Instituto Superior Técnico

Redes e Serviços Internet

Laboratório 3 - Multicast

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2.1

b)

```
PC4#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
PC4(config)#no ip routing
PC4(config)#interface fastEthernet 0/0
PC4(config-if)#ip address 192.168.1.4 255.255.255.0
PC4(config-if)#no shutdown
PC4(config-if)#end
*Oct 30 15:44:31.655: %LINK-3-UPDOWN: Interface FastEthernet0/0, changed state to up
*Oct 30 15:44:32.655: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/0, changed state to up
PC4(config-if)#end
PC4#
*Oct 30 15:44:38.055: %SYS-5-CONFIG_I: Configured from console by console
PC4#write
Warning: Attempting to overwrite an NVRAM configuration previously written
by a different version of the system image.
Overwrite the previous NVRAM configuration?[confirm]
Building configuration...
```

Figura 1: Comandos inseridos para configurar o PC4.

d)

```
R2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R2(config)#ip multicast-routing
R2(config)#interface fastEthernet 0/0
R2(config-if)#ip address 192.168.1.2 255.255.255.0
R2(config-if)#ip pim dense-mode
R2(config-if)#no shutdown
R2(config-if)#end
*Oct 30 15:48:48.003: %PIM-5-NBRCHG: neighbor 192.168.1.1 UP on interface FastEthernet0/0
R2(config-if)#end
*Oct 30 15:48:49.103: %PIM-5-DRCHG: DR change from neighbor 0.0.0.0 to 192.168.1.2 on interface FastEthernet0/0
R2(config-if)#end
*Oct 30 15:48:49.911: %LINK-3-UPDOWN: Interface FastEthernet0/0, changed state to up
*Oct 30 15:48:50.911: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/0, changed state to up
R2(config-if)#end
R2#w
*Oct 30 15:48:54.579: %SYS-5-CONFIG_I: Configured from console by console
R2#write
Warning: Attempting to overwrite an NVRAM configuration previously written
by a different version of the system image.
Overwrite the previous NVRAM configuration?[confirm]
Building configuration...
```

Figura 2: Comandos inseridos para configurar o router R2.

2.2

a)

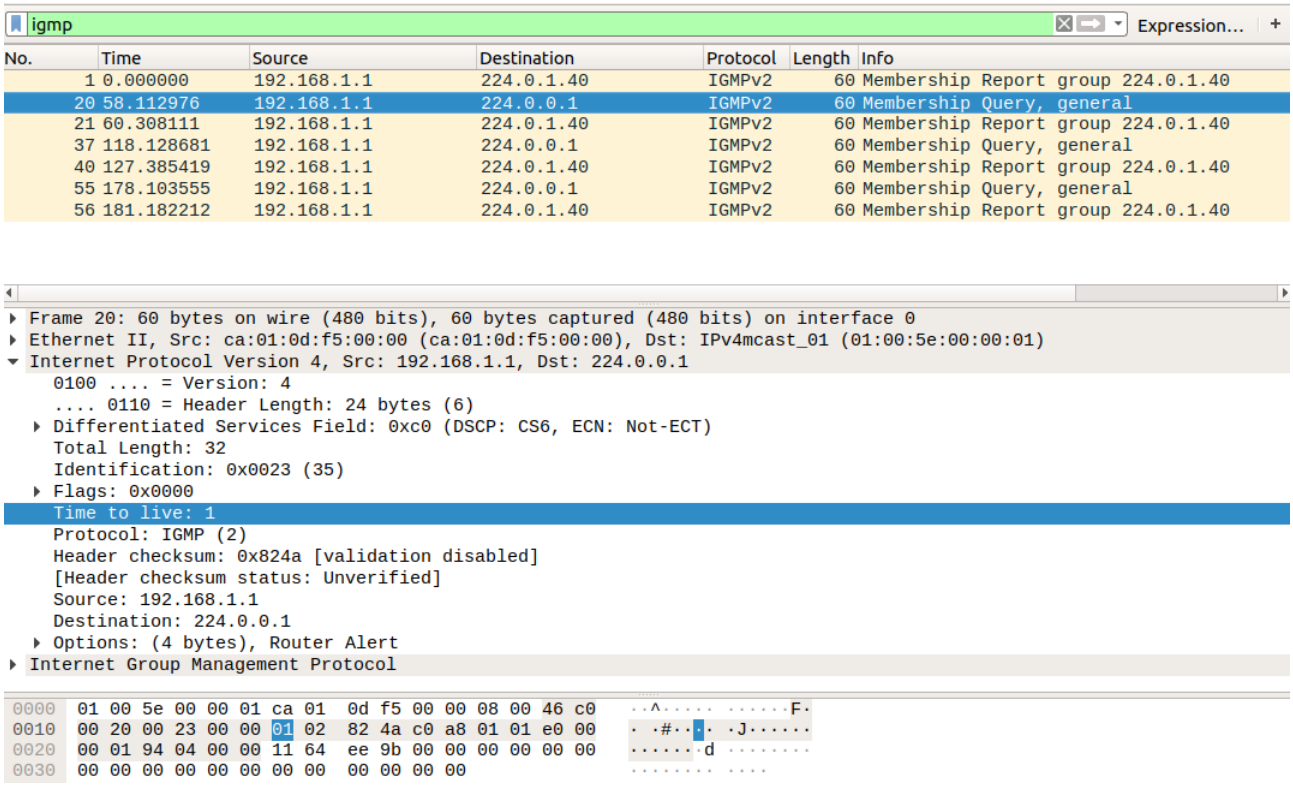

Figura 3: Captura do tráfego utilizando o Wireshark em f0/0 do PC3.

O período das mensagens QUERY é de 60 segundos. As mensagens multicast são enviadas pelo router R1 (192.168.1.1) para o endereço multicast 224.0.0.1. Este endereço destina-se a "All Hosts on this Subnet". O valor do campo TTL do cabeçalho IP é 1, dado que são mensagens para a LAN.

d)

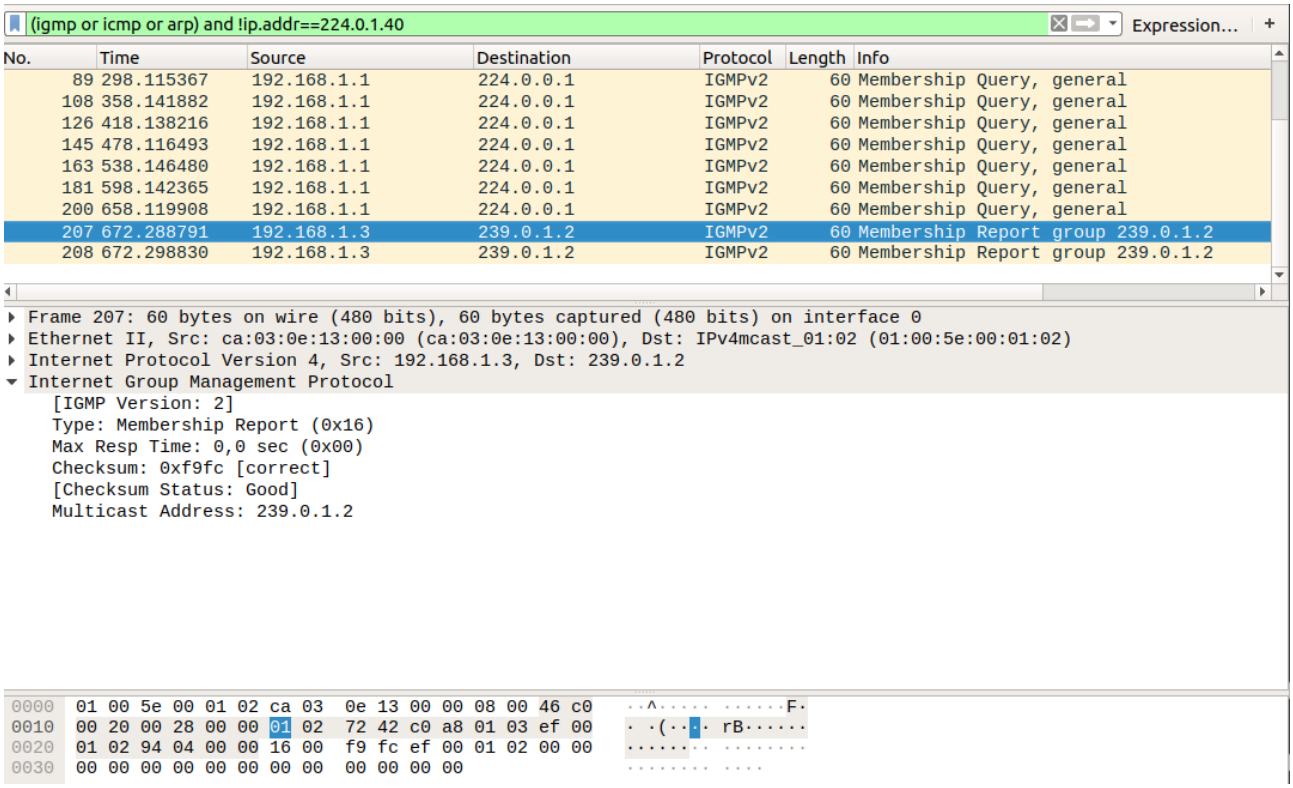

Figura 4: Mensagem obtida a partir do PC3.

A mensagem originada é "Membership report", a partir do PC3 (192.168.1.3) para o endereço multicast 239.0.1.2. Não há resposta a esta mensagem.

e)

```
PC5#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
PC5(config)#interface fastEthernet 0/0
PC5(config-if)#ip igmp join-group 239.0.1.2
PC5(config-if)#end
PC5#
*Oct 30 16:09:04.447: %SYS-5-CONFIG_I: Configured from console by console
```

Figura 5: Comandos utilizados para o PC5 juntar-se ao grupo de multicast 239.0.1.2.

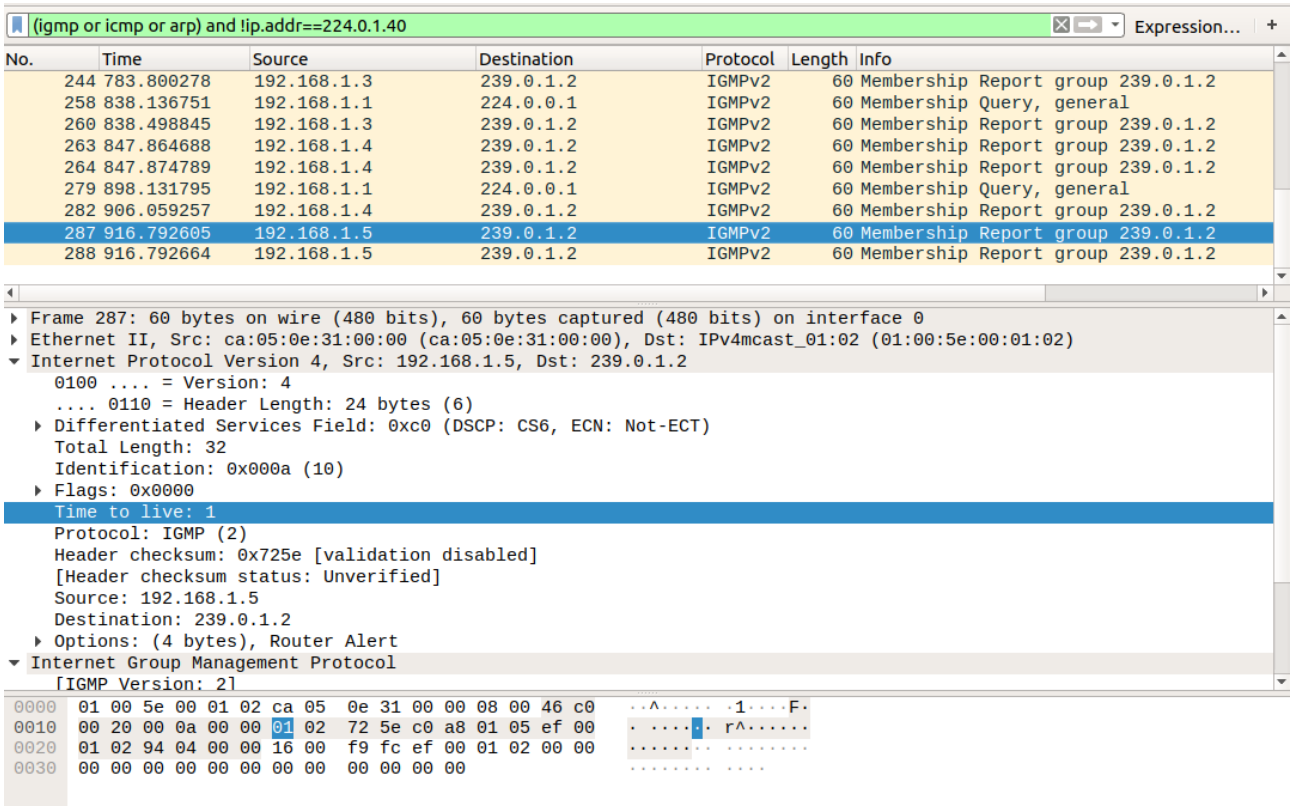

Figura 6: Mensagens observadas após o PC4 e o PC5 se terem juntado ao grupo de multicast.

Sim, as mensagens observadas são "Membership report group 239.0.1.2", a partir dos PC4 (192.168.1.4) e PC5 (192.168.1.5). Não existem respostas a estas mensagens.

f)

```
PC3#ping 239.0.1.2
Type escape sequence to abort.
Sending 1, 100-byte ICMP Echos to 239.0.1.2, timeout is 2 seconds:

Reply to request 0 from 192.168.1.3, 4 ms
Reply to request 0 from 192.168.1.4, 32 ms
Reply to request 0 from 192.168.1.5, 20 ms
PC3#ping 239.0.1.2
Type escape sequence to abort.
Sending 1, 100-byte ICMP Echos to 239.0.1.2, timeout is 2 seconds:

Reply to request 0 from 192.168.1.3, 1 ms
Reply to request 0 from 192.168.1.5, 12 ms
Reply to request 0 from 192.168.1.4, 8 ms
```

Figura 7: Execução do ping do PC3 para o grupo de multicast 239.0.1.2.

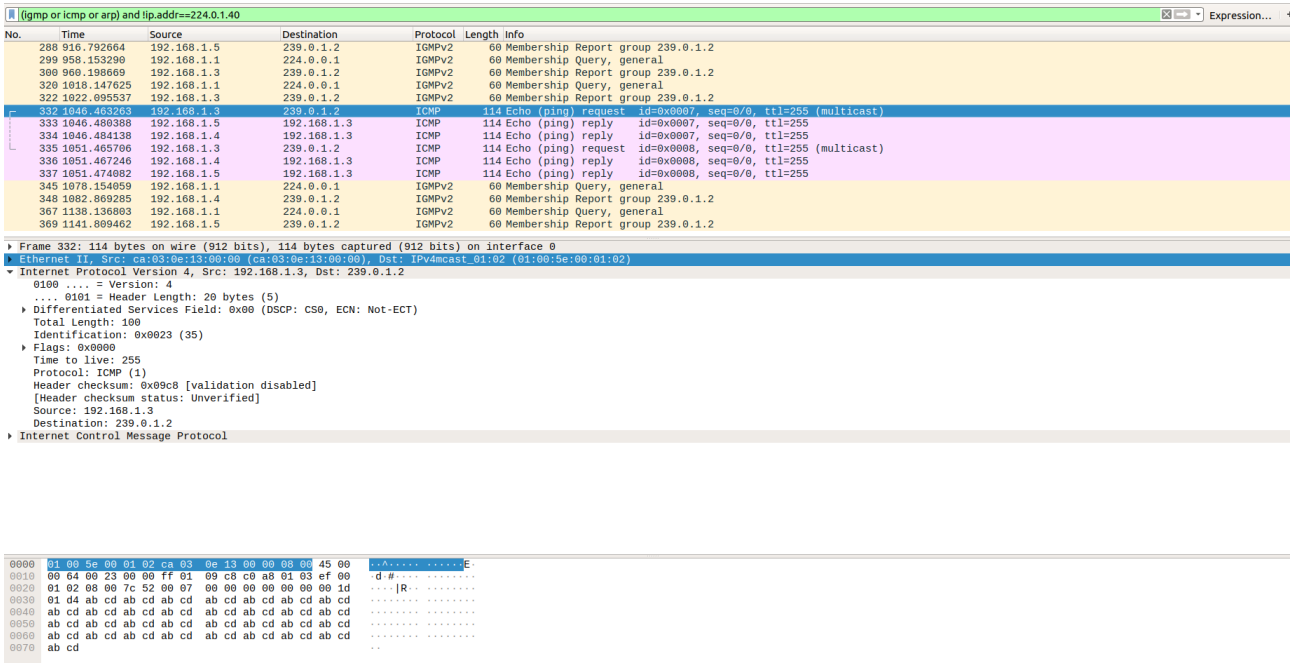

Figura 8: Captura de tráfego de modo a observar os protocolos utilizados durante a execução do ping.

O PC3 recebeu três respostas ao ping multicast, uma de cada PC (incluindo o próprio PC3). As mensagens ping foram enviadas para o endereço IP 239.0.1.2 e endereço MAC 01:00:5e:00:01:02. O endereço MAC de destino é obtido através do endereço IP multicast: os primeiros 3 bytes são o prefixo OUI (01:00:5E), depois existe um bit a 0 e os 23 bits menos significativos são copiados dos 23 bits menos significativos do endereço IP multicast (0.1.2). Não é utilizado o protocolo ARP. Como podemos observar na imagem 8, as respostas ao ping são enviadas diretamente para o endereço do PC3 (192.168.1.3), pelo que são unicast.

g)

```
R1#show ip igmp groups
IGMP Connected Group Membership
Group Address    Interface                Uptime    Expires   Last Reporter   Group Accounted
239.0.1.2        FastEthernet0/0          00:15:51  00:02:54  192.168.1.5
224.0.1.40       FastEthernet0/0          00:32:06  00:02:57  192.168.1.1
```

Figura 9: Execução do comando "show igmp groups"no router R1.

```
R2#show ip igmp  groups
IGMP Connected Group Membership
Group Address    Interface                Uptime    Expires   Last Reporter   Group Accounted
239.0.1.2        FastEthernet0/0          00:14:26  00:02:20  192.168.1.5
224.0.1.40       FastEthernet0/0          00:28:24  00:02:25  192.168.1.1
```

Figura 10: Execução do comando "show igmp groups"no router R2.

Através do resultado do comando "show ip igmp groups" nos dois routers nas figuras 9 e 10, verificamos que os routers não têm conhecimento acerca dos endereços de todos os membros do grupo multicast nem quantos são: apenas têm informação acerca do endereço do último membro a responder a um query.

h)

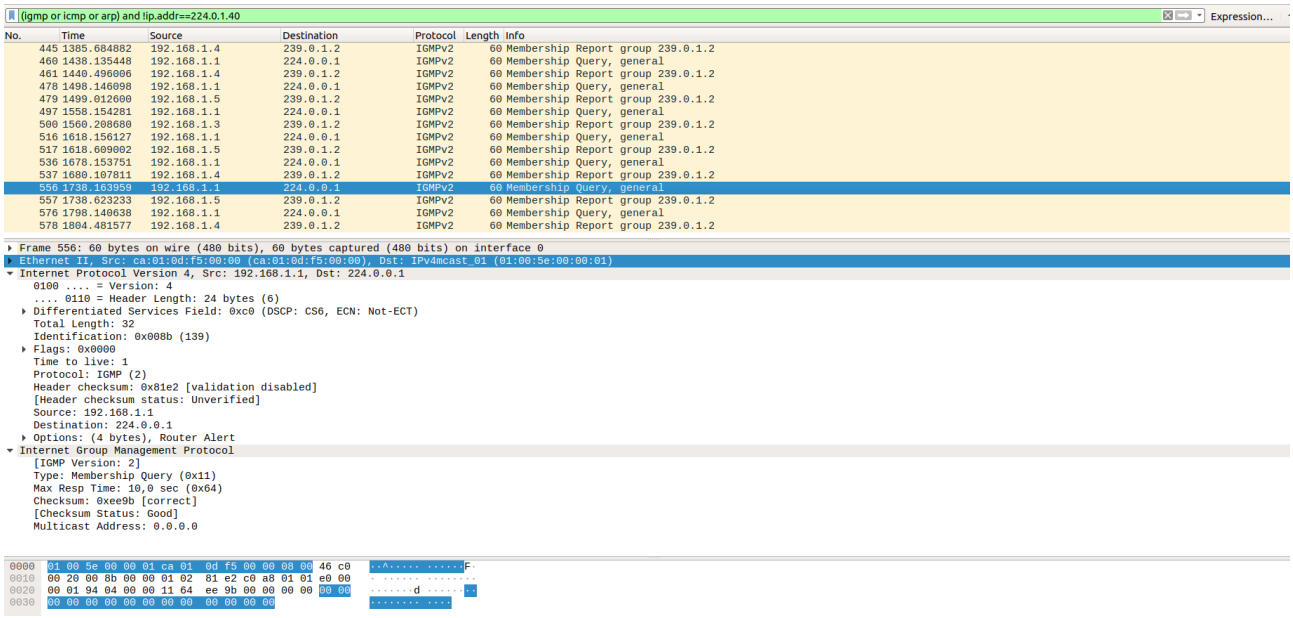

Figura 11: Captura do tráfego de modo a observar as respostas a cada query.

Observando a figura 11, verificamos que cada query apenas tem uma resposta, que pode vir de qualquer um dos PCs e o intervalo entre a query e a resposta é sempre diferente. Isto acontece porque, ao receberem uma query, os PCs definem um intervalo de tempo que irão esperar para responder (abaixo de 10 segundos) e apenas enviam se nenhum dos outros PCs já tiver respondido. Desta forma, o PC que envia a resposta é o que escolheu o intervalo de tempo mais curto e esse intervalo é escolhido de forma aleatória.

2.3

a)

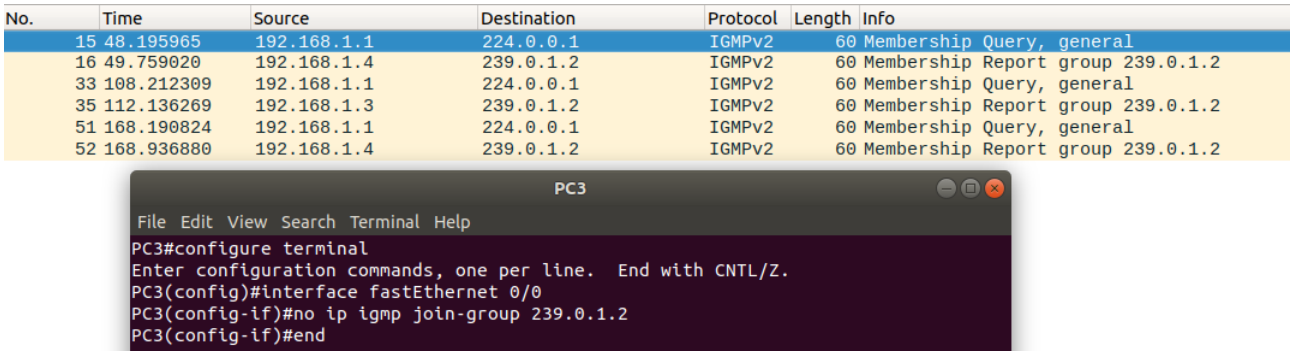

Figura 12: Comandos para a saída do PC3 do grupo de multicast 239.0.1.2 e captura do tráfego após a saída.

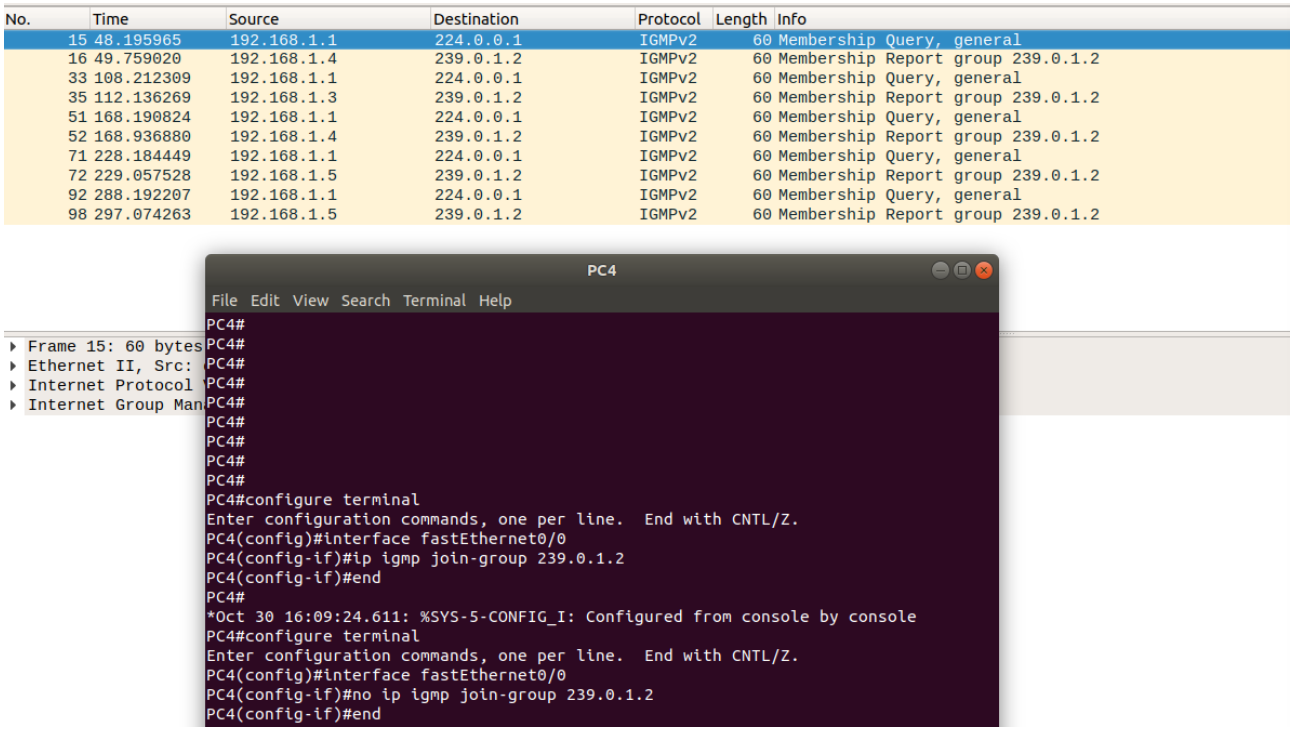

Figura 13: Comandos para a saída do PC4 do grupo de multicast 239.0.1.2 e captura do tráfego após a saída.

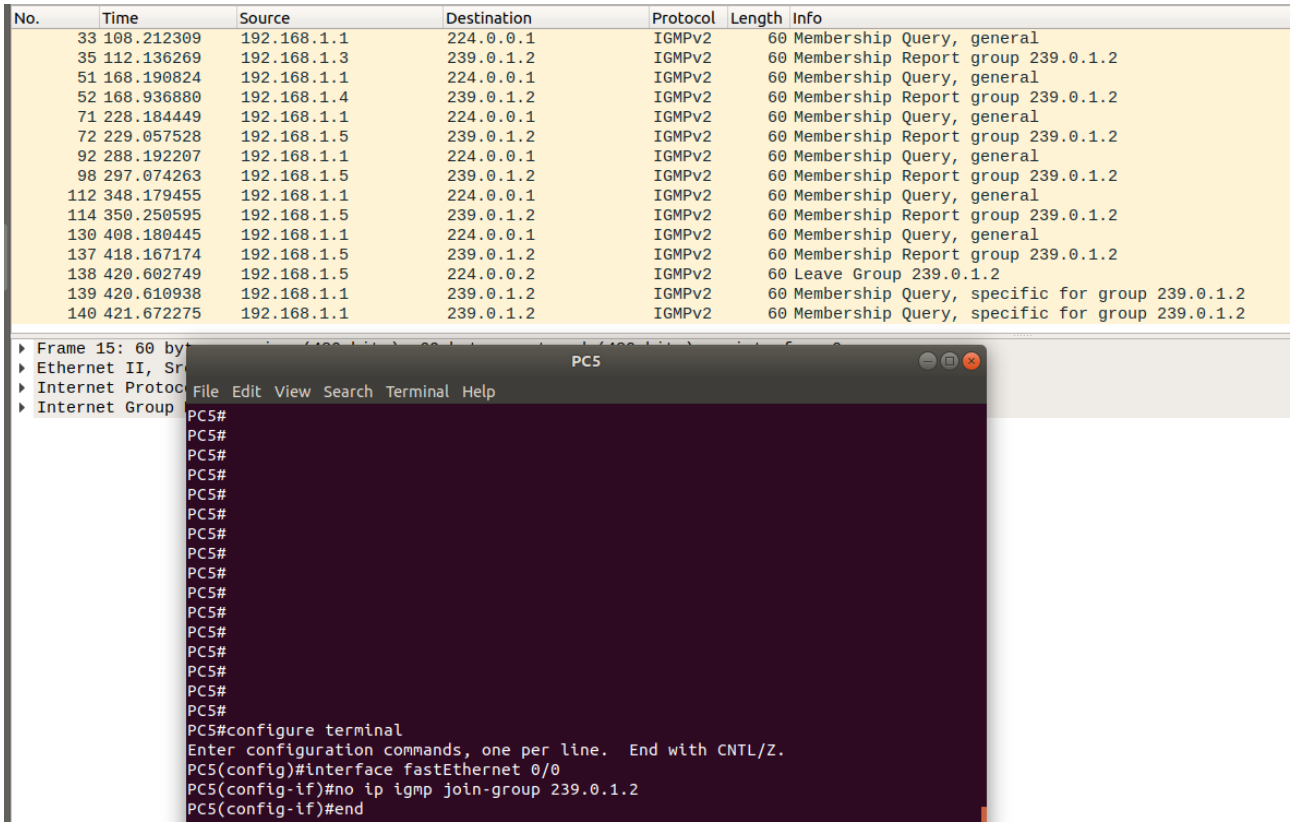

Figura 14: Comandos para a saída do PC5 do grupo de multicast 239.0.1.2 e captura do tráfego após a saída..

Nas imagens 12, 13 e 14 podemos ver, sucessivamente o tráfego no wireshark quando ocorre a saída do PC3, PC4 e PC5 do grupo multicast. Nos dois primeiros casos, verificamos que não existe qualquer tipo de resposta de saída uma vez que a resposta ao último query não foi feita pelo PC que saiu (quando o PC3 saiu, o último query tinha sido respondido pelo PC4 e quando o PC4 saiu, o último query tinha sido respondido pelo PC5). Já quando foi o PC5 a sair, verificamos que este envia uma mensagem "Leave Group 239.0.1.2"para o endereço 224.0.0.2. Ao contrário dos casos anteriores, o PC5 tinha sido o último a responder a um query, por isso existe

a necessidade de este enviar a mensagem "Leave Group". Este endereço para o qual foi enviada a mensagem "Leave Group"(224.0.0.2) tem o significado "All Routers on this Subnet". Após o PC5 sair do grupo, o router R1 envia imediatamente duas mensagens "Membership Query"para determinar se ainda existem membros do grupo naquela subrede.

b)

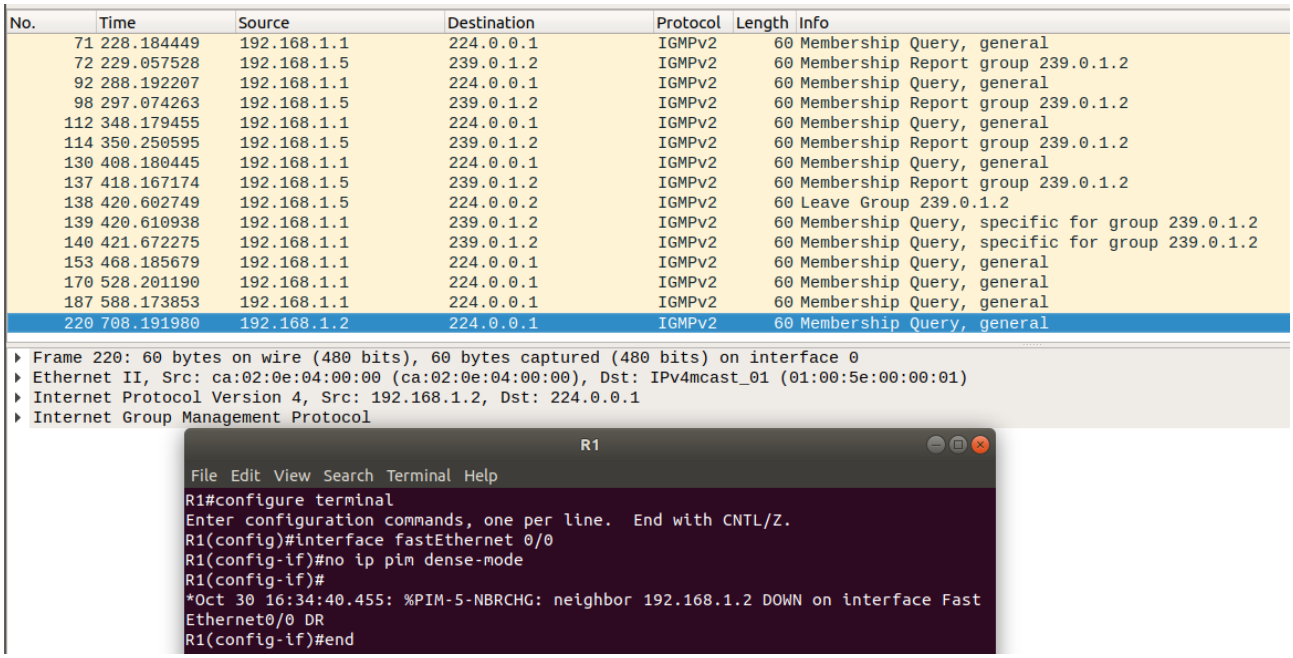

Figura 15: Comandos para a saída do modo de multicast do router R1 e captura do tráfego para a saída.

Na figura 15 observamos o tráfego wireshark quando R1 saiu do processo de multicast. Como podemos ver, não existe qualquer mensagem quando R1 sai. O router que passou a enviar as querys foi R2, cerca de 2 minutos (2*Query period) depois do último query de R1.

c)

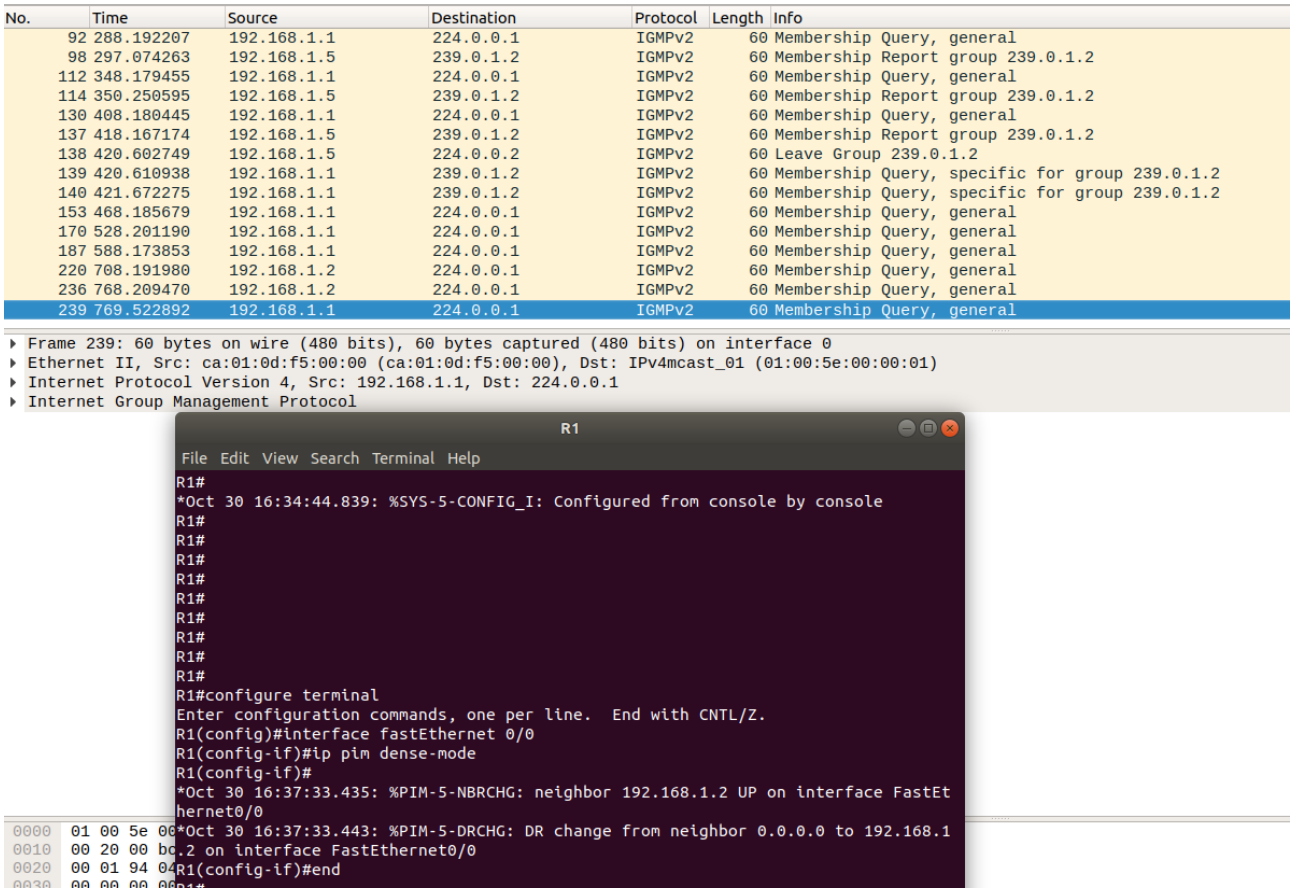

Figura 16: Comandos para o router R1 voltar ao modo de multicast e captura do tráfego.

Quando o router R1 se volta a juntar ao processo multicast, verificamos que este envia imediatamente uma query IGMP. Podemos concluir que a eleição do router que irá fazer as queries é feita sempre com base no IP dos routers existentes no processo: é escolhido o router com menor IP.

3.2

a)

```
PC3#ping 192.168.6.9
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.6.9, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 72/84/92 ms
PC3#ping 192.168.1.4
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.4, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 56/82/92 ms
PC3#ping 192.168.1.5
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.5, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 56/82/96 ms
PC3#ping 192.168.5.8
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.5.8, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 88/333/1060 ms
```

Figura 17: Realização do ping do PC3 para todos os outros PCs.

```
R1#show ip mroute
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       V - RD & Vector, v - Vector
Outgoing interface flags: H - Hardware switched, A - Assert winner
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 239.0.1.2), 01:00:43/stopped, RP 0.0.0.0, flags: DC
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:56:00/stopped
    FastEthernet0/0, Forward/Dense, 01:00:43/stopped

(192.168.6.9, 239.0.1.2), 00:02:45/00:00:14, flags: T
  Incoming interface: FastEthernet1/0, RPF nbr 192.168.4.7
  Outgoing interface list:
    FastEthernet0/0, Forward/Dense, 00:02:45/stopped, A

(*, 224.0.1.40), 01:00:45/00:02:17, RP 0.0.0.0, flags: DCL
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:56:00/stopped
    FastEthernet0/0, Forward/Dense, 01:00:45/stopped
```

Figura 18: Realização do comando "show ip mroute"no router R1.

```
R6#show ip mroute
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       V - RD & Vector, v - Vector
Outgoing interface flags: H - Hardware switched, A - Assert winner
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 239.0.1.2), 00:02:18/stopped, RP 0.0.0.0, flags: D
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:02:18/stopped
    FastEthernet0/0, Forward/Dense, 00:02:18/stopped

(192.168.6.9, 239.0.1.2), 00:02:18/00:00:41, flags: T
  Incoming interface: FastEthernet0/0, RPF nbr 192.168.3.7
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:02:18/stopped

(*, 224.0.1.40), 00:54:39/00:02:27, RP 0.0.0.0, flags: DCL
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:54:38/stopped
    FastEthernet0/0, Forward/Dense, 00:54:39/stopped
```

Figura 19: Realização do comando "show ip mroute"no router R6.

```
R2#show ip mroute
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       V - RD & Vector, v - Vector
Outgoing interface flags: H - Hardware switched, A - Assert winner
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 239.0.1.2), 00:56:40/stopped, RP 0.0.0.0, flags: DC
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet2/0, Forward/Dense, 00:54:25/stopped
    FastEthernet1/0, Forward/Dense, 00:56:40/stopped
    FastEthernet0/0, Forward/Dense, 00:56:40/stopped

(192.168.6.9, 239.0.1.2), 00:02:06/00:00:53, flags: T
  Incoming interface: FastEthernet2/0, RPF nbr 192.168.2.6
  Outgoing interface list:
    FastEthernet0/0, Prune/Dense, 00:02:06/00:00:53
    FastEthernet1/0, Forward/Dense, 00:02:06/stopped

(*, 224.0.1.40), 00:56:42/00:02:56, RP 0.0.0.0, flags: DCL
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet2/0, Forward/Dense, 00:54:25/stopped
    FastEthernet0/0, Forward/Dense, 00:56:42/stopped
```

Figura 20: Realização do comando "show ip mroute"no router R2.

```
R7#show ip mroute
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       V - RD & Vector, v - Vector
Outgoing interface flags: H - Hardware switched, A - Assert winner
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 239.0.1.2), 00:55:41/stopped, RP 0.0.0.0, flags: DC
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet2/0, Forward/Dense, 00:54:47/stopped
    FastEthernet1/0, Forward/Dense, 00:55:41/stopped
    FastEthernet0/0, Forward/Dense, 00:55:41/stopped

(192.168.6.9, 239.0.1.2), 00:02:27/00:00:32, flags: T
  Incoming interface: FastEthernet0/0, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:02:27/stopped
    FastEthernet2/0, Forward/Dense, 00:02:27/stopped

(*, 224.0.1.40), 00:55:42/00:02:25, RP 0.0.0.0, flags: DCL
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet2/0, Forward/Dense, 00:54:47/stopped
    FastEthernet1/0, Forward/Dense, 00:55:42/stopped
    FastEthernet0/0, Forward/Dense, 00:55:42/stopped
```

Figura 21: Realização do comando "show ip mroute"no router R7.

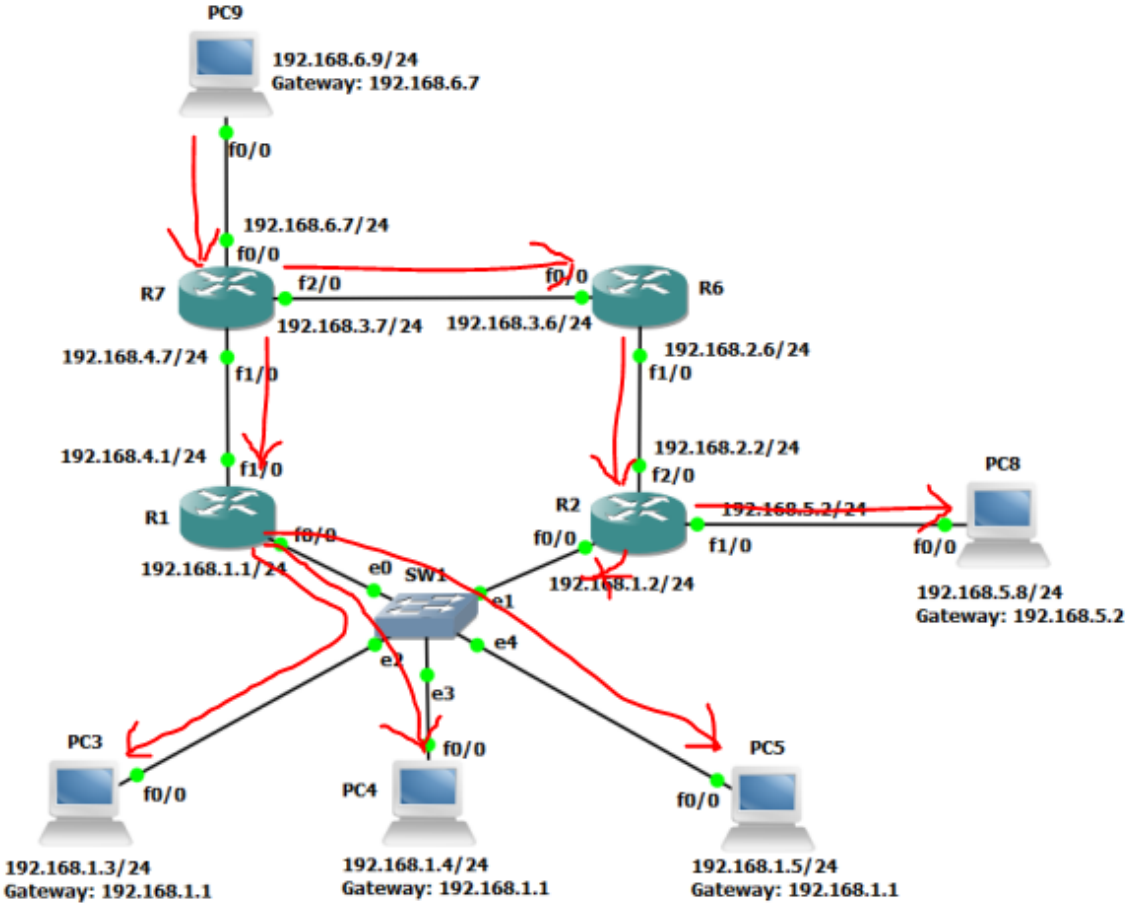

Figura 22: Desenho da árvore de multicast para o grupo 239.0.1.2.

Com base no resultado dos comando "show ip mroute"em todos os routers (figuras 18, 19, 20 e 21), conseguimos desenhar a àrvore multicast com origem no PC9 (figura 22),

b)

```
R1#show ip mroute
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       V - RD & Vector, v - Vector
Outgoing interface flags: H - Hardware switched, A - Assert winner
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 239.0.1.2), 00:13:17/stopped, RP 0.0.0.0, flags: DC
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:12:48/stopped
    FastEthernet0/0, Forward/Dense, 00:13:17/stopped

(192.168.6.9, 239.0.1.2), 00:00:22/00:02:37, flags: T
  Incoming interface: FastEthernet1/0, RPF nbr 192.168.4.7
  Outgoing interface list:
    FastEthernet0/0, Forward/Dense, 00:00:22/stopped, A

(192.168.1.3, 239.0.1.2), 00:00:47/00:02:12, flags: T
  Incoming interface: FastEthernet0/0, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:00:47/stopped

(*, 224.0.1.40), 00:13:17/00:02:49, RP 0.0.0.0, flags: DCL
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:12:48/stopped
    FastEthernet0/0, Forward/Dense, 00:13:17/stopped
```

Figura 23: Realização do comando "show ip mroute"no router R1.

```
R2#show ip mroute
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       V - RD & Vector, v - Vector
Outgoing interface flags: H - Hardware switched, A - Assert winner
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 239.0.1.2), 00:10:47/stopped, RP 0.0.0.0, flags: DC
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:10:46/stopped
    FastEthernet2/0, Forward/Dense, 00:10:47/stopped
    FastEthernet0/0, Forward/Dense, 00:10:47/stopped

(192.168.6.9, 239.0.1.2), 00:00:21/00:02:38, flags: T
  Incoming interface: FastEthernet2/0, RPF nbr 192.168.2.6
  Outgoing interface list:
    FastEthernet0/0, Prune/Dense, 00:00:21/00:02:38
    FastEthernet1/0, Forward/Dense, 00:00:21/stopped

(192.168.1.3, 239.0.1.2), 00:00:38/00:02:21, flags: T
  Incoming interface: FastEthernet0/0, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet2/0, Prune/Dense, 00:00:37/00:02:22
    FastEthernet1/0, Forward/Dense, 00:00:38/stopped

(*, 224.0.1.40), 00:10:48/00:02:45, RP 0.0.0.0, flags: DCL
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet2/0, Forward/Dense, 00:10:48/stopped
    FastEthernet0/0, Forward/Dense, 00:10:48/stopped
```

Figura 24: Realização do comando "show ip mroute"no router R2.

```
R6#show ip mroute
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       V - RD & Vector, v - Vector
Outgoing interface flags: H - Hardware switched, A - Assert winner
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 239.0.1.2), 00:01:08/stopped, RP 0.0.0.0, flags: D
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:01:08/stopped
    FastEthernet0/0, Forward/Dense, 00:01:08/stopped

(192.168.6.9, 239.0.1.2), 00:00:42/00:02:17, flags: T
  Incoming interface: FastEthernet0/0, RPF nbr 192.168.3.7
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:00:42/stopped

(192.168.1.3, 239.0.1.2), 00:01:08/00:01:51, flags: PT
  Incoming interface: FastEthernet1/0, RPF nbr 192.168.2.2
  Outgoing interface list:
    FastEthernet0/0, Prune/Dense, 00:01:08/00:01:51

(*, 224.0.1.40), 00:12:58/00:02:04, RP 0.0.0.0, flags: DCL
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:12:29/stopped
    FastEthernet0/0, Forward/Dense, 00:12:58/stopped
```

Figura 25: Realização do comando "show ip mroute"no router R6.

```
R7#show ip mroute
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       V - RD & Vector, v - Vector
Outgoing interface flags: H - Hardware switched, A - Assert winner
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 239.0.1.2), 00:13:25/stopped, RP 0.0.0.0, flags: DC
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:12:57/stopped
    FastEthernet2/0, Forward/Dense, 00:12:58/stopped
    FastEthernet0/0, Forward/Dense, 00:13:25/stopped

(192.168.6.9, 239.0.1.2), 00:00:51/00:02:08, flags: T
  Incoming interface: FastEthernet0/0, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet2/0, Forward/Dense, 00:00:51/stopped
    FastEthernet1/0, Forward/Dense, 00:00:51/stopped

(192.168.1.3, 239.0.1.2), 00:01:16/00:01:48, flags: T
  Incoming interface: FastEthernet1/0, RPF nbr 192.168.4.1
  Outgoing interface list:
    FastEthernet0/0, Forward/Dense, 00:01:16/stopped
    FastEthernet2/0, Prune/Dense, 00:01:16/00:01:45, A

(*, 224.0.1.40), 00:13:26/00:02:57, RP 0.0.0.0, flags: DCL
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:12:57/stopped
    FastEthernet2/0, Forward/Dense, 00:13:25/stopped
    FastEthernet0/0, Forward/Dense, 00:13:26/stopped
```

Figura 26: Realização do comando "show ip mroute"no router R7.

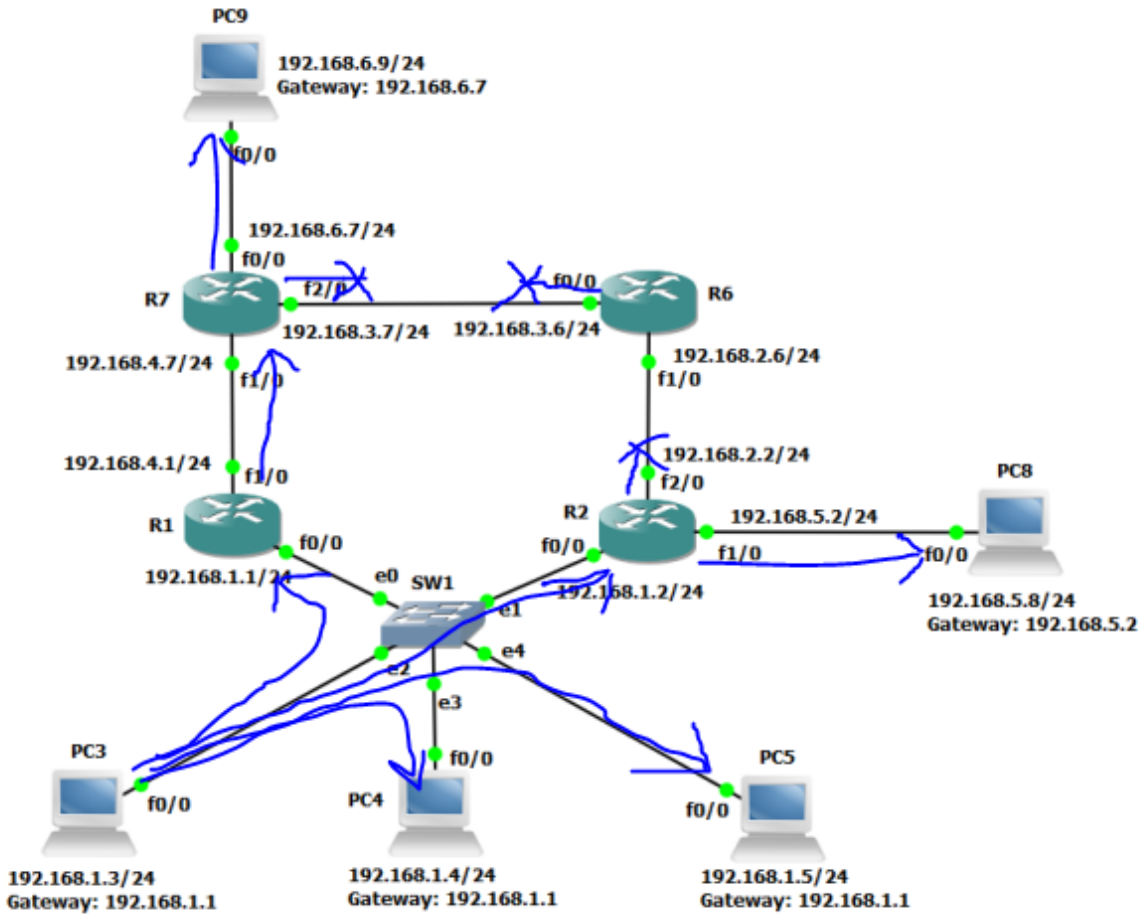

Figura 27: Desenho da árvore de multicast para o PC3 como fonte.

Como podemos observar pelos resultados dos comandos "show ip mroute", existem duas àrvores multicast: uma com raiz no PC3 e uma com raiz no PC9. A àrvore com raiz no PC3 encontra-se desenhada na figura 27.

c)

```
PC9#ping 239.0.1.2
Type escape sequence to abort.
Sending 1, 100-byte ICMP Echos to 239.0.1.2, timeout is 2 seconds:

Reply to request 0 from 192.168.6.9, 1 ms
Reply to request 0 from 192.168.5.8, 196 ms
Reply to request 0 from 192.168.1.5, 192 ms
Reply to request 0 from 192.168.1.4, 192 ms
Reply to request 0 from 192.168.1.4, 188 ms
Reply to request 0 from 192.168.1.3, 188 ms
Reply to request 0 from 192.168.1.3, 188 ms
Reply to request 0 from 192.168.1.5, 164 ms
```

Figura 28: Realização do ping do PC9 para o grupo de multicast 239.0.1.2.

O primeiro datagrama enviado para a rede multicast é o ping. Antes deste datagrama, a àrvore ainda não tinha sido criada, pelo que o primeiro datagrama é utilizado para construir a àrvore utilizando Reverse Path Forwarding. Neste processo, são enviados dois datagramas para a rede 192.168.1.0/24 (um por R1 e um por

R2), que são recebidos pelos PCs desta rede. Daí o PC9 receber dois datagramas de cada PC dessa rede (PC2, PC4, PC5) no primeiro ping.

d)

```
R1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)#interface fastEthernet 1/0
R1(config-if)#ip ospf cost 3
R1(config-if)#end
```

Figura 29: Alterações efectuadas de modo a obter o novo percurso.

```
R6#show ip mroute
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       V - RD & Vector, v - Vector
Outgoing interface flags: H - Hardware switched, A - Assert winner
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 239.0.1.2), 00:06:43/stopped, RP 0.0.0.0, flags: D
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:06:43/stopped
    FastEthernet0/0, Forward/Dense, 00:06:43/stopped

(192.168.6.9, 239.0.1.2), 00:00:12/00:02:47, flags: T
  Incoming interface: FastEthernet0/0, RPF nbr 192.168.3.7
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 00:00:12/stopped

(192.168.1.3, 239.0.1.2), 00:01:06/00:01:53, flags: PT
  Incoming interface: FastEthernet1/0, RPF nbr 192.168.2.2
  Outgoing interface list:
    FastEthernet0/0, Prune/Dense, 00:01:06/00:01:53

(*, 224.0.1.40), 01:02:49/00:02:17, RP 0.0.0.0, flags: DCL
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 01:02:20/stopped
    FastEthernet0/0, Forward/Dense, 01:02:49/stopped
```

Figura 30: Realização do comando "show ip mroute"no router R6 com as alterações.

```
R7#show ip mroute
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       V - RD & Vector, v - Vector
Outgoing interface flags: H - Hardware switched, A - Assert winner
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 239.0.1.2), 01:03:04/stopped, RP 0.0.0.0, flags: DC
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 01:02:36/stopped
    FastEthernet2/0, Forward/Dense, 01:02:37/stopped
    FastEthernet0/0, Forward/Dense, 01:03:04/stopped

(192.168.6.9, 239.0.1.2), 00:00:08/00:02:51, flags: T
  Incoming interface: FastEthernet0/0, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet2/0, Forward/Dense, 00:00:08/stopped
    FastEthernet1/0, Prune/Dense, 00:00:08/00:02:51

(192.168.1.3, 239.0.1.2), 00:01:03/00:01:56, flags: T
  Incoming interface: FastEthernet1/0, RPF nbr 192.168.4.1
  Outgoing interface list:
    FastEthernet0/0, Forward/Dense, 00:01:03/stopped
    FastEthernet2/0, Prune/Dense, 00:01:03/00:01:56, A

(*, 224.0.1.40), 01:03:06/00:02:21, RP 0.0.0.0, flags: DCL
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 01:02:36/stopped
    FastEthernet2/0, Forward/Dense, 01:03:04/stopped
    FastEthernet0/0, Forward/Dense, 01:03:06/stopped
```

Figura 31: Realização do comando "show ip mroute"no router R7 com as alterações.

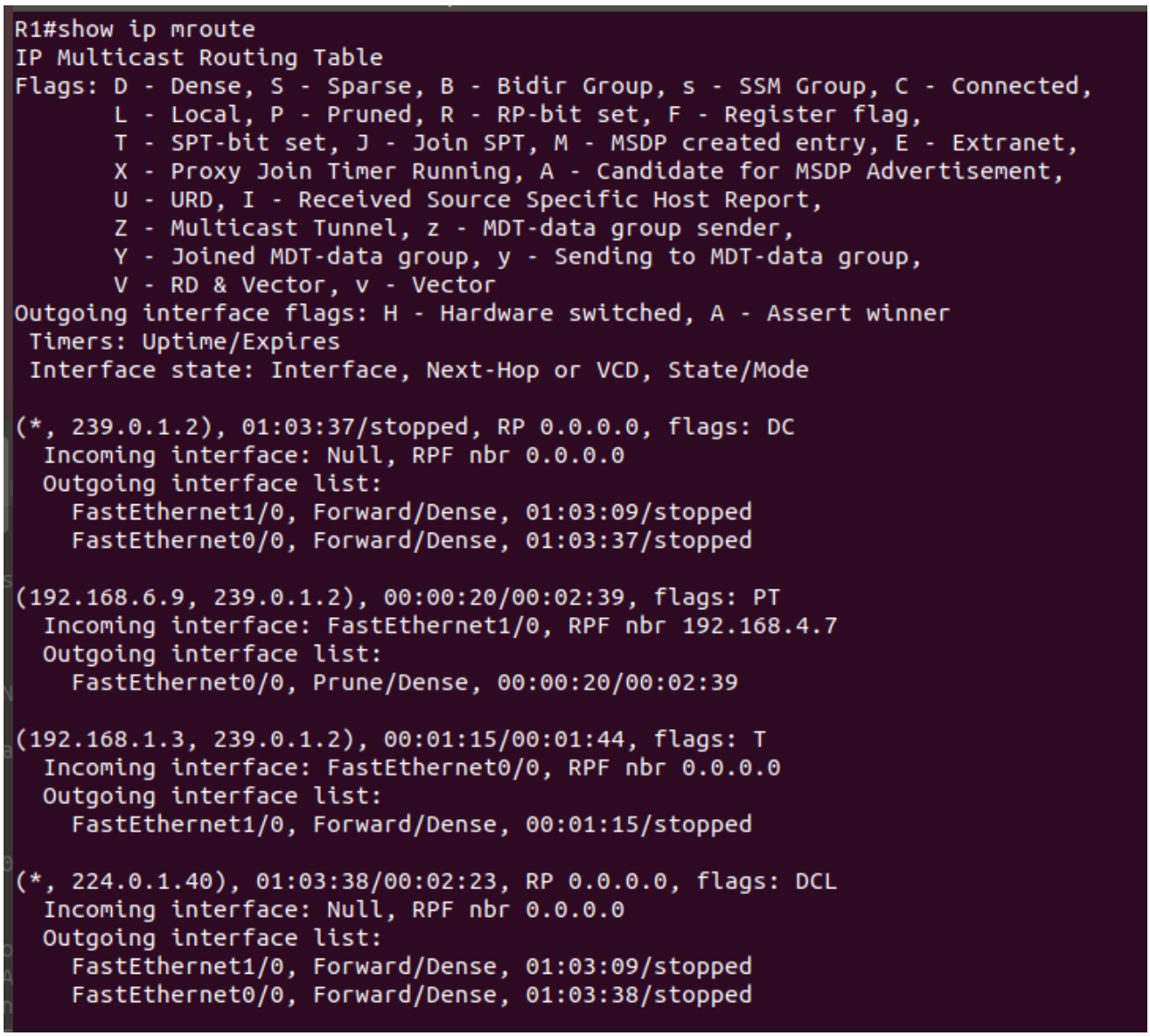

Figura 32: Realização do comando "show ip mroute"no router R1 com as alterações.

```
R2#show ip mroute
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       V - RD & Vector, v - Vector
Outgoing interface flags: H - Hardware switched, A - Assert winner
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 239.0.1.2), 01:00:42/stopped, RP 0.0.0.0, flags: DC
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet1/0, Forward/Dense, 01:00:41/stopped
    FastEthernet2/0, Forward/Dense, 01:00:42/stopped
    FastEthernet0/0, Forward/Dense, 01:00:42/stopped

(192.168.6.9, 239.0.1.2), 00:00:05/00:02:54, flags: T
  Incoming interface: FastEthernet2/0, RPF nbr 192.168.2.6
  Outgoing interface list:
    FastEthernet0/0, Forward/Dense, 00:00:05/stopped, A
    FastEthernet1/0, Forward/Dense, 00:00:05/stopped

(192.168.1.3, 239.0.1.2), 00:00:59/00:02:00, flags: T
  Incoming interface: FastEthernet0/0, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet2/0, Prune/Dense, 00:00:59/00:02:00
    FastEthernet1/0, Forward/Dense, 00:00:59/stopped

(*, 224.0.1.40), 01:00:43/00:02:39, RP 0.0.0.0, flags: DCL
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    FastEthernet2/0, Forward/Dense, 01:00:43/stopped
    FastEthernet0/0, Forward/Dense, 01:00:43/stopped
```

Figura 33: Realização do comando "show ip mroute"no router R2 com as alterações.

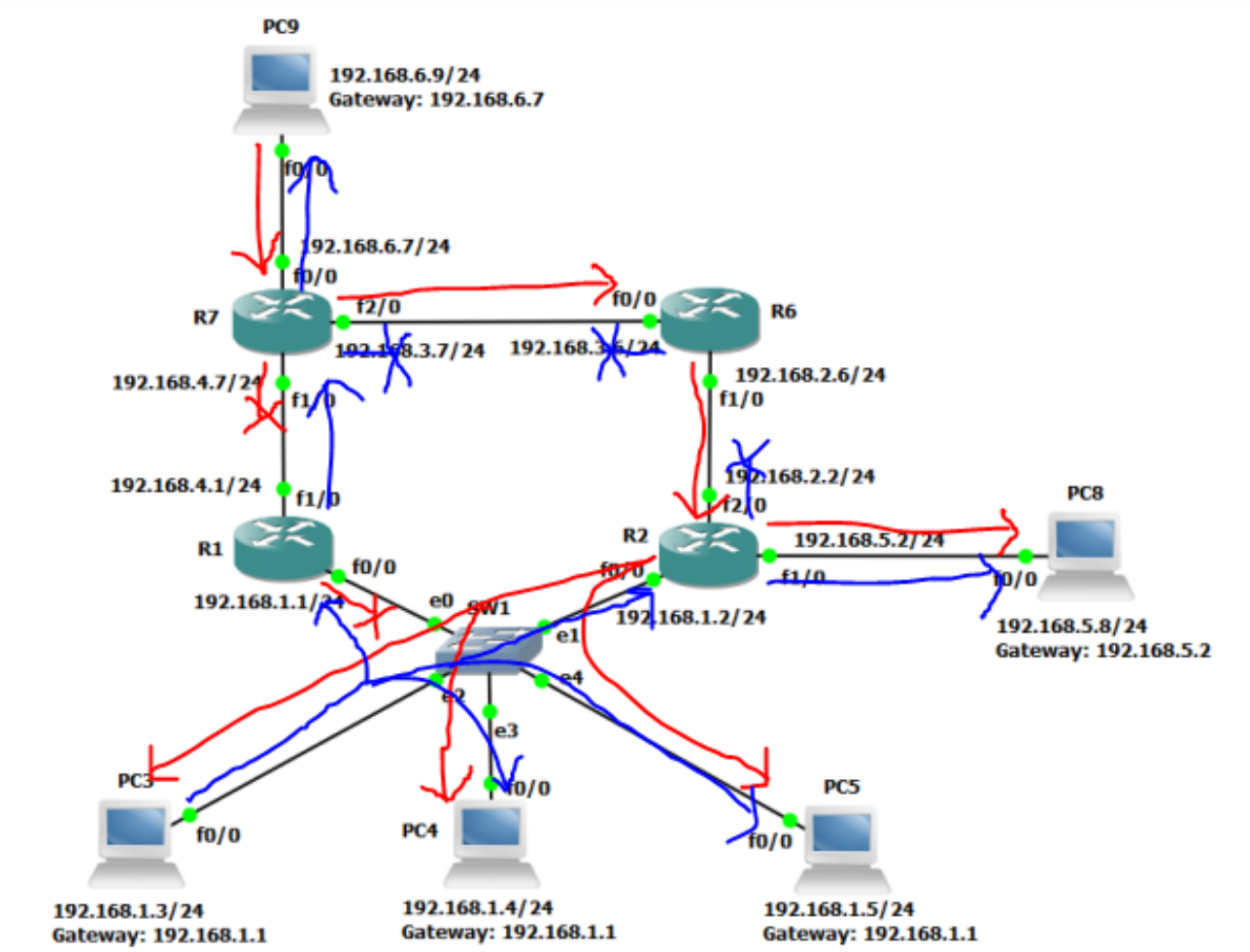

Figura 34: Desenho das novas árvores de multicast após as alterações. Encontra-se a azul a árvore com raiz no PC3 (sem alterações) e a vermelho a com raiz no PC9 (alterada).

Relativamente ao tráfego multicast do PC3 para o PC9, como podemos ver pela àrvore, já está a ir por R1, pelo que as alterações a fazer são para que o tráfego multicast com origem no PC9, passe por R6 no seu caminho para o PC3, ou seja, que este siga o caminho PC9 $\rightarrow$ R7 $\rightarrow$ R6 $\rightarrow$ R2 $\rightarrow$ PC3 em vez do caminho PC9 $\rightarrow$ R7 $\rightarrow$ R1 $\rightarrow$ PC3. Para tal, precisamos de fazer com que o custo inverso do caminho que passa por R6 seja menor que o custo inverso do caminho que passa por R1, ou seja, R1(f1/0) + R7(f0/0) > R2(f2/0) + R6(f0/0) + R7(f0/0). Como todos os custos valem 1, esta condição verifica-se se se alterar o custo de R1(f1/0) para 3 (figura 29). Nas figuras 30, 31, 32 e 33 encontram-se os resultados dos comandos "show ip mroute"em todos os routers depois desta modificação e na figura 34 as àrvores resultantes. Como podemos observar, a àrvore com raiz no PC3 manteve-se inalterada enquanto que a àrvore com raiz no PC9 passa a incluir o caminho por R6.