第五章 组播协议

实验 5-1 组播、IGMP 及 PIM DM 协议

学习目的

- 掌握路由器启动组播路由功能的配置方法
- 掌握配置接口IGMP功能的方法
- 掌握PIM DM的配置方法
- 掌握查看和测试组播的方法
- 掌握PIM一些高级特性的配置方法

拓扑图

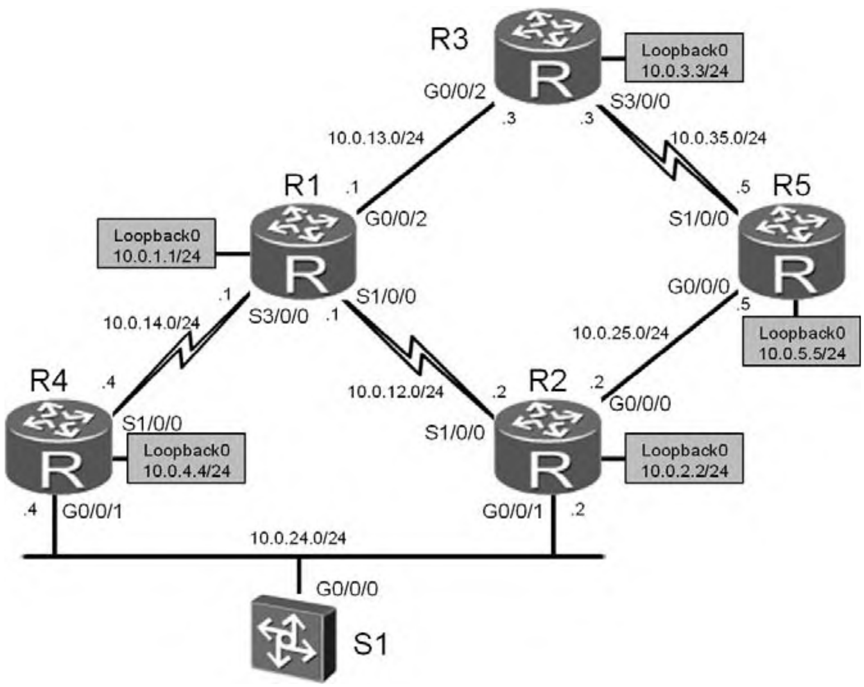

图5-1 组播、IGMP及PIM DM协议

场景

你是公司的网络管理员。公司准备使用组播来进行一些业务的转发。在当前网络上，网络规模较小，你决定使用PIM的DM模式来实现组播路由信息的学习。组播转发的实现过程中，你需要考虑到主机应用对IGMP不同版本的兼容，同时需要考虑使用合适的方式测试网络中组播是否正常工作。为了提升网络的效率和安全性，你采用了PIM DM的一些手段，包括PIM邻居的控制、嫁接和其他安全措施。同时实现网络的组播转发之前，你也遇到了一些网络故障，经过一些故障排除步骤，最终网络正常工作了。

学习任务

步骤一.　基础配置与 IP 编址

S2参与到本次实验（实现R1和R3的互联），但无需配置。实验之前，请清空S2的配置，并重启它。

给所有路由器配置IP地址和掩码。配置时注意所有的Loopback接口配置掩码均为32位。

```
<Huawei>system-view
Enter system view, return user view with Ctrl+Z.
[Huawei]sysname R1
[R1]interface Serial 1/0/0
[R1-Serial1/0/0]ip address 10.0.12.1 24
[R1-Serial1/0/0]interface Serial 3/0/0
[R1-Serial3/0/0]ip address 10.0.14.1 24
[R1-Serial3/0/0]interface Serial 1/0/0
[R1-Serial1/0/0]ip address 10.0.12.1 24
[R1-Serial1/0/0]interface GigabitEthernet 0/0/2
[R1-GigabitEthernet0/0/2]ip address 10.0.13.1 24
[R1-GigabitEthernet0/0/2]interface LoopBack 0
[R1-LoopBack0]ip address 10.0.1.1 24

<Huawei>system-view
Enter system view, return user view with Ctrl+Z.
[Huawei]sysname R2
[R2]interface Serial 1/0/0
[R2-Serial1/0/0]ip address 10.0.12.2 24
[R2-Serial1/0/0] interface GigabitEthernet 0/0/0
[R2-GigabitEthernet0/0/0]ip address 10.0.25.2 24
[R2-GigabitEthernet0/0/0]interface GigabitEthernet 0/0/1
```

```
[R2-GigabitEthernet0/0/1]ip address 10.0.24.2 24
[R2-GigabitEthernet0/0/1]interface LoopBack 0
[R2-LoopBack0]ip address 10.0.2.2 24

<Huawei>system-view
Enter system view, return user view with Ctrl+Z.
[Huawei]sysname R3
[R3]interface GigabitEthernet 0/0/2
[R3-GigabitEthernet0/0/2]ip address 10.0.13.3 24
[R3-GigabitEthernet0/0/2]interface Serial 3/0/0
[R3-Serial3/0/0]ip address 10.0.35.3 24
[R3-Serial3/0/0]interface LoopBack 0
[R3-LoopBack0]ip address 10.0.3.3 24

<Huawei>system-view
Enter system view, return user view with Ctrl+Z.
[Huawei]sysname R4
[R4]interface Serial 1/0/0
[R4-Serial1/0/0]ip address 10.0.14.4 24
[R4-Serial1/0/0]interface GigabitEthernet 0/0/1
[R4-GigabitEthernet0/0/1]ip address 10.0.24.4 24
[R4-GigabitEthernet0/0/1]interface LoopBack 0
[R4-LoopBack0]ip address 10.0.4.4 24

<Huawei>system-view
Enter system view, return user view with Ctrl+Z.
[Huawei]sysname R5
[R5]interface Serial 1/0/0
[R5-Serial1/0/0]ip address 10.0.35.5 24
[R5-Serial1/0/0]interface GigabitEthernet 0/0/0
[R5-GigabitEthernet0/0/0]ip address 10.0.25.5 24
[R5-GigabitEthernet0/0/0]interface LoopBack 0
[R5-LoopBack0]ip address 10.0.5.5 24
```

配置完成以后，验证路由器之间的连通性。

```
[R1]ping -c 1 10.0.13.3
  PING 10.0.13.3: 56  data bytes, press CTRL_C to break
    Reply from 10.0.13.3: bytes=56 Sequence=1 ttl=255 time=5 ms

  --- 10.0.13.3 ping statistics ---
    1 packet(s) transmitted
    1 packet(s) received
    0.00% packet loss
```

```
    round-trip min/avg/max = 5/5/5 ms

[R1]ping -c 1 10.0.12.2
  PING 10.0.12.2: 56  data bytes, press CTRL_C to break
    Reply from 10.0.12.2: bytes=56 Sequence=1 ttl=255 time=37 ms

  --- 10.0.12.2 ping statistics ---
    1 packet(s) transmitted
    1 packet(s) received
    0.00% packet loss
    round-trip min/avg/max = 37/37/37 ms

[R1]ping -c 1 10.0.14.4
  PING 10.0.14.4: 56  data bytes, press CTRL_C to break
    Reply from 10.0.14.4: bytes=56 Sequence=1 ttl=255 time=38 ms

  --- 10.0.14.4 ping statistics ---
    1 packet(s) transmitted
    1 packet(s) received
    0.00% packet loss
    round-trip min/avg/max = 38/38/38 ms

[R5]ping -c 1 10.0.35.3
  PING 10.0.35.3: 56 data bytes, press CTRL_C to break
    Reply from 10.0.35.3: bytes=56 Sequence=1 ttl=255 time=33 ms

  --- 10.0.35.3 ping statistics ---
    1 packet(s) transmitted
    1 packet(s) received
    0.00% packet loss
    round-trip min/avg/max = 33/33/33 ms

[R5]ping -c 1 10.0.25.2
  PING 10.0.25.2: 56 data bytes, press CTRL_C to break
    Reply from 10.0.25.2: bytes=56 Sequence=1 ttl=255 time=10 ms

  --- 10.0.25.2 ping statistics ---
    1 packet(s) transmitted
    1 packet(s) received
    0.00% packet loss
    round-trip min/avg/max = 10/10/10 ms
```

步骤二. 配置所有路由器启用组播路由功能

启用R1、R2、R3、R4及R5的组播路由功能。要开启组播功能，首先在系统视图下运行命令**multicast routing-enable**。

默认情况下，VRP平台的组播功能是关闭的。无论要使用PIM还是IGMP都需要先在全局下开启组播功能。

```
[R1]multicast routing-enable
```

对于要运行PIM DM的接口，在接口视图下运行**pim dm**开启组播路由协议。

```
[R1]interface GigabitEthernet 0/0/2
[R1-GigabitEthernet0/0/2]pim dm
[R1-GigabitEthernet0/0/2]interface Serial 1/0/0
[R1-Serial1/0/0]pim dm
[R1-Serial1/0/0]interface Serial 3/0/0
[R1-Serial3/0/0]pim dm
```

在R2、R3、R4、R5上进行相同的配置，注意在路由器与路由器的互联接口上开启PIM DM的功能。

```
[R2]multicast routing-enable
[R2]interface Serial 1/0/0
[R2-Serial1/0/0]pim dm
[R2-Serial1/0/0]interface GigabitEthernet 0/0/0
[R2-GigabitEthernet0/0/0]pim dm

[R3]multicast routing-enable
[R3]interface GigabitEthernet 0/0/2
[R3-GigabitEthernet0/0/2]pim dm
[R3-GigabitEthernet0/0/2]interface Serial 3/0/0
[R3-Serial3/0/0]pim dm

[R4]multicast routing-enable
[R4]interface Serial 1/0/0
[R4-Serial1/0/0]pim dm
[R4-Serial1/0/0]interface GigabitEthernet 0/0/1
[R4-GigabitEthernet0/0/1]pim dm

[R5]multicast routing-enable
[R5]interface Serial 1/0/0
[R5-Serial1/0/0]pim dm
[R5-Serial1/0/0]interface  GigabitEthernet 0/0/0
```

```
[R5-GigabitEthernet0/0/0]pim dm
```

配置完成后，查看路由器PIM在接口上的运行状态。

```
[R1]display pim interface
 VPN-Instance: public net
 Interface           State NbrCnt HelloInt DR-Pri     DR-Address
 GE0/0/2               up    1      30         1        10.0.13.3
 S1/0/0                up    1      30         1        10.0.12.2
 S3/0/0                up    1      30         1        10.0.14.4
```

可以看到R1有3个接口运行了PIM，并且在每个接口上各有一个邻居（NbrCnt），同时我们还可以发现，在一个网段上接口IP地址较大的路由器将成为这个网段的DR。

查看R1上接口G0/0/2的PIM详细信息。

```
[R1]display pim interface GigabitEthernet 0/0/2 verbose
 VPN-Instance: public net
 Interface: GigabitEthernet0/0/2, 10.0.13.1
     PIM version: 2
     PIM mode: Dense
     PIM state: up
     PIM DR: 10.0.13.3
     PIM DR Priority (configured): 1
     PIM neighbor count: 1
     PIM hello interval: 30 s
     PIM LAN delay (negotiated): 500 ms
     PIM LAN delay (configured): 500 ms
     PIM hello override interval (negotiated): 2500 ms
     PIM hello override interval (configured): 2500 ms
     PIM Silent: disabled
     PIM neighbor tracking (negotiated): disabled
     PIM neighbor tracking (configured): disabled
     PIM generation ID: 0X5325911
     PIM require-GenID: disabled
     PIM hello hold interval: 105 s
     PIM assert hold interval: 180 s
     PIM triggered hello delay: 5 s
     PIM J/P interval: 60 s
     PIM J/P hold interval: 210 s
     PIM state-refresh processing: enabled
     PIM state-refresh interval: 60 s
     PIM graft retry interval: 3 s
     PIM state-refresh capability on link: capable
```

```
    PIM dr-switch-delay timer : not configured
    Number of routers on link not using DR priority: 0
    Number of routers on link not using LAN delay: 0
    Number of routers on link not using neighbor tracking: 2
    ACL of PIM neighbor policy: -
    ACL of PIM ASM join policy: -
    ACL of PIM SSM join policy: -
    ACL of PIM join policy: -
```

可以看到PIM DM默认的Hello间隔是30秒，Hello的保持时间是Hello间隔的3.5倍，也就是105秒。

查看R1的邻居列表，共有3台路由器与R1形成PIM邻居关系，邻居默认的DR优先级均为1。

```
[R1]display pim neighbor
 VPN-Instance: public net
 Total Number of Neighbors = 3

 Neighbor        Interface           Uptime   Expires  Dr-Priority
 10.0.13.3       GE0/0/2              01:40:27 00:01:18    1
 10.0.12.2       S1/0/0               01:42:21 00:01:24    1
 10.0.14.4       S3/0/0               01:38:02 00:01:16    1
```

查看邻居R3的详细信息，Uptime表示邻居关系已经建立的时间，Expiry time表示PIM邻居还有多少时间就要超时，LAN delay表示传递Prune剪枝消息的延迟时间，Override interval表示否决Prune剪枝的时间间隔。

```
[R1]display pim neighbor 10.0.13.3 verbose
 VPN-Instance: public net
 Neighbor: 10.0.13.3
    Interface: GigabitEthernet0/0/2
    Uptime: 01:41:00
    Expiry time: 00:01:45
    DR Priority: 1
    Generation ID: 0XD1A5CA9
    Holdtime: 105 s
    LAN delay: 500 ms
    Override interval: 2500 ms
    State refresh interval: 60 s
    Neighbor tracking: Disabled
```

步骤三. 配置 IGMP

在这个实验中，我们模拟组播用户连接在交换机S1上。在R2和R4的G0/0/1接口开启IGMP功能。要开启IGMP的功能，在接口模式下运行**igmp enable**。

```
[R2]interface GigabitEthernet 0/0/1
[R2-GigabitEthernet0/0/1]igmp enable

[R4]interface GigabitEthernet 0/0/1
[R4-GigabitEthernet0/0/1]igmp enable
```

为了实验需要，在R2和R4的G0/0/1接口添加静态组播组。这样，该接口始终会转发目的地址为225.1.1.1的组播流量。

```
[R2]interface GigabitEthernet 0/0/1
[R2-GigabitEthernet0/0/1]igmp static-group 225.1.1.1

[R4]interface GigabitEthernet 0/0/1
[R4-GigabitEthernet0/0/1]igmp static-group 225.1.1.1
```

默认情况下，VRP平台使用的IGMP版本为v2。从下面的输出中可以看到现在在G0/0/1接口所在网段的查询器是10.0.24.2，即为R2。对于IGMP v2来说，选取网段上IP地址较小的那台路由器作为查询器。

```
[R2]display igmp interface GigabitEthernet 0/0/1
Interface information
 GigabitEthernet0/0/1(10.0.24.2):
   IGMP is enabled
   Current IGMP version is 2
   IGMP state: up
   IGMP group policy: none
   IGMP limit: -
   Value of query interval for IGMP (negotiated): -
   Value of query interval for IGMP (configured): 60 s
   Value of other querier timeout for IGMP: 0 s
   Value of maximum query response time for IGMP: 10 s
   Querier for IGMP: 10.0.24.2 (this router)

[R4]display igmp interface GigabitEthernet 0/0/1
Interface information
 GigabitEthernet0/0/1(10.0.24.4):
   IGMP is enabled
   Current IGMP version is 2
   IGMP state: up
```

```
   IGMP group policy: none
   IGMP limit: -
   Value of query interval for IGMP (negotiated): -
   Value of query interval for IGMP (configured): 60 s
   Value of other querier timeout for IGMP: 123 s
   Value of maximum query response time for IGMP: 10 s
   Querier for IGMP: 10.0.24.2
```

查看接口的静态IGMP组，可以看到225.1.1.1这个组是刚才我们手工添加的组播组。

```
[R2]display igmp group static
Static join group information
 Total 1 entry, Total 1 active entry
  Group Address   Source Address  Interface          State    Expires
  225.1.1.1         0.0.0.0        GE0/0/1             UP       never
```

在接口下查看IGMP路由表。

```
[R2]display igmp routing-table
Routing table
 Total 1 entry

 00001. (*, 225.1.1.1)
      List of 1 downstream interface
       GigabitEthernet0/0/1 (10.0.24.2),
                Protocol: STATIC
```

若在接口上只配置了IGMP，没有配置PIM，且接口为查询器的情况下，才会生成IGMP路由表项。该路由表条目在R4上是看不到的，因为现在R2是网段10.0.24.0/24的查询器。

默认情况下，查询器的查询周期为60秒，为了加快用户加入组播组的速度，我们可以通过**igmp timer query**修改发送查询报文的时间间隔。

```
[R2]interface GigabitEthernet 0/0/1
[R2-GigabitEthernet0/0/1]igmp timer query 20
```

配置完成以后，验证配置已生效。

```
[R2]display igmp interface GigabitEthernet 0/0/1
Interface information
 GigabitEthernet0/0/1(10.0.24.4):
   IGMP is enabled
   Current IGMP version is 1
   IGMP state: up
```

```
IGMP group policy: none
IGMP limit: -
Value of query interval for IGMP (negotiated): -
Value of query interval for IGMP (configured): 20 s
Value of other querier timeout for IGMP: 0 s
Value of maximum query response time for IGMP: -
Querier for IGMP: 10.0.24.4 (this router)
```

开启Debugging后可以看到接口每隔20秒发送一次成员关系查询(general query)。

```
<R2>terminal debugging
<R2>debugging igmp query send
Dec 29 2011 16:33:17.350.1+00:00 R4 MGMD/7/QUERY:Send version 1 general query
on GigabitEthernet0/0/1(10.0.24.4) to destination 224.0.0.1 (G073088)
Dec 29 2011 16:33:37.130.1+00:00 R4 MGMD/7/QUERY:Send version 1 general query
on GigabitEthernet0/0/1(10.0.24.4) to destination 224.0.0.1 (G073088)
Dec 29 2011 16:33:57.510.1+00:00 R4 MGMD/7/QUERY:Send version 1 general query
on GigabitEthernet0/0/1(10.0.24.4) to destination 224.0.0.1 (G073088)
Dec 29 2011 16:34:17.480.1+00:00 R4 MGMD/7/QUERY:Send version 1 general query
on GigabitEthernet0/0/1(10.0.24.4) to destination 224.0.0.1 (G073088)
```

路由器的健壮系数描述了IGMP路由器的健壮程度。路由器默认的健壮系数为2，这里通过关闭接口的方式测试健壮系数。首先观察默认情况下IGMP查询消息的间隔。

```
<R2>terminal debugging
<R2>debugging igmp query send
Dec 31 2011 12:37:58.100.1+00:00 R2 MGMD/7/QUERY:Send version 2 general query
on GigabitEthernet0/0/1(10.0.24.2) to destination 224.0.0.1 (G073088)
Dec 31 2011 12:38:18.100.1+00:00 R2 MGMD/7/QUERY:Send version 2 general query
on GigabitEthernet0/0/1(10.0.24.2) to destination 224.0.0.1 (G073088)
<R2>system-view
Enter system view, return user view with Ctrl+Z.
Dec 31 2011 12:38:38.100.1+00:00 R2 MGMD/7/QUERY:Send version 2 general query
on GigabitEthernet0/0/1(10.0.24.2) to destination 224.0.0.1 (G073088)
[R2]interface GigabitEthernet 0/0/1
[R2-GigabitEthernet0/0/1]shutdown
Dec 31 2011 12:38:53+00:00 R2 %%01IFPDT/4/IF_STATE(l)[0]:Interface
GigabitEthernet0/0/1 has turned into DOWN state.
Dec 31 2011 12:38:53+00:00 R2 %%01IFNET/4/LINK_STATE(l)[1]:The line protocol  on
the interface GigabitEthernet0/0/1 has entered the DOWN state.
[R2-GigabitEthernet0/0/1]undo shutdown
Dec 31 2011 12:39:02+00:00 R2 %%01IFPDT/4/IF_STATE(l)[2]:Interface
```

```
GigabitEthernet0/0/1 has turned into UP state.
Dec 31 2011 12:39:02+00:00 R2 %%01IFNET/4/LINK_STATE(l)[3]:The line protocol  on
the interface GigabitEthernet0/0/1 has entered the UP state.
Dec 31 2011 12:39:03.100.1+00:00 R2 MGMD/7/QUERY:Send version 2 general query
on GigabitEthernet0/0/1(10.0.24.2) to destination 224.0.0.1 (G073088)
Dec 31 2011 12:39:08.100.1+00:00 R2 MGMD/7/QUERY:Send version 2 general query
on GigabitEthernet0/0/1(10.0.24.2) to destination 224.0.0.1 (G073088)
Dec 31 2011 12:39:28.100.1+00:00 R2 MGMD/7/QUERY:Send version 2 general query
on GigabitEthernet0/0/1(10.0.24.2) to destination 224.0.0.1 (G073088)
```

在没有关闭接口之前，路由器的接口仍按照每20秒一次的间隔发送普遍查询消息，当接口被关闭又重新打开之后，前面2个查询报文的时间间隔为5秒。当路由器启动时会发送“健壮系数”次的“普遍组查询消息”，发送间隔是“IGMP普遍组查询消息的发送间隔”的1/4。

执行命令**robust-count**可配置IGMP健壮系数，注意该参数只有在IGMP v2和IGMP v3中才有效，在R2的G0/0/1上将健壮系数修改为3。

```
[R2-GigabitEthernet0/0/1]igmp robust-count 3
```

再使用Debugging观察普遍查询消息的发送。

```
<R2>terminal debugging
Info: Current terminal debugging is on.
<R2>debugging igmp query send
Dec 31 2011 13:17:48.440.1+00:00 R2 MGMD/7/QUERY:Send version 2 general query
on GigabitEthernet0/0/1(10.0.24.2) to destination 224.0.0.1 (G073088)
<R2>system-view
Enter system view, return user view with Ctrl+Z.
[R2]interface GigabitEthernet 0/0/1
[R2-GigabitEthernet0/0/1]shutdown
Dec 31 2011 13:17:58+00:00 R2 %%01IFPDT/4/IF_STATE(l)[0]:Interface
GigabitEthernet0/0/1 has turned into DOWN state.
Dec 31 2011 13:17:58+00:00 R2 %%01IFNET/4/LINK_STATE(l)[1]:The line protocol  on
the interface GigabitEthernet0/0/1 has entered the DOWN state.
[R2-GigabitEthernet0/0/1]undo shutdown
Dec 31 2011 13:18:05+00:00 R2 %%01IFPDT/4/IF_STATE(l)[2]:Interface
GigabitEthernet0/0/1 has turned into UP state.
Dec 31 2011 13:18:05+00:00 R2 %%01IFNET/4/LINK_STATE(l)[3]:The line protocol  on
the interface GigabitEthernet0/0/1 has entered the UP state.
Dec 31 2011 13:18:06.440.1+00:00 R2 MGMD/7/QUERY:Send version 2 general query
on GigabitEthernet0/0/1(10.0.24.2) to destination 224.0.0.1 (G073088)
Dec 31 2011 13:18:11.440.1+00:00 R2 MGMD/7/QUERY:Send version 2 general query
on GigabitEthernet0/0/1(10.0.24.2) to destination 224.0.0.1 (G073088)
Dec 31 2011 13:18:16.440.1+00:00 R2 MGMD/7/QUERY:Send version 2 general query
```

```
on GigabitEthernet0/0/1(10.0.24.2) to destination 224.0.0.1 (G073088)
Dec 31 2011 13:18:36.440.1+00:00 R2 MGMD/7/QUERY:Send version 2 general query
on GigabitEthernet0/0/1(10.0.24.2) to destination 224.0.0.1 (G073088)
```

可以看到当健壮系数修改为3以后，当接口启用后前3个普遍组查询消息的时间间隔为5秒，从第四个普遍组查询消息开始时间间隔为20秒。

步骤四. 观察组播路由表

为了观察组播路由的传递，在该拓扑上启用OSPF作为单播路由协议。

```
[R1]ospf 1 router-id 10.0.1.1
[R1-ospf-1]area 0
[R1-ospf-1-area-0.0.0.0]network 10.0.1.1 0.0.0.0
[R1-ospf-1-area-0.0.0.0]network 10.0.14.1 0.0.0.0
[R1-ospf-1-area-0.0.0.0]network 10.0.13.1 0.0.0.0
[R1-ospf-1-area-0.0.0.0]network 10.0.12.1 0.0.0.0

[R2]ospf 1 router-id 10.0.2.2
[R2-ospf-1]area 0
[R2-ospf-1-area-0.0.0.0]network 10.0.2.2 0.0.0.0
[R2-ospf-1-area-0.0.0.0]network 10.0.25.2 0.0.0.0
[R2-ospf-1-area-0.0.0.0]network 10.0.12.2 0.0.0.0

[R3]ospf 1 router-id 10.0.3.3
[R3-ospf-1]area 0
[R3-ospf-1-area-0.0.0.0]network 10.0.3.3 0.0.0.0
[R3-ospf-1-area-0.0.0.0]network 10.0.13.3 0.0.0.0
[R3-ospf-1-area-0.0.0.0]network 10.0.35.3 0.0.0.0

[R4]ospf 1 router-id 10.0.4.4
[R4-ospf-1]area 0
[R4-ospf-1-area-0.0.0.0]network 10.0.4.4 0.0.0.0
[R4-ospf-1-area-0.0.0.0]network 10.0.14.4 0.0.0.0

[R5]ospf 1 router-id 10.0.5.5
[R5-ospf-1]area 0
[R5-ospf-1-area-0.0.0.0]network 10.0.5.5 0.0.0.0
[R5-ospf-1-area-0.0.0.0]network 10.0.25.5 0.0.0.0
[R5-ospf-1-area-0.0.0.0]network 10.0.35.5 0.0.0.0
```

配置完成以后，检查各路由器已能学习到其他路由器的Loopback地址。

```
[R2]display ip routing-table protocol ospf
Route Flags: R - relay, D - download to fib
------------------------------------------------------------------------------
Public routing table : OSPF
        Destinations : 7       Routes : 8

OSPF routing table status : <Active>
        Destinations : 7       Routes : 8

Destination/Mask  Proto Pre  Cost     Flags NextHop        Interface

      10.0.1.1/32  OSPF 10   1562        D   10.0.12.1       Serial1/0/0
      10.0.3.3/32  OSPF 10   1563        D   10.0.12.1       Serial1/0/0
                   OSPF 10   1563        D   10.0.25.5     GigabitEthernet0/0/0
      10.0.4.4/32  OSPF 10   3124        D   10.0.12.1       Serial1/0/0
      10.0.5.5/32  OSPF 10   1           D   10.0.25.5     GigabitEthernet0/0/0
     10.0.13.0/24  OSPF 10   1563        D   10.0.12.1       Serial1/0/0
     10.0.14.0/24  OSPF 10   3124        D   10.0.12.1       Serial1/0/0
     10.0.35.0/24  OSPF 10   1563        D   10.0.25.5     GigabitEthernet0/0/0

OSPF routing table status : <Inactive>
        Destinations : 0       Routes : 0
```

为了模拟组播信息的传递，我们在R3上以自己的Loopback接口作为源地址，向目的地址225.1.1.1发送Ping数据包，模拟组播源。

```
[R3]ping -a 10.0.3.3 -c 300 225.1.1.1
```

间隔几分钟后，我们可以在其他所有路由器上看到组播路由表。在R2上查看组播路由表。

```
[R2]display pim routing-table
 VPN-Instance: public net
 Total 1(*, G) entry; 1 (S, G) entry

(*, 225.1.1.1)
    Protocol: pim-dm, Flag: WC EXT
    UpTime: 00:09:04
    Upstream interface: NULL
       Upstream neighbor: NULL
       RPF prime neighbor: NULL
    Downstream interface(s) information: None

 (10.0.3.3, 225.1.1.1)
```

```
    Protocol: pim-dm, Flag:
    UpTime: 00:00:52
    Upstream interface: GigabitEthernet0/0/0
       Upstream neighbor: 10.0.25.5
       RPF prime neighbor: 10.0.25.5
    Downstream interface(s) information: None
```

可以看到2个条目。

第一个条目(*, 225.1.1.1)为该接口配置了静态IGMP组产生的。

第二个条目(10.0.3.3, 225.1.1.1)为组播流量进行扩散后在该路由器上产生的条目。

从输出中我们还可以看到对于R2来说，该组播流的上游路由器为10.0.25.5。

启用了PIM以后，路由器会采用单播路由表进行RPF检查，从下面的输出中可以看到，对于组播源10.0.3.3，RPF的邻居是10.0.25.5。

```
[R2]display multicast rpf-info 10.0.3.3
 VPN-Instance: public net
 RPF information about source: 10.0.3.3
    RPF interface: GigabitEthernet0/0/0, RPF neighbor: 10.0.25.5
    Referenced route/mask: 10.0.3.3/32
    Referenced route type: unicast
    Route selection rule: preference-preferred
    Load splitting rule: disable
```

步骤五. 调整 PIM DM 参数

有时我们希望流量不按照单播路由的路径流向目的地，就可以通过**rpf-route-static**静态修改RPF路径。这个试验中，我们把RPF路径由原来的10.0.25.5修改为10.0.12.1。

```
[R2]ip rpf-route-static 10.0.3.0 255.255.255.0 10.0.12.1
```

配置完成以后，可验证RPF邻居已变成了10.0.12.1。

```
[R2]display multicast rpf-info 10.0.3.3
 VPN-Instance: public net
 RPF information about source: 10.0.3.3
    RPF interface: Serial1/0/0, RPF neighbor: 10.0.12.1
    Referenced route/mask: 10.0.3.0/24
    Referenced route type: mstatic
    Route selection rule: preference-preferred
```

```
    Load splitting rule: disable
```

为了观察PIM的剪枝及嫁接消息，我们通过删除及添加IGMP静态组的方式来模拟用户的离开及加入。首先在R2上打开Debugging。

```
<R2>debugging pim join-prune
<R2>terminal debugging
```

然后把R2的静态IGMP组225.1.1.1删除。

```
[R2-GigabitEthernet0/0/1]undo  igmp static-group 225.1.1.1
Dec 31 2011 15:00:05.300.1+00:00 R2 PIM/7/JP:(public net): PIM ver 2 JP  sending
10.0.12.2 -> 224.0.0.13 on Serial1/0/0  (P012689)
Dec 31 2011 15:00:05.300.2+00:00 R2 PIM/7/JP:(public net): Upstream 10.0.12.1,
Groups 1, Holdtime 210 (P012693)
Dec 31 2011 15:00:05.300.3+00:00 R2 PIM/7/JP:(public net): Group: 225.1.1.1/32
--- 0 joins 1 prunes  (P012701)
Dec 31 2011 15:00:05.310.1+00:00 R2 PIM/7/JP:(public net): Prune: 10.0.3.3/32
(P012707)
Dec 31 2011 15:00:05.350.1+00:00 R2 PIM/7/JP:(public net): PIM ver 2 JP  receiving
10.0.12.1 -> 224.0.0.13 on Serial1/0/0  (P012689)
Dec 31 2011 15:00:05.350.2+00:00 R2 PIM/7/JP:(public net): Upstream 10.0.12.1,
Groups 1, Holdtime 207 (P012693)
Dec 31 2011 15:00:05.350.3+00:00 R2 PIM/7/JP:(public net): Group: 225.1.1.1/32
--- 0 joins 1 prunes (P012701)
Dec 31 2011 15:00:05.350.4+00:00 R2 PIM/7/JP:(public net): Prune: 10.0.3.3/32
(P012707)
```

可以看到R2立刻以组播地址224.0.0.13向上游接口发送剪枝消息，上游路由器的地址为10.0.12.1，此时225.1.1.1这个组播组已被剪枝。随后R1向R2发送消息确认剪枝。

然后再把刚才删除的静态IGMP组播组添加回去。

```
[R2-GigabitEthernet0/0/1] igmp static-group 225.1.1.1
Dec 31 2011 15:00:19.440.1+00:00 R2 PIM/7/JP:(public net): PIM ver 2 GFT sending
10.0.12.2 -> 10.0.12.1 on Serial1/0/0  (P012633)
Dec 31 2011 15:00:19.440.2+00:00 R2 PIM/7/JP:(public net): Upstream 10.0.12.1,
Groups 1, Holdtime 0 (P012639)
Dec 31 2011 15:00:19.440.3+00:00 R2 PIM/7/JP:(public net): Group: 225.1.1.1/32
--- 1 joins 0 prunes  (P012648)
Dec 31 2011 15:00:19.440.4+00:00 R2 PIM/7/JP:(public net): Join: 10.0.3.3/32
(P012654)
Dec 31 2011 15:00:19.480.1+00:00 R2 PIM/7/JP:(public net): PIM ver 2 GAK receiving
10.0.12.1 -> 10.0.12.2 on Serial1/0/0  (P012633)
```

```
Dec 31 2011 15:00:19.480.2+00:00 R2 PIM/7/JP:(public net): Upstream 10.0.12.2,
Groups 1, Holdtime 0 (P012639)
Dec 31 2011 15:00:19.480.3+00:00 R2 PIM/7/JP:(public net): Group: 225.1.1.1/32
--- 1 joins 0 prunes (P012648)
Dec 31 2011 15:00:19.480.4+00:00 R2 PIM/7/JP:(public net): Join: 10.0.3.3/32
(P012654)
```

这时R2立刻向上游以单播的形式发送了嫁接消息，加入225.1.1.1，同时R1也以单播的形式向R2回应了嫁接确认。

从这里可以总结出：**剪枝消息是以组播地址224.0.0.13发送的，而嫁接消息是以单播向上游发送的。**

有时我们希望组播流量只在规定的范围内传递，这时候可以在接口下通过**multicast boundary**为某个特定的组播组或组播地址段定界。

控制组播组225.1.1.2的流量不要传递到R4上，在R1连接到R4的接口上增加如下配置。

```
[R1-Serial3/0/0]multicast boundary 225.1.1.2 255.255.255.255
```

在R3上模拟目的地址为225.1.1.2的组播流量。

```
[R3]ping -a 10.0.3.3 -c 300 225.1.1.2
```

等待在R2和R4上分别查看组播路由表，可以看到在R2上存在表项(10.0.3.3, 225.1.1.2)，而在R4上没有该组播组路由条目，说明组播流量并没有扩散到R4上。

```
[R2]display pim routing-table
 VPN-Instance: public net
 Total 1 (*, G) entry; 2 (S, G) entries

 (*, 225.1.1.1)
     Protocol: pim-dm, Flag: WC EXT
     UpTime: 00:09:04
     Upstream interface: NULL
         Upstream neighbor: NULL
         RPF prime neighbor: NULL
     Downstream interface(s) information: None

 (10.0.3.3, 225.1.1.1)
     Protocol: pim-dm, Flag: EXT
     UpTime: 00:02:11
     Upstream interface: Serial1/0/0
         Upstream neighbor: 10.0.12.1
```

```
       RPF prime neighbor: 10.0.12.1
    Downstream interface(s) information: None

 (10.0.3.3, 225.1.1.2)
    Protocol: pim-dm, Flag:
    UpTime: 00:00:08
    Upstream interface: Serial1/0/0
       Upstream neighbor: 10.0.12.1
       RPF prime neighbor: 10.0.12.1
    Downstream interface(s) information: None

[R4]display pim routing-table
 VPN-Instance: public net
 Total 1 (*, G) entry; 1 (S, G) entry

 (*, 225.1.1.1)
    Protocol: pim-dm, Flag: WC
    UpTime: 00:08:03
    Upstream interface: NULL
       Upstream neighbor: NULL
       RPF prime neighbor: NULL
    Downstream interface(s) information:
    Total number of downstreams: 1
       1: GigabitEthernet0/0/1
          Protocol: static, UpTime: 00:08:03, Expires: never

 (10.0.3.3, 225.1.1.1)
    Protocol: pim-dm, Flag:
    UpTime: 00:02:43
    Upstream interface: Serial1/0/0
       Upstream neighbor: 10.0.14.1
       RPF prime neighbor: 10.0.14.1
    Downstream interface(s) information:
    Total number of downstreams: 1
       1: GigabitEthernet0/0/1
          Protocol: pim-dm, UpTime: 00:02:43, Expires:  -
```

默认情况下PIM DM选取接口IP地址较大的路由器作为DR。

```
[R2]display pim interface
 VPN-Instance: public net
 Interface          State NbrCnt HelloInt  DR-Pri   DR-Address
 GE0/0/0              up    1      30         1         10.0.25.5
 S1/0/0               up    1      30         1         10.0.12.2      (local)
```

在R2上查看接口状态可以看到在与R5连接的接口上，R5是DR。我们可以通过修改接口的优先级来影响DR的选举，该优先级值是一个32bit长度的数值，默认值为1。在下面的例子中，将R2连接到R5的接口的优先级改成100。

```
[R2-GigabitEthernet0/0/0]pim hello-option dr-priority 100
```

```
[R2]display pim interface
 VPN-Instance: public net
 Interface          State  NbrCnt  HelloInt  DR-Pri     DR-Address
 GE0/0/0             up     1       30         100        10.0.25.2       (local)
 S1/0/0              up     1       30         1          10.0.12.2       (local)
```

可以看到当把路由器接口优先级更改到100以后，R2立刻抢占了DR的位置。

有时为了安全需要，我们希望面向用户侧的接口上不再收发PIM的Hello包，使用**pim silent**可实现该功能。

```
[R4-GigabitEthernet0/0/1]pim silent
```

配置完成以后检查PIM Silent已生效。

```
[R4]display pim interface GigabitEthernet 0/0/1 verbose
 VPN-Instance: public net
 Interface: GigabitEthernet0/0/1, 10.0.24.4
     PIM version: 2
     PIM mode: Dense
     PIM state: up
     PIM DR: 10.0.24.4 (local)
     PIM DR Priority (configured): 1
     PIM neighbor count: 0
     PIM hello interval: 30 s
     PIM LAN delay (negotiated): 500 ms
     PIM LAN delay (configured): 500 ms
     PIM hello override interval (negotiated): 2500 ms
     PIM hello override interval (configured): 2500 ms
     PIM Silent: enabled
     PIM neighbor tracking (negotiated): disabled
     PIM neighbor tracking (configured): disabled
     PIM generation ID: 0XAD457D14
     PIM require-GenID: disabled
     PIM hello hold interval: 105 s
     PIM assert hold interval: 180 s
     PIM triggered hello delay: 5 s
     PIM J/P interval: 60 s
```

```
    PIM J/P hold interval: 210 s
    PIM state-refresh processing: enabled
    PIM state-refresh interval: 60 s
    PIM graft retry interval: 3 s
    PIM state-refresh capability on link: capable
    PIM dr-switch-delay timer : not configured
    Number of routers on link not using DR priority: 0
    Number of routers on link not using LAN delay: 0
    Number of routers on link not using neighbor tracking: 1
    ACL of PIM neighbor policy: -
    ACL of PIM ASM join policy: -
    ACL of PIM SSM join policy: -
    ACL of PIM join policy: -
```

附加实验：思考并验证

PIM的DM模式适合于用户比较多，比较密集的场景。

思考一下生活中哪些网络应用适合使用PIM DM模式的组播来实现数据转发？它们的特点是什么？

PIM的DM模式在应用在大规模网络上，有哪些劣势？

最终设备配置

```
<R1>display current-configuration
[V200R001C00SPC200]
#
 sysname R1
#
interface Serial1/0/0
 link-protocol ppp
 ip address 10.0.12.1 255.255.255.0
 pim dm
#
interface Serial3/0/0
 link-protocol ppp
 ip address 10.0.14.1 255.255.255.0
 pim dm
```

```
 multicast boundary 225.1.1.2 32
#
ip address 10.0.13.1 255.255.255.0
 pim dm
#
interface LoopBack0
 ip address 10.0.1.1 255.255.255.255
#
ospf 1 router-id 10.0.1.1
 area 0.0.0.0
  network 10.0.1.1 0.0.0.0
  network 10.0.14.1 0.0.0.0
  network 10.0.13.1 0.0.0.0
  network 10.0.12.1 0.0.0.0
#
return

<R2>display current-configuration
[V200R001C00SPC200]
#
 sysname R2
#
interface Serial1/0/0
 link-protocol ppp
 ip address 10.0.12.2 255.255.255.0
 pim dm
#
interface GigabitEthernet0/0/0
 ip address 10.0.25.2 255.255.255.0
 pim hello-option dr-priority 100
 pim dm
#
interface GigabitEthernet0/0/1
 ip address 10.0.24.2 255.255.255.0
 igmp enable
 igmp robust-count 3
 igmp timer query 20
 igmp static-group 225.1.1.1
#
interface LoopBack0
 ip address 10.0.2.2 255.255.255.255
#
ospf 1 router-id 10.0.2.2
```

```
 area 0.0.0.0
  network 10.0.2.2 0.0.0.0
  network 10.0.25.2 0.0.0.0
  network 10.0.12.2 0.0.0.0
#
 ip rpf-route-static 10.0.3.0 24 10.0.12.1
#
return
```

```
<R3>display current-configuration
[V200R001C00SPC200]
#
 sysname R3
#
interface Serial3/0/0
 link-protocol ppp
 ip address 10.0.35.3 255.255.255.0
 pim dm
#
interface GigabitEthernet0/0/2
 ip address 10.0.13.3 255.255.255.0
 pim dm
#
interface LoopBack0
 ip address 10.0.3.3 255.255.255.255
#
ospf 1 router-id 10.0.3.3
 area 0.0.0.0
  network 10.0.3.3 0.0.0.0
  network 10.0.13.3 0.0.0.0
  network 10.0.35.3 0.0.0.0
#
return
```

```
<R4>display current-configuration
[V200R001C00SPC200]
#
 sysname R4
#
interface Serial1/0/0
 link-protocol ppp
 ip address 10.0.14.4 255.255.255.0
 pim dm
```

```
#
interface GigabitEthernet0/0/1
 ip address 10.0.24.4 255.255.255.0
 pim silent
 igmp enable
 igmp static-group 225.1.1.1
#
interface LoopBack0
 ip address 10.0.4.4 255.255.255.255
#
ospf 1 router-id 10.0.4.4
 area 0.0.0.0
  network 10.0.4.4 0.0.0.0
  network 10.0.14.4 0.0.0.0
#
return

<R5>display current-configuration
[V200R001C00SPC200]
#
 sysname R5
#
interface Serial1/0/0
 link-protocol ppp
 ip address 10.0.35.5 255.255.255.0
 pim dm
#
interface GigabitEthernet0/0/0
 ip address 10.0.25.5 255.255.255.0
 pim dm
#
interface LoopBack0
 ip address 10.0.5.5 255.255.255.255
#
ospf 1 router-id 10.0.5.5
 area 0.0.0.0
  network 10.0.5.5 0.0.0.0
  network 10.0.25.5 0.0.0.0
  network 10.0.35.5 0.0.0.0
#
return
```

实验 5-2 PIM SM 及动态 RP

学习目的

- 掌握PIM SM协议的配置方法
- 掌握静态RP和RP负载均衡的配置方法
- 掌握RPT与SPT之间切换的控制方法
- 掌握Auto-RP的配置方法

拓扑图

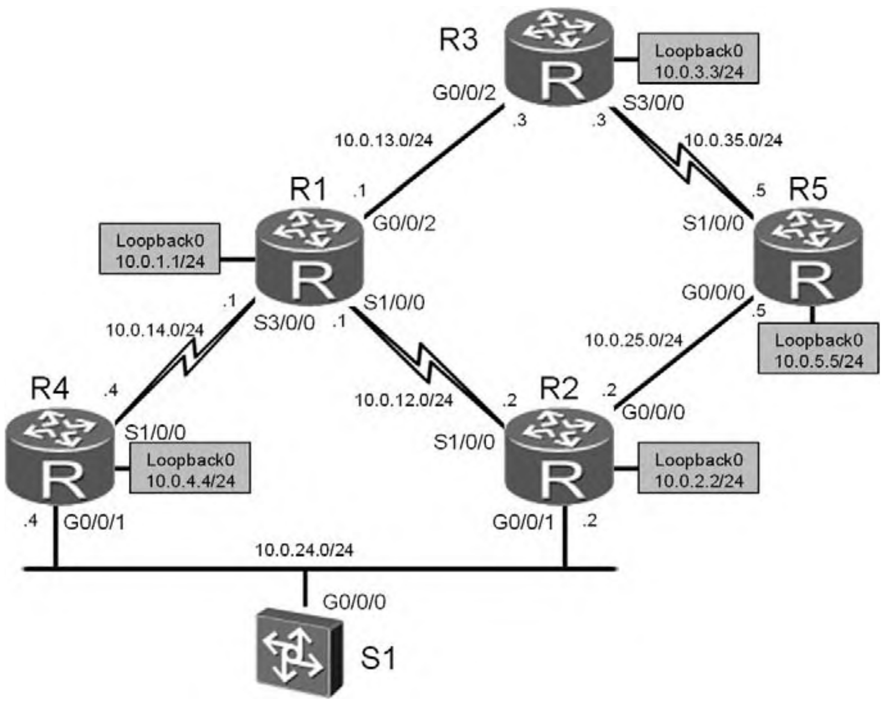

图5-2 PIM SM及动态RP

场景

你是公司的网络管理员。公司以前使用过PIM的DM模式来实现组播路由学习，但是后来发现随着组播应用的发展，组播用户分部越来越广，这时组播质量显示出一定程度的下降。为了提高组播的可靠性、安全性和效率，你决定使用PIM的SM模式来实现组播路由学习。

在PIM的SM模式中，你需要定义RP，作为SM模式的共享树的树根。但是在实际的使用中，只是这样简单的配置是不够的，组播还需要实现RP之间的负载分担。并且考虑到以后组播规模的增大，你需要考虑使用Auto-RP功能。

在实现网络的组播转发之前，你也遇到了一些网络故障，经过一些故障排除步骤，最终网络正常工作了。

学习任务

步骤一. 基础配置与 IP 编址

S2参与到本次实验，但无需配置。实验之前，请清空S2的配置，并重启它。

给所有路由器配置IP地址和掩码。配置时注意所有的Loopback接口配置掩码均为32位。

```
<Huawei>system-view
Enter system view, return user view with Ctrl+Z.
[Huawei]sysname R1
[R1]interface GigabitEthernet0/0/2
[R1-GigabitEthernet0/0/2]ip address 10.0.13.1 24
[R1-GigabitEthernet0/0/2]interface Serial 1/0/0
[R1-Serial1/0/0]ip address 10.0.12.1 24
[R1-Serial1/0/0]interface Serial 3/0/0
[R1-Serial3/0/0]ip address 10.0.14.1 24
[R1-Serial3/0/0]interface loopback 0
[R1-LoopBack0]ip address 10.0.1.1 32

<Huawei>system-view
Enter system view, return user view with Ctrl+Z.
[Huawei]sysname R2
[R2]interface GigabitEthernet0/0/0
[R2-GigabitEthernet0/0/0]ip address 10.0.25.2 24
[R2-GigabitEthernet0/0/0]interface GigabitEthernet0/0/1
[R2-GigabitEthernet0/0/1]ip address 10.0.24.2 24
[R2-GigabitEthernet0/0/1]interface Serial 1/0/0
```

```
[R2-Serial1/0/0]ip address 10.0.12.2 24
[R2-Serial1/0/0]interface loopback 0
[R2-LoopBack0]ip address 10.0.2.2 32

<Huawei>system-view
Enter system view, return user view with Ctrl+Z.
[Huawei]sysname R3
[R3]interface GigabitEthernet0/0/2
[R3-GigabitEthernet0/0/2]ip address 10.0.13.3 24
[R3-GigabitEthernet0/0/2]interface Serial 3/0/0
[R3-Serial3/0/0]ip address 10.0.35.3 24
[R3-Serial3/0/0]interface loopback 0
[R3-LoopBack0]ip address 10.0.3.3 32

<Huawei>system-view
Enter system view, return user view with Ctrl+Z.
[Huawei]sysname R4
[R4]interface GigabitEthernet0/0/1
[R4-GigabitEthernet0/0/1]ip address 10.0.24.4 24
[R4-GigabitEthernet0/0/1]interface Serial 1/0/0
[R4-Serial1/0/0]ip address 10.0.14.4 24
[R4-Serial1/0/0]interface loopback 0
[R4-LoopBack0]ip address 10.0.4.4 32

<Huawei>system-view
Enter system view, return user view with Ctrl+Z.
[Huawei]sysname R5
[R5]interface GigabitEthernet0/0/0
[R5-GigabitEthernet0/0/0]ip address 10.0.25.5 24
[R5-GigabitEthernet0/0/0]interface Serial 1/0/0
[R5-Serial1/0/0]ip add 10.0.35.5 24
[R5-Serial1/0/0]interface loopback 0
[R5-LoopBack0]ip add 10.0.5.5 32

<Quidway>system-view
Enter system view, return user view with Ctrl+Z.
[Quidway]sysname S1
[S1]interface Vlanif 1
[S1-Vlanif1]ip address 10.0.24.1 24
[S1-Vlanif1]interface loopback 0
[S1-LoopBack0]ip address 10.0.11.11 24
```

配置完成后，测试直连链路的连通性。

```
[R1]ping -c 1 10.0.12.2
  PING 10.0.12.2: 56  data bytes, press CTRL_C to break
    Reply from 10.0.12.2: bytes=56 Sequence=1 ttl=255 time=41 ms

  --- 10.0.12.2 ping statistics ---
    1 packet(s) transmitted
    1 packet(s) received
    0.00% packet loss
    round-trip min/avg/max = 41/41/41 ms

[R1]ping -c 1 10.0.13.3
  PING 10.0.13.3: 56  data bytes, press CTRL_C to break
    Reply from 10.0.13.3: bytes=56 Sequence=1 ttl=255 time=5 ms

  --- 10.0.13.3 ping statistics ---
    1 packet(s) transmitted
    1 packet(s) received
    0.00% packet loss
    round-trip min/avg/max = 5/5/5 ms

[R1]ping -c 1 10.0.14.4
  PING 10.0.14.4: 56  data bytes, press CTRL_C to break
    Reply from 10.0.14.4: bytes=56 Sequence=1 ttl=255 time=62 ms

  --- 10.0.14.4 ping statistics ---
    1 packet(s) transmitted
    1 packet(s) received
    0.00% packet loss
    round-trip min/avg/max = 62/62/62 ms

[R5]ping -c 1 10.0.25.2
  PING 10.0.25.2: 56 data bytes, press CTRL_C to break
    Reply from 10.0.25.2: bytes=56 Sequence=1 ttl=255 time=7 ms

  --- 10.0.25.2 ping statistics ---
    1 packet(s) transmitted
    1 packet(s) received
    0.00% packet loss
    round-trip min/avg/max = 7/7/7 ms

[R5]ping -c 1 10.0.35.3
  PING 10.0.35.3: 56 data bytes, press CTRL_C to break
    Reply from 10.0.35.3: bytes=56 Sequence=1 ttl=255 time=37 ms
```

```
 --- 10.0.35.3 ping statistics ---
   1 packet(s) transmitted
   1 packet(s) received
   0.00% packet loss
   round-trip min/avg/max = 37/37/37 ms

[S1]ping -c 1 10.0.24.2
 PING 10.0.24.2: 56  data bytes, press CTRL_C to break
   Reply from 10.0.24.2: bytes=56 Sequence=1 ttl=255 time=1 ms

 --- 10.0.24.2 ping statistics ---
   1 packet(s) transmitted
   1 packet(s) received
   0.00% packet loss
   round-trip min/avg/max = 1/1/1 ms
```

在R1、R2、R3、R4、 R5和S1上启用OSPF路由协议。实现所有网络互通。

```
[R1]ospf 1
[R1-ospf-1]area 0
[R1-ospf-1-area-0.0.0.0]network 10.0.14.1 0.0.0.0
[R1-ospf-1-area-0.0.0.0]network 10.0.12.1 0.0.0.0
[R1-ospf-1-area-0.0.0.0]network 10.0.13.1 0.0.0.0
[R1-ospf-1-area-0.0.0.0]network 10.0.1.1 0.0.0.0

[R2]ospf 1
[R2-ospf-1]area 0
[R2-ospf-1-area-0.0.0.0]network 10.0.12.2 0.0.0.0
[R2-ospf-1-area-0.0.0.0]network 10.0.24.2 0.0.0.0
[R2-ospf-1-area-0.0.0.0]network 10.0.25.2 0.0.0.0
[R2-ospf-1-area-0.0.0.0]network 10.0.2.2 0.0.0.0

[R3]ospf 1
[R3-ospf-1]area 0
[R3-ospf-1-area-0.0.0.0]network 10.0.13.3 0.0.0.0
[R3-ospf-1-area-0.0.0.0]network 10.0.35.3 0.0.0.0
[R3-ospf-1-area-0.0.0.0]network 10.0.3.3 0.0.0.0

[R4]ospf 1
[R4-ospf-1]area 0
[R4-ospf-1-area-0.0.0.0]network 10.0.14.4 0.0.0.0
[R4-ospf-1-area-0.0.0.0]network 10.0.24.4 0.0.0.0
[R4-ospf-1-area-0.0.0.0]network 10.0.4.4 0.0.0.0
```

```
[R5]ospf 1
[R5-ospf-1]area 0
[R5-ospf-1-area-0.0.0.0]network 10.0.25.5 0.0.0.0
[R5-ospf-1-area-0.0.0.0]network 10.0.35.5 0.0.0.0
[R5-ospf-1-area-0.0.0.0]network 10.0.5.5 0.0.0.0

[S1]ospf 1
[S1-ospf-1]area 0
[S1-ospf-1-area-0.0.0.0]network 10.0.24.1 0.0.0.0
[S1-ospf-1-area-0.0.0.0]network 10.0.11.11 0.0.0.0
```

配置完成后，稍等片刻，待OSPF邻居关系连接，路由信息交互完成后，测试S1与路由器R3的Loopback 0地址之间的连通性。

```
[S1]ping -c 1 10.0.3.3
  PING 10.0.3.3: 56  data bytes, press CTRL_C to break
    Reply from 10.0.3.3: bytes=56 Sequence=1 ttl=253 time=37 ms

  --- 10.0.3.3 ping statistics ---
    1 packet(s) transmitted
    1 packet(s) received
    0.00% packet loss
    round-trip min/avg/max = 37/37/37 ms
```

如测试显示，网络工作正常。

步骤二. 配置所有路由器启用 PIM SM

启用R1、R2、R3、R4、R5和S1的组播路由功能。

```
[R1]multicast routing-enable

[R2]multicast routing-enable

[R3]multicast routing-enable

[R4]multicast routing-enable

[R5]multicast routing-enable

[S1]multicast routing-enable
```

在所有设备的所有接口上配置运行SM模式的PIM。

```
[R1]interface GigabitEthernet0/0/2
[R1-GigabitEthernet0/0/2]pim sm
[R1-GigabitEthernet0/0/2]interface Serial 1/0/0
[R1-Serial1/0/0]pim sm
[R1-Serial1/0/0]interface Serial 3/0/0
[R1-Serial3/0/0]pim sm
[R1-Serial3/0/0]interface loopback 0
[R1-LoopBack0]pim sm

[R2]interface GigabitEthernet0/0/0
[R2-GigabitEthernet0/0/0]pim sm
[R2-GigabitEthernet0/0/0]interface GigabitEthernet0/0/1
[R2-GigabitEthernet0/0/1]pim sm
[R2-GigabitEthernet0/0/1]interface Serial 1/0/0
[R2-Serial1/0/0]pim sm
[R2-Serial1/0/0]interface loopback 0
[R2-LoopBack0]pim sm

[R3]interface GigabitEthernet0/0/2
[R3-GigabitEthernet0/0/2]pim sm
[R3-GigabitEthernet0/0/2]interface Serial 3/0/0
[R3-Serial3/0/0]pim sm
[R3-Serial3/0/0]interface loopback 0
[R3-LoopBack0]pim sm

[R4]interface GigabitEthernet0/0/1
[R4-GigabitEthernet0/0/1]pim sm
[R4-GigabitEthernet0/0/1]interface Serial 1/0/0
[R4-Serial1/0/0]pim sm
[R4-Serial1/0/0]interface loopback 0
[R4-LoopBack0]pim sm

[R5]interface GigabitEthernet0/0/0
[R5-GigabitEthernet0/0/0]pim sm
[R5-GigabitEthernet0/0/0]interface Serial 1/0/0
[R5-Serial1/0/0]pim sm
[R5-Serial1/0/0]interface loopback 0
[R5-LoopBack0]pim sm

[S1]interface Vlanif 1
[S1-Vlanif1]pim sm
[S1-Vlanif1]interface loopback 0
```

```
[S1-LoopBack0]pim sm
```

配置完成后，查看R1、R5和S1的PIM邻居学习的情况。

```
<R1>display pim neighbor
 VPN-Instance: public net
 Total Number of Neighbors = 3

 Neighbor        Interface          Uptime   Expires  Dr-Priority
 10.0.13.3       GE0/0/2            00:08:52 00:01:23 1
 10.0.12.2       S1/0/0             00:40:44 00:01:30 1
 10.0.14.4       S3/0/0             00:07:53 00:01:23 1

[R5]display pim neighbor
 VPN-Instance: public net
 Total Number of Neighbors = 2

 Neighbor        Interface          Uptime   Expires  Dr-Priority
 10.0.25.2       GE0/0/0            00:08:38 00:01:30 1
 10.0.35.3       S1/0/0             00:08:38 00:01:28 1

[S1]display pim neighbor
 VPN-Instance: public net
 Total Number of Neighbors = 2

 Neighbor        Interface          Uptime   Expires  Dr-Priority  BFD-Session
 10.0.24.4       Vlanif1            00:01:24 00:01:23 1            N
 10.0.24.2       Vlanif1            00:01:22 00:01:17 1            N
```

从命令输出结果可以看到，PIM协议已经在网络中正确运行。

步骤三.　静态 RP 和静态 RP 负载均衡

通过给网络手动指定静态RP来控制网络中组播数据流。

在所有设备配置R1的S3/0/0接口作为网络中的静态RP。

```
[R1]pim
[R1-pim]static-rp 10.0.14.1

[R2]pim
[R2-pim]static-rp 10.0.14.1

[R3]pim
```

```
[R3-pim]static-rp 10.0.14.1

[R4]pim
[R4-pim]static-rp 10.0.14.1

[R5]pim
[R5-pim]static-rp 10.0.14.1

[S1]pim
[S1-pim]static-rp 10.0.14.1
```

S1模拟网络中组播用户接入的三层交换机，在S1的Loopback 0接口上开启IGMP功能。

```
[S1]interface LoopBack 0
[S1-LoopBack0]igmp enable
```

将S1的Loopback 0接口静态加入225.0.0.1组播组，模拟连接有225.0.0.1组播组的用户。

```
[S1]interface LoopBack 0
[S1-LoopBack0]igmp static-group 225.0.0.1
```

在R1、R4和S1上使用命令**display pim routing-table**查看PIM路由表。

```
[R1]display pim routing-table
 VPN-Instance: public net
 Total 1 (*, G) entry; 0 (S, G) entry

 (*, 225.0.0.1)
     RP: 10.0.14.1 (local)
     Protocol: pim-sm, Flag: WC
     UpTime: 00:02:40
     Upstream interface: Register
        Upstream neighbor: NULL
        RPF prime neighbor: NULL
     Downstream interface(s) information:
     Total number of downstreams: 1
        1: Serial3/0/0
            Protocol: pim-sm, UpTime: 00:02:40, Expires: 00:02:50

[R4]display pim routing-table
 VPN-Instance: public net
 Total 1 (*, G) entry; 0 (S, G) entry
```

```
 (*, 225.0.0.1)
    RP: 10.0.14.1
    Protocol: pim-sm, Flag: WC
    UpTime: 00:01:46
    Upstream interface: Serial1/0/0
        Upstream neighbor: 10.0.14.1
        RPF prime neighbor: 10.0.14.1
    Downstream interface(s) information:
    Total number of downstreams: 1
        1: GigabitEthernet0/0/1
            Protocol: pim-sm, UpTime: 00:01:46, Expires: 00:02:43

[S1-LoopBack0]display pim routing-table
 VPN-Instance: public net
 Total 1 (*, G) entry; 0 (S, G) entry

 (*, 225.0.0.1)
    RP: 10.0.14.1
    Protocol: pim-sm, Flag: WC
    UpTime: 00:01:19
    Upstream interface: Vlanif1
        Upstream neighbor: 10.0.24.4
        RPF prime neighbor: 10.0.24.4
    Downstream interface(s) information:
    Total number of downstreams: 1
        1: LoopBack0
            Protocol: static, UpTime: 00:01:19, Expires: -
```

从命令输出结果可以看到，在指定静态RP的网络中，R1是网络中的RP。S1生成了一条经过R4到达RP路由器R1的组播路径。

创建ACL并应用到静态RP上，定义R1作为RP，服务的组播范围是225.0.0.0/24网段，定义R5作为RP，服务的组播范围是225.0.1.0/24网段。

```
[R1]acl 2000
[R1-acl-basic-2000]rule permit source 225.0.0.0 0.0.0.255
[R1-acl-basic-2000]acl 2001
[R1-acl-basic-2001]rule permit source 225.0.1.0 0.0.0.255
[R1-acl-basic-2001]pim
[R1-pim]static-rp 10.0.14.1 2000
[R1-pim]static-rp 10.0.25.5 2001

[R2]acl 2000
[R2-acl-basic-2000]rule permit source 225.0.0.0 0.0.0.255
```

```
[R2-acl-basic-2000]acl 2001
 [R2-acl-basic-2001]rule permit source 225.0.1.0 0.0.0.255
[R2-acl-basic-2001]pim
 [R2-pim]static-rp 10.0.14.1 2000
[R2-pim]static-rp 10.0.25.5 2001

[R3]acl 2000
[R3-acl-basic-2000]rule permit source 225.0.0.0 0.0.0.255
[R3-acl-basic-2000]acl 2001
 [R3-acl-basic-2001]rule permit source 225.0.1.0 0.0.0.255
[R3-acl-basic-2001]pim
[R3-pim]static-rp 10.0.14.1 2000
[R3-pim]static-rp 10.0.25.5 2001

[R4]acl 2000
[R4-acl-basic-2000]rule permit source 225.0.0.0 0.0.0.255
[R4-acl-basic-2000]acl 2001
[R4-acl-basic-2001]rule permit source 225.0.1.0 0.0.0.255
[R4-acl-basic-2001]pim
[R4-pim]static-rp 10.0.14.1 2000
[R4-pim]static-rp 10.0.25.5 2001

[R5]acl 2000
[R5-acl-basic-2000]rule permit source 225.0.0.0 0.0.0.255
[R5-acl-basic-2000]acl 2001
[R5-acl-basic-2001]rule permit source 225.0.1.0 0.0.0.255
[R5-acl-basic-2001]pim
[R5-pim]static-rp 10.0.14.1 2000
[R5-pim]static-rp 10.0.25.5 2001

[S1]acl 2000
[S1-acl-basic-2000]rule permit source 225.0.0.0 0.0.0.255
[S1-acl-basic-2000]acl 2001
[S1-acl-basic-2001]rule permit source 225.0.1.0 0.0.0.255
[S1-acl-basic-2001]pim
[S1-pim]static-rp 10.0.14.1 2000
[S1-pim]static-rp 10.0.25.5 2001
```

将S1的Loopback 0接口静态加入225.0.1.1组播组，模拟连接有225.0.1.1组播组的用户。

```
[S1]interface LoopBack 0
[S1-LoopBack0]igmp static-group 225.0.1.1
```

在S1、R2和 R5上使用命令**display pim routing-table**查看PIM路由表。

```
[R5]dis pim routing-table
 VPN-Instance: public net
 Total 1 (*, G) entry; 0 (S, G) entry

 (*, 225.0.1.1)
     RP: 10.0.25.5 (local)
     Protocol: pim-sm, Flag: WC
     UpTime: 00:03:13
     Upstream interface: Register
         Upstream neighbor: NULL
         RPF prime neighbor: NULL
     Downstream interface(s) information:
     Total number of downstreams: 1
         1: GigabitEthernet0/0/0
             Protocol: pim-sm, UpTime: 00:03:13, Expires: 00:03:17

[R2]display pim routing-table
 VPN-Instance: public net
 Total 1 (*, G) entry; 0 (S, G) entry

 (*, 225.0.1.1)
     RP: 10.0.25.5
     Protocol: pim-sm, Flag: WC
     UpTime: 00:03:41
     Upstream interface: GigabitEthernet0/0/0
         Upstream neighbor: 10.0.25.5
         RPF prime neighbor: 10.0.25.5
     Downstream interface(s) information:
     Total number of downstreams: 1
         1: GigabitEthernet0/0/1
             Protocol: pim-sm, UpTime: 00:03:41, Expires: 00:02:48

[S1]display pim routing-table
 VPN-Instance: public net
 Total 2 (*, G) entries; 0 (S, G) entry

 (*, 225.0.0.1)
     RP: 10.0.14.1
     Protocol: pim-sm, Flag: WC
     UpTime: 00:17:09
     Upstream interface: Vlanif1
         Upstream neighbor: 10.0.24.4
```

```
        RPF prime neighbor: 10.0.24.4
     Downstream interface(s) information:
     Total number of downstreams: 1
        1: LoopBack0
           Protocol: static, UpTime: 00:17:09, Expires: -

 (*, 225.0.1.1)
     RP: 10.0.25.5
     Protocol: pim-sm, Flag: WC
     UpTime: 00:03:58
     Upstream interface: Vlanif1
        Upstream neighbor: 10.0.24.2
        RPF prime neighbor: 10.0.24.2
     Downstream interface(s) information:
     Total number of downstreams: 1
        1: LoopBack0
           Protocol: static, UpTime: 00:03:58, Expires: -
```

从命令输出结果可以看到，S1针对225.0.0.1和225.0.1.1生成了二条组播路径。225.0.1.1组播路径经过R2到达RP路由器R5。

步骤四. 配置 Auto-RP

使用Auto-RP方式配置R3作为C-BSR控制组播边界，同时让PIM自动在R1和R5之间选举出RP。

删除所有路由器上的静态RP配置，避免静态配置干扰Auto-RP实验。

```
[R1]undo pim
Warning: This operation will lead to the deletion of all the IPv4 global PIM
configurations in the public instance. Continue? [Y/N]:y

[R2]undo pim
Warning: This operation will lead to the deletion of all the IPv4 global PIM
configurations in the public instance. Continue? [Y/N]:y

[R3]undo pim
Warning: This operation will lead to the deletion of all the IPv4 global PIM
configurations in the public instance. Continue? [Y/N]:y

[R4]undo pim
Warning: This operation will lead to the deletion of all the IPv4 global PIM
configurations in the public instance. Continue? [Y/N]:y
```

```
[R5]undo pim
Warning: This operation will lead to the deletion of all the IPv4 global PIM
configurations in the public instance. Continue? [Y/N]:y

[S1]undo pim
```

在R1和R5上配置Auto-RP。

```
[R1]pim
[R1-pim]c-rp LoopBack 0

[R5]pim
[R5-pim]c-rp LoopBack 0
```

将R3配置为C-BSR。

```
[R3]pim
[R3-pim]c-bsr LoopBack 0
```

在R1上使用**display pim bsr-info**命令查看网络中的C-BSR信息。

```
[R1]display pim bsr-info
 VPN-Instance: public net
 Elected AdminScoped BSR Count: 0
 Elected BSR Address: 10.0.3.3
     Priority: 0
     Hash mask length: 30
     State: Accept Preferred
     Scope: Not scoped
     Uptime: 00:02:46
     Expires: 00:01:34
     C-RP Count: 2
```

在R1上使用display pim rp-info命令查看网络中的RP信息。

```
[R1]display pim rp-info
 VPN-Instance: public net
 PIM-SM BSR RP Number:2
 Group/MaskLen: 224.0.0.0/4
     RP: 10.0.1.1 (local)
     Priority: 0
     Uptime: 00:04:51
     Expires: 00:01:39
 Group/MaskLen: 224.0.0.0/4
     RP: 10.0.5.5
```

```
    Priority: 0
    Uptime: 00:04:51
    Expires: 00:01:39
```

在S1上查看PIM信息。

```
[S1]display pim routing-table
 VPN-Instance: public net
 Total 2 (*, G) entries; 0 (S, G) entry

 (*, 225.0.0.1)
    RP: 10.0.5.5
    Protocol: pim-sm, Flag: WC
    UpTime: 00:31:32
    Upstream interface: Vlanif1
       Upstream neighbor: 10.0.24.2
       RPF prime neighbor: 10.0.24.2
    Downstream interface(s) information:
    Total number of downstreams: 1
       1: LoopBack0
          Protocol: static, UpTime: 00:31:32, Expires: -

 (*, 225.0.1.1)
    RP: 10.0.1.1
    Protocol: pim-sm, Flag: WC
    UpTime: 00:18:21
    Upstream interface: Vlanif1
       Upstream neighbor: 10.0.24.4
       RPF prime neighbor: 10.0.24.4
    Downstream interface(s) information:
    Total number of downstreams: 1
       1: LoopBack0
          Protocol: static, UpTime: 00:18:21, Expires: -
```

从输出结果可以看到，R3是网络中的C-BSR，R1是225.0.1.1组播组的RP，R5是225.0.0.1组播组的RP。225.0.1.1组播组的路径是从R4到R1，225.0.0.1组播组的路径是从R2到R5。

附加实验：思考并验证

PIM的SM模式适合于用户比较分散的场景。

思考一下生活中哪些网络应用适合使用PIM SM模式的组播来实现数据转发？

它们的特点是什么？

最终设备配置

```
[R1]display current-configuration
[V200R001C00SPC200]
#
 sysname R1
#
 board add 0/1 1SA
 board add 0/2 1SA
 board add 0/3 1SA
#
 multicast routing-enable
#
acl number 2000
 rule 5 permit source 225.0.0.0 0.0.0.255
#
acl number 2001
 rule 5 permit source 225.0.1.0 0.0.0.255
#
interface Serial1/0/0
 link-protocol ppp
 ip address 10.0.12.1 255.255.255.0
 pim sm
#
interface Serial3/0/0
 link-protocol ppp
 ip address 10.0.14.1 255.255.255.0
 pim sm
#
interface GigabitEthernet0/0/2
 ip address 10.0.13.1 255.255.255.0
 pim sm
#
interface LoopBack0
 ip address 10.0.1.1 255.255.255.255
 pim sm
#
ospf 1
 area 0.0.0.0
  network 10.0.14.1 0.0.0.0
  network 10.0.12.1 0.0.0.0
```

```
  network 10.0.13.1 0.0.0.0
  network 10.0.1.1 0.0.0.0
#
pim
 c-rp LoopBack0
#
Return
```

[R2]**display current-configuration**

```
[V200R001C00SPC200]
#
 sysname R2
#
 board add 0/1 1SA
 board add 0/2 1SA
 board add 0/3 1SA
#
 multicast routing-enable
#
acl number 2000
 rule 5 permit source 225.0.0.0 0.0.0.255
#
acl number 2001
 rule 5 permit source 225.0.1.0 0.0.0.255
#
interface Serial1/0/0
 link-protocol ppp
 ip address 10.0.12.2 255.255.255.0
 pim sm
#
interface GigabitEthernet0/0/0
 ip address 10.0.25.2 255.255.255.0
 pim sm
#
interface GigabitEthernet0/0/1
 ip address 10.0.24.2 255.255.255.0
 pim sm
#
interface LoopBack0
 ip address 10.0.2.2 255.255.255.255
 pim sm
#
ospf 1
```

```
 area 0.0.0.0
  network 10.0.12.2 0.0.0.0
  network 10.0.24.2 0.0.0.0
  network 10.0.25.2 0.0.0.0
  network 10.0.2.2 0.0.0.0
#
Return
```

```
[R3]display current-configuration
[V200R001C00SPC200]
#
 sysname R3
#
 board add 0/1 1SA
 board add 0/2 1SA
 board add 0/3 1SA
#
 multicast routing-enable
#
acl number 2000
 rule 5 permit source 225.0.0.0 0.0.0.255
#
acl number 2001
 rule 5 permit source 225.0.1.0 0.0.0.255
#
interface Serial3/0/0
 link-protocol ppp
 ip address 10.0.35.3 255.255.255.0
 pim sm
#
interface GigabitEthernet0/0/2
 ip address 10.0.13.3 255.255.255.0
 pim sm
#
interface LoopBack0
 ip address 10.0.3.3 255.255.255.255
 pim sm
#
ospf 1
 area 0.0.0.0
  network 10.0.13.3 0.0.0.0
  network 10.0.35.3 0.0.0.0
  network 10.0.3.3 0.0.0.0
```

```
#
pim
 c-bsr LoopBack0
#
Return
```

```
[R4]display current-configuration
[V200R001C00SPC500]
#
 sysname R4
#
 board add 0/1 1SA
 board add 0/2 2FE
#
 multicast routing-enable
#
acl number 2000
 rule 5 permit source 225.0.0.0 0.0.0.255
#
acl number 2001
 rule 5 permit source 225.0.1.0 0.0.0.255
#
interface Serial1/0/0
 link-protocol ppp
 ip address 10.0.14.4 255.255.255.0
 pim sm
#
interface GigabitEthernet0/0/1
 ip address 10.0.24.4 255.255.255.0
 pim sm
#
interface LoopBack0
 ip address 10.0.4.4 255.255.255.255
 pim sm
#
ospf 1
 area 0.0.0.0
  network 10.0.14.4 0.0.0.0
  network 10.0.24.4 0.0.0.0
  network 10.0.4.4 0.0.0.0
#
Return
```

```
[R5]display current-configuration
[V200R001C00SPC500]
#
 sysname R5
#
 board add 0/1 1SA
 board add 0/2 2FE
#
 multicast routing-enable
#
acl number 2000
 rule 5 permit source 225.0.0.0 0.0.0.255
#
acl number 2001
 rule 5 permit source 225.0.1.0 0.0.0.255
#
interface Serial1/0/0
 link-protocol ppp
 ip address 10.0.35.5 255.255.255.0
 pim sm
#
interface GigabitEthernet0/0/0
 ip address 10.0.25.5 255.255.255.0
 pim sm
#
interface LoopBack0
 ip address 10.0.5.5 255.255.255.255
 pim sm
#
ospf 1
 area 0.0.0.0
  network 10.0.25.5 0.0.0.0
  network 10.0.35.5 0.0.0.0
  network 10.0.5.5 0.0.0.0
#
pim
 c-rp LoopBack0
#
Return
```

```
[S1]display current-configuration
!Software Version V100R006C00SPC800
 sysname S1
```

```
#
 multicast routing-enable
#
acl number 2000
 rule 5 permit source 225.0.0.0 0.0.0.255
#
acl number 2001
 rule 5 permit source 225.0.1.0 0.0.0.255
#
interface Vlanif1
 ip address 10.0.24.1 255.255.255.0
 pim sm
#
interface LoopBack0
 ip address 10.0.11.11 255.255.255.0
 pim sm
 igmp enable
 igmp static-group 225.0.0.1
 igmp static-group 225.0.1.1
#
ospf 1
 area 0.0.0.0
  network 10.0.24.1 0.0.0.0
  network 10.0.11.11 0.0.0.0
#
pim
#
Return
```