


```
1.722352] ata5: SATA link down (SStatus 0 SControl 300)
1.722800] ata2.00: configured for UDMA/100
1.723222] ata1.00: configured for UDMA/100
1.723885] scsi 1:0:0:0: CD-ROM QEMU QEMU DVD-ROM 2.5+ PQ: 0 ANSI: 5
1.725007] sr 1:0:0:0: [sr0] scsi3-mmc drive: 4x/4x cd/rw xa/form2 tray
1.725399] cdrom: Uniform CD-ROM driver Revision: 3.20
1.728217] sr 1:0:0:0: Attached scsi generic sg0 type 5
1.729978] scsi 2:0:0:0: Direct-Access ATA QEMU HARDDISK 2.5+ PQ: 0 ANSI: 5
1.730940] sd 2:0:0:0: [sda] 2097152 512-byte logical blocks: (1.07 GB/1.00 GiB)
1.731349] sd 2:0:0:0: [sda] Write Protect is off
1.731770] sd 2:0:0:0: [sda] Write cache: enabled, read cache: enabled, doesn't support DPO or FUA
1.732315] sd 2:0:0:0: [sda] Preferred minimum I/O size 512 bytes
1.732973] sd 2:0:0:0: Attached scsi generic sg1 type 0
1.736551] sda: sda1
1.738051] sd 2:0:0:0: [sda]
1.759660] usb 1-1: New USB device found, idVendor=0000, idProduct=0001, bcdDevice= 1.00
1.760134] usb 1-1: New USB device strings: Mfr=1, Product=3, SerialNumber=10
1.760579] usb 1-1: Product: QEMU USB Tablet
1.760945] usb 1-1: Manufacturer: QEMU
1.761285] usb 1-1: SerialNumber: 28754-0000:00:02:1:00:0-1
1.774516] hid: raw HID events driver (C) Jiri Kosina
1.780563] usbcore: registered new interface driver usbhid
1.781181] usbhid: USB HID core driver
1.786292] input: QEMU QEMU USB Tablet as /devices/pci0000:00/0000:00:02.1/0000:02:00.0/usb1/1-1/1-1:1.0/0003:0627:0001.0001/input/input0
1.787775] hid-generic 0003:0627:0001.0001: input,hidraw0: USB HID v0.01 Mouse [QEMU QEMU USB Tablet] on usb-0000:02:00.0-1/input0
begin: Loading essential drivers ... [ 1.962932] raid6: avx2x4 gen() 35408 MB/s
1.979904] raid6: avx2x2 gen() 32166 MB/s
1.996936] raid6: avx2x1 gen() 26080 MB/s
1.997333] raid6: using algorithm xor() 25100 MB/s
2.013909] raid6: .... xor() 15594 MB/s, rmm enabled
2.014196] raid6: using avx2x2 recovery algorithm
2.015909] xor: automatically using best checksumming function avx
2.017878] async_tx: api initialized (async)
```

Routujeme IPv4 provoz prostřednictvím IPv6 sousedů

Radek Zajíc, radek@zajic.v.pytli.cz • Den IPv6, 6. 6. 2025





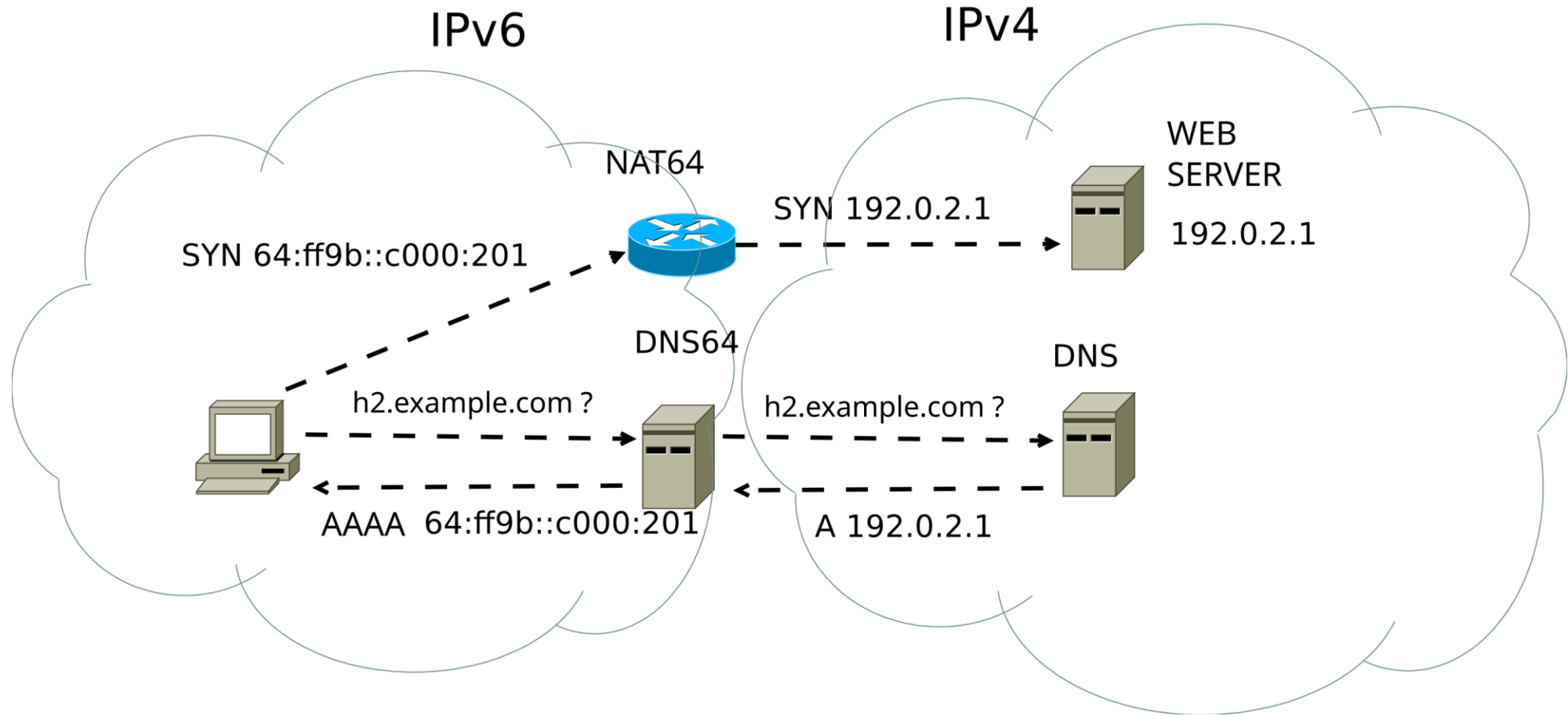
Máte
IPv6?

Dual-Stack je jen dočasným řešením

Dual IP Layer Operation

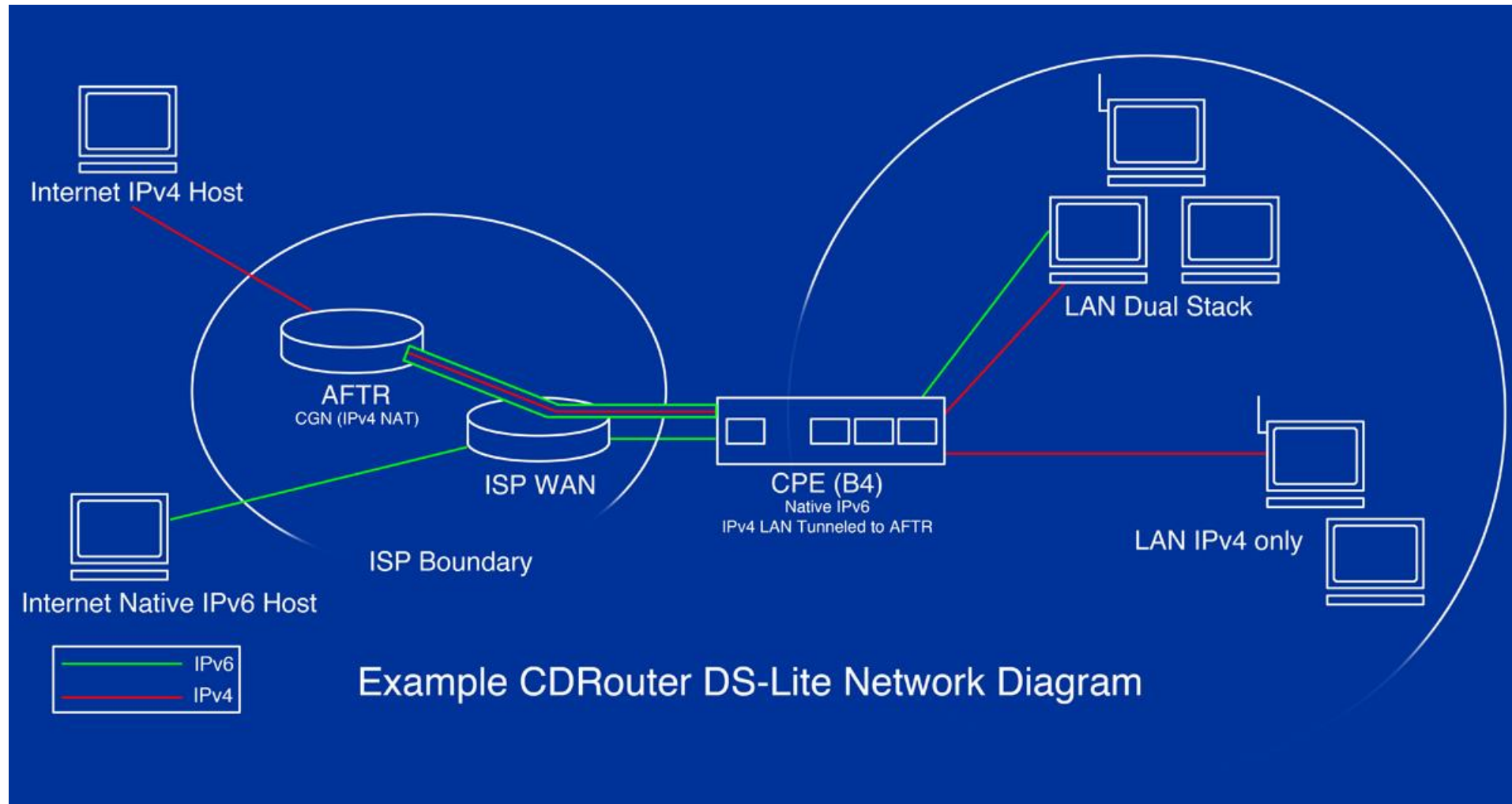
The most straightforward way for IPv6 nodes to remain compatible with IPv4-only nodes is by providing a complete IPv4 implementation. IPv6 nodes that provide a complete IPv4 and IPv6 implementations are called "IPv6/IPv4 nodes." IPv6/IPv4 nodes have the ability to send and receive both IPv4 and IPv6 packets. They can directly interoperate with IPv4 nodes using IPv4 packets, and also directly interoperate with IPv6 nodes using IPv6 packets. (RFC 2893, **Transition Mechanisms for IPv6 Hosts and Routers**, 08/2000)

Přechodové mechanismy – NAT64, DNS64 (2011)



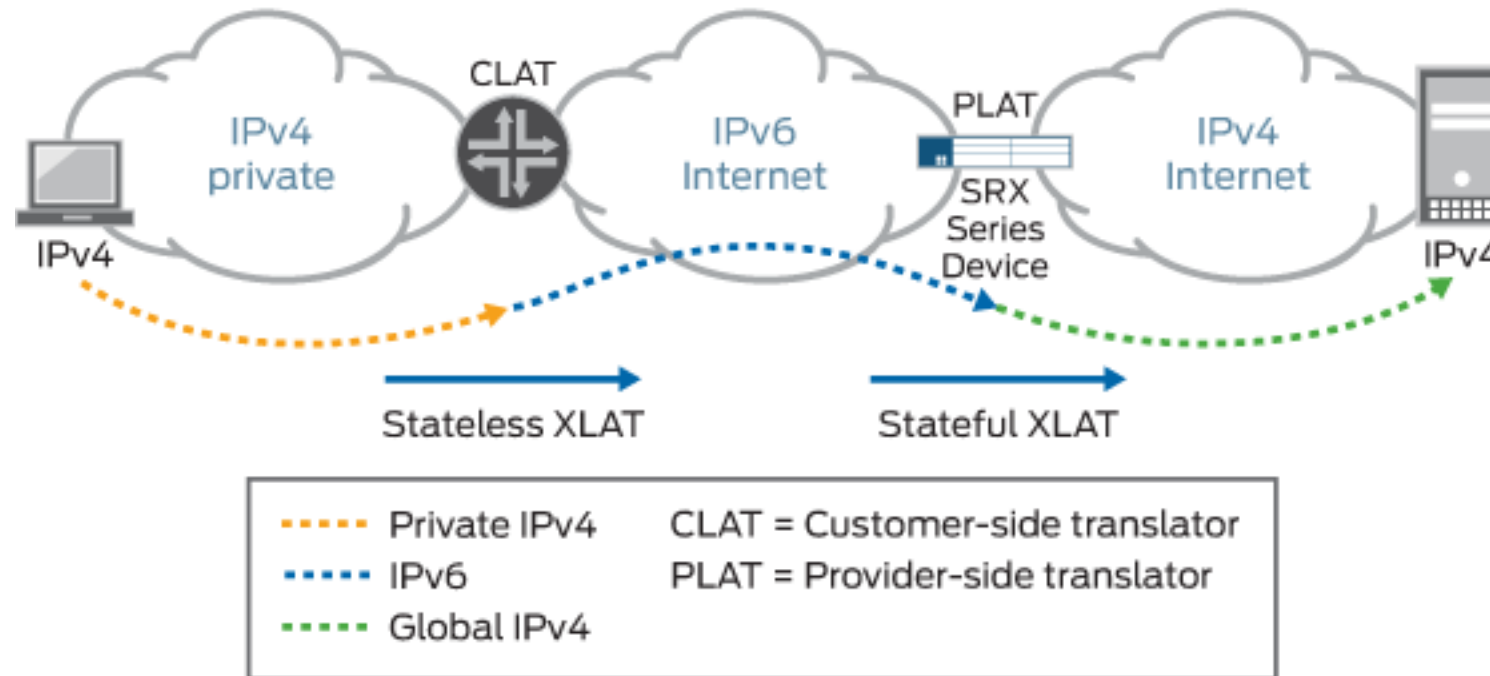
Wikipedia: [Mro](#), CC BY-SA 3.0; <https://en.wikipedia.org/wiki/NAT64>

Přechodové mechanismy – DS-Lite (2011)



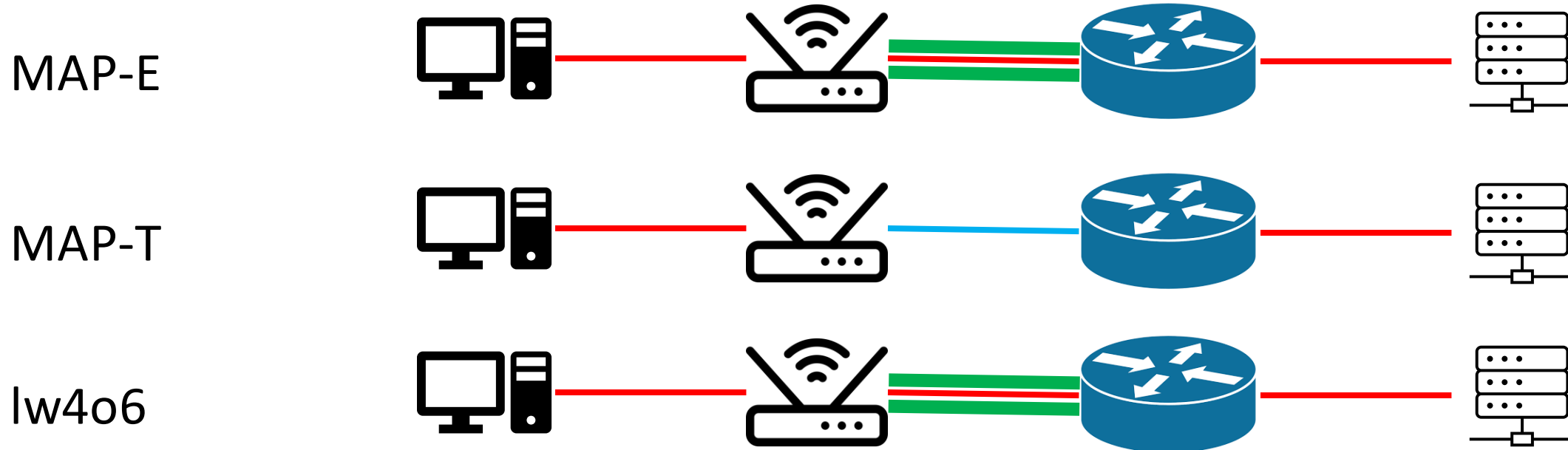
<https://support.qacafe.com/cdrouter/knowledge-base/ds-lite-testing-with-cdrouter/>

Přechodové mechanismy – 464XLAT (2013)



<https://www.juniper.net/documentation/us/en/software/junos/alg/topics/concept/security-xlat-alg-traffic-support-understanding.html>

Přechodové mechanismy – MAP-T, MAP-E, Iw4o6 (2015)



— IPv4 — IPv6 — IPv4 mapped into IPv6

Přechodové mechanismy – IPv6-mostly

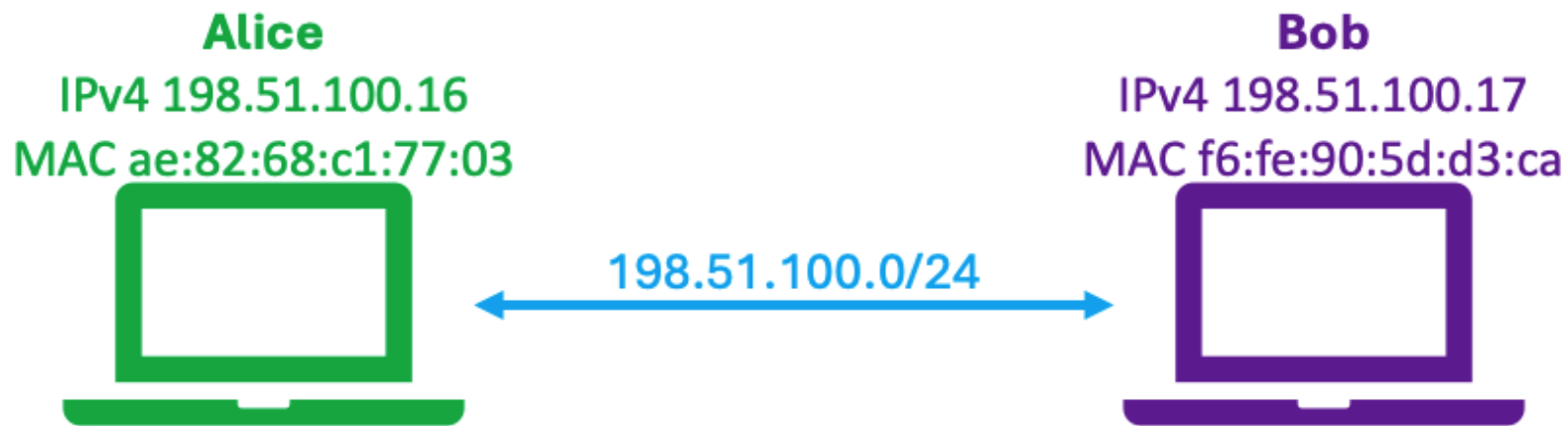


**"IPv6 Mostly": A
Smart Strategy for
Balancing Legacy
and Modern
Networking Needs**

IPv6 BUZZ 158

Přechodové mechanismy – IPv6 next hops

IPv4 Routing 101



Alice: IP 198.51.100.16, MAC ae:82:68:c1:77:03

Bob: IP 198.51.100.17, MAC f6:fe:90:5d:d3:ca

```
bob@bob:~# ip route
```

```
198.51.100.0/24 dev from_bob proto kernel scope link src 198.51.100.17
```

Kde je sakra Alice?

```
f6:fe:90:5d:d3:ca > ff:ff:ff:ff:ff:ff, ARP: Request who-has 198.51.100.16  
tell 198.51.100.17
```

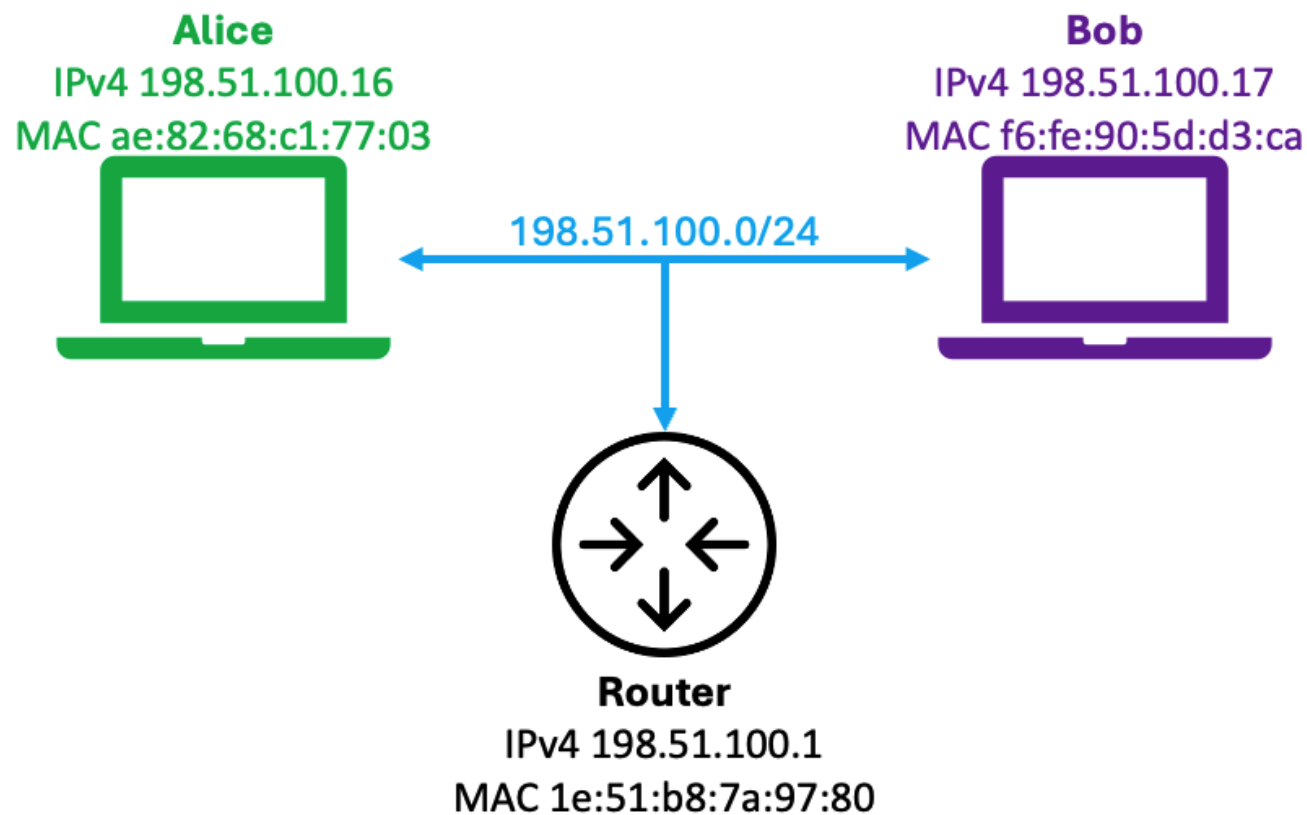
```
ae:82:68:c1:77:03 > f6:fe:90:5d:d3:ca, ARP: Reply 198.51.100.16 is-at  
ae:82:68:c1:77:03
```

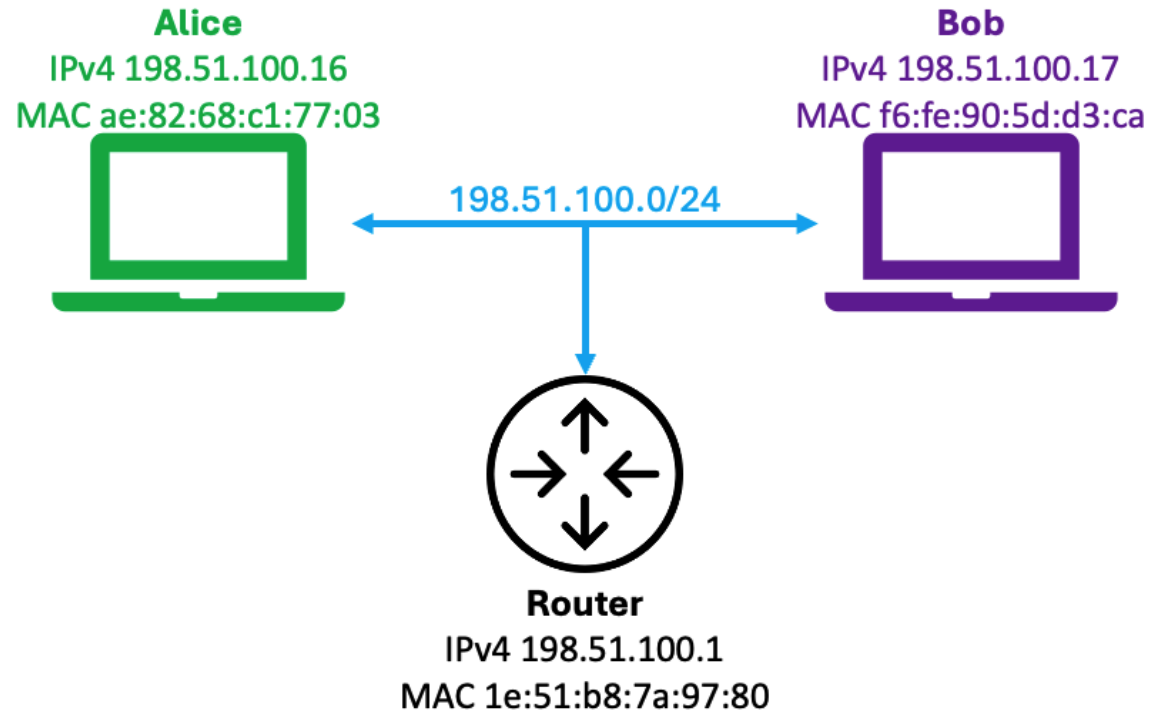
```
bob@bob:~# ip route
```

```
198.51.100.0/24 dev from_bob proto kernel scope link src 198.51.100.17
```

```
bob@bob:~# ping 8.8.8.8
```

```
ping: connect: Network is unreachable
```





```
Router IP 198.51.100.1, MAC 1e:51:b8:7a:97:80
Alice IP 198.51.100.16, MAC ae:82:68:c1:77:03
Bob IP 198.51.100.17, MAC f6:fe:90:5d:d3:ca
```

```
bob@bob:~# ip route add 0.0.0.0/0 via 198.51.100.1
bob@bob:~# ip route
default via 198.51.100.1 dev from_bob
198.51.100.0/24 dev from_bob proto kernel scope link src 198.51.100.17
```

IPv4 Neighbor Discovery, IPv4 provoz

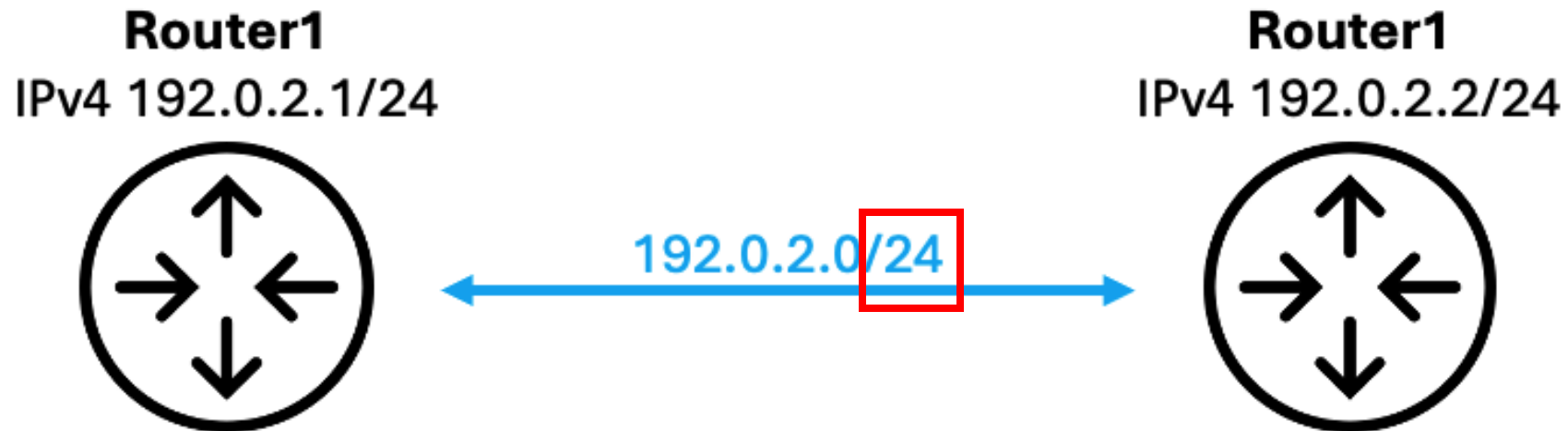
Router IP 198.51.100.1, MAC 1e:51:b8:7a:97:80

Bob IP 198.51.100.17, MAC f6:fe:90:5d:d3:ca

Source	Destination	Info
f6:fe:90:5d:d3:ca	Broadcast	Who has 198.51.100.1? Tell 198.51.100.17
1e:51:b8:7a:97:80	f6:fe:90:5d:d3:ca	198.51.100.1 is at 1e:51:b8:7a:97:80
198.51.100.17	8.8.8.8	Echo (ping) request id=0xa3dc, seq=1/256, ttl=64 (reply in 1831)
8.8.8.8	198.51.100.17	Echo (ping) reply id=0xa3dc, seq=1/256, ttl=118 (request in 1830)
198.51.100.1	224.0.0.251	Standard query response 0x0000 TXT, cache flush NSEC, cache flush 8\
198.51.100.17	8.8.8.8	Echo (ping) request id=0xa3dc, seq=2/512, ttl=64 (reply in 1835)

```
> Frame 1830: 98 bytes on wire (784 bits), 98 bytes captured (784 bits)
✓ Ethernet II, Src: f6:fe:90:5d:d3:ca (f6:fe:90:5d:d3:ca), Dst: 1e:51:b8:7a:97:80 (1e:51:b8:7a:97:80)
  > Destination: 1e:51:b8:7a:97:80 (1e:51:b8:7a:97:80)
  > Source: f6:fe:90:5d:d3:ca (f6:fe:90:5d:d3:ca)
  Type: IPv4 (0x0800)
  > Internet Protocol Version 4, Src: 198.51.100.17, Dst: 8.8.8.8
  > Internet Control Message Protocol
```

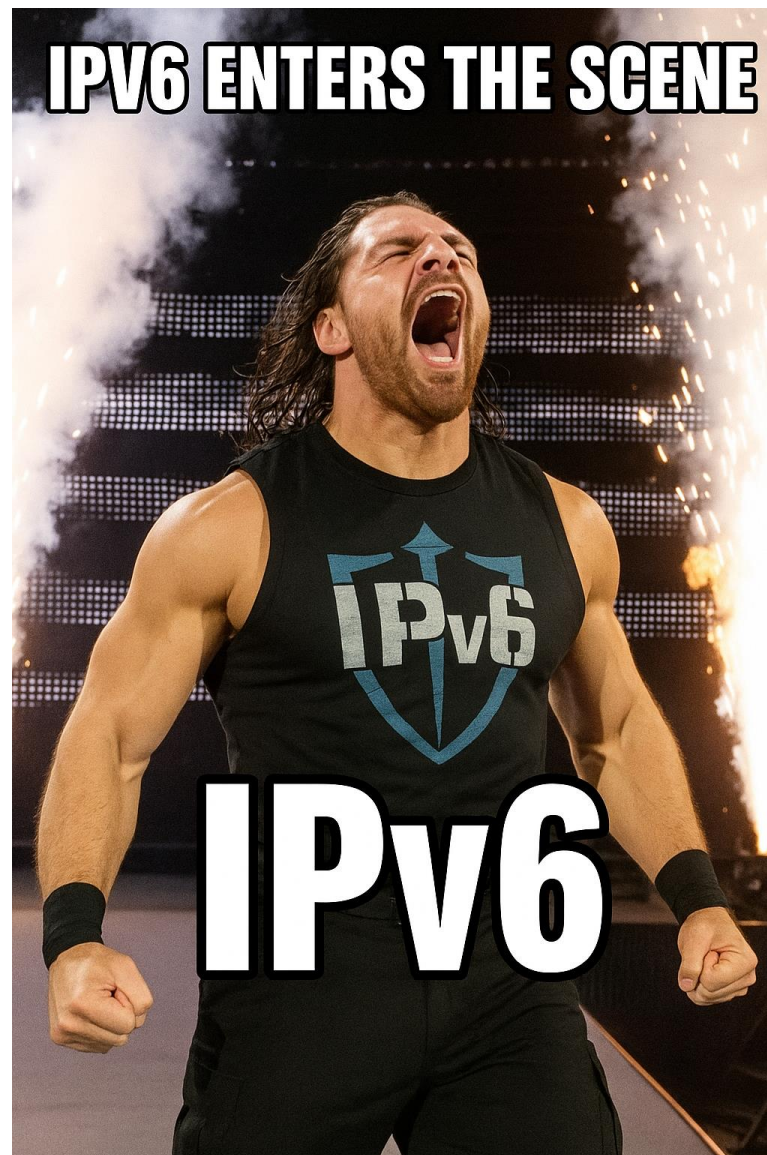
Sítě mezi routery



- /32 Ne ☺
- /31 RFC 3021 (2000)
- /30
- /29
- atd.

Využití masky /32 v IPv4 – Loopback/dummy





*Obrázek vytvořen pomocí promptu "Vytvoř mi meme, jak IPv6 přichází na scénu!"
s využitím ChatGPT-4o (OpenAI, 2025).*

Network Working Group
Request for Comments: 5549
Category: Standards Track

F. Le Faucheur
E. Rosen
Cisco Systems
May 2009

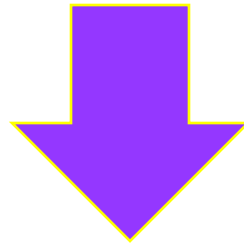
**Advertising IPv4 Network Layer Reachability Information
with an IPv6 Next Hop**

Internet Engineering Task Force (IETF)
Request for Comments: [8950](#)
Obsoletes: [5549](#)
Category: Standards Track
Published: November 2020
ISSN: 2070-1721

S. Litkowski
Cisco
S. Agrawal
Cisco
K. Ananthamurthy
Cisco
K. Patel
Arrcus

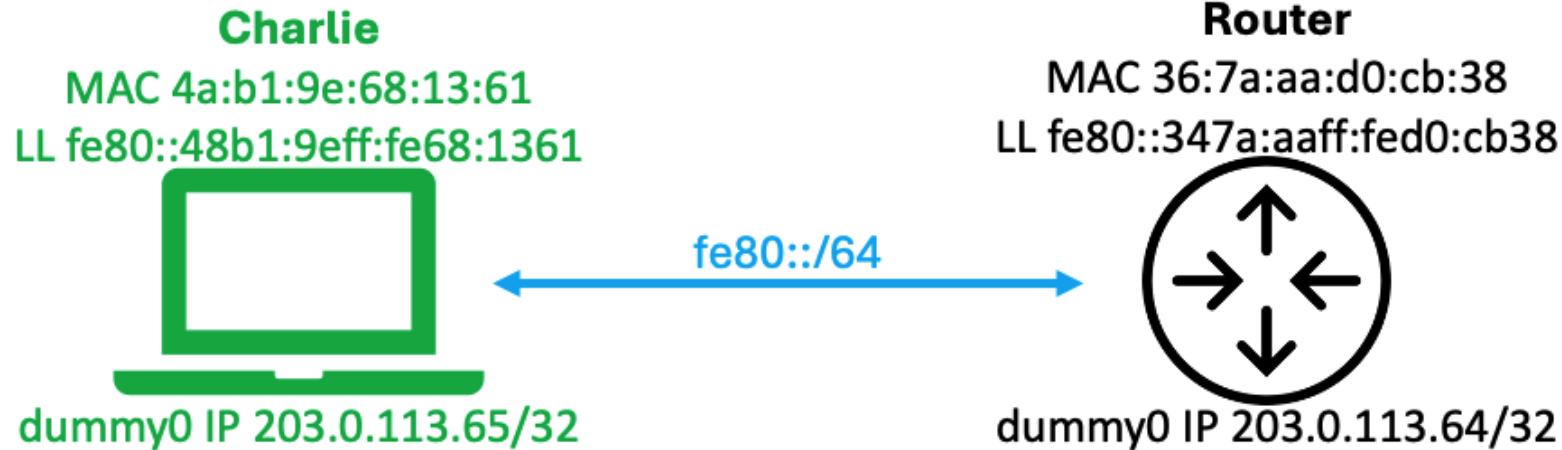
**Advertising IPv4 Network Layer Reachability Information (NLRI) with an
IPv6 Next Hop**

```
bob@bob:~# ip route add 0.0.0.0/0 via 198.51.100.1  
bob@bob:~# ip route  
default via 198.51.100.1 dev from_bob  
198.51.100.0/24 dev from_bob proto kernel scope link src 198.51.100.17
```



```
bob@bob:~# ip route add 0.0.0.0/0 via inet6 fe80::1 dev from_bob  
bob@bob:~# ip route  
default via inet6 fe80::1 dev from_bob  
198.51.100.0/24 dev from_bob proto kernel scope link src 198.51.100.17
```

Konfigurace rozhraní typu Loopback/dummy



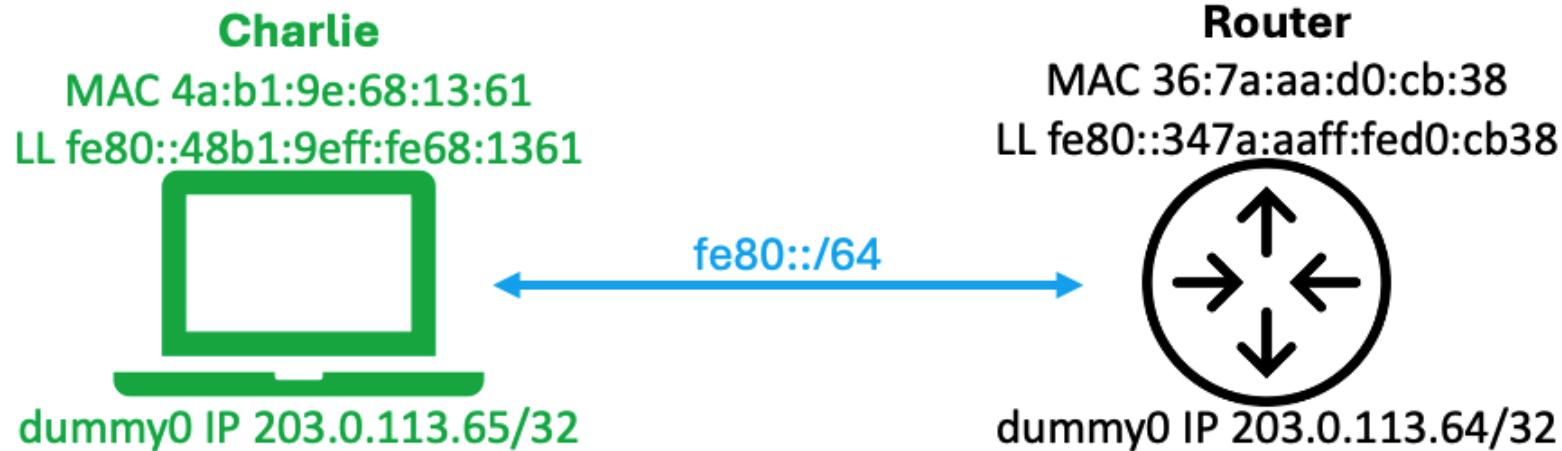
```
charlie@charlie:~# ip a s dev dummy0
```

```
3: dummy0: <BROADCAST,NOARP,UP,LOWER_UP> mtu 1500  
    link/ether 22:89:1c:bb:97:fe brd ff:ff:ff:ff:ff:ff  
    inet 203.0.113.65/32 scope global dummy0  
        valid_lft forever preferred_lft forever
```

```
operator@router:~# ip a s dev dummy0
```

```
76: dummy0: <BROADCAST,NOARP,UP,LOWER_UP> mtu 1500  
    link/ether 06:7e:d5:e2:ea:47 brd ff:ff:ff:ff:ff:ff  
    inet 203.0.113.64/32 scope global dummy0  
        valid_lft forever preferred_lft forever
```

Výchozí brána na zařízení „Charlie“



```
charlie@charlie:~# ip route
```

```
charlie@charlie:~# ping 8.8.8.8
```

```
ping: connect: Network is unreachable
```

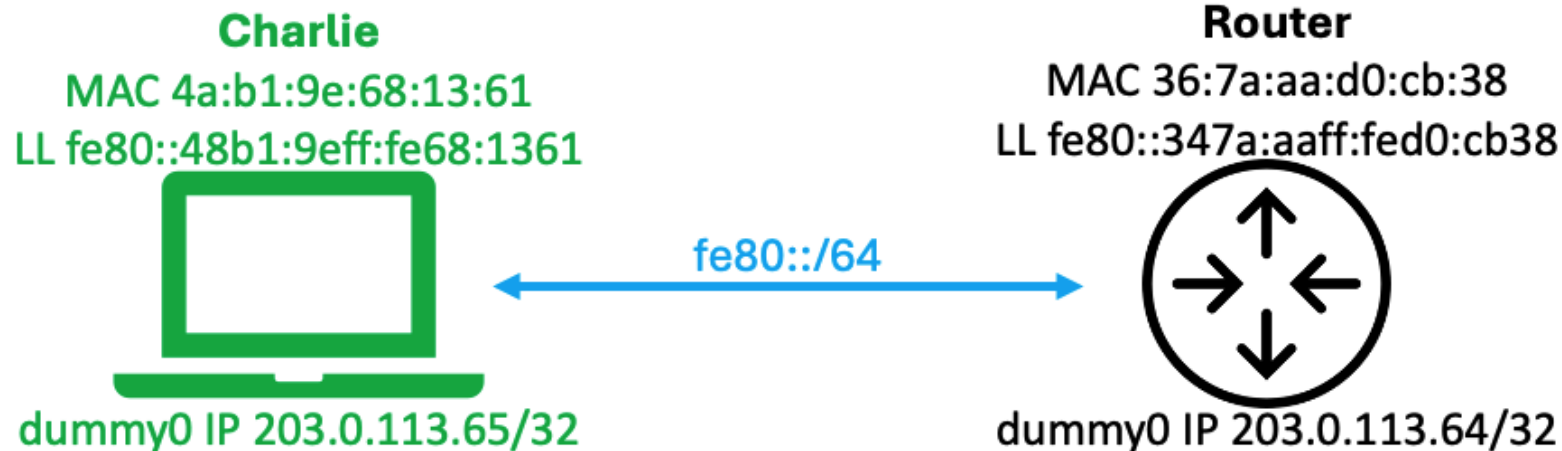
```
charlie@charlie:~# ip -4 route add 0.0.0.0/0 via inet6 \
```

```
    fe80::347a:aaff:fed0:cb38 dev from_charlie src 203.0.113.65
```

```
charlie@charlie:~# ip -4 route
```

```
default via inet6 fe80::347a:aaff:fed0:cb38 dev from_charlie src 203.0.113.65
```


Host route na zařízení „Router“



```
operator@router:~# ip route | grep 203.0.113.65
```

```
203.0.113.65 dev to_charlie scope link
```

```
operator@router:~# arp -n | grep 203.0.113.65 # (arp_ignore == 0)
```

```
203.0.113.65 ether 4a:b1:9e:68:13:61 C to_charlie
```

```
10:19:01.537002 ARP, Request who-has 203.0.113.65 tell 203.0.113.64, length 28
```

```
10:19:01.537006 ARP, Reply 203.0.113.65 is-at 4a:b1:9e:68:13:61, length 28
```

IPv6 next-hop na zařízení „Router“

```
operator@router:~# ip route add 203.0.113.65 via inet6 \  
                fe80::48b1:9eff:fe68:1361 dev to_charlie
```

```
operator@router:~# ip route | grep 203.0.113.65  
203.0.113.65 via inet6 fe80::48b1:9eff:fe68:1361 dev to_charlie
```

```
10:21:29.516907 IP6 fe80::347a:aaff:fed0:cb38 > ff02::1:ff68:1361: ICMP6,  
neighbor solicitation, who has fe80::48b1:9eff:fe68:1361  
10:21:29.516914 IP6 fe80::48b1:9eff:fe68:1361 > fe80::347a:aaff:fed0:cb38:  
ICMP6, neighbor advertisement, tgt is fe80::48b1:9eff:fe68:1361
```

```
charlie@charlie:~# ip -6 neigh  
fe80::347a:aaff:fed0:cb38 dev from_charlie lladdr 36:7a:aa:d0:cb:38 router  
REACHABLE
```

IPv6 Neighbor Discovery, IPv4 provoz

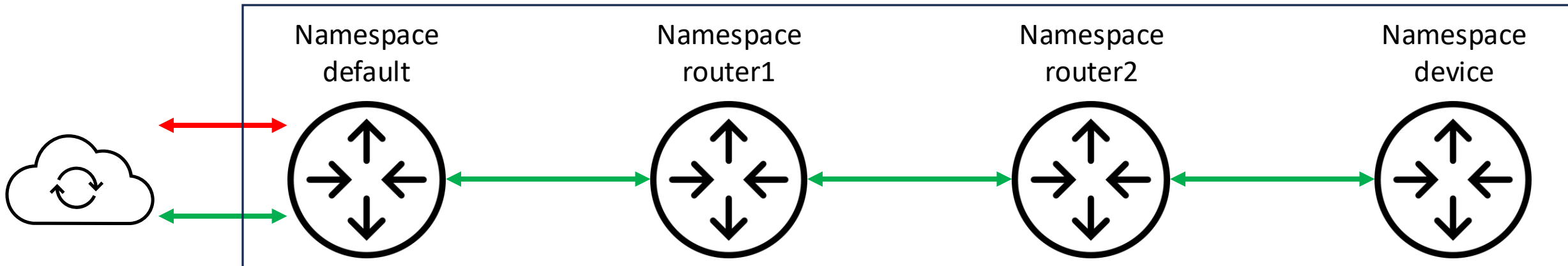
Source	Destination	Info
fe80::48b1:9eff:fe68:...	ff02::1:ff00::cb38	Neighbor Solicitation for fe80::347a:aaff:fed0:cb38 from 4a:b1:9e:68:13:61
fe80::347a:aaff:fed0:...	fe80::48b1:9eff:fe68:1361	Neighbor Advertisement fe80::347a:aaff:fed0:cb38 (rtr, sol, ovr) is at 36:7a:aa:d0:cb:38
203.0.113.65	8.8.8.8	Echo (ping) request id=0x22cf, seq=1/256, ttl=64 (reply in 4)
8.8.8.8	203.0.113.65	Echo (ping) reply id=0x22cf, seq=1/256, ttl=118 (request in 3)
203.0.113.65	8.8.8.8	Echo (ping) request id=0x22cf, seq=2/512, ttl=64 (reply in 6)
8.8.8.8	203.0.113.65	Echo (ping) reply id=0x22cf, seq=2/512, ttl=118 (request in 5)
203.0.113.65	8.8.8.8	Echo (ping) request id=0x22cf, seq=3/768, ttl=64 (reply in 8)
8.8.8.8	203.0.113.65	Echo (ping) reply id=0x22cf, seq=3/768, ttl=118 (request in 7)

```
> Frame 3: 98 bytes on wire (784 bits), 98 bytes captured (784 bits)
< Ethernet II, Src: 4a:b1:9e:68:13:61 (4a:b1:9e:68:13:61), Dst: 36:7a:aa:d0:cb:38 (36:7a:aa:d0:cb:38)
  > Destination: 36:7a:aa:d0:cb:38 (36:7a:aa:d0:cb:38)
  > Source: 4a:b1:9e:68:13:61 (4a:b1:9e:68:13:61)
  Type: IPv4 (0x0800)
> Internet Protocol Version 4, Src: 203.0.113.65, Dst: 8.8.8.8
> Internet Control Message Protocol
```

IPv6 a IPv4 next-hopy lze kombinovat

```
root@router:~# ip route | egrep '(default|203.0.113.65) '  
default dev ppp0 scope link metric 9  
default via 192.0.2.1 dev wan1 metric 10  
203.0.113.65 via inet6 fe80::48b1:9eff:fe68:1361 dev to_charlie
```

Chained routers using IPv6 next hops: Hetzner VM

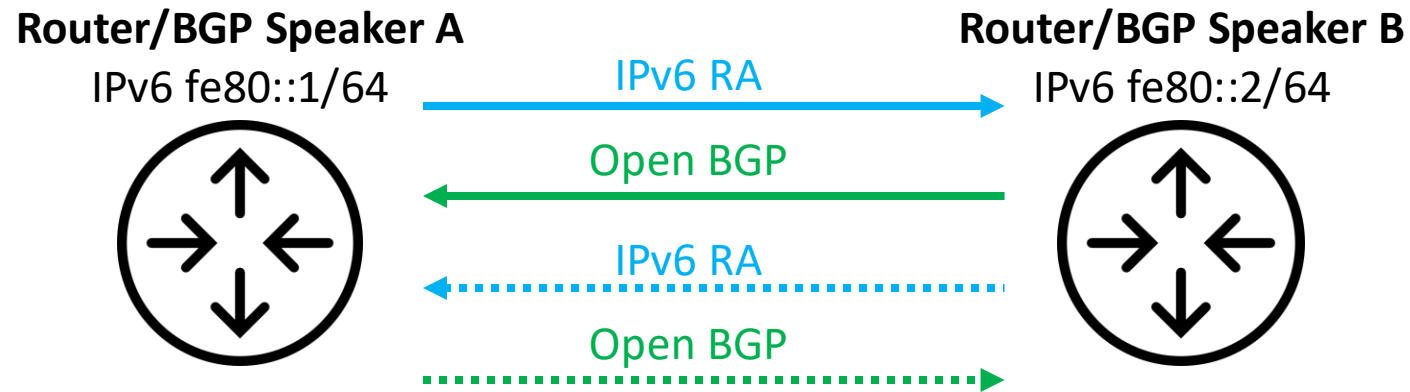


```
7. |-- spine15.cloud2.fsn1.hetzner.com (2a01:4f8:0:3::5bd)
8. |-- spine3.cloud2.fsn1.hetzner.com (2a01:4f8:0:e172::a14e)
9. |-- ???
10. |-- 20371.your-cloud.host (2a01:4f8:0:e172::2635)
11. |-- 2a01:4f8:1c17:7039::1 # default
12. |-- 2a01:4f8:1c17:7039::1:2 # router1
13. |-- 2a01:4f8:1c17:7039::2:2 # router2
14. |-- 2a01:4f8:1c17:7039::4:1 # device
7. |-- spine16.cloud2.fsn1.hetzner.com (213.239.227.221)
8. |-- spine3.cloud2.fsn1.hetzner.com (213.239.239.154)
9. |-- ???
10. |-- 20371.your-cloud.host (49.12.26.24)
11. |-- ??? # default
12. |-- ??? # router1
13. |-- ??? # router2
14. |-- 188.245.88.112 # device
```

Demo time?

BGP

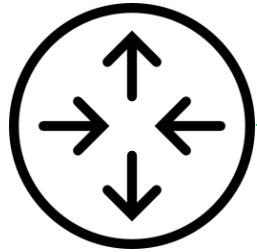
BGP Unnumbered



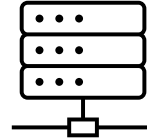
- Pro komunikaci protokolu BGP se používají IPv6 link-local adresy místo globálních adres
- Router A vyšle IPv6 router advertisement
- Router B zaslechne IPv6 router advertisement a nakonfiguruje s adresou, ze které přišel RA, BGP session
- Bird umí fungovat pouze v roli Router A (vysílá RA), ale už ne v roli Router B (naslouchá/čeká na RA a sestaví BGP)
- Arista umí fungovat v roli Router B i Router A

Adresní plán

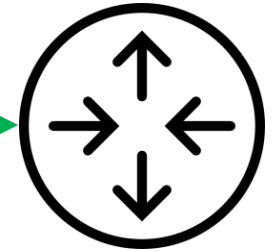
Et1/1: 2001:db8:dead::**Z:2**/127
Lo0: 198.51.100.1/32



dummy0
 2001:db8:dead::**Z:1**/128
 198.51.100.**Y**/32



Et1/1: 2001:db8:dead::**Z:4**/127
Lo0: 198.51.100.1/32



uplink1
 2001:db8:dead::**Z:3**/127

uplink2
 2001:db8:dead::**Z:5**/127

Adresa	Použití
2001:db8:dead:: Z:1 /128	IPv6 Loopback na serveru
2001:db8:dead:: Z:2 /127	L3 interface na první Aristě
2001:db8:dead:: Z:3 /127	Uplink1 interface na serveru
2001:db8:dead:: Z:4 /127	L3 interface na druhé Aristě
2001:db8:dead:: Z:5 /127	Uplink2 interface na serveru
198.51.100.Y/32	IPv4 Loopback na serveru
198.51.100.1/32	IPv4 Loopback0 na první Aristě
198.51.100.2/32	IPv4 Loopback0 na druhé Aristě (ip address unnumbered Loopback0)

Konfigurace sítě na serveru

```
uplink1: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500  
link/ether 1c:34:da:56:3a:d0 brd ff:ff:ff:ff:ff:ff  
inet6 2001:db8:dead::z:3/127 scope global  
inet6 fe80::f8a8:96ff:febe:58b0/64 scope link
```

```
uplink2: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500  
link/ether 1c:34:da:56:3a:d1 brd ff:ff:ff:ff:ff:ff  
inet6 2001:db8:dead::z:5/127 scope global  
inet6 fe80::1e34:daff:fe56:3ad1/64 scope link
```

```
dummy0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500  
inet 198.51.100.Y/32 scope global dummy0  
inet6 2001:db8:dead::z:1/128 scope global
```

Konfigurace sítě na serveru

```
$ ip route
```

```
default proto bird src 198.51.100.Y metric 32
```

```
    nexthop via inet6 fe80::d089:20ff:fe64:f39a dev uplink1 weight 1
```

```
    nexthop via inet6 fe80::5001:68ff:fef4:170e dev uplink2 weight 1
```

```
$ ip -6 route
```

```
::1 dev lo proto kernel metric 256 pref medium
```

```
2001:db8:dead::Z:1 dev dummy0 proto kernel metric 256 pref medium
```

```
2001:db8:dead::Z:2/127 dev uplink1 proto kernel metric 256 pref medium
```

```
2001:db8:dead::Z:4/127 dev uplink2 proto kernel metric 256 pref medium
```

```
fe80::/64 dev dummy0 proto kernel metric 256 pref medium
```

```
fe80::/64 dev uplink2 proto kernel metric 256 pref medium
```

```
fe80::/64 dev uplink1 proto kernel metric 256 pref medium
```

```
default proto bird src 2001:db8:dead::Z:1 metric 32 pref medium
```

```
    nexthop via fe80::d089:20ff:fe64:f39a dev uplink1 weight 1
```

```
    nexthop via fe80::5001:68ff:fef4:170e dev uplink2 weight 1
```

```
default via 2001:db8:dead::Z:2 dev uplink1 proto static metric 100
```

```
default via 2001:db8:dead::Z:4 dev uplink2 proto static metric 200
```

Bird

```
router id 198.51.100.Y;
```

```
protocol device {  
    scan time 10;  
}
```

```
# Direct, IPv4
```

```
protocol direct {
```

```
    ipv4;
```

```
# Connect to default IPv4 table
```

```
    interface "dummy*";
```

```
}
```

```
# Direct, IPv4
```

```
protocol direct {
```

```
    ipv6;
```

```
# ... and to default IPv6 table
```

```
    interface "dummy*";
```

```
}
```

Bird

```
router id 198.51.100.Y;
```

```
# Kernel, IPv4
protocol kernel {
    ipv4 {
        export filter {
            krt_prefsrc = 198.51.100.Y;
            if (source = RTS_BGP) then accept;
            reject;
        };
        import none;
    };
    persist;
    scan time 20;
    merge paths on;      # Add multipath to route to kernel e.g. for ECMP egress
}
```

Bird

```
router id 198.51.100.Z;
```

```
# Kernel, IPv6
protocol kernel {
    ipv6 {
        export filter {
            krt_prefsrc = 2001:db8:dead::Z:1;
            if (source = RTS_BGP) then accept;
            reject;
        };
        import none;
    };
    persist;
    scan time 20;
    merge paths on;      # Add multipath to route to kernel e.g. for ECMP egress
}
```


Bird

```
# BGP to advertise the loopback (dummy) addresses
template bgp spine {
    direct;
    # ...
    dynamic name "uplink";
    local as 4200000000;
    # IP unnumbered, using router advertisements to tell Aristas we're a router
    neighbor range fe80::/64 as 64511;
    # (...)
    ipv4 {
        extended next hop;
        import all;
        export filter {
            if (net.len = 32 && source = RTS_DEVICE) then accept;
            reject;
        };
    };
    # (...)
}
```

Bird

```
# BGP to advertise the loopback (dummy) addresses
# (... continuing)
  ipv6 {
    import all;
    export filter {
      if (net.len = 128 && source = RTS_DEVICE) then accept;
      reject;
    };
  };
}

protocol bgp spine1 from spine {
  interface "uplink1";
}

protocol bgp spine2 from spine {
  interface "uplink2";
}
```

Bird

```
# This is necessary for the unnumbered BGP sessions to work
# Aristas wait for the RA and then initiate connection to us
protocol radv {
    propagate routes no;
    ipv6 {
        import none;
        export none;
    };
    interface "uplink*" {
        max ra interval 15;
    };
}
```

Arista – L3 port

```
ipv6 dhcp relay option link-layer address
```

```
interface Ethernet1/1
  description aristaX-server1
  no switchport
  ip proxy-arp
  ip address unnumbered Loopback0
  ipv6 dhcp relay destination 2001:db8:babe::2
  ipv6 address 2001:db8:dead::Z:X/127
  ipv6 nd ra mtu suppress
  ipv6 nd managed-config-flag
  ipv6 nd reachable-time 900000
  ipv6 nd prefix 2001:db8:dead::Z:X/127 no-onlink no-autoconfig
```

```
interface Loopback0
  ip address 198.51.100.1/32
  ipv6 address 2001:db8:dead::1/128
```

Arista

```
router bgp 64511
  neighbor SERVERS peer group
  neighbor SERVERS remove-private-as
  neighbor SERVERS graceful-restart
  neighbor interface Et1/1 peer-group SERVERS remote-as 4200000000
  !
  address-family ipv4
    neighbor SERVERS activate
    neighbor SERVERS default-originate always
    neighbor SERVERS next-hop address-family ipv6 originate
  !
  address-family ipv6
    neighbor SERVERS activate
    neighbor SERVERS default-originate always
  !
```

Arista

```
# sh ip bgp summary | include fe80::f8a8:96ff:febe:58b0
fe80::f8a8:96ff:febe:58b0%Et1/1 4 4200000000 0 0 42d17h Estab 1 1
```

```
# show ipv6 bgp peers fe80::f8a8:96ff:febe:58b0%Et1/1 received-routes
BGP routing table information for VRF default
Router identifier 198.51.100.1, local AS number 64511
```

	Network	Next Hop	Path
* >	198.51.100.Z /32	fe80::f8a8:96ff:febe:58b0%Et1/1	4200000000 i
* >	2001:db8:dead::Z:1 /128	fe80::f8a8:96ff:febe:58b0%Et1/1	4200000000 i

Q & A



linkedin.com/in/radek-zajic/



@zajDee