Network Working Group   Deborah   Estrin   (USC)
Internet Draft   Dino Farinacci (CISCO)
                                               Ahmed Helmy (USC)
                                               Van Jacobson (LBL)
                                               Liming Wei (USC)

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Protocol Independent   Multicast-Dense   Mode   (PIM-DM):   Protocol
Specification

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1 Introduction

This specification defines a multicast routing algorithm for multicast groups that are densely distributed across an internet. The protocol is unicast routing protocol independent. It is based on the PIM sparse-mode [Deering95] and employs the same packet formats. This protocol is called dense-mode PIM. The design is based largely on foundational work by Deering [Deering91].

2 PIM-DM Protocol Overview

Dense-mode PIM uses Reverse Path Multicasting (RPM). RPM is a technique in which a multicast datagram is forwarded if the receiving interface is one used to forward unicast datagrams to the source of the datagram. The multicast datagram is then forwarded out all other interfaces. Dense-mode PIM builds source-based acyclic trees.

Dense-mode PIM is data driven, whereby it is assumed that all downstream systems want to receive multicast datagrams. For densely populated groups this is optimal. If some areas of the network do not have group members, dense-mode PIM will prune branches of the source-based tree. When group members leave the group, branches will also be pruned.

Unlike DVMRP [DVMRP] packets are forwarded on all outgoing interfaces (except the incoming) until pruning and truncation occurs. DVMRP makes use of parent-child data to reduce the number of outgoing interfaces used before pruning. In both protocols, once truncation occurs pruning state is maintained and packets are only forwarded onto outgoing interfaces that in fact reach downstream members.

We chose to accept additional overhead in favor of reduced dependency on the unicast routing protocol, and reduced overall protocol complexity.

Dense-mode PIM differs from sparse-mode PIM in two essential points: 1) there are no periodic joins transmitted, only explicit triggered grafts/prunes, and 2) there is no Rendezvous Point (RP).

3 Background

Reverse Path Broadcasting (RPB) is different from RPF because duplicate packets are avoided in the RPB that are sent in RPF. In general, the number of duplicates sent on a link can be as high as the number of routers directly connected to that link.

Reverse Path Multicasting (RPM) is different from RPF or RPB because
pruning information is propagated upstream. Leaf routers must know
that they are leaf routers so that in response to no IGMP reports for
a group, those leaf routers know to initiate the prune process.

In DVMRP there are routing protocol dependencies for a) building a
parent-child database so that duplicate packets can be eliminated, b)
eliminating duplicate packets on multi-access LANs, and c) sending
"split horizon with poison reverse" information to detect that a
router is not a leaf router (if a router does not receive any poison
reverse messages from other routers on a multi-access LAN then that
router acts as a leaf router for that LAN and knows to prune if there
are not IGMP reports on that LAN for a group G).

Dense-mode PIM will accept some duplicate packets in order to avoid
being routing protocol dependent and avoid building a child parent
database.

We introduce a simple prune mechanism for reducing duplicates on
multi-access LANs. We introduce a simple graft mechanism to reduce
join latency on previously pruned branches of a source-based
multicast tree.

We introduce an alternative leaf-router detection mechanism that does
not rely on a specific unicast routing protocol mechanism such as
split horizon with poison reverse.

These mechanisms are described below.

4 Protocol Description

4.1 Leaf network detection

In DVMRP poison reverse information tells a router that other routers
on the shared LAN use the LAN as their incoming interface. As a
result, even if the DR for that LAN does not hear any IGMP Reports
for a group, the DR will know to continue to forward multicast data

packets to that group, and NOT to send a prune message to its
upstream neighbor.

Since dense-mode PIM does not rely on any unicast routing protocol
mechanisms, this problem is solved by using prune messages sent
upstream on a LAN. If a downstream router on a LAN determines that it
has no more downstream members for a group, then it can multicast a
prune message on the LAN.

A leaf router detects that there are no members downstream when it is

the only router on a network and there are no IGMP Host-Report
messages received from hosts. It determines there are no other
routers by not receiving PIM Router-Hello messages.

When a prune message is sent on an upstream LAN, it is data link
multicast and IP addressed to the all routers group address
224.0.0.13. The router to process the prune will be indicated by
inserting its address in the "Address" field of the message. The
address is obtained by an RPF lookup from the unicast routing table.
When the prune message is sent, the expected upstream router will
schedule a deletion request of the LAN from its outgoing interfaces
for the (S,G) entry from the prune list. The suggested delay time
before deletion should be greater than 3 seconds.

Note the special case for equal-cost paths. When an upstream router
is chosen by an RPF lookup there may be equal-cost paths to reach the
source. The higher IP addressed system is always chosen. If the
unicast routing protocol does not store all available equal-cost
paths in the routing table, the "Address" field may contain the
address of the wrong upstream router. To avoid this situation, the
"Address" field may optionally be set to 0.0.0.0 which means that all
upstream routers (the ones that have the LAN as an outgoing interface
for the (S,G) entry) may process the packet.

Other routers on the LAN will hear the prune message and respond with
a join if they still expect multicast datagrams from the expected
upstream router. The PIM-Join message is data link multicast and IP
addressed to the all routers group address 224.0.0.13. The router to
process the join will be indicated by inserting its address in the
"Address" field of the message. The address is determined by an RPF

lookup from the unicast routing table. When the expected router
receives the join message, it will cancel the deletion request.

Routers will randomly generate a join message delay timer. If a join
is heard from another router before a router sends its own, it will
cancel sending its own join. This will reduce traffic on the LAN. The
suggested join delay timer should be from 1 to 3 seconds.

If the expected upstream router does not receive any PIM-Join
messages before the schedule time for the deletion request expires,
it deletes the outgoing LAN interface from the (S,G) multicast
forwarding entry.

Note that if the join message is lost, the deletion will occur and there
will be a no data delivery for the amount of time the interface remains
in Prune state. To reduce the probability of this occurrence, a router that
overrides a prune may send multiple joins back-to-back or have a small
delay between successive joins.

If an (S,G) entry contains an empty outgoing interface list, a prune
is sent upstream. Prune information is flushed periodically. This (or
a loss of state) causes the packets to be sent in RPF mode again
which in turn triggers prune messages.

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4.2 New members joining an existing group

   If a router is directly connected to a host that wants to become a
   member of a group, the router may optionally, send a PIM-Graft
   message towards known sources. This allows join latency to be reduced
   below that indicated by the relatively large timeout value suggested
   for prune information.

   If a receiving router has state for group G, it adds the interface on
   which the IGMP Report or PIM-Graft was received for all known (S,G).
   If the (S,G) entry was a negative cache entry, the router sends a
   PIM-Graft message upstream towards S.

   If routers have no group state, they do nothing since dense-mode PIM
   will deliver a multicast datagram to all interfaces when creating
   state for a group.

   Any routers receiving the PIM-Graft message, uses the received

interface as an incoming interface for any (S,G) entry, will not add
the interface to the outgoing interface list.

The PIM-Graft message is the only PIM message that uses a positive
acknowledgment strategy. Senders of PIM-Graft messages unicast them
to their upstream RPF neighbors. The neighbor processes each (S,G)
and immediately acknowledges each (S,G) in a PIM-GraftAck message.
This is relatively easy, since the receiver simply changes the IGMP
code from Graft to Graft-Ack and unicasts the original packet back to
the source. The sender periodically retransmits the PIM-Graft message
for any (S,G) that has not been acknowledged. Note that the sender
need not keep a retransmission list for each neighbor since PIM-
Grafts are only sent to the RPF neighbor. Only the (S,G) entry needs
to be tagged for retransmission.

[4.3](#) Protocol Scenario

A multicast datagram is sent by a source host. If a receiving router
has no forwarding cache state for the source sending to group G, it
creates an (S,G) entry. The incoming interface for (S,G)   is
determined by doing an RPF lookup in the unicast routing table. The
(S,G) outgoing interface list contains dense-mode configured
interfaces that have PIM routers present or host members for group G.

A PIM-Prune message is triggered when an (S,G) entry is built with an
empty outgoing interface list. This type of entry is called a
negative cache entry. This can occur when a leaf router has no local
members for group G or a prune message was received from a downstream
router which causes the outgoing interface list to become NULL. PIM-

Prune messages are never sent on LANs in response to a received
multicast packet that is associated with a negative cache entry.

PIM-Prune messages received on a point to point link are not delayed
before processing as they are in the LAN procedure. If the prune is
received on an interface that is in the outgoing interface list, it
is deleted immediately. Otherwise the prune is ignored.

When a multicast datagram is received on the incorrect LAN interface
(i.e. not the RPF interface) the packet is silently discarded. If it
is received on an incorrect point-to-point interface, Prunes may be

sent in a rate-limited fashion. Prunes may also be rate-limited on
point-to-point interfaces when a multicast datagram is received for a
negative cache entry.

4.4 Designated Router election

The dense-mode PIM designated router (DR) election uses the same
procedure as in sparse-mode PIM. A DR is necessary for each multi-
access LAN so a single router sends IGMP Host-Query messages to
solicit host group membership.

Each PIM router connected to a multi-access LAN should transmit PIM
Router-Hello messages every 30 seconds onto the LAN to support DR
election. The highest addressed router becomes the DR. The discovered
PIM routers should be timed out after 90 seconds. If the DR goes
down, a new DR is elected.

DR election is only necessary on multi-access networks. It is not
required that PIM Hello messages be sent on point-to-point links.

4.5 Parallel paths to a source

Two or more routers may receive the same multicast datagram that was
replicated upstream. In particular, if two routers have equal cost
paths to a source and are connected on a common multi-access network,
duplicate datagrams will travel downstream onto the LAN. Dense-mode
PIM will detect such a situation and will not let it persist.

If a router receives a multicast datagram on a multi-access LAN from
a source whose corresponding (S,G) outgoing interface list includes
the received interface, the packet must be a duplicate. In this case
a single forwarder must be elected. Using PIM Assert messages
addressed to 224.0.0.13 on the LAN, upstream routers can decide which
one becomes the forwarder. Downstream routers listen to the Asserts
so they know which one was elected (i.e. typically this is the same

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as the downstream router's RPF neighbor but there are circumstances
when using different unicast protocols where this might not be the
case).

The upstream router elected is the one that has the shortest distance
to the source. Therefore, when a packet is received on an outgoing
interface a router will send an Assert packet on the LAN indicating
what metric it uses to reach the source of the data packet. The
router with the smallest numerical metric will become the forwarder.
All other upstream routers will delete the interface from their
outgoing interface list. The downstream routers also do   the
comparison in case the forwarder is different than the RPF neighbor.
This is important so downstream routers send subsequent Prunes or
Grafts to the correct neighbor.

Associated with the metric is a metric preference value. This is
provided to deal with the case where the upstream routers may run
different unicast routing protocols. The numerically smaller metric
preference is always preferred. The metric preference should be
treated as the high-order part of an Assert metric comparison.
Therefore, a metric value can be compared with another metric value
provided both metric preferences are the same. A metric preference
can be assigned per unicast routing protocol and needs to be
consistent for all routers on the LAN.

The following Assert rules are provided:

Multicast packet received on outgoing interface:

    1   Do unicast routing table lookup on source IP address   from
         data packet.

    2   Send Assert on interface for source IP address from data
         packet, include metric preference of routing protocol and
         metric from routing table lookup.

    3   If route is not found, Use metric preference of 0x7fffffff
         and metric 0xffffffff.

    Asserts received on outgoing interface:

    1   Compare metric received in Assert with the one you would
         have advertised in an Assert. If the value in the Assert is

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less than your value, prune the interface. If the value is
the same, compare IP addresses, if your address is less
than the Assert sender, prune the interface.

2   If you have won the election and there are directly
connected members on the LAN, keep the interface in your
outgoing interface list. You are the forwarder for the LAN.

3   If you have won the election but there are no directly
connected members on the LAN, schedule to prune the
interface. The LAN might be a stub LAN with no members (and
no   downstream   routers). If no subsequent Joins are
received, delete the interface from the outgoing interface
list.   Otherwise keep the interface in your outgoing
interface. You are the forwarder for the LAN.

Asserts received on incoming interface:

1   Downstream routers will select the upstream router with the
smallest metric   as their RPF neighbor. If two metrics are
the same, the highest IP address is chosen to break the
tie.

2   If the downstream routers have downstream members, they
must schedule a join to inform the upstream router packets
should be forwarded on the LAN. This will cause the
upstream forwarder to cancel its delayed pruning of the
interface.

4.6 Timing out multicast forwarding entries

Each (S,G) entry has timers associated with it. During this time
source-based tree state is kept in the network.

There should be multiple timers set. One for the multicast
routing entry itself and one for each interface in the outgoing
interface list. The outgoing interface stays active in the list
as long as there is multicast traffic for the entry or there is
an explicit Graft received on the interface. If neither occurs
the interface will be deleted from the list after 3 minutes, by
default.

Once all interfaces in the outgoing interface list are not

active, a timer should be set for the (S,G) entry. During this
time the entry is known as a negative state entry at which a
prune is triggered. Once the (S,G) entry times out, it can be
recreated when the next multicast packet or join arrives.

4.7 Source address aggregation and Pruning

An (S,G) entry in the multicast routing table will contain a
source address to be as specific as necessary depending where
the router is in relation to a source. Close to the source, this
will typically be a subnet number. Far from the source, it may
be a network number or a supernet route. Prunes sent may be
rather ineffective if the source being pruned is not specific
enough.

For example, initially a multicast datagram may be flooded
throughout an Autonomous System (AS). Within the AS, there is
complete subnet information in the unicast routing tables of all
routers. Once the datagram exits the AS, it is likely there are
routers that don't have subnet information. If these routers
send Prunes for aggregate sources, routers close to the source
will not know where to reach the source since they have more
specific information than what was provided in the Prune
message. This results in traffic being sent further on a branch
of the multicast tree than necessary.

The problem is fixed by sending source host specific prunes.
However, to maintain proper scaling of routing information, each
router along the path performs longest match lookups for the
source specified in the Prune message. Therefore, they keep the
level of aggregation that best suits thier position to the
source in the topology.

A source host specific Prune is encoded by copying   the
instigating source IP address from the multicast datagram into
the PIM message using a mask length of 32.

5 Packet Formats

   This section describes the details of the packet formats for PIM control
   messages.

   All PIM control messages have protocol number 103.

   Basically, PIM messages are either unicast (e.g. Registers and
   Register-Stop), or multicast hop-by-hop to `ALL-PIM-ROUTERS' group
   `224.0.0.13' (e.g. Join/Prune, Asserts, etc.).

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|PIM Ver| Type  | Addr length   |           Checksum            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

    PIM Ver
          PIM Version number is 2.

    Type
         Types for specific PIM messages.
    PIM Types are:

       0 = Hello
       1 = Register
       2 = Register-Stop
       3 = Join/Prune
       4 = Bootstrap
       5 = Assert
       6 = Graft
       7 = Graft-Ack
       8 = Candidate-RP-Advertisement

  Addr length
    Address length in bytes. Throughout this section this would
    indicate the number of bytes in the Address field of an address,
    including unicast and group addresses.

  Checksum
    The checksum is the 16-bit one's complement of the one's
    complement sum of the entire PIM message,
    (excluding the data portion in the Register message).
    For computing the checksum, the checksum field is zeroed.

  { For all the packet format details, refer to the PIM sparse-
  mode specification.}

  5.1 PIM-Hello Message

    It is sent periodically by PIM routers on all interfaces.

  5.2 PIM-SM-Register Message

    Used in sparse-mode. Refer to PIM sparse-mode specification.

  5.3 PIM-SM-Register-Stop Message

    Used in sparse-mode. Refer to PIM sparse-mode specification.

  5.4 Join/Prune Message

    It is sent by routers towards upstream sources. A join creates
    forwarding state and a prune destroys forwarding state. Joins
    are sent to build source specific trees. Prunes are sent to

prune source trees when members leave groups as well as sources
that do not use the shared tree.

5.5 PIM-SM-Bootstrap Message

Used in sparse-mode. Refer to PIM sparse-mode specification.

5.6 PIM-Assert Message

The PIM-Assert message is sent when a multicast data packet is
received on an outgoing interface corresponding to the (S,G) or
(*,G) associated with the source.

5.7 PIM-Graft Message

This message is sent by a downstream router to a neighboring
upstream router to reinstate a previously pruned branch of a
source tree. This is done for dense-mode groups only. The format
is the same as a Join/Prune message.

5.8 PIM-Graft-Ack Message

Sent in response to a received Graft message. The Graft-Ack is
only sent if the interface in which the Graft was received is
not the incoming interface for the respective (S,G). This is
done for dense-mode groups only. The format is the same as
Join/Prune message.

5.9 Candidate-RP-Advertisement

Used in sparse-mode. Refer to PIM sparse-mode specification.

6 References

[Deering91] S.E. Deering. Multicast Routing in a Datagram
Internetwork. PhD thesis, Electrical Engineering Dept., Stanford
University, December 1991.

[DVMRP] RFC 1075, Distance Vector Multicast Routing Protocol.
Waitzman, D., Partridge, C., Deering, S.E, November 1988

[Deering95] Protocol Independent Multicast Sparse-Mode (PIM-SM):
Protocol Specification. S. Deering, D. Estrin, D. Farinacci, V.
Jacobson, G. Liu, L. Wei, P. Sharma, A. Helmy, September 1995

[Deering94b] An Architecture for Wide-Area Multicast Routing, S.
Deering, D. Estrin, D. Farinacci, V. Jacobson, G. Liu,L. Wei,
USC Technical Report, available from authors, Feburary 1994.

[RFC1112] Host Extensions for IP Multicasting, Network Working
Group, RFC 1112, S. Deering, August 1989

References