCLUDE and source list {a, b, c, d}.

   After a multicast packet has been accepted from an interface by the
   IP layer, its subsequent delivery to the application or process
   listening on a particular socket depends on the multicast reception
   state of that socket [and possibly also on other conditions, such
   as what transport-layer port the socket is bound to]. So, in the
   above example, if a packet arrives on interface i, destined to
   multicast address m, with source address a, it will be delivered on
   socket s1 but not on socket s2. Note that IGMP Queries and Reports
   are not subject to source filtering and must always be processed by
   hosts and routers.

   Filtering of packets based upon a socket's multicast reception
   state is a new feature of this service interface. The previous
   service interface [RFC1112] described no filtering based upon
   multicast join state; rather, a join on a socket simply caused the
   host to join a group on the given interface, and packets destined
   for that group could be delivered to all sockets whether they had
   joined or not.

   The general rules for deriving the per-interface state from the
   per-socket state are as follows: For each distinct (interface,
   multicast-address) pair that appears in any socket state, a per-
   interface record is created for that multicast address on that
   interface. Considering all socket records containing the same
   (interface, multicast-address) pair,

   o if *any* such record has a filter mode of EXCLUDE, then the filter
     mode of the interface record is EXCLUDE, and the source list of the
     interface record is the intersection of the source lists of all
     socket records in EXCLUDE mode, minus those source addresses that
     appear in any socket record in INCLUDE mode. For example, if the
     socket records for multicast address m on interface i are:

         from socket s1: (i, m, EXCLUDE, {a, b, c, d})
         from socket s2: (i, m, EXCLUDE, {b, c, d, e})
         from socket s3: (i, m, INCLUDE, {d, e, f})

       then the corresponding interface record on interface i is:

                        (m, EXCLUDE, {b, c})

    If a fourth socket is added, such as:

       from socket s4: (i, m, EXCLUDE, {})

    then the interface record becomes:

                        (m, EXCLUDE, {})

 o if *all* such records have a filter mode of INCLUDE, then the
   filter mode of the interface record is INCLUDE, and the source list
   of the interface record is the union of the source lists of all the
   socket records. For example, if the socket records for multicast
   address m on interface i are:

       from socket s1: (i, m, INCLUDE, {a, b, c})
       from socket s2: (i, m, INCLUDE, {b, c, d})
       from socket s3: (i, m, INCLUDE, {e, f})

    then the corresponding interface record on interface i is:

                    (m, INCLUDE, {a, b, c, d, e, f})

    An implementation MUST NOT use an EXCLUDE interface record to
    represent a group when all sockets for this group are in INCLUDE
    state. If system resource limits are reached when an interface
    state source list is calculated, an error MUST be returned to the
    application which requested the operation.

 The above rules for deriving the interface state are (re-)evaluated
 whenever an IPMulticastListen invocation modifies the socket state by
 adding, deleting, or modifying a per-socket state record. Note that
 a change of socket state does not necessarily result in a change of
 interface state.

4. Message Formats

 IGMP messages are encapsulated in IPv4 datagrams, with an IP protocol
 number of 2. Every IGMP message described in this document is sent
 with an IP Time-to-Live of 1, IP Precedence of Internetwork Control
 (e.g., Type of Service 0xc0), and carries an IP Router Alert option
 [RFC-2113] in its IP header. IGMP message types are registered by
 the IANA [IANA-REG] as described by [RFC-3228].

There are two IGMP message types of concern to the IGMPv3 protocol
described in this document:

    Type Number (hex)   Message Name
    -----------------   ------------

        0x11   Membership Query

        0x22   Version 3 Membership Report

An implementation of IGMPv3 MUST also support the following three
message types, for interoperation with previous versions of IGMP (see
section 7):

        0x12   Version 1 Membership Report   [RFC-1112]

        0x16   Version 2 Membership Report   [RFC-2236]

        0x17   Version 2 Leave Group   [RFC-2236]

Unrecognized message types MUST be silently ignored. Other message
types may be used by newer versions or extensions of IGMP, by
multicast routing protocols, or for other uses.

In this document, unless otherwise qualified, the capitalized words
"Query" and "Report" refer to IGMP Membership Queries and IGMP
Version 3 Membership Reports, respectively.

4.1. Membership Query Message

Membership Queries are sent by IP multicast routers to query the
multicast reception state of neighboring interfaces. Queries have
the following format:

```
      0                   1                   2                   3
      0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     | Type = 0x11   | Max Resp Code |           Checksum            |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                         Group Address                         |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     | Resv  |S| QRV |     QQIC      |     Number of Sources (N)     |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |                       Source Address [1]                      |
     +-                                                             -+
     |                       Source Address [2]                      |
     +-                              .                              -+
     .                               .                               .
     .                               .                               .
     +-                                                             -+
     |                       Source Address [N]                      |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
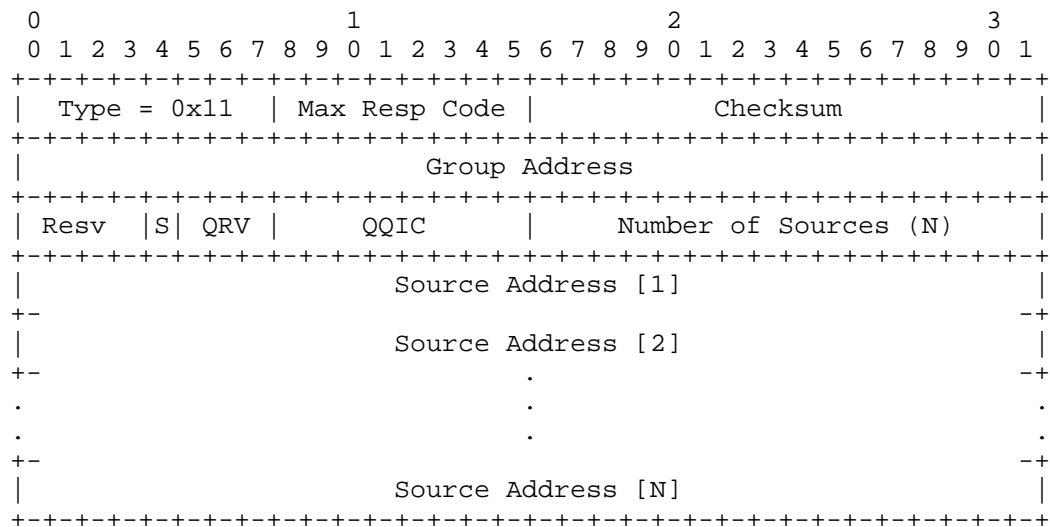
4.1.1. Max Resp Code

   The Max Resp Code field specifies the maximum time allowed before
   sending a responding report. The actual time allowed, called the Max
   Resp Time, is represented in units of 1/10 second and is derived from
   the Max Resp Code as follows:

   If Max Resp Code < 128, Max Resp Time = Max Resp Code

   If Max Resp Code >= 128, Max Resp Code represents a floating-point
   value as follows:

```
      0 1 2 3 4 5 6 7
     +-+-+-+-+-+-+-+-+
     |1| exp | mant  |
     +-+-+-+-+-+-+-+-+
```
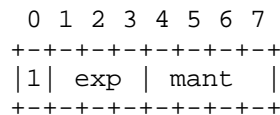
   Max Resp Time = (mant | 0x10) << (exp + 3)

   Small values of Max Resp Time allow IGMPv3 routers to tune the "leave
   latency" (the time between the moment the last host leaves a group
   and the moment the routing protocol is notified that there are no
   more members). Larger values, especially in the exponential range,
   allow tuning of the burstiness of IGMP traffic on a network.

4.1.2. Checksum

   The Checksum is the 16-bit one's complement of the one's complement
   sum of the whole IGMP message (the entire IP payload). For computing
   the checksum, the Checksum field is set to zero. When receiving
   packets, the checksum MUST be verified before processing a packet.
   [RFC-1071]

4.1.3. Group Address

   The Group Address field is set to zero when sending a General Query,
   and set to the IP multicast address being queried when sending a
   Group-Specific Query or Group-and-Source-Specific Query (see section
   4.1.9, below).

4.1.4. Resv (Reserved)

   The Resv field is set to zero on transmission, and ignored on
   reception.

4.1.5. S Flag (Suppress Router-Side Processing)

   When set to one, the S Flag indicates to any receiving multicast
   routers that they are to suppress the normal timer updates they
   perform upon hearing a Query. It does not, however, suppress the
   querier election or the normal "host-side" processing of a Query that
   a router may be required to perform as a consequence of itself being
   a group member.

4.1.6. QRV (Querier's Robustness Variable)

   If non-zero, the QRV field contains the [Robustness Variable] value
   used by the querier, i.e., the sender of the Query. If the querier's
   [Robustness Variable] exceeds 7, the maximum value of the QRV field,
   the QRV is set to zero. Routers adopt the QRV value from the most
   recently received Query as their own [Robustness Variable] value,
   unless that most recently received QRV was zero, in which case the
   receivers use the default [Robustness Variable] value specified in
   section 8.1 or a statically configured value.

4.1.7. QQIC (Querier's Query Interval Code)

   The Querier's Query Interval Code field specifies the [Query
   Interval] used by the querier. The actual interval, called the
   Querier's Query Interval (QQI), is represented in units of seconds
   and is derived from the Querier's Query Interval Code as follows:

   If QQIC < 128, QQI = QQIC

   If QQIC >= 128, QQIC represents a floating-point value as follows:

       0 1 2 3 4 5 6 7
      +-+-+-+-+-+-+-+-+
      |1| exp | mant |
      +-+-+-+-+-+-+-+-+

   QQI = (mant | 0x10) << (exp + 3)

   Multicast routers that are not the current querier adopt the QQI
   value from the most recently received Query as their own [Query
   Interval] value, unless that most recently received QQI was zero, in
   which case the receiving routers use the default [Query Interval]
   value specified in section 8.2.

4.1.8. Number of Sources (N)

   The Number of Sources (N) field specifies how many source addresses
   are present in the Query. This number is zero in a General Query or
   a Group-Specific Query, and non-zero in a Group-and-Source-Specific
   Query. This number is limited by the MTU of the network over which
   the Query is transmitted. For example, on an Ethernet with an MTU of
   1500 octets, the IP header including the Router Alert option consumes
   24 octets, and the IGMP fields up to including the Number of Sources
   (N) field consume 12 octets, leaving 1464 octets for source
   addresses, which limits the number of source addresses to 366
   (1464/4).

4.1.9. Source Address [i]

   The Source Address [i] fields are a vector of n IP unicast addresses,
   where n is the value in the Number of Sources (N) field.

4.1.10. Additional Data

   If the Packet Length field in the IP header of a received Query
   indicates that there are additional octets of data present, beyond
   the fields described here, IGMPv3 implementations MUST include those
   octets in the computation to verify the received IGMP Checksum, but
   MUST otherwise ignore those additional octets. When sending a Query,
   an IGMPv3 implementation MUST NOT include additional octets beyond
   the fields described here.

4.1.11. Query Variants

   There are three variants of the Query message:
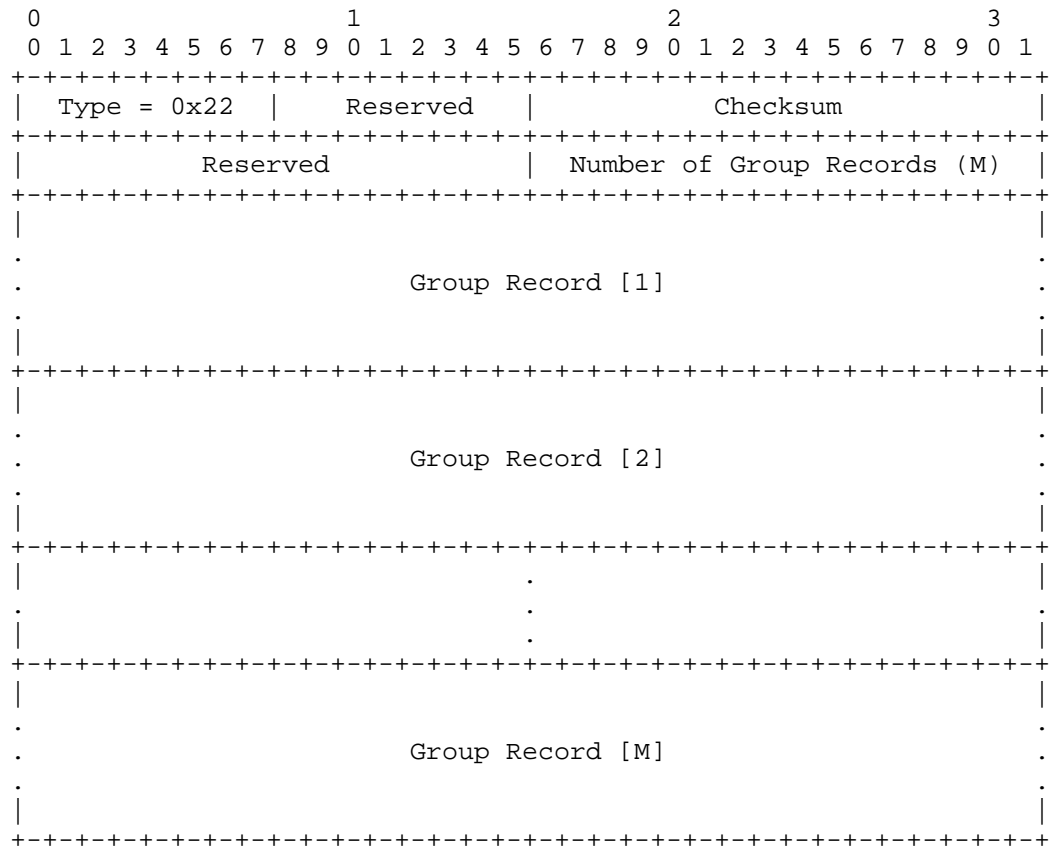
   1. A "General Query" is sent by a multicast router to learn the
      complete multicast reception state of the neighboring interfaces
      (that is, the interfaces attached to the network on which the
      Query is transmitted). In a General Query, both the Group Address
      field and the Number of Sources (N) field are zero.

   2. A "Group-Specific Query" is sent by a multicast router to learn
      the reception state, with respect to a *single* multicast address,
      of the neighboring interfaces. In a Group-Specific Query, the
      Group Address field contains the multicast address of interest,
      and the Number of Sources (N) field contains zero.

   3. A "Group-and-Source-Specific Query" is sent by a multicast router
      to learn if any neighboring interface desires reception of packets
      sent to a specified multicast address, from any of a specified
      list of sources. In a Group-and-Source-Specific Query, the Group
      Address field contains the multicast address of interest, and the
      Source Address [i] fields contain the source address(es) of
      interest.

4.1.12. IP Destination Addresses for Queries

   In IGMPv3, General Queries are sent with an IP destination address of
   224.0.0.1, the all-systems multicast address. Group-Specific and
   Group-and-Source-Specific Queries are sent with an IP destination
   address equal to the multicast address of interest. *However*, a
   system MUST accept and process any Query whose IP Destination
   Address field contains *any* of the addresses (unicast or multicast)
   assigned to the interface on which the Query arrives.

4.2. Version 3 Membership Report Message

   Version 3 Membership Reports are sent by IP systems to report (to
   neighboring routers) the current multicast reception state, or
   changes in the multicast reception state, of their interfaces.
   Reports have the following format:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Type = 0x22  |    Reserved   |           Checksum            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Reserved            |  Number of Group Records (M)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
.                                                               .
.                        Group Record [1]                       .
.                                                               .
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
.                                                               .
.                        Group Record [2]                       .
.                                                               .
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                               .                               |
.                               .                               .
|                               .                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
.                                                               .
.                        Group Record [M]                       .
.                                                               .
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   where each Group Record has the following internal format:

```
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |  Record Type  |  Aux Data Len |     Number of Sources (N)     |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       Multicast Address                       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                       Source Address [1]                      |
   +-                                                             -+
   |                       Source Address [2]                      |
   +-                                                             -+
   .                               .                               .
   .                               .                               .
   .                               .                               .
   +-                                                             -+
   |                       Source Address [N]                      |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   .                                                               .
   .                        Auxiliary Data                         .
   .                                                               .
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

4.2.1. Reserved

   The Reserved fields are set to zero on transmission, and ignored on
   reception.

4.2.2. Checksum

   The Checksum is the 16-bit one's complement of the one's complement
   sum of the whole IGMP message (the entire IP payload). For computing
   the checksum, the Checksum field is set to zero. When receiving
   packets, the checksum MUST be verified before processing a message.

4.2.3. Number of Group Records (M)

   The Number of Group Records (M) field specifies how many Group
   Records are present in this Report.

4.2.4. Group Record

   Each Group Record is a block of fields containing information
   pertaining to the sender's membership in a single multicast group on
   the interface from which the Report is sent.

4.2.5. Record Type

   See section 4.2.12, below.

4.2.6. Aux Data Len

   The Aux Data Len field contains the length of the Auxiliary Data
   field in this Group Record, in units of 32-bit words. It may contain
   zero, to indicate the absence of any auxiliary data.

4.2.7. Number of Sources (N)

   The Number of Sources (N) field specifies how many source addresses
   are present in this Group Record.

4.2.8. Multicast Address

   The Multicast Address field contains the IP multicast address to
   which this Group Record pertains.

4.2.9. Source Address [i]

   The Source Address [i] fields are a vector of n IP unicast addresses,
   where n is the value in this record's Number of Sources (N) field.

4.2.10. Auxiliary Data

   The Auxiliary Data field, if present, contains additional information
   pertaining to this Group Record. The protocol specified in this
   document, IGMPv3, does not define any auxiliary data. Therefore,
   implementations of IGMPv3 MUST NOT include any auxiliary data (i.e.,
   MUST set the Aux Data Len field to zero) in any transmitted Group
   Record, and MUST ignore any auxiliary data present in any received
   Group Record. The semantics and internal encoding of the Auxiliary
   Data field are to be defined by any future version or extension of
   IGMP that uses this field.

4.2.11. Additional Data

   If the Packet Length field in the IP header of a received Report
   indicates that there are additional octets of data present, beyond
   the last Group Record, IGMPv3 implementations MUST include those
   octets in the computation to verify the received IGMP Checksum, but
   MUST otherwise ignore those additional octets. When sending a
   Report, an IGMPv3 implementation MUST NOT include additional octets
   beyond the last Group Record.

4.2.12. Group Record Types

   There are a number of different types of Group Records that may be
   included in a Report message:

   o A "Current-State Record" is sent by a system in response to a Query
     received on an interface. It reports the current reception state
     of that interface, with respect to a single multicast address. The
     Record Type of a Current-State Record may be one of the following
     two values:

        Value Name and Meaning
        ----- ----------------

          1   MODE_IS_INCLUDE - indicates that the interface has a
               filter mode of INCLUDE for the specified multicast
               address. The Source Address [i] fields in this Group
               Record contain the interface's source list for the
               specified multicast address, if it is non-empty.

          2   MODE_IS_EXCLUDE - indicates that the interface has a
               filter mode of EXCLUDE for the specified multicast
               address. The Source Address [i] fields in this Group
               Record contain the interface's source list for the
               specified multicast address, if it is non-empty.

   o A "Filter-Mode-Change Record" is sent by a system whenever a local
     invocation of IPMulticastListen causes a change of the filter mode
     (i.e., a change from INCLUDE to EXCLUDE, or from EXCLUDE to
     INCLUDE), of the interface-level state entry for a particular
     multicast address. The Record is included in a Report sent from
     the interface on which the change occurred. The Record Type of a
     Filter-Mode-Change Record may be one of the following two values:

          3   CHANGE_TO_INCLUDE_MODE - indicates that the interface
               has changed to INCLUDE filter mode for the specified
               multicast address. The Source Address [i] fields
               in this Group Record contain the interface's new
               source list for the specified multicast address,
               if it is non-empty.

          4   CHANGE_TO_EXCLUDE_MODE - indicates that the interface
               has changed to EXCLUDE filter mode for the specified
               multicast address. The Source Address [i] fields
               in this Group Record contain the interface's new
               source list for the specified multicast address,
               if it is non-empty.

   o A "Source-List-Change Record" is sent by a system whenever a local
     invocation of IPMulticastListen causes a change of source list that
     is *not* coincident with a change of filter mode, of the
     interface-level state entry for a particular multicast address.
     The Record is included in a Report sent from the interface on which
     the change occurred. The Record Type of a Source-List-Change
     Record may be one of the following two values:

        5   ALLOW_NEW_SOURCES - indicates that the Source Address
              [i] fields in this Group Record contain a list of the
              additional sources that the system wishes to
              hear from, for packets sent to the specified
              multicast address. If the change was to an INCLUDE
              source list, these are the addresses that were added
              to the list; if the change was to an EXCLUDE source
              list, these are the addresses that were deleted from
              the list.

        6   BLOCK_OLD_SOURCES - indicates that the Source Address
              [i] fields in this Group Record contain a list of the
              sources that the system no longer wishes to
              hear from, for packets sent to the specified
              multicast address. If the change was to an INCLUDE
              source list, these are the addresses that were
              deleted from the list; if the change was to an
              EXCLUDE source list, these are the addresses that
              were added to the list.

   If a change of source list results in both allowing new sources and
   blocking old sources, then two Group Records are sent for the same
   multicast address, one of type ALLOW_NEW_SOURCES and one of type
   BLOCK_OLD_SOURCES.

   We use the term "State-Change Record" to refer to either a Filter-
   Mode-Change Record or a Source-List-Change Record.

   Unrecognized Record Type values MUST be silently ignored.

4.2.13. IP Source Addresses for Reports

   An IGMP report is sent with a valid IP source address for the
   destination subnet. The 0.0.0.0 source address may be used by a
   system that has not yet acquired an IP address. Note that the
   0.0.0.0 source address may simultaneously be used by multiple systems
   on a LAN. Routers MUST accept a report with a source address of
   0.0.0.0.

4.2.14. IP Destination Addresses for Reports

   Version 3 Reports are sent with an IP destination address of
   224.0.0.22, to which all IGMPv3-capable multicast routers listen. A
   system that is operating in version 1 or version 2 compatibility
   modes sends version 1 or version 2 Reports to the multicast group
   specified in the Group Address field of the Report. In addition, a
   system MUST accept and process any version 1 or version 2 Report
   whose IP Destination Address field contains *any* of the addresses
   (unicast or multicast) assigned to the interface on which the Report
   arrives.

4.2.15. Notation for Group Records

   In the rest of this document, we use the following notation to
   describe the contents of a Group Record pertaining to a particular
   multicast address:

        IS_IN (x) - Type MODE_IS_INCLUDE, source addresses x
        IS_EX (x) - Type MODE_IS_EXCLUDE, source addresses x
        TO_IN (x) - Type CHANGE_TO_INCLUDE_MODE, source addresses x
        TO_EX (x) - Type CHANGE_TO_EXCLUDE_MODE, source addresses x
        ALLOW (x) - Type ALLOW_NEW_SOURCES, source addresses x
        BLOCK (x) - Type BLOCK_OLD_SOURCES, source addresses x

   where x is either:

   o a capital letter (e.g., "A") to represent the set of source
     addresses, or

   o a set expression (e.g., "A+B"), where "A+B" means the union of sets
     A and B, "A*B" means the intersection of sets A and B, and "A-B"
     means the removal of all elements of set B from set A.

4.2.16. Membership Report Size

   If the set of Group Records required in a Report does not fit within
   the size limit of a single Report message (as determined by the MTU
   of the network on which it will be sent), the Group Records are sent
   in as many Report messages as needed to report the entire set.

   If a single Group Record contains so many source addresses that it
   does not fit within the size limit of a single Report message, if its
   Type is not MODE_IS_EXCLUDE or CHANGE_TO_EXCLUDE_MODE, it is split
   into multiple Group Records, each containing a different subset of
   the source addresses and each sent in a separate Report message. If
   its Type is MODE_IS_EXCLUDE or CHANGE_TO_EXCLUDE_MODE, a single Group
   Record is sent, containing as many source addresses as can fit, and

the remaining source addresses are not reported; though the choice of
which sources to report is arbitrary, it is preferable to report the
same set of sources in each subsequent report, rather than reporting
different sources each time.

5. Description of the Protocol for Group Members

   IGMP is an asymmetric protocol, specifying separate behaviors for
   group members -- that is, hosts or routers that wish to receive
   multicast packets -- and multicast routers. This section describes
   the part of IGMPv3 that applies to all group members. (Note that a
   multicast router that is also a group member performs both parts of
   IGMPv3, receiving and responding to its own IGMP message
   transmissions as well as those of its neighbors. The multicast
   router part of IGMPv3 is described in section 6.)

   A system performs the protocol described in this section over all
   interfaces on which multicast reception is supported, even if more
   than one of those interfaces is connected to the same network.

   For interoperability with multicast routers running older versions of
   IGMP, systems maintain a MulticastRouterVersion variable for each
   interface on which multicast reception is supported. This section
   describes the behavior of group member systems on interfaces for
   which MulticastRouterVersion = 3. The algorithm for determining
   MulticastRouterVersion, and the behavior for versions other than 3,
   are described in section 7.

   The all-systems multicast address, 224.0.0.1, is handled as a special
   case. On all systems -- that is all hosts and routers, including
   multicast routers -- reception of packets destined to the all-systems
   multicast address, from all sources, is permanently enabled on all
   interfaces on which multicast reception is supported. No IGMP
   messages are ever sent regarding the all-systems multicast address.

   There are two types of events that trigger IGMPv3 protocol actions on
   an interface:

   o a change of the interface reception state, caused by a local
     invocation of IPMulticastListen.

   o reception of a Query.

   (Received IGMP messages of types other than Query are silently
   ignored, except as required for interoperation with earlier versions
   of IGMP.)

The following subsections describe the actions to be taken for each
of these two cases. In those descriptions, timer and counter names
appear in square brackets. The default values for those timers and
counters are specified in section 8.

5.1. Action on Change of Interface State

An invocation of IPMulticastListen may cause the multicast reception
state of an interface to change, according to the rules in section
3.2. Each such change affects the per-interface entry for a single
multicast address.

A change of interface state causes the system to immediately transmit
a State-Change Report from that interface. The type and contents of
the Group Record(s) in that Report are determined by comparing the
filter mode and source list for the affected multicast address before
and after the change, according to the table below. If no interface
state existed for that multicast address before the change (i.e., the
change consisted of creating a new per-interface record), or if no
state exists after the change (i.e., the change consisted of deleting
a per-interface record), then the "non-existent" state is considered
to have a filter mode of INCLUDE and an empty source list.

Old State	New State	State-Change Record Sent
INCLUDE (A)	INCLUDE (B)	ALLOW (B-A), BLOCK (A-B)
EXCLUDE (A)	EXCLUDE (B)	ALLOW (A-B), BLOCK (B-A)
INCLUDE (A)	EXCLUDE (B)	TO_EX (B)
EXCLUDE (A)	INCLUDE (B)	TO_IN (B)

If the computed source list for either an ALLOW or a BLOCK State-
Change Record is empty, that record is omitted from the Report
message.

To cover the possibility of the State-Change Report being missed by
one or more multicast routers, it is retransmitted [Robustness
Variable] - 1 more times, at intervals chosen at random from the
range (0, [Unsolicited Report Interval]).

If more changes to the same interface state entry occur before all
the retransmissions of the State-Change Report for the first change
have been completed, each such additional change triggers the
immediate transmission of a new State-Change Report.

The contents of the new transmitted report are calculated as follows.
As was done with the first report, the interface state for the
affected group before and after the latest change is compared. The
report records expressing the difference are built according to the
table above. However these records are not transmitted in a message
but instead merged with the contents of the pending report, to create
the new State-Change report. The rules for merging the difference
report resulting from the state change and the pending report are
described below.

The transmission of the merged State-Change Report terminates
retransmissions of the earlier State-Change Reports for the same
multicast address, and becomes the first of [Robustness Variable]
transmissions of State-Change Reports.

Each time a source is included in the difference report calculated
above, retransmission state for that source needs to be maintained
until [Robustness Variable] State-Change reports have been sent by
the host. This is done in order to ensure that a series of
successive state changes do not break the protocol robustness.

If the interface reception-state change that triggers the new report
is a filter-mode change, then the next [Robustness Variable] State-
Change Reports will include a Filter-Mode-Change record. This
applies even if any number of source-list changes occur in that
period. The host has to maintain retransmission state for the group
until the [Robustness Variable] State-Change reports have been sent.
When [Robustness Variable] State-Change reports with Filter-Mode-
Change records have been transmitted after the last filter-mode
change, and if source-list changes to the interface reception have
scheduled additional reports, then the next State-Change report will
include Source-List-Change records.

Each time a State-Change Report is transmitted, the contents are
determined as follows. If the report should contain a Filter-Mode-
Change record, then if the current filter-mode of the interface is
INCLUDE, a TO_IN record is included in the report, otherwise a TO_EX
record is included. If instead the report should contain Source-
List-Change records, an ALLOW and a BLOCK record are included. The
contents of these records are built according to the table below.

```
    Record   Sources included
    ------   ----------------
    TO_IN    All in the current interface state that must be forwarded
    TO_EX    All in the current interface state that must be blocked
    ALLOW    All with retransmission state that must be forwarded
    BLOCK    All with retransmission state that must be blocked
```

   If the computed source list for either an ALLOW or a BLOCK record is
   empty, that record is omitted from the State-Change report.

   Note: When the first State-Change report is sent, the non-existent
   pending report to merge with, can be treated as a source-change
   report with empty ALLOW and BLOCK records (no sources have
   retransmission state).

5.2. Action on Reception of a Query

   When a system receives a Query, it does not respond immediately.
   Instead, it delays its response by a random amount of time, bounded
   by the Max Resp Time value derived from the Max Resp Code in the
   received Query message. A system may receive a variety of Queries on
   different interfaces and of different kinds (e.g., General Queries,
   Group-Specific Queries, and Group-and-Source-Specific Queries), each
   of which may require its own delayed response.

   Before scheduling a response to a Query, the system must first
   consider previously scheduled pending responses and in many cases
   schedule a combined response. Therefore, the system must be able to
   maintain the following state:

   o A timer per interface for scheduling responses to General Queries.

   o A per-group and interface timer for scheduling responses to Group-
     Specific and Group-and-Source-Specific Queries.

   o A per-group and interface list of sources to be reported in the
     response to a Group-and-Source-Specific Query.

   When a new Query with the Router-Alert option arrives on an
   interface, provided the system has state to report, a delay for a
   response is randomly selected in the range (0, [Max Resp Time]) where
   Max Resp Time is derived from Max Resp Code in the received Query
   message. The following rules are then used to determine if a Report
   needs to be scheduled and the type of Report to schedule. The rules
   are considered in order and only the first matching rule is applied.

   1. If there is a pending response to a previous General Query
      scheduled sooner than the selected delay, no additional response
      needs to be scheduled.

   2. If the received Query is a General Query, the interface timer is
      used to schedule a response to the General Query after the
      selected delay. Any previously pending response to a General
      Query is canceled.

   3. If the received Query is a Group-Specific Query or a Group-and-
      Source-Specific Query and there is no pending response to a
      previous Query for this group, then the group timer is used to
      schedule a report. If the received Query is a Group-and-Source-
      Specific Query, the list of queried sources is recorded to be used
      when generating a response.

   4. If there already is a pending response to a previous Query
      scheduled for this group, and either the new Query is a Group-
      Specific Query or the recorded source-list associated with the
      group is empty, then the group source-list is cleared and a single
      response is scheduled using the group timer. The new response is
      scheduled to be sent at the earliest of the remaining time for the
      pending report and the selected delay.

   5. If the received Query is a Group-and-Source-Specific Query and
      there is a pending response for this group with a non-empty
      source-list, then the group source list is augmented to contain
      the list of sources in the new Query and a single response is
      scheduled using the group timer. The new response is scheduled to
      be sent at the earliest of the remaining time for the pending
      report and the selected delay.

   When the timer in a pending response record expires, the system
   transmits, on the associated interface, one or more Report messages
   carrying one or more Current-State Records (see section 4.2.12), as
   follows:

   1. If the expired timer is the interface timer (i.e., it is a pending
      response to a General Query), then one Current-State Record is
      sent for each multicast address for which the specified interface
      has reception state, as described in section 3.2. The Current-
      State Record carries the multicast address and its associated
      filter mode (MODE_IS_INCLUDE or MODE_IS_EXCLUDE) and source list.
      Multiple Current-State Records are packed into individual Report
      messages, to the extent possible.

      This naive algorithm may result in bursts of packets when a system
      is a member of a large number of groups. Instead of using a
      single interface timer, implementations are recommended to spread
      transmission of such Report messages over the interval (0, [Max
      Resp Time]). Note that any such implementation MUST avoid the
      "ack-implosion" problem, i.e., MUST NOT send a Report immediately
      on reception of a General Query.

2. If the expired timer is a group timer and the list of recorded
   sources for the that group is empty (i.e., it is a pending
   response to a Group-Specific Query), then if and only if the
   interface has reception state for that group address, a single
   Current-State Record is sent for that address. The Current-State
   Record carries the multicast address and its associated filter
   mode (MODE_IS_INCLUDE or MODE_IS_EXCLUDE) and source list.

3. If the expired timer is a group timer and the list of recorded
   sources for that group is non-empty (i.e., it is a pending
   response to a Group-and-Source-Specific Query), then if and only
   if the interface has reception state for that group address, the
   contents of the responding Current-State Record is determined from
   the interface state and the pending response record, as specified
   in the following table:

interface state	set of sources in the pending response record	Current-State Record
INCLUDE (A)	B	IS_IN (A*B)
EXCLUDE (A)	B	IS_IN (B-A)

If the resulting Current-State Record has an empty set of source
addresses, then no response is sent.

Finally, after any required Report messages have been generated, the
source lists associated with any reported groups are cleared.

6. Description of the Protocol for Multicast Routers

   The purpose of IGMP is to enable each multicast router to learn, for
   each of its directly attached networks, which multicast addresses are
   of interest to the systems attached to those networks. IGMP version
   3 adds the capability for a multicast router to also learn which
   sources are of interest to neighboring systems, for packets sent to
   any particular multicast address. The information gathered by IGMP
   is provided to whichever multicast routing protocol is being used by
   the router, in order to ensure that multicast packets are delivered
   to all networks where there are interested receivers.

   This section describes the part of IGMPv3 that is performed by
   multicast routers. Multicast routers may also themselves become
   members of multicast groups, and therefore also perform the group
   member part of IGMPv3, described in section 5.

A multicast router performs the protocol described in this section
over each of its directly-attached networks. If a multicast router
has more than one interface to the same network, it only needs to
operate this protocol over one of those interfaces. On each
interface over which this protocol is being run, the router MUST
enable reception of multicast address 224.0.0.22, from all sources
(and MUST perform the group member part of IGMPv3 for that address on
that interface).

Multicast routers need to know only that *at least one* system on an
attached network is interested in packets to a particular multicast
address from a particular source; a multicast router is not required
to keep track of the interests of each individual neighboring system.
(However, see Appendix A.2 point 1 for discussion.)

IGMPv3 is backward compatible with previous versions of the IGMP
protocol. In order to remain backward compatible with older IGMP
systems, IGMPv3 multicast routers MUST also implement versions 1 and
2 of the protocol (see section 7).

6.1. Conditions for IGMP Queries

Multicast routers send General Queries periodically to request group
membership information from an attached network. These queries are
used to build and refresh the group membership state of systems on
attached networks. Systems respond to these queries by reporting
their group membership state (and their desired set of sources) with
Current-State Group Records in IGMPv3 Membership Reports.

As a member of a multicast group, a system may express interest in
receiving or not receiving traffic from particular sources. As the
desired reception state of a system changes, it reports these changes
using Filter-Mode-Change Records or Source-List-Change Records.
These records indicate an explicit state change in a group at a
system in either the group record's source list or its filter-mode.
When a group membership is terminated at a system or traffic from a
particular source is no longer desired, a multicast router must query
for other members of the group or listeners of the source before
deleting the group (or source) and pruning its traffic.

To enable all systems on a network to respond to changes in group
membership, multicast routers send specific queries. A Group-
Specific Query is sent to verify there are no systems that desire
reception of the specified group or to "rebuild" the desired
reception state for a particular group. Group-Specific Queries are
sent when a router receives a State-Change record indicating a system
is leaving a group.

A Group-and-Source Specific Query is used to verify there are no
systems on a network which desire to receive traffic from a set of
sources. Group-and-Source Specific Queries list sources for a
particular group which have been requested to no longer be forwarded.
This query is sent by a multicast router to learn if any systems
desire reception of packets to the specified group address from the
specified source addresses. Group-and-Source Specific Queries are
only sent in response to State-Change Records and never in response
to Current-State Records. Section 4.1.11 describes each query in
more detail.

6.2. IGMP State Maintained by Multicast Routers

Multicast routers implementing IGMPv3 keep state per group per
attached network. This group state consists of a filter-mode, a list
of sources, and various timers. For each attached network running
IGMP, a multicast router records the desired reception state for that
network. That state conceptually consists of a set of records of the
form:

    (multicast address, group timer, filter-mode, (source records))

Each source record is of the form:

    (source address, source timer)

If all sources within a given group are desired, an empty source
record list is kept with filter-mode set to EXCLUDE. This means
hosts on this network want all sources for this group to be
forwarded. This is the IGMPv3 equivalent to a IGMPv1 or IGMPv2 group
join.

6.2.1. Definition of Router Filter-Mode

To reduce internal state, IGMPv3 routers keep a filter-mode per group
per attached network. This filter-mode is used to condense the total
desired reception state of a group to a minimum set such that all
systems' memberships are satisfied. This filter-mode may change in
response to the reception of particular types of group records or
when certain timer conditions occur. In the following sections, we
use the term "router filter-mode" to refer to the filter-mode of a
particular group within a router. Section 6.4 describes the changes
of a router filter-mode per group record received.

Conceptually, when a group record is received, the router filter-mode
for that group is updated to cover all the requested sources using
the least amount of state. As a rule, once a group record with a
filter-mode of EXCLUDE is received, the router filter-mode for that
group will be EXCLUDE.

When a router filter-mode for a group is EXCLUDE, the source record
list contains two types of sources. The first type is the set which
represents conflicts in the desired reception state; this set must be
forwarded by some router on the network. The second type is the set
of sources which hosts have requested to not be forwarded. Appendix
A describes the reasons for keeping this second set when in EXCLUDE
mode.

When a router filter-mode for a group is INCLUDE, the source record
list is the list of sources desired for the group. This is the total
desired set of sources for that group. Each source in the source
record list must be forwarded by some router on the network.

Because a reported group record with a filter-mode of EXCLUDE will
cause a router to transition its filter-mode for that group to
EXCLUDE, a mechanism for transitioning a router's filter-mode back to
INCLUDE must exist. If all systems with a group record in EXCLUDE
filter-mode cease reporting, it is desirable for the router filter-
mode for that group to transition back to INCLUDE mode. This
transition occurs when the group timer expires and is explained in
detail in section 6.5.

6.2.2. Definition of Group Timers

The group timer is only used when a group is in EXCLUDE mode and it
represents the time for the *filter-mode* of the group to expire and
switch to INCLUDE mode. We define a group timer as a decrementing
timer with a lower bound of zero kept per group per attached network.
Group timers are updated according to the types of group records
received.

A group timer expiring when a router filter-mode for the group is
EXCLUDE means there are no listeners on the attached network in
EXCLUDE mode. At this point, a router will transition to INCLUDE
filter-mode. Section 6.5 describes the actions taken when a group
timer expires while in EXCLUDE mode.

The following table summarizes the role of the group timer. Section
6.4 describes the details of setting the group timer per type of
group record received.

Group Filter-Mode	Group Timer Value	Actions/Comments
INCLUDE	Timer >= 0	All members in INCLUDE mode.
EXCLUDE	Timer > 0	At least one member in EXCLUDE mode.
EXCLUDE	Timer == 0	No more listeners to group. If all source timers have expired then delete Group Record. If there are still source record timers running, switch to INCLUDE filter-mode using those source records with running timers as the INCLUDE source record state.

6.2.3. Definition of Source Timers

   A source timer is kept per source record and is a decrementing timer
   with a lower bound of zero. Source timers are updated according to
   the type and filter-mode of the group record received. Source timers
   are always updated (for a particular group) whenever the source is
   present in a received record for that group. Section 6.4 describes
   the setting of source timers per type of group records received.

   A source record with a running timer with a router filter-mode for
   the group of INCLUDE means that there is currently one or more
   systems (in INCLUDE filter-mode) which desire to receive that source.
   If a source timer expires with a router filter-mode for the group of
   INCLUDE, the router concludes that traffic from this particular
   source is no longer desired on the attached network, and deletes the
   associated source record.

   Source timers are treated differently when a router filter-mode for a
   group is EXCLUDE. If a source record has a running timer with a
   router filter-mode for the group of EXCLUDE, it means that at least
   one system desires the source. It should therefore be forwarded by a
   router on the network. Appendix A describes the reasons for keeping
   state for sources that have been requested to be forwarded while in
   EXCLUDE state.

If a source timer expires with a router filter-mode for the group of
EXCLUDE, the router informs the routing protocol that there is no
longer a receiver on the network interested in traffic from this
source.

When a router filter-mode for a group is EXCLUDE, source records are
only deleted when the group timer expires. Section 6.3 describes the
actions that should be taken dependent upon the value of a source
timer.

6.3. IGMPv3 Source-Specific Forwarding Rules

When a multicast router receives a datagram from a source destined to
a particular group, a decision has to be made whether to forward the
datagram onto an attached network or not. The multicast routing
protocol in use is in charge of this decision, and should use the
IGMPv3 information to ensure that all sources/groups desired on a
subnetwork are forwarded to that subnetwork. IGMPv3 information does
not override multicast routing information; for example, if the
IGMPv3 filter-mode group for G is EXCLUDE, a router may still forward
packets for excluded sources to a transit subnet.

To summarize, the following table describes the forwarding
suggestions made by IGMP to the routing protocol for traffic
originating from a source destined to a group. It also summarizes
the actions taken upon the expiration of a source timer based on the
router filter-mode of the group.

Group Filter-Mode	Source Timer Value	Action
INCLUDE	TIMER > 0	Suggest to forward traffic from source
INCLUDE	TIMER == 0	Suggest to stop forwarding traffic from source and remove source record. If there are no more source records for the group, delete group record.
INCLUDE	No Source Elements	Suggest to not forward source
EXCLUDE	TIMER > 0	Suggest to forward traffic from source

EXCLUDE	TIMER == 0	Suggest to not forward traffic from source (DO NOT remove record)
EXCLUDE	No Source Elements	Suggest to forward traffic from source

6.4. Action on Reception of Reports

6.4.1. Reception of Current-State Records

   When receiving Current-State Records, a router updates both its group
   and source timers. In some circumstances, the reception of a type of
   group record will cause the router filter-mode for that group to
   change. The table below describes the actions, with respect to state
   and timers that occur to a router's state upon reception of Current-
   State Records.

   The following notation is used to describe the updating of source
   timers. The notation (A, B) will be used to represent the total
   number of sources for a particular group, where

   A = set of source records whose source timers > 0 (Sources that at
       least one host has requested to be forwarded)
   B = set of source records whose source timers = 0 (Sources that IGMP
       will suggest to the routing protocol not to forward)

   Note that there will only be two sets when a router's filter-mode for
   a group is EXCLUDE. When a router's filter-mode for a group is
   INCLUDE, a single set is used to describe the set of sources
   requested to be forwarded (e.g., simply (A)).

   In the following tables, abbreviations are used for several variables
   (all of which are described in detail in section 8). The variable
   GMI is an abbreviation for the Group Membership Interval, which is
   the time in which group memberships will time out. The variable LMQT
   is an abbreviation for the Last Member Query Time, which is the total
   time spent after Last Member Query Count retransmissions. LMQT
   represents the "leave latency", or the difference between the
   transmission of a membership change and the change in the information
   given to the routing protocol.

   Within the "Actions" section of the router state tables, we use the
   notation 'A=J', which means that the set A of source records should
   have their source timers set to value J. 'Delete A' means that the
   set A of source records should be deleted. 'Group Timer=J' means
   that the Group Timer for the group should be set to value J.

Router State	Report Rec'd	New Router State	Actions
INCLUDE (A)	IS_IN (B)	INCLUDE (A+B)	(B)=GMI
INCLUDE (A)	IS_EX (B)	EXCLUDE (A*B,B-A)	(B-A)=0 Delete (A-B) Group Timer=GMI
EXCLUDE (X,Y)	IS_IN (A)	EXCLUDE (X+A,Y-A)	(A)=GMI
EXCLUDE (X,Y)	IS_EX (A)	EXCLUDE (A-Y,Y*A)	(A-X-Y)=GMI Delete (X-A) Delete (Y-A) Group Timer=GMI

6.4.2. Reception of Filter-Mode-Change and Source-List-Change Records

   When a change in the global state of a group occurs in a system, the
   system sends either a Source-List-Change Record or a Filter-Mode-
   Change Record for that group. As with Current-State Records, routers
   must act upon these records and possibly change their own state to
   reflect the new desired membership state of the network.

   Routers must query sources that are requested to be no longer
   forwarded to a group. When a router queries or receives a query for
   a specific set of sources, it lowers its source timers for those
   sources to a small interval of Last Member Query Time seconds. If
   group records are received in response to the queries which express
   interest in receiving traffic from the queried sources, the
   corresponding timers are updated.

   Similarly, when a router queries a specific group, it lowers its
   group timer for that group to a small interval of Last Member Query
   Time seconds. If any group records expressing EXCLUDE mode interest
   in the group are received within the interval, the group timer for
   the group is updated and the suggestion to the routing protocol to
   forward the group stands without any interruption.

   During a query period (i.e., Last Member Query Time seconds), the
   IGMP component in the router continues to suggest to the routing
   protocol that it forwards traffic from the groups or sources that it
   is querying. It is not until after Last Member Query Time seconds
   without receiving a record expressing interest in the queried group
   or sources that the router may prune the group or sources from the
   network.

   The following table describes the changes in group state and the
   action(s) taken when receiving either Filter-Mode-Change or Source-
   List-Change Records. This table also describes the queries which are
   sent by the querier when a particular report is received.

   We use the following notation for describing the queries which are
   sent. We use the notation 'Q(G)' to describe a Group-Specific Query
   to G. We use the notation 'Q(G,A)' to describe a Group-and-Source
   Specific Query to G with source-list A. If source-list A is null as
   a result of the action (e.g., A*B) then no query is sent as a result
   of the operation.

   In order to maintain protocol robustness, queries sent by actions in
   the table below need to be transmitted [Last Member Query Count]
   times, once every [Last Member Query Interval].

   If while scheduling new queries, there are already pending queries to
   be retransmitted for the same group, the new and pending queries have
   to be merged. In addition, received host reports for a group with
   pending queries may affect the contents of those queries. Section
   6.6.3 describes the process of building and maintaining the state of
   pending queries.

Router State	Report Rec'd	New Router State	Actions
INCLUDE (A)	ALLOW (B)	INCLUDE (A+B)	(B)=GMI
INCLUDE (A)	BLOCK (B)	INCLUDE (A)	Send Q(G,A*B)
INCLUDE (A)	TO_EX (B)	EXCLUDE (A*B,B-A)	(B-A)=0 Delete (A-B) Send Q(G,A*B) Group Timer=GMI
INCLUDE (A)	TO_IN (B)	INCLUDE (A+B)	(B)=GMI Send Q(G,A-B)
EXCLUDE (X,Y)	ALLOW (A)	EXCLUDE (X+A,Y-A)	(A)=GMI
EXCLUDE (X,Y)	BLOCK (A)	EXCLUDE (X+(A-Y),Y)	(A-X-Y)=Group Timer Send Q(G,A-Y)
EXCLUDE (X,Y)	TO_EX (A)	EXCLUDE (A-Y,Y*A)	(A-X-Y)=Group Timer Delete (X-A) Delete (Y-A) Send Q(G,A-Y) Group Timer=GMI

```
EXCLUDE (X,Y)  TO_IN (A)     EXCLUDE (X+A,Y-A)       (A)=GMI
                                                     Send Q(G,X-A)
                                                     Send Q(G)
```

6.5. Switching Router Filter-Modes

   The group timer is used as a mechanism for transitioning the router
   filter-mode from EXCLUDE to INCLUDE.

   When a group timer expires with a router filter-mode of EXCLUDE, a
   router assumes that there are no systems with a *filter-mode* of
   EXCLUDE present on the attached network. When a router's filter-mode
   for a group is EXCLUDE and the group timer expires, the router
   filter-mode for the group transitions to INCLUDE.

   A router uses source records with running source timers as its state
   for the switch to a filter-mode of INCLUDE. If there are any source
   records with source timers greater than zero (i.e., requested to be
   forwarded), a router switches to filter-mode of INCLUDE using those
   source records. Source records whose timers are zero (from the
   previous EXCLUDE mode) are deleted.

   For example, if a router's state for a group is EXCLUDE(X,Y) and the
   group timer expires for that group, the router switches to filter-
   mode of INCLUDE with state INCLUDE(X).

6.6. Action on Reception of Queries

6.6.1. Timer Updates

   When a router sends or receives a query with a clear Suppress
   Router-Side Processing flag, it must update its timers to reflect the
   correct timeout values for the group or sources being queried. The
   following table describes the timer actions when sending or receiving
   a Group-Specific or Group-and-Source Specific Query with the Suppress
   Router-Side Processing flag not set.

```
       Query       Action
       -----       ------
       Q(G,A)      Source Timer for sources in A are lowered to LMQT
       Q(G)        Group Timer is lowered to LMQT
```

   When a router sends or receives a query with the Suppress Router-Side
   Processing flag set, it will not update its timers.

6.6.2. Querier Election

   IGMPv3 elects a single querier per subnet using the same querier
   election mechanism as IGMPv2, namely by IP address. When a router
   receives a query with a lower IP address, it sets the Other-Querier-
   Present timer to Other Querier Present Interval and ceases to send
   queries on the network if it was the previously elected querier.
   After its Other-Querier Present timer expires, it should begin
   sending General Queries.

   If a router receives an older version query, it MUST use the oldest
   version of IGMP on the network. For a detailed description of
   compatibility issues between IGMP versions see section 7.

6.6.3. Building and Sending Specific Queries

6.6.3.1. Building and Sending Group Specific Queries

   When a table action "Send Q(G)" is encountered, then the group timer
   must be lowered to LMQT. The router must then immediately send a
   group specific query as well as schedule [Last Member Query Count -
   1] query retransmissions to be sent every [Last Member Query
   Interval] over [Last Member Query Time].

   When transmitting a group specific query, if the group timer is
   larger than LMQT, the "Suppress Router-Side Processing" bit is set in
   the query message.

6.6.3.2. Building and Sending Group and Source Specific Queries

   When a table action "Send Q(G,X)" is encountered by a querier in the
   table in section 6.4.2, the following actions must be performed for
   each of the sources in X of group G, with source timer larger than
   LMQT:

   o Set number of retransmissions for each source to [Last Member Query
     Count].

   o Lower source timer to LMQT.

   The router must then immediately send a group and source specific
   query as well as schedule [Last Member Query Count - 1] query
   retransmissions to be sent every [Last Member Query Interval] over
   [Last Member Query Time]. The contents of these queries are
   calculated as follows.

When building a group and source specific query for a group G, two
separate query messages are sent for the group. The first one has
the "Suppress Router-Side Processing" bit set and contains all the
sources with retransmission state and timers greater than LMQT. The
second has the "Suppress Router-Side Processing" bit clear and
contains all the sources with retransmission state and timers lower
or equal to LMQT. If either of the two calculated messages does not
contain any sources, then its transmission is suppressed.

Note: If a group specific query is scheduled to be transmitted at the
same time as a group and source specific query for the same group,
then transmission of the group and source specific message with the
"Suppress Router-Side Processing" bit set may be suppressed.

7. Interoperation With Older Versions of IGMP

   IGMP version 3 hosts and routers interoperate with hosts and routers
   that have not yet been upgraded to IGMPv3. This compatibility is
   maintained by hosts and routers taking appropriate actions depending
   on the versions of IGMP operating on hosts and routers within a
   network.

7.1. Query Version Distinctions

   The IGMP version of a Membership Query message is determined as
   follows:

      IGMPv1 Query: length = 8 octets AND Max Resp Code field is zero

      IGMPv2 Query: length = 8 octets AND Max Resp Code field is
                    non-zero

      IGMPv3 Query: length >= 12 octets

   Query messages that do not match any of the above conditions (e.g., a
   Query of length 10 octets) MUST be silently ignored.

7.2. Group Member Behavior

7.2.1. In the Presence of Older Version Queriers

   In order to be compatible with older version routers, IGMPv3 hosts
   MUST operate in version 1 and version 2 compatibility modes. IGMPv3
   hosts MUST keep state per local interface regarding the compatibility
   mode of each attached network. A host's compatibility mode is

determined from the Host Compatibility Mode variable which can be in
one of three states: IGMPv1, IGMPv2 or IGMPv3. This variable is
kept per interface and is dependent on the version of General Queries
heard on that interface as well as the Older Version Querier Present
timers for the interface.

In order to switch gracefully between versions of IGMP, hosts keep
both an IGMPv1 Querier Present timer and an IGMPv2 Querier Present
timer per interface. IGMPv1 Querier Present is set to Older Version
Querier Present Timeout seconds whenever an IGMPv1 Membership Query
is received. IGMPv2 Querier Present is set to Older Version Querier
Present Timeout seconds whenever an IGMPv2 General Query is received.

The Host Compatibility Mode of an interface changes whenever an older
version query (than the current compatibility mode) is heard or when
certain timer conditions occur. When the IGMPv1 Querier Present
timer expires, a host switches to Host Compatibility mode of IGMPv2
if it has a running IGMPv2 Querier Present timer. If it does not
have a running IGMPv2 Querier Present timer then it switches to Host
Compatibility of IGMPv3. When the IGMPv2 Querier Present timer
expires, a host switches to Host Compatibility mode of IGMPv3.

The Host Compatibility Mode variable is based on whether an older
version General query was heard in the last Older Version Querier
Present Timeout seconds. The Host Compatibility Mode is set
depending on the following:

```
Host Compatibility Mode          Timer State
-----------------------          -----------

     IGMPv3 (default)            IGMPv2 Querier Present not running
                                 and IGMPv1 Querier Present not running

     IGMPv2                      IGMPv2 Querier Present running
                                 and IGMPv1 Querier Present not running

     IGMPv1                      IGMPv1 Querier Present running
```

If a host receives a query which causes its Querier Present timers to
be updated and correspondingly its compatibility mode, it should
switch compatibility modes immediately.

When Host Compatibility Mode is IGMPv3, a host acts using the IGMPv3
protocol on that interface. When Host Compatibility Mode is IGMPv2,
a host acts in IGMPv2 compatibility mode, using only the IGMPv2
protocol, on that interface. When Host Compatibility Mode is IGMPv1,
a host acts in IGMPv1 compatibility mode, using only the IGMPv1
protocol on that interface.

An IGMPv1 router will send General Queries with the Max Resp Code set
to 0. This MUST be interpreted as a value of 100 (10 seconds).

An IGMPv2 router will send General Queries with the Max Resp Code set
to the desired Max Resp Time, i.e., the full range of this field is
linear and the exponential algorithm described in section 4.1.1 is
not used.

Whenever a host changes its compatibility mode, it cancels all its
pending response and retransmission timers.

7.2.2. In the Presence of Older Version Group Members

An IGMPv3 host may be placed on a network where there are hosts that
have not yet been upgraded to IGMPv3. A host MAY allow its IGMPv3
Membership Record to be suppressed by either a Version 1 Membership
Report, or a Version 2 Membership Report.

7.3. Multicast Router Behavior

7.3.1. In the Presence of Older Version Queriers

IGMPv3 routers may be placed on a network where at least one router
on the network has not yet been upgraded to IGMPv3. The following
requirements apply:

o If any older versions of IGMP are present on routers, the querier
  MUST use the lowest version of IGMP present on the network. This
  must be administratively assured; routers that desire to be
  compatible with IGMPv1 and IGMPv2 MUST have a configuration option
  to act in IGMPv1 or IGMPv2 compatibility modes. When in IGMPv1
  mode, routers MUST send Periodic Queries with a Max Resp Code of 0
  and truncated at the Group Address field (i.e., 8 bytes long), and
  MUST ignore Leave Group messages. They SHOULD also warn about
  receiving an IGMPv2 or IGMPv3 query, although such warnings MUST be
  rate-limited. When in IGMPv2 mode, routers MUST send Periodic
  Queries truncated at the Group Address field (i.e., 8 bytes long),
  and SHOULD also warn about receiving an IGMPv3 query (such warnings
  MUST be rate-limited). They also MUST fill in the Max Resp Time in
  the Max Resp Code field, i.e., the exponential algorithm described
  in section 4.1.1 is not used.

o If a router is not explicitly configured to use IGMPv1 or IGMPv2
  and hears an IGMPv1 Query or IGMPv2 General Query, it SHOULD log a
  warning. These warnings MUST be rate-limited.

7.3.2. In the Presence of Older Version Group Members

   IGMPv3 routers may be placed on a network where there are hosts that
   have not yet been upgraded to IGMPv3. In order to be compatible with
   older version hosts, IGMPv3 routers MUST operate in version 1 and
   version 2 compatibility modes. IGMPv3 routers keep a compatibility
   mode per group record. A group's compatibility mode is determined
   from the Group Compatibility Mode variable which can be in one of
   three states: IGMPv1, IGMPv2 or IGMPv3. This variable is kept per
   group record and is dependent on the version of Membership Reports
   heard for that group as well as the Older Version Host Present timer
   for the group.

   In order to switch gracefully between versions of IGMP, routers keep
   an IGMPv1 Host Present timer and an IGMPv2 Host Present timer per
   group record. The IGMPv1 Host Present timer is set to Older Version
   Host Present Timeout seconds whenever an IGMPv1 Membership Report is
   received. The IGMPv2 Host Present timer is set to Older Version Host
   Present Timeout seconds whenever an IGMPv2 Membership Report is
   received.

   The Group Compatibility Mode of a group record changes whenever an
   older version report (than the current compatibility mode) is heard
   or when certain timer conditions occur. When the IGMPv1 Host Present
   timer expires, a router switches to Group Compatibility mode of
   IGMPv2 if it has a running IGMPv2 Host Present timer. If it does not
   have a running IGMPv2 Host Present timer then it switches to Group
   Compatibility of IGMPv3. When the IGMPv2 Host Present timer expires
   and the IGMPv1 Host Present timer is not running, a router switches
   to Group Compatibility mode of IGMPv3. Note that when a group
   switches back to IGMPv3 mode, it takes some time to regain source-
   specific state information. Source-specific information will be
   learned during the next General Query, but sources that should be
   blocked will not be blocked until [Group Membership Interval] after
   that.

   The Group Compatibility Mode variable is based on whether an older
   version report was heard in the last Older Version Host Present
   Timeout seconds. The Group Compatibility Mode is set depending on
   the following:

```
Group Compatibility Mode       Timer State
-----------------------        -----------

    IGMPv3 (default)           IGMPv2 Host Present not running
                               and IGMPv1 Host Present not running

    IGMPv2                     IGMPv2 Host Present running
                               and IGMPv1 Host Present not running

    IGMPv1                     IGMPv1 Host Present running
```

If a router receives a report which causes its older Host Present timers to be updated and correspondingly its compatibility mode, it SHOULD switch compatibility modes immediately.

When Group Compatibility Mode is IGMPv3, a router acts using the IGMPv3 protocol for that group.

When Group Compatibility Mode is IGMPv2, a router internally translates the following IGMPv2 messages for that group to their IGMPv3 equivalents:

```
    IGMPv2 Message             IGMPv3 Equivalent
    --------------             -----------------

      Report                   IS_EX( {} )

      Leave                    TO_IN( {} )
```

IGMPv3 BLOCK messages are ignored, as are source-lists in TO_EX() messages (i.e., any TO_EX() message is treated as TO_EX({})).

When Group Compatibility Mode is IGMPv1, a router internally translates the following IGMPv1 and IGMPv2 messages for that group to their IGMPv3 equivalents:

```
    IGMP Message               IGMPv3 Equivalent
    ------------               -----------------

      v1 Report                IS_EX( {} )

      v2 Report                IS_EX( {} )
```

In addition to ignoring IGMPv3 BLOCK messages and source-lists in TO_EX() messages as in IGMPv2 Group Compatibility Mode, IGMPv2 Leave messages and IGMPv3 TO_IN() messages are also ignored.

8. List of Timers, Counters and Their Default Values

   Most of these timers are configurable. If non-default settings are
   used, they MUST be consistent among all systems on a single link.
   Note that parentheses are used to group expressions to make the
   algebra clear.

8.1. Robustness Variable

   The Robustness Variable allows tuning for the expected packet loss on
   a network. If a network is expected to be lossy, the Robustness
   Variable may be increased. IGMP is robust to (Robustness Variable -
   1) packet losses. The Robustness Variable MUST NOT be zero, and
   SHOULD NOT be one. Default: 2

8.2. Query Interval

   The Query Interval is the interval between General Queries sent by
   the Querier. Default: 125 seconds.

   By varying the [Query Interval], an administrator may tune the number
   of IGMP messages on the network; larger values cause IGMP Queries to
   be sent less often.

8.3. Query Response Interval

   The Max Response Time used to calculate the Max Resp Code inserted
   into the periodic General Queries. Default: 100 (10 seconds)

   By varying the [Query Response Interval], an administrator may tune
   the burstiness of IGMP messages on the network; larger values make
   the traffic less bursty, as host responses are spread out over a
   larger interval. The number of seconds represented by the [Query
   Response Interval] must be less than the [Query Interval].

8.4. Group Membership Interval

   The Group Membership Interval is the amount of time that must pass
   before a multicast router decides there are no more members of a
   group or a particular source on a network.

   This value MUST be ((the Robustness Variable) times (the Query
   Interval)) plus (one Query Response Interval).

8.5. Other Querier Present Interval

   The Other Querier Present Interval is the length of time that must
   pass before a multicast router decides that there is no longer
   another multicast router which should be the querier. This value
   MUST be ((the Robustness Variable) times (the Query Interval)) plus
   (one half of one Query Response Interval).

8.6. Startup Query Interval

   The Startup Query Interval is the interval between General Queries
   sent by a Querier on startup. Default: 1/4 the Query Interval.

8.7. Startup Query Count

   The Startup Query Count is the number of Queries sent out on startup,
   separated by the Startup Query Interval. Default: the Robustness
   Variable.

8.8. Last Member Query Interval

   The Last Member Query Interval is the Max Response Time used to
   calculate the Max Resp Code inserted into Group-Specific Queries sent
   in response to Leave Group messages. It is also the Max Response
   Time used in calculating the Max Resp Code for Group-and-Source-
   Specific Query messages. Default: 10 (1 second)

   Note that for values of LMQI greater than 12.8 seconds, a limited set
   of values can be represented, corresponding to sequential values of
   Max Resp Code. When converting a configured time to a Max Resp Code
   value, it is recommended to use the exact value if possible, or the
   next lower value if the requested value is not exactly representable.

   This value may be tuned to modify the "leave latency" of the network.
   A reduced value results in reduced time to detect the loss of the
   last member of a group or source.

8.9. Last Member Query Count

   The Last Member Query Count is the number of Group-Specific Queries
   sent before the router assumes there are no local members. The Last
   Member Query Count is also the number of Group-and-Source-Specific
   Queries sent before the router assumes there are no listeners for a
   particular source. Default: the Robustness Variable.

8.10. Last Member Query Time

   The Last Member Query Time is the time value represented by the Last
   Member Query Interval, multiplied by the Last Member Query Count. It
   is not a tunable value, but may be tuned by changing its components.

8.11. Unsolicited Report Interval

   The Unsolicited Report Interval is the time between repetitions of a
   host's initial report of membership in a group. Default: 1 second.

8.12. Older Version Querier Present Timeout

   The Older Version Querier Interval is the time-out for transitioning
   a host back to IGMPv3 mode once an older version query is heard.
   When an older version query is received, hosts set their Older
   Version Querier Present Timer to Older Version Querier Interval.

   This value MUST be ((the Robustness Variable) times (the Query
   Interval in the last Query received)) plus (one Query Response
   Interval).

8.13. Older Host Present Interval

   The Older Host Present Interval is the time-out for transitioning a
   group back to IGMPv3 mode once an older version report is sent for
   that group. When an older version report is received, routers set
   their Older Host Present Timer to Older Host Present Interval.

   This value MUST be ((the Robustness Variable) times (the Query
   Interval)) plus (one Query Response Interval).

8.14. Configuring Timers

   This section is meant to provide advice to network administrators on
   how to tune these settings to their network. Ambitious router
   implementations might tune these settings dynamically based upon
   changing characteristics of the network.

8.14.1. Robustness Variable

   The Robustness Variable tunes IGMP to expected losses on a link.
   IGMPv3 is robust to (Robustness Variable - 1) packet losses, e.g., if
   the Robustness Variable is set to the default value of 2, IGMPv3 is
   robust to a single packet loss but may operate imperfectly if more

losses occur. On lossy subnetworks, the Robustness Variable should
be increased to allow for the expected level of packet loss. However,
increasing the Robustness Variable increases the leave latency of the
subnetwork. (The leave latency is the time between when the last
member stops listening to a source or group and when the traffic
stops flowing.)

8.14.2. Query Interval

The overall level of periodic IGMP traffic is inversely proportional
to the Query Interval. A longer Query Interval results in a lower
overall level of IGMP traffic. The Query Interval MUST be equal to
or longer than the Max Response Time inserted in General Query
messages.

8.14.3. Max Response Time

The burstiness of IGMP traffic is inversely proportional to the Max
Response Time. A longer Max Response Time will spread Report
messages over a longer interval. However, a longer Max Response Time
in Group-Specific and Source-and-Group-Specific Queries extends the
leave latency. (The leave latency is the time between when the last
member stops listening to a source or group and when the traffic
stops flowing.) The expected rate of Report messages can be
calculated by dividing the expected number of Reporters by the Max
Response Time. The Max Response Time may be dynamically calculated
per Query by using the expected number of Reporters for that Query as
follows:

```
    Query Type            Expected number of Reporters
    ----------            ----------------------------

    General Query         All systems on subnetwork

    Group-Specific Query  All systems that had expressed interest
                          in the group on the subnetwork

    Source-and-Group-     All systems on the subnetwork that had
    Specific Query        expressed interest in the source and group
```

A router is not required to calculate these populations or tune the
Max Response Time dynamically; these are simply guidelines.

9. Security Considerations

We consider the ramifications of a forged message of each type, and
describe the usage of IPSEC AH to authenticate messages if desired.

9.1. Query Message

   A forged Query message from a machine with a lower IP address than
   the current Querier will cause Querier duties to be assigned to the
   forger. If the forger then sends no more Query messages, other
   routers' Other Querier Present timer will time out and one will
   resume the role of Querier. During this time, if the forger ignores
   Leave Messages, traffic might flow to groups with no members for up
   to [Group Membership Interval].

   A DoS attack on a host could be staged through forged Group-and-
   Source-Specific Queries. The attacker can find out about membership
   of a specific host with a general query. After that it could send a
   large number of Group-and-Source-Specific queries, each with a large
   source list and the Maximum Response Time set to a large value. The
   host will have to store and maintain the sources specified in all of
   those queries for as long as it takes to send the delayed response.
   This would consume both memory and CPU cycles in order to augment the
   recorded sources with the source lists included in the successive
   queries.

   To protect against such a DoS attack, a host stack implementation
   could restrict the number of Group-and-Source-Specific Queries per
   group membership within this interval, and/or record only a limited
   number of sources.

   Forged Query messages from the local network can be easily traced.
   There are three measures necessary to defend against externally
   forged Queries:

   o Routers SHOULD NOT forward Queries. This is easier for a router to
     accomplish if the Query carries the Router-Alert option.

   o Hosts SHOULD ignore v2 or v3 Queries without the Router-Alert
     option.

   o Hosts SHOULD ignore v1, v2 or v3 General Queries sent to a
     multicast address other than 224.0.0.1, the all-systems address.

9.2. Current-State Report messages

   A forged Report message may cause multicast routers to think there
   are members of a group on a network when there are not. Forged
   Report messages from the local network are meaningless, since joining
   a group on a host is generally an unprivileged operation, so a local
   user may trivially gain the same result without forging any messages.
   Forged Report messages from external sources are more troublesome;
   there are two defenses against externally forged Reports:

   o Ignore the Report if you cannot identify the source address of the
     packet as belonging to a network assigned to the interface on which
     the packet was received. This solution means that Reports sent by
     mobile hosts without addresses on the local network will be
     ignored. Report messages with a source address of 0.0.0.0 SHOULD
     be accepted on any interface.

   o Ignore Report messages without Router Alert options [RFC-2113], and
     require that routers not forward Report messages. (The requirement
     is not a requirement of generalized filtering in the forwarding
     path, since the packets already have Router Alert options in them.)
     This solution breaks backwards compatibility with implementations
     of IGMPv1 or earlier versions of IGMPv2 which did not require
     Router Alert.

   A forged Version 1 Report Message may put a router into "version 1
   members present" state for a particular group, meaning that the
   router will ignore Leave messages. This can cause traffic to flow to
   groups with no members for up to [Group Membership Interval]. This
   can be solved by providing routers with a configuration switch to
   ignore Version 1 messages completely. This breaks automatic
   compatibility with Version 1 hosts, so should only be used in
   situations where "fast leave" is critical.

   A forged Version 2 Report Message may put a router into "version 2
   members present" state for a particular group, meaning that the
   router will ignore IGMPv3 source-specific state messages. This can
   cause traffic to flow from unwanted sources for up to [Group
   Membership Interval]. This can be solved by providing routers with a
   configuration switch to ignore Version 2 messages completely. This
   breaks automatic compatibility with Version 2 hosts, so should only
   be used in situations where source include and exclude is critical.

9.3. State-Change Report Messages

   A forged State-Change Report message will cause the Querier to send
   out Group-Specific or Source-and-Group-Specific Queries for the group
   in question. This causes extra processing on each router and on each
   member of the group, but can not cause loss of desired traffic.
   There are two defenses against externally forged State-Change Report
   messages:

   o Ignore the State-Change Report message if you cannot identify the
     source address of the packet as belonging to a subnet assigned to
     the interface on which the packet was received. This solution
     means that State-Change Report messages sent by mobile hosts
     without addresses on the local subnet will be ignored. State-
     Change Report messages with a source address of 0.0.0.0 SHOULD be
     accepted on any interface.

   o Ignore State-Change Report messages without Router Alert options
     [RFC-2113], and require that routers not forward State-Change
     Report messages. (The requirement is not a requirement of
     generalized filtering in the forwarding path, since the packets
     already have Router Alert options in them.)

9.4. IPSEC Usage

   In addition to these measures, IPSEC in Authentication Header mode
   [AH] may be used to protect against remote attacks by ensuring that
   IGMPv3 messages came from a system on the LAN (or, more specifically,
   a system with the proper key). When using IPSEC, the messages sent
   to 224.0.0.1 and 224.0.0.22 should be authenticated using AH. When
   keying, there are two possibilities:

   1. Use a symmetric signature algorithm with a single key for the LAN
      (or a key for each group). This allows validation that a packet
      was sent by a system with the key. This has the limitation that
      any system with the key can forge a message; it is not possible to
      authenticate the individual sender precisely. It also requires
      disabling IPSec's Replay Protection.

   2. When appropriate key management standards have been developed, use
      an asymmetric signature algorithm. All systems need to know the
      public key of all routers, and all routers need to know the public
      key of all systems. This requires a large amount of key
      management but has the advantage that senders can be authenticated
      individually so e.g., a host cannot forge a message that only
      routers should be allowed to send.

   This solution only directly applies to Query and Leave messages in
   IGMPv1 and IGMPv2, since Reports are sent to the group being reported
   and it is not feasible to agree on a key for host-to-router
   communication for arbitrary multicast groups.

10. IANA Considerations

    All IGMP types described in this document are already assigned in
    [IANA-REG].

11. Acknowledgments

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    comments and suggestions on this document.

    Portions of the text of this document were copied from [RFC-1112] and
    [RFC-2236].

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Appendix A.   Design Rationale

A.1 The Need for State-Change Messages

   IGMPv3 specifies two types of Membership Reports: Current-State and
   State Change. This section describes the rationale for the need for
   both these types of Reports.

   Routers need to distinguish Membership Reports that were sent in
   response to Queries from those that were sent as a result of a change
   in interface state. Membership reports that are sent in response to
   Membership Queries are used mainly to refresh the existing state at
   the router; they typically do not cause transitions in state at the
   router. Membership Reports that are sent in response to changes in
   interface state require the router to take some action in response to
   the received report (see Section 6.4).

   The inability to distinguish between the two types of reports would
   force a router to treat all Membership Reports as potential changes
   in state and could result in increased processing at the router as
   well as an increase in IGMP traffic on the network.

A.2 Host Suppression

   In IGMPv1 and IGMPv2, a host would cancel sending a pending
   membership reports if a similar report was observed from another
   member on the network. In IGMPv3, this suppression of host
   membership reports has been removed. The following points explain
   the reasons behind this decision.

   1. Routers may want to track per-host membership status on an
      interface. This allows routers to implement fast leaves (e.g.,
      for layered multicast congestion control schemes) as well as track
      membership status for possible accounting purposes.

   2. Membership Report suppression does not work well on bridged LANs.
      Many bridges and Layer2/Layer3 switches that implement IGMP
      snooping do not forward IGMP messages across LAN segments in order
      to prevent membership report suppression. Removing membership
      report suppression eases the job of these IGMP snooping devices.

   3. By eliminating membership report suppression, hosts have fewer
      messages to process; this leads to a simpler state machine
      implementation.

      4. In IGMPv3, a single membership report now bundles multiple
         multicast group records to decrease the number of packets sent.
         In comparison, the previous versions of IGMP required that each
         multicast group be reported in a separate message.

A.3 Switching Router Filter Modes from EXCLUDE to INCLUDE

   If there exist hosts in both EXCLUDE and INCLUDE modes for a single
   multicast group in a network, the router must be in EXCLUDE mode as
   well (see section 6.2.1). In EXCLUDE mode, a router forwards traffic
   from all sources unless that source exists in the exclusion source
   list. If all hosts in EXCLUDE mode cease to exist, it would be
   desirable for the router to switch back to INCLUDE mode seamlessly
   without interrupting the flow of traffic to existing receivers.

   One of the ways to accomplish this is for routers to keep track of
   all sources desired by hosts that are in INCLUDE mode even though the
   router itself is in EXCLUDE mode. If the group timer now expires in
   EXCLUDE mode, it implies that there are no hosts in EXCLUDE mode on
   the network (otherwise a membership report from that host would have
   refreshed the group timer). The router can then switch to INCLUDE
   mode seamlessly with the list of sources currently being forwarded in
   its source list.

Appendix B. Summary of Changes from IGMPv2

   While the main additional feature of IGMPv3 is the addition of source
   filtering, the following is a summary of other changes from RFC 2236.

   o State is maintained as Group + List-of-Sources, not simply Group as
     in IGMPv2.

   o Interoperability with IGMPv1 and IGMPv2 systems is defined as
     operations on the IGMPv3 state.

   o The IP Service Interface has changed to allow specification of
     source-lists.

   o The Querier includes its Robustness Variable and Query Interval in
     Query packets to allow synchronization of these variables on non-
     Queriers.

   o The Max Response Time in Query messages has an exponential range,
     changing the maximum from 25.5 seconds to about 53 minutes, for use
     on links with huge numbers of systems.

   o Hosts retransmit state-change messages for increased robustness.

   o Additional data sections are defined to allow later extensions.

   o Report packets are sent to 224.0.0.22, to assist layer-2 switches
     in "snooping".

   o Report packets can contain multiple group records, to allow
     reporting of full current state using fewer packets.

   o Hosts no longer perform suppression, to simplify implementations
     and permit explicit membership tracking.

   o New Suppress Router-Side Processing (S) flag in Query messages
     fixes robustness issues which were also present in IGMPv2.

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