

## Práctica 1.4. Protocolo IPv6

### Objetivos

En esta práctica se estudian los aspectos básicos del protocolo IPv6, el manejo de los diferentes tipos de direcciones y mecanismos de configuración. Además se analizarán las características más importantes del protocolo ICMP versión 6.



Activar el **portapapeles bidireccional** (menú Dispositivos) en las máquinas virtuales.

Usar la opción de Virtualbox (menú Ver) para realizar **capturas de pantalla**.

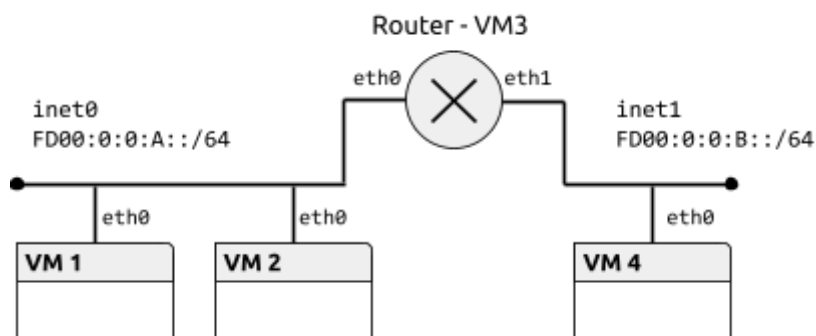
La **contraseña** del usuario cursoredes es cursoredes.

### Contenidos

- Preparación del entorno para la práctica
- Direcciones de enlace local
- Direcciones ULA
- Encaminamiento estático
- Configuración persistente
- Autoconfiguración. Anuncio de prefijos
- ICMPv6

### Preparación del entorno para la práctica

Configuraremos la topología de red que se muestra en la siguiente figura:



El fichero de configuración de la topología tendría el siguiente contenido:

```
netprefix inet
machine 1 0 0
machine 2 0 0
machine 3 0 0 1 1
machine 4 0 1
```

### Direcciones de enlace local

Una dirección de enlace local es únicamente válida en la subred que está definida. Ningún encaminador dará salida a un datagrama con una dirección de enlace local como destino. El prefijo de formato para estas direcciones es fe80::/10.

**Ejercicio 1 [VM1, VM2].** Activar el interfaz eth0 en VM1 y VM2. Comprobar las direcciones de enlace local que tienen asignadas con el comando ip.

```
ip link set dev eth0 up (VM1 y VM2)

VM1:
ip address
inet6 fe80::a00:27ff:fee4:5035/64 scope link

VM2:
ip address
inet6 fe80::a00:27ff:fe5a:c2d5/64 scope link
```

**Ejercicio 2 [VM1, VM2].** Comprobar la conectividad entre VM1 y VM2 con la orden ping6 (o ping -6). Cuando se usan direcciones de enlace local, y **sólo en ese caso**, es necesario especificar el interfaz origen, añadiendo %<nombre\_interfaz> a la dirección. Consultar las opciones del comando ping6 en la página de manual. Observar el tráfico generado con Wireshark, especialmente los protocolos encapsulados en cada datagrama y los parámetros del protocolo IPv6.

```
VM1:
[cursoredes@localhost ~]$ ping6 fe80::a00:27ff:fe5a:c2d5%eth0 -c 1
PING fe80::a00:27ff:fe5a:c2d5%eth0(fe80::a00:27ff:fe5a:c2d5%eth0) 56 data bytes
64 bytes from fe80::a00:27ff:fe5a:c2d5%eth0: icmp_seq=1 ttl=64 time=0.333 ms

--- fe80::a00:27ff:fe5a:c2d5%eth0 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.333/0.333/0.333/0.000 ms
```

No.	Time	Source	Destination	Protoc	Leng	Info
1	0.00000000	fe80::a00:27ff:fee4:5035	fe80::a00:27ff:fe5a:c2d5	ICMPv6	118	Echo (ping) request id=0x08e0, seq=1, hop limit=64 (reply in 2)
2	0.00017600	fe80::a00:27ff:fe5a:c2d5	fe80::a00:27ff:fee4:5035	ICMPv6	118	Echo (ping) reply id=0x08e0, seq=1, hop limit=64 (request in 1)

```
Frame 2: 118 bytes on wire (944 bits), 118 bytes captured (944 bits) on interface 0
Ethernet II, Src: CadmusCo_5a:c2:d5 (08:00:27:5a:c2:d5), Dst: CadmusCo_e4:50:35 (08:00:27:e4:50:35)
Internet Protocol Version 6, Src: fe80::a00:27ff:fe5a:c2d5 (fe80::a00:27ff:fe5a:c2d5), Dst: fe80::a00:27ff:fee4:5035 (fe80::a00:27ff:fee4:5035)
  0110 .... = Version: 6
  .... 0000 0000 .... = Traffic class: 0x00000000
  .... 0000 0000 0000 0000 0000 0000 = Flowlabel: 0x00000000
  Payload length: 64
  Next header: ICMPv6 (58)
  Hop limit: 64
  Source: fe80::a00:27ff:fe5a:c2d5 (fe80::a00:27ff:fe5a:c2d5)
  [Source SA MAC: CadmusCo_5a:c2:d5 (08:00:27:5a:c2:d5)]
  Destination: fe80::a00:27ff:fee4:5035 (fe80::a00:27ff:fee4:5035)
  [Destination SA MAC: CadmusCo_e4:50:35 (08:00:27:e4:50:35)]
Internet Control Message Protocol v6
  Type: Echo (ping) reply (129)
  Code: 0
  Checksum: 0x42e4 [correct]
  Identifier: 0x08e0
  Sequence: 1
  [Response To: 1]
  [Response Time: 0.176 ms]
```

**Ejercicio 3 [Router, VM4].** Activar el interfaz de VM4 y los dos interfaces de Router. Comprobar la conectividad entre Router y VM1, y entre Router y VM4 usando la dirección de enlace local.

```
ip link set dev eth0 up (Router y VM4)
ip link set dev eth1 up (Router)
```

```

Router:
ip address
eth0: inet6 fe80::a00:27ff:feac:57e4/64 scope link
eth1: inet6 fe80::a00:27ff:fed9:eb70/64 scope link

VM4:
ip address
inet6 fe80::a00:27ff:fe0c:e735/64 scope link

Router:
-Para VM1
[cursoredes@localhost ~]$ ping6 fe80::a00:27ff:fee4:5035%eth0 -c 1
PING fe80::a00:27ff:fee4:5035%eth0(fe80::a00:27ff:fee4:5035%eth0) 56 data bytes
64 bytes from fe80::a00:27ff:fee4:5035%eth0: icmp_seq=1 ttl=64 time=0.313 ms

--- fe80::a00:27ff:fee4:5035%eth0 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.313/0.313/0.313/0.000 ms

-Para VM4
[cursoredes@localhost ~]$ ping6 fe80::a00:27ff:fe0c:e735%eth1 -c 1
PING fe80::a00:27ff:fe0c:e735%eth1(fe80::a00:27ff:fe0c:e735%eth1) 56 data bytes
64 bytes from fe80::a00:27ff:fe0c:e735%eth1: icmp_seq=1 ttl=64 time=0.281 ms

--- fe80::a00:27ff:fe0c:e735%eth1 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.281/0.281/0.281/0.000 ms

```

**Para saber más...** En el protocolo IPv4 también se reserva el bloque 169.254.0.0/16 para direcciones de enlace local, cuando no es posible la configuración de los interfaces por otras vías. Los detalles se describen en el RFC 3927.

## Direcciones ULA

Una dirección ULA (*Unique Local Address*) puede usarse dentro de una organización, de forma que los encaminadores internos del sitio deben encaminar los datagramas con una dirección ULA como destino. El prefijo de formato para estas direcciones es fc00::/7.

**Ejercicio 4 [VM1, VM2].** Configurar VM1 y VM2 para que tengan una dirección ULA en la red fd00:0:0:a::/64 con el comando ip. La parte de identificador de interfaz puede elegirse libremente, siempre que no coincida para ambas máquinas. Incluir la longitud del prefijo al fijar las direcciones.

```

ip link set dev eth0 up (VM1 y VM2)
ip address add fd00:0:0:a::1/64 dev eth0 (VM1)
ip address add fd00:0:0:a::2/64 dev eth0 (VM2)

```

**Ejercicio 5 [VM1, VM2].** Comprobar la conectividad entre VM1 y VM2 con la orden ping6 usando la nueva dirección. Observar los mensajes intercambiados con Wireshark.

```

[cursoredes@localhost ~]$ ping6 fd00:0:0:a::2 -I eth0 -c 1
PING fd00:0:0:a::2(fd00:0:0:a::2) from fd00:0:0:a::1 eth0: 56 data bytes
64 bytes from fd00:0:0:a::2: icmp_seq=1 ttl=64 time=0.168 ms

--- fd00:0:0:a::2 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms

```

No.	Time	Source	Destination	Protoc	Length	Info
7	23.7177263	fd00:0:0:a::1	fd00:0:0:a::2	ICMPv6	118	Echo (ping) request id=0x0a26, seq=1, hop limit=64 (reply in 8)
8	23.7178856	fd00:0:0:a::2	fd00:0:0:a::1	ICMPv6	118	Echo (ping) reply id=0x0a26, seq=1, hop limit=64 (request in 7)

```

▶ Frame 8: 118 bytes on wire (944 bits), 118 bytes captured (944 bits) on interface 0
  Ethernet II, Src: CadmusCo_5a:c2:d5 (08:00:27:5a:c2:d5), Dst: CadmusCo_e4:50:35 (08:00:27:e4:50:35)
▶ Internet Protocol Version 6, Src: fd00:0:0:a::2 (fd00:0:0:a::2), Dst: fd00:0:0:a::1 (fd00:0:0:a::1)
  0110 .... = Version: 6
  .... 0000 0000 .... .... .... = Traffic class: 0x00000000
  .... 0000 0000 0000 0000 0000 0000 = Flowlabel: 0x00000000
  Payload length: 64
  Next header: ICMPv6 (58)
  Hop limit: 64
  Source: fd00:0:0:a::2 (fd00:0:0:a::2)
  Destination: fd00:0:0:a::1 (fd00:0:0:a::1)
▶ Internet Control Message Protocol v6
  Type: Echo (ping) reply (129)
  Code: 0
  Checksum: 0x59ac [correct]
  Identifier: 0x0a26
  Sequence: 1
  [Response To: 7]
  [Response Time: 0.159 ms]
  Data (56 bytes)

```

```
ip link set dev eth0 up (Router y VM4)
ip link set dev eth1 up (Router)
ip address add fd00:0:0:a::3/64 dev eth0 (Router)
ip address add fd00:0:0:b::2/64 dev eth1 (Router)
ip address add fd00:0:0:b::1/64 dev eth0 (VM4)
```

```
Router:
-Para VM1
[cursoredes@localhost ~]$ ping6 fd00:0:0:a::1 -I eth0 -c 1
PING fd00:0:0:a::1(fd00:0:0:a::1) from fd00:0:0:a::3 eth0: 56 data bytes
64 bytes from fd00:0:0:a::1: icmp_seq=1 ttl=64 time=0.323 ms

--- fd00:0:0:a::1 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.323/0.323/0.323/0.000 ms

-Para VM4
[cursoredes@localhost ~]$ ping6 fd00:0:0:b::1 -I eth1 -c 1
PING fd00:0:0:b::1(fd00:0:0:b::1) from fd00:0:0:b::2 eth1: 56 data bytes
64 bytes from fd00:0:0:b::1: icmp_seq=1 ttl=64 time=0.249 ms

--- fd00:0:0:b::1 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.249/0.249/0.249/0.000 ms

VM1:
-Para VM4
[cursoredes@localhost ~]$ ping6 fd00:0:0:b::1 -I eth0 -c 1
connect: Network is unreachable
```

## Encaminamiento estático

Según la topología que hemos configurado en esta práctica, Router debe encaminar el tráfico entre las redes `fd00:0:0:a::/64` y `fd00:0:0:b::/64`. En esta sección vamos a configurar un encaminamiento estático basado en las rutas que fijaremos manualmente en todas las máquinas.

**Ejercicio 8 [VM1, Router].** Consultar las tablas de rutas en VM1 y Router con el comando `ip route`. Consultar la página de manual del comando para seleccionar las rutas IPv6.

```
VM1:
[cursoredes@localhost ~]$ ip -6 route
unreachable ::/96 dev lo metric 1024 error -113 pref medium
unreachable ::ffff:0.0.0.0/96 dev lo metric 1024 error -113 pref medium
unreachable 2002:a00::/24 dev lo metric 1024 error -113 pref medium
unreachable 2002:7f00::/24 dev lo metric 1024 error -113 pref medium
unreachable 2002:a9fe::/32 dev lo metric 1024 error -113 pref medium
unreachable 2002:ac10::/28 dev lo metric 1024 error -113 pref medium
unreachable 2002:c0a8::/32 dev lo metric 1024 error -113 pref medium
unreachable 2002:e000::/19 dev lo metric 1024 error -113 pref medium
unreachable 3ffe:ffff::/32 dev lo metric 1024 error -113 pref medium
fd00:0:0:a::/64 dev eth0 proto kernel metric 256 pref medium
fe80::/64 dev eth0 proto kernel metric 256 pref medium
```

```
Router:
[cursoredes@localhost ~]$ ip -6 route
unreachable ::/96 dev lo metric 1024 error -113 pref medium
unreachable ::ffff:0.0.0.0/96 dev lo metric 1024 error -113 pref medium
unreachable 2002:a00::/24 dev lo metric 1024 error -113 pref medium
unreachable 2002:7f00::/24 dev lo metric 1024 error -113 pref medium
unreachable 2002:a9fe::/32 dev lo metric 1024 error -113 pref medium
unreachable 2002:ac10::/28 dev lo metric 1024 error -113 pref medium
unreachable 2002:c0a8::/32 dev lo metric 1024 error -113 pref medium
unreachable 2002:e000::/19 dev lo metric 1024 error -113 pref medium
unreachable 3ffe:ffff::/32 dev lo metric 1024 error -113 pref medium
fd00:0:0:a::/64 dev eth0 proto kernel metric 256 pref medium
fd00:0:0:b::/64 dev eth1 proto kernel metric 256 pref medium
fe80::/64 dev eth0 proto kernel metric 256 pref medium
fe80::/64 dev eth1 proto kernel metric 256 pref medium
```

**Ejercicio 9 [Router].** Para que Router actúe efectivamente como encaminador, hay que activar el reenvío de paquetes (*packet forwarding*). De forma temporal, se puede activar con el comando `sysctl -w net.ipv6.conf.all.forwarding=1`.

```
[cursoredes@localhost ~]$ sudo sysctl -w net.ipv6.conf.all.forwarding=1
net.ipv6.conf.all.forwarding = 1
```

**Ejercicio 10 [VM1, VM2, VM4].** Finalmente, hay que configurar la tabla de rutas en las máquinas virtuales. Añadir la dirección correspondiente de Router como ruta por defecto con el comando `ip route`. Comprobar la conectividad entre VM1 y VM4 usando el comando `ping6`.

```
sudo ip route add default via fd00:0:0:a::3 (VM1 y VM2)
sudo ip route add default via fd00:0:0:b::2 (VM4)
Copiar los comandos utilizados y su salida.
```

```
VM1:
```

```
-Para VM4
[cursoredes@localhost ~]$ ping6 fd00:0:0:b::1 -I eth0 -c 1
PING fd00:0:0:b::1(fd00:0:0:b::1) from fd00:0:0:a::1 eth0: 56 data bytes
64 bytes from fd00:0:0:b::1: icmp_seq=1 ttl=63 time=0.327 ms

--- fd00:0:0:b::1 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 0.327/0.327/0.327/0.000 ms
```

**Ejercicio 11 [VM1, Router, VM4].** Abrir Wireshark en Router e iniciar dos capturas, una en cada interfaz de red. Borrar la tabla de vecinos en VM1 y Router (con `ip neigh flush dev <interfaz>`). Usar la orden `ping6` entre VM1 y VM4. Completar la siguiente tabla con todos los mensajes hasta el primer ICMP Echo Reply:

**Red fd00:0:0:a::/64 - Router (eth0)**

MAC Origen	MAC Destino	IPv6 Origen	IPv6 Destino	ICMPv6 Tipo
MAC VM1	BROADCAST	IP VM1	Solicited-node multicast	Neighbor solicitation (135)
MAC Router	MAC VM1	IP Router	IP VM1	Neighbor advertisement (136)
MAC VM1	MAC Router	IP VM1	IP VM4	Echo request (128)
MAC Router	MAC VM1	IP VM4	IP VM1	Echo reply (129)

**Red fd00:0:0:b::/64 - Router (eth1)**

MAC Origen	MAC Destino	IPv6 Origen	IPv6 Destino	ICMPv6 Tipo
MAC VM4	BROADCAST	IP Router	Solicited-node multicast	Neighbor solicitation (135)
MAC Router	MAC VM4	IP VM4	IP Router	Neighbor advertisement (136)
MAC VM4	MAC Router	IP VM1	IP VM4	Echo request (128)
MAC Router	MAC VM4	IP VM4	IP VM1	Echo reply (129)

*eth0:*

No.	Time	Source	Destination	Protoc	Lengj	Info
1	0.00000000	fd00:0:0:a::1	ff02::1:ff00:3	ICMPv6	86	Neighbor Solicitation for fd00:0:0:a::3 from 08:00:27:e4:50:35
2	0.00002773	fd00:0:0:a::3	fd00:0:0:a::1	ICMPv6	86	Neighbor Advertisement fd00:0:0:a::3 (rtr, sol, ovr) is at 08:00:27:ac:57:e4
3	0.00003874	fe80::a00:27ff:fee4ff02::1:ff00:3	ff02::1:ff00:3	ICMPv6	86	Neighbor Solicitation for fd00:0:0:a::3 from 08:00:27:e4:50:35
4	0.00004116	fd00:0:0:a::3	fe80::a00:27ff:fee4ff02::1:ff00:3	ICMPv6	86	Neighbor Advertisement fd00:0:0:a::3 (rtr, sol, ovr) is at 08:00:27:ac:57:e4
5	0.00004437	fe80::a00:27ff:fee4ff02::1:ff00:3	ff02::1:ff00:3	ICMPv6	86	Neighbor Solicitation for fd00:0:0:a::3 from 08:00:27:e4:50:35
6	0.00004689	fd00:0:0:a::3	fe80::a00:27ff:fee4ff02::1:ff00:3	ICMPv6	86	Neighbor Advertisement fd00:0:0:a::3 (rtr, sol, ovr) is at 08:00:27:ac:57:e4
7	0.00015088	fd00:0:0:a::1	fd00:0:0:b::1	ICMPv6	118	Echo (ping) request id=0x0bc9, seq=1, hop limit=64 (reply in 8)
8	0.00044942	fd00:0:0:b::1	fd00:0:0:a::1	ICMPv6	118	Echo (ping) reply id=0x0bc9, seq=1, hop limit=63 (request in 7)

▶	Frame 1: 86 bytes on wire (688 bits), 86 bytes captured (688 bits) on interface 0
▶	Ethernet II, Src: CadmusCo_e4:50:35 (08:00:27:e4:50:35), Dst: IPv6mcast_ff:00:00:03 (33:33:ff:00:00:03)
▼	Internet Protocol Version 6, Src: fd00:0:0:a::1 (fd00:0:0:a::1), Dst: ff02::1:ff00:3 (ff02::1:ff00:3)
▶	0110 .... = Version: 6
▶	.... 0000 0000 .... = Traffic class: 0x00000000
▶	.... 0000 0000 0000 0000 = Flowlabel: 0x00000000
▶	Payload length: 32
▶	Next header: ICMPv6 (58)
▶	Hop limit: 255
▶	Source: fd00:0:0:a::1 (fd00:0:0:a::1)
▶	Destination: ff02::1:ff00:3 (ff02::1:ff00:3)
▼	Internet Control Message Protocol v6
▶	Type: Neighbor Solicitation (135)
▶	Code: 0
▶	Checksum: 0xffff68 [correct]
▶	Reserved: 00000000
▶	Target Address: fd00:0:0:a::3 (fd00:0:0:a::3)
▶	ICMPv6 Option (Source link-layer address : 08:00:27:e4:50:35)

eth1:

No.	Time	Source	Destination	Protoc	Lengj	Info
1	0.00000000	fe80::a00:27ff:fed9ff02::1:ff00:1	ff02::1:ff00:1	ICMPv6	86	Neighbor Solicitation for fd00:0:0:b::1 from 08:00:27:d9:eb:70
2	0.00014149	fd00:0:0:b::1	fe80::a00:27ff:fed9ff02::1:ff00:1	ICMPv6	86	Neighbor Advertisement fd00:0:0:b::1 (sol, ovr) is at 08:00:27:0c:e7:35
3	0.00014693	fd00:0:0:a::1	fd00:0:0:b::1	ICMPv6	118	Echo (ping) request id=0x0bc9, seq=1, hop limit=63 (reply in 4)
4	0.00027823	fd00:0:0:b::1	fd00:0:0:a::1	ICMPv6	118	Echo (ping) reply id=0x0bc9, seq=1, hop limit=64 (request in 3)

▶	Frame 1: 86 bytes on wire (688 bits), 86 bytes captured (688 bits) on interface 0
▶	Ethernet II, Src: CadmusCo_d9:eb:70 (08:00:27:d9:eb:70), Dst: IPv6mcast_ff:00:00:01 (33:33:ff:00:00:01)
▼	Internet Protocol Version 6, Src: fe80::a00:27ff:fed9:eb70 (fe80::a00:27ff:fed9:eb70), Dst: ff02::1:ff00:1 (ff02::1:ff00:1)
▶	0110 .... = Version: 6
▶	.... 0000 0000 .... = Traffic class: 0x00000000
▶	.... 0000 0000 0000 0000 = Flowlabel: 0x00000000
▶	Payload length: 32
▶	Next header: ICMPv6 (58)
▶	Hop limit: 255
▶	Source: fe80::a00:27ff:fed9:eb70 (fe80::a00:27ff:fed9:eb70)
▶	[Source SA MAC: CadmusCo_d9:eb:70 (08:00:27:d9:eb:70)]
▶	Destination: ff02::1:ff00:1 (ff02::1:ff00:1)
▼	Internet Control Message Protocol v6
▶	Type: Neighbor Solicitation (135)
▶	Code: 0
▶	Checksum: 0x467c [correct]
▶	Reserved: 00000000
▶	Target Address: fd00:0:0:b::1 (fd00:0:0:b::1)
▶	ICMPv6 Option (Source link-layer address : 08:00:27:d9:eb:70)

## Configuración persistente

Las configuraciones realizadas en los apartados anteriores son volátiles y desaparecen cuando se reinician las máquinas. Durante el arranque del sistema se pueden configurar automáticamente los interfaces según la información almacenada en el disco.

**Ejercicio 12 [Router].** Crear los ficheros ifcfg-eth0 e ifcfg-eth1 en el directorio /etc/sysconfig/network-scripts/ con la configuración de cada interfaz. Usar las siguientes opciones (descritas en /usr/share/doc/initscripts-\*/sysconfig.txt):

```
TYPE=Ethernet
BOOTPROTO=none
IPV6ADDR=<dirección IP en formato CIDR>
IPV6_DEFAULTGW=<dirección IP del encaminador por defecto (en este caso, no tiene)>
DEVICE=<nombre del interfaz>
```

ifcfg-eth0:

```
TYPE=Ethernet
BOOTPROTO=none
IP6ADDR=fd00:0:0:a::3
DEVICE=eth0
```

```
ifcfg-eth1:
TYPE=Ethernet
BOOTPROTO=none
IP6ADDR=fd00:0:0:b::2
DEVICE=eth1
```

**Ejercicio 13 [Router].** Comprobar la configuración persistente con las órdenes ifup e ifdown.

```
[cursoredes@localhost ~]$ sudo ifdown eth0
```

```
[cursoredes@localhost ~]$ sudo ifup eth0
```

```
INFO : [ipv6_wait_tentative] Waiting for interface eth0 IPv6 address(es) to leave the 'tentative' state
INFO : [ipv6_wait_tentative] Waiting for interface eth0 IPv6 address(es) to leave the 'tentative' state
```

```
[cursoredes@localhost ~]$ sudo ifdown eth1
```

```
[cursoredes@localhost ~]$ sudo ifup eth1
```

```
INFO : [ipv6_wait_tentative] Waiting for interface eth1 IPv6 address(es) to leave the 'tentative' state
INFO : [ipv6_wait_tentative] Waiting for interface eth1 IPv6 address(es) to leave the 'tentative' state
INFO : [ipv6_wait_tentative] Waiting for interface eth1 IPv6 address(es) to leave the 'tentative' state
INFO : [ipv6_wait_tentative] Waiting for interface eth1 IPv6 address(es) to leave the 'tentative' state
```

```
[cursoredes@localhost ~]$ ip address
```

```
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group default qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
        valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
        valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP group default
    qlen 1000
    link/ether 08:00:27:ac:57:e4 brd ff:ff:ff:ff:ff:ff
    inet6 fd00:0:0:a::3/64 scope global
        valid_lft forever preferred_lft forever
    inet6 fe80::a00:27ff:feac:57e4/64 scope link
        valid_lft forever preferred_lft forever
3: eth1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP group default
    qlen 1000
    link/ether 08:00:27:d9:eb:70 brd ff:ff:ff:ff:ff:ff
    inet6 fd00:0:0:b::2/64 scope global
        valid_lft forever preferred_lft forever
    inet6 fe80::a00:27ff:fed9:eb70/64 scope link
        valid_lft forever preferred_lft forever
```

## Autoconfiguración. Anuncio de prefijos

El protocolo de descubrimiento de vecinos se usa también para la autoconfiguración de los interfaces de red. Cuando se activa un interfaz, se envía un mensaje de descubrimiento de encaminadores. Los encaminadores presentes responden con un anuncio que contiene, entre otros, el prefijo de la red.

**Ejercicio 14 [VM1, VM2, VM4].** Eliminar las direcciones ULA de los interfaces desactivándolos con ip



link.

```
ip link set dev eth0 down (VM1, VM2 y VM4)
```

**Ejercicio 15 [Router].** Configurar el servicio zebra para que el encaminador anuncie prefijos. Para ello, crear el archivo `/etc/quagga/zebra.conf` e incluir la información de los prefijos para las dos redes. Cada entrada será de la forma:

```
interface eth0
  no ipv6 nd suppress-ra
  ipv6 nd prefix fd00:0:0:a::/64
```

Finalmente, arrancar el servicio con el comando `service zebra start`.

**Ejercicio 16 [VM4].** Comprobar la autoconfiguración del interfaz de red en VM4, volviendo a activar el interfaz y consultando la dirección asignada.

```
inet6 fd00::b:a00:27ff:fe0c:e735/64 scope global mngtmpaddr dynamic
  valid_lft 2591977sec preferred_lft 604777sec
```

**Ejercicio 17 [VM1, VM2].** Estudiar los mensajes del protocolo de descubrimiento de vecinos:

- Activar el interfaz en VM2, comprobar que está configurado correctamente e iniciar una captura de paquetes con Wireshark.
- Activar el interfaz en VM1 y estudiar los mensajes ICMP de tipo Router Solicitation y Router Advertisement.
- Comprobar las direcciones destino y origen de los datagramas, así como las direcciones destino y origen de la trama Ethernet. Especialmente la relación entre las direcciones IP y MAC. Estudiar la salida del comando `ip maddr`.

```
[cursoredes@localhost ~]$ ip maddr
1:      lo
      inet 224.0.0.1
      inet6 ff02::1
      inet6 ff01::1
2:      eth0
      link 33:33:00:00:00:01
      link 01:00:5e:00:00:01
      link 33:33:ff:e4:50:35
      inet 224.0.0.1
      inet6 ff02::1:ffe4:5035 users 2
      inet6 ff02::1
      inet6 ff01::1
```

No.	Time	Source	Destination	Protoc	Length	Info
1	0.00000000	::	ff02::16	ICMPv6	90	Multicast Listener Report Message v2
2	0.72446184	::	ff02::16	ICMPv6	90	Multicast Listener Report Message v2
3	0.85881738	::	ff02::1:ff5a:c2d5	ICMPv6	78	Neighbor Solicitation for fe80::a00:27ff:fe5a:c2d5
4	1.86040813	fe80::a00:27ff:fe5a:ff02::16	ff02::16	ICMPv6	90	Multicast Listener Report Message v2
5	1.86041882	fe80::a00:27ff:fe5a:ff02::2	ff02::16	ICMPv6	70	Router Solicitation from 08:00:27:5a:c2:d5
6	1.86055581	fe80::a00:27ff:feac:ff02::1	ff02::16	ICMPv6	110	Router Advertisement from 08:00:27:ac:57:e4
7	2.39263897	::	ff02::1:ff5a:c2d5	ICMPv6	78	Neighbor Solicitation for fd00::a:00:27ff:fe5a:c2d5
8	2.45430894	fe80::a00:27ff:fe5a:ff02::16	ff02::16	ICMPv6	90	Multicast Listener Report Message v2

▶	Frame 3: 78 bytes on wire (624 bits), 78 bytes captured (624 bits) on interface 0
▶	Ethernet II, Src: CadmusCo_5a:c2:d5 (08:00:27:5a:c2:d5), Dst: IPv6mcast_ff:5a:c2:d5 (33:33:ff:5a:c2:d5)
▼	Internet Protocol Version 6, Src: :: (::), Dst: ff02::1:ff5a:c2d5 (ff02::1:ff5a:c2d5)
▶	0110 .... = Version: 6
▶	.... 0000 0000 .... = Traffic class: 0x00000000
....	.... 0000 0000 0000 0000 = Flowlabel: 0x00000000
	Payload length: 24
	Next header: ICMPv6 (58)
	Hop limit: 255
	Source: :: (::)
	Destination: ff02::1:ff5a:c2d5 (ff02::1:ff5a:c2d5)
▼	Internet Control Message Protocol v6
	Type: Neighbor Solicitation (135)
	Code: 0
	Checksum: 0xc5c7 [correct]
	Reserved: 00000000
	Target Address: fe80::a00:27ff:fe5a:c2d5 (fe80::a00:27ff:fe5a:c2d5)

**Para saber más...** En el proceso de autoconfiguración se genera también el identificador de interfaz según el *Extended Unique Identifier* (EUI-64) modificado. La configuración del protocolo de anuncio de encaminadores tiene múltiples opciones que se pueden consultar en la documentación de zebra (ej. intervalo entre anuncios no solicitados). Cuando sólo se necesita un servicio que implemente el anuncio de prefijos, y no algoritmos de encaminamiento para el router, se puede usar el proyecto de código libre *Router Advertisement Daemon*, *radvd*.

**Ejercicio 18 [VM1].** La generación del identificador de interfaz mediante EUI-64 supone un problema de privacidad para las máquinas clientes, que pueden ser rastreadas por su dirección MAC. En estos casos, es conveniente activar las extensiones de privacidad para generar un identificador de interfaz pseudoaleatorio temporal para las direcciones globales. Activar las extensiones de privacidad en VM1 con `sysctl -w net.ipv6.conf.eth0.use_tempaddr=2`.

```
[cursoredes@localhost ~]$ ip address
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group default qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
        valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
        valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP group default
    qlen 1000
    link/ether 08:00:27:5a:c2:d5 brd ff:ff:ff:ff:ff:ff
    inet6 fd00::a:2d0e:66c3:ae3:833a/64 scope global temporary dynamic
        valid_lft 604799sec preferred_lft 85799sec
    inet6 fd00::a:a00:27ff:fe5a:c2d5/64 scope global tentative mngtmpaddr dynamic
        valid_lft 2591999sec preferred_lft 604799sec
    inet6 fe80::a00:27ff:fe5a:c2d5/64 scope link
        valid_lft forever preferred_lft forever
```

## ICMPv6

El protocolo ICMPv6 permite el intercambio de mensajes para el control de la red, tanto para la detección de errores como para la consulta de la configuración de ésta. Durante el desarrollo de la práctica hemos visto los más importantes.

**Ejercicio 19.** Generar mensajes de los siguientes tipos en la red y estudiarlos con ayuda de Wireshark:

- Solicitud y respuesta de eco.
- Solicitud y anuncio de encaminador.
- Solicitud y anuncio de vecino.
- Destino inalcanzable - Sin ruta al destino (Code: 0).
- Destino inalcanzable - Dirección inalcanzable (Code: 3)
- Destino inalcanzable - Puerto inalcanzable (Code: 4)

#### *Solicitud y respuesta de eco:*

2	0.00015817	fd00::a:a00:27ff:fe4d00::a:a00:27ff:fe1c	ICMPv6	86 Neighbor Advertisement fd00::a:a00:27ff:fe5a:c2d5 (sol, ov
3	0.00016532	fd00::a:a00:27ff:fe4d00::a:a00:27ff:fe1c	ICMPv6	118 Echo (ping) request id=0x0b0e, seq=1, hop limit=64 (reply
4	0.00025399	fd00::a:a00:27ff:fe4d00::a:a00:27ff:fe1c	ICMPv6	118 Echo (ping) reply id=0x0b0e, seq=1, hop limit=64 (request

▶	Frame 1: 86 bytes on wire (688 bits), 86 bytes captured (688 bits) on interface 0
▶	Ethernet II, Src: CadmusCo_e4:50:35 (08:00:27:e4:50:35), Dst: IPv6mcast_ff:5a:c2:d5 (33:33:ff:5a:c2:d5)
▼	Internet Protocol Version 6, Src: fd00::a:a00:27ff:fee4:5035 (fd00::a:a00:27ff:fee4:5035), Dst: ff02::1:ff5a:c2d5 (ff02::1:ff5a:c2d5)
▶	0110 .... = Version: 6
▶	.... 0000 0000 .... = Traffic class: 0x00000000
....	.... 0000 0000 0000 0000 0000 0000 = FlowLabel: 0x00000000
	Payload length: 32
	Next header: ICMPv6 (58)
	Hop limit: 255
	Source: fd00::a:a00:27ff:fee4:5035 (fd00::a:a00:27ff:fee4:5035)
	[Source SA MAC: CadmusCo_e4:50:35 (08:00:27:e4:50:35)]
	Destination: ff02::1:ff5a:c2d5 (ff02::1:ff5a:c2d5)
▼	Internet Control Message Protocol v6
	Type: Neighbor Solicitation (135)
	Code: 0
	Checksum: 0xc7f6 [correct]
	Reserved: 00000000
	Target Address: fd00::a:a00:27ff:fe5a:c2d5 (fd00::a:a00:27ff:fe5a:c2d5)
▶	ICMPv6 Option (Source link-layer address : 08:00:27:e4:50:35)

#### *Solicitud y anuncio de encaminador:*

2	0.28358449	::	ff02::16	ICMPv6	90 Multicast Listener Report Message v2
3	0.61316094	fe80::a00:27ff:feacff02::1		ICMPv6	110 Router Advertisement from 08:00:27:ac:57:e4
4	0.76269397	::	ff02::1:ff5a:c2d5	ICMPv6	78 Neighbor Solicitation for fe80::a00:27ff:fe5a:c2d5
5	1.06081807	::	ff02::1:ff5a:c2d5	ICMPv6	78 Neighbor Solicitation for fd00::a:a00:27ff:fe5a:c2d5
6	1.76442967	fe80::a00:27ff:fe5aff02::16		ICMPv6	90 Multicast Listener Report Message v2
7	1.76444133	fe80::a00:27ff:fe5aff02::2		ICMPv6	70 Router Solicitation from 08:00:27:5a:c2:d5
8	1.76454772	fe80::a00:27ff:feacff02::1		ICMPv6	110 Router Advertisement from 08:00:27:ac:57:e4
9	1.85543122	fe80::a00:27ff:fe5aff02::16		ICMPv6	90 Multicast Listener Report Message v2

▶	Frame 8: 110 bytes on wire (880 bits), 110 bytes captured (880 bits) on interface 0
▶	Ethernet II, Src: CadmusCo_ac:57:e4 (08:00:27:ac:57:e4), Dst: IPv6mcast_00:00:00:01 (33:33:00:00:00:01)
▼	Internet Protocol Version 6, Src: fe80::a00:27ff:feac:57e4 (fe80::a00:27ff:feac:57e4), Dst: ff02::1 (ff02::1)
▶	0110 .... = Version: 6
▶	.... 0000 0000 .... = Traffic class: 0x00000000
....	.... 0000 0000 0000 0000 0000 0000 = FlowLabel: 0x00000000
	Payload length: 56
	Next header: ICMPv6 (58)
	Hop limit: 255
	Source: fe80::a00:27ff:feac:57e4 (fe80::a00:27ff:feac:57e4)
	[Source SA MAC: CadmusCo_ac:57:e4 (08:00:27:ac:57:e4)]
	Destination: ff02::1 (ff02::1)
▼	Internet Control Message Protocol v6
	Type: Router Advertisement (134)
	Code: 0
	Checksum: 0x1b5e [correct]
	Cur hop limit: 64
▶	Flags: 0x00
	Router lifetime (s): 1800
	Reachable time (ms): 0
	Retrans timer (ms): 0
▶	ICMPv6 Option (Prefix information : fd00:0:0:a::/64)
▶	ICMPv6 Option (Source link-layer address : 08:00:27:ac:57:e4)

### Solicitud de vecino:

4	0.76269397::	ff02::1:ff5a:c2d5	ICMPv6	78 Neighbor Solicitation for fe80::a00:27ff:fe5a:c2d5
5	1.06081807::	ff02::1:ff5a:c2d5	ICMPv6	78 Neighbor Solicitation for fd00::a:a00:27ff:fe5a:c2d5
6	1.76442967	fe80::a00:27ff:fe5a:ff02::16	ICMPv6	90 Multicast Listener Report Message v2
7	1.76444133	fe80::a00:27ff:fe5a:ff02::2	ICMPv6	70 Router Solicitation from 08:00:27:5a:c2:d5
8	1.76454772	fe80::a00:27ff:feac:ff02::1	ICMPv6	110 Router Advertisement from 08:00:27:ac:57:e4
9	1.85543122	fe80::a00:27ff:fe5a:ff02::16	ICMPv6	90 Multicast Listener Report Message v2

▶	Frame 4: 78 bytes on wire (624 bits), 78 bytes captured (624 bits) on interface 0
▶	Ethernet II, Src: CadmusCo_5a:c2:d5 (08:00:27:5a:c2:d5), Dst: IPv6mcast_ff:5a:c2:d5 (33:33:ff:5a:c2:d5)
▼	Internet Protocol Version 6, Src: :: (:), Dst: ff02::1:ff5a:c2d5 (ff02::1:ff5a:c2d5)
▶	0110 .... = Version: 6
▶	.... 0000 0000 .... = Traffic class: 0x00000000
....	.... 0000 0000 0000 0000 0000 = FlowLabel: 0x00000000
Payload length: 24	
Next header: ICMPv6 (58)	
Hop limit: 255	
Source: :: (:)	
Destination: ff02::1:ff5a:c2d5 (ff02::1:ff5a:c2d5)	
▼	Internet Control Message Protocol v6
Type: Neighbor Solicitation (135)	
Code: 0	
Checksum: 0xc5c7 [correct]	
Reserved: 00000000	
Target Address: fe80::a00:27ff:fe5a:c2d5 (fe80::a00:27ff:fe5a:c2d5)	

### Anuncio de vecino:

11	42.6006278	fe80::a00:27ff:fee4:fe80::a00:27ff:feac	ICMPv6	78 Neighbor Advertisement fe80::a00:27ff:fee4:5035 (sol)
----	------------	---	--------	--

▶	Frame 11: 78 bytes on wire (624 bits), 78 bytes captured (624 bits) on interface 0
▶	Ethernet II, Src: CadmusCo_e4:50:35 (08:00:27:e4:50:35), Dst: CadmusCo_ac:57:e4 (08:00:27:ac:57:e4)
▼	Internet Protocol Version 6, Src: fe80::a00:27ff:fee4:5035 (fe80::a00:27ff:fee4:5035), Dst: fe80::a00:27ff:feac:57e4 (fe80::a00:27ff:feac:57e4)
▶	0110 .... = Version: 6
▶	.... 0000 0000 .... = Traffic class: 0x00000000
....	.... 0000 0000 0000 0000 0000 = FlowLabel: 0x00000000
Payload length: 24	
Next header: ICMPv6 (58)	
Hop limit: 255	
Source: fe80::a00:27ff:fee4:5035 (fe80::a00:27ff:fee4:5035)	
[Source SA MAC: CadmusCo_e4:50:35 (08:00:27:e4:50:35)]	
Destination: fe80::a00:27ff:feac:57e4 (fe80::a00:27ff:feac:57e4)	
[Destination SA MAC: CadmusCo_ac:57:e4 (08:00:27:ac:57:e4)]	
▼	Internet Control Message Protocol v6
Type: Neighbor Advertisement (136)	
Code: 0	
Checksum: 0xb166 [correct]	
▶	Flags: 0x40000000
Target Address: fe80::a00:27ff:fee4:5035 (fe80::a00:27ff:fee4:5035)	

### No route to destination:

181	426.751730	fd00:0:0:a::1	fd00:0:0:b::1	ICMPv6	118 Echo (ping) request id=0x0bad, seq=9, hop limit=64
182	426.751893	fd00:0:0:a::3	fd00:0:0:a::1	ICMPv6	166 Destination Unreachable (no route to destination)
183	427.751799	fd00:0:0:a::1	fd00:0:0:b::1	ICMPv6	118 Echo (ping) request id=0x0bad, seq=10, hop limit=64
184	427.751979	fd00:0:0:a::3	fd00:0:0:a::1	ICMPv6	166 Destination Unreachable (no route to destination)

▶	Frame 182: 166 bytes on wire (1328 bits), 166 bytes captured (1328 bits) on interface 0
▶	Ethernet II, Src: CadmusCo_ac:57:e4 (08:00:27:ac:57:e4), Dst: CadmusCo_e4:50:35 (08:00:27:e4:50:35)
▼	Internet Protocol Version 6, Src: fd00:0:0:a::3 (fd00:0:0:a::3), Dst: fd00:0:0:a::1 (fd00:0:0:a::1)
▶	0110 .... = Version: 6
▶	.... 0000 0000 .... = Traffic class: 0x00000000
....	.... 0000 0000 0000 0000 0000 = FlowLabel: 0x00000000
Payload length: 112	
Next header: ICMPv6 (58)	
Hop limit: 64	
Source: fd00:0:0:a::3 (fd00:0:0:a::3)	
Destination: fd00:0:0:a::1 (fd00:0:0:a::1)	
▼	Internet Control Message Protocol v6
Type: Destination Unreachable (1)	
Code: 0 (no route to destination)	
Checksum: 0x6a35 [correct]	
Reserved: 00000000	
▶	Internet Protocol Version 6, Src: fd00:0:0:a::1 (fd00:0:0:a::1), Dst: fd00:0:0:b::1 (fd00:0:0:b::1)
▶	Internet Control Message Protocol v6

### Address unreachable:

No.	Time	Source	Destination	Protoc	Lengt	Info
11	3.00624010	fd00:0:0:a::3	fd00:0:0:a::1	ICMPv6	166	Destination Unreachable (Address unreachable)
12	3.00625329	fd00:0:0:a::3	fd00:0:0:a::1	ICMPv6	166	Destination Unreachable (Address unreachable)
13	3.00625496	fd00:0:0:a::3	fd00:0:0:a::1	ICMPv6	166	Destination Unreachable (Address unreachable)
14	3.00636852	fd00:0:0:a::3	fd00:0:0:a::1	ICMPv6	166	Destination Unreachable (Address unreachable)

▶	Frame 11: 166 bytes on wire (1328 bits), 166 bytes captured (1328 bits) on interface 0
▶	Ethernet II, Src: CadmusCo_ac:57:e4 (08:00:27:ac:57:e4), Dst: CadmusCo_e4:50:35 (08:00:27:e4:50:35)
▼	Internet Protocol Version 6, Src: fd00:0:0:a::3 (fd00:0:0:a::3), Dst: fd00:0:0:a::1 (fd00:0:0:a::1)
▶	0110 .... = Version: 6
▶	.... 0000 0000 .... = Traffic class: 0x00000000
▶	.... 0000 0000 0000 0000 = FlowLabel: 0x00000000
▶	Payload length: 112
▶	Next header: ICMPv6 (58)
▶	Hop limit: 64
▶	Source: fd00:0:0:a::3 (fd00:0:0:a::3)
▶	Destination: fd00:0:0:a::1 (fd00:0:0:a::1)
▼	Internet Control Message Protocol v6
▶	Type: Destination Unreachable (1)
▶	Code: 3 (Address unreachable)
▶	Checksum: 0x6a33 [correct]
▶	Reserved: 00000000
▶	Internet Protocol Version 6, Src: fd00:0:0:a::1 (fd00:0:0:a::1), Dst: fd00:0:0:b::3 (fd00:0:0:b::3)
▶	Internet Control Message Protocol v6

### Port unreachable:

No.	Time	Source	Destination	Protoc	Lengt	Info
1	0.00000000	fe80::a00:27ff:fee4:fe80::a00:27ff:fe5a	fe80::a00:27ff:fe5a	UDP	66	Source port: 54082 Destination port: 7780
2	0.00018209	fe80::a00:27ff:fee4:fe80::a00:27ff:fee4	fe80::a00:27ff:fee4	ICMPv6	114	Destination Unreachable (Port unreachable)
3	5.01124279	fe80::a00:27ff:fee4:fe80::a00:27ff:fe5a	fe80::a00:27ff:fe5a	ICMPv6	86	Neighbor Solicitation for fe80::a00:27ff:fe5a:c2d5 from 08:00:27:e4:50:35
4	5.01131160	fe80::a00:27ff:fe5a:fe80::a00:27ff:fee4	fe80::a00:27ff:fee4	ICMPv6	86	Neighbor Solicitation for fe80::a00:27ff:fee4:5035 from 08:00:27:5a:35
5	5.01132054	fe80::a00:27ff:fee4:fe80::a00:27ff:fe5a	fe80::a00:27ff:fe5a	ICMPv6	78	Neighbor Advertisement fe80::a00:27ff:fee4:5035 (sol)
6	5.01144716	fe80::a00:27ff:fe5a:fe80::a00:27ff:fee4	fe80::a00:27ff:fee4	ICMPv6	78	Neighbor Advertisement fe80::a00:27ff:fe5a:c2d5 (sol)

▶	Frame 2: 114 bytes on wire (912 bits), 114 bytes captured (912 bits) on interface 0
▶	Ethernet II, Src: CadmusCo_5a:c2:d5 (08:00:27:5a:c2:d5), Dst: CadmusCo_e4:50:35 (08:00:27:e4:50:35)
▼	Internet Protocol Version 6, Src: fe80::a00:27ff:fe5a:c2d5 (fe80::a00:27ff:fe5a:c2d5), Dst: fe80::a00:27ff:fee4:5035 (fe80::a00:27ff:fee4:5035)
▶	0110 .... = Version: 6
▶	.... 0000 0000 .... = Traffic class: 0x00000000
▶	.... 0000 0000 0000 0000 = FlowLabel: 0x00000000
▶	Payload length: 60
▶	Next header: ICMPv6 (58)
▶	Hop limit: 64
▶	Source: fe80::a00:27ff:fe5a:c2d5 (fe80::a00:27ff:fe5a:c2d5)
▶	[Source SA MAC: CadmusCo_5a:c2:d5 (08:00:27:5a:c2:d5)]
▶	Destination: fe80::a00:27ff:fee4:5035 (fe80::a00:27ff:fee4:5035)
▶	[Destination SA MAC: CadmusCo_e4:50:35 (08:00:27:e4:50:35)]
▼	Internet Control Message Protocol v6
▶	Type: Destination Unreachable (1)
▶	Code: 4 (Port unreachable)
▶	Checksum: 0x1c0b [correct]
▶	Reserved: 00000000
▶	Internet Protocol Version 6, Src: fe80::a00:27ff:fee4:5035 (fe80::a00:27ff:fee4:5035), Dst: fe80::a00:27ff:fe5a:c2d5 (fe80::a00:27ff:fe5a:c2d5)
▶	User Datagram Protocol, Src Port: 54082 (54082), Dst Port: 7780 (7780)
▶	Data (4 bytes)