Configuring Multihome Networking on VM Hosts

WHAT?

This article explains how to configure multihome networking on a SUSE Linux Enterprise Server VM host using the strong host model.

WHY?

Switching from the default weak host model to the strong host model improves security and network reliability in multihome environments.

EFFORT

The setup takes about 20 minutes. Allow up to an hour to fully understand the VM host and multihome networking concepts.

GOAL

Gain a basic understanding of how to configure VM host networking and multihome settings.

REQUIREMENTS

Access to a machine that serves as the VM host

Basic understanding of networking and IP addresses

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Contents

1 Network topology

The network topology in this setup includes three virtual machines: `vm7`, `vm8`, `vm9` and one uplink router `gw1`.

- The `vm7` VM acts as a router between an uplink router `gw1` and the external network (192.168.7.0/24) of `vm8` and `vm9`. The configuration of the `vm7 uplink` is not relevant for this setup.
- The `vm8` and `vm9` have an uplink in the external network (192.168.7.0/24) with `vm7` as a router and are connected to two private networks (192.168.8.0/24 and 192.168.9.0/24).

```
    gw1 (1)
             |
          ---+----       net1: 192.168.1.0/24 on eth1/enp1s0
             |           [uplink network: not relevant here]
           vm7 (107)
             |
      --+-----+-----+--   net7: 192.168.7.0/24 on eth7/enp7s0
        |           |
(108) vm8         vm9 (109)
       | |         | |
       | +---------+ |    net8: 192.168.8.0/24 on eth8/enp8s0
       +-------------+    net9: 192.168.9.0/24 on eth9/enp9s0
```

2 Checking the VM host network configuration

The following procedure outlines the steps for setting up a VM host.

The VM host has four bridges involved in the setup.

When the VM host is on a productive network with IP connectivity independent of the test networks, there is no IP configured on any of these bridges, including `net1`. However, you can use the same network service as the host, such as DHCP on `net1`.

The `net1` bridge contains an uplink port `eth1` providing access to an external test/LAN network for the `vm7` router VM.

PROCEDURE 1: SETTING UP VM HOST

1. Check the configuration of the `ifcfg-net1` bridge:

```
$ cat /etc/sysconfig/network/ifcfg-net1

  STARTMODE='auto'
```

```
BOOTPROTO='none'
LINK_REQUIRED=no
BRIDGE='yes'
BRIDGE_STP='off'
BRIDGE_FORWARDDELAY='0'
BRIDGE_PORTS='eth1'
```

2. The `net7`, `net8` and `net9` are host-only bridges that have only dynamic VM ports, specific and relevant for this setup. To view the `net7` network settings, run:

```
$ cat /etc/sysconfig/network/ifcfg-net7

  STARTMODE='auto'
  BOOTPROTO='none'
  LINK_REQUIRED=no
  LLADDR=66:00:00:00:00:07
  BRIDGE='yes'
  BRIDGE_STP='off'
  BRIDGE_FORWARDDELAY='0'
  BRIDGE_PORTS=''
```

3. View the `ifcfg-net8` network settings:

```
$ cat /etc/sysconfig/network/ifcfg-net8

  STARTMODE='auto'
  BOOTPROTO='none'
  LINK_REQUIRED=no
  LLADDR=66:00:00:00:00:08
  BRIDGE='yes'
  BRIDGE_STP='off'
  BRIDGE_FORWARDDELAY='0'
  BRIDGE_PORTS=''
```

4. View the `ifcfg-net9` network settings:

```
$ cat /etc/sysconfig/network/ifcfg-net9

  STARTMODE='auto'
  BOOTPROTO='none'
  LINK_REQUIRED=no
  LLADDR=66:00:00:00:00:09
  BRIDGE='yes'
  BRIDGE_STP='off'
  BRIDGE_FORWARDDELAY='0'
  BRIDGE_PORTS=''
```

3 Checking the VM network configuration

The following procedure outlines how the network of a VM host must be configured.

Configuration of the VM network shown in this document uses a so-called tweaked assignment of the IP, MAC and interface names. Every packet uses identical VM identification, just like packet captures. The following list shows the IP addresses for VMs on each network:

- net1
  vm7: no relevant uplink
- net7
  - vm7: 192.168.7.107 52:54:00:00:07:07 (eth7/enp7s0)
  - vm8: 192.168.7.108 52:54:00:00:07:08 (eth7/enp7s0)
  - vm9: 192.168.7.109 52:54:00:00:07:09 (eth7/enp7s0)
- net8
  - vm8: 192.168.8.108 52:54:00:00:08:08 (eth8/enp8s0)
  - vm9: 192.168.8.109 52:54:00:00:08:09 (eth8/enp8s0)
- net9
  - vm8: 192.168.9.108 52:54:00:00:09:08 (eth9/enp9s0)
  - vm9: 192.168.9.109 52:54:00:00:09:09 (eth9/enp9s0)

PROCEDURE 2: CONFIGURE VIRTUAL MACHINES

1. Set up vm7.
   This setup uses `SLES 15 SP7`, with the VM acting as a router: it connects to the external network through the `eth1` uplink (for example, assigned to an external firewalld zone for masquerading) and to the `common` test network `net7`, which serves as the uplink for the other VMs. `vm7` has no connection to the `private`, `net8` and `net9` networks.

   a. View the IP address:

      ```
      ip a s
      [...]
      2: eth1: >BROADCAST,MULTICAST,UP,LOWER_UP< mtu 1500 qdisc pfifo_fast state UP
       group default qlen 1000
      ```

```
    link/ether 52:54:00:00:01:07 brd ff:ff:ff:ff:ff:ff
    altname enp1s0
    inet 192.168.1.107/24 brd 192.168.1.255 scope global eth1
       valid_lft forever preferred_lft forever
3: eth7: >BROADCAST,MULTICAST,UP,LOWER_UP< mtu 1500 qdisc pfifo_fast state UP
 group default qlen 1000
    link/ether 52:54:00:00:07:07 brd ff:ff:ff:ff:ff:ff
    altname enp7s0
    inet 192.168.7.107/24 brd 192.168.7.255 scope global eth7
       valid_lft forever preferred_lft forever
```

b. View the routing table:

```
default via 192.168.1.1 dev eth1
192.168.1.0/24 dev eth1 proto kernel scope link src 192.168.1.107
192.168.7.0/24 dev eth7 proto kernel scope link src 192.168.7.107
```

c. In `/etc/sysctl.d/90-network.conf`, set the following value to `1` to ensure this machine acts as a router:

```
net.ipv4.conf.all.forwarding = 1
```

2. Set up `vm8`.
This configuration runs on `SLES 15 SP7`, using `eth7` as the network uplink and including interfaces for two private networks: `net8` and `net9`.

a. View the IP address:

```
>
  ip a s
3: eth7: >BROADCAST,MULTICAST,UP,LOWER_UP< mtu 1500 qdisc pfifo_fast state UP
 group default qlen 1000
    link/ether 52:54:00:00:07:08 brd ff:ff:ff:ff:ff:ff
    altname enp7s0
    inet 192.168.7.108/24 brd 192.168.7.255 scope global eth7
       valid_lft forever preferred_lft forever
4: eth8: >BROADCAST,MULTICAST,UP,LOWER_UP< mtu 1500 qdisc pfifo_fast state UP
 group default qlen 1000
    link/ether 52:54:00:00:08:08 brd ff:ff:ff:ff:ff:ff
    altname enp8s0
    inet 192.168.8.108/24 brd 192.168.8.255 scope global eth8
       valid_lft forever preferred_lft forever
5: eth9: >BROADCAST,MULTICAST,UP,LOWER_UP< mtu 1500 qdisc pfifo_fast state UP
 group default qlen 1000
    link/ether 52:54:00:00:09:08 brd ff:ff:ff:ff:ff:ff
    altname enp9s0
```

```
    inet 192.168.9.108/24 brd 192.168.9.255 scope global eth9
       valid_lft forever preferred_lft forever
```

b. View the network routes

```
> ip r s
      default via 192.168.7.107 dev eth7
192.168.7.0/24 dev eth7 proto kernel scope link src 192.168.7.108
192.168.8.0/24 dev eth8 proto kernel scope link src 192.168.8.108
192.168.9.0/24 dev eth9 proto kernel scope link src 192.168.9.108
```

c. Set the following value in `/etc/sysctl.d/90-network.conf` to `0` to ensure that the machine acts as a host.

```
net.ipv4.conf.all.forwarding = 0
```

3. Set up `vm9`.
   This configuration runs on `SLES 16.0`, using `eth7` as the network uplink and connecting to two private networks: `net8` and `net9`.

a. View the IP address:

```
> ip a s
3: enp7s0: >BROADCAST,MULTICAST,UP,LOWER_UP< mtu 1500 qdisc pfifo_fast state
 UP group default qlen 1000
    link/ether 52:54:00:00:07:09 brd ff:ff:ff:ff:ff:ff
    altname enx525400a8076d
    inet 192.168.7.109/24 brd 192.168.7.255 scope global noprefixroute enp7s0
       valid_lft forever preferred_lft forever
4: enp8s0: >BROADCAST,MULTICAST,UP,LOWER_UP< mtu 1500 qdisc pfifo_fast state
 UP group default qlen 1000
    link/ether 52:54:00:00:08:09 brd ff:ff:ff:ff:ff:ff
    altname enx525400a8086d
    inet 192.168.8.109/24 brd 192.168.8.255 scope global noprefixroute enp8s0
       valid_lft forever preferred_lft forever
5: enp9s0: >BROADCAST,MULTICAST,UP,LOWER_UP< mtu 1500 qdisc pfifo_fast state
 UP group default qlen 1000
    link/ether 52:54:00:00:09:09 brd ff:ff:ff:ff:ff:ff
    altname enx525400a8096d
    inet 192.168.9.109/24 brd 192.168.9.255 scope global noprefixroute enp9s0
       valid_lft forever preferred_lft forever
```

b. View the network routes:

```
>
```

```
ip r s

default via 192.168.7.107 dev enp7s0 proto static metric 100
192.168.7.0/24 dev enp7s0 proto kernel scope link src 192.168.7.109 metric
 100
192.168.8.0/24 dev enp8s0 proto kernel scope link src 192.168.8.109 metric
 101
192.168.9.0/24 dev enp9s0 proto kernel scope link src 192.168.9.109 metric 102
```

c. Set the following value in `/etc/sysctl.d/90-network.conf` to `0` to ensure that the machine acts as a host.

```
net.ipv4.conf.all.forwarding = 0
```

4 IP **sysctl** settings for the multihome host

System-level networking parameters in Linux are stored in `/proc/sys/net/` and can be managed using the **`sysctl`** command or by modifying configuration files.

4.1 The **sysctl** command variables

The **`sysctl`** variables offered by the Linux kernel are documented here (https://www.kernel.org/doc/Documentation/networking/ip-sysctl.txt).

The following `net.ipv4.conf.all.arp_*` variables affect the `arp` behavior on a multihome host.

`arp_announce = 0`

- Define different restriction levels for announcing the local source IP address from IP packets in ARP requests sent on the interface:

  1. `0` (default) Use any local address, configured on any interface.

  2. `1` Try to avoid local addresses that are not in the target's subnet for this interface. This mode is useful when target hosts reachable via this interface require the source IP address in ARP requests to be part of their logical network configured on the receiving interface. When gen-

erating the request, all subnets that include the target IP are checked. If such a subnet exists, the source address is preserved. Otherwise, the source address is selected according to the rules for level 2.

3. `2` Always use the best local address for this target. In this mode, the source address in the IP packet is ignored, and the preferred local address is selected from the outgoing interface that includes the target IP address. If no suitable address is found, the first local address on the outgoing interface or other interfaces is used, hoping to receive a reply.

The max value from `conf/{all,interface}/arp_announce` is used.
Increasing the restriction level gives a better chance of receiving an answer from the resolved target, while decreasing the level announces more valid sender information.

- `aarp_ignore = 0`
  Define different modes for sending replies in response to received ARP requests that resolve local target IP addresses:

1. `0` (default) Reply to requests for any local target IP address, configured on any interface.

2. `1` Reply only if the target IP address is configured on the incoming interface.

3. `2` Reply only if the target IP address is configured on the incoming interface and both it and the sender's IP address are in the same subnet on this interface.

4. `3`Do not reply to requests for local addresses configured with scope host; only resolutions for global and link addresses are replied.

5. `4–7` Reserved.

6. `8`Do not reply to requests for any local address.

The max value from `conf/{all,interface}/arp_ignore` is used when ARP requests are received on the {interface}.

- `arp_filter = 0`

Controls ARP response behavior for interfaces on the same subnet:

1. `0` (default) The kernel can respond to ARP requests with addresses from other interfaces. This increases the chance of successful communication. IP addresses are owned by the complete host on Linux, not by particular interfaces. In more complex setups like load-balancing, this behavior can cause problems.

2. `1` Each interface responds only if the kernel would route the packet through it. Requires source-based routing and ensures ARP replies are interface-specific.

`arp_filter` for the interface will be enabled if at least one of `conf/{all,interface}/arp_filter` is set to TRUE; otherwise it is disabled.

Additionally, the `net.ipv4.conf.all.rp_filter` settings permit filtering of L3 / IPv4 packets using reverse routing table lookups:

- `rp_filter = 0`
  Modes for source validation:

  1. `0` No source validation.

  2. `1` Strict mode (RFC3704). Each incoming packet is tested against the FIB. If the interface is not the best reverse path, the packet check fails, and the packet is discarded.

  3. `2` Loose mode (RFC3704). Each incoming packet's source address is tested against the FIB, and if it is not reachable via any interface, the packet check fails.

  Current recommended practice in RFC3704 is to enable strict mode to prevent IP spoofing from DDoS attacks. If using asymmetric routing or other complicated routing, loose mode is recommended.
  The max value from `conf/{all,interface}/rp_filter` is used when doing source validation on the interface.
  The default value is `0`. Note that some distributions enable it in startup scripts.

On SUSE systems, `net.ipv4.conf.all.rp_filter = 2` (RFC3704 Loose Reverse Path) is enabled by default instead of the kernel default to disable it (`rp_filter = 0`). Unlike the strict `rp_filter = 1` mode, `rp_filter = 2` permits asymmetric routing, using the same subnet on multiple interfaces (considers `arp_announce=0`, `arp_ignore=0` and `arp_filter=0` defaults).

The `net.ipv4.conf.all.log_martians` enables logging of packets filtered/dropped by `rp_filter`:

```
log_martians = 0
```

This logs packets with impossible addresses to the kernel log. The `log_martians` setting for an interface will be enabled if at least one of `conf/{all,interface}/log_martians` is set to `TRUE`. Otherwise, it will be disabled.

5 Default behavior

Linux uses a weak host model (https://en.wikipedia.org/wiki/Host_model) as default, configurable via IP-Sysctl settings offered by the kernel.

In this model, an IP address belongs to the machine and is not restricted to being used only on the interface it is assigned to. The machine can use/associate any interface MAC address with any IP address, regardless of the interface.

The following procedures describe the default behavior using vm7, vm8, and vm9.

PROCEDURE 3: DEFAULT BEHAVIOR

1. vm7

   This VM acts as a router in `net7` and even though it is not connected to `net8` and `net9`, it is still involved in the ARP resolution process.

   The following ping commands illustrate the default behavior:

   ```
   vm7:~ ping -c 1 192.168.7.108: reply (regular)
   ```

   Regular pinging of an IP on a directly connected network (network route) triggers a routing table lookup that selects the `eth7` interface and the preferred source from the route (src 192.168.7.107):

   ```
   192.168.7.0/24 dev eth7 proto kernel scope link src 192.168.7.107
   ```

   Output:

   ```
     PING 192.168.7.108 (192.168.7.108) 56(84) bytes of data.
     64 bytes from 192.168.7.108: icmp_seq=1 ttl=64 time=0.446 ms

     --- 192.168.7.108 ping statistics ---
     1 packets transmitted, 1 received, 0% packet loss, time 0ms
     rtt min/avg/max/mdev = 0.446/0.446/0.446/0.000 ms

   - capture (net7):

   No.     Time           Source                Destination           Protocol Length
    Info
   ```

```
       1 0.000000000    52:54:00:00:07:07     Broadcast             ARP      42
Who has 192.168.7.108? Tell 192.168.7.107
       2 0.000178399    52:54:00:00:07:08     52:54:00:00:07:07     ARP      42
192.168.7.108 is at 52:54:00:00:07:08
       3 0.000261527    192.168.7.107         192.168.7.108         ICMP     98
Echo (ping) request  id=0x0001, seq=1/256, ttl=64 (reply in 4)
       4 0.000334225    192.168.7.108         192.168.7.107         ICMP     98
Echo (ping) reply    id=0x0001, seq=1/256, ttl=64 (request in 3)
       5 5.180898743    52:54:00:00:07:08     52:54:00:00:07:07     ARP      42
Who has 192.168.7.107? Tell 192.168.7.108
       6 5.181116066    52:54:00:00:07:07     52:54:00:00:07:08     ARP      42
192.168.7.107 is at 52:54:00:00:07:07
```

```
vm7:~ ping -c 1 192.168.7.109: reply (regular)
```

Same as `vm7:~ ping -c 1 192.168.7.108 (#vm7--ping--c-1-1921687108-reply)`.

```
vm7:~ ping -c 1 192.168.8.108: error (regular)
```

Regular pinging of an IP *outside* of a directly connected network causes the packet to be sent via the gateway (default) route. This uses the `eth1` interface with the source IP (`192.168.1.107`) from the preferred source in the route used to reach the gateway:

```
default via 192.168.1.1 dev eth1 192.168.1.0/24 dev eth1 proto kernel scope link src
 192.168.1.107
```

The result depends on the configuration of the uplink routers. If there is a `kind router` sending an `unreachable` ICMP message, for example, because of an `unreachable` route (on Linux, to avoid routing the packets to the Internet):

```
ip r s type unreachable
unreachable 192.168.0.0/16
```

or dropping the packets (because of a `blackhole` route entry or a firewall).
Output:

```
PING 192.168.8.108 (192.168.8.108) 56(84) bytes of data.

 --- 192.168.8.108 ping statistics ---
 1 packets transmitted, 0 received, 100% packet loss, time 0ms

 or:

 PING 192.168.8.108 (192.168.8.108) 56(84) bytes of data.
 From 192.168.1.1 icmp_seq=1 Destination Host Unreachable
```

```
  --- 192.168.8.108 ping statistics ---
  1 packets transmitted, 0 received, +1 errors, 100% packet loss, time 0ms

- capture (net1):
  - packet capture on net1 incl. unreachable message (if any):

  No.     Time           Source                Destination           Protocol Length
 Info

      131 1995.230774    192.168.1.107         192.168.8.108         ICMP     104
 Echo (ping) request  id=0x002a, seq=1/256, ttl=64 (no response found!)
      132 1995.231275    192.168.1.1           192.168.1.107         ICMP     132
 Destination unreachable (Host unreachable)
```

```
vm7:~ ping -c 1 192.168.8.109: error (regular)
```

Same as `vm7:~ # ping -c 1 192.168.8.108 (#vm7--ping--c-1-1921688108-error)`.

```
vm7:~ ping -c 1 192.168.9.108: error (regular)
```

Same as `vm7:~ # ping -c 1 192.168.8.108 (#vm7--ping--c-1-1921688108-error)`.

```
vm7:~ ping -c 1 192.168.9.109: error (regular)
```

Same as `vm7:~ # ping -c 1 192.168.8.108 (#vm7--ping--c-1-1921688108-error)`.

```
vm7:~ ping -I eth7 -c 1 192.168.8.108: reply (enforced)
```

Pinging an IP *outside* of a directly connected network, while enforcing the use of the specified `eth7` interface, is done instead of looking up the destination in the routing table to select an interface and source IP address. In other words, it ignores the routing table.
This causes the machine to resolve the MAC address of the machine having the IP address via ARP on the `eth7` interface and to use the primary IP address on this interface as the source IP. The destination machine has a route back to the source IP network and can deliver the reply.
Output:

```
  PING 192.168.8.108 (192.168.8.108) from 192.168.7.107 eth7: 56(84) bytes of data.
  64 bytes from 192.168.8.108: icmp_seq=1 ttl=64 time=0.431 ms

  --- 192.168.8.108 ping statistics ---
  1 packets transmitted, 1 received, 0% packet loss, time 0ms
  rtt min/avg/max/mdev = 0.431/0.431/0.431/0.000 ms
```

```
- capture:

  No.     Time           Source                Destination           Protocol Length
 Info
       55 1090.280252902 52:54:00:00:07:07     Broadcast             ARP      42
 Who has 192.168.8.108? Tell 192.168.7.107
       56 1090.280444897 52:54:00:00:07:08     52:54:00:00:07:07     ARP      42
 192.168.8.108 is at 52:54:00:00:07:08
       57 1090.280492377 192.168.7.107         192.168.8.108         ICMP     98
 Echo (ping) request  id=0x000c, seq=1/256, ttl=64 (reply in 58)
       58 1090.280553072 192.168.8.108         192.168.7.107         ICMP     98
 Echo (ping) reply    id=0x000c, seq=1/256, ttl=64 (request in 57)
       59 1095.512647002 52:54:00:00:07:08     52:54:00:00:07:07     ARP      42
 Who has 192.168.7.107? Tell 192.168.7.108
       60 1095.512893801 52:54:00:00:07:07     52:54:00:00:07:08     ARP      42
 192.168.7.107 is at 52:54:00:00:07:07

- arp-cache:

  192.168.8.108 dev eth7 lladdr 52:54:00:00:07:08 REACHABLE
  192.168.7.108 dev eth7 lladdr 52:54:00:00:07:08 REACHABLE

- strace:

  socket(AF_INET, SOCK_DGRAM, IPPROTO_ICMP) = 3
  setsockopt(3, SOL_SOCKET, SO_BINDTODEVICE, "eth7\0", 5) = 0
  sendto(3, "\10\0\2\371\377\377\0\1J\274sh\0\0\0\0j
\16\16\0\0\0\0\0\20\21\22\23\24\25\26\27"..., 64, 0, {sa_family=AF_INET, sin
  _port=htons(0), sin_addr=inet_addr("192.168.8.108")}, 16) = 64
  recvmsg(3, {msg_name={sa_family=AF_INET, sin_port=htons(0),
 sin_addr=inet_addr("192.168.8.108")}, msg_namelen=128 => 16, msg_i
  ov=[{iov_base="\0\0\n\346\0\23\0\1J\274sh\0\0\0\0j
\16\16\0\0\0\0\0\20\21\22\23\24\25\26\27"..., iov_len=192}], msg_iovlen=1, m
  sg_control=[{cmsg_len=32, cmsg_level=SOL_SOCKET, cmsg_type=SO_TIMESTAMP_OLD,
 cmsg_data={tv_sec=1752415306, tv_usec=921573}}, {
  cmsg_len=20, cmsg_level=SOL_IP, cmsg_type=IP_TTL, cmsg_data=[64]}],
 msg_controllen=56, msg_flags=0}, 0) = 64
  write(1, "64 bytes from 192.168.8.108: icm"..., 61) = 61
```

```
vm7:~ ping -I eth7 -c 1 192.168.8.109: reply (enforced)
```

Same as `vm7:~ # ping -I eth7 -c 1 192.168.8.108` (#vm7--ping--i-eth7--c-1-1921688108-reply).

```
vm7:~ ping -I eth7 -c 1 192.168.9.108: reply (enforced)
```

Same as `vm7:~ # ping -I eth7 -c 1 192.168.8.108` (#vm7--ping--i-eth7--c-1-1921688108-reply).

```
vm7:~ # ping -I eth7 -c 1 192.168.9.109: reply (enforced)
```

Same as `vm7:~ # ping -I eth7 -c 1 192.168.8.108` (#vm7--ping--i-eth7--c-1-1921688108-reply).

2. vm8

   In our setup, `vm8` and `vm9` behave the same way. See `vm9` (#vm9) for more details.

3. vm9

```
vm9:~ ping -c 1 192.168.7.107: reply (regular)
```

Regular pinging of an IP on a directly connected network (network route) triggers a routing table lookup that selects the `enp7s0` interface and the preferred source from the route (src 192.168.7.109):

```
192.168.7.0/24 dev enp7s0 proto kernel scope link src 192.168.7.109 metric 100
```

Output:

```
  PING 192.168.7.107 (192.168.7.107) 56(84) bytes of data.
  64 bytes from 192.168.7.107: icmp_seq=1 ttl=64 time=0.567 ms

  --- 192.168.7.107 ping statistics ---
  1 packets transmitted, 1 received, 0% packet loss, time 0ms
  rtt min/avg/max/mdev = 0.567/0.567/0.567/0.000 ms

- capture:

  No.     Time           Source                Destination           Protocol Length
 Info
        1 0.000000000    52:54:00:00:07:09     Broadcast             ARP      42
 Who has 192.168.7.107? Tell 192.168.7.109
        2 0.000356939    52:54:00:00:07:07     52:54:00:00:07:09     ARP      42
 192.168.7.107 is at 52:54:00:00:07:07
        3 0.000453833    192.168.7.109         192.168.7.107         ICMP     98
 Echo (ping) request  id=0x0006, seq=1/256, ttl=64 (reply in 4)
        4 0.000512905    192.168.7.107         192.168.7.109         ICMP     98
 Echo (ping) reply    id=0x0006, seq=1/256, ttl=64 (request in 3)
        5 23.564217607   52:54:00:00:07:07     52:54:00:00:07:09     ARP      42
 Who has 192.168.7.109? Tell 192.168.7.107
        6 23.564482951   52:54:00:00:07:09     52:54:00:00:07:07     ARP      42
 192.168.7.109 is at 52:54:00:00:07:09
```

```
- arp-cache:

  192.168.7.107 dev enp7s0 lladdr 52:54:00:00:07:07 REACHABLE
```

```
vm9:~ ping -c 1 192.168.7.108: reply (regular)
```

Same as `vm9:~ # ping -c 1 192.168.7.107(#vm9--ping--c-1-1921687107-reply)`.

```
vm9:~ ping -c 1 192.168.8.108: reply (regular)
```

Regular pinging of an IP on a directly connected network (network route) triggers a routing table lookup that selects the `enp8s0` interface and the preferred source from the route (src 192.168.8.109):

```
192.168.8.0/24 dev enp8s0 proto kernel scope link src 192.168.8.109 metric 101
```

Output:

```
PING 192.168.8.108 (192.168.8.108) 56(84) bytes of data.
  64 bytes from 192.168.8.108: icmp_seq=1 ttl=64 time=0.460 ms

  --- 192.168.8.108 ping statistics ---
  1 packets transmitted, 1 received, 0% packet loss, time 0ms
  rtt min/avg/max/mdev = 0.460/0.460/0.460/0.000 ms

- capture:

  No.     Time           Source                Destination           Protocol Length
 Info
        1 0.000000000    52:54:00:00:08:09     Broadcast             ARP      42
 Who has 192.168.8.108? Tell 192.168.8.109
        2 0.000155876    52:54:00:00:08:08     52:54:00:00:08:09     ARP      42
 192.168.8.108 is at 52:54:00:00:08:08
        3 0.000268681    192.168.8.109         192.168.8.108         ICMP     98
 Echo (ping) request  id=0x0008, seq=1/256, ttl=64 (reply in 4)
        4 0.000336540    192.168.8.108         192.168.8.109         ICMP     98
 Echo (ping) reply    id=0x0008, seq=1/256, ttl=64 (request in 3)
        5 5.109132370    52:54:00:00:08:08     52:54:00:00:08:09     ARP      42
 Who has 192.168.8.109? Tell 192.168.8.108
        6 5.109320257    52:54:00:00:08:09     52:54:00:00:08:08     ARP      42
 192.168.8.109 is at 52:54:00:00:08:09

- arp-cache:

  192.168.8.108 dev enp8s0 lladdr 52:54:00:00:08:08 REACHABLE
```

```
vm9:~ ping -c 1 192.168.9.108: reply (regular)
```

```
Regular pinging of an IP on a directly connected network (network route) and using
a lookup of the destination IP via routing table causing to select the enp9s0
interface and the preferred source from the route (src 192.168.9.109):
```

Output:

```
 PING 192.168.9.108 (192.168.9.108) 56(84) bytes of data.
  64 bytes from 192.168.9.108: icmp_seq=1 ttl=64 time=0.488 ms

  --- 192.168.9.108 ping statistics ---
  1 packets transmitted, 1 received, 0% packet loss, time 0ms
  rtt min/avg/max/mdev = 0.488/0.488/0.488/0.000 ms

- capture:

  No.     Time           Source                Destination           Protocol Length
 Info
        1 0.000000000    52:54:00:00:09:09     Broadcast             ARP      42
 Who has 192.168.9.108? Tell 192.168.9.109
        2 0.000212864    52:54:00:00:09:08     52:54:00:00:09:09     ARP      42
 192.168.9.108 is at 52:54:00:00:09:08
        3 0.000302044    192.168.9.109         192.168.9.108         ICMP     98
 Echo (ping) request  id=0x0009, seq=1/256, ttl=64 (reply in 4)
        4 0.000364673    192.168.9.108         192.168.9.109         ICMP     98
 Echo (ping) reply    id=0x0009, seq=1/256, ttl=64 (request in 3)
        5 5.157113256    52:54:00:00:09:08     52:54:00:00:09:09     ARP      42
 Who has 192.168.9.109? Tell 192.168.9.108
        6 5.157392878    52:54:00:00:09:09     52:54:00:00:09:08     ARP      42
 192.168.9.109 is at 52:54:00:00:09:09

- arp-cache:

  192.168.9.108 dev enp9s0 lladdr 52:54:00:00:09:08 REACHABLE
```

```
vm9:~ # ping -I enp9s0 -c 1 192.168.8.108: reply (enforced)
```

Pinging an IP address while *binding* the ping to the specified `enp9s0` interface is done instead of looking up the destination in the routing table. In other words, it ignores the routing table.
This causes the machine to resolve the MAC address of the machine having the IP address via ARP on the `enp9s0` interface and to use the primary IP address (`192.168.9.109`) as the source.

The destination machine answers with the MAC address of `enp8s0` on `enp9s0`, causing an additional MAC and IP ARP association in caches, and sends the ICMP echo reply using the same interface as in the request.
Output:

```
PING 192.168.8.108 (192.168.8.108) from 192.168.9.109 enp9s0: 56(84) bytes of data.
   64 bytes from 192.168.8.108: icmp_seq=1 ttl=64 time=0.895 ms

   --- 192.168.8.108 ping statistics ---
   1 packets transmitted, 1 received, 0% packet loss, time 0ms
   rtt min/avg/max/mdev = 0.895/0.895/0.895/0.000 ms

 - capture (net9):

   No.     Time           Source                Destination           Protocol
Length Info
        13 2139.146557619 52:54:00:00:09:09     Broadcast             ARP      42
  Who has 192.168.8.108? Tell 192.168.9.109
        14 2139.146934545 52:54:00:00:09:08     52:54:00:00:09:09     ARP      42
  192.168.8.108 is at 52:54:00:00:09:08
        15 2139.146993788 192.168.9.109         192.168.8.108         ICMP     98
  Echo (ping) request  id=0x0015, seq=1/256, ttl=64 (reply in 16)
        16 2139.147062178 192.168.8.108         192.168.9.109         ICMP     98
  Echo (ping) reply    id=0x0015, seq=1/256, ttl=64 (request in 15)
        17 2144.347165844 52:54:00:00:09:08     52:54:00:00:09:09     ARP      42
  Who has 192.168.9.109? Tell 192.168.9.108
        18 2144.347432020 52:54:00:00:09:09     52:54:00:00:09:08     ARP      42
  192.168.9.109 is at 52:54:00:00:09:09

 - arp-cache:
   (when used ping with/without interface binding multiple times)

   192.168.8.108 dev enp9s0 lladdr 52:54:00:00:09:08 REACHABLE
   192.168.8.108 dev enp8s0 lladdr 52:54:00:00:08:08 REACHABLE
```

```
vm9:~ ping -I enp8s0 -c 1 192.168.9.108: reply (enforced)
```

Same as `vm9:~ # ping -I enp9s0 -c 1 192.168.8.108 (#vm9--ping--i-enp9s0--c-1-1921688108-reply)`.
just binding the `enp8s0` interface to ping IP on `enp9s0`.

```
vm9:~ ping -I enp7s0 -c 1 192.168.9.108: error (regular)
```

Pinging an IP address bound/enforced to the specified `enp7s0` interface is done instead of looking up the destination in the routing table. In other words, it ignores the routing table.
Similar to `vm7:~ # ping -c 1 192.168.8.108 (#vm7--ping--c-1-1921688108-error)`, failing *regardless* of the interface binding because the router on the `enp7s0` interface does not have routing to the 192.168.9.0/24 network and routes the packet to the uplink.
Output (incl. unreachable error):

```
PING 192.168.9.108 (192.168.9.108) from 192.168.7.109 enp7s0: 56(84) bytes of data.
  From 192.168.1.1 icmp_seq=1 Destination Host Unreachable

  --- 192.168.9.108 ping statistics ---
  1 packets transmitted, 0 received, +1 errors, 100% packet loss, time 0ms

- capture (net7):

  No.     Time           Source                Destination           Protocol Length
 Info
       35 468.566259392  192.168.7.109         192.168.9.108         ICMP     98
 Echo (ping) request  id=0x000c, seq=1/256, ttl=64 (no response found!)
       36 471.671403634  192.168.1.1           192.168.7.109         ICMP     126
 Destination unreachable (Host unreachable)

- arp-cache: no entry (on enp7s0)
```

```
vm9:~ # ping -I enp7s0 -c 1 192.168.8.108: error (regular)
```

Same as `vm9:~ # ping -I enp7s0 -c 1 192.168.9.108 (#vm9--ping--i-enp7s0--c-1-1921689108-error)`.

6 Multihome setup

This section shows how to configure a multihome system using kernel ARP and reverse path filtering settings to control network traffic.

6.1 Setting up multihoming

The kernel's multihome ARP filtering is controlled by the following `sysctl` settings, which are typically placed in `/etc/sysctl.d/90-network.conf` config:

PROCEDURE 4: MULTIHOME SETUP

1. Mode for announcing local IP in requests:

   ```
   net.ipv4.conf.all.arp_announce = 2
   ```

2. Mode for sending replies to ARP requests:

   ```
   net.ipv4.conf.all.arp_ignore = 1
   ```

   or `higher` filtering levels (`arp_ignore = 2` if desired) on all involved machines `vm7`, `vm8`, `vm9`. The `rp_filter = 2` filtering of IP packets according to the route table matches is already set by SUSE by default to `rp_filter = 2`. When desired, in can be "increased" to stricter filtering using `rp_filter = 1`, but please note that this may cause packet drops, for example, in an asymmetric routing setup.

3. The following ping commands illustrate the multihome behavior and difference to the default behavior:

   a. vm7

      ```
      vm7:~ ping -c 1 192.168.7.108`: reply (regular)
      ```

      Same as default behavior (#vm7--ping--c-1-1921687108-reply).

      ```
      vm7:~ ping -c 1 192.168.7.109`: reply (regular)
      ```

      Same as default behavior (#vm7--ping--c-1-1921687108-reply).

      ```
      vm7:~ # ping -c 1 192.168.8.108`: error (regular)
      ```

      Same as default behavior (#vm7--ping--c-1-1921688108-error).

      ```
      vm7:~ # ping -c 1 192.168.8.109`: error (regular)
      ```

      Same as default behavior (#vm7--ping--c-1-1921688108-error).

      ```
      vm7:~ # ping -c 1 192.168.9.108`: error (regular)
      ```

Same as default behavior (#vm7--ping--c-1-1921688108-error).

```
vm7:~ # ping -c 1 192.168.9.109`: error (regular)
```

Same as default behavior (#vm7--ping--c-1-1921688108-error).

```
vm7:~ # ping -I eth7 -c 1 192.168.8.108`: error (filtered)
```

The multihome ARP settings cause the system to ignore ARP requests due to a subnet mismatch, and as a result, the enforcement via the `-I` interface binding no longer works.

Output:

```
PING 192.168.8.108 (192.168.8.108) from 192.168.7.107 eth7: 56(84) bytes of
 data.
From 192.168.7.107 icmp_seq=1 Destination Host Unreachable

--- 192.168.8.108 ping statistics ---
1 packets transmitted, 0 received, +1 errors, 100% packet loss, time 0ms

- capture:

No.     Time           Source                Destination           Protocol
 Length Info
     56 461.814511760  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.8.108? Tell 192.168.7.107
     57 462.819873108  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.8.108? Tell 192.168.7.107
     58 463.844043402  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.8.108? Tell 192.168.7.107
```

```
vm7:~ # ping -I eth7 -c 1 192.168.8.109`: error (filtered)
```

The multihome ARP settings cause the system to ignore ARP requests due to a subnet mismatch, and as a result, the enforcement via the `-I` interface binding no longer works.

Output:

```
PING 192.168.8.109 (192.168.8.109) from 192.168.7.107 eth7: 56(84) bytes of
 data.
From 192.168.7.107 icmp_seq=1 Destination Host Unreachable

--- 192.168.8.109 ping statistics ---
1 packets transmitted, 0 received, +1 errors, 100% packet loss, time 0ms

- capture:
```

```
No.     Time           Source                Destination           Protocol
 Length Info
     74 623.897407366  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.8.109? Tell 192.168.7.107
     75 624.903906694  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.8.109? Tell 192.168.7.107
     76 625.928060996  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.8.109? Tell 192.168.7.107
```

```
vm7:~ ping -I eth7 -c 1 192.168.9.108: error (filtered)
```

The multihome ARP settings cause the system to ignore ARP requests due to a subnet mismatch, and as a result, the enforcement via the `-I` interface binding no longer works.
Output:

```
PING 192.168.9.108 (192.168.9.108) from 192.168.7.107 eth7: 56(84) bytes of
 data.
From 192.168.7.107 icmp_seq=1 Destination Host Unreachable

--- 192.168.9.108 ping statistics ---
1 packets transmitted, 0 received, +1 errors, 100% packet loss, time 0ms

- capture:

No.     Time           Source                Destination           Protocol
 Length Info
     81 726.553781184  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.9.108? Tell 192.168.7.107
     82 727.562690381  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.9.108? Tell 192.168.7.107
     83 728.586537241  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.9.108? Tell 192.168.7.107
```

```
vm7:~ ping -I eth7 -c 1 192.168.9.109: error (filtered)
```

The multihome ARP settings cause the system to ignore ARP requests due to a subnet mismatch, and as a result, the enforcement via the `-I` interface binding no longer works.
Output:

```
PING 192.168.9.109 (192.168.9.109) from 192.168.7.107 eth7: 56(84) bytes of
 data.
From 192.168.7.107 icmp_seq=1 Destination Host Unreachable

--- 192.168.9.109 ping statistics ---
```

```
1 packets transmitted, 0 received, +1 errors, 100% packet loss, time 0ms

- capture:

No.     Time           Source                Destination           Protocol
 Length Info
     92 817.265392026  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.9.109? Tell 192.168.7.107
     93 818.284912731  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.9.109? Tell 192.168.7.107
     94 819.309070330  52:54:00:00:07:07     Broadcast             ARP      42
     Who has 192.168.9.109? Tell 192.168.7.107
```

b. vm8

In our setup, `vm8` and `vm9` behave the same way. See `vm9` (#vm9-1) for more details.

c. vm9

```
vm9:~ # ping -c 1 192.168.7.107: reply (regular)
```

Same as default behavior (#vm9--ping--c-1-1921687107-reply-regular).

```
vm9:~ # ping -c 1 192.168.7.108: reply (regular)
```

Same as default behavior (#vm9--ping--c-1-1921687107-reply-regular).

```
vm9:~ # ping -c 1 192.168.8.108 : reply (regular)
```

Same as default behavior (#vm9--ping--c-1-1921688108-reply-regular).

```
vm9:~ # ping -c 1 192.168.9.108 : reply (regular)
```

Same as default behavior (#vm9--ping--c-1-1921689108-reply-regular).

```
vm9:~ ping -I enp9s0 -c 1 192.168.8.108 : error (filtered)
```

The multihome ARP settings cause the system to ignore ARP requests due to a subnet mismatch, and as a result, the enforcement via the `-I` interface binding no longer works.

Output:

```
PING 192.168.8.108 (192.168.8.108) from 192.168.9.109 enp9s0: 56(84) bytes of
 data.
From 192.168.9.109 icmp_seq=1 Destination Host Unreachable

--- 192.168.8.108 ping statistics ---
```

```
1 packets transmitted, 0 received, +1 errors, 100% packet loss, time 0ms

- capture:

No.     Time           Source                Destination           Protocol
 Length Info
      1 0.000000000    52:54:00:00:09:09     Broadcast             ARP      42
     Who has 192.168.8.108? Tell 192.168.9.109
      2 1.053440783    52:54:00:00:09:09     Broadcast             ARP      42
     Who has 192.168.8.108? Tell 192.168.9.109
      3 2.077406483    52:54:00:00:09:09     Broadcast             ARP      42
     Who has 192.168.8.108? Tell 192.168.9.109
```

```
vm9:~ ping -I enp8s0 -c 1 192.168.9.108 : error (filtered)
```

The multihome ARP settings cause the system to ignore ARP requests due to a subnet mismatch, and as a result, the enforcement via the `-I` interface binding no longer works. Output:

```
PING 192.168.9.108 (192.168.9.108) from 192.168.8.109 enp8s0: 56(84) bytes of
 data.
From 192.168.8.109 icmp_seq=1 Destination Host Unreachable

--- 192.168.9.108 ping statistics ---
1 packets transmitted, 0 received, +1 errors, 100% packet loss, time 0ms

- capture:

No.     Time           Source                Destination           Protocol
 Length Info
      1 0.000000000    52:54:00:00:08:09     Broadcast             ARP      42
     Who has 192.168.9.108? Tell 192.168.8.109
      2 1.030989481    52:54:00:00:08:09     Broadcast             ARP      42
     Who has 192.168.9.108? Tell 192.168.8.109
      3 2.054972421    52:54:00:00:08:09     Broadcast             ARP      42
     Who has 192.168.9.108? Tell 192.168.8.109
```

```
vm9:~ ping -I enp7s0 -c 1 192.168.9.108: error (regular)
```

Same as default behavior (#vm9--ping--c-1-1921689108-reply-regular).

```
vm9:~ ping -I enp7s0 -c 1 192.168.8.108: error (regular)
```

Same as default behavior (#vm9--ping--c-1-1921689108-reply-regular).

6.2 Policy routing

By default, all unicast routing entries are placed in the `main` table (and local/broadcast routes `local` table) and the lookups use the destination only.

The direct routes (without a gateway) are created automatically by the kernel while adding the address to the interface, e.g. (on `vm7`). **`ip addr add 192.168.7.107/24 dev eth7`** causes to create the following routes.

```
ip route show table main dev eth7
  192.168.7.0/24 dev eth7 proto kernel scope link src 192.168.7.107
```

```
ip route show table local dev eth7

    local 192.168.7.107 proto kernel scope host src 192.168.7.107
    broadcast 192.168.7.255 proto kernel scope link src 192.168.7.107
```

Using a `/32` IP address prefix length **`ip addr add 192.168.7.107/32`** causes the kernel to avoid adding routes automatically in favor of own routes.

In complex setups involving asynchronous routing or the use of multiple interfaces in the same subnet, `arp_filter=1` may not work properly due to the filtering, especially in the strict `rp_filter=1` mode.

Policy routing permits adding a rule that matches the source IP and then using a different routing table (for example, one for each interface) that has different direct and gateway routes than the standard `main` table, such as its own unique default gateway.

For more information, see also LARTC HOWTO (https://lartc.org/lartc.html#AEN267), the `man 5 ifrule`, `man 8 ip-rule`, `man 5 ifroute`, `man 8 ip-route` man pages and the `/etc/iproute2/rt_tables` file, which is used to define names for custom tables.

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