Chapter 12
Multicasting
And
Multicast
Routing
Protocols
Chapter Outline

12.1 Introduction
12.2 Multicast Addresses
12.3 IGMP
12.4 Multicast Routing
12.5 Routing Protocols
12.6 MBONE
We have learned that forwarding a datagram is normally based on the prefix of the destination address in the datagram. Address aggregation mechanism may combine several datagrams to be delivered to an ISP and then separate them to be delivered to their final destination networks, but the principle does not change.

Understanding the above forwarding principle, we can now define unicasting, multicasting, and broadcasting. Let us clarify these terms as they relate to the Internet.
Topics Discussed in the Section

✓ Unicasting
✓ Multicasting
✓ Broadcasting
Figure 12.1 Unicasting

Legend
- Ethernet switch
- Point-to-point WAN
- Unicast router

Source

R1
1
2
R3
R4
3
1
2

N1
N2
N3
N4
N5
N6

Recipient is here
In unicasting, the router forwards the received datagram through only one of its interfaces.
Figure 12.2 Multicasting

Legend
- Ethernet switch
- Point-to-point WAN
- Multicast router

TCP/IP Protocol Suite
In multicasting, the router may forward the received datagram through several of its interfaces.
Figure 12.3  Multicasting versus multiple unicasting

Legend
- Multicast router
- Unicast router
- Di Unicast destination
- G Un Group member

(a) Multicasting

(b) Multiple unicasting

Legend:
- Multicast router
- Unicast router
- Di Unicast destination
- G Group member

S1

G1  G1  G1

Multicast router
Unicast router
Di  Unicast destination
G  Group member
Emulation of multicasting through multiple unicasting is not efficient and may create long delays, particularly with a large group.
Multicasting Applications

✓ Access to Distributed Databases
✓ Information Dissemination
✓ Dissemination of News
✓ Teleconferencing
✓ Distance Learning
A multicast address is a destination address for a group of hosts that have joined a multicast group. A packet that uses a multicast address as a destination can reach all members of the group unless there are some filtering restriction by the receiver.
Topics Discussed in the Section

✓ Multicast Addresses in IPv4
✓ Selecting Multicast Addresses
✓ Delivery of Multicast Packets at Data Link Layer
<table>
<thead>
<tr>
<th>CIDR</th>
<th>Range</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>224.0.0.0/24</td>
<td>224.0.0.0 → 224.0.0.255</td>
<td>Local Network Control Block</td>
</tr>
<tr>
<td>224.0.1.0/24</td>
<td>224.0.1.0 → 224.0.1.255</td>
<td>Internetwork Control Block</td>
</tr>
<tr>
<td></td>
<td>224.0.2.0 → 224.0.255.255</td>
<td>AD HOC Block</td>
</tr>
<tr>
<td>224.1.0.0/16</td>
<td>224.1.0.0 → 224.1.255.255</td>
<td>ST Multicast Group Block</td>
</tr>
<tr>
<td>224.2.0.0/16</td>
<td>224.2.0.0 → 224.2.255.255</td>
<td>SDP/SAP Block</td>
</tr>
<tr>
<td></td>
<td>224.3.0.0 → 231.255.255.255</td>
<td>Reserved</td>
</tr>
<tr>
<td>232.0.0.0/8</td>
<td>232.0.0.0 → 224.255.255.255</td>
<td>Source Specific Multicast (SSM)</td>
</tr>
<tr>
<td>233.0.0.0/8</td>
<td>233.0.0.0 → 233.255.255.255</td>
<td>GLOP Block</td>
</tr>
<tr>
<td></td>
<td>234.0.0.0 → 238.255.255.255</td>
<td>Reserved</td>
</tr>
<tr>
<td>239.0.0.0/8</td>
<td>239.0.0.0 → 239.255.255.255</td>
<td>Administratively Scoped Block</td>
</tr>
<tr>
<td>Address</td>
<td>Assignment</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>224.0.0.0</td>
<td>Base address (reserved)</td>
<td></td>
</tr>
<tr>
<td>224.0.0.1</td>
<td>All systems (hosts or routers) on this network</td>
<td></td>
</tr>
<tr>
<td>224.0.0.2</td>
<td>All routers on this network</td>
<td></td>
</tr>
<tr>
<td>224.0.0.4</td>
<td>DMVRP routers</td>
<td></td>
</tr>
<tr>
<td>224.0.0.5</td>
<td>OSPF routers</td>
<td></td>
</tr>
<tr>
<td>224.0.0.7</td>
<td>ST (stream) routers</td>
<td></td>
</tr>
<tr>
<td>224.0.0.8</td>
<td>ST (stream) hosts</td>
<td></td>
</tr>
<tr>
<td>224.0.0.9</td>
<td>RIP2 routers</td>
<td></td>
</tr>
<tr>
<td>224.0.0.10</td>
<td>IGRP routers</td>
<td></td>
</tr>
<tr>
<td>224.0.0.11</td>
<td>Mobile Agents</td>
<td></td>
</tr>
<tr>
<td>224.0.0.12</td>
<td>DHCP servers</td>
<td></td>
</tr>
<tr>
<td>224.0.0.13</td>
<td>PIM routers</td>
<td></td>
</tr>
<tr>
<td>224.0.0.14</td>
<td>RSVP encapsulation</td>
<td></td>
</tr>
<tr>
<td>224.0.0.15</td>
<td>CBT routers</td>
<td></td>
</tr>
<tr>
<td>224.0.0.22</td>
<td>IGMPv3</td>
<td></td>
</tr>
</tbody>
</table>
Example 12.1

We use netstat with three options, -n, -r, and -a. The -n option gives the numeric versions of IP addresses, the -r option gives the routing table, and the -a option gives all addresses (unicast and multicast). Note that we show only the fields relative to our discussion. The multicast address is shown in color.

```
$netstat -nra
```

<table>
<thead>
<tr>
<th>Destination</th>
<th>Gateway</th>
<th>Mask</th>
<th>Flags</th>
<th>Iface</th>
</tr>
</thead>
<tbody>
<tr>
<td>153.18.16.0</td>
<td>0.0.0.0</td>
<td>255.255.240.0</td>
<td>U</td>
<td>eth0</td>
</tr>
<tr>
<td>169.254.0.0</td>
<td>0.0.0.0</td>
<td>255.255.0.0</td>
<td>U</td>
<td>eth0</td>
</tr>
<tr>
<td>127.0.0.0</td>
<td>0.0.0.0</td>
<td>255.0.0.0</td>
<td>U</td>
<td>lo</td>
</tr>
<tr>
<td><strong>224.0.0.0</strong></td>
<td><strong>0.0.0.0</strong></td>
<td><strong>224.0.0.0</strong></td>
<td><strong>U</strong></td>
<td><strong>eth0</strong></td>
</tr>
<tr>
<td>0.0.0.0</td>
<td>153.18.31</td>
<td>0.0.0.0</td>
<td>UG</td>
<td>eth0</td>
</tr>
</tbody>
</table>
Figure 12.4 Mapping class D to Ethernet physical address

32-bit multicast address

1110 5 bits unused 23 bits of multicast address

00000001000000000010111100 23 bits of physical address

48-bit Ethernet address
An Ethernet multicast physical address is in the range 01:00:5E:00:00:00 to 01:00:5E:7F:FF:FF.
Example 12.2

Change the multicast IP address 232.43.14.7 to an Ethernet multicast physical address.

Solution

We can do this in two steps:

a. We write the rightmost 23 bits of the IP address in hexadecimal. This can be done by changing the rightmost 3 bytes to hexadecimal and then subtracting 8 from the leftmost digit if it is greater than or equal to 8. In our example the result is 2B:0E:07.

b. We add the result of part a to the starting Ethernet multicast address, which is 01:00:5E:00:00:00. The result is 01:00:5E:2B:0E:07.
Example 12.3

Change the multicast IP address 238.212.24.9 to an Ethernet multicast address.

Solution
We can do this in two steps:

a. The rightmost 3 bytes in hexadecimal are D4:18:09. We need to subtract 8 from the leftmost digit, resulting in 54:18:09.

b. We add the result of part a to the Ethernet multicast starting address. The result is 01:00:5E:54:18:09.
Figure 12.5  Tunneling

Multicast IP datagram

Header  Data

Header  Data

Unicast IP datagram
We first discuss the idea of optimal routing, common in all multicast protocols. We then give an overview of multicast routing protocols.
Topics Discussed in the Section

✓ Optimal Routing: Shortest Path Trees
✓ Unicast routing
✓ Multicast routing
Figure 12.18  *Shortest path tree in unicast routing*
Note

In unicast routing, each router in the domain has a table that defines a shortest path tree to possible destinations.
Multicast Routing

Some Objectives of multicast routing (very complex)

✓ Each Rx of the group must get only one copy of the packet

✓ Rx’s not belonging to the group DO NOT get a copy of the packet

✓ The packet can not visit the same router more than once (no loops)

✓ The route from Tx to various Rx’s must be optimal (shortest path)
In multicast routing, each involved router needs to construct a shortest path tree for each group.

Two approaches:

✓ Source-based trees
✓ Group-shared trees
In the source-based tree approach, each router needs to have one shortest path tree for each group.
Source-based tree approach

Figure 12.19

- Shortest path tree
  - G1, G2
  - G3, G5
  - G1, G2, G4

Destination | Next-hop
---|---
G1 | R2, R4
G2 | R2
G3 | R2
G4 | R2, R4
G5 | R2, R4

R1 Table
In the group-shared tree approach, only the core router, which has a shortest path tree for each group, is involved in multicasting.
Figure 12.20  Group-shared tree approach

TCP/IP Protocol Suite
During the last few decades, several multicast routing protocols have emerged. Some of these protocols are extensions of unicast routing protocols; some are totally new. We discuss these protocols in the remainder of this chapter. Figure 12.21 shows the taxonomy of these protocols.
- Multicast Link State Routing: MOSPF
- Multicast Distance Vector: DVMRP
- Core-Based Tree: CBT
- Protocol Independent Multicast: PIM
• Distance Vector Multicast Routing Protocol (DVMRP) – similar to the distance vector routing protocol we covered for the unicast case – RIP.

How do we build a tree using the DVMRP approach?

• Use a modified “flooding” approach

• Recall what flooding is: a router sends a copy of a packet out of all of it’s interfaces – all interfaces except the interface the packet came in on

• Flooding will cause looping problems (ie. the same packet copy that left the router will re-visit the router)
DVMRP - RPF

• Instead of forwarding copies of the packet through all interfaces (except the receiving interface), ONLY FORWARD THE PACKET IF IT CAME IN ON THE SHORTEST PATH

• This approach of only forwarding the packet if it comes in on the shortest path is called Reverse Path Forwarding (RPF) – RPF prevents looping

If it comes in on the non-shortest path – drop it
Figure 12.22  RPF

Legend
- Received
- Forwarded

Source

R1

m3

R2

m3

R3

m1

m2

R4

m1

m2

R5

R6
EXAMPLE

A multicast router receives a packet with source address 190.34.23.7 and destination address 227.45.9.5 from interface 2. Should the router discard or forward the packet based on the following unicast table?

<table>
<thead>
<tr>
<th>Destination</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>121.0.0.0</td>
<td>1</td>
</tr>
<tr>
<td>185.67.0.0</td>
<td>2</td>
</tr>
<tr>
<td>190.34.0.0</td>
<td>3</td>
</tr>
</tbody>
</table>

SOLUTION: In interpreting the source address of 190.34.23.7 using the default mask, the router would send the packet to network 190.34.0.0 via interface 3 (not interface 2). Recall the packet came in on interface 2 – therefore, the router would DROP the packet (and not forward it).
What RPF guarantees is: each network will receive a copy of the multicast packet WITHOUT the loop problem

What RPF doesn’t guarantee is: each network will receive ONLY ONE COPY
Reverse Path Broadcasting (RPB): to eliminate networks (nodes) receiving more than one copy, ONLY THE PARENT HAS THE RIGHT TO FORWARD

Policy: the router sends the packet only out of those interfaces for which it is the designated parent.
RPB creates a shortest path broadcast tree from the source to each destination. It guarantees that each destination receives one and only one copy of the packet.
Figure 12.25  **RPF, RPB, and RPM**

- **a. RPF**
  - Net1
  - Net2
  - Net3

- **Legend**
  - P: Pruned route
  - G: Grafted route

- **c. RPM (after pruning)**
  - Net1
  - Net2
  - Net3

- **b. RPB**
  - Net1
  - Net2
  - Net3

- **d. RPM (after grafting)**
  - R1
  - Net1
  - Net2
  - Net3
RPM adds pruning and grafting to RPB to create a multicast shortest path tree that supports dynamic membership changes.
Figure 12.21  Taxonomy of common multicast protocols

- Multicast Link State Routing: MOSPF
- Multicast Distance Vector: DVMRP
- Core-Based Tree: CBT
- Protocol Independent Multicast: PIM
Multicast Open Shortest Path First (MOSPF)

• Extension of the OSPF protocol

• Each router could then use Dijkstra’s algorithm and obtain a least cost tree for each router (or node)

• For multicasting routing, we need a tree for each source/group pair

• MOSPF is a data-driven protocol – the first time a MOSPF router sees a datagram with a given source and group address, the router calculates Dijkstra
Core-Based Tree (CBT) Protocol

- Is a group-shared protocol
- Autonomous systems are divided into regions and a core router or rendezvous point is used for each region
- In forming a tree:
  - 1\textsuperscript{st}: the core router or rendezvous router is selected
  - 2\textsuperscript{nd}: all other routers are informed of the unicast address of rendezvous router
  - 3\textsuperscript{rd}: all routers wanting to join group sends a “join message” to the rendezvous router
  - 4\textsuperscript{th}: the intermediate routers between the rendezvous router and Tx router record the address of the source and the interface in which the packet came into the router on
  - 5\textsuperscript{th}: after the rendezvous has received all joined messages – the tree is formed
Figure 12.26  Group-shared tree with rendezvous router
Figure 12.27 Sending a multicast packet to the rendezvous router
In CBT, the source sends the multicast packet (encapsulated in a unicast packet) to the core router. The core router decapsulates the packet and forwards it to all interested interfaces.
DVMRP & MOSPF Versus CBT

• For DVMRP and MOSPF, the tree is created from the root
• For CBT, the tree is created starting from the leaves
• For DVMRP, the tree is first made via broadcast and then pruned into a multicast tree
• For CBT, initially there is no tree and then a tree is created gradually via grafting (ie. announcing to the core you want to be apart of the group)
### Protocol Independent Multicast – Dense Mode (PIM-DM)

<table>
<thead>
<tr>
<th>Note</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>PIM-DM is used in a dense multicast environment, such as a LAN.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>PIM-DM uses RPF and pruning/grafting strategies to handle multicasting.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>However, it is independent from the underlying unicast protocol.</th>
</tr>
</thead>
</table>
Protocol Independent Multicast – Sparse Mode (PIM-SM)

Note

PIM-SM is used in a sparse multicast environment such as a WAN.

PIM-SM is similar to CBT but uses a simpler procedure.
• There are many more unicast oriented routers in the Internet than multicast routers (ie. routers able to multicast)

• In creating more links between multicast routers, the concept of “tunneling” is used

• Tunneling - via unicast routers, multicast routers are logically connected – in essence we create a multicast backbone in logically linking the multicast routers
How to create a tunnel

- 1\textsuperscript{st}: encapsulate multicast packet inside a unicast packet (in the data field)
- 2\textsuperscript{nd}: the unicast intermediate routers route the packet to the next multicast router
Summaries:

- To compare and contrast unicasting, multicasting, and broadcasting communication.

- To define multicast addressing space in IPv4 and show the division of the space into several blocks.

- To discuss the general idea behind multicast routing protocols and their division into two categories based on the creation of the shortest path trees.

- To discuss multicast link state routing in general and its implementation in the Internet: a protocol named MOSPF.
Summaries (continued):

- To discuss multicast distance vector routing in general and its implementation in the Internet: a protocol named DVMRP.

- To discuss core-based protocol (CBT) and briefly discuss two independent multicast protocols PIM-DM and PIM-SM.

- To discuss multicast backbone (MBONE) that shows how to create a tunnel when the multicast messages need to pass through an area with no multicast routers.