

Configuring Multihome Networking on VM Hosts

WHAT?

This article explains how to configure multihome networking on a SUSE Linux Enterprise Server for SAP applications 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

Publication Date: 07 Nov 2025

Contents

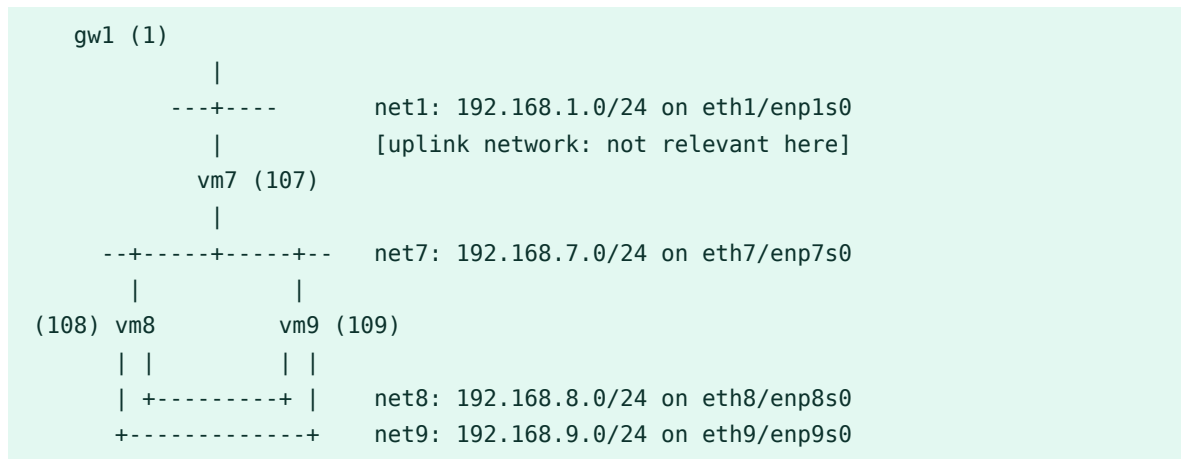
- 1 Network topology 3

2	Checking the VM host network configuration	3
3	Checking the VM network configuration	5
4	IP sysctl settings for the multihome host	8
5	Default behavior	11
6	Multihome setup	19
7	Legal Notice	25
A	GNU Free Documentation License	26

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).



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 firewall 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 enpls0
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 \(https://www.kernel.org/doc/Documentation/networking/ip-sysctl.txt\)](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.

- arp_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 \(https://en.wikipedia.org/wiki/Host_model\)](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. Info	Time	Source	Destination	Protocol	Length
131 Echo (ping) request	1995.230774	192.168.1.107	192.168.8.108	ICMP	104
id=0x002a, seq=1/256, ttl=64 (no response found!)					
132 Destination unreachable	1995.231275	192.168.1.1	192.168.1.107	ICMP	132
(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
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\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\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: icmp"... , 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
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 pingging 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
1	0.0000000000	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
   ---  ---
   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-en-p7s0--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, it 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 \(https://lartc.org/lartc.html#AEN267\)](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.

7 Legal Notice

Copyright© 2006–2025 SUSE LLC and contributors. All rights reserved.

Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License, Version 1.2 or (at your option) version 1.3; with the Invariant Section being this copyright notice and license. A copy of the license version 1.2 is included in the section entitled “GNU Free Documentation License”.

For SUSE trademarks, see <https://www.suse.com/company/legal/>. All other third-party trademarks are the property of their respective owners. Trademark symbols (®, ™ etc.) denote trademarks of SUSE and its affiliates. Asterisks (*) denote third-party trademarks.

All information found in this book has been compiled with utmost attention to detail. However, this does not guarantee complete accuracy. Neither SUSE LLC, its affiliates, the authors, nor the translators shall be held liable for possible errors or the consequences thereof.

A GNU Free Documentation License

Copyright (C) 2000, 2001, 2002 Free Software Foundation, Inc. 51 Franklin St, Fifth Floor, Boston, MA 02110-1301 USA. Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed.

0. PREAMBLE

The purpose of this License is to make a manual, textbook, or other functional and useful document "free" in the sense of freedom: to assure everyone the effective freedom to copy and redistribute it, with or without modifying it, either commercially or non-commercially. Secondly, this License preserves for the author and publisher a way to get credit for their work, while not being considered responsible for modifications made by others.

This License is a kind of "copyleft", which means that derivative works of the document must themselves be free in the same sense. It complements the GNU General Public License, which is a copyleft license designed for free software.

We have designed this License to use it for manuals for free software, because free software needs free documentation: a free program should come with manuals providing the same freedoms that the software does. But this License is not limited to software manuals; it can be used for any textual work, regardless of subject matter or whether it is published as a printed book. We recommend this License principally for works whose purpose is instruction or reference.

1. APPLICABILITY AND DEFINITIONS

This License applies to any manual or other work, in any medium, that contains a notice placed by the copyright holder saying it can be distributed under the terms of this License. Such a notice grants a world-wide, royalty-free license, unlimited in duration, to use that work under the conditions stated herein. The "Document", below, refers to any such manual or work. Any member of the public is a licensee, and is addressed as "you". You accept the license if you copy, modify or distribute the work in a way requiring permission under copyright law.

A "Modified Version" of the Document means any work containing the Document or a portion of it, either copied verbatim, or with modifications and/or translated into another language.

A "Secondary Section" is a named appendix or a front-matter section of the Document that deals exclusively with the relationship of the publishers or authors of the Document to the Document's overall subject (or to related matters) and contains nothing that could fall directly within that overall subject. (Thus, if the Document is in part a textbook of mathematics, a Secondary Section may not explain any mathematics.) The relationship could be a matter of historical connection with the subject or with related matters, or of legal, commercial, philosophical, ethical or political position regarding them.

The "Invariant Sections" are certain Secondary Sections whose titles are designated, as being those of Invariant Sections, in the notice that says that the Document is released under this License. If a section does not fit the above definition of Secondary then it is not allowed to be designated as Invariant. The Document may contain zero Invariant Sections. If the Document does not identify any Invariant Sections then there are none.

The "Cover Texts" are certain short passages of text that are listed, as Front-Cover Texts or Back-Cover Texts, in the notice that says that the Document is released under this License. A Front-Cover Text may be at most 5 words, and a Back-Cover Text may be at most 25 words.

A "Transparent" copy of the Document means a machine-readable copy, represented in a format whose specification is available to the general public, that is suitable for revising the document straightforwardly with generic text editors or (for images composed of pixels) generic paint programs or (for drawings) some widely available drawing editor, and that is suitable for input to text formatters or for automatic translation to a variety of formats suitable for input to text formatters. A copy made in an otherwise Transparent file format whose markup, or absence of markup, has been arranged to thwart or discourage subsequent modification by readers is not Transparent. An image format is not Transparent if used for any substantial amount of text. A copy that is not "Transparent" is called "Opaque".

Examples of suitable formats for Transparent copies include plain ASCII without markup, Texinfo input format, LaTeX input format, SGML or XML using a publicly available DTD, and standard-conforming simple HTML, PostScript or PDF designed for human modification. Examples of transparent image formats include PNG, XCF and JPG. Opaque formats include proprietary formats that can be read and edited only by proprietary word processors, SGML or XML for which the DTD and/or processing tools are not generally available, and the machine-generated HTML, PostScript or PDF produced by some word processors for output purposes only.

The "Title Page" means, for a printed book, the title page itself, plus such following pages as are needed to hold, legibly, the material this License requires to appear in the title page. For works in formats which do not have any title page as such, "Title Page" means the text near the most prominent appearance of the work's title, preceding the beginning of the body of the text.

A section "Entitled XYZ" means a named subunit of the Document whose title either is precisely XYZ or contains XYZ in parentheses following text that translates XYZ in another language. (Here XYZ stands for a specific section name mentioned below, such as "Acknowledgements", "Dedications", "Endorsements", or "History".) To "Preserve the Title" of such a section when you modify the Document means that it remains a section "Entitled XYZ" according to this definition.

The Document may include Warranty Disclaimers next to the notice which states that this License applies to the Document. These Warranty Disclaimers are considered to be included by reference in this License, but only as regards disclaiming warranties: any other implication that these Warranty Disclaimers may have is void and has no effect on the meaning of this License.

2. VERBATIM COPYING

You may copy and distribute the Document in any medium, either commercially or non-commercially, provided that this License, the copyright notices, and the license notice saying this License applies to the Document are reproduced in all copies, and that you add no other conditions whatsoever to those of this License. You may not use technical measures to obstruct or control the reading or further copying of the copies you make or distribute. However, you may accept compensation in exchange for copies. If you distribute a large enough number of copies you must also follow the conditions in section 3.

You may also lend copies, under the same conditions stated above, and you may publicly display copies.

3. COPYING IN QUANTITY

If you publish printed copies (or copies in media that commonly have printed covers) of the Document, numbering more than 100, and the Document's license notice requires Cover Texts, you must enclose the copies in covers that carry, clearly and legibly, all these Cover Texts: Front-Cover Texts on the front cover, and Back-Cover Texts on the back cover. Both covers must also clearly and legibly identify you as the publisher of these copies. The front cover must present the full title with all words of the title equally prominent and visible. You may add other material on the covers in addition. Copying with changes limited to the covers, as long as they preserve the title of the Document and satisfy these conditions, can be treated as verbatim copying in other respects.

If the required texts for either cover are too voluminous to fit legibly, you should put the first ones listed (as many as fit reasonably) on the actual cover, and continue the rest onto adjacent pages.

If you publish or distribute Opaque copies of the Document numbering more than 100, you must either include a machine-readable Transparent copy along with each Opaque copy, or state in or with each Opaque copy a computer-network location from which the general network-using public has access to download

using public-standard network protocols a complete Transparent copy of the Document, free of added material. If you use the latter option, you must take reasonably prudent steps, when you begin distribution of Opaque copies in quantity, to ensure that this Transparent copy will remain thus accessible at the stated location until at least one year after the last time you distribute an Opaque copy (directly or through your agents or retailers) of that edition to the public.

It is requested, but not required, that you contact the authors of the Document well before redistributing any large number of copies, to give them a chance to provide you with an updated version of the Document.

4. MODIFICATIONS

You may copy and distribute a Modified Version of the Document under the conditions of sections 2 and 3 above, provided that you release the Modified Version under precisely this License, with the Modified Version filling the role of the Document, thus licensing distribution and modification of the Modified Version to whoever possesses a copy of it. In addition, you must do these things in the Modified Version:

- A. Use in the Title Page (and on the covers, if any) a title distinct from that of the Document, and from those of previous versions (which should, if there were any, be listed in the History section of the Document). You may use the same title as a previous version if the original publisher of that version gives permission.
- B. List on the Title Page, as authors, one or more persons or entities responsible for authorship of the modifications in the Modified Version, together with at least five of the principal authors of the Document (all of its principal authors, if it has fewer than five), unless they release you from this requirement.
- C. State on the Title page the name of the publisher of the Modified Version, as the publisher.
- D. Preserve all the copyright notices of the Document.
- E. Add an appropriate copyright notice for your modifications adjacent to the other copyright notices.
- F. Include, immediately after the copyright notices, a license notice giving the public permission to use the Modified Version under the terms of this License, in the form shown in the Addendum below.
- G. Preserve in that license notice the full lists of Invariant Sections and required Cover Texts given in the Document's license notice.
- H. Include an unaltered copy of this License.

- I. Preserve the section Entitled "History", Preserve its Title, and add to it an item stating at least the title, year, new authors, and publisher of the Modified Version as given on the Title Page. If there is no section Entitled "History" in the Document, create one stating the title, year, authors, and publisher of the Document as given on its Title Page, then add an item describing the Modified Version as stated in the previous sentence.
- J. Preserve the network location, if any, given in the Document for public access to a Transparent copy of the Document, and likewise the network locations given in the Document for previous versions it was based on. These may be placed in the "History" section. You may omit a network location for a work that was published at least four years before the Document itself, or if the original publisher of the version it refers to gives permission.
- K. For any section Entitled "Acknowledgements" or "Dedications", Preserve the Title of the section, and preserve in the section all the substance and tone of each of the contributor acknowledgements and/or dedications given therein.
- L. Preserve all the Invariant Sections of the Document, unaltered in their text and in their titles. Section numbers or the equivalent are not considered part of the section titles.
- M. Delete any section Entitled "Endorsements". Such a section may not be included in the Modified Version.
- N. Do not retitle any existing section to be Entitled "Endorsements" or to conflict in title with any Invariant Section.
- O. Preserve any Warranty Disclaimers.

If the Modified Version includes new front-matter sections or appendices that qualify as Secondary Sections and contain no material copied from the Document, you may at your option designate some or all of these sections as invariant. To do this, add their titles to the list of Invariant Sections in the Modified Version's license notice. These titles must be distinct from any other section titles.

You may add a section Entitled "Endorsements", provided it contains nothing but endorsements of your Modified Version by various parties--for example, statements of peer review or that the text has been approved by an organization as the authoritative definition of a standard.

You may add a passage of up to five words as a Front-Cover Text, and a passage of up to 25 words as a Back-Cover Text, to the end of the list of Cover Texts in the Modified Version. Only one passage of Front-Cover Text and one of Back-Cover Text may be added by (or through arrangements made by) any one entity. If the Document already includes a cover text for the same cover, previously added by you or by arrangement made by the same entity you are acting on behalf of, you may not add another; but you may replace the old one, on explicit permission from the previous publisher that added the old one.

The author(s) and publisher(s) of the Document do not by this License give permission to use their names for publicity for or to assert or imply endorsement of any Modified Version.

5. COMBINING DOCUMENTS

You may combine the Document with other documents released under this License, under the terms defined in section 4 above for modified versions, provided that you include in the combination all of the Invariant Sections of all of the original documents, unmodified, and list them all as Invariant Sections of your combined work in its license notice, and that you preserve all their Warranty Disclaimers.

The combined work need only contain one copy of this License, and multiple identical Invariant Sections may be replaced with a single copy. If there are multiple Invariant Sections with the same name but different contents, make the title of each such section unique by adding at the end of it, in parentheses, the name of the original author or publisher of that section if known, or else a unique number. Make the same adjustment to the section titles in the list of Invariant Sections in the license notice of the combined work.

In the combination, you must combine any sections Entitled "History" in the various original documents, forming one section Entitled "History"; likewise combine any sections Entitled "Acknowledgements", and any sections Entitled "Dedications". You must delete all sections Entitled "Endorsements".

6. COLLECTIONS OF DOCUMENTS

You may make a collection consisting of the Document and other documents released under this License, and replace the individual copies of this License in the various documents with a single copy that is included in the collection, provided that you follow the rules of this License for verbatim copying of each of the documents in all other respects.

You may extract a single document from such a collection, and distribute it individually under this License, provided you insert a copy of this License into the extracted document, and follow this License in all other respects regarding verbatim copying of that document.

7. AGGREGATION WITH INDEPENDENT WORKS

A compilation of the Document or its derivatives with other separate and independent documents or works, in or on a volume of a storage or distribution medium, is called an "aggregate" if the copyright resulting from the compilation is not used to limit the legal rights of the compilation's users beyond what the individual works permit. When the Document is included in an aggregate, this License does not apply to the other works in the aggregate which are not themselves derivative works of the Document.

If the Cover Text requirement of section 3 is applicable to these copies of the Document, then if the Document is less than one half of the entire aggregate, the Document's Cover Texts may be placed on covers that bracket the Document within the aggregate, or the electronic equivalent of covers if the Document is in electronic form. Otherwise they must appear on printed covers that bracket the whole aggregate.

8. TRANSLATION

Translation is considered a kind of modification, so you may distribute translations of the Document under the terms of section 4. Replacing Invariant Sections with translations requires special permission from their copyright holders, but you may include translations of some or all Invariant Sections in addition to the original versions of these Invariant Sections. You may include a translation of this License, and all the license notices in the Document, and any Warranty Disclaimers, provided that you also include the original English version of this License and the original versions of those notices and disclaimers. In case of a disagreement between the translation and the original version of this License or a notice or disclaimer, the original version will prevail.

If a section in the Document is Entitled "Acknowledgements", "Dedications", or "History", the requirement (section 4) to Preserve its Title (section 1) will typically require changing the actual title.

9. TERMINATION

You may not copy, modify, sublicense, or distribute the Document except as expressly provided for under this License. Any other attempt to copy, modify, sublicense or distribute the Document is void, and will automatically terminate your rights under this License. However, parties who have received copies, or rights, from you under this License will not have their licenses terminated so long as such parties remain in full compliance.

10. FUTURE REVISIONS OF THIS LICENSE

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns. See <https://www.gnu.org/copyleft/> ↗.

Each version of the License is given a distinguishing version number. If the Document specifies that a particular numbered version of this License "or any later version" applies to it, you have the option of following the terms and conditions either of that specified version or of any later version that has been

published (not as a draft) by the Free Software Foundation. If the Document does not specify a version number of this License, you may choose any version ever published (not as a draft) by the Free Software Foundation.

ADDENDUM: How to use this License for your documents

```
Copyright (c) YEAR YOUR NAME.  
Permission is granted to copy, distribute and/or modify this document  
under the terms of the GNU Free Documentation License, Version 1.2  
or any later version published by the Free Software Foundation;  
with no Invariant Sections, no Front-Cover Texts, and no Back-Cover Texts.  
A copy of the license is included in the section entitled "GNU  
Free Documentation License".
```

If you have Invariant Sections, Front-Cover Texts and Back-Cover Texts, replace the “with...Texts.” line with this:

```
with the Invariant Sections being LIST THEIR TITLES, with the  
Front-Cover Texts being LIST, and with the Back-Cover Texts being LIST.
```

If you have Invariant Sections without Cover Texts, or some other combination of the three, merge those two alternatives to suit the situation.

If your document contains nontrivial examples of program code, we recommend releasing these examples in parallel under your choice of free software license, such as the GNU General Public License, to permit their use in free software.